2021 INTERNATIONAL CONFERENCE ON UNMANNED AIRCRAFT SYSTEMS

ICUAS'21

June 15-18, 2021

DIVANI CARAVEL HOTEL
ATHENS, GREECE, GR-16121

FINAL PROGRAM

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Welcome Message from the ICUAS Association

Dear participants and attendees:
On behalf of the ICUAS Association Inc., and in my capacity as the President of the Association, it is a privilege, a great pleasure and an honor to welcome you to the *2021 International Conference on Unmanned Aircraft Systems* (ICUAS'21).

For the second year in a row, I write this welcome message while the COVID-19 pandemic is still present world-wide, perhaps more manageable, and despite on-going and accelerated vaccination efforts from all countries.

This year, 2021, the annual conference takes place, again, in Athens, Greece, in the same location as in 2020, the Divani Caravel Hotel. This was a logical calculated risk decision at the time it was made, which offered a 'second chance' to visit Greece and mix business and pleasure. However, the COVID-19 challenge does not allow for the level of flexibility we had hoped for. In any case, I strongly believe that the conference will meet and exceed your expectations.

I also take this opportunity to update you about the ICUAS Association, Inc. The Association's web has been modernized and updated to include important links with information items; visit www.icuas.com for details. The quarterly Newsletter continues, and as I write this welcome, the Spring 2021 issue has already been published and distributed.

We are looking forward to your active involvement in the Association and the conference, and to your contributions and feedback. We do welcome your participation and we are open to your ideas and suggestions to register the Association and the annual technical conference as primary contributors, which: benefit students, researchers, scientists, engineers, practitioners, and end-users; advance the state-of-the-art in unmanned aviation; promote higher education.

I offer my best wishes for a successful and productive event, I look forward to seeing all of you, physically or virtually, in Athens, Greece, and I also look forward to continuing working with you.

Kimon P. Valavanis

Welcome Message from the ICUAS'21 Honorary Chairs

Dear participants and attendees:

On behalf of the 2021 ICUAS Organizing Committee and in our capacity as Honorary Chairs, it is a privilege and a great pleasure to welcome you to this year's conference. This is the second time we have the honor to host ICUAS in Europe. The conference is organized in Athens, Greece. Athens is a magnificent location for such an international event like the 2021 ICUAS.

We are proud to greet and host this important scientific event that spans a three-day technical conference, preceded by a one-day Workshop/Tutorials program. We are convinced that you will appreciate and enjoy the conference.

We look forward to seeing all of you in Athens, assuming that travel is allowed. We wish you have a satisfying and pleasant attendance, coupling business and pleasure.

With our warmest regards,

Stjepan Bogdan, Youmin Zhang

Welcome Message from the ICUAS'21 General Chairs

Dear participants and attendees:
On behalf of the 2021 ICUAS Organizing Committee, it is a privilege and a great pleasure to welcome you to this year's conference. ICUAS '21 is organized, again, in Athens, Greece. The venue is the Divani Caravel Hotel. The three-day conference is preceded by a one-day Workshops/Tutorials program, which is composed of four (4) Tutorials. We are certain you will be very pleased with the conference venue, and you will enjoy all the attractions that Athens offers – assuming we can all travel given the COVID-19 challenges.

As in previous years, conference participants represent academia, industry, government agencies, lawyers, policy makers, manufacturers, students, and end-users, all having deep interest in the state-of-the-art and future directions in unmanned aircraft systems. In response to the Call for Papers, we received 259 contributed, invited session, and poster papers. This is the 3rd highest number of submissions compared to all previous years. Given that the conference is organized in the middle of the pandemic crisis, the number of received contributions is indicative of the reputation of the conference and the appeal it has to the technical society. Following a very thorough and in-depth peer review process in which each paper had at least three reviews (plus an additional review from a member of the organizing committee), roughly 75% of contributed, invited session and poster papers were accepted. All papers were also checked following the *iThenticate Document Viewer Guide* receiving a 'similarity score' and a 'm percentage match' before the final decision was made. We have assembled a full three-day top-quality Technical Program. We also have five plenary Lectures in which the keynote speakers address pressing, and important issues related to autonomy, and several aspects of unmanned aviation.

The Organizing Committee members have devoted an enormous amount of time and effort to make sure that the conference is exciting, informative, and educational. We are privileged to know all the members. We are honored to have worked with them and we are truly indebted to everyone for their dedication and professionalism. We also extend a wholehearted "thank you" to all reviewers, Associate Editors, and members of the Technical Program Committees; their help is integral to assembling a top-quality Technical Program.

The peer review process is coordinated by the Program Chairs, who assign groups of papers to the Associate Editors. We thank all of them for their extremely valuable contributions and dedication. Dr. Pradeep Misra is the "glue" that keeps everything together, as papers are submitted through the PaperCept Conference Management System (https://controls.papercept.net), managed by Pradeep. Pradeep is indispensable throughout, and we would not have been able to complete the paper review process without his help.

We thank you for your participation and contributions. We hope you enjoy the conference, as well as Athens, the other surrounding areas and the Greek Islands.

With our warmest regards,

Didier Theilliol, Nikos Tsourveloudis

Welcome Message from the ICUAS'21 Program Chairs

Dear participants and attendees:
Welcome to ICUAS'21. This year we received 259 contributed, invited session, and poster papers.

The paper review process has been extremely thorough and rigorous. All papers were also checked for originality using the *iThenticate Document Viewer Guide*. Our goal was for each paper to have at least three reviews. We met and exceeded this goal as each of the submitted papers, in addition to the reviews, was also checked and reviewed by one of the Program Chairs or members of the Organizing Committee.

Authors of submitted papers used among the following key words to classify their paper: Airspace Control, Airspace Management, Airworthiness, Air Vehicle Operations, Autonomy, Biologically Inspired UAS, Certification, Control Architectures, Energy Efficient UAS, Environmental Issues, Fail-Safe Systems, Frequency Management, Integration, Interoperability, Levels of Safety, Manned/Unmanned Aviation, Micro- and Mini- UAS, Navigation, Networked Swarms, Payloads, Path Planning, Regulations, Reliability of UAS, Risk Analysis, See-and-avoid Systems, Security, Sensor Fusion, Simulation, Smart Sensors, Standardization, Swarms, Technology Challenges, Training, UAS Applications, UAS Communications, UAS Testbeds.

The review process resulted in the technical program composed of 205 contributed, invited and poster session peer reviewed papers. Table I shows the contributed and accepted papers per country. The technical program spans three days, during which all accepted papers are presented, physically or virtually.

Table I: Submitted - Accepted Papers per Country

	Received	*Accepted*
USA	51	45
India	23	15
Brazil	18	13
China	16	11
Italy	15	12
France	12	11
Singapore	12	7
Mexico	10	9
Germany	9	9
Canada	8	8
Norway	8	6
Denmark	7	7
Spain	7	7
UK	7	6
Czech Republic	5	5
Botswana	4	3
Cyprus	4	4
Greece	4	3
Russia	4	2
Argentina	3	3
Croatia	3	2
Japan	3	2
Korea, South	3	1
Poland	3	2
Sweden	3	3

Turkey	3	1
UAE	3	3
Australia	2	1
Belgium	1	1
Egypt	1	0
Latvia	1	0
Lebanon	1	1
Morocco	1	1
Oman	1	0
Portugal	1	1
Saudi Arabia	1	0
Taiwan	1	0
Totals	259	205

We would like to thank all the authors for their contributions. The rigorous review process would not have been possible if we did not have such a strong community of expert reviewers in unmanned aircraft systems. We thank all reviewers for their professional service.

Dr. Pradeep Misra helped us in working and effectively using the on-line paper submission and review system. He has been very responsive and helpful in technical issues related to the on-line system. In most cases, our questions were due to our novice and inexperience with the on-line system. We acknowledge that this system is very sophisticated and yet very practical to use for both small and large-scale conferences. It is very hard to imagine how things would have been done without this excellent tool!

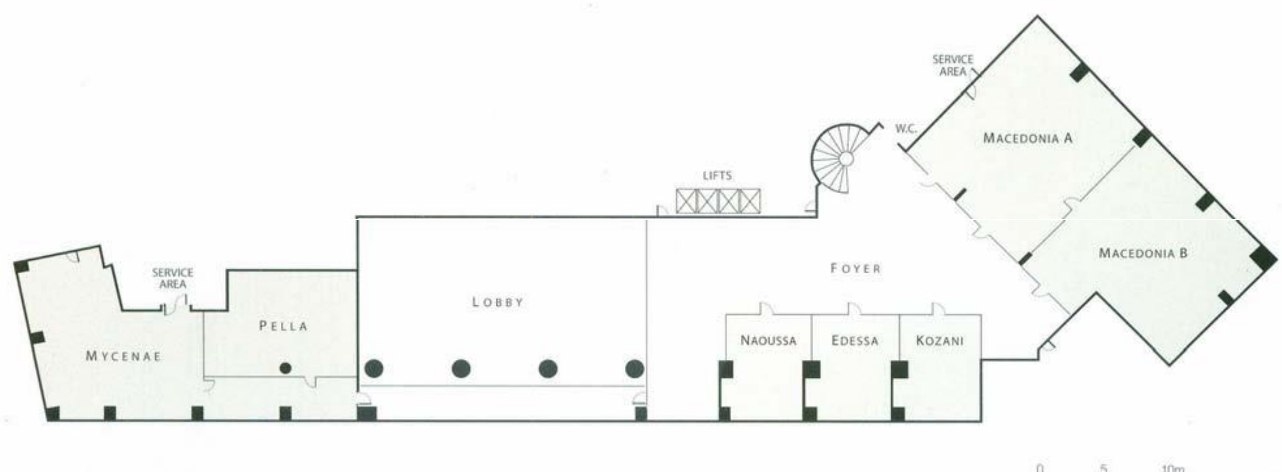
We hope you enjoy not only the technical aspects of the conference but also beautiful Athens. Fly high and safe, to the next ICUAS!

Andrea Monteriu, Matko Orsag

ICUAS'21 General Information

The Venue
The Conference will take place in Athens, Greece. The venue is the luxurious Divani Caravel Hotel (https://divanicaravelhotel.com), which is located close to the city's most exclusive neighborhood (Kolonaki), and to the old city (Plaka). The street address of the Divani Caravel hotel is Vassileos Alexandrou 2, 16121 Athens, Greece.

General Information
ICUAS '21 is a four-day event. The conference area is situated in the Mezzanine Level of the Hotel, above the main Lobby, as shown in the figure below. All Workshops, Tutorials, and Technical Sessions will be in the rooms, *Macedonia Hall* (A and B), *Kozani*, *Edessa*, and *Naoussa*, Tutorials and Workshops will take place on Tuesday, followed by the three-day conference on Wednesday to Friday. All Keynote/Plenary talks will take place in the *Macedonia Hall*. The *Foyer* area will be used for Poster Papers, exhibits, research demo booths, etc.



Conference Technical Sessions - Wednesday, June 16 - Friday, June 18
In addition to the Plenary/Keynote lectures, there are four parallel technical sessions each day. All conference sessions, including Workshops and Tutorials, will be in the Mezzanine Level. Technical Sessions and Workshops/Tutorials will be in *Macedonia Hall, Kozani, Edessa,* and *Naoussa.*

Exhibits
Exhibits will be in the Mezzanine Level, in the *Foyer* area, to maximize traffic and exposure.

Poster Papers
Poster papers will be on display for physical presentation, or video-recorded presentation. Poster papers will be presented on Friday, June 18, 9:00 AM – 12:00 Noon.

Conference Registration
All Conference attendees must register by using the on-line registration when they upload the final version of their papers. This is the preferred option. Late and on-site registration is also available for non-authors who want to attend the conference. It is not required to present a paper in the

conference program to register and to attend the conference. All registered participants must check in at the Registration Desk to pick up their registration packages. Personal badges will be provided to all registered participants. Attendees must wear their badges at all times when attending any ICUAS'21 event (workshops, tutorials, technical sessions and social functions). Conference details will be posted and updated daily in the registration area. To register, follow the steps:

- ✓ Go to https://controls.papercept.net
- ✓ Scroll down the list until you find ICUAS 2021 - Choose ICUAS 2021 (from the list of conferences)
- ✓ Click on Register for ICUAS'21
- ✓ Login with your PIN and Password. *First time users must create a 'profile', to get a PIN and Password.*
- ✓ After you Log in, choose **Registree**
- ✓ Follow the self-explained screens to register.

The registration area is the *Foyer* area outside the *Macedonia Hall* (A and B). The registration desk will be open during the following hours:

TUESDAY, JUNE 15:	*Workshop/Tutorial Registration* (**Only**)	8:00 AM – 10:00 AM
	Conference Registration	3:00 PM – 5:00 PM
WEDNESDAY, JUNE 16:		8:00 AM – 5:00 PM
THURSDAY, JUNE 17:		8:00 AM – 4:00 PM
FRIDAY, JUNE 18:		8:00 AM – 12:00 PM

On-site conference registration policy & fees

Attendees will be able to register for the Conference under the following registration categories/rates, which, due to COVID-19 are the same with Advanced- or Pre- Registration fees:

ATTENDEE STATUS	ON-SITE REGISTRATION FEE
Academic, Industry, Government, Others	$500
Student	$300
Tutorial - T1	$120
Tutorial - T2	$120
Tutorial - T3	$150
Tutorial - T4	$150
Extra Banquet Ticket	$100
Extra Proceedings	$40

Internet Access

All registered attendees will have complementary internet access.

Breakfast and Lunch for participants with accommodations in the Divani Caravel Hotel

We encourage you to take advantage of the package the conference venue and ICUAS offers. For participants who have made accommodations in the conference venue, full buffet Breakfast is included in their hotel room rate. Lunch will be served to registered conference participants. Lunch tickets will be provided.

Coffee Breaks with snacks

There will be two coffee breaks per day for all registered participants, one in the morning and one in the afternoon. Coffee breaks will be served in the *Foyer* area.

Events and Receptions

The ICUAS'21 social agenda includes: *Welcome Reception* on Tuesday, June 15; *Banquet*, on Thursday, June 17. Both events will be in the *Roof Garden Pool area*.

Travel to Athens

Athens is easily accessible by air, sea, and road. Once there, the public transportation system provides a safe, dependable, and efficient way to move around the city. The public transportation network consists of underground (metro), train, suburban railways, buses, trolley buses, and trams. Athens is also connected with other parts of the mainland through a network of roads and railways.

Visitors arriving by air will land in the *Athens International Airport "Eleftherios Venizelos"* (IATA code: ATH). This award-winning airport is one of the world's leading airports in overall passenger satisfaction and has been named the Airport of the Year (2014) in the 10-30 million-passenger category by internationally acclaimed web portal Air Transport News. During World Routes 2019, the biggest global networking route development annual forum, the Athens International Airport received one more significant distinction, voted by airlines as "Highly Commended" in the competitive 20-50 million passenger category. In Routes Europe 2019 in Hannover, the Athens Airport received the Marketing Award - the Greek gateway took the winning title in the over 20 million annual passenger category.

The Athens International Airport is serviced by all major airlines, offering direct non-stop flights from/to most of the major European cities, New York, Philadelphia, Montreal/Toronto, North Africa, Gulf States, South Africa, and easy connections to the rest of the world. ATH is also serviced by low-cost and/or charter airlines that offer attractive packages. Note that there may be slight changes to flights due to COVID-19.

Transportation from/to Airport to/from Divani Caravel Hotel

Upon arrival to the airport, one may reach the Divani Caravel Hotel by taxi, subway ("metro"), bus or private car.

Taxi: Taxis are available at the designated taxi waiting area located by Exit 3 at the Arrivals level. Ask the driver to get you to the Divani Caravel Hotel. The average cost on normal traffic is 40 EUR and it takes about 30 minutes to arrive at the hotel. In general, the drive from the airport to locations in the city center takes about 35-40 minutes and costs 38 EUR (flat rate – regular fare, from 5 a.m. until midnight) and 54 EUR (flat rate – night fare, from midnight to 5 a.m.).

Metro: The airport is connected to the city center via Metro Line 3 (Blue line) *Aghia Marina – Douk. Plakentias – Aghia Marina*. The Athens metro is convenient, clean, and safe. The trip to the city center takes about 40 minutes and costs 10 EUR (one way). Walk to the metro station, adjacent to the Airport. Take the Blue line. Get off the metro at the Evangelismos Station. While exiting from the station, take the left exit towards Vas. Sofia's avenue. Walk pass the Hilton hotel (on your left-hand side), cross Michalakopoulou Street, continue straight on Vas. Alexandrou Street. You will see the Divani Caravel Hotel on your right. If you do not want to walk (approximately 5-7-minute walk), you may take the 224 bus (the stop is across the metro station exit), and get off at "Caravel Bus Stop", right in front of the hotel.

Bus: Bus X95 to Syntagma Square takes about 40 minutes and costs 6 EUR one way.

Car: Exit from the Airport, take the Attiki Odos highway following the signs for the Imittos ring. Exit right at the Katechaki / Mesogion avenue signs. Where Katechaki meets Mesogion avenue, turn left and follow directions to Michalakopoulou avenue. Driving down on Michalakopoulou avenue you will see the Hilton hotel on your right-hand side. At this point, make a left turn into Vas. Alexandrou avenue and you will see the Divani Caravel Hotel, 2 Vas. Alexandrou avenue.

ICUAS'21 Tutorials and Workshops

ICUAS'21 offers pre-conference Workshops/Tutorials addressing current and future topics in unmanned aircraft systems from experts in academia, national laboratories, and industry. Interested participants may find details on www.uasconferences.com, and they may use the on-line system for registration. Tutorials/Workshops will take place on Tuesday, June 15, 2020. Duration is either *Full-Day* (09:00 - 17:00) or *Half-Day* (09:00 - 13:00, or 14:00 – 18:00).

TUTORIALS / WORKSHOPS - Tuesday, June 15, 2021		
Location	**Time**	**Title**
Kozani-T1	Half-Day 9:00 - 13:00	*Networked Airborne Computing: State-of-the-Art in Challenges, Applications and Enabling Technologies*
Kozani-T2	Half-Day 14:00 – 18:00	*Integrated Prognostics and Health Management Technologies for UAS Resilience and Safety*
Edessa-T3	Full-Day 9:00 – 17:00	*State-of-the-Art in Fault-Tolerant Control (FTC), Fault-Tolerant Cooperative Control (FTCC) and Sense-and-Avoid in Unmanned Aircraft Systems* **CANCELLED**
Naoussa-T4	Full-Day 9:00 - 17:00	*Drones as Edge Devices: Challenges, Technologies and Applications*

ICUAS'21 Plenary Lectures

ICUAS'21 includes five Keynote/Plenary Lectures given by leading authorities in their fields. We are proud to include them in the technical program. Plenary/Keynote lectures will be in the General Session Room, *Macedonia Hall*. The schedule for the lectures is shown next.

KEYNOTE / PLENARY TALKS		
Day	**Time**	**Macedonia Hall**
Wednesday June 16	09:00 – 10:00	***Mitigation of Inflight Icing on Unmanned Aerial Vehicles***, *Tor Arne Johansen,* Norwegian University of Science and Technology, Trondheim, Norway
	16:00 – 17:00	***Resilient Fault-Tolerant Control for Multiagent UAV in Formations: Reinforcement Learning for Robust Synchronization***, *Frank L. Lewis*, The University of Texas at Arlington, USA
	17:00 – 18:00	***An Around-the-World Review of Drone Regulations*** *Dawn Zoldi*, CEO**,** P3 Tech Consulting, USA
Thursday June 17	09:00 - 10:00	***Refined Anti-Disturbance Control and Applications for UAVs: Green, Immunity and Survival***, *Lei Guo*, Beihang University, Beijing, China
	16:00 - 17:00	**From Optic Flow Sensors to Optic Flow Based Guidance**, *Franck Ruffier*, CNRS –Aix Marseille Université, France

ICUAS' 21 TECHNICAL PROGRAM AT A GLANCE

Wednesday, June 16

Macedonia Hall	Kozani	Edessa	Naoussa
10:30-12:30 WeA1 Fault Tolerant Control	**10:30-12:30 WeA2** Learning Methods I	**10:30-12:30 WeA3** Path Planning I	**10:30-12:30 WeA4** Sensor Fusion I
14:00–15:40 WeB1 Navigation	**14:00–15:40 WeB2** Learning Methods II	**14:00-15:40 WeB3** Path Planning II	**14:00-15:40 WeB4** Sensor Fusion II

Thursday, June 17

Macedonia Hall	Kozani	Edessa	Naoussa
10:30-12:30 ThA1 FDI and Safety	**10:30-12:30 ThA2** Control Design I	**10:30-12:30 ThA3** Path Planning III	**10:30-12:30 ThA4** UAS Applications I
14:00-15:40 ThB1 Reliability of UAS	**14:00-15:40 ThB2** Control Design II	**14:00-15:40 ThB3** Path Planning IV	**14:00-15:40 ThB4** UAS Applications II
17:00-18:40 ThC1 Micro and Mini UAS	**17:00-18:40 ThC2** Control Design III	**17:00-18:40 ThC3** Path Planning V	**17:00-18:40 ThC4** UAS Applications III

Friday, June 18

Macedonia Hall	Kozani	Edessa	Naoussa

Poster Paper Session, Friday, 09:00 – 12:00 Registration Foyer

09:00-10:40 FrA1 Autonomy I	**09:00-10:40 FrA2** Control Design IV	**09:00-10:40 FrA3** Path Planning VI	**09:00-10:40 FrA4** UAS Applications IV
11:00-13:00 FrB1 Autonomy II	**11:00-13:00 FrB2** Control Design V	**11:00-13:00 FrB3** Neural Networks	**11:00-13:00 FrB4** Safety, Security and Reliability
14:00-15:40 FrC1 Estimation and Bio-Inspired UAVs	**14:00-15:40 FrC2** See-And-Avoid Systems	**14:00-15:40 FrC3** Swarms I	**14:00-15:40 FrC4** Technology Challenges
16:00-17:40 FrD1 Manned/Unmanned Aviation and UAS Testbeds	**16:00-17:40 FrD2** UAS Communications	**16:00-17:40 FrD3** Swarms II	**16:00-18:00 FrD4** Airspace Control and Management

ICUAS'21 TECHNICAL SESSIONS AND CONTENT LIST

Technical Program for Wednesday June 16, 2021

WeA1	Macedonia Hall
Fault-Tolerant Control (Regular Session)	
Chair: Freddi, Alessandro	Università Politecnica Delle Marche
Co-Chair: Cristofaro, Andrea	Sapienza Università Di Roma

10:30-10:50 — WeA1.1

Fault-Tolerant Formation Control of a Team of Quadrotors with a Suspended Payload, pp. 1-9.

Saiella, Lorenzo	Sapienza Università Di Roma
Cristofaro, Andrea	Sapienza Università Di Roma
Ferro, Marco	Sapienza Università Di Roma
Vendittelli, Marilena	Sapienza Università Di Roma

10:50-11:10 — WeA1.2

Adaptive Control of Unmanned Quadrotor with Partial Actuator Failure Using Model Reference Adaptive Control (MRAC) with Dynamic Inversion, pp. 10-19.

Agarwal, Anmol	Technical University of Munich
Ng, Ee Meng	Nanyang Technological University
Low, Kin Huat	Nanyang Technological University

11:10-11:30 — WeA1.3

Disturbance Observer Based Fault Tolerant Control for Tilted Hexarotors, pp. 20-27.

Baldini, Alessandro	Università Politecnica Delle Marche
Felicetti, Riccardo	Università Politecnica Delle Marche
Freddi, Alessandro	Università Politecnica Delle Marche
Longhi, Sauro	Università Politecnica Delle Marche
Monteriù, Andrea	Università Politecnica Delle Marche

11:30-11:50 — WeA1.4

A Preliminary Parametric Analysis of PID Delay-Based Controllers for Quadrotor UAVs, pp. 28-37.

Castillo Zamora, Jose de Jesus	University Paris Saclay & IPSA
Hernández-Díez, José Enrique	Universidad Autónoma De San Luis Potosí
Boussaada, Islam	University Paris Saclay & IPSA
Escareno Castro, Juan Antonio	XLIM Research Institute, University of Limoges
Alvarez Muñoz, Jonatan Uziel	EXTIA

11:50-12:10 — WeA1.5

Multirotor Fault Tolerance Based on Center-Of-Mass Shifting in Case of Rotor Failure, pp. 38-46.

Pose, Claudio Daniel	Universidad De Buenos Aires
Giribet, Juan Ignacio	Universidad De San Andrés

12:10-12:30 — WeA1.6

Adaptive Fault-Tolerant Control of Fixed-Wing UAV under Actuator Saturation and State Constraints, pp. 47-52.

Fu, Minrui	Nanjing University of Aeronautics and Astronautics
Yu, Ziquan	Nanjing University of Aeronautics and Astronautics
Zhang, Youmin	Concordia University

WeA2	Kozani
Learning Methods I (Regular Session)	
Chair: Orsag, Matko	University of Zagreb
Co-Chair: Dezan, Catherine	Université De Bretagne Occidentale

10:30-10:50 — WeA2.1

Area Surveillance Using a UAV with Mounted Chaotic Camera, pp. 53-62.

Kafetzis, Ioannis	Aristotle University of Thessaloniki

Moysis, Lazaros	Aristotle University of Thessaloniki
Volos, Christos	Aristotle University of Thessaloniki
Stouboulos, Ioannis	Aristotle University of Thessaloniki
Valavanis, Kimon P.	University of Denver

10:50-11:10 WeA2.2

Identification of Drone Thermal Signature by Convolutional Neural Network, pp. 63-70.

Chong, Yu Quan	National University of Singapore
Ong, Edmond	National University of Singapore
Srigrarom, Sutthiphong	National University of Singapore

11:10-11:30 WeA2.3

Simultaneous Learning and Planning Using Rapidly Exploring Random Tree and Reinforcement Learning*, pp. 71-80.

Sadhu, Arup Kumar	Tata Consultancy Services Ltd
Shukla, Shubham	Tata Consultancy Services Ltd
Sortee, Sarvesh	Tata Consultancy Services Ltd
Ludhiyani, Mohit	Tata Consultancy Services Ltd
Dasgupta, Ranjan	Tata Consultancy Services Ltd

11:30-11:50 WeA2.4

Detection of Objects on the Ocean Surface from a UAV with Visual and Thermal Cameras: A Machine Learning Approach, pp. 81-90.

Arnegaard, Ola Tranum	Norwegian University of Science and Technology
Stendahl Leira, Frederik	Norwegian University of Science and Technology
Helgesen, Håkon Hagen	Norwegian University of Science and Technology
Kemna, Stephanie	Maritime Robotics AS
Johansen, Tor Arne	Norwegian University of Science and Technology

11:50-12:10 WeA2.5

Event-Based Human Intrusion Detection in UAS Using Deep Learning, pp. 91-100.

Pérez-Cutiño, Miguel Angel	Universidad De Sevilla
Gómez Eguíluz, Augusto	Universidad De Sevilla
Martinez-de Dios, J.R.	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

12:10-12:30 WeA2.6

Comparison of Value Iteration, Policy Iteration and Q-Learning for Solving Decision-Making Problems, pp. 101-110.

Hamadouche, Mohand	Université De Bretagne Occidentale
Dezan, Catherine	Université De Bretagne Occidentale
Espes, David	Université De Bretagne Occidentale
Branco, Kalinka Regina Lucas Jaquie Castelo	University of São Paulo

WeA3 Edessa

Path Planning I (Regular Session)

Chair: Primatesta, Stefano	Politecnico Di Torino
Co-Chair: Pinto, Joao	Instituto Superior Técnico

10:30-10:50 WeA3.1

Model Predictive Sample-Based Motion Planning for Unmanned Aircraft Systems, pp. 111-119.

Primatesta, Stefano	Politecnico Di Torino
Pagliano, Alessandro	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino

10:50-11:10 WeA3.2

Three Dimensional Optimal Path Generation and Tracking for Quadrotors in Dynamic Environment, pp. 120-128.

Ravichandran, Hariharan	Indian Institute of Technology Kharagpur
Yadla, Siddarth	Indian Institute of Technology Kharagpur

Hota, Sikha	Indian Institute of Technology Kharagpur

11:10-11:30	WeA3.3

Lyapunov Vector Field Based Guidance Algorithm for Standoff Target Tracking by Formation Flight, pp. 129-136.

Gopalabhatla, Avinash	Indian Institute of Technology Kharagpur
Tammineni, Harinarayana	Indian Institute of Technology Kharagpur
Hota, Sikha	Indian Institute of Technology Kharagpur

11:30-11:50	WeA3.4

Planning Parcel Relay Manoeuvres for Quadrotors, pp. 137-145.

Pinto, Joao	Instituto Superior Técnico
Guerreiro, Bruno J. N.	NOVA School of Science and Technology
Cunha, Rita	Instituto Superior Técnico

11:50-12:10	WeA3.5

Dubins-Based Autolanding Procedure for Fixed-Wing UAS, pp. 146-154.

Xu, Jeffrey	University of Kansas
Keshmiri, Shawn	University of Kansas

12:10-12:30	WeA3.6

Cooperative Route Planning of Multiple Fuel-Constrained Unmanned Aerial Vehicles with Recharging on an Unmanned Ground Vehicle, pp. 155-164.

Ramasamy, Subramanian	University of Illinois at Chicago
Reddinger, Jean-Paul	Army Research Lab
Dotterweich, James	Army Research Lab
Childers, Marshal	Army Research Lab
Bhounsule, Pranav	University of Illinois at Chicago

WeA4	Naoussa
Sensor Fusion I (Regular Session)	

Chair: Rizzo, Alessandro	Politecnico Di Torino
Co-Chair: Alparslan, Onder	National Defense University Hezarfen

10:30-10:50	WeA4.1

Vision-Aided State Estimator for Positioning UAVs, pp. 165-174.

Hu, Xiao	Technical University of Denmark
Olesen, Daniel	Technical University of Denmark
Knudsen, Per	Technical University of Denmark

10:50-11:10	WeA4.2

Fast and Effective Identification of Window and Door Openings for UAVs' Indoor Navigation, pp. 175-181.

Alparslan, Onder	National Defense University Hezarfen
Cetin, Omer	National Defense University Hezarfen

11:10-11:30	WeA4.3

Fast Adaptive Complementary Filter for Quadrotor Attitude Estimation During Aggressive Maneuvers, pp. 182-187.

Peng, Rui	The University of Hong Kong
Lu, Peng	The University of Hong Kong

11:30-11:50	WeA4.4

Feedback State Estimation for Multi-Rotor Drones Stabilisation Using Low-Pass Filter and a Complementary Kalman Filter, pp. 188-194.

Kangunde, Vemema	Botswana International University of Science and Technology
Mohutsiwa, Lucky Odirile	Botswana International University of Science and Technology
Jamisola, Rodrigo S. Jr.	Botswana International University of Science and Technology

11:50-12:10	WeA4.5

On the Development of a Tether-Based Drone Localization System, pp. 195-201.

Lima, Rogerio	West Virginia University

Pereira, Guilherme	West Virginia University

12:10-12:30	WeA4.6

Velocity Estimation for UAVs Using Ultra Wide-Band System, pp. 202-209.

Safaei, Ali	McGill University
Sharf, Inna	McGill University

WeB1 — Macedonia Hall

Navigation (Regular Session)

Chair: Saska, Martin	Czech Technical University in Prague
Co-Chair: Bryne, Torleiv Håland	Norwegian University of Science and Technology

14:00-14:20	WeB1.1

Phased Array Radio Navigation System on UAVs: GNSS-Based Calibration in the Field, pp. 210-218.

Okuhara, Mika	Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

14:20-14:40	WeB1.2

Snake-SLAM: Efficient Global Visual Inertial SLAM Using Decoupled Nonlinear Optimization, pp. 219-228.

Rückert, Darius	University of Erlangen-Nuremberg
Stamminger, Marc	University of Erlangen-Nuremberg

14:40-15:00	WeB1.3

Real-Time Relative Positioning System Implementation Employing Signals of Opportunity, Inertial, and Optical Flow Modalities, pp. 229-236.

Souli, Nicolas	University of Cyprus
Makrigiorgis, Rafael	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Ellinas, Georgios	University of Cyprus

15:00-15:20	WeB1.4

Development and Implementation of a New Flight Mode Called Cartesian Flight Mode for Easy Piloting of Muli-Rotor UAVs, pp. 237-242.

Flores, Alejandro	Center for Research in Optics, A.C
Flores, Gerardo	Center for Research in Optics, A.C

15:20-15:40	WeB1.5

LIDAR-Based Stabilization, Navigation and Localization for UAVs Operating in Dark Indoor Environments, pp. 243-251.

Petrlik, Matej	Czech Technical University in Prague
Krajnik, Tomas	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague

WeB2 — Kozani

Learning Methods II (Regular Session)

Chair: Alqahtani, Sarra	Wake Forest University
Co-Chair: Ide, Jaime, S.	Yale University & Lockheed Martin

14:00-14:20	WeB2.1

Deep Learning Assisted Visual Tracking of Evader-UAV, pp. 252-257.

Tsoukalas, Athanasios	New York University Abu Dhabi
Xing, Daitao	New York University
Evangeliou, Nikolaos	New York University Abu Dhabi
Giakoumidis, Nikolaos	New York University Abu Dhabi
Tzes, Anthony	New York University Abu Dhabi

14:20-14:40	WeB2.2

Overriding Learning-Based Perception Systems for Control of Autonomous Unmanned Aerial Vehicles, pp. 258-264.

Patel, Naman Kamleshbhai	NYU Tandon School of Engineering
Krishnamurthy, Prashanth	NYU Tandon School of Engineering
Tzes, Anthony	New York University Abu Dhabi
Khorrami, Farshad	NYU Tandon School of Engineering

14:40-15:00 WeB2.3

Deep Reinforcement Learning for Adaptive Exploration of Unknown Environments, pp. 265-274.

Peake, Ashley	Wake Forest University
McCalmon, Joe	Wake Forest University
Zhang, Yixin	Wake Forest University
Myers,, Daniel	Wake Forest University
Alqahtani, Sarra	Wake Forest University
Pauca, Paul	Wake Forest University

15:00-15:20 WeB2.4

Hierarchical Reinforcement Learning for Air-To-Air Combat, pp. 275-284.

Pope, Adrian, P	Primordial Labs
Ide, Jaime, S.	Yale University & Lockheed Martin
Micovic, Daria	Lockheed Martin
Diaz, Henry	Lockheed Martin
Rosenbluth, David	Lockheed Martin
Ritholtz, Lee	Lockheed Martin
Twedt, Jason	Lockheed Martin
Walker, Thayne	University of Denver & Lockheed Martin
Alcedo, Kevin	Lockheed Martin
Javorsek, Daniel	US Airforce

15:20-15:40 WeB2.5

Temporal-Logic-Constrained Hybrid Reinforcement Learning to Perform Optimal Aerial Monitoring with Delivery Drones, pp. 285-294.

Asarkaya, Ahmet	University of Minnesota
Aksaray, Derya	University of Minnesota
Yazicioglu, Yasin	University of Minnesota

WeB3 Edessa

Path Planning II (Regular Session)

Chair: Bertrand, Sylvain	ONERA
Co-Chair: Satler, Massimo	Scuola Superiore Sant'Anna

14:00-14:20 WeB3.1

Formation Tracking of Target Moving on Natural Surfaces, pp. 295-302.

Nadour, Housseyne	Gipsa-Lab, CNRS
Marchand, Nicolas	Gipsa-Lab, CNRS
Reveret, Lionel	INRIA
Legneur, Pierre	University Lyon I

14:20-14:40 WeB3.2

Deployment Optimization of a Fleet of Drones for Routine Inspection of Networks of Linear Infrastructures, pp. 303-310.

Petitprez, Etienne	ONERA
Georges, Frederic	ONERA
Raballand, Nicolas	ONERA
Bertrand, Sylvain	ONERA

14:40-15:00 WeB3.3

Planning Approach Trajectories to Enable Late Aborts for Fixed-Wing UAV Recovery on Ships, pp. 311-320.

Sollie, Martin Lysvand	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

15:00-15:20 WeB3.4

Efficient Online Jerk-Limited Trajectory Generation for Multicopters Using Barrier Functions, pp. 321-329.

Zaini, Abdul Hanif	Nanyang Technological University
Cao, Kun	Nanyang Technological University
Xie, Lihua	Nanyang Technological University

15:20-15:40 WeB3.5

An Efficient Object-Oriented Exploration Algorithm for Unmanned Aerial Vehicles, pp. 330-337.

Herrera Alarcon, Edwin Paul	Scuola Superiore Sant'Anna
Bagheri, Davide	Scuola Superiore Sant'Anna
Baris, Gabriele	Scuola Superiore Sant'Anna
Mugnai, Michael	Scuola Superiore Sant'Anna
Satler, Massimo	Scuola Superiore Sant'Anna
Avizzano, Carlo Alberto	Scuola Superiore Sant'Anna

WeB4 Naoussa

Sensor Fusion II (Regular Session)

Chair: Milutinovic, Dejan	University of California, Santa Cruz
Co-Chair: Malle, Nicolaj Haarhøj	University of Southern Denmark

14:00-14:20 WeB4.1

Gamma Radiation Source Localization for Micro Aerial Vehicles with a Miniature Single-Detector Compton Event Camera, pp. 338-346.

Baca, Tomas	Czech Technical University in Prague
Stibinger, Petr	Czech Technical University in Prague
Doubravova, Daniela	Advacam, S.r.o
Turecek, Daniel	Advacam, S.r.o
Solc, Jaroslav	Czech Metrology Institute
Rusnak, Jan	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague
Jakubek, Jan	Advacam, S.r.o

14:20-14:40 WeB4.2

Interacting Multiple Model Filter Based Autonomous Landing Considering Camera Model Uncertainty, pp. 347-353.

Jeong, Hyeon-Mun	Korea Advanced Institute of Science and Technology
Lee, Woo-Cheol	Korea Advanced Institute of Science and Technology
Choi, Han-Lim	Korea Advanced Institute of Science and Technology

14:40-15:00 WeB4.3

Monte-Carlo Localization for Aerial Robots Using 3D LiDAR and UWB Sensing, pp. 354-360.

Carrasco, Paloma	Advanced Center for Aerospace Technologies (FADA-CATEC)
Cuesta, Francisco	Advanced Center for Aerospace Technologies (FADA-CATEC)
Caballero González, Rafael	Advanced Center for Aerospace Technologies (FADA-CATEC)
Perez-Grau, Francisco Javier	Advanced Center for Aerospace Technologies (FADA-CATEC)
Viguria, Antidio	Advanced Center for Aerospace Technologies (FADA-CATEC)

15:00-15:20 WeB4.4

Survey and Evaluation of Sensors for Overhead Cable Detection Using UAVs, pp. 361-370.

Malle, Nicolaj Haarhøj	University of Southern Denmark
Nyboe, Frederik Falk	University of Southern Denmark
Ebeid, Emad Samuel Malki	University of Southern Denmark

15:20-15:40 WeB4.5

Relative Spherical-Visual Localization for Cooperative Unmanned Aerial Systems, pp. 371-376.

Holter, Steffen	New York University Abu Dhabi

Tsoukalas, Athanasios	New York University Abu Dhabi
Evangeliou, Nikolaos	New York University Abu Dhabi
Giakoumidis, Nikolaos	New York University Abu Dhabi
Tzes, Anthony	New York University Abu Dhabi

Technical Program for Thursday, June 17, 2021

ThA1 — Macedonia Hall

FDI and Safety (Regular Session)

Chair: Fourlas, George K.	University of Thessaly
Co-Chair: Haaland, Ole Max	Norwegian University of Science and Technology

10:30-10:50 — ThA1.1

Detection and Isolation of Propeller Icing and Electric Propulsionsystem Faults in Fixed-Wing UAVs, pp. 377-386.

Haaland, Ole Max	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Hann, Richard	Norwegian University of Science and Technology
Wenz, Andreas Wolfgang	Norwegian University of Science and Technology

10:50-11:10 — ThA1.2

Adaptation of Lazy-Theta for UAS 3D Path Planning Considering Safety Costs*, pp. 387-393.

Rey, Rafael	Universidad Pablo De Olavide
Cobano, Jose Antonio	Universidad Pablo De Olavide
Merino, Luis	Universidad Pablo De Olavide
Caballero, Fernando	Universidad De Sevilla

11:10-11:30 — ThA1.3

A Survey on Fault Diagnosis Methods for UAVs, pp. 394-403.

Fourlas, George K.	University of Thessaly
Karras, George	University of Thessaly

11:30-11:50 — ThA1.4

Nonlinear Estimation of Sensor Faults with Unknown Dynamics for a Fixed Wing Unmanned Aerial Vehicle, pp. 404-412.

Iglésis, Enzo	Coventry University
Horri, Nadjim	Coventry University
Dahia, Karim	ONERA
Brusey, James	Coventry University
Piet-Lahanier, Hélène	ONERA

11:50-12:10 — ThA1.5

Safe Sampling-Based Air-Ground Rendezvous Algorithm for Complex Dense Street Maps, pp. 413-422.

Barsi Haberfeld, Gabriel	University of Illinois at Urbana-Champaign
Gahlawat, Aditya	University of Illinois at Urbana-Champaign
Hovakimyan, Naira	University of Illinois at Urbana-Champaign

12:10-12:30 — ThA1.6

Prognostics-Informed Battery Reconfiguration in a Multi-Battery Small UAS Energy System, pp. 423-432.

Sharma, Prashin	University of Michigan
Atkins, Ella	University of Michigan

ThA2 — Kozani

Control Design I (Regular Session)

Chair: Rodas, Jorge	Universidad Nacional De Asunción
Co-Chair: Boukal, Yassine	Altran by Capgemini

10:30-10:50	ThA2.1

New Hybrid Fractional-Order Control-Based Disturbances Observer on of Autonomous Quadrotor Vehicles Subjected to Disturbances, pp. 433-438.

Labbadi, Moussa	Mohammed V University in Rabat
Boudaraia, Karima	Mohammed V University in Rabat
Boukal, Yassine	Altran by Capgemini
Zerrougui, Mohamed	Aix Marseille University
Cherkaoui, Mohamed	Mohammed V University in Rabat

10:50-11:10	ThA2.2

Flight Transition Control for Ducted Fan UAV with Saturation on Control Surfaces, pp. 439-446.

Cheng, Zihuan	South China University of Technology
Pei, Hai-Long	South China University of Technology

11:10-11:30	ThA2.3

EPRL Sliding Mode Flight Controller with Model-Based Switching Manifold of a Quad-Rotor UAV, pp. 447-453.

Kali, Yassine	Ecole De Technologie Superieure
Fallaha, Charles	Ecole De Technologie Superieure
Rodas, Jorge	Universidad Nacional De Asunción
Saad, Maarouf	Ecole De Technologie Superieure
Lesme, Fernando	Universidad Catolica Nuestra Senora De La Asuncion

11:30-11:50	ThA2.4

Robust Reduced-Attitude Control of Fixed-Wing UAVs Using a Generalized Multivariable Super-Twisting Algorithm, pp. 454-464.

Coates, Erlend M.	Norwegian University of Science and Technology
Griffiths, Jenny Bogen	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

11:50-12:10	ThA2.5

Nonlinear Model Predictive Control Combined with Geometric Attitude and Speed Control for Fixed-Wing UAVs, pp. 465-475.

Reinhardt, Dirk	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

12:10-12:30	ThA2.6

Turbulent Wind Gusts Estimation and Compensation Via High-Gain Extended Observer-Based Adaptive Sliding Mode for a Quadrotor UAV, pp. 476-481.

Miranda-Moya, Armando	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey
Wang, Hesheng	Shanghai Jiaotong University

ThA3	Edessa
Path Planning III (Regular Session)	
Chair: Monteriù, Andrea	Università Politecnica Delle Marche
Co-Chair: Skaltsis, George Marios	Cranfield University

10:30-10:50	ThA3.1

Safe Traversal Guidance for Quadrotors Using Gap Bearing Information, pp. 482-487.

E K, Midhun	Indian Institute of Science
Ratnoo, Ashwini	Indian Institute of Science

10:50-11:10	ThA3.2

A Survey of Task Allocation Techniques in MAS, pp. 488-497.

Skaltsis, George Marios	Cranfield University
Shin, Hyo-Sang	Cranfield University
Tsourdos, Antonios	Cranfield University

11:10-11:30	ThA3.3

A Lyapunov Guidance Vector Field Based Continuous Curvature Path Generation for Waypoint Following of UAVs, pp. 498-506.

Harinarayana, Tammineni	Indian Institute of Technology Kharagpur
Krishnan, Siva Vignesh	Indian Institute of Technology Kharagpur
Hota, Sikha	Indian Institute of Technology Kharagpur
Kushwaha, Rahul	Indian Institute of Technology Kharagpur

11:30-11:50 ThA3.4

Path Planning and Reactive Based Control for a Quadrotor with a Suspended Load, pp. 507-516.

Corona, Jose	The Arctic University of Norway
Kristiansen, Raymond	The Arctic University of Norway
Andersen, Tom Stian	The Arctic University of Norway

11:50-12:10 ThA3.5

3D Trajectory Planning for UAV-Based Search Missions: An Integrated Assessment and Search Planning Approach, pp. 517-526.

Papaioannou, Savvas	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Theocharides, Theocharis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Polycarpou, Marios M.	University of Cyprus

12:10-12:30 ThA3.6

Real-Time On-Board Path Planning for UAS-Based Wildfire Monitoring, pp. 527-535.

Islam, S.M. Towhidul	Georgia State University
Hu, Xiaolin	Georgia State University

ThA4 Naoussa

UAS Applications I (Regular Session)

Chair: Nikolakopoulos, George	Luleå University of Technology,
Co-Chair: Kim, Dongbin	University of Nevada, Las Vegas

10:30-10:50 ThA4.1

Aerial Thermal Image Based Convolutional Neural Networks for Human Detection in SubT Environments, pp. 536-541.

Koval, Anton	Luleå University of Technology
Sharif Mansouri, Sina	Luleå University of Technology
Kanellakis, Christoforos	Luleå University of Technology
Nikolakopoulos, George	Luleå University of Technology

10:50-11:10 ThA4.2

Civil Infrastructure Data Acquisition in Urban Environments Based on Multi-UAV Mission, pp. 542-551.

Goricanec, Jurica	University of Zagreb
Ivanovic, Antun	University of Zagreb
Markovic, Lovro	University of Zagreb
Pavlak, Ivan	University of Zagreb
Bogdan, Stjepan	University of Zagreb

11:10-11:30 ThA4.3

Admittance Force-Based UAV-Wall Stabilization and Press Exertion for Documentation andInspection of Historical Buildings, pp. 552-559.

Smrcka, Daniel	Czech Technical University in Prague
Baca, Tomas	Czech Technical University in Prague
Nascimento, Tiago	Universidade Federal Da Paraiba
Saska, Martin	Czech Technical University in Prague

11:30-11:50 ThA4.4

Towards Robust and Efficient Plane Detection from 3D Point Cloud, pp. 560-566.

Sharif Mansouri, Sina	Luleå University of Technology

Kanellakis, Christoforos	Luleå University of Technology
Pourkamali-Anaraki, Farhad	University of Massachusetts Lowell
Nikolakopoulos, George	Luleå University of Technology

11:50-12:10 ThA4.5

Toward Avatar-Drone: A Human-Embodied Drone for Aerial Manipulation, pp. 567-574.

Kim, Dongbin	University of Nevada, Las Vegas
Oh, Paul	University of Nevada, Las Vegas

12:10-12:30 ThA4.6

Aircraft Inspection by Multirotor UAV Using Coverage Path Planning, pp. 575-581.

Silberberg, Patrick	Naval School of Aviation Safety
Leishman, Robert	Air Force Institute of Technology

ThB1 — Macedonia Hall

Reliability of UAS (Regular Session)

Chair: Zhang, Youmin	Concordia University
Co-Chair: Konert, Anna	Lazarski University

14:00-14:20 ThB1.1

Which Is the Best Real-Time Operating System for Drones? Evaluation of the Real-Time Characteristics of NuttX and ChibiOS, pp. 582-590.

Zhang, Mingyang	KU Leuven
Timmerman, Martin	Dedicated Systems Experts NV
Perneel, Luc	Dedicated Systems Experts NV
Toon, Goedemé	KU Leuven

14:20-14:40 ThB1.2

Safely Flying BVLOS in the EU with an Unreliable UAS, pp. 591-601.

Terkildsen, Kristian Husum	University of Southern Denmark
Schultz, Ulrik Pagh	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

14:40-15:00 ThB1.3

Legal and Ethical Aspects of Rules for the Operation of Autonomous Unmanned Aircraft with Artificial Intelligence, pp. 602-609.

Konert, Anna	Lazarski University
Balcerzak, Tomasz	Lazarski University

15:00-15:20 ThB1.4

Flight Test Validation and Verification of the Novel Ln Guidance for Unmanned Aerial Systems, pp. 610-618.

Xu, Jeffrey	University of Kansas
Keshmiri, Shawn	University of Kansas

15:20-15:40 ThB1.5

UAVAT Framework: UAV Auto Test Framework for Experimental Validation of Multirotor sUAS Using a Motion Capture System, pp. 619-629.

Jepsen, Jes Hundevadt	University of Southern Denmark
Terkildsen, Kristian Husum	University of Southern Denmark
Hasan, Agus	Norwegian University of Science and Technology
Jensen, Kjeld	University of Southern Denmark
Schultz, Ulrik Pagh	University of Southern Denmark

ThB2 — Kozani

Control Design II (Regular Session)

Chair: Sarcinelli-Filho, Mário	Federal University of Espirito Santo
Co-Chair: Chowdhury, Mozammal	University of Kansas

14:00-14:20	ThB2.1
Scaled Nonlinear H Infinity Control of an Aerial Manipulator, pp. 630-638.	
Morais Aquino, Junio Eduardo	Federal University of Minas Gerais
Raffo, Guilherme Vianna	Federal University of Minas Gerais

14:20-14:40	ThB2.2
Design and Flight Test Validation of a UAS Lateral-Directional Model Predictive Controller, pp. 639-646.	
Chowdhury, Mozammal	University of Kansas
Keshmiri, Shawn	University of Kansas
Xu, Jeffrey	University of Kansas

14:40-15:00	ThB2.3
Energy-Aware Model Predictive Control with Obstacle Avoidance, pp. 647-655.	
Santos, Marcelo Alves	Federal University of Minas Gerais
Ferramosca, Antonio	University of Bergamo
Raffo, Guilherme Vianna	Federal University of Minas Gerais

15:00-15:20	ThB2.4
Singularity-Free Quaternion Representation to Control a UGV-UAV Formation Performing Trajectory-Tracking Tasks, pp. 656-665.	
Marciano, Harrison	Federal University of Espirito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

15:20-15:40	ThB2.5
Robust Visual Tracking Control Based on Adaptive Sliding Mode Strategy: Quadrotor UAV - Catamaran USV Heterogeneous System, pp. 666-672.	
Gonzalez-Garcia, Alejandro	Tecnologico De Monterrey
Miranda-Moya, Armando	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey

ThB3	Edessa
Path Planning IV (Regular Session)	
Chair: Schwung, Michael	Ruhr-Universität Bochum
Co-Chair: Lorenzo Becce, Lorenzo	Politecnico Di Torino

14:00-14:20	ThB3.1
Minimum-Time Path Planning for Autonomous Landing of UAV on Aerial Drone Carrier, pp. 673-678.	
Alijani, Morteza	Università Di Trento
Osman, Anas	Università Di Trento

14:20-14:40	ThB3.2
Inspection Path Planning for Aerial Vehicles Via Sampling-Based Sequential Optimization, pp. 679-687.	
Shi, Liping	Aarhus University
Mehrooz, Golizheh	University of Southern Denmark
Jacobsen, Rune	Aarhus University

14:40-15:00	ThB3.3
A UAV Global Planner to Improve Path Planning in Unstructured Environments, pp. 688-697.	
Rocha, Lidia	Federal University of São Carlos
Santos, Marcela	Federal University of São Carlos
Igor, Araújo	Federal University of São Carlos
Kelen, Vivaldini	Federal University of São Carlos

15:00-15:20	ThB3.4
Optimal Path Planning for Autonomous Spraying UAS Framework in Precision Agriculture, pp. 698-707.	
Becce, Lorenzo	Politecnico Di Torino
Bloise, Nicoletta	Politecnico Di Torino

Guglieri, Giorgio — Politecnico Di Torino

15:20-15:40 — ThB3.5

Online Trajectory Planning with Application to an UAV Relay Station, pp. 708-713.

Schwung, Michael — Ruhr-Universität Bochum

Lunze, Jan — Ruhr-Universität Bochum

ThB4 — Naoussa

UAS Applications II (Regular Session)

Chair: Flores, Gerardo — Center for Research in Optics, A.C

Co-Chair: Xie, Wenfang — Concordia University

14:00-14:20 — ThB4.1

A UAS Equipped with a Thermal Imaging System with Temperature Calibration for Crop Water Stress Index Computation, pp. 714-720.

Montes de Oca Rebolledo, Andres — Center for Research in Optics, A.C

Flores, Gerardo — Center for Research in Optics, A.C

14:20-14:40 — ThB4.2

A Multi-UAV System for Exploration and Target Finding in Cluttered and GPS-Denied Environments, pp. 721-729.

Zhu, Xiaolong — Queensland University of Technology

Vanegas Alvarez, Fernando — Queensland University of Technology

Gonzalez, Luis Felipe — Queensland University of Technology (QUT)/ QUT Centre for Roboti

Sanderson, Conrad — Data61/CSIRO

14:40-15:00 — ThB4.3

Collaboration between Multiple UAVs for Fire Detection and Suppression, pp. 730-737.

Moffatt, Andrew — California State Polytechnic University, Pomona

Turcios, Nicholas — California State Polytechnic University, Pomona

Edwards, Chase — California State Polytechnic University, Pomona

Karnik, Atharva — California State Polytechnic University, Pomona

Kim, David — California State Polytechnic University, Pomona

Kleinman, Andrew — California State Polytechnic University, Pomona

Nguyen, Hien — California State Polytechnic University, Pomona

Ramos, Victor Javier — California State Polytechnic University, Pomona

Earvin Ranario, Earvin — California State Polytechnic University, Pomona

Sato, Tomo — California State Polytechnic University, Pomona

Uryeu, Dzianis — California State Polytechnic University, Pomona

Bhandari, Subodh — California State Polytechnic University, Pomona

15:00-15:20 — ThB4.4

Detecting and Localizing Objects on an Unmanned Aerial System (UAS) Integrated Witha Mobile Device, pp. 738-743.

Kim, Jinho — United States Military Academy

Lin, Kevin — United States Military Academy

Nogar, Stephen — U.S. Army Research Laboratory

Larkin, Dominic — United States Military Academy

Korpela, Christopher — United States Military Academy

15:20-15:40 — ThB4.5

Forest Fire Detection and Localization Using Thermal and Visual Cameras, pp. 744-749.

Sadi, Mohsen — Concordia University

Zhang, Youmin — Concordia University

Xie, Wenfang — Concordia University

Hossain, F. M. Anim — Concordia University

ThC1	Macedonia Hall
Micro and Mini UAS (Regular Session)	
Chair: Castillo, Pedro	Unviersité De Technologie De Compiègne
Co-Chair: Behera, Laxmidhar	Indian Institute of Technology Kanpur

17:00-17:20 ThC1.1

Least Airspeed Reduction Strategy & Flight Recuperation of a Fixed-Wing Drone, pp. 750-757.

Alatorre, Armando	Université De Technologie De Compiègne
Castillo, Pedro	Université De Technologie De Compiègne
Lozano, Rogelio	Université De Technologie De Compiègne

17:20-17:40 ThC1.2

MicroBrosh UAV: A Basic Risk Operation Self Handled Platform, pp. 758-766.

Lucena, Alysson	Universidade Federal Do Rio Grande Do Norte
Goncalves, Luiz M. G.	Universidade Federal Do Rio Grande Do Norte

17:40-18:00 ThC1.3

Sum of Square Based Event-Triggered Control of Nano-Quadrotor in Presence of Packet Dropouts, pp. 767-776.

Singh, Padmini	Indian Institute of Technology Kanpur
Gupta, Sandeep	Indian Institute of Technology Kanpur
Behera, Laxmidhar	Indian Institute of Technology Kanpur
Verma, Nishchal Kumar	Indian Institute of Technology Kanpur

18:00-18:20 ThC1.4

The MiniHawk-VTOL: Design, Modeling, and Experiments of a Rapidly-Prototyped Tiltrotor UAV, pp. 777-786.

Carlson, Stephen	University of Nevada, Reno
Papachristos, Christos	University of Nevada, Reno

18:20-18:40 ThC1.5

Extinguishing of Ground Fires by Fully Autonomous UAVs Motivated by the MBZIRC 2020 Competition, pp. 787-793.

Walter, Viktor	Czech Technical University in Prague
Spurny, Vojtech	Czech Technical University in Prague
Petrlik, Matej	Czech Technical University in Prague
Baca, Tomas	Czech Technical University in Prague
Žaitlík, David	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague

ThC2	Kozani
Control Design III (Regular Session)	
Chair: Zhang, Youmin	Concordia University
Co-Chair: Osborne, Matthew Hewitt	Cranfield University

17:00-17:20 ThC2.1

A Review of Safe Online Learning for Nonlinear Control Systems, pp. 794-803.

Osborne, Matthew Hewitt	Cranfield University
Shin, Hyo-Sang	Cranfield University
Tsourdos, Antonios	Cranfield University

17:20-17:40 ThC2.2

Cooperative Aerial Slung Load Transportation Using a Novel Adaptive Sliding Mode Controller, pp. 804-813.

N. S., Abhinay	Tata Consultancy Services Ltd
Shobhit, Shubhankar	Tata Consultancy Services Ltd
Sridhar, Nithya	Tata Consultancy Services Ltd
Das, Kaushik	Tata Consultancy Services Ltd

17:40-18:00 ThC2.3

Integrated Guidance and Control for Autonomous Rendezvous of Unmanned Aerial Vehicle During Aerial Refueling, pp. 814-820.

Zhao, Wenbi	Northwestern Polytechnical University

Duan, You — Northwestern Polytechnical University
Yu, Ziquan — Nanjing University of Aeronautics and Astronautics
Qu, Yaohong — Northwestern Ploytechnical University
Zhang, Youmin — Concordia University

18:00-18:20 — ThC2.4

Flatness-Based Control of a Gimballed Fixed-Wing UAS, pp. 821-826.

Morgan, Hayden — Brigham Young University
Beard, Randal W. — Brigham Young University

18:20-18:40 — ThC2.5

An Ellipsoidal-Polytopic Based Approach for Aggressive Navigation Using Nonlinear Model Predictive Control, pp. 827-835.

Pereira, Jean Carlos — CEFET-MG/Campus Divinopolis
Leite, Valter J. S. — CEFET-MG/Campus Divinopolis
Raffo, Guilherme Vianna — Federal University of Minas Gerais

ThC3 — Edessa

Path Planning V (Regular Session)

Chair: Tanner, Herbert G. — University of Delaware
Co-Chair: Eslamiat, Hossein — Southern Illinois University Carbondale

17:00-17:20 — ThC3.1

Exact Reactive Receding Horizon Motion Planning for Aerial Vehicles, pp. 836-842.

Yadav, Indrajeet — University of Delaware
Tanner, Herbert G. — University of Delaware

17:20-17:40 — ThC3.2

Discrete Time Optimal Trajectory Generation and Transversality Condition with Free Final Time, pp. 843-852.

Eslamiat, Hossein — Southern Illinois University Carbondale
Sanyal, Amit — Syracuse University
Lindsay, Clark — Southern Illinois University Carbondale

17:40-18:00 — ThC3.3

Curvature-Constrained Vector Field for Path Following Guidance, pp. 853-857.

Shivam, Amit — Indian Institute of Science
Ratnoo, Ashwini — Indian Institute of Science

18:00-18:20 — ThC3.4

NMPC-Based UAV 3D Target Tracking in the Presence of Obstacles and Visibility Constraints, pp. 858-867.

Tyagi, Prakrit — Delhi Technological University
Kumar, Yogesh — IIIT Delhi
Baliyarasimhuni, Sujit P. — IISER Bhopal

18:20-18:40 — ThC3.5

MK-RRT: Multi-Robot Kinodynamic RRT* Trajectory Planning*, pp. 868-876.

Cain, Brennan — University of South Carolina
Kalaitzakis, Michail — University of South Carolina
Vitzilaios, Nikolaos — University of South Carolina

ThC4 — Naoussa

UAS Applications III (Regular Session)

Chair: Vitzilaios, Nikolaos — University of South Carolina
Co-Chair: Castaneda, Herman — Tecnologico De Monterrey

17:00-17:20 — ThC4.1

3D Multi-Camera Coverage Control of Unmanned Aerial Multirotors, pp. 877-884.

Huang, Sunan — National Universtiy of Singapore

Leong, Wai Lun	National University of Singapore
Teo, S. H.	National Universtiy of Singapore

17:20-17:40	ThC4.2

Visual Rotational Constraints of General UAS Configurations, pp. 885-894.

Morgan, Hayden	Brigham Young University
Beard, Randal W.	Brigham Young University

17:40-18:00	ThC4.3

UAS Sensor Deployment and Retrieval to the Underside of Structures, pp. 895-900.

Carroll, Sabrina	University of South Carolina
Kalaitzakis, Michail	University of South Carolina
Vitzilaios, Nikolaos	University of South Carolina

18:00-18:20	ThC4.4

Payload Swing Attenuation of a Fully-Actuated Hexacopter Via Extended High Gain Observer Based Adaptive Sliding Control, pp. 901-908.

Arizaga-Leon, Jorge Manuel	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey
Castillo, Pedro	Unviersité De Technologie De Compiègne

18:20-18:40	ThC4.5

A Distributed Task Allocation Protocol for Cooperative Multi-UAV Search and Rescue Systems, pp. 909-917.

Pignaton de Freitas, Edison	Federal University of Rio Grande Do Sul
Basso, Maik	Federal University of Rio Grande Do Sul
Arlis Santos da Silva, Antonio	Federal University of Rio Grande Do Sul
Schein, Mateus Schein	Federal University of Rio Grande Do Sul
Rodrigues Vizzotto, Marcos	Federal University of Rio Grande Do Sul

Technical Program for Friday, June 18, 2021

FrA1	Macedonia Hall
Autonomy I (Regular Session)	
Chair: Valavanis, Kimon P.	University of Denver
Co-Chair: Monteriù, Andrea	Università Politecnica Delle Marche

09:00-09:20	FrA1.1

ICARUS: Automatic Autonomous Power Infrastructure Inspection with UAVs, pp. 918-926.

Savva, Antonis	University of Cyprus
Zacharia, Angelos	University of Cyprus
Makrigiorgis, Rafael	University of Cyprus
Anastasiou, Andreas	University of Cyprus
Kyrkou, Christos	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Theocharides, Theocharis	University of Cyprus

09:20-09:40	FrA1.2

Hyperion: A Robust Drone-Based Target Tracking System, pp. 927-933.

Anastasiou, Andreas	University of Cyprus
Makrigiorgis, Rafael	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus

09:40-10:00	FrA1.3

Autonomous Fire Fighting with a UAV-UGV Team at MBZIRC 2020, pp. 934-941.

Quenzel, Jan	University of Bonn

Splietker, Malte	University of Bonn
Pavlichenko, Dmytro	University of Bonn
Schleich, Daniel	University of Bonn
Lenz, Christian	University of Bonn
Schwarz, Max	University of Bonn
Schreiber, Michael	University of Bonn
Beul, Marius	University of Bonn
Behnke, Sven	University of Bonn

10:00-10:20 FrA1.4

Autonomous Cave Exploration Using Aerial Robots, pp. 942-949.

Dharmadhikari, Mihir Rahul	University of Nevada, Reno
Nguyen, Huan	Norwegian University of Science and Technology
Mascarich, Frank	University of Nevada, Reno
Khedekar, Nikhil Vijay	University of Nevada, Reno
Alexis, Konstantinos	Norwegian University of Science and Technology

10:20-10:40 FrA1.5

Autonomous Flight in Unknown GNSS-Denied Environments for Disaster Examination, pp. 950-957.

Schleich, Daniel	University of Bonn
Beul, Marius	University of Bonn
Quenzel, Jan	University of Bonn
Behnke, Sven	University of Bonn

FrA2 Kozani

Control Design IV (Regular Session)

Chair: Koumboulis, Fotis N.	National and Kapodistrian University of Athens
Co-Chair: Baldini, Alessandro	Università Politecnica Delle Marche

09:00-09:20 FrA2.1

Trim Point Transitions Via I/O Decoupling Controllers for 6DOF Quadrotors, pp. 958-967.

Kouvakas, Nikolaos	National and Kapodistrian University of Athens
Koumboulis, Fotis N.	National and Kapodistrian University of Athens

09:20-09:40 FrA2.2

Talking to Autonomous Drones: Command and Control Based on Hierarchical Task Decomposition, pp. 968-977.

Jünger, Franz	German Aerospace Center (DLR)
Schopferer, Simon	German Aerospace Center (DLR)
Benders, Sebastian	German Aerospace Center (DLR)
Dauer, Johann	German Aerospace Center (DLR)

09:40-10:00 FrA2.3

Optimal Hovering Control of a Tail-Sitter Via Model-Free Fast Terminal Slide Mode Controller and Cuckoo Search Algorithm, pp. 978-984.

Zou, Xu	School of Aviation, Northwestern Polytechnical University
Liu, Zhenbao	Northwestern Polytechnical University
Zhao, Wen	School of Aviation, Northwestern Polytechnical University
Chao, Zhang	Northwestern Polytechnical University

10:00-10:20 FrA2.4

Attitude Tracking Control of a Light Aircraft Using Classical and Incremental Nonlinear Dynamic Inversion Approaches, pp. 985-993.

Jayaraman, Balaji	Indian Institute of Technology, Kanpur
Giri, Dipak Kumar	Indian Institute of Technology, Kanpur
Ghosh, A. K. Ghosh	Indian Institute of Technology, Kanpur

10:20-10:40 FrA2.5

Hierarchical Control of Redundant Aerial Manipulators with Enhanced Field of View, pp. 994-1002.

Coelho, Andre	German Aerospace Center (DLR)
Sarkisov, Yuri	Skolkovo Institute of Science and Technology
Lee, Jongseok	German Aerospace Center (DLR)
Balachandran, Ribin	German Aerospace Center (DLR)
Franchi, Antonio	University of Twente
Kondak, Konstantin	German Aerospace Center (DLR)
Ott, Christian	German Aerospace Center (DLR)

FrA3 Edessa

Path Planning VI (Regular Session)

Chair: Theilliol, Didier	University of Lorraine
Co-Chair: Orsag, Matko	University of Zagreb

09:00-09:20 FrA3.1

Multiple Lane UAV Corridor Planning for Urban Mobility System Applications, pp. 1003-1009.

Challa, Vinay	Indian Institute of Science
Gupta, Mohit	Indian Institute of Science
Ratnoo, Ashwini	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

09:20-09:40 FrA3.2

UAS Flight Path Planning Using Numerical Potential Fields in Dense Non-Segregated Airspace, pp. 1010-1019.

M. A., Sajid Ahamed	Indian Institute of Science
Kushwaha, Satya Prakash	Indian Institute of Science
Jana, Shuvrangshu	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

09:40-10:00 FrA3.3

Decentralized Path Planning Approach for Crowd Surveillance Using Drones, pp. 1020-1028.

Nagrare, Samiksha	Indian Institute of Science
Chopra, Onkar	Indian Institute of Science
Jana, Shuvrangshu	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

10:00-10:20 FrA3.4

Quadrotor UAV 3D Path Planning with Optical-Flow-Based Obstacle Avoidance, pp. 1029-1036.

Allasia, Giancarlo	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino
Valavanis, Kimon P.	University of Denver

10:20-10:40 FrA3.5

3D Real-Time Energy Efficient Path Planning for a Fleet of Fixed-Wing UAVs, pp. 1037-1046.

Aiello, Giuseppe	Politecnico Di Torino
Valavanis, Kimon P.	University of Denver
Rizzo, Alessandro	Politecnico Di Torino

FrA4 Naoussa

UAS Applications IV (Regular Session)

Chair: Yang, Chenhao	University of Tübingen
Co-Chair: Freddi, Alessandro	Università Politecnica Delle Marche

09:00-09:20 FrA4.1

Learning-Based Camera Relocalization with Domain Adaptation Via Image-To-Image Translation, pp. 1047-1054.

Yang, Chenhao	University of Tübingen
Liu, Yuyi	Kyoto University
Zell, Andreas	University of Tübingen

09:20-09:40	FrA4.2

SwarmPaint: Human-Swarm Interaction for Trajectory Generation and Formation Control by DNN-Based Gesture Interface, pp. 1055-1062.

Serpiva, Valerii	Skolkovo Institute of Science and Technology
Karmanova, Ekaterina	Skolkovo Institute of Science and Technology
Fedoseev, Aleksey	Skolkovo Institute of Science and Technology
Perminov, Stepan	Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry	Skolkovo Institute of Science and Technology

09:40-10:00	FrA4.3

Design of an Aerial Manipulator System Applied to Capture Missions, pp. 1063-1069.

Zhang, Wenyu	Beihang University
Liu, Qianyuan	Beihang University
Wang, Meng	Beihang University
Jia, Jindou	Beihang University
Lyu, Shangke	Beihang University
Guo, Kexin	Beihang University
Yu, Xiang	Beihang University
Guo, Lei	Beihang University

10:00-10:20	FrA4.4

Soft-Landing of Multi-Rotor Drones Using a Robust Nonlinear Control and Wind Modeling, pp. 1070-1079.

Nekoo, Saeed Rafee	Universidad De Sevilla
Acosta, Jose Angel	Universidad De Sevilla
Heredia, Guillermo	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

10:20-10:40	FrA4.5

Rogue Agent Identification and Collision Avoidance in Formation Flights Using Potential Fields, pp. 1080-1088.

Jyoti, Ravinder Kumar	Indian Institute of Science
Malhotra, Mohit Kumar	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

FrB1	Macedonia Hall
Autonomy II (Regular Session)	
Chair: Monteriù, Andrea	Università Politecnica Delle Marche
Co-Chair: Wu, Xiangyu	University of California, Berkelely

11:00-11:20	FrB1.1

Exploitation of Thermals in Powered and Unpowered Flight of Autonomous Gliders, pp. 1089-1095.

El Tin, Fares	McGill University
Patience, Christian	McGill University
Borowczyk, Alexandre	Notos Technologies
Nahon, Meyer	McGill University
Sharf, Inna	McGill University

11:20-11:40	FrB1.2

Geometrically Based Collision Avoidance for Quadrotors under Short Sensing Distance Conditions, pp. 1096-1105.

Maalouly, Anthony	McGill University
Sharf, Inna	McGill University
Mantegh, Iraj	National Research Council Canada

11:40-12:00	FrB1.3

Vision-Based Guidance for Tracking Dynamic Objects, pp. 1106-1115.

Karmokar, Pritam	University of Texas at Arlington
Dhal, Kashish	University of Texas at Arlington
Beksi, William	University of Texas at Arlington

Chakravarthy, Animesh	University of Texas at Arlington

12:00-12:20	FrB1.4

ATAK Integration through ROS for Autonomous Air-Ground Team, pp. 1116-1122.

Larkin, Dominic	United States Military Academy
Novitzky, Michael	United States Military Academy
Kim, Jinho	United States Military Academy
Korpela, Christopher	United States Military Academy

12:20-12:40	FrB1.5

Development of an Autonomous Soaring Algorithm for Small Unmanned Aircraft Systems, pp. 1123-1130.

Rosales, Jesus	New Mexico State University
Guijarro Reyes, Gabriel Alexis	New Mexico State University
Sun, Liang	New Mexico State University
Garcia Carrillo, Luis Rodolfo	New Mexico State University
Gross, Andreas	New Mexico State University

12:40-13:00	FrB1.6

Autonomous Flight through Cluttered Outdoor Environments Using a Memoryless Planner, pp. 1131-1138.

Lee, Junseok	University of California, Berkeley
Wu, Xiangyu	University of California, Berkeley
Lee, Seung Jae	Seoul National University
Mueller, Mark Wilfried	University of California, Berkeley

FrB2	Kozani
Control Design V (Regular Session)	

Chair: Bogdan, Stjepan	University of Zagreb
Co-Chair: Milijas, Robert	University of Zagreb

11:00-11:20	FrB2.1

Autonomous Collaborative Transport of a Beam-Type Payload by a Pair of Multi-Rotor Helicopters, pp. 1139-1147.

Horyna, Jiri	Czech Technical University in Prague
Baca, Tomas	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague

11:20-11:40	FrB2.2

A Comparison of LiDAR-Based SLAM Systems for Control of Unmanned Aerial Vehicles, pp. 1148-1154.

Milijas, Robert	University of Zagreb
Markovic, Lovro	University of Zagreb
Ivanovic, Antun	University of Zagreb
Petric, Frano	University of Zagreb
Bogdan, Stjepan	University of Zagreb

11:40-12:00	FrB2.3

Low Level Controller for Quadrotors, pp. 1155-1161.

Rodriguez-Cortes, Hugo	CINVESTAV-IPN
Tlatelpa-Osorio, Yarai E.	CINVESTAV-IPN
Ramirez-Rodriguez, Jose Miguel	CINVESTAV-IPN

12:00-12:20	FrB2.4

Controlling a Formation of a MARV in Backward Movements with an UAV for Inspection Tasks, pp. 1162-1170.

Bertolani, Diego Nunes	Federal Institute of Espírito Santo
Bacheti, Vinicius	Federal University of Espirito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

12:20-12:40	FrB2.5

High-Fidelity Modeling and Control Design for a Cooperative High Altitude Long Endurance Aircraft Landing System, pp. 1171-1178.

Rodrigues Della Noce, Eduardo	German Aerospace Center (DLR)

Kalra, Arti	German Aerospace Center (DLR)
Coelho, Andre	German Aerospace Center (DLR)
Muskardin, Tin	German Aerospace Center (DLR)
Kondak, Konstantin	German Aerospace Center (DLR)

12:40-13:00 FrB2.6

Pilot-Assist Landing System for Hover-Capable Fixed-Wing Unmanned Aerial Vehicles in All Flight Regimes, pp. 1179-1186.

Hernandez Ramirez, Juan Carlos	McGill University
Nahon, Meyer	McGill University

FrB3 Edessa

Neural Networks (Regular Session)

Chair: Lerro, Angelo	Politecnico Di Torino
Co-Chair: Orsag, Matko	University of Zagreb

11:00-11:20 FrB3.1

Neural Network Techniques to Solve a Model-Free Scheme for Flow Angle Estimation, pp. 1187-1193.

Lerro, Angelo	Politecnico Di Torino
Brandl, Alberto	Politecnico Di Torino
Gili, Piero	Politecnico Di Torino

11:20-11:40 FrB3.2

Thrust--To--Weight Ratio Optimization for Multi--Rotor Drones Using Neural Network with Six Input Parameters, pp. 1194-1199.

Mogorosi, Tony Oliver	Botswana International University of Science and Technology
Jamisola, Rodrigo S. Jr.	Botswana International University of Science and Technology
Subaschandar, N.	Botswana International University of Science and Technology
Mohutsiwa, Lucky Odirile	Botswana International University of Science and Technology

11:40-12:00 FrB3.3

A Neural Autopilot Training Platform Based on a Matlab and X-Plane Co-Simulation, pp. 1200-1209.

Pinguet, Jérémy	Safrran Electronics & Defense
Feyel, Philippe	Safran Electronics and Defense
Sandou, Guillaume	École Supérieure D'électricité

12:00-12:20 FrB3.4

Neural Network Based Algorithm for Multi-UAV Coverage Path Planning, pp. 1210-1217.

Sanna, Giovanni	Politecnico Di Torino
Godio, Simone	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino

12:20-12:40 FrB3.5

Adaptive Tracking Control for a UAV with Neural Adaptive Compensation Using SMC, pp. 1218-1224.

Rossomando, Francisco	CONICET - Universidad Nacional De San Juan
Rosales, Claudio	CONICET - Universidad Nacional De San Juan
Soria, Carlos	CONICET - Universidad Nacional De San Juan
Gandolfo, Daniel Ceferino	CONICET - Universidad Nacional De San Juan
Carelli, Ricardo	CONICET - Universidad Nacional De San Juan

12:40-13:00 FrB3.6

Nonlinear Adaptive Control of Unmanned Aerial Vehicle Using Echo State Neural Networks, pp. 1225-1232.

Duggan, Christopher	California State Polytechnic University, Pomona
Bhandari, Subodh	California State Polytechnic University, Pomona

FrB4	Naoussa
Safety, Security and Reliability (Regular Session)	
Chair: Valasek, John	Texas A&M University
Co-Chair: la Cour-Harbo, Anders	Aalborg University

11:00-11:20	FrB4.1

Emergency Landing Decision Method for Unmanned Aircraft, pp. 1233-1239.

Ramirez Gomez, Aitor	Aalborg University
la Cour-Harbo, Anders	Aalborg University

11:20-11:40	FrB4.2

Collision Severity Evaluation of Generalized Unmanned Aerial Vehicles (UAVs) Impacting on Aircraft Engines, pp. 1240-1247.

Sivakumar, Anush Kumar	Nanyang Technological University
Che Man, Mohd Hasrizam	Nanyang Technological University
Liu, Hu	Nanyang Technological University
Low, Kin Huat	Nanyang Technological University

11:40-12:00	FrB4.3

Impact Probability Maps Computation and Risk Analysis for 3D Ground Infrastructures Due to UAV Operations, pp. 1248-1257.

Levasseur, Baptiste	ONERA
Bertrand, Sylvain	ONERA

12:00-12:20	FrB4.4

Safety Challenges for Integrating U-Space in Urban Environments, pp. 1258-1267.

Gutierrez, Daniel	Technological Institute of Galicia Foundation
Ventas García, Enrique	Technological Institute of Galicia Foundation

12:20-12:40	FrB4.5

Investigating Malware-In-The-Loop Autopilot Attack Using Falsification of Sensor Data, pp. 1268-1276.

Jares, Garrett	Texas A&M University
Valasek, John	Texas A&M University

12:40-13:00	FrB4.6

Cyber-Security through Dynamic Watermarking for 2-Rotor Aerial Vehicle Flight Control Systems, pp. 1277-1283.

Kim, Jaewon	Texas A&M University
Ko, Woo-Hyun	Texas A&M University
Kumar, P. R.	Texas A&M University

FrC1	Macedonia Hall
Estimation and Bio-Inspired (Regular Session)	
Chair: Arrue, B.C.	Universidad De Sevilla
Co-Chair: Perez Sanchez, Vicente	Universidad De Sevilla

14:00-14:20	FrC1.1

Analysis of Forces Involved in the Perching Maneuver of Flapping-Wing Aerial Systems and Development of an Ultra-Lightweight Perching System, pp. 1284-1290.

Perez Sanchez, Vicente	Universidad De Sevilla
Gómez Tamm, Alejandro Ernesto	Universidad De Sevilla
Garcia Rubiales, Francisco Javier	Universidad De Sevilla
Arrue Ulles, Begoña Chiquinquira	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

14:20-14:40	FrC1.2

Estimation of the Distance from a Surface Based on Local Optic Flow Divergence, pp. 1291-1298.

Bergantin, Lucia	Aix-Marseille Université
Raharijaona, Thibaut	Université De Lorraine
Ruffier, Franck	Aix-Marseille Université

14:40-15:00	FrC1.3
Feedforward Formation Control Based on Self-Organized Body-Schema, pp. 1299-1307.	
Franco-Robles, Jesus	XLIM Research Institute, University of Limoges
Escareno Castro, Juan Antonio	XLIM Research Institute, University of Limoges
Soto-Guerrero, Daniel	XLIM Research Institute, University of Limoges
Labbani-Igbida, Ouiddad	XLIM Research Institute, University of Limoges

15:00-15:20	FrC1.4
Mutli-UAV Method for Continuous Source Rate Estimation of Fugitive Gas Emissions from a Point Source, pp. 1308-1313.	
Hollenbeck, Derek	University of California, Merced
Chen, YangQuan	University of California, Merced

15:20-15:40	FrC1.5
A Flow Disturbance Estimation and Rejection Strategy for Multirotors with Round-Trip Trajectories, pp. 1314-1320.	
Byun, Jaeseung	University of California, Berkeley
Makiharju, Simo	University of California, Berkeley
Mueller, Mark Wilfried	University of California, Berkeley

FrC2	Kozani
See-And-Avoid Systems (Regular Session)	
Chair: McKinnis, Aaron	University of Kansas
Co-Chair: Riordan, James	University of the West of Scotland

14:00-14:20	FrC2.1
Monocular Vision-Based Obstacle Avoidance Scheme for Micro Aerial Vehicle Navigation, pp. 1321-1327.	
Karlsson, Samuel	Luleå University of Technology
Kanellakis, Christoforos	Luleå University of Technology
Sharif Mansouri, Sina	Luleå University of Technology
Nikolakopoulos, George	Luleå University of Technology, Sweden

14:20-14:40	FrC2.2
Flight Test Validation of Adaptive Collision Avoidance Algorithms Using Multiple Unmanned Aircraft, pp. 1328-1336.	
McKinnis, Aaron	University of Kansas
Hauptman, Dustin Hauptman	University of Kansas
Keshmiri, Shawn	University of Kansas
Ewing, Mark	University of Kansas

14:40-15:00	FrC2.3
Multi-Camera Multi-Target Drone Tracking Systems with Trajectory-Based Target Matching and Re-Identification, pp. 1337-1344.	
Sie, Jun Liang Niven	National University of Singapore
Srigrarom, Sutthiphong	National University of Singapore

15:00-15:20	FrC2.4
Vision-Based Sense and Avoid with Monocular Vision and Real-Time Object Detection for UAVs, pp. 1345-1354.	
Leong, Wai Lun	National University of Singapore
Huang, Sunan	National Universtiy of Singapore
Wang, Pengfei	National University of Singapore
Ma, Zhengtian	National University of Singapore
Yang, Hong	National University of Singapore
Sun, Jingxuan	National University of Singapore
Zhou, Yu	National University of Singapore
Abdul Hamid, Mohamed Redhwan	National University of Singapore
Srigrarom, Sutthiphong	National University of Singapore
Teo, Rodney	National University of Singapore

15:20-15:40	FrC2.5

LiDAR Simulation for Performance Evaluation of UAS Detect and Avoid, pp. 1355-1363.

Riordan, James	University of the West of Scotland
Manduhu, Manduhu	University of the West of Scotland
Black, Julie	University of the West of Scotland
Dow, Alexander	University of the West of Scotland
Dooly, Gerard	University of Limerick
Matalonga, Santiago	University of the West of Scotland

FrC3 Edessa

Swarms I (Regular Session)

Chair: Morgado Belo, Eduardo — Universidade De São Paulo

Co-Chair: Felicetti, Riccardo — Università Politecnica Delle Marche

14:00-14:20 FrC3.1

Distributed Event-Based Sliding-Mode Consensus Control in Dynamic Formation for VTOL-UAVs, pp. 1364-1373.

Alvarez Muñoz, Jonatan Uziel	EXTIA
Chevalier, Jérémy	EXTIA
Castillo Zamora, Jose de Jesus	IPSA & CentraleSupelec
Escareno Castro, Juan Antonio	XLIM Research Institute, University of Limoges

14:20-14:40 FrC3.2

Self-Organized UAV Flocking Based on Proximal Control, pp. 1374-1382.

Amorim, Thulio G. S.	Universidade Federal Da Paraiba
Nascimento, Tiago	Universidade Federal Da Paraiba
Petracek, Pavel	Czech Technical University in Prague
De Masi, Giulia	Technology Innovation Institute
Ferrante, Eliseo	Technology Innovation Institute
Saska, Martin	Czech Technical University in Prague

14:40-15:00 FrC3.3

Virtual Structure Formation Flight Control Based on Nonlinear MPC, pp. 1383-1390.

Rosa, Victor Stafy Megda	Universidade De São Paulo
Morgado Belo, Eduardo	Universidade De São Paulo

15:00-15:20 FrC3.4

Safe Tightly-Constrained UAV Swarming inGNSS-Denied Environments, pp. 1391-1399.

Dmytruk, Andriy	Czech Technical University in Prague
Nascimento, Tiago	Universidade Federal Da Paraiba
Ahmad, Afzal	Czech Technical University in Prague
Baca, Tomas	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague

15:20-15:40 FrC3.5

Expanding Domains for Multi-Vehicle Unmanned Systems, pp. 1400-1409.

Giles, Kathleen	Naval Postgraduate School
Davis, Duane	Naval Postgraduate School
Jones, Kevin	Naval Postgraduate School
Jones, Marianna	Naval Postgraduate School

FrC4 Naoussa

Technology Challenges (Regular Session)

Chair: Tzes, Anthony — New York University Abu Dhabi

Co-Chair: Taylor, Max — The Ohio State University

14:00-14:20 FrC4.1

Computationally Efficient RGB-T UAV Detection and Tracking System, pp. 1410-1415.

Xing, Daitao	New York University
Tsoukalas, Athanasios	New York University Abu Dhabi
Giakoumidis, Nikolaos	New York University Abu Dhabi
Tzes, Anthony	New York University Abu Dhabi

14:20-14:40 FrC4.2

Air-Ground Cooperative Exploration of 3D Complex Environment with Maximized Visibility and Obstacles Avoidance, pp. 1416-1421.

Wu, YuXuan	Beijing University of Chemical Technology
Wang, Jing	North China University of Technology
Zhou, Meng	North China University of Technology
Dong, Zhe	North China University of Technology
Chen, YangQuan	University of California, Merced

14:40-15:00 FrC4.3

Asymmetric Quadrotor Modeling and State-Space System Identification, pp. 1422-1431.

Leshikar, Christopher	Texas A&M University
Ninan, Nidhin	Texas A&M University
Eves, Kameron	Texas A&M University
Valasek, John	Texas A&M University

15:00-15:20 FrC4.4

Low Electromagnetic Interference Design and Simulation of Lithium Battery Powered UAV, pp. 1432-1438.

Ge, Jiahao	Beijing Institute of Technology
Liu, Li	Beijing Institute of Technology
He, Yuntao	Beijing Institute of Technology
Cao, Xiao	Beijing Institute of Technology

15:20-15:40 FrC4.5

A Study on Software Bugs in Unmanned Aerial Systems, pp. 1439-1448.

Taylor, Max	The Ohio State University
Boubin, Jayson	The Ohio State University
Chen, Haicheng	The Ohio State University
Stewart, Christopher	The Ohio State University
Qin, Feng	The Ohio State University

FrD1 Macedonia Hall

Manned/Unmanned Aviation and UAS Testbeds (Regular Session)

Chair: Papanikolopoulos, Nikos	University of Minnesota
Co-Chair: Canelon, Dario	University of Minnesota

16:00-16:20 FrD1.1

OpenUAS Version 1.0, pp. 1449-1458.

Johannsen, Chris	Iowa State University
Anderson, Marcella	Iowa State University
Burken, William	Iowa State University
Diersen, Ellie	Iowa State University
Edgren, John	Iowa State University
Glick, Colton	Iowa State University
Jou, Stephanie	Iowa State University
Kumar, Adkyaksh	Iowa State University
Levandowski, John	Iowa State University
Moyer, Evelyn	Iowa State University
Roquet, Taylor	Iowa State University
Vande Loo, Alexander	Iowa State University
Rozier, Kristin Yvonne	Iowa State University

16:20-16:40	FrD1.2
Design Optimization of Wingtip Devices to Reduce Induced Drag on Fixed-Wings, pp. 1459-1465.	
Makgantai, Boitumelo	Botswana International University of Science and Technology
Subaschandar, N.	Botswana International University of Science and Technology
Jamisola, Rodrigo S Jr.	Botswana International University of Science and Technology

16:40-17:00	FrD1.3
Design and Characterization of a Multi-Domain Unmanned Vehicle Operating in Aerial, Terrestrial, and Underwater Environments, pp. 1466-1471.	
Canelon, Dario	University of Minnesota
Westlake, Samuel	University of Minnesota
Wang, Youbing	University of Minnesota
Papanikolopoulos, Nikos	University of Minnesota

17:00-17:20	FrD1.4
A 3D Printing Hexacopter: Design and Demonstration, pp. 1472-1477.	
Nettekoven, Alexander	The University of Texas at Austin
Topcu, Ufuk	The University of Texas at Austin

17:20-17:40	FrD1.5
The Polish Perspective of Using Unmanned Aerial Vehicle Systems in International Firefighting and Crisis Management Missions - Legal and Technological Analysis, pp. 1478-1487.	
Balcerzak, Tomasz	Lazarski University
Jasiuk, Ewa	Lazarski University
Fellner, Andrzej	Silesian University of Technology
Feltynowski, Mariusz	The Main School of Fire Service

FrD2	Kozani
UAS Communications (Regular Session)	
Chair: Brandao, Alexandre Santos	Universidade Federal De Viçosa
Co-Chair: Purucker, Patrick	University of Applied Sciences Amberg-Weiden

16:00-16:20	FrD2.1
Teleoperated Aerial Manipulator and Its Avatar. Communication, System's Interconnection, and Virtual World, pp. 1488-1493.	
Verdìn, Rodolfo Isaac	Center for Research in Optics, A.C
Ramírez, Germán	Center for Research in Optics, A.C
Rivera Quezada, Carlos Arturo	Center for Research in Optics, A.C
Flores, Gerardo	Center for Research in Optics, A.C

16:20-16:40	FrD2.2
RF Detection and Classification of Unmanned Aerial Vehicles in Environments with Wireless Interference, pp. 1494-1498.	
Swinney, Carolyn J.	University of Essex
Woods, John C.	University of Essex

16:40-17:00	FrD2.3
System Requirements Specification for Unmanned Aerial Vehicle (UAV) to Server Communication, pp. 1499-1508.	
Purucker, Patrick	University of Applied Sciences Amberg-Weiden
Schmid, Josef	University of Applied Sciences Amberg-Weiden
Hoess, Alfred	University of Applied Sciences Amberg-Weiden
Schuller, Björn	University of Augsburg

17:00-17:20	FrD2.4
Towards SORA-Compliant BVLOS Communication, pp. 1509-1519.	
Andersen, Frederik Mazur	University of Southern Denmark
Terkildsen, Kristian Husum	University of Southern Denmark
Schultz, Ulrik Pagh	University of Southern Denmark

Jensen, Kjeld	University of Southern Denmark

17:20-17:40	FrD2.5

On the Evaluation of Access-Point Handovers for UAVs in Long-Distance Missions, pp. 1520-1529.

Alves Fagundes Junior, Leonardo	Universidade Federal De Viçosa
Souza, Vitor Barbosa	Universidade Federal De Viçosa
Brandao, Alexandre Santos	Universidade Federal De Viçosa

FrD3 Edessa

Swarms II (Regular Session)

Chair: Causa, Flavia	Università Di Napoli Federico II
Co-Chair: Vazquez Trejo, Juan Antonio	University of Lorraine

16:00-16:20	FrD3.1

Formation-Containment for a MAV Fleet UnderPerturbations Via Adaptive Sliding Mode Approach, pp. 1530-1537.

Katt, Carlos	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey
Castillo, Pedro	Unviersité De Technologie De Compiègne

16:20-16:40	FrD3.2

Cooperative Navigation and Visual Tracking with Passive Ranging for UAV Flight in GNSS-Challenging Environments, pp. 1538-1547.

Causa, Flavia	Università Di Napoli Federico II
Opromolla, Roberto	Università Di Napoli Federico II
Fasano, Giancarmine	Università Di Napoli Federico II

16:40-17:00	FrD3.3

A Review of Consensus-Based Multi-Agent UAV Applications, pp. 1548-1557.

Lizzio, Fausto Francesco	Politecnico Di Torino
Capello, Elisa	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino

17:00-17:20	FrD3.4

Unified Control Solution for Mobile Robot Formations, pp. 1558-1564.

Rosales, Claudio	CONICET - Universidad Nacional De San Juan
Rossomando, Francisco	CONICET - Universidad Nacional De San Juan
Salinas, Lucio Rafael	CONICET - Universidad Nacional De San Juan
Gimenez, Javier	CONICET - Universidad Nacional De San Juan
Carelli, Ricardo	CONICET - Universidad Nacional De San Juan

17:20-17:40	FrD3.5

Robust Observer-Based Leader-Following Control for a Class of Nonlinear Multi-Agent Systems: Application to Fleet of UAVs, pp. 1565-1572.

Vazquez Trejo, Juan Antonio	University of Lorraine
Rotondo, Damiano	University of Stavanger
Adam-Medina, Manuel	National Center for Research and Technological Development
Theilliol, Didier	University of Lorraine

FrD4

Airspace Control and Management (Regular Session) Naoussa

Chair: Milutinovic, Dejan	University of California, Santa Cruz
Co-Chair: Quan, Quan	Beihang University

16:00-16:20	FrD4.1

Modeling, Design and Manufacturing of Delta-Wing UAV, pp. 1573-1579.

Srour, Ali	Paris Saclay
Noura, Hassan	Islamic University of Lebanon

16:20-16:40	FrD4.2
Ring Formation Maneuvering with Double Integrator Dynamics, pp. 1580-1586.	
Tran, Dzung	Air Force Research Laboratory
Casbeer, David	Air Force Research Laboratory
Garcia, Eloy	Air Force Research Laboratory
Weintraub, Isaac E.	Air Force Research Laboratory
Milutinovic, Dejan	University of California, Santa Cruz

16:40-17:00	FrD4.3
RflySim: A Rapid Multicopter Development Platform for Education and Research Based on Pixhawk and MATLAB, pp. 1587-1594.	
Wang, Shuai	Beihang University
Dai, Xunhua	Central South University
Ke, Chenxu	Beihang University
Quan, Quan	Beihang University

17:00-17:20	FrD4.4
Enhancing SkyVision: Integrating UAS Flight Information with ATC Data, pp. 1595-1604.	
Lamping, Anthony	University of Cincinnati
Ouwerkerk, Justin	University of Cincinnati
Barnes, Evan	University of Cincinnati
DeGroote, Nicholas	University of Cincinnati
Wessels, Austin	University of Cincinnati
Brown, Bryan	University of Cincinnati
Cohen, Kelly	University of Cincinnati

17:20-17:40	FrD4.5
A Lifting Wing Fixed on Multirotor UAVs for Long Flight Ranges, pp. 1605-1610.	
Xiao, Kun	Beihang University
Meng, Yao	Beihang University
Dai, Xunhua	Central South University
Zhang, Haotian	Beihang University
Quan, Quan	Beihang University

17:40-18:00	FrD4.6
Lane Geometry, Compliance Levels, and Adaptive Geo-Fencing in CORRIDRONE Architecture for Urban Mobility, pp. 1611-1617.	
Tony, Lima Agnel	Indian Institute of Science
Ratnoo, Ashwini	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

FrPS	Foyer, Mezzanine Level
Poster Papers Session (Poster Session)	
Chair: Silano, Giuseppe	Czech Technical University in Prague
Co-Chair: Khanam, Zeba	University of Essex

09:00-09:15	FrPS.1
A Dual Frequency Blade Antenna Enabling UAV-Based Operations in ADS-B and 5G Environments, pp. 1618-1623.	
Arpaio, Maximilian James	Alma Mater Studiorum, Università Di Bologna
Fuschini, Franco	Alma Mater Studiorum, Università Di Bologna
Masotti, Diego	Alma Mater Studiorum, Università Di Bologna

09:15-09:30	FrPS.2
A Multi-Layer Software Architecture for Aerial Cognitive Multi-Robot Systems in Power Line Inspection Tasks, pp. 1624-1629.	
Silano, Giuseppe	Czech Technical University in Prague
Bednar, Jan	Czech Technical University in Prague

Nascimento, Tiago	Universidade Federal Da Paraiba
Capitan, Jesus	Universidad De Sevilla
Saska, Martin	Czech Technical University in Prague
Ollero, Anibal	Universidad De Sevilla

09:30-09:45 FrPS.3

A Vision-Based Algorithm for a Path Following Problem, pp. 1630-1635.

Terlizzi, Mario	Università Del Sannio
Silano, Giuseppe	Czech Technical University in Prague
Russo, Luigi	Università Del Sannio
Aatif, Muhammad	Università Del Sannio
Basiri, Amin	Università Del Sannio
Mariani, Valerio	Università Del Sannio
Iannelli, Luigi	Università Del Sannio
Glielmo, Luigi	Università Del Sannio

09:45-10:00 FrPS.4

Appraisal of Autonomous Swarms through Analysis of Observed Behavior, pp. 1636-1641.

Helble, Sarah	Johns Hopkins Applied Physics Laboratory
Guinn, Andrew	Johns Hopkins Applied Physics Laboratory
Blake, Joshua	Johns Hopkins University Applied Physics Laboratory

10:00-10:15 FrPS.5

Assisted Canopy Sampling Using Unmanned Aerial Vehicles (UAVs), pp. 1642-1647.

La Vigne, Hughes	Université De Sherbrooke
Charron, Guillaume	Université De Sherbrooke
Hovington, Samuel	Université De Sherbrooke
Desbiens, Alexis Lussier	Université De Sherbrooke

10:15-10:30 FrPS.6

Flight Plan Management System for Unmanned Aircraft Vehicles Using Blockchain, pp. 1648-1652.

Yaguchi, Yuichi	University of Aizu
Wakazono, Takuya	University of Aizu

10:30-10:45 FrPS.7

Impedance-Based Control for Soft UAV Landing on a Ground Robot in Heterogeneous Robotic System, pp. 1653-1658.

Kalinov, Ivan	Skolkovo Institute of Science and Technology
Petrovsky, Alexander	Skolkovo Institute of Science and Technology
Agishev, Ruslan	Skolkovo Institute of Science and Technology
Karpyshev, Pavel	Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry	Skolkovo Institute of Science and Technology

10:45-11:00 FrPS.8

Near-Optimal Coverage Path Planning of Distributed Regions for Aerial Robots with Energy Constraint, pp. 1659-1664.

Khanam, Zeba	University of Essex
McDonald-Maier, Klaus	University of Essex
Ehsan, Shoaib	University of Essex

11:00-11:15 FrPS.9

Neural Networks Algorithms for Ornithopter Trajectory Optimization, pp. 1665-1670.

Pérez-Cutiño, Miguel Angel	Universidad De Sevilla
Rodríguez, Fabio	Universidad De Sevilla
Pascual Callejo, Luis David	Universidad De Sevilla
Díaz-Báñez, José-Miguel	Universidad De Sevilla

11:15-11:30 FrPS.10

Performance of Sliding Mode and Consensus-Based Control Approaches for Quadrotor Leader-Follower Formation Flight, pp. 1671-1676.

Wu, Falin	Beihang University

He, Jiaqi | Beihang University
Zhou, Guopeng | Beihang University
Li, Haolun | Beihang University
Liu, Yushuang | Beijing System Design Institute of Electro-Mechanic Engineering

11:30-11:45 FrPS.11

Region Coverage Flight Path Planning Using Multiple UAVs to Monitor the Huge Areas, pp. 1677-1682.

Yaguchi, Yuichi | University of Aizu
Tomeba, Tomoki | University of Aizu

11:45-12:00 FrPS.12

Time Cooperation Method for Multiple UCAVs Based on Hybrid Non-Uniform Adjustment, pp. 1683-1688.

Bi, Wenhao | Northwestern Polytechnical University
Li, Chong | 28th Research Institute of China Electronics Technology Group
Zhang, An | Northwestern Polytechnical University
Gao, Fei | Northwestern Polytechnical University

ICUAS'21 PAPER ABSTRACTS

Technical Program for Wednesday June 16, 2021

WeA1	Macedonia Hall
Fault-Tolerant Control (Regular Session)	

10:30-10:50	WeA1.1

Fault-Tolerant Formation Control of a Team of Quadrotors with a Suspended Payload, pp. 1-9

Saiella, Lorenzo	Sapienza University of Rome
Cristofaro, Andrea	Sapienza University of Rome
Ferro, Marco	Sapienza University of Rome
Vendittelli, Marilena	Sapienza University of Rome

This paper proposes a fault-tolerant architecture for formation control and cooperative trajectory tracking for a team of autonomous quadrotors carrying a suspended load. Formation stability is provided by the combination of passivity-based techniques and backstepping control, while a supervisory fault-tolerant control policy is responsible to reconfigure the network topology and the control objectives upon detection of faults among the vehicles.

10:50-11:10	WeA1.2

Adaptive Control of Unmanned Quadrotor with Partial Actuator Failure Using Model Reference Adaptive Control (MRAC) with Dynamic Inversion, pp. 10-19

Agarwal, Anmol	Technical University of Munich
Ng, Ee Meng	Nanyang Technological University
Low, Kin Huat	Nanyang Technological University

Unmanned Aerial Vehicles (UAVs) often experience disturbances during operation, which will degrade its performance and may cause potential failure, affecting safety risks to civilians and other 3rd parties. In such event, UAVs with the common cascaded PID control might not be sufficient to compensate for this reduction in performance. This paper proposes to analyze algorithm for adaptive control, mainly focused on the model reference adaptive control (MRAC) such that despite any uncertainty the plant parameters remain close to the behavior of a desired reference model along with dynamic inversion as an adaptive controller for such scenarios which helps in decoupling of the flight states for the non-linear system. The results of the proposed method are compared with conventional PID based controller by implanting faults in motor outputs. The performance of the control are in terms of trajectory following is the compared.

11:10-11:30	WeA1.3

Disturbance Observer Based Fault Tolerant Control for Tilted Hexarotors, pp. 20-27

Baldini, Alessandro	Università Politecnica Delle Marche
Felicetti, Riccardo	Università Politecnica Delle Marche
Freddi, Alessandro	Università Politecnica Delle Marche
Longhi, Sauro	Università Politecnica Delle Marche
Monteriù, Andrea	Università Politecnica Delle Marche

Tilted multirotors have superior redundancy and tracking capabilities over conventional multirotors with coplanar and collinear rotors. As such, they can potentially cope with actuator faults while still achieving tracking in both position and attitude. In this paper, the tracking fault tolerant control problem for a tilted hexarotor is addressed. Actuator partial loss of effectiveness is treated as a multiplicative fault, and the design approach is that of the disturbance observer-based control. A feedback linearization based composite controller is then proposed for the fault's accommodation. Simulation results show that the proposed active fault tolerant control scheme is able to cope with actuator faults.

11:30-11:50	WeA1.4

A Preliminary Parametric Analysis of PID Delay-Based Controllers for Quadrotor UAVs, pp. 28-37

Castillo Zamora, Jose de Jesus	University Paris Saclay & IPSA
Hernández-Díez, José Enrique	Universidad Autónoma De San Luis Potosí
Boussaada, Islam	University Paris Saclay & IPSA
Escareno Castro, Juan Antonio	XLIM Research Institute, University of Limoges
Alvarez Muñoz, Jonatan Uziel	EXTIA

The actual paper provides a set of parametric stability charts considering a quadrotor rotorcraft performing stabilizing maneuvers under the presence of feedback time-delays and subjected to PID controllers. The analysis considers the couplings between the translational (slow dynamics) and the rotational (fast dynamics) motions. The parameters of the controllers, within the overall control scheme, are computed using the well-known stability crossing roots theory. Numerical simulation results, including the full dynamic model and the corresponding linear model of the vehicle, are presented to validate the proposal.

11:50-12:10	WeA1.5

Multirotor Fault Tolerance Based on Center-Of-Mass Shifting in Case of Rotor Failure, pp. 38-46

Pose, Claudio Daniel	Universidad De Buenos Aires
Giribet, Juan Ignacio	Universidad De San Andrés

This work carries out an analysis on fault tolerance in multirotor vehicles, particularly for an hexarotor one, where such feature is achieved by shifting the center of mass in case of a motor failure. It will be shown that, for an hexarotor vehicle, for each of the possible motor failures, there exists an optimal fixed position for the center of mass, in order to keep independent control of four degrees of freedom, and to obtain the best maneuverability. The performance of this solution will be compared with a previous design based on motor reconfiguration in case of a motor failure.

12:10-12:30	WeA1.6

Adaptive Fault-Tolerant Control of Fixed-Wing UAV under Actuator Saturation and State Constraints, pp. 47-52

Fu, Minrui	Nanjing University of Aeronautics and Astronautics
Yu, Ziquan	Nanjing University of Aeronautics and Astronautics
Zhang, Youmin	Concordia University

This paper proposes a fault-tolerant control (FTC) scheme for unmanned aerial vehicles (UAVs) with state constraints, actuator saturation, and faults. Firstly, a nonlinear mapping function is designed to transform the limited states into new unlimited states. Furthermore, based on the transformed system, neural network (NN) is used to approximate the unknown nonlinear function caused by the parametric uncertainties, external disturbances, and actuator faults. Then, dynamic surface control (DSC) technique is used to solve the problem of “explosion of complexity”. Moreover, an auxiliary system is designed to avoid actuator saturation and a Nussbaum function is used to simplify solving the inverse of the matrix in the auxiliary system. Finally, the Lyapunov method is used to prove the correctness of the FTC scheme, and simulation results show the effectiveness of this scheme.

WeA2	Kozani
Learning Method I (Regular Session)	

10:30-10:50	WeA2.1

Area Surveillance Using a UAV with Mounted Chaotic Camera, pp. 53-62

Kafetzis, Ioannis	Aristotle University of Thessaloniki
Moysis, Lazaros	Aristotle University of Thessaloniki
Volos, Christos	Aristotle University of Thessaloniki
Stouboulos, Ioannis	Aristotle University of Thessaloniki
Valavanis, Kimon P.	University of Denver

This research focuses on the problem of area surveillance, using a UAV with a mounted camera that is controlled chaotically. The chaotic motion of the camera is performed by using the values of a chaotic map, to generate random rotation angles for the camera head, which periodically captures photos of the area to be surveyed. In this way, the position of the camera footprint on the ground is unpredictable, and this makes the surveillance path impossible to predict for an adversary. Thus, this approach allows for increased security when required, since the use of unpredictable agents will make it hard to design infiltration strategies. Simulations are performed for several different scenarios, to evaluate the ground coverage of the chaotic camera, as compared to a camera that constantly looks directly below the UAV.

10:50-11:10	WeA2.2

Identification of Drone Thermal Signature by Convolutional Neural Network, pp. 63-70

Chong, Yu Quan	National University of Singapore
Ong, Edmond	National University of Singapore
Srigrarom, Sutthiphong	National University of Singapore

This paper presents the work on drone detection and identification by using thermal infrared emission for night operation. Through both indoor and outdoor trials, the characteristics of the thermal signature emitted by a drone when captured by a drone detection system is examined, and their implications on a machine learning problem are studied. Thermal maps are processed through a transfer learning using YOLOv3 based CNN model to detect and generate a bounding box around the thermal signature of the drone. The presented approach also seeks to utilise the characteristics of drone motion for more effective drone detection through machine learning.

11:10-11:30	WeA2.3

Simultaneous Learning and Planning Using Rapidly Exploring Random Tree and Reinforcement Learning*, pp. 71-80

Sadhu, Arup Kumar	Tata Consultancy Services Ltd
Shukla, Shubham	Tata Consultancy Services Ltd
Sortee, Sarvesh	Tata Consultancy Services Ltd
Ludhiyani, Mohit	Tata Consultancy Services Ltd

Dasgupta, Ranjan Tata Consultancy Services Ltd

The paper proposes an approach to learn and plan simultaneously in a partially known environment. The proposed framework exploits the Voronoi-based property of Rapidly exploring Random Tree ∗ (RRT∗), which balances the exploration-exploitation in Reinforcement Learning (RL). RL is employed to learn policy (sequence of actions), while RRT∗ is planning simultaneously. Once policy is learned for a fixed start and goal, repeated planning for identical start and goal can be avoided. In case of any environmental uncertainties, RL dynamically adapts the learned policy with the help of RRT∗. Apparently, both learning and planning complement each other to handle environmental uncertainties dynamically in real-time and online. Interestingly, more the proposed algorithm runs, its efficiency increases in terms of planning time and uncertainty handling capability over the contender algorithm (i.e., RRT∗). Simulation results are shown to demonstrate the efficacy of the proposed approach.

11:30-11:50 WeA2.4

Detection of Objects on the Ocean Surface from a UAV with Visual and Thermal Cameras: A Machine Learning Approach, pp. 81-90

Arnegaard, Ola Tranum Norwegian University of Science and Technology
Stendahl Leira, Frederik Norwegian University of Science and Technology
Helgesen, Håkon Hagen Norwegian University of Science and Technology
Kemna, Stephanie Maritime Robotics AS
Johansen, Tor Arne Norwegian University of Science and Technology

Unmanned aerial vehicles (UAVs) can provide great value in offshore operations that require aerial surveillance, for example by detecting objects on the water surface. For efficient operations by autonomous aerial surveillance, a reliable automatic detection system must be in place: one that will limit the amount of false negatives, but not at the expense of too many false positives. In this paper, we assess multiple aspects of the detection system that may provide significant impact in offshore aerial surveillance: First by assessing detection architectures based on convolutional neural networks, then by adding tracking algorithms to utilize temporal information, and finally by investigating the use of different imaging modalities. Through a comparison of several detection models, the experiments prove that misclassification of objects is a particular issue, where input resolution and size of objects influence the overall model performance. The use of a tracking algorithm allows for decreasing the confidence threshold, which results in fewer false negatives, without a significant increase in false positives. In addition, comparing information obtained from visual and thermal imaging systems shows that these modalities provide complementary information in the presence of sunlight reflection.

11:50-12:10 WeA2.5

Event-Based Human Intrusion Detection in UAS Using Deep Learning, pp. 91-100

Pérez-Cutiño, Miguel Angel Universidad De Sevilla
Gómez Eguíluz, Augusto Universidad De Sevilla
Martinez-de Dios, J.R. Universidad De Sevilla
Ollero, Anibal Universidad De Sevilla

Automatic intrusion detection in unstructured and complex environments using autonomous Unmanned Aerial Systems (UAS) poses perception challenges in which traditional techniques are severely constrained. Event cameras have high temporal resolution and dynamic range, which make them robust against motion blur and lighting conditions. This paper presents an event-by-event processing scheme for detecting human intrusion using UAS. It includes: 1) one method for detecting clusters of events caused by moving objects in static background; and 2) one method based on Convolutional Neural Networks to compute the probability that a cluster corresponds to a person. The proposed scheme has been implemented and validated in challenging scenarios.

12:10-12:30 WeA2.6

Comparison of Value Iteration, Policy Iteration and Q-Learning for Solving Decision-Making Problems, pp. 101-110

Hamadouche, Mohand Université De Bretagne Occidentale
Dezan, Catherine Université De Bretagne Occidentale
Espes, David Université De Bretagne Occidentale
Branco, Kalinka Regina Lucas Jaquie Castelo University of São Paulo

21st century has seen a lot of progress, especially in robotics. Today, the evolution of electronics and computing capacities allows to develop more precise, faster and autonomous robots. They are able to automatically perform certain delicate or dangerous tasks. Robots should move, perceive their environment and make decisions by taking into account the goal(s) of a mission under uncertainty. One of the most current probabilistic model for description of missions and for planning under uncertainty is Markov Decision Process (MDP). In addition, there are three fundamental classes of methods for solving these MDPs: dynamic programming, Monte Carlo methods, and temporal difference learning. Each class of methods has its strengths and weaknesses. In this paper, we present our comparison on three methods for solving MDPs, Value Iteration and Policy Iteration (Dynamic Programming methods) and Q-Learning (Temporal-Difference method). We give new criteria to adapt the decision-making method to the application problem, with the parameters explanations. Policy Iteration is the most effective method for complex (and irregular) scenarios, and the modified Q-Learning for simple (and regular) scenarios. So, the regularity aspect of the decision-making has to be taken into account to choose the most appropriate resolution method in terms of execution time. Numerical simulation shows the conclusion results over simple and regular case of the grid, over the irregular case of the grid example and finally over the mission planning of an Unmanned Aerial Vehicle (UAV), representing is a very irregular case. We demonstrate that the Dynamic Programming (DP) methods are more efficient methods than the Temporal-Difference (TD) method while facing an irregular set of actions.

WeA3	Edessa
Path Planning I (Regular Session)	

10:30-10:50	WeA3.1

Model Predictive Sample-Based Motion Planning for Unmanned Aircraft Systems, pp. 111-119

Primatesta, Stefano	Politecnico Di Torino
Pagliano, Alessandro	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino

This paper presents an innovative kinodynamic motion planning algorithm for Unmanned Aircraft Systems, called MP-RRT#. MP-RRT# leverages the idea of RRT# and the Model Predictive Control strategy to solve a motion planning problem under differential constraints. Similar to RRT#, the algorithm explores the map by constructing an asymptotically optimal graph. Each time the graph is extended with a new vertex, a forward simulation is performed with a Model Predictive Control to evaluate the motion between two adjacent vertices and compute the trajectory in the state space and the control space. As result, the MP-RRT# algorithm generates a feasible trajectory for the UAS satisfying dynamic constraints. Preliminary simulation results corroborate the proposed approach, in which the computed trajectory is executed by a simulated drone controlled with the PX4 autopilot.

10:50-11:10	WeA3.2

Three Dimensional Optimal Path Generation and Tracking for Quadrotors in Dynamic Environment, pp. 120-128

Ravichandran, Hariharan	Indian Institute of Technology Kharagpur
Yadla, Siddarth	Indian Institute of Technology Kharagpur
Hota, Sikha	Indian Institute of Technology Kharagpur

This paper presents a collision avoidance algorithm for quadrotors in a three-dimensional (3D) cluttered environment filled with dynamic obstacles, including a path re-planning algorithm to rejoin with its original trajectory in optimal time. The algorithms are based on a geometrical approach, accomplished by changing the heading and the pitch angles of the quadrotor simultaneously while keeping its speed constant. The novelty of the proposed work is that the algorithm ensures a smooth path generation for both the collision avoidance and re-planning maneuvers for the quadrotor with very low tracking error, including optimality in path length. To validate the proposed algorithm, the generated path is tracked using a dynamic model of a quadrotor using a Lyapunov-based backstepping controller in the presence of external disturbances.

11:10-11:30	WeA3.3

Lyapunov Vector Field Based Guidance Algorithm for Standoff Target Tracking by Formation Flight, pp. 129-136

Gopalabhatla, Avinash	Indian Institute of Technology Kharagpur
Tammineni, Harinarayana	Indian Institute of Technology Kharagpur
Hota, Sikha	Indian Institute of Technology Kharagpur

This paper deals with the formation of multiple fixed-wing Unmanned Aerial Vehicles (UAVs) for standoff target tracking. The formation of all the UAVs is made to function as a single rigid UAV and which is operated by commanding a virtual UAV imagined to be at the centre of the formation. A new Lyapunov vector field based guidance algorithm is proposed to Control the virtual UAV for the tracking the targets, both stationary and moving. The algorithm also ensures continuous curvature near optimal path generation, which is hitherto unexplored as the solution available in the existing literature is of discontinuous curvature. The work finds a solution to the practical problem caused by the inherent deficiency of a single UAV e.g. the limitation of the sensor coverage, data integrity and sudden break down etc., especially in a critical mission. Finally, simulation results of both formation flight and standoff target tracking of the UAVs are illustrated to demonstrate the efficacy of the guidance law.

11:30-11:50	WeA3.4

Planning Parcel Relay Manoeuvres for Quadrotors, pp. 137-145

Pinto, Joao	Instituto Superior Técnico
Guerreiro, Bruno J. N.	NOVA School of Science and Technology
Cunha, Rita	Instituto Superior Técnico

In this paper, a strategy for planning aggressive collision-free parcel relay manoeuvres for quadrotors is proposed. The method relies on the generation of optimal polynomial trajectories with acceleration constraints in order to coordinate the attitude of the vehicles during the package exchange. The problem is formulated as a mixed-integer quadratic program where the integer constraints ensure collision avoidance. The manoeuvre is divided into three phases and the dynamical model of the robots is considered to ensure the vehicles keep a suitable relative orientation during the parcel transfer. Simulation results demonstrate the success of the presented strategy.

11:50-12:10	WeA3.5

Dubins-Based Autolanding Procedure for Fixed-Wing UAS, pp. 146-154

Xu, Jeffrey	University of Kansas
Keshmiri, Shawn	University of Kansas

Unmanned aerial systems are quickly growing in usage in both military and civilian applications. Unmanned aerial systems are quickly growing in usage in both military and civilian applications. The exponential growth in applications of unmanned aerial systems has provided many new opportunities such as urban air mobility. With the imminent entrance of unmanned aerial systems to the national airspace aircraft will be flying at lower heights over people and properties and will be landing in spatially constraint landing fields. Piloting UASs is an extremely exhausting endeavor, especially when complexities like landing in constraint spaces is involved. This paper introduces cognitive autolanding algorithms, where the standard landing stages of flare, glideslope, and approach, are employed to land the aircraft safely and the same time spatial and aircraft dynamic constraints are satisfied efficiently. The use of Dubins paths during the approach stage is explored and employed in this work showing how algorithms can be used to direct the aircraft towards any landing field from adverse initial headings and positions. The autolanding generated path is then flown in a six-degrees-of-freedom simulation environment. The robustness of this cognitive autolanding algorithm is validated using Monte Carlo analysis.

12:10-12:30 WeA3.6

Cooperative Route Planning of Multiple Fuel-Constrained Unmanned Aerial Vehicles with Recharging on an Unmanned Ground Vehicle, pp. 155-164

Ramasamy, Subramanian	University of Illinois at Chicago
Reddinger, Jean-Paul	Army Research Lab
Dotterweich, James	Army Research Lab
Childers, Marshal	Army Research Lab
Bhounsule, Pranav	University of Illinois at Chicago

Multiple small, low-cost, multi-rotor unmanned aerial vehicles (UAVs) are ideal for aerial surveillance over large areas. However, their limited battery capacity restricts them to areas in proximity of stationary recharging depots. One solution is to use an unmanned ground vehicle (UGV) to provide a moving recharging depot. The problem is then to find the time- or energy-optimal paths for the multiple fuel-constrained UAVs to visit a set of mission points while being recharged by stopping at the UGV, whose path also needs to be determined. This is a combinatorial optimization problem that is computationally challenging, but maybe solved relatively fast using heuristics. In this paper, we present two-level optimization that involves, (1) finding a UGV path by fixing waypoints using K-means and then formulating and solving a traveling salesman problem (TSP), and (2) finding paths for the multiple UAVs using a vehicle routing problem (VRP) formulation with capacity constraints, time windows, and dropped visits. We used constraint programming to solve these problems in less than a minute on a standard desktop computer for up to 25 mission points and 4 UAVs. Our main observation is that increasing the number of UAVs decreases the mission time and refueling stops, but does not decrease the total distance covered or total time taken.

WeA4 Naoussa

Sensor Fusion I (Regular Session)

10:30-10:50 WeA4.1

Vision-Aided State Estimator for Positioning UAVs, pp. 165-174

Hu, Xiao	Technical University of Denmark
Olesen, Daniel	Technical University of Denmark
Knudsen, Per	Technical University of Denmark

Recent developments of UAVs have sparked interest in building UAV-based magnetic surveying systems. Due to the sensitivity of magnetic sensors, direct positioning the magnetometer via traditional devices, e.g., GNSS and UWB, is not possible. However, to get obtain georeferenced data, it is necessary to localize the payload accurately. This paper presents the sensor fusion technique used for the development of an accurate vision-based positioning solution. The sensor fusion module builds upon a square-root unscented Kalman filter to fuse the relative positioning results computed by a monocular camera with the global positioning results from a GNSS/IMU system to determine a target's global positions. The developed method has been validated by real flight experiments. Experimental results show it can provide accurate position estimations, achieving single-axis centimeter-level positioning accuracy and decimeter-level overall 3D positioning accuracy.

10:50-11:10 WeA4.2

Fast and Effective Identification of Window and Door Openings for UAVs' Indoor Navigation, pp. 175-181

Alparslan, Onder	National Defense University Hezarfen
Cetin, Omer	National Defense University Hezarfen

As one of today's popular research field, autonomous unmanned systems are widely used in entertainment, search and rescue, health, military, agriculture and many other fields with the advantages of technological developments. Object detection is one of the methods used for autonomous vehicles to gather and report information about its environment during mission. With the ability to detect and classify objects, an unmanned vehicle can determine the type and number of objects around it and use this information in its autonomous motion and path planning or reporting the objects with the desired features. In an indoor environment, the data coming from an optic sensor provides enough capability to detect crossing points for an intelligent unmanned aerial vehicle such as doors, windows and stairs. However, sliding objects like windows and doors need to be classified as open or closed if this information will be used for path planning. Moreover, the crossing point's width needs to be calculated to ensure it is safe to go through it. So as to provide a robust navigation plan, LIDAR sensor data can be used to ensure object classification. In this study, a method to fuse LIDAR and optic sensors data has been developed and by the way a stronger object detection method is created. A crossing point is classified as an open/closed and determined

whether to have enough space or not to pass through. This method was operated in a developer board mountable in a flying quadrotor which makes it possible to use it in a real-time scenario. The success of the approach has been shown with different scenarios.

11:10-11:30 WeA4.3

Fast Adaptive Complementary Filter for Quadrotor Attitude Estimation During Aggressive Maneuvers, pp. 182-187

Peng, Rui — The University of Hong Kong
Lu, Peng — The University of Hong Kong

It is challenging to provide accurate attitude estimation for a quadrotor during aggressive maneuvers, which involve violent and fast motion with uncertainty on sensors. In this unique case, we propose a fast adaptive Complementary Filter, which fuses raw measurements from a MARG sensor system and could cope with the large range of quadrotor maneuvers. The performance of the filter is validated on an actual quadrotor platform, by comparing with the Extended Kalman Filter (EKF) and the Error State Kalman Filter (ESKF) simultaneously. The experimental results show that the proposed CF has better estimate accuracy, low time-latency and stable orientation outputs in a quadrotor's attitude estimate.

11:30-11:50 WeA4.4

Feedback State Estimation for Multi-Rotor Drones Stabilisation Using Low-Pass Filter and a Complementary Kalman Filter, pp. 188-194

Kangunde, Vemema — Botswana International University of Science and Technology
Mohutsiwa, Lucky Odirile — Botswana International University of Science and Technology
Jamisola, Rodrigo S. Jr. — Botswana International University of Science and Technology

This paper presents a low-pass filter and a complementary Kalman filter for improving the quality of UAV feedback control information by means of onboard UAV sensor fusion. The control of UAVs requires real-time feedback from onboard sensors to update the status of the UAV. Localisation is achieved by determining the UAV attitude and position. While the UAV position can be provided by sensors such as the GPS receiver, attitude estimation for UAVs is provided, mostly, by an IMU. IMU sensors are mainly the accelerometer, gyroscope, and magnetometer. These sensors have limitations in the accuracy caused by sensor drift and noise and thus needed post-processing for sensor data improvement. This paper focuses on correctly estimating roll and pitch angles using a Kalman filter and tests the performance of the estimated feedback angle information on a quadrotor platform. Index Terms—Multi-rotor drones, inertial measurement unit, Kalman filte

11:50-12:10 WeA4.5

On the Development of a Tether-Based Drone Localization System, pp. 195-201

Lima, Rogerio — West Virginia University
Pereira, Guilherme — West Virginia University

This paper proposes an approach for localization of tethered drones using information from the shape of the tether and the vehicles' inertial data. Our approach relies on the fact that, in static or quasi-static conditions, a flexible tether will assume a catenary shape, thus allowing the use of known equations to formulate the localization algorithm. These equations are based on tether variables such as tether length, tension, and azimuth and elevation angles on both endpoints. To deal with uncertainties and to improve localization performance, a sensor fusion algorithm based on the Extended Kalman Filter (EKF) is applied. In this preliminary validation, we tested our method through experiments with a static real-world tether, and simulations with a drone in slow flight. In both cases, the proposed method successfully estimated positions in the presence of noisy measurements.

12:10-12:30 WeA4.6

Velocity Estimation for UAVs Using Ultra Wide-Band System, pp. 202-209

Safaei, Ali — McGill University
Sharf, Inna — McGill University

In this paper, a 3D velocity estimation solution based on ultra wide-band (UWB) signals is developed for navigation of unmanned aerial vehicles (UAVs) in indoor spaces. The solution incorporates two consecutive gradient descent optimizations for position and velocity estimation, as well as two linear Kalman filters for removing noise on the range measurements and the vertical position estimate. The solution is verified by three experimental scenarios with manual and autonomous flights of a quadrotor. In our implementation, 8 anchors are employed to construct the UWB system, while the Vicon MoCap system is utilized as the ground-truth for assessing the performance of the solution. All proposed algorithms are implemented on a computer on-board the quadrotor, with the low-level control for the quadrotor provided by the PX4 platform. Compared to a motion capturing system, relatively cheap solution for absolute position/velocity estimation is achieved using the UWB system, with appropriate accuracy enough for autonomous flight of UAVs in indoor areas.

WeB1 Macedonia Hall

Navigation (Regular Session)

14:00-14:20 WeB1.1

Phased Array Radio Navigation System on UAVs: GNSS-Based Calibration in the Field, pp. 210-218

Okuhara, Mika — Norwegian University of Science and Technology
Bryne, Torleiv Håland — Norwegian University of Science and Technology

Gryte, Kristoffer — Norwegian University of Science and Technology
Johansen, Tor Arne — Norwegian University of Science and Technology

With global coverage, high accuracy, and lightweight receivers, global navigation satellite system (GNSS) has been the major positioning solution for unmanned aerial vehicles (UAV). However, GNSS is prone to electromagnetic interference and malicious attacks such as jamming or spoofing due to its low signal-to-noise ratio (SNR). To ensure the continuity and safety of UAV operation, the use of redundant navigation systems is crucial. Phased array radio system (PARS) has proven its potential as a local navigation solution in the last few years. PARS is robust against malicious attacks due to significantly higher SNR than GNSS together with directional and encrypted transmission. One of the challenges of the PARS-based navigation is the radio antenna at ground station, as its orientation needs to be determined precisely to obtain accurate navigation solution for unmanned vehicles. This paper presents an automatic calibration algorithm for the ground radio antenna orientation using a multiplicative extended Kalman filter (MEKF) based on GNSS and PARS measurements. The calibration algorithm was tested with data obtained from a field test using a fixed wing UAV and validated by a residual analysis comparing the PARS- and GNSS-based positioning.

14:20-14:40 — WeB1.2

Snake-SLAM: Efficient Global Visual Inertial SLAM Using Decoupled Nonlinear Optimization, pp. 219-228

Rückert, Darius — University of Erlangen-Nuremberg
Stamminger, Marc — University of Erlangen-Nuremberg

Snake-SLAM is a scalable visual inertial SLAM system for autonomous navigation in low-power aerial devices. The tracking front-end features map reuse, loop closing, relocalization, and supports monocular, stereo, and RGBD input. The keyframes are reduced by a graph-based simplification approach and further refined using a novel deferred mapping stage to ensure a sparse yet accurate global map. The optimization back-end decouples IMU state estimation from visual bundle adjustment and solves them separately in two simplified sub problems. This greatly reduces computational complexity and allows Snake-SLAM to use a larger local window size than existing SLAM methods. Our system implements a novel multi-stage VI initialization scheme, which uses gyroscope data to detect visual outliers and recovers metric velocity, gravity, and scale. We evaluate Snake-SLAM on the EuRoC dataset and show that it outperforms all other approaches in efficiency while also achieving state-of-the-art tracking accuracy.

14:40-15:00 — WeB1.3

Real-Time Relative Positioning System Implementation Employing Signals of Opportunity, Inertial, and Optical Flow Modalities, pp. 229-236

Souli, Nicolas — University of Cyprus
Makrigiorgis, Rafael — University of Cyprus
Kolios, Panayiotis — University of Cyprus
Ellinas, Georgios — University of Cyprus

Current navigation technologies are relying on global navigation satellite system (GNSS) information. As in terms of reliability and precision next-generation autonomous vehicle requirements cannot be fully satisfied by GNSS, a sensor information fusion must be employed, leading to the exploration of new positioning methods. In this work, a reliable relative positioning solution in GNSS-challenged areas is investigated, using a combination of signals of opportunity (SOPs), inertial, and optical flow data. The proposed real-time relative positioning system exploits the fused data in the absence of GNSS signals for localization, employing a tracking algorithm to estimate the agent's trajectory in space and time. Extensive outdoor experiments employing an Unmanned Aerial Vehicle (UAV) are carried out to demonstrate the applicability of the proposed technique, validating its performance against various positioning approaches, including GNSS.

15:00-15:20 — WeB1.4

Development and Implementation of a New Flight Mode Called Cartesian Flight Mode for Easy Piloting of Muli-Rotor UAVs, pp. 237-242

Flores, Alejandro — Center for Research in Optics, A.C
Flores, Gerardo — Center for Research in Optics, A.C

This paper presents the development and implementation of a variant of the manual flight mode, the Cartesian mode, which consists of the directional control of a multi-rotor UAV wrt its heading and pilot's heading. The main objective of the presented flight mode is to ease the manual displacement control while the pilot has a ground Point of View (POV). The flight mode's concept is implemented in the PX4 firmware under Software-in-the-Loop (SITL) simulations and real flights to assess its performance applied to a real quadrotor. The results obtained during simulations and real experiments show that the flight mode performs correctly.

15:20-15:40 — WeB1.5

LIDAR-Based Stabilization, Navigation and Localization for UAVs Operating in Dark Indoor Environments, pp. 243-251

Petrlik, Matej — Czech Technical University in Prague
Krajnik, Tomas — Czech Technical University in Prague
Saska, Martin — Czech Technical University in Prague

Autonomous operation of UAVs in a closed environment requires precise and reliable pose estimate that can stabilize the UAV without using external localization systems such as GNSS. In this work, we are concerned with estimating the pose from laser scans generated by an inexpensive and lightweight LIDAR. We propose a localization system for lightweight (under 200 g) LIDAR sensors with high

reliability in arbitrary environments, where other methods fail. The general nature of the proposed method allows deployment in wide array of applications. Moreover, seamless transitioning between different kinds of environments is possible.

The advantage of LIDAR localization is that it is robust to poor illumination, which is often challenging for camera-based solutions in dark indoor environments and in the case of the transition between indoor and outdoor environment. Our approach allows executing tasks in poorly-illuminated indoor locations such as historic buildings and warehouses, as well as in the tight outdoor environment, such as forest, where vision-based approaches fail due to large contrast of the scene, and where large well-equipped UAVs cannot be deployed due to the constrained space.

WeB2	Kozani
Learning Method II (Regular Session)	

14:00-14:20	WeB2.1

Deep Learning Assisted Visual Tracking of Evader-UAV, pp. 252-257

Tsoukalas, Athanasios	New York University Abu Dhabi
Xing, Daitao	New York University
Evangeliou, Nikolaos	New York University Abu Dhabi
Giakoumidis, Nikolaos	New York University Abu Dhabi
Tzes, Anthony	New York University Abu Dhabi

IIn this work the visual tracking of an evading UAV using a pursuer-UAV is examined. The developed method combines principles of deep learning, optical flow, intra-frame homography and correlation based tracking. A Yolo tracker for short term tracking is employed, complimented by optical flow and homography techniques. In case there is no detected evader- UAV, the MOSSE tracking algorithm re-initializes the search and the PTZ-camera zooms-out to cover a wider Filed of View. The camera's controller adjusts the pan and tilt angles so that the evader-UAV is as close to the center of view as possible, while its zoom is commanded in order to for the captured evader-UAV bounding box cover as much as possible the captured-frame. Experimental studies are offered to highlight the algorithm's principle and evaluate its performance.

14:20-14:40	WeB2.2

Overriding Learning-Based Perception Systems for Control of Autonomous Unmanned Aerial Vehicles, pp. 258-264

Patel, Naman Kamleshbhai	NYU Tandon School of Engineering
Krishnamurthy, Prashanth	NYU Tandon School of Engineering
Tzes, Anthony	New York University Abu Dhabi
Khorrami, Farshad	NYU Tandon School of Engineering

In this paper, we demonstrate the vulnerabilities of learning-based algorithms for perception-based autonomy as applied to unmanned aerial systems (UAS). We present an attack framework to compromise the controls of a UAS, which uses a deep neural network (DNN) to track different types of targets in varying terrains. The DNN uses the UAS camera image as input to estimate the six degree-of-freedom (6D) pose of the target relative to the UAS. The UAS flight-controller uses the estimated relative 6D pose to output the motor throttle commands to maintain a specified relative height while keeping the target in the center of the camera's frame. The attacker's objective is to reduce the height of the UAS relative to the target in a controlled fashion (e.g., so as to obtain unauthorized physical access to the UAS). This is achieved by dynamically modifying the texture of the target in the environment. To this end, the attacker uses a digital poster to generate the adversarial tracking target remotely. The digital poster has an integrated camera to estimate the UAS pose relative to itself. The digital poster continuously adapts to the UAS pose while being robust to lighting variations. The attack is effectively demonstrated on the Virtual Robotics Experimentation Platform (V-REP) in a custom-developed environment testbed.

14:40-15:00	WeB2.3

Deep Reinforcement Learning for Adaptive Exploration of Unknown Environments, pp. 265-274

Peake, Ashley	Wake Forest University
McCalmon, Joe	Wake Forest University
Zhang, Yixin	Wake Forest University
Myers,, Daniel	Wake Forest University
Alqahtani, Sarra	Wake Forest University
Pauca, Paul	Wake Forest University

Autonomous exploration is an essential task for unmanned aerial vehicles (UAVs) operating in unknown environments. Often, UAVs on these missions must first build a map of the environment via pure exploration and subsequently use (i.e. exploit) the generated map for downstream navigation tasks. Accomplishing these navigation tasks in two separate steps is not always possible and can even be disadvantageous for UAVs deployed in outdoor and dynamically changing environments. Current exploration approaches typically use a priori human-generated maps or heuristics such as frontier-based exploration. Other approaches use learning but focus only on learning policies for specific tasks and use sample inefficient random exploration or make impractical assumptions about full map availability. In this paper, we develop an adaptive exploration approach that allows for a trade off between exploration and exploitation in a single step using Deep Reinforcement Learning (DRL). We specifically focus on UAVs searching for areas of interest (AoIs) in an unknown environment. The proposed approach uses a map segmentation technique to decompose the environment map into smaller, tractable

maps. DDQN and A2C algorithms are extended with a stack of LSTM layers and trained to generate optimal policies for the exploration and exploitation tasks, respectively. Then, an information gain function is repeatedly computed to determine the optimal trade-off between them. We test our approach in 3 different tasks against 4 baselines. The results demonstrate that our proposed approach is capable of navigating through randomly generated environments and covering more AoI in less time compared to the baselines.

15:00-15:20	WeB2.4

Hierarchical Reinforcement Learning for Air-To-Air Combat, pp. 275-284

Pope, Adrian, P	Primordial Labs
Ide, Jaime, S.	Yale University & Lockheed Martin
Micovic, Daria	Lockheed Martin
Diaz, Henry	Lockheed Martin
Rosenbluth, David	Lockheed Martin
Ritholtz, Lee	Lockheed Martin
Twedt, Jason	Lockheed Martin
Walker, Thayne	University of Denver & Lockheed Martin
Alcedo, Kevin	Lockheed Martin
Javorsek, Daniel	US Airforce

Artificial Intelligence (AI) is becoming a critical component in the defense industry, as recently demonstrated by DARPA's AlphaDogfight Trials (ADT). ADT sought to vet the feasibility of AI algorithms capable of piloting an F-16 in simulated air-to-air combat. As a participant in ADT, Lockheed Martin's (LM) approach combines a hierarchical architecture with maximum-entropy reinforcement learning (RL), integrates expert knowledge through reward shaping, and supports modularity of policies. This approach achieved a 2nd place finish in the final ADT event (among eight total competitors) and defeated a graduate of the US Air Force's (USAF) F-16 Weapons Instructor Course in match play.

15:20-15:40	WeB2.5

Temporal-Logic-Constrained Hybrid Reinforcement Learning to Perform Optimal Aerial Monitoring with Delivery Drones, pp. 285-294

Asarkaya, Ahmet	University of Minnesota
Aksaray, Derya	University of Minnesota
Yazicioglu, Yasin	University of Minnesota

In this paper, we consider a package delivery drone that is desired to simultaneously perform aerial monitoring as a secondary mission. To integrate this secondary mission, we utilize a reward function representing the value of information gathered via aerial monitoring. We use time window temporal logic (TWTL) specifications to define the pickup and delivery tasks while utilizing reinforcement learning (RL) to maximize the expected sum of rewards. The high-level decision-making of the drone is modeled as a Markov decision process (MDP). In this regard, we extend the previous work where a model-free RL algorithm was used to solve this optimization problem. We propose a modified Dyna-Q algorithm to address the shortage of online samples. We provide extensive simulation results to compare the performance of the model-free and hybrid RL algorithms in this application and investigate the effect of the different system parameters on the overall performance.

WeB3	Edessa
Path Planning II (Regular Session)	

14:00-14:20	WeB3.1

Formation Tracking of Target Moving on Natural Surfaces, pp. 295-302

Nadour, Housseyne	Gipsa-Lab, CNRS
Marchand, Nicolas	Gipsa-Lab, CNRS
Reveret, Lionel	INRIA
Legneur, Pierre	University Lyon I

In this paper, we focus mainly on formation control of a swarm of UAV's tracking a moving target on a non-regular mountainous surface. The main objective is to show how to dispatch the whole swarm of the quadrotors around the target (climber) with respect to the natural environment (mountain) taking advantage as much as possible from the free space around the climber. The formation shape adapts with the neighbor environment topology, so that it avoids the collision with the environment and the concealing of the target from the UAV's cameras sights, and ensures as well the formation compactness and its closure to the target respecting the agent-agent and the agent-target security distances. The procedure to define the free and safe hovering space (SHS) is then demonstrated with two other procedures to determine for each agent its desired position within the SHS. This work, that is considered as an introduction for upcoming works, does not miss to provide a simple control for each individual agent based on an established and corrected approximate dynamic model. The main idea to resolve this problem is explained in 2D and will be expanded for 3D environment, with other necessary and complementary enhancements.

14:20-14:40	WeB3.2

Deployment Optimization of a Fleet of Drones for Routine Inspection of Networks of Linear Infrastructures, pp. 303-310

Petitprez, Etienne	ONERA
Georges, Frederic	ONERA
Raballand, Nicolas	ONERA
Bertrand, Sylvain	ONERA

In this paper, the problem of optimizing the deployment of a fleet of Unmanned Aerial Vehicles (UAVs) for the inspection of networks of linear infrastructures is addressed. In this optimization problem, two levels need to be considered: the UAVs need to follow a trajectory allowing them to flyover linear infrastructures, with a limited endurance, while ground vehicles need to be deployed to act as platforms that can launch and retrieve the UAVs from fixed parking positions. Both parking positions of ground vehicles and the UAVs fleet routes along the linear infrastructures have to be optimized to improve the inspection efficiency, which is related to multiple contradictory objectives such as minimizing operational cost and maximizing inspection performance. The algorithm proposed in this paper was developed by expanding upon several algorithms from literature. More precisely, we propose to solve a Two-Echelon Vehicle Routing Problem (2E-VRP) with a custom multi-objective Hybrid Genetic Algorithm (HGA) based on a Capacitated Arc Routing Problem (CARP). Simulation results are provided on a benchmark of networks of linear infrastructures along with a sensitivity analysis on the parameters of the algorithm, showing promising results.

14:40-15:00 WeB3.3

Planning Approach Trajectories to Enable Late Aborts for Fixed-Wing UAV Recovery on Ships, pp. 311-320

Sollie, Martin Lysvand	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

For a fixed-wing UAV performing an autonomous recovery in a ship-mounted arrest system, several events can make it preferrable to abort the landing, including issues with communication systems, navigation sensors, or wind gusts exceeding required limits, in order to retry when conditions improve. If the recovery involves impacting an arrest system, aborts cannot necessarily be performed arbitrarily late without a risk of colliding with other parts of the ship. Automatic aborts should therefore only be possible when a safe abort is feasible. We propose a concept where optimization is used to generate an approach trajectory which enables aborts as late as safely possible. The concept is demonstrated using a simple three-dimensional UAV model, for several different scenarios. This is then compared to less complex approach plans. The implemented example demonstrates that optimization can be useful for planning approach trajectories and allow later aborts than the simple methods.

15:00-15:20 WeB3.4

Efficient Online Jerk-Limited Trajectory Generation for Multicopters Using Barrier Functions, pp. 321-329

Zaini, Abdul Hanif	Nanyang Technological University
Cao, Kun	Nanyang Technological University
Xie, Lihua	Nanyang Technological University

This paper proposes a jerk-limited trajectory generation algorithm using a discrete implementation of the Zeroing Control Barrier Function method. This method achieves greater computational efficiency than previous works as it requires only a single pass in the forward simulation of the triple integrator and does not require a bisection search. A time-optimal trajectory can be generated from any arbitrary initial state with asymmetric constraints on velocity, acceleration and jerk for a target position with any final velocity and zero final acceleration. In addition, we demonstrate a one step ahead trajectory controller combined with an Extended State Observer in simulation of a hexacopter model.

15:20-15:40 WeB3.5

An Efficient Object-Oriented Exploration Algorithm for Unmanned Aerial Vehicles, pp. 330-337

Herrera Alarcon, Edwin Paul	Scuola Superiore Sant'Anna
Bagheri, Davide	Scuola Superiore Sant'Anna
Baris, Gabriele	Scuola Superiore Sant'Anna
Mugnai, Michael	Scuola Superiore Sant'Anna
Satler, Massimo	Scuola Superiore Sant'Anna
Avizzano, Carlo Alberto	Scuola Superiore Sant'Anna

Autonomous exploration of unknown environments usually focuses on maximizing the volumetric exploration of the surroundings. Object-oriented exploration, on the other hand, tries to minimize the time spent on the localization of some given objects of interest. While the former problem equally considers map growths in any free direction, the latter fosters exploration towards objects of interest partially seen and not yet accurately identified.

The proposed work relates to a novel algorithm that focuses on an object-oriented exploration of unknown environments for aerial robots, able to generate volumetric representations of surroundings, semantically enhanced by labels for each object of interest.

As a case study, this method is applied both in a simulated environment and in real-life experiments on a small aerial platform.

WeB4 Naoussa

Sensor Fusion II (Regular Session)

14:00-14:20 WeB4.1

Gamma Radiation Source Localization for Micro Aerial Vehicles with a Miniature Single-Detector Compton Event Camera, pp. 338-346

Baca, Tomas — Czech Technical University in Prague
Stibinger, Petr — Czech Technical University in Prague
Doubravova, Daniela — Advacam, S.r.o
Turecek, Daniel — Advacam, S.r.o
Solc, Jaroslav — Czech Metrology Institute
Rusnak, Jan — Czech Technical University in Prague
Saska, Martin — Czech Technical University in Prague
Jakubek, Jan — Advacam, S.r.o

A novel method for localization and estimation of compact sources of gamma radiation for Micro Aerial Vehicles (MAVs) is presented in this paper. The method is developed for a novel single-detector Compton camera, developed by the authors. The detector is extremely small and weighs only 40 g, which opens the possibility for use on the widely accepted sub-1 kg class of drones. The Compton camera uses the MiniPIX TPX3 CdTe event camera to measure Compton scattering products of incoming high-energy gamma photons. The 3D position and the sub-nanosecond time delay of the measured scattering products are used to reconstruct sets of possible directions to the source. The proposed method utilizes a filter for fusing the measurements and estimating the radiation source position during the flight. The computations are executed in real-time onboard and allow integration of the detector info into a fully-autonomous system. Moreover, the real-time nature of the estimator potentially allows estimating states of a moving radiation source. The proposed method was validated in simulations and demonstrated in a real-world experiment with a Cs137 radiation source. The approach can localize a gamma source without estimating the gradient or contours of radiation intensity, which opens possibilities for localizing sources in a cluttered and urban environment.

14:20-14:40 WeB4.2

Interacting Multiple Model Filter Based Autonomous Landing Considering Camera Model Uncertainty, pp. 347-353

Jeong, Hyeon-Mun — Korea Advanced Institute of Science and Technology
Lee, Woo-Cheol — Korea Advanced Institute of Science and Technology
Choi, Han-Lim — Korea Advanced Institute of Science and Technology

This paper deals with the state estimation and control for camera-assisted landing. Uncertainties in measurement models, such as lens distortion, can adversely affect the camera's target detection and navigational functions. We propose an effective state estimator based on the Interacting Multiple Model filter to account for the uncertainties in the camera measurement model. We further introduce a phase update rule, which determines the feasibility of autonomous landing in a stochastic manner, and filter and control management logic is proposed by which to handle the different phases. The proposed framework is simulated using a multi-rotor type UAV equipped with a camera and rangefinder in the Gazebo simulation environment. The experiments validate the performance of the framework in terms of accuracy in state estimation and control.

14:40-15:00 WeB4.3

Monte-Carlo Localization for Aerial Robots Using 3D LiDAR and UWB Sensing, pp. 354-360

Carrasco, Paloma — Advanced Center for Aerospace Technologies (FADA-CATEC)
Cuesta, Francisco — Advanced Center for Aerospace Technologies (FADA-CATEC)
Caballero González, Rafael — Advanced Center for Aerospace Technologies (FADA-CATEC)
Perez-Grau, Francisco Javier — Advanced Center for Aerospace Technologies (FADA-CATEC)
Viguria, Antidio — Advanced Center for Aerospace Technologies (FADA-CATEC)

The relevance of unmanned aerial robots in industrial applications has increased with the prevalence of such systems in recent years. Moreover, their use in indoor environments, or where GNSS signals are degraded, is growing. This manuscript presents a solution for robust localization of aerial robots without the need for GNSS signals. In order to truly use them for added-value cases in such scenarios, high levels of robustness are required. Our proposed method is based on a probabilistic approach that makes use of a 3D LiDAR, UWB sensors and a previously built map of environment, to obtain aerial robot pose estimations. Experimental results show the feasibility of the approach, both in accuracy and computational efficiency, being all computations carried out onboard the aerial platform. A video of the results can be accessed at https://youtu.be/Dn6LxH-WLRA.

15:00-15:20 WeB4.4

Survey and Evaluation of Sensors for Overhead Cable Detection Using UAVs, pp. 361-370

Malle, Nicolaj Haarhøj — University of Southern Denmark
Nyboe, Frederik Falk — University of Southern Denmark
Ebeid, Emad Samuel Malki — University of Southern Denmark

Inspecting overhead cables using autonomous Unmanned Aerial Vehicles (UAVs) is an affordable and promising future solution for providing a clear picture of the energy infrastructure. However, most of today's UAVs for power line inspection are designed to use the

Global Navigation Satellite System (GNSS) to follow the power pylons which compromises the detection accuracy. In this paper, we provide an overview of the current state-of-the-art in sensors that can be used to remotely detect power lines using UAVs. The work compares 20+ low-cost, low-power, and light-weight sensors. The performance of 6 different kinds of sensors is evaluated thoroughly in a real outdoor power line test setup using a custom UAV. The sensor data is obtained and analyzed using Robot Operating System (ROS) and is provided openly.

15:20-15:40 WeB4.5

Relative Spherical-Visual Localization for Cooperative Unmanned Aerial Systems, pp. 371-376

Holter, Steffen — New York University Abu Dhabi
Tsoukalas, Athanasios — New York University Abu Dhabi
Evangeliou, Nikolaos — New York University Abu Dhabi
Giakoumidis, Nikolaos — New York University Abu Dhabi
Tzes, Anthony — New York University Abu Dhabi

Cooperative Unmanned Aerial Systems (UASs) in GPS-denied environments demand an accurate pose-localization system to ensure efficient operation. In this paper we present a novel visual relative localization system capable of monitoring a 360o Field-of-View (FoV) in the immediate surroundings of the UAS using a spherical camera. Collaborating UASs carry a set of fiducial markers which are detected by the camera-system. The spherical image is partitioned and rectified into a set of square images. An algorithm is proposed to select the number of images that balances the computational load while maintaining a minimum tracking-accuracy level. The developed system tracks UASs in the vicinity of the spherical camera and experimental studies using two UASs are offered to validate the performance of the relative visual localization against that of a motion capture system.

Technical Program for Thursday June 17, 2021

ThA1 Macedonia Hall

FDI and Safety (Regular Session)

10:30-10:50 ThA1.1

Detection and Isolation of Propeller Icing and Electric Propulsionsystem Faults in Fixed-Wing UAVs, pp. 377-386

Haaland, Ole Max — Norwegian University of Science and Technology
Johansen, Tor Arne — Norwegian University of Science and Technology
Gryte, Kristoffer — Norwegian University of Science and Technology
Hann, Richard — Norwegian University of Science and Technology
Wenz, Andreas Wolfgang — Norwegian University of Science and Technology

Fault in the propulsion system of UAVs is one of the main causes for incidents and loss of the aircraft. In electric propulsion systems typical faults are ball-bearing degradation leading to increased friction and losses, as well as propeller icing when operating in certain conditions. In this paper we propose a fault detection and isolation (FDI) framework that uses model-based estimators of the various faults, implemented with multiple Kalman and Bayes filters. The method is tested and shown to be effective in a simulation setup using a fixed-wing UAV simulator.

10:50-11:10 ThA1.2

Adaptation of Lazy-Theta for UAS 3D Path Planning Considering Safety Costs*, pp. 387-393

Rey, Rafael — Universidad Pablo De Olavide
Cobano, Jose Antonio — Universidad Pablo De Olavide
Merino, Luis — Universidad Pablo De Olavide
Caballero, Fernando — Universidad De Sevilla

This paper presents a 3D path planning solution for UAS to obtain a safe and smooth path. The safety plays an important role in the missions with UAS surrounding or entering the buildings. The heuristic search algorithms are good candidates to address this problem. The Lazy Theta* algorithm has been modified to foster safety and smoothness maintaining a distance from obstacles of the environment. Modifications to consider a new cost component related to the distance to the obstacles are performed. Tests in a realistic environment are shown to evaluate how the modified algorithm computes safer and smoother paths. Moreover, a comparison with the A* algorithm, the A* algorithm considering the new cost component and the original Lazy Theta* is presented.

11:10-11:30 ThA1.3

A Survey on Fault Diagnosis Methods for UAVs, pp. 394-403

Fourlas, George K. — University of Thessaly
Karras, George — University of Thessaly

The continuous evolution of modern technology has led to the creation of increasingly complex and advanced systems. The growing demands for more reliable performance on such systems as the Unmanned Aerial Vehicles (UAVs), have made it imperative to develop

sophisticated techniques that provide fault diagnosis in a timely and accurate manner. It is emphasized that the issues of safe operation of such systems are of utmost importance and their continuous monitoring is required in order to manage emergencies as quickly as possible when faults have occurred. In fault diagnosis, an automated system can be consisted of three main types of subsystems: actuators, main structure and sensors. Typically, a fault monitoring system is specifically designed to supervise and debug each of these subsystems. Successful execution of UAVs missions is associated with the timely detection and isolation of serious faults occurring to their sensors and actuators. Therefore, it is crucial for the UAV to track its reliable operation so that any faults can be addressed before they lead to disastrous consequences. In this survey article we provide a detailed overview of recent advances and studies regarding fault diagnosis methodologies for UAVs, focusing primarily on sensor and actuator faults.

11:30-11:50 ThA1.4

Nonlinear Estimation of Sensor Faults with Unknown Dynamics for a Fixed Wing Unmanned Aerial Vehicle, pp. 404-412

Iglésis, Enzo — Coventry University
Horri, Nadjim — Coventry University
Dahia, Karim — ONERA
Brusey, James — Coventry University
Piet-Lahanier, Hélène — ONERA

In this paper, the estimation of additive inertial navigation sensor faults with unknown dynamics is considered with application to the longitudinal navigation and control of a fixed wing unmanned aerial vehicle. The faulty measurement is on the pitch angle. A jump Markov regularized particle filter is proposed for fault and state estimation of the nonlinear aircraft dynamics, with a Markovian jump strategy to manage the probabilistic transitions between the fault free and faulty modes. The jump strategy uses a small number of sentinel particles to continue testing the alternate hypothesis under both fault free and faulty modes. The proposed filter is shown to outperform the regularized particle filter for this application in terms of fault estimation accuracy and convergence time for scenarios involving both abrupt and incipient faults, without prior knowledge of the fault models. The state estimation is also more accurate and robust to faults using the proposed approach. The root-mean-square error for the altitude is reduced by 77% using the jump Markov regularized particle filter under a pitch sensor fault amplitude of up to 10 degrees. Performance enhancement compared to the regularized particle filter was found to be more pronounced when fault amplitudes increase.

11:50-12:10 ThA1.5

Safe Sampling-Based Air-Ground Rendezvous Algorithm for Complex Dense Street Maps, pp. 413-422

Barsi Haberfeld, Gabriel — University of Illinois at Urbana-Champaign
Gahlawat, Aditya — University of Illinois at Urbana-Champaign
Hovakimyan, Naira — University of Illinois at Urbana-Champaign

Demand for fast and economical parcel deliveries in urban environments has risen considerably in recent years. A framework envisions efficient last-mile delivery in urban environments by leveraging a network of ride-sharing vehicles, where Unmanned Aerial Systems (UASs) drop packages on said vehicles, which then cover the majority of the distance before final aerial delivery. Notably, we consider the problem of planning a rendezvous path for the UAS to reach a human driver, who may choose between possible paths and has uncertain behavior, while meeting strict safety constraints. The long planning horizon and safety constraints require robust heuristics that combine learning and optimal control using Gaussian Process Regression, sampling-based optimization, and Model Predictive Control. The resulting algorithm is computationally efficient and shown to be effective in a variety of qualitative scenarios.

12:10-12:30 ThA1.6

Prognostics-Informed Battery Reconfiguration in a Multi-Battery Small UAS Energy System, pp. 423-432

Sharma, Prashin — University of Michigan
Atkins, Ella — University of Michigan

Batteries have been identified as one of the most likely small, unmanned aircraft system (sUAS) components to fail in flight. sUAS safety will therefore be improved with redundant or backup batteries. This paper presents a prognostics-informed Markov Decision Process model for managing multi-battery reconfiguration for sUAS missions. Typical lithium polymer battery properties are experimentally characterized and used in Monte Carlo simulations to establish battery dynamics in sUAS flights of varying duration. Case studies illustrate the trade-off between multi-battery system increased complexity/weight and resilience to non-ideal battery performance.

ThA2 Kozani

Control Design I (Regular Session)

10:30-10:50 ThA2.1

New Hybrid Fractional-Order Control-Based Disturbances Observer on of Autonomous Quadrotor Vehicles Subjected to Disturbances, pp. 433-438

Labbadi, Moussa — Mohammed V University in Rabat
Boudaraia, Karima — Mohammed V University in Rabat
Boukal, Yassine — Altran by Capgemini
Zerrougui, Mohamed — Aix Marseille University

Cherkaoui, Mohamed	Mohammed V University in Rabat

This paper concerns the problem of designing a new hybrid flight controller for trajectory-tracking of a quadrotor subjected to external disturbances. It gives a hybrid fractional-order control (HFOC) with disturbance observer (DO). The proposed control approach is based on fractional calculus and sliding mode controller (SMC). A disturbance observer combining with FOSM control approach is designed for rotational subsystem to exactly attenuate the external disturbances. The chattering problem is eliminated by the proposed controller with higher robustness against disturbances. The stability of the proposed HFOC has been verified by Lyapunov analysis. The effectiveness of the HFOC combined with DO has been confirmed by numerical simulation results.

10:50-11:10 ThA2.2

Flight Transition Control for Ducted Fan UAV with Saturation on Control Surfaces, pp. 439-446

Cheng, Zihuan	South China University of Technology
Pei, Hai-Long	South China University of Technology

In this paper, we focus on the hover/high-speed-cruising transition flight control of a ducted fan unmanned aerial vehicle (UAV), in which saturation on control surfaces is taken into consideration. To achieve full-envelope flight control, we propose an adaptive cascaded structure on the velocity tracking control for the nonlinear aircraft system. By introducing adaptive neural network, the closed-loop system tracks a prescribed reference system with all the nonlinear tracking errors well canceled. In the meanwhile, to tackle the control surface saturation, we propose a control effectiveness enhancement (CEE) algorithm in attaining sufficient control moment to the ducted fan vehicle. Under the proposed cascaded adaptive control scheme in conjunction with the CEE algorithm, the state tracking performance is proved to be bounded when encountering surface saturation. Finally, comparison experiments in terms of the forward and backward flight transition are conducted on the ducted fan UAV. The results are satisfactory and convincing in exhibiting the flight transition course that demonstrates the effectiveness of the proposed method.

11:10-11:30 ThA2.3

EPRL Sliding Mode Flight Controller with Model-Based Switching Manifold of a Quad-Rotor UAV, pp. 447-453

Kali, Yassine	Ecole De Technologie Superieure
Fallaha, Charles	Ecole De Technologie Superieure
Rodas, Jorge	Universidad Nacional De Asunción
Saad, Maarouf	Ecole De Technologie Superieure
Lesme, Fernando	Universidad Catolica Nuestra Senora De La Asuncion

In this paper, the problems of chattering in sliding mode and high-accuracy flight tracking are tackled. Indeed, a nonlinear controller for the position, altitude, and attitude tracking has been developed for a quad-rotor system. The developed method in this manuscript is the exponential power reaching law sliding mode with mode-based switching manifold. This proposed method simplifies the computed control inputs while decoupling the chattering effect between Euler angles. This latter, in addition to the used reaching law, reduces the chattering phenomenon. Moreover, this method is effective since it ensures, as conventional sliding mode, high precision tracking. Based on Lyapunov theory, the stability analysis of the closed-loop system is presented. Finally, numerical simulations and comparative studies with the sliding mode with model-based switching manifold are performed on a quad-rotor model to prove the claimed features.

11:30-11:50 ThA2.4

Robust Reduced-Attitude Control of Fixed-Wing UAVs Using a Generalized Multivariable Super-Twisting Algorithm, pp. 454-464

Coates, Erlend M.	Norwegian University of Science and Technology
Griffiths, Jenny Bogen	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

Operation of fixed-wing unmanned aerial vehicles (UAVs) outside their nominal operating conditions require autopilots that can effectively compensate for highly uncertain aerodynamics, and coupled disturbances due to turbulent winds. In this paper, we propose to use a generalized multivariable super-twisting algorithm to solve the robust attitude control problem for fixed-wing UAVs. A sliding surface is designed, based on geometric methods, to perform reduced-attitude tracking while simultaneously stabilizing a turn rate based on the coordinated-turn equation. The reduced-attitude representation evolves on the unit two-sphere and is independent of the yaw/heading angle. The resulting control design is lightweight, has no singularities, and can be used with standard hierarchical control architectures for fixed-wing UAVs. The efficacy of the proposed design is demonstrated in a simulation study with highly turbulent conditions.

11:50-12:10 ThA2.5

Nonlinear Model Predictive Control Combined with Geometric Attitude and Speed Control for Fixed-Wing UAVs, pp. 465-475

Reinhardt, Dirk	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

We propose the combination of a Nonlinear Model Predictive Controller (NMPC) with a Geometric Controller (GC) for the attitude and speed control problem of fixed-wing unmanned aerial vehicles (UAVs). The NMPC sends reference vectors for attitude, angular rates and angular acceleration to the low-level GC that can be run at a significantly higher bandwidth. This way we generate optimal references for the GC, increase its region of attraction while also addressing performance and constraint satisfaction. The efficacy of the proposed approach is illustrated in numerical simulation examples.

12:10-12:30 ThA2.6

Turbulent Wind Gusts Estimation and Compensation Via High-Gain Extended Observer-Based Adaptive Sliding Mode for a Quadrotor UAV, pp. 476-481

Miranda-Moya, Armando — Tecnologico De Monterrey
Castaneda, Herman — Tecnologico De Monterrey
Wang, Hesheng — Shanghai Jiaotong University

This paper presents a high-gain extended observer-based adaptive sliding mode scheme for a quadrotor rotorcraft influenced by turbulent wind gusts while performing a defined trajectory. The drag forces caused by the turbulent wind field are estimated through an extended state which collects all uncertainties and perturbations affecting the system. Such estimation is then compensated in the feedback control loop performed by a class of adaptive sliding mode control which provides properties such as robustness, non-overestimation of the control gain, and finite-time convergence. Computer simulation results corroborate the successful performance and feasibility of the proposed strategy even under output noise circumstances.

ThA3 Edessa

Path Planning III (Regular Session)

10:30-10:50 ThA3.1

Safe Traversal Guidance for Quadrotors Using Gap Bearing Information, pp. 482-487

E K, Midhun — Indian Institute of Science
Ratnoo, Ashwini — Indian Institute of Science

This paper considers bearing-only measurement-based guidance for a quadrotor unmanned aerial vehicle to navigate through gaps between obstacles in a two-dimensional plane. The proposed method uses a biased elliptic shaping function for the commanded heading which facilitates a lateral traversal through the gap. Multiple phase portraits demonstrate guaranteed safe traversal. Numerical simulation results show the effectiveness of the proposed guidance method.

10:50-11:10 ThA3.2

A Survey of Task Allocation Techniques in MAS, pp. 488-497

Skaltsis, George Marios — Cranfield University
Shin, Hyo-Sang — Cranfield University
Tsourdos, Antonios — Cranfield University

Multi-agent systems and especially unmanned vehicles are a crucial part of the solution to a lot of real-world problems, making essential the improvement of task allocation techniques. In this review, we present the main techniques used for task allocation algorithms, categorising them based on the techniques used, focusing mainly on recent works. We also analyse these methods, focusing mainly on their complexity, optimality and scalability. We also refer to common communication schemes used in task allocation methods, as well as to the role of uncertainty in task allocation. Finally, we compare them based on the above criteria, trying to find gaps in the literature and to propose the most promising ones.

11:10-11:30 ThA3.3

A Lyapunov Guidance Vector Field Based Continuous Curvature Path Generation for Waypoint Following of UAVs, pp. 498-506

Harinarayana, Tammineni — Indian Institute of Technology Kharagpur
Krishnan, Siva Vignesh — Indian Institute of Technology Kharagpur
Hota, Sikha — Indian Institute of Technology Kharagpur
Kushwaha, Rahul — Indian Institute of Technology Kharagpur

This paper generates a continuous curvature path for Unmanned Aerial Vehicles (UAVs) to converge to a straight-line path using the Lyapunov Guidance Vector Field (LGVF) approach. Further, a waypoint following method that utilizes the straight-line convergence algorithm along with a switching technique to transit between two consecutive waypoint segments to find a near time-optimal and smooth path has been presented. Numerical examples demonstrate that the proposed algorithm is better in comparison to the other well-performing algorithms existing in the literature and the corresponding results have been included.

11:30-11:50 ThA3.4

Path Planning and Reactive Based Control for a Quadrotor with a Suspended Load, pp. 507-516

Corona, Jose — The Arctic University of Norway
Kristiansen, Raymond — The Arctic University of Norway
Andersen, Tom Stian — The Arctic University of Norway

This paper presents a solution to quadrotor cargo transportation, precisely when cargo is suspended as a sling load. The challenge lies in payload position control and swing attenuation, which we approach by dividing the model into subsystems: attitude quadrotor in free flight, translational load dynamics, and attitude load dynamics. We propose a solution based on reactive control, in the sense that we utilize a reactive force that reacts to the error position and the oscillation in the load. Asymptotic stability of the system's closed-loop is proved using Lyapunov theory. Additionally, a three-dimensional path planning algorithm is proposed based on cubic splines, which give us a natural path between initial and final desired points. Moreover, we convert the path planning problem into trajectory tracking one with a spline's correct parametrization. Control and path planning performance are demonstrating with numerical simulations in three different scenarios.

11:50-12:10 ThA3.5

3D Trajectory Planning for UAV-Based Search Missions: An Integrated Assessment and Search Planning Approach, pp. 517-526

Papaioannou, Savvas — University of Cyprus
Kolios, Panayiotis — University of Cyprus
Theocharides, Theocharis — University of Cyprus
Panayiotou, Christos — University of Cyprus
Polycarpou, Marios M. — University of Cyprus

The ability to efficiently plan and execute search missions in challenging and complex environments during natural and man-made disasters is imperative. In many emergency situations, precise navigation between obstacles and time-efficient searching around 3D structures is essential for finding survivors. In this work we propose an integrated assessment and search planning approach which allows an autonomous UAV (unmanned aerial vehicle) agent to plan and execute collision-free search trajectories in 3D environments. More specifically, the proposed search-planning framework aims to integrate and automate the first two phases (i.e., the assessment phase and the search phase) of a traditional search-and-rescue (SAR) mission. In the first stage, termed assessment-planning we aim to find a high-level assessment plan which the UAV agent can execute in order to visit a set of points of interest. The generated plan of this stage guides the UAV to fly over the objects of interest thus providing a first assessment of the situation at hand. In the second stage, termed search-planning, the UAV trajectory is further fine-tuned to allow the UAV to search in 3D (i.e., across all faces) the objects of interest for survivors. The performance of the proposed approach is demonstrated through extensive simulation analysis.

12:10-12:30 ThA3.6

Real-Time On-Board Path Planning for UAS-Based Wildfire Monitoring, pp. 527-535

Islam, S.M. Towhidul — Georgia State University
Hu, Xiaolin — Georgia State University

The use of Unmanned Aircraft System (UAS) in wildfire monitoring is increasing significantly due to its benefits in terms of flexibility, lower cost, and safety. To effectively monitor and collect data about a wildfire, UAS path planning is essential. Many of the applications adopt a centralized approach that uses a computer on the ground to provide path planning information for individual UASs. The applicability and robustness of such centralized approaches are limited due to the challenging wildfire environments. In addition, very few of the existing applications focus on the most actively spreading region of the fire which needs special monitoring attention. In this paper, we present an on-board path planning algorithm for UAS-based wildfire monitoring. The proposed algorithm uses real-time data collected by the UAS to direct the UAS to monitor the wildfire with special attention to the most active regions of the fire. Simulation results have been presented to show the effectiveness of the algorithm in different simulated wildfire scenarios.

ThA4 — Naoussa

UAS Applications I (Regular Session)

10:30-10:50 ThA4.1

Aerial Thermal Image Based Convolutional Neural Networks for Human Detection in SubT Environments, pp. 536-541

Koval, Anton — Luleå University of Technology
Sharif Mansouri, Sina — Luleå University of Technology
Kanellakis, Christoforos — Luleå University of Technology
Nikolakopoulos, George — Luleå University of Technology

This article proposes a novel strategy for detecting humans in harsh Sub-terranean (SubT) environments, with a thermal camera mounted on an aerial platform, based on the AlexNet Convolutional Neural Network (CNN). A transfer learning framework will be utilized for detecting the humans, where the aerial thermal images are fed to the trained network, which binary classifies them image content into two categories: a) human, and b) no human. Moreover, the AlexNet based framework is compared with two related popular CNN approaches as the GoogleNet and the Inception3Net. The efficacy of the proposed scheme has been experimentally evaluated through multiple datasets, collected from a FLIR thermal camera during flights on an underground mining environment, fully demonstrating the performance and merits of the proposed module.

10:50-11:10 ThA4.2

Civil Infrastructure Data Acquisition in Urban Environments Based on Multi-UAV Mission, pp. 542-551

Goricanec, Jurica — University of Zagreb
Ivanovic, Antun — University of Zagreb
Markovic, Lovro — University of Zagreb

Pavlak, Ivan | University of Zagreb
Bogdan, Stjepan | University of Zagreb

Increased capabilities of modern unmanned aerial vehicles (UAVs) in terms of autonomy and payload operations lead towards development of multi-agent UAV systems. While the multi-UAV systems have a great potential in many different scenarios, increasing complexity of missions gave raise to a new set of problems. Some of them include high workload periods of a single operator supervising multiple agents, loss of the situation awareness, increased amount of the data generated by the system and problems in communication channels between the operator and UAVs. All of them could lead to performance degradation in the mission execution or even critical failures of system elements. In general, there are two aspects that help to avoid or at least to decrease mentioned problems - mission planning and human-machine interface (HMI) design. In this paper, we mainly address the mission planning aspect and only briefly present an HMI design that allows simultaneous handling of three UAVs in civil infrastructure data acquisition missions. The proposed HMI, among the standard telemetry data, includes data download/upload from/to external services, a trajectory planner and the acquired data representation. The proposed architecture has been tested in a simulation and in a real environment.

11:10-11:30 | ThA4.3

Admittance Force-Based UAV-Wall Stabilization and Press Exertion for Documentation and Inspection of Historical Buildings, pp. 552-559

Smrcka, Daniel | Czech Technical University in Prague
Baca, Tomas | Czech Technical University in Prague
Nascimento, Tiago | Universidade Federal Da Paraiba
Saska, Martin | Czech Technical University in Prague

An approach that enables autonomous Unmanned Aerial Vehicles (UAV) with onboard sensor-based force control to interact with the indoor walls of historical buildings is proposed in this paper. The motivation for enabling UAVs to be pressed against walls is twofold: 1) it enables providing strong-side lighting on places where a light source needs to be remotely pressed against the wall for documentation by another drone with a camera and 2) it is a technique for enabling remote placement of infrastructure in difficult-to-access indoor locations, e.g., smart sensors for continuous monitoring of temperature and humidity. We propose therefore an admittance force-based control system that enables a UAV to interact with a wall in a stabilized manner at a pre-defined location. The UAV is coupled with a mechanism that can measure the interacting force, allowing the proposed controller to be in constant contact with the wall based on a measured force, and to regulate the force to the amount required by a given application. The proposed approach has been verified through numerous simulations in Gazebo and experiments with real robots in GNSS-denied environments relying solely on onboard sensors.

11:30-11:50 | ThA4.4

Towards Robust and Efficient Plane Detection from 3D Point Cloud, pp. 560-566

Sharif Mansouri, Sina | Luleå University of Technology
Kanellakis, Christoforos | Luleå University of Technology
Pourkamali-Anaraki, Farhad | University of Massachusetts Lowell
Nikolakopoulos, George | Luleå University of Technology

This article proposes a robust and scalable clustering method for 3D point-cloud plane segmentation with applications in Micro Aerial Vehicle (MAVs), such as Simultaneous Localization and Mapping (SLAM), collision avoidance, and object detection. Our approach builds on the sparse subspace clustering framework, which seeks a collection of subspaces that fit the data. Since subspace clustering requires solving a global sparse representation problem and forming a similarity graph, its high computational complexity is known to be a significant drawback, and performance is sensitive to a few hyperparameters. To tackle these challenges, our method has two key ingredients. We use randomized sampling to accelerate subspace clustering by solving a reduced optimization problem. We also analyze the obtained segmentation for quality assurance and performing a post-processing process to resolve two forms of model mismatch. We present numerical experiments to demonstrate the benefits and merits of our method.

11:50-12:10 | ThA4.5

Toward Avatar-Drone: A Human-Embodied Drone for Aerial Manipulation, pp. 567-574

Kim, Dongbin | University of Nevada, Las Vegas
Oh, Paul | University of Nevada, Las Vegas

This paper presents Avatar-Drone to advance aerial manipulation. The mobile-manipulating drone is a haptics-based human-in-the-loop platform. This is married to an immersive framework based on Unity and virtual (VR) and augmented (AR) reality. The net effect provides the operator a sense of presence and see, hear, and feel what the drone is doing in the work environment. Two scenarios involving package delivery illustrate efficacy of this marriage.

12:10-12:30 | ThA4.6

Aircraft Inspection by Multirotor UAV Using Coverage Path Planning, pp. 575-581

Silberberg, Patrick | Naval School of Aviation Safety
Leishman, Robert | Air Force Institute of Technology

All military and commercial aircraft must undergo frequent visual inspections in order to identify damage that could pose a danger to safety of flight. Currently, these inspections are primarily conducted by maintenance personnel. Inspectors must scrutinize the aircraft's surface to find and document defects such as dents, hail damage, broken fasteners, etc.; this is a time consuming, tedious, and hazardous

process. The goal of this work is to develop a visual inspection system which can be used by an Unmanned Aerial Vehicle (UAV), and to test the feasibility of this system on military aircraft. Using an autonomous system in place of trained personnel will improve the safety and efficiency of the inspection process. Open-source software for coverage path planning (CPP) is modified and used to create a path from which the UAV can view the entire top surface of the aircraft. Simulated and experimental flight testing is conducted to validate the generated paths by collecting imagery, flight data, and coverage estimates. Simulation is also used to predict UAV performance for an inspection of a full-size aircraft. Analysis shows that multirotor UAVs are a viable inspection platform for military aircraft.

ThB1	Macedonia Hall
Reliability of UAS (Regular Session)	

14:00-14:20 ThB1.1

Which Is the Best Real-Time Operating System for Drones? Evaluation of the Real-Time Characteristics of NuttX and ChibiOS, pp. 582-590

Zhang, Mingyang — KU Leuven
Timmerman, Martin — Dedicated Systems Experts NV
Perneel, Luc — Dedicated Systems Experts NV
Toon, Goedemé — KU Leuven

With the evolvement of various drone platforms, the constraints of such embedded systems are getting more and more strict and specific. As the low-level technology, correct behaviours and decent performance of an RTOS play a vital role in guaranteeing such constraints. This paper studies the real-time performance and behaviour of two popular RTOSs used in drones, presenting both quantitative and qualitative results. We also exploited the source code to locate the origin of possible misbehaviors. By analysing the results, we draw several conclusions on the comparison of NuttX and ChibiOS, which can be useful for drone developers and users. NuttX has a vital defect in the implementation of priority inheritance. And in most tests, ChibiOS beats NuttX, therefore, it is the winner in this comparison.

14:20-14:40 ThB1.2

Safely Flying BVLOS in the EU with an Unreliable UAS, pp. 591-601

Terkildsen, Kristian Husum — University of Southern Denmark
Schultz, Ulrik Pagh — University of Southern Denmark
Jensen, Kjeld — University of Southern Denmark

Safe autonomous Beyond Visual Line of Sight (BVLOS) flight is critical for the widespread exploitation of Unmanned Aerial Systems (UASs). Satisfying safety legislation requires documenting compliance with a raft of substantial requirements, a step which very few commercially available UASs have yet taken. Assessments under BVLOS conditions are required – but illegal for unassessed UASs. We propose to enable safe BVLOS flight tests using an Independent Fail-safe System (IFS), which can be added to an Unmanned Aerial Vehicle (UAV) and enable a pilot to remotely monitor flights and terminate them safely via parachute if necessary. Our IFS has been designed for use under the European Union(EU) UAS legislation. In this paper, we describe this IFS and define a systematic approach for integrating its use into the Specific Operations Risk Assessment (SORA) process necessary for BVLOS certification. The use of this IFS to safely fly an (otherwise) unsafe UAV has been approved by the Danish Civilian Aviation Authority (CAA) for BVLOS flights with a range of small multirotor UAVs. The results of experimental evaluations in closed airspace are presented.

14:40-15:00 ThB1.3

Legal and Ethical Aspects of Rules for the Operation of Autonomous Unmanned Aircraft with Artificial Intelligence, pp. 602-609

Konert, Anna — Lazarski University
Balcerzak, Tomasz — Lazarski University

Introduction. This paper will analyze the legal and ethical aspects of using autonomous unmanned aircraft. Full autonomy requires the use of AI which is replete with its own controversies: technological, ethical, moral and legal. The main problem to consider is whether the public is ready for autonomous drones since it is extremely difficult to develop satisfactory validation systems which would make the technology safe and would act like humans. And if so, do we have the technological infrastructure ready for such operations? And if we do, what are the legal consequences in case of an accident? Material and methods: The method of study comprises a survey analysis and a content analysis of existing legislations and literature. Results: The study results show that the more formalized the process of ensuring the safe and compatible functioning of systems based on artificial intelligence and machine learning, the greater the level of trust. There is also a practical problem in determining what an autonomous drone is and who should bear responsibility in the case of autonomous or semi-autonomous systems with no human control. The current civil liability regulations need to be adjusted to consider the problems that may arise in the event of damages caused by autonomous unmanned aircraft.

15:00-15:20 ThB1.4

Flight Test Validation and Verification of the Novel Ln Guidance for Unmanned Aerial Systems, pp. 610-618

Xu, Jeffrey — University of Kansas
Keshmiri, Shawn — University of Kansas

This paper presents the validation and verification of a novel fixed-wing UAS guidance logic designed to accurately follow paths given complex missions and tight turns with no oscillations or overshoots. Expanding on the existing popular L1 and L2+ guidance logics, the

novel Ln guidance logic tracks multiple reference points on the desired path, resulting in a robust guidance logic with anticipatory ability and no steady state errors. The novel Ln is implemented, where several successful real-world flight tests were conducted and compared with L1 and L2+ guidance logics.

15:20-15:40 ThB1.5

UAVAT Framework: UAV Auto Test Framework for Experimental Validation of Multirotor sUAS Using a Motion Capture System, pp. 619-629

Jepsen, Jes Hundevadt — University of Southern Denmark
Terkildsen, Kristian Husum — University of Southern Denmark
Hasan, Agus — Norwegian University of Science and Technology
Jensen, Kjeld — University of Southern Denmark
Schultz, Ulrik Pagh — University of Southern Denmark

The development of Unmanned Aerial Systems (UASs) continuously improves and advances the technology, which is a key enabler for many new applications, such as autonomous Beyond Visual Line of Sight (BVLOS) operations. However, ensuring a sufficient level of safety and performance of an UAS can be a challenging task, since it requires systematic experimental validation in order verify and document the reliability, robustness, and fault tolerance of the UAS and its critical components. In this paper we propose the UAV Auto Test Framework (UAVAT Framework), a framework for easy, systematic, and efficient experimental validation of the reliability, fault tolerance, and robustness of a multirotor small Unmanned Aerial Systems (sUAS) and its software and hardware components. We describe the hardware and software used for the UAVAT Framework setup, which consists of a Motion Capture (MoCap) system, a multirotor sUAS, and a tethered power system. In addition, we introduce the concept of test modules, a "plug-and-play" software component with a set of recommended guidelines for defining testing configurations and enabling easy reuse and distribution of software components for sUAS testing. The capabilities of the UAVAT Framework are demonstrated by presenting the results from two developed test modules targeting endurance testing of a multirotor sUAS and Fault Detection (FD) for abnormal behaviour detection.

ThB2 Kozani

Control Design II (Regular Session)

14:00-14:20 ThB2.1

Scaled Nonlinear H Infinity Control of an Aerial Manipulator, pp. 630-638

Morais Aquino, Junio Eduardo — Federal University of Minas Gerais
Raffo, Guilherme Vianna — Federal University of Minas Gerais

This paper proposes a scaled nonlinear H infinity control of an Unmanned Aerial Manipulator (UAM) from the perspective of the end-effector. The equations of motion of the UAM, obtained from the Euler-Lagrange approach, describe the end-effector dynamical behavior, taking into account the multi-body mechanical system composed by a quadrotor UAV and a planar manipulator. Then, a single-layer control strategy is designed in order to directly control the pose of the end-effector. Aiming to improve the inertia matrix conditioning, the UAM dynamic model is scaled to be used into the proposed nonlinear H infinity controller, which is implemented in an embedded system. Finally, a numerical experiment is executed in a Hardware-In-the-Loop framework using the ProVANT Simulator software, corroborating the good performance of the proposed controller.

14:20-14:40 ThB2.2

Design and Flight Test Validation of a UAS Lateral-Directional Model Predictive Controller, pp. 639-646

Chowdhury, Mozammal — University of Kansas
Keshmiri, Shawn — University of Kansas
Xu, Jeffrey — University of Kansas

Recent advances in computer technologies have increased the processing power on-board unmanned aerial aircraft. Computationally potent avionic systems have provided new opportunities to implement more adaptive and capable flight controllers. Model predictive control is emerging as a method for controlling unmanned aircraft, satisfying state and control constraints, and improving aircraft performance in the presence of external disturbances and nonlinear and unsteady aerodynamics. Although model predictive controllers provide many advantages over classical or modern control methods (such as PID or LQR), their practical applications have been limited to high-level path plannings, guidance logic, and control of slow robots with less complex dynamics. This work presents the development of an inner-loop model predictive control flight controller and successful validation and verification of its performance in actual flight tests. The work also investigates the impact of number of horizon points on the performance of the model predictive controller in the presence of wind and other external disturbances.

14:40-15:00 ThB2.3

Energy-Aware Model Predictive Control with Obstacle Avoidance, pp. 647-655

Santos, Marcelo Alves — Federal University of Minas Gerais
Ferramosca, Antonio — University of Bergamo
Raffo, Guilherme Vianna — Federal University of Minas Gerais

This work proposes a single-layer finite-horizon optimal control strategy to solve the autonomous navigation problem while accounting for

energy efficiency and providing obstacle avoidance feature in cluttered environments with unknown obstacles. Considering the rate capacity effect of electric batteries, the nonlinear state-of-charge behavior is described and included in the optimal control problem to achieve energy-awareness. Besides, artificial potential fields are considered to obtain obstacle avoidance capabilities. The control problem is formulated inspired by the tracking model predictive control framework, and it considers the central idea of including artificial variables into the control problem to obtain a closed-loop system with an enlarged domain of attraction and with feasibility insurance. Finally, numerical results in a case study considering a quadrotor UAV are provided to corroborate the proposed strategy.

15:00-15:20 ThB2.4

Singularity-Free Quaternion Representation to Control a UGV-UAV Formation Performing Trajectory-Tracking Tasks, pp. 656-665

Marciano, Harrison — Federal University of Espirito Santo
Brandao, Alexandre Santos — Federal University of Vicosa
Sarcinelli-Filho, Mário — Federal University of Espirito Santo

A formation composed by a ground unmanned vehicle (UGV) and an unmanned aerial vehicle (UAV) is considered here. The UAV should land on the UGV, which emulates a static or moving base station for the UAV. In such case, issues related to formation singularities may occur. An example of singularity is the fact that the UAV is not guaranteed to be laterally aligned with the UGV, thus not allowing to precisely get the current state of the formation when starting the landing maneuver. Focusing on this specific situation, this paper proposes a singularity-free representation of the formation, based on quaternions, and a formation controller, based on this formulation, to guide the formation in trajectory-tracking tasks. Besides the theoretical development, the paper also provides results of experiments run using a formation composed by a Pioneer 3-DX UGV and a Bebop 2 UAV, which validate the proposed formulation and controller.

15:20-15:40 ThB2.5

Robust Visual Tracking Control Based on Adaptive Sliding Mode Strategy: Quadrotor UAV - Catamaran USV Heterogeneous System, pp. 666-672

Gonzalez-Garcia, Alejandro — Tecnologico De Monterrey
Miranda-Moya, Armando — Tecnologico De Monterrey
Castaneda, Herman — Tecnologico De Monterrey

This paper presents a robust visual control for the tracking of a catamaran USV from a quadrotor UAV via image-based visual servoing. A virtual camera approach is used for the extraction of the image features from the target, allowing the design of the rotorcraft position controller based on a class of adaptive sliding mode strategy, providing robustness against bounded external disturbances and uncertainties. The speed and heading control for the vessel is also designed by the same adaptive algorithm, which is in close-loop with a line-of-sight-based guidance law. Simulation results show the feasibility and performance of the proposed visual tracking control in a cooperation UAV-USV scheme in the presence of disturbances.

ThB3 Edessa

Path Planning IV (Regular Session)

14:00-14:20 ThB3.1

Minimum-Time Path Planning for Autonomous Landing of UAV on Aerial Drone Carrier, pp. 673-678

Alijani, Morteza — University of Trento
Osman, Anas — University of Trento

The motivation for this work stems from the need to develop trajectory planning algorithms for small UAVs with limited resources. The goal is to address one of the most critical problems in UAV design, namely weight constraints. Therefore, in order to reduce the weight, small batteries are used which affect the flight duration and overall performance. To increase the operating time during a mission, frequent recharging is typically required. To solve this problem, an autonomous air-to-air take-off and landing on a drone carrier for recharging is proposed. The main objective of this study is to calculate the minimum time and thus the shortest maneuver route between the UAV and the drone carrier. To achieve this goal, the path planning algorithm is utilized through the closed-loop direct optimal control approach to calculate the optimal time, which is defined as a cost function. In addition to the optimization techniques, the singular perturbation technique (SPT) and the Hamiltonian are used to solve and refine the optimal control problem (OCP). Finally, the numerical simulation results in both open and closed loop are presented and the performance of the proposed algorithm is evaluated.

14:20-14:40 ThB3.2

Inspection Path Planning for Aerial Vehicles Via Sampling-Based Sequential Optimization, pp. 679-687

Shi, Liping — Aarhus University
Mehrooz, Golizheh — University of Southern Denmark
Jacobsen, Rune — Aarhus University

Unmanned Aerial Vehicles (UAVs) commonly named drones are gaining interest for infrastructure inspection due to their ability to automize and monitor large areas more securely at a lower cost. Autonomous inspection and path planning are essential capabilities for the drone's autonomous flight. In this paper, we propose a novel inspection path planning method for achieving a complete and efficient inspection via drones. A point cloud generated from a 3D mapping service is used to represent complex inspection targets and provided as the input of the path planning method. The method is designed as a sampling-based sequential optimization to calculate and optimize

an inspection path while considering the limitation of the sensors, inspection efficiency, and safety requirements of the drones. The proposed method is evaluated for both the use case of bridge inspection and power pylon inspection. A comparison between the proposed path search algorithm and TSP solver is made. Furthermore, the scalability of the method is assessed with different sizes of the inspection problem.

14:40-15:00 ThB3.3

A UAV Global Planner to Improve Path Planning in Unstructured Environments, pp. 688-697

Rocha, Lidia — Federal University of São Carlos
Santos, Marcela — Federal University of São Carlos
Igor, Araújo — Federal University of São Carlos
Kelen, Vivaldini — Federal University of São Carlos

A good performance for path planning is essential to carry out real-world missions. In this paper, the path planning consists of a global planner, that finds the optimal path, and in a local planner, recalculates the path to avoid obstacles. The main focus is to improve the performance of local planning techniques decreasing the complexity. There are two main ways to do it: bidirectional algorithms, improving time, and global planners, improving time and completeness. Thus, we propose a global planner algorithm that generates auxiliary nodes, backtracking by the goal node. We perform a comparison among A*, Bi A*, Artificial Potential Field (APF), Bi APF, Rapid Exploring Random Tree (RRT), and Bi RRT with and without the global planner through statistical metrics of time, path length, CPU, and memory. The results show the advantages of using bidirectional algorithms and the proposed global planner. The bidirectional algorithms decrease the time to return to the trajectory and sometimes assist in the algorithm's completeness. The proposed global planner reduced the planning time by 91.6% and improved the completeness of all algorithms in an unstructured indoor environment.

15:00-15:20 ThB3.4

Optimal Path Planning for Autonomous Spraying UAS Framework in Precision Agriculture, pp. 698-707

Lorenzo Becce, Lorenzo — Politecnico Di Torino
Bloise, Nicoletta — Politecnico Di Torino
Guglieri, Giorgio — Politecnico Di Torino

This paper presents a novel guidance and control strategy for multirotor Unmanned Aerial Systems (UASs) which aims to provide an autonomous and safe mission in precision agriculture applications.

In the last few years, the research in this field has always improved thanks to the advent of new technologies and with the launch of the first smart farms. Precision aerial spraying of Plant Protection Products (PPP) in vineyards is the focus of this work, highlighting several advantages in terms of quality management, time and cost. In particular, we propose a combination of a Traveling Salesman Problem (TSP) solver with the well-known Theta* algorithm to investigate optimal UAS trajectories in order to visit a specific number of plants that require intervention. The final goal is to demonstrate the fulfillment of the evaluated trajectory with the on-board control system of the vehicle in provision for UAS field testing.

Finally, the planning strategy is applied to two case studies so as to present the feasibility of a more efficient autonomous UAS path planning.

15:20-15:40 ThB3.5

Online Trajectory Planning with Application to an UAV Relay Station, pp. 708-713

Schwung, Michael — Ruhr-Universität Bochum
Lunze, Jan — Ruhr-Universität Bochum

This paper presents a new online trajectory planning method for an unmanned aerial vehicle (UAV) acting as an aerial base station for the communication relay between moving ground vehicles, which have different quality-of-service (QoS) requirements. The ground vehicles follow locally planned trajectories, which are communicated to the aerial base station. The UAV possesses a network estimator, which determines the channel properties between the UAV and each ground vehicle and a trajectory planning unit, which changes the UAV trajectory online whenever the estimated QoS violates the requirements. The aim is to keep all individual requirements of the vehicles fulfilled during their movement. In contrast to literature, the method adjusts the UAV trajectory online to ensure the communication relay to moving vehicles with different QoS requirements. The effectiveness of the method is shown in two simulation scenarios.

ThB4 Naoussa

UAS Applications II (Regular Session)

14:00-14:20 ThB4.1

A UAS Equipped with a Thermal Imaging System with Temperature Calibration for Crop Water Stress Index Computation, pp. 714-720

Montes de Oca Rebolledo, Andres — Center for Research in Optics, A.C
Flores, Gerardo — Center for Research in Optics, A.C

This paper presents the development of an Unmanned Aerial System (UAS) for thermal imaging through the equipment of a thermal camera Flir Boson 640. The proposed UAS can capture and process the thermal imagery to compute an important vegetation index, as is the Crop Water Stress Index (CWSI). Such index is applicable to determine water stress and evaluate the irrigation process among

vegetation. For the latter purposes, we present the image processing workflow to obtain the temperature map required for the computation of the CWSI. The image processing tasks applied to the imagery are a) image correction, b) orthomosaic generation, c) temperature calibration and d) vegetation index computation. For every task, we provide a detailed description. We have also designed an interface system based on a Raspberry Pi. The interface systems allow to collect the required imagery through the thermal camera, according to the trigger signal commanded by the autopilot. To assess the performance of the proposed system and methodology, we conduct experiments over a small area of a park. The results show that the CWSI can be computed effectively with our proposed methodology. The computed CWSI highlights water-stressed spots within the vegetation area. The developed code and open-source software used in this work are available on our Github page.

14:20-14:40 ThB4.2

A Multi-UAV System for Exploration and Target Finding in Cluttered and GPS-Denied Environments, pp. 721-729

Zhu, Xiaolong — Queensland University of Technology
Vanegas Alvarez, Fernando — Queensland University of Technology
Gonzalez, Luis Felipe — Queensland University of Technology (QUT)/ QUT Centre for Roboti
Sanderson, Conrad — Data61/CSIRO

The use of multi-rotor Unmanned Aerial Vehicles (UAVs) for Search and Rescue (SAR) and Remote Sensing is rapidly increasing. Multi-rotor UAVs, however, have limited endurance. The range of UAV applications can be widened if teams of multiple UAVs are used. We propose a framework for a team of UAVs to cooperatively explore and find a target in complex GPS-denied environments with obstacles. The team of UAVs autonomously navigates, explores, detects, and finds the target in a cluttered environment with a known map. Examples of such environments include indoor scenarios, urban or natural canyons, caves, and tunnels, where the GPS signal is limited or blocked. The framework is based on a probabilistic Decentralised Partially Observable Markov Decision Processes (Dec-POMDP) which accounts for the uncertainties in sensing and the environment. The team can cooperate efficiently, with each UAV sharing only limited processed observations and their locations during the mission. The system is simulated using the Robotic Operating System (ROS) and Gazebo. Performance of the system with an increasing number of UAVs in several indoor scenarios with obstacles is tested. Results indicate that the proposed multi-UAV system has improvements in terms of time-cost, the proportion of search area surveyed, and successful rates for search and rescue missions.

14:40-15:00 ThB4.3

Collaboration between Multiple UAVs for Fire Detection and Suppression, pp. 730-737

Moffatt, Andrew — California State Polytechnic University, Pomona
Turcios, Nicholas — California State Polytechnic University, Pomona
Edwards, Chase — California State Polytechnic University, Pomona
Karnik, Atharva — California State Polytechnic University, Pomona
Kim, David — California State Polytechnic University, Pomona
Kleinman, Andrew — California State Polytechnic University, Pomona
Nguyen, Hien — California State Polytechnic University, Pomona
Ramos, Victor Javier — California State Polytechnic University, Pomona
Earvin Ranario, Earvin — California State Polytechnic University, Pomona
Sato, Tomo — California State Polytechnic University, Pomona
Uryeu, Dzianis — California State Polytechnic University, Pomona
Bhandari, Subodh — California State Polytechnic University, Pomona

This paper presents the use of two UAVs to detect and suppress fires. The first UAV is the detection system and begins the mission by autonomously flying a predetermined route while scanning an area of interest. The UAV is equipped with an infrared sensor for fire detection and a LiDAR for obstacle detection. The fire intensity and fire location information collected by the detection UAV is then relayed to the suppression UAV to start the next phase of the mission. The second UAV features a suppression system capable of suppressing localized fires using a bucket carrying a retardant appropriate for the mission. It will then navigate autonomously to the desired location, and deploy the suppressant. Development of UAV platforms and experimental results including flight test results are shown.

15:00-15:20 ThB4.4

Detecting and Localizing Objects on an Unmanned Aerial System (UAS) Integrated Witha Mobile Device, pp. 738-743

Kim, Jinho — United States Military Academy
Lin, Kevin — United States Military Academy
Nogar, Stephen — U.S. Army Research Laboratory
Larkin, Dominic — United States Military Academy
Korpela, Christopher — United States Military Academy

There is a strong need for Unmanned Aerial Systems (UAS) that can navigate autonomously using visual information for GPS denied and other degraded environments. In this paper, a system architecture is proposed that utilizes visual-inertial odometry (VIO) and object recognition and localization for a quadrotor UAS. It also incorporates communication with an Android Team Awareness Kit (ATAK) device, allowing users to share situational awareness of the UAS in real-time. The system architecture is validated through experiments in which

a human is detected and localized as the object of interest.

15:20-15:40 ThB4.5

Forest Fire Detection and Localization Using Thermal and Visual Cameras, pp. 744-749

Sadi, Mohsen — Concordia University
Zhang, Youmin — Concordia University
Xie, Wenfang — Concordia University
Hossain, F. M. Anim — Concordia University

In this paper, a system targeting for using unmanned aerial vehicle (UAV) to application of detecting and locating forest fires is developed. It utilizes the information of two cameras: one charged coupled device (CCD) camera and one thermal camera. The information of both cameras are aligned and then fused to verify if a fire has occurred. In the alignment process, a homography matrix is calculated to assure that the corresponding pixels in both images point to the same area. An image-based thermo-visual servoing (IBTVS) system is implemented for the fire tracking process. A two-degree-of-freedom (2DOF) frame is fabricated based on IBTVS to test the tracking and locating capabilities of the system. Experimental tests show that the designed system can extract fire features from thermal and visual cameras, calculate the position of fire, and command the frame for pointing to the fire.

ThC1 Macedonia Hall

Micro and Mini UAS (Regular Session)

17:00-17:20 ThC1.1

Least Airspeed Reduction Strategy & Flight Recuperation of a Fixed-Wing Drone, pp. 750-757

Alatorre, Armando — Université De Technologie De Compiègne
Castillo, Pedro — Université De Technologie De Compiègne
Lozano, Rogelio — Université De Technologie De Compiègne

An energy reduction strategy for a fixed-wing drone with classic configuration is presented in this paper. The strategy is developed using the longitudinal non-linear motion equations of the aircraft, considering the stall effects in the determination of lift and drag forces. Our strategy imposes the aircraft to track a special trajectory allowing the vehicle to perform a curve in ascend, acting against the gravity force. As a consequence of this tracking, the angle of attack of the vehicle is increased arriving to critical values that need to be compensated for avoiding the crash of the vehicle. Therefore, a strategy to avoid the stall stage and recovering the flight stability in the vehicle is proposed. The strategy is evaluated in simulations for validating the performance of the whole system.

17:20-17:40 ThC1.2

MicroBrosh UAV: A Basic Risk Operation Self Handled Platform, pp. 758-766

Lucena, Alysson — Universidade Federal Do Rio Grande Do Norte
Goncalves, Luiz M. G. — Universidade Federal Do Rio Grande Do Norte

The present proposal refers to a wing type micro unmanned aerial vehicle that provides low operation risk to people and installations (Micro-Brosh). The UAV is intended for aerospace use, having dimensions less than 30 cm and a weight less than 200 g, what guarantees low danger to the handler and physical installations if compared to traditional aircrafts in operation. The proposal also has low production and maintenance costs, with takeoff by manual launch and landing without the need for appropriate runways, in addition to low RCS (Radar Cross Section) or radar signature, what makes it useful in military applications. We show the design details, depicting the used techniques for determining sustainability, minimum flight velocity, maximum time of flight (autonomy) and other solved issues related to the development. The experiments and results include tests done with the platform for proving its navigability. This work is a good starting point to researchers that intend to enter this area nowadays.

17:40-18:00 ThC1.3

Sum of Square Based Event-Triggered Control of Nano-Quadrotor in Presence of Packet Dropouts, pp. 767-776

Singh, Padmini — Indian Institute of Technology Kanpur
Gupta, Sandeep — Indian Institute of Technology Kanpur
Behera, Laxmidhar — Indian Institute of Technology Kanpur
Verma, Nishchal Kumar — Indian Institute of Technology Kanpur

This paper presents perching of quadrotor on vertical wall using the sum of square (SOS) method based event-triggered second order relay free control. In perching, task quadrotor moves from 3-dimensional cartesian space to 2-dimensional cartesian space. The quadrotor is an underactuated multi-input multi-output device, where four control inputs control twelve states. Here a second-order homogenous relay free controller is designed for trajectory tracking, which is easy to develop and also exhibits the property of fast convergence. Next, to mitigate the disturbance of the system, a second-order homogenous super twisting-based disturbance observer is clubbed with the relay free controller. The stability of the proposed controller and disturbance observer is derived using Polya's method. Furthermore, for reducing the controller's effort and the disturbance observer effort, SOS tools are used for finding the threshold on event-triggering error. Using event-triggering conditions allowable number of packet-dropouts from controller to plant side are also derived. Simulation Results shows that the proposed controller performs better than the existing fast non- singular terminal sliding mode control (FNTSMC). Experiments are conducted on rough vertical wall to validate the proposed theory.

18:00-18:20	ThC1.4

The MiniHawk-VTOL: Design, Modeling, and Experiments of a Rapidly-Prototyped Tiltrotor UAV, pp. 777-786

Carlson, Stephen — University of Nevada, Reno
Papachristos, Christos — University of Nevada, Reno

This work addresses the rapidly prototyped design of a small Tricopter/Fixed-Wing Vertical Take-Off and Landing UAS with solar-recharge-capability, capable of repeatedly landing, recharging, and taking off, without need for physical intervention or externally placed maintenance devices or platforms. The design uses Fused Deposition Modeling 3D printing to rapidly prototype and fabricate the majority of the aircraft structures and parts. Provisions are made for carrying high-level single board computing solutions, or other similar payloads. Details are provided for mechanisms, aerodynamic geometry, solar cell integration and manufacturability. The design is analyzed to estimate inertial moments, aerodynamic performance, and static and dynamic stability. Simulation models for the Gazebo and RealFlight environments are provided, targeting Software-In-The-Loop architectures that run the ArduPilot and PX4 flight stacks. A flight-testing methodology is developed, and results are presented with multiple prototype vehicles constructed. We finally contribute all production definitions, files, and models as open-access resources, with the goal of supporting and promoting migratory/swarming behavior and autonomy research.

18:20-18:40	ThC1.5

Extinguishing of Ground Fires by Fully Autonomous UAVs Motivated by the MBZIRC 2020 Competition, pp. 787-793

Walter, Viktor — Czech Technical University in Prague
Spurny, Vojtech — Czech Technical University in Prague
Petrlik, Matej — Czech Technical University in Prague
Baca, Tomas — Czech Technical University in Prague
Žaitlík, David — Czech Technical University in Prague
Saska, Martin — Czech Technical University in Prague

In this paper, a system for autonomous extinguishing of ground fires using the placement of fire blankets by Multi-rotor Unmanned Aerial Vehicles (UAVs) is proposed. The proposed system, relying on the fusion of multiple onboard sensors using only onboard computers, is infrastructure independent with a focus on high reliability in safety-critical missions that require power-on-and-go full autonomy. This task was part of the third challenge of MBZIRC 2020 aimed at the development of autonomous robotic systems for extinguishing fires inside and outside of buildings. The MBZIRC competition promotes the development of such robotics applications that are highly demanded by society and, due to their complexity and required robot abilities, go beyond the current robotic state of the art. As far as we are aware, our team was one of only two teams to achieve successful system for placement of fire blankets fully autonomously with vision-based target localization without using Real-time kinematic (RTK)-global navigation satellite system (GNSS), as was required in the competition and also for the real missions of first responders.

ThC2	Kozani
Control Design III (Regular Session)	

17:00-17:20	ThC2.1

A Review of Safe Online Learning for Nonlinear Control Systems, pp. 794-803

Osborne, Matthew Hewitt — Cranfield University
Shin, Hyo-Sang — Cranfield University
Tsourdos, Antonios — Cranfield University

Learning for autonomous dynamic control systems that can adapt to unforeseen environmental changes are of great interest, but the realisation of a practical and safe online learning algorithm is incredibly challenging. This paper highlights some of the main approaches for safe online learning of stabilisable nonlinear control systems with a focus on safety certification for stability. We categorise a non-exhaustive list of salient techniques, with a focus on traditional control theory as opposed to reinforcement learning and approximate dynamic programming. This paper also aims to provide a simplified overview of techniques as an introduction to the field. It is the first paper to our knowledge that compares key attributes and advantages of each technique in one paper.

17:20-17:40	ThC2.2

Cooperative Aerial Slung Load Transportation Using a Novel Adaptive Sliding Mode Controller, pp. 804-813

N. S., Abhinay — Tata Consultancy Services Ltd
Shobhit, Shubhankar — Tata Consultancy Services Ltd
Sridhar, Nithya — Tata Consultancy Services Ltd
Das, Kaushik — Tata Consultancy Services Ltd

This paper presents a decentralized approach to transport a cable suspended load using multiple Unmanned Aerial Vehicles (UAVs). The proposed approach is decentralized in the sense that the trajectory for each of the UAVs is computed offline using the kinematics of the system and the desired path of the load. This approach enabled the task of cooperative transportation to be treated as a problem of multiple UAVs, each carrying a cable suspended load. A neural adaptive sliding mode controller proposed by the authors in an earlier work is then deployed on each of the UAVs to track the trajectory while minimizing the load swing. Since the system of an UAV carrying

a suspended load is underactuated, the conditions on the sliding surface variables that ensure the stability of the system are also given. The performance of the proposed approach is tested with payloads of non-uniform density and uncertain mass, using Gazebo simulations. The performance is compared against an adaptive sliding mode controller which motivated the design of the proposed controller.

17:40-18:00 ThC2.3

Integrated Guidance and Control for Autonomous Rendezvous of Unmanned Aerial Vehicle During Aerial Refueling, pp. 814-820

Zhao, Wenbi — Northwestern Polytechnical University
Duan, You — Northwestern Polytechnical University
Yu, Ziquan — Nanjing University of Aeronautics and Astronautics
Qu, Yaohong — Northwestern Ploytechnical University
Zhang, Youmin — Concordia University

The guidance law and the flight control system design problem for the unmanned aerial vehicle (UAV) in the autonomous rendezvous phase of aerial refueling have been studied in this paper. Firstly, according to the relative relationship between virtual tanker aircraft and UAV, the guidance law of UAV is designed by dividing terminal angle restriction and speed restriction. With respect to the terminal angle restriction guidance law, global fast terminal sliding mode control strategy is introduced to ensure that UAV can quickly track the virtual tanker aircraft in finite time. Then, the tracking angle obtained by the guidance law is converted to the desired attitude angle signal. Moreover, a double integration-based sliding mode control method is applied to design the UAV flight control scheme, and the radial basis function (RBF) neural network is used to estimate the uncertain terms of UAV. The designed double integral sliding mode method is capable of meticulous control for the UAV attitude, and make the attitude of the UAV reach the desired command signal in a limited time. Finally, the effectiveness of the designed control system is demonstrated by numerical simulations.

18:00-18:20 ThC2.4

Flatness-Based Control of a Gimballed Fixed-Wing UAS, pp. 821-826

Morgan, Hayden — Brigham Young University
Beard, Randal W. — Brigham Young University

This paper derives a differential flatness model for a fixed-wing Unmanned Aircraft System (UAS) together with a gimballed camera. The flat output is the 3D trajectory of the aircraft and the 3D trajectory of a ground target. An LQR controller is then derived so that the UAS follows the desired trajectory and the optical axis is aligned with the line-of-sight vector between the UAS and the target. A simple simulation study shows that the framework can be used to visually track and follow a ground target, maintaining the line-of-sight vector alignment to within 1.2 degree.

18:20-18:40 ThC2.5

An Ellipsoidal-Polytopic Based Approach for Aggressive Navigation Using Nonlinear Model Predictive Control, pp. 827-835

Pereira, Jean Carlos — CEFET-MG/Campus Divinopolis
Leite, Valter J. S. — CEFET-MG/Campus Divinopolis
Raffo, Guilherme Vianna — Federal University of Minas Gerais

This work addresses the development of a nonlinear model predictive controller (NMPC) for controlling autonomous motion systems navigating within cluttered environments with unknown obstacles. More specifically, this work concerns the aggressive maneuverability of motion systems, allowing them to navigate at high speed while reacting dynamically to obstacles. Additionally, these applications require the ability to generate and control large linear and angular accelerations. In this regard, a new ellipsoidal-polytopic approach for obstacle avoidance is incorporated by the NMPC. As a result, the new control method considers the orientation of the motion system in the collision avoidance, allowing aggressive maneuvers to improve the motion system performance for the obstacle deviation. The new controller is corroborated with a quadrotor UAV, which accomplishes a point-to-point motion avoiding obstacles positioned between the starting point and the destination point.

ThC3 Edessa

Path Planning V (Regular Session)

17:00-17:20 ThC3.1

Exact Reactive Receding Horizon Motion Planning for Aerial Vehicles, pp. 836-842

Yadav, Indrajeet — University of Delaware
Tanner, Herbert G. — University of Delaware

This article presents a motion planning strategy that integrates a reactive receding horizon local trajectory generation methodology with a navigation function based global planner to guarantee that a quadrotor type acs{mav} navigating in partially known cluttered environment can reach its goal. The environment is partially known in the sense that there can be obstacles which are not a priori known to be included in the navigation function construction and used by the global planner. These obstacles are avoided reactively at the level of the local planner, which reacts to sensing information within the ac{fov} of the onboard sensors and keeps generating dynamically feasible safe trajectories along the segments generated by the global planner. The proposed motion planning strategy combines the advantages of global and reactive aerial navigation, producing locally optimal (in a minimum-jerk sense) vehicle motion. The effectiveness of the planner is demonstrated through realistic acs{ros}-Gazebo simulations.

17:20-17:40	ThC3.2

Discrete Time Optimal Trajectory Generation and Transversality Condition with Free Final Time, pp. 843-852

Eslamiat, Hossein — Southern Illinois University Carbondale
Sanyal, Amit — Syracuse University
Lindsay, Clark — Southern Illinois University Carbondale

A discrete time, optimal trajectory planning scheme for position trajectory generation of a vehicle is given here, considering the mission duration as a free variable. The vehicle is actuated in three rotational degrees of freedom and one translational degree of freedom. This model is applicable to vehicles that have a body-fixed thrust vector direction for translational motion control, including fixed-wing and rotorcraft unmanned aerial vehicles (UAVs), unmanned underwater vehicles (UUVs) and spacecraft. The lightweight scheme proposed here generates the trajectory in inertial coordinates, and is intended for real time, on-the-go applications. The unspecified terminal time can be considered as an additional design parameter. This is done by deriving the optimality conditions in a discrete time setting, which results in the discrete transversality condition. The trajectory starts from an initial position and reaches a desired final position in an unspecified final time that ensures the cost on state and control is optimized. The trajectory generated by this scheme can be considered as the desired trajectory for a tracking control scheme. Numerical simulation results validate the performance of this trajectory generation scheme used in conjunction with a nonlinear tracking control scheme.

17:40-18:00	ThC3.3

Curvature-Constrained Vector Field for Path Following Guidance, pp. 853-857

Shivam, Amit — Indian Institute of Science
Ratnoo, Ashwini — Indian Institute of Science

This paper introduces a new vector field guidance method to generate safe and continuously flyable paths for unmanned air vehicles. The central idea of the proposed vector field approach is imbibed in the commanded course angle, which is expressed as a nonlinear function of the position error with respect to the desired path. Considering straight line and circular paths, the asymptotic behaviour of position error is shown to converge to zero. Analysis of path curvature establishes a significantly lower maximum value as compared to a popular existing method. Simulation results are presented considering a two-dimensional kinematic model. Overall, the method presents an easily computable path following a solution with superior curvature characteristics.

18:00-18:20	ThC3.4

NMPC-Based UAV 3D Target Tracking in the Presence of Obstacles and Visibility Constraints, pp. 858-867

Tyagi, Prakrit — Delhi Technological University
Kumar, Yogesh — IIIT Delhi
Baliyarasimhuni, Sujit P. — IISER Bhopal

Persistent target tracking using fixed-wing unmanned aerial vehicles (UAVs) in urban areas is an important application. However, due to the kinematic constraints of the UAV coupled with the visibility obstruction due to terrain impose hard constraints on the UAV motion for persistent tracking. In this paper, we propose a nonlinear model predictive control (NMPC) based controller with a gimballed camera to persistently track a target on the ground. The controller determines the control commands for the UAV and the gimbal azimuth and elevation angles. Simulations results show that the proposed approach can efficiently track the target compared to the NMPC framework without gimbal.

18:20-18:40	ThC3.5

MK-RRT: Multi-Robot Kinodynamic RRT* Trajectory Planning*, pp. 868-876

Cain, Brennan — University of South Carolina
Kalaitzakis, Michail — University of South Carolina
Vitzilaios, Nikolaos — University of South Carolina

This paper introduces MK-RRT*: a Multi-robot Kinodynamic RRT*-based framework for trajectory planning of multiple dynamically-modeled robots. The framework includes both tightly coupled and loosely-coupled methods for planning. The simultaneous, tightly coupled, method provides an asymptotically optimal solution to the multi-robot trajectory planning problem. A sequential, loosely coupled, method is also developed to compare costs of the generated trajectories and computational complexity of both methods. An application of this framework to multi-UAV trajectory planning is presented and experimentally evaluated using a team of Ryze Tello EDU UAVs.

ThC4	Naoussa
UAS Applications III (Regular Session)	

17:00-17:20	ThC4.1

3D Multi-Camera Coverage Control of Unmanned Aerial Multirotors, pp. 877-884

Huang, Sunan — National Universtiy of Singapore
Leong, Wai Lun — National University of Singapore
Teo, S. H. — National Universtiy of Singapore

Unmanned aerial vehicles (UAVs) are gaining a lot of attentions over the past two decades. They have a wide range of civil applications such as for persistent surveillance, exploration, and rescue, monitoring operations in hazardous environment and providing mobile sensor networks. Currently, an important issue in UAVs is coverage control, especially in 3D space. In this paper, we propose a 3D coverage control. First, we consider a wall coverage issue in a 3D environment. The approach is to design a view angle and occlusion which intersects with the wall. For each UAV, it is a distributed coverage control with exchanging neighbouring UAV information. Subsequently, we extend this approach to cover a 3D polyhedron form. Finally, the proposed 3D coverage control algorithm is tested in two case studies and the results show that the proposed method is effective.

17:20-17:40 ThC4.2

Visual Rotational Constraints of General UAS Configurations, pp. 885-894

Morgan, Hayden — Brigham Young University
Beard, Randal W. — Brigham Young University

This paper introduces an algorithm for determining the relative rotational limits of a camera along a given axis or set of axes for maintaining a known target within a defined visual field-of-view. An additional algorithm is given for identifying the axis and rotation from a set available rotational degree of freedom resulting in the shortest transition of target visibility. Bound outputs are shown for a generic unmanned aircraft system (UAS) equipped with a two-axis gimbal in simulation. A variety of illustrative examples are provided for applications involving a gimballed UAS.

17:40-18:00 ThC4.3

UAS Sensor Deployment and Retrieval to the Underside of Structures, pp. 895-900

Carroll, Sabrina — University of South Carolina
Kalaitzakis, Michail — University of South Carolina
Vitzilaios, Nikolaos — University of South Carolina

Unmanned Aircraft Systems (UAS, commonly known as aerial drones) are widely used for remote inspection and evaluation in Structural Health Monitoring (SHM) applications. While in most cases the drone is only equipped with a camera and collects images and videos, there is a high interest for structural evaluation that goes beyond visual inspection and provides information on the internal structure. For the latter, specialized sensors need to be used which in many cases need to be attached to the structure. This work presents an autonomous, low-cost, UAS for attaching and retrieving sensor packages to the underside of structures for SHM applications. Such a system can be used for nondestructive evaluation of structures by deploying sensors like accelerometers on bridges or tunnels. The proposed system is experimentally evaluated and is shown to be capable of the task utilizing only onboard systems and an artificial landmark with an operator to change between deployment and retrieval missions.

18:00-18:20 ThC4.4

Payload Swing Attenuation of a Fully-Actuated Hexacopter Via Extended High Gain Observer Based Adaptive Sliding Control, pp. 901-908

Arizaga-Leon, Jorge Manuel — Tecnologico De Monterrey
Castaneda, Herman — Tecnologico De Monterrey
Castillo, Pedro — Unviersité De Technologie De Compiègne

This paper introduces a suspended-payload swing attenuation trajectory control for a fully-actuated hexacopter unmanned aerial vehicle. The system modeling is formulated using the Euler-Lagrange convention. By assuming only rotorcraft position available, whereas the payload position unavailable, an extended high gain observer is designed to provide a full state and estimate the effect of the suspended payload over the aircraft. Then, such estimation is used to dampen the oscillations produced by motion and external perturbations. Furthermore, a flight control based on the adaptive sliding mode algorithm is conceived to satisfy the desired trajectories even in presence of disturbances. Finally, the simulation results show the feasibility of our proposed strategy to perform a flight by the hexacopter, while dampening the swings of the payload.

18:20-18:40 ThC4.5

A Distributed Task Allocation Protocol for Cooperative Multi-UAV Search and Rescue Systems, pp. 909-917

Pignaton de Freitas, Edison — Federal University of Rio Grande Do Sul
Basso, Maik — Federal University of Rio Grande Do Sul
Arlis Santos da Silva, Antonio — Federal University of Rio Grande Do Sul
Schein, Mateus Schein — Federal University of Rio Grande Do Sul
Rodrigues Vizzotto, Marcos — Federal University of Rio Grande Do Sul

Nowadays, applications involving multiple robotic systems connected through a wireless network - to perform tasks together - have an increased research interest. Unmanned Aerial Vehicles (UAVs) are excellent tools for evaluating and surveying distributed robotic systems applications due to their flexibility and three-dimensional mobility capability. Cooperative systems composed of multiples UAVs may have a centralized coordination which assists the members of team to make their decisions in a distributed manner regarding the tasks to be performed. This paper proposes a system composed of embedded hardware and a high-level communication protocol that serves as a basis for identifying, distributing, and allocating tasks in a simple and distributed way to be used by groups of UAVs. The proposal is evaluated in a search and rescue scenario. The setup is configured with two types of UAVs - namely, searchers (search for new tasks) and workers (execution of tasks). Also, a set of nine simulation experiments covering three different setups were performed. Then the

proposal is evaluated by two sets of field experiments with real vehicles. The obtained results in the proposed experiments demonstrate that the system can be successfully used in the proposed scenario for task distribution and allocation.

Technical Program for Friday June 18, 2021

FrA1	Macedonia Hall
Autonomy I (Regular Session)	

09:00-09:20	FrA1.1

ICARUS: Automatic Autonomous Power Infrastructure Inspection with UAVs, pp. 918-926

Savva, Antonis	University of Cyprus
Zacharia, Angelos	University of Cyprus
Makrigiorgis, Rafael	University of Cyprus
Anastasiou, Andreas	University of Cyprus
Kyrkou, Christos	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Theocharides, Theocharis	University of Cyprus

Power transmission and distribution networks mostly span across harsh environments and thus, frequent faults and failures are observed, increasing the maintenance costs, pressing the authorities to provide electricity continuously and uninterruptedly. To this end, thorough field inspections with skilled personnel are regularly conducted, which are labor-intensive, costly and slow, whereby efficiency and staff safety cannot be always ensured. UAVs stem as a promising solution for power infrastructure inspection; however, their use is mostly limited by the fact that a remote pilot is in control of flight and mission processes, rendering reliable data acquisition in short time interval a tedious task. Despite research efforts for automating inspection procedures, these have not been widely adopted. In this study, we address this challenge by developing a Power Distribution Network Inspection Platform Using UAVs (ICARUS), based on a vision-based artificial intelligence toolkit, that integrates multiple sensors and automates many tasks, such as detection, tracking and identification of infrastructure components, gathering reliable spatial/time data associated to these components autonomously, safely and fast.

09:20-09:40	FrA1.2

Hyperion: A Robust Drone-Based Target Tracking System, pp. 927-933

Anastasiou, Andreas	University of Cyprus
Makrigiorgis, Rafael	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus

Recent advances in mobile computing and embedded systems have had a transformative impact in the field of Unmanned Aircraft Systems (UASs). These advances have unlocked a great number of new capabilities ranging from real time machine learning for detection and tracking of targets, and autonomous intelligent control for mission-critical trajectory planning. This paper introduces Hyperion, a robust detect, track and follow algorithm for UASs, leveraging and integrating various computer vision techniques and a combination of two proportional integral derivative (PID) controllers for following a moving vehicle. The proposed system is evaluated under real settings using off-the-shelf hardware and an elaborated comparison is made with a variety of state-of-the-art trackers available in the OpenCV library.

09:40-10:00	FrA1.3

Autonomous Fire Fighting with a UAV-UGV Team at MBZIRC 2020, pp. 934-941

Quenzel, Jan	University of Bonn
Splietker, Malte	University of Bonn
Pavlichenko, Dmytro	University of Bonn
Schleich, Daniel	University of Bonn
Lenz, Christian	University of Bonn
Schwarz, Max	University of Bonn
Schreiber, Michael	University of Bonn
Beul, Marius	University of Bonn
Behnke, Sven	University of Bonn

Every day burning buildings threaten the lives of occupants and first responders trying to save them. Quick action is of essence, but some areas are not accessible or too dangerous to enter. Robotic systems have become a promising addition to fire fighting, but at this stage, they are mostly manually controlled, which is error-prone and requires specially trained personal.

We present two systems for autonomous fire fighting from air and ground we developed for the Mohamed Bin Zayed International Robotics

Challenge (MBZIRC) 2020. The systems use LiDAR for reliable localization within narrow, potentially GNSS-restricted environments while maneuvering close to obstacles. Measurements from LiDAR and thermal cameras are fused to track fires, while relative navigation ensures successful extinguishing.

We analyze and discuss our successful participation during the MBZIRC 2020, present further experiments, and provide insights into our lessons learned from the competition.

10:00-10:20 FrA1.4

Autonomous Cave Exploration Using Aerial Robots, pp. 942-949

Dharmadhikari, Mihir Rahul — University of Nevada, Reno
Nguyen, Huan — Norwegian University of Science and Technology
Mascarich, Frank — University of Nevada, Reno
Khedekar, Nikhil Vijay — University of Nevada, Reno
Alexis, Konstantinos — Norwegian University of Science and Technology

In this paper we present the complete system design for an aerial robot capable of autonomous exploration inside natural cave environments. Cave networks involve diverse and complicated topologies, complex geometries and degraded conditions rendering the process of robotic mapping a particularly daunting adventure. In response to these challenges, we outline the core algorithmic modules relating to localization and mapping, exploration path planning and control, alongside the developed perception and computing solutions onboard an aerial robot tailored to undertake such complex tasks given no prior information for the cave environments in which it is deployed. A set of extensive results is presented including both simulation studies in multi-branching and maze-like cave environments, as well as field experiments inside the Moaning Caverns natural cave environment in California, US.

10:20-10:40 FrA1.5

Autonomous Flight in Unknown GNSS-Denied Environments for Disaster Examination, pp. 950-957

Schleich, Daniel — University of Bonn
Beul, Marius — University of Bonn
Quenzel, Jan — University of Bonn
Behnke, Sven — University of Bonn

Micro aerial vehicles (MAVs) have high potential for information gathering tasks to support situation awareness in search and rescue scenarios. Manually controlling MAVs in such scenarios requires experienced pilots and is error-prone, especially in stressful situations of real emergencies. The conditions of disaster scenarios are also challenging for autonomous MAV systems. The environment is usually not known in advance and GNSS might not always be available.

We present a system for autonomous MAV flights in unknown environments which does not rely on global positioning systems. The method is evaluated in multiple search and rescue scenarios and allows for safe autonomous flights, even when transitioning between indoor and outdoor areas.

FrA2 Kozani

Control Design IV (Regular Session)

09:00-09:20 FrA2.1

Trim Point Transitions Via I/O Decoupling Controllers for 6DOF Quadrotors, pp. 958-967

Kouvakas, Nikolaos — National and Kapodistrian University of Athens
Koumboulis, Fotis N. — National and Kapodistrian University of Athens

The problem of trim point transitions is investigated for 6DOF quadrotors, using I/O decoupling controllers. The linear approximant of the quadrotor is derived in parametric form with respect to the physical parameters of the nonlinear model and the trim points. Based upon the linear approximant, a static state feedback control law achieving I/O decoupling, command following and arbitrary pole assignment for the linear approximant of the closed loop system, is derived. The controller is expressed in terms of the physical parameters and the closed loop characteristic polynomial arbitrary coefficients. To increase the range of accurate transition among different trim points of the nonlinear model, appropriate cost criteria are used and a trim point transition algorithm is proposed. The performance of the overall scheme is demonstrated through simulation results.

09:20-09:40 FrA2.2

Talking to Autonomous Drones: Command and Control Based on Hierarchical Task Decomposition, pp. 968-977

Jünger, Franz — German Aerospace Center (DLR)
Schopferer, Simon — German Aerospace Center (DLR)
Benders, Sebastian — German Aerospace Center (DLR)
Dauer, Johann — German Aerospace Center (DLR)

With increasing onboard intelligence and planning capabilities, autonomous unmanned aircraft system (UAS) can execute a wide spectrum of tasks ranging from low-level flight tasks to complex abstract mission tasks. Regardless of their onboard intelligence, most

state-of-the-art UAS are commanded with waypoint-based command and control (C2) interfaces. However, waypoint-based interfaces are not well suited to represent mission tasks at different levels of abstraction. In this work, we address the problem of designing a C2 interface for autonomous UAS at a conceptual level. We propose a C2 interface that allows operating UAS at different levels of autonomy using task decomposition and a hierarchical data format for transmission. This interface is designed to enable transparent and consistent communication of mission tasks between the ground control station and the onboard systems. We demonstrate the application of the interface for two different UAS mission scenarios in detail. The proposed interface is designed to supersede waypoint-based C2 interfaces for the next generation of UAS providing high-level autonomy through onboard intelligence.

09:40-10:00 FrA2.3

Optimal Hovering Control of a Tail-Sitter Via Model-Free Fast Terminal Slide Mode Controller and Cuckoo Search Algorithm, pp. 978-984

Zou, Xu — School of Aviation, Northwestern Polytechnical University
Liu, Zhenbao — Northwestern Polytechnical University
Zhao, Wen — School of Aviation, Northwestern Polytechnical University
Chao, Zhang — Northwestern Polytechnical University

This paper presents the design process of the model-free-based fast terminal slide mode (MF-FTSM) controller and the implementation of the control structure, for realizing the stability control of the tail-sitter UAV during the hovering process under the interference of the external environment. The designed control algorithm merges the abilities of the fast terminal slide mode control and the model-free control technology so that it has a fast convergence speed and can compensate for the unknown part of the dynamic model. Besides, the cuckoo search method is applied to this study for optimizing the parameters of the designed controller. Finally, verified by the real flight test, the proposed controller has better controlling effect and is more robust than the common slide mode controller, which benefits engineering application.

10:00-10:20 FrA2.4

Attitude Tracking Control of a Light Aircraft Using Classical and Incremental Nonlinear Dynamic Inversion Approaches, pp. 985-993

Jayaraman, Balaji — Indian Institute of Technology, Kanpur
Giri, Dipak Kumar — Indian Institute of Technology, Kanpur
Ghosh, A. K. Ghosh — Indian Institute of Technology, Kanpur

This paper presents a framework for attitude command tracking flight controller for a general aviation aircraft using Classical and Incremental Nonlinear Dynamic Inversion approaches. The theoretical background and a framework for attitude tracking flight control framework based on the controllers are presented in this paper. A comparative study of attitude tracking performance of the model dependent Nonlinear Dynamic Inversion Controller and the measurement dependent Incremental Nonlinear Dynamic Inversion Controller for a light aircraft is performed through numerical simulations. Also, Performance evaluation of the Classical and Incremental Nonlinear Dynamic Inversion controllers are carried out under nominal conditions, external disturbances and model uncertainties.

10:20-10:40 FrA2.5

Hierarchical Control of Redundant Aerial Manipulators with Enhanced Field of View, pp. 994-1002

Coelho, Andre — German Aerospace Center (DLR)
Sarkisov, Yuri — Skolkovo Institute of Science and Technology
Lee, Jongseok — German Aerospace Center (DLR)
Balachandran, Ribin — German Aerospace Center (DLR)
Franchi, Antonio — University of Twente
Kondak, Konstantin — German Aerospace Center (DLR)
Ott, Christian — German Aerospace Center (DLR)

Providing the operator with a good view of the remote site is of paramount importance in aerial telemanipulation. In light of that, this paper proposes the application of a hierarchical control framework in order to tackle the problem of adjusting the field of view of an on-board camera as a secondary task. The proposed approach ensures that the flying base, and consequently the camera, can be steered in order to provide a distant operator with a desired field of view without disturbing the end-effector pose. The approach is focused on aerial manipulators with torque-controlled arms, like the DLR Suspended Aerial Manipulator (SAM), while allowing the base to be directly torque-controlled or, alternatively, through an inner-loop velocity controller. Quantitative, qualitative, and real-scenario experimental validation is carried out using the SAM and confirms the need for such an approach and its efficacy in achieving decoupled field-of-view control.

FrA3 Edessa

Path Planning VI (Regular Session)

09:00-09:20 FrA3.1

Multiple Lane UAV Corridor Planning for Urban Mobility System Applications, pp. 1003-1009

Challa, Vinay — Indian Institute of Science
Gupta, Mohit — Indian Institute of Science

Ratnoo, Ashwini | Indian Institute of Science
Ghose, Debasish | Indian Institute of Science

The aim of this work is to achieve smooth multiple parallel paths (lanes) confined within a bounded volume (corridor) through controlled airspace in urban scenarios. The problem is formulated as two subproblems: cross-section planning and corridor planning. The corridor cross-section is optimized for minimizing the corridor width for the required number of parallel paths while taking into account the downwash effects. Corridor planning utilizes a modified A^* algorithm for waypoint generation in conjunction with a logistic curve based path for smoothly connecting these waypoints while accounting for curvature limits of individual paths. Waypoint heading angles are optimized to find minimum length corridor. The work provides an optimal solution of corridor planning with the capability of accommodating multiple UAVs simultaneously.

09:20-09:40 FrA3.2

UAS Flight Path Planning Using Numerical Potential Fields in Dense Non-Segregated Airspace, pp. 1010-1019

M. A., Sajid Ahamed | Indian Institute of Science
Kushwaha, Satya Prakash | Indian Institute of Science
Jana, Shuvrangshu | Indian Institute of Science
Ghose, Debasish | Indian Institute of Science

This paper addresses the problem of Urban aerial mobility (UAM), which refers to an air transportation system wherein unmanned aircraft systems (UAS's) are utilized to deliver small payloads on-demand by safely maneuvering in the known urban infrastructure occupied by dynamic air traffic. A multilevel framework is proposed that provides a solution for UAM in the non-segregated airspace. The proposed method takes advantage of a prediction-based zone partitioning algorithm that minimizes high-density traffic encounters. Numerical potential fields are used for global path planning as they provide optimum standoff clearance from obstacles and high-density traffic present in the environment. In the event of low-density traffic, a simple but effective octant-based local collision avoidance strategy is used.

09:40-10:00 FrA3.3

Decentralized Path Planning Approach for Crowd Surveillance Using Drones, pp. 1020-1028

Nagrare, Samiksha | Indian Institute of Science
Chopra, Onkar | Indian Institute of Science
Jana, Shuvrangshu | Indian Institute of Science
Ghose, Debasish | Indian Institute of Science

The problem of periodical surveillance of multiple moving targets using multiple drones in a decentralized manner is addressed in this paper. The strategy proposes a traverse order generation scheme by which the sequence in which targets are tracked can be determined. To cover all the targets by visiting them sequentially, the predicted targets' future position is used in path planning. The proposed algorithm takes care of drones' assignment to targets and eventual hand-off to neighboring drones as targets move from one region to another. The proposed strategy is used for a crowd monitoring system, and it attempts to detect the anomalous activity of a crowd via target trajectories. Complete surveillance architecture is validated using simulation for tracking of multiple walking agents using multi drones.

10:00-10:20 FrA3.4

Quadrotor UAV 3D Path Planning with Optical-Flow-Based Obstacle Avoidance, pp. 1029-1036

Allasia, Giancarlo | Politecnico Di Torino
Rizzo, Alessandro | Politecnico Di Torino
Valavanis, Kimon P. | University of Denver

A real-time waypoint-based 3D local path planning algorithm is proposed for obstacle avoidance using the optical flow obtained by a frontal monocular camera mounted on a quadrotor UAV. The algorithm accounts for vertical and horizontal obstacle avoidance, as well as for avoidance of frontally approaching obstacles. Implementation and testing are carried out in the ROS environment and the algorithm effectiveness is demonstrated via Gazebo simulations. Real-time algorithm performance is also assessed through software profiling and in terms of worst case execution time using the NVIDIA Jetson TX1 and RaspberryPi 4 for hardware-in-the-loop (HIL) tests.

10:20-10:40 FrA3.5

3D Real-Time Energy Efficient Path Planning for a Fleet of Fixed-Wing UAVs, pp. 1037-1046

Aiello, Giuseppe | Politecnico Di Torino
Valavanis, Kimon P. | University of Denver
Rizzo, Alessandro | Politecnico Di Torino

UAV path planning requires finding an optimal (or sub-optimal) collision free path in a cluttered environment, while taking into account geometric, physical, and temporal constraints, eventually allowing UAVs to perform their tasks despite several uncertainty sources. This paper reviews the current state-of-the-art in path planning, and subsequently introduces a novel node-based algorithm based on the called EEA*. EEA* is based on the A* Search algorithm and aims at mitigating some of its key limitations. The proposed EEA* deals with 3D environments, it provides robustness quickly converging to the solution, it is energy efficient, and it is real-time implementable and executable. Along with the proposed EEA*, a local path planner is developed to cope with unknown dynamic threats in the environment. Applicability and effectiveness is first demonstrated via simulated experiments using a fixed-wing UAV that operates in different mountain-

like 3D environments in the presence of several unknown dynamic obstacles. Then, the algorithm is applied in a multi-agent setting with three UAVs that are commanded to follow their respective paths in a safe way. The energy efficiency of the EEA* algorithm has also been tested and compared with the conventional A* algorithm.

FrA4	Naoussa
UAS Applications IV (Regular Session)	

09:00-09:20	FrA4.1

Learning-Based Camera Relocalization with Domain Adaptation Via Image-To-Image Translation, pp. 1047-1054

Yang, Chenhao	University of Tübingen
Liu, Yuyi	Kyoto University
Zell, Andreas	University of Tübingen

Camera relocalization is promising for robot navigation; however, the lack of sufficient reference images and challenging shifts of conditions limit its further application. This paper proposes a learning-based three-step pipeline that applies spatial information features for camera relocalization problems. We first introduce a frustum intersection over union (IoU) to represent the image pair's spatial similarity. This representation is used to train an image retrieval model to find nearest neighbor candidates for query images. A spatial sample consensus (SPASAC) operation is then deployed to filter the outliers in the candidates. Afterward, a relative camera pose regressor is used with the valid candidates to predict every query image's absolute pose. Besides, we introduce two implementations of image-to-image translation networks for camera relocalization to increase the number of synthetic reference images and challenging night-to-day localization performance. Experiments show that our method can estimate camera poses across different domains and outperforms related methods in four benchmarks. Specifically, the experiments on the Tuebingen Buildings dataset demonstrate the robustness of our approach when localizing UAV-captured images with high-speed movement and large viewpoint variation.

09:20-09:40	FrA4.2

SwarmPaint: Human-Swarm Interaction for Trajectory Generation and Formation Control by DNN-Based Gesture Interface, pp. 1055-1062

Serpiva, Valerii	Skolkovo Institute of Science and Technology
Karmanova, Ekaterina	Skolkovo Institute of Science and Technology
Fedoseev, Aleksey	Skolkovo Institute of Science and Technology
Perminov, Stepan	Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry	Skolkovo Institute of Science and Technology

Teleoperation tasks with multi-agent systems have a high potential in supporting human-swarm collaborative teams in exploration and rescue operations. However, it requires an intuitive and adaptive control approach to ensure swarm stability in a cluttered and dynamically shifting environment. We propose a novel human-swarm interaction system, allowing the user to control swarm position and formation by either direct hand motion or by trajectory drawing with a hand gesture interface based on the DNN gesture recognition.

The key technology of the SwarmPaint is the user's ability to perform various tasks with the swarm without additional devices by switching between interaction modes. Two types of interaction were proposed and developed to adjust a swarm behavior: free-form trajectory generation control and shaped formation control.

The experimental results revealed a sufficient accuracy in the trajectory tracing task (Mean error of 5.6 cm by gesture draw and 3.1 cm by mouse draw with the pattern of 1 m) over three evaluated trajectory patterns and up to 7.3 cm accuracy in targeting task with two target patterns of 1 m achieved by SwarmPaint interface.

Therefore, the proposed SwarmPaint technology can be potentially applied in various human-swarm scenarios, including complex environment exploration, dynamic lighting generation, and interactive drone shows, allowing users to actively participate in the swarm behavior decision on a different scale of control.

09:40-10:00	FrA4.3

Design of an Aerial Manipulator System Applied to Capture Missions, pp. 1063-1069

Zhang, Wenyu	Beihang University
Liu, Qianyuan	Beihang University
Wang, Meng	Beihang University
Jia, Jindou	Beihang University
Lyu, Shangke	Beihang University
Guo, Kexin	Beihang University
Yu, Xiang	Beihang University
Guo, Lei	Beihang University

This paper proposes the design of an aerial manipulator system for capture missions. A novel mechanical layout is designed. A 5-degree-of freedom manipulator and the battery are placed at the front and back part of a quadrotor unmanned aerial vehicle (UAV) respectively. This layout can expand the task space and minimize the shift of the center of mass. To improve the success rate of capture, inspired by

the predation maneuver of birds, online trajectory generation law for capture mission is proposed. The aerial manipulator points towards its target during the flight. Experimental results show that the proposed aerial manipulator system can capture the target on a moving platform successfully.

10:00-10:20 FrA4.4

Soft-Landing of Multi-Rotor Drones Using a Robust Nonlinear Control and Wind Modeling, pp. 1070-1079

Nekoo, Saeed Rafee — Universidad De Sevilla
Acosta, Jose Angel — Universidad De Sevilla
Heredia, Guillermo — Universidad De Sevilla
Ollero, Anibal — Universidad De Sevilla

Grasping, manipulation, and inspection by multirotor systems require soft landing without any bumps; hence, the one-shot landing subject is critical due to aerodynamics effects under a multirotor unmanned aerial vehicle (UAV). One of the tasks in the HYFLIERS project is landing on a rack of pipes for inspection, mainly measurement of the pipe thickness and corrosion. The rack of pipes generates an unknown disturbance caused by the induced airflow by the propellers during the landing phase. The modeling of this problem is developed for two cases, landing on the ground and rack of pipes. The ground effect modeling is straightforward; however, the rack of pipes imposes more uncertainty on the system modeling. The source of aerodynamics disturbance also could be either external wind or the one caused by the UAV's propellers near the pipes or ground. This work proposes a solution for the one-shot landing of a quadrotor considering the ground effect. First, the induced wind by the rotors near the ground is computed and then the reflection model of that near the ground is defined. Modeling of the quadrotor considering the wind in the environment is done. Next, the reflected wind by the ground is set in the wind model of the system. The uncertainty in the modeling exists due to interference of airflow under the UAV and behavior of that, so a robust nonlinear control is selected to control the system. The correction gain of the sliding mode controller was defined based on the steady-state thrust that plays the role of an upper bound of uncertainty. A simulation has been successfully done to present the advantages of the soft landing method considering the ground effect. The resultant input thrust decreased smoothly near the pipes that compensated the ground effect thrust.

10:20-10:40 FrA4.5

Rogue Agent Identification and Collision Avoidance in Formation Flights Using Potential Fields, pp. 1080-1088

Jyoti, Ravinder Kumar — Indian Institute of Science
Malhotra, Mohit Kumar — Indian Institute of Science
Ghose, Debasish — Indian Institute of Science

In this paper, an artificial potential field based technique is proposed for maintaining a formation of drones, for identifying rogue drones, and for avoiding collision with obstacles and rogue drones. Rogue drone identification is done by using a threshold potential value which is also used to identify the threat level of neighbouring drones. A novel assistive potential field concept is introduced to implement a collision avoidance strategy that helps the formation to avoid collision with the rogue drone as well as other obstacles. A pair of hyperplanes are defined using which the repulsive forces are generated. Simulations are presented to demonstrate the efficacy of the approach.

FrB1 Macedonia Hall

Autonomy II (Regular Session)

11:00-11:20 FrB1.1

Exploitation of Thermals in Powered and Unpowered Flight of Autonomous Gliders, pp. 1089-1095

El Tin, Fares — McGill University
Patience, Christian — McGill University
Borowczyk, Alexandre — Notos Technologies
Nahon, Meyer — McGill University
Sharf, Inna — McGill University

Unmanned Aerial Gliders (UAGs) are a class fixed-wing Unmanned Aerial Vehicles (UAVs) that are particularly well-suited to applications involving long endurance and range. By relying on atmospheric energy, most commonly in the form of thermal updraft, UAGs are able to gain altitude and extend flight time while preserving on-board battery energy to further prolong the mission. While previous research has investigated autonomous soaring for UAGs, the focus has been on detecting and exploiting thermals while in gliding flight. In this work, soaring algorithms are adapted to detect the presence of thermal updraft while in either powered or gliding flight. This allows the aircraft to latch onto thermals at any point during flight and capitalize on atmospheric energy to preserve on-board battery energy. Furthermore, to generate a sink polar for use in the soaring algorithms, both analytically and experimentally, digital DATCOM is used to analyze the aerodynamics of the aircraft in the former case, and a Rauch-Tung-Striebel smoother is proposed to filter experimental flight data for post-processing. The algorithm is subsequently integrated into the PX4 flight stack and testing is performed in a Software-in-the-Loop environment. Simulation results show the improvement in efficiency gained by using atmospheric energy through all phases of flight.

11:20-11:40 FrB1.2

Geometrically Based Collision Avoidance for Quadrotors under Short Sensing Distance Conditions, pp. 1096-1105

Maalouly, Anthony — McGill University
Sharf, Inna — McGill University

Mantegh, Iraj National Research Council Canada

Quadrotors have seen a surge in popularity in many applications such as medical deliveries, surveying tasks, mapping tasks and much more. Urban operations, such as deliveries of parcels, require the quadrotor, referred to as the ownship in this paper, to be capable of autonomous navigation and collision avoidance, relying only on its onboard sensors. The focus of this paper is on the maneuvering of the ownship to avoid a potential collision with another neutral vehicle pursuing its own mission. We present a geometrical collision avoidance scheme based on the original 3DVO algorithm. The novelty of the improved 3DVO (I-3DVO) lies in its abilities to select an optimal collision avoidance plane and to vary the speed of the ownship to achieve collision avoidance under the short sensing distance conditions. We validate our proposed algorithm via a Matlab simulation accounting for the often neglected dynamics of the quadrotor ownship.

11:40-12:00 FrB1.3

Vision-Based Guidance for Tracking Dynamic Objects, pp. 1106-1115

Karmokar, Pritam University of Texas at Arlington
Dhal, Kashish University of Texas at Arlington
Beksi, William University of Texas at Arlington
Chakravarthy, Animesh University of Texas at Arlington

In this paper, we present a novel vision-based framework for tracking dynamic objects using guidance laws based on a rendezvous cone approach. These guidance laws enable an unmanned aircraft system equipped with a monocular camera to continuously follow a moving object within the sensor's field of view. We identify and classify feature point estimators for managing the occurrence of occlusions during the tracking process in an exclusive manner. Furthermore, we develop an open-source simulation environment and perform a series of simulations to show the efficacy of our methods.

12:00-12:20 FrB1.4

ATAK Integration through ROS for Autonomous Air-Ground Team, pp. 1116-1122

Larkin, Dominic United States Military Academy
Novitzky, Michael United States Military Academy
Kim, Jinho United States Military Academy
Korpela, Christopher United States Military Academy

This work introduces a methodology to interact with a heterogeneous team of autonomous robots performing a search and rescue mission. The autonomous robot team consists of a quadrotor and an unmanned ground vehicle. The robot team's human interface is the Android Team Awareness Kit (ATAK), which both military and emergency management first responders have found useful. This work's contribution is creating a platform-agnostic robot operating system (ROS) node used by the various autonomy stacks of each platform. This node is called atak_bridge. In order to limit the need to modify the ATAK client applications, atak_bridge leverages currently available standard messages within the ATAK framework. This eliminated the need for any specific ATAK plugin. A robot using atak_bridge shares its location and the locations of any objects of interest it detects to a user's ATAK device. Using the same ATAK device, the user can send waypoints to the robot, which the atak_bridge interprets into appropriate autonomy stack representations. We demonstrate the feasibility of integrating ATAK, using atak_bridge, into an air-ground team of autonomous robots for a search and rescue mission. The first responder sends the aerial platform to search an area and relays to the ATAK user any possible victims' locations. Upon receiving these locations, a first responder can dispatch an autonomous ground vehicle to confirm a victim and deliver food, water, and a first aid kit.

12:20-12:40 FrB1.5

Development of an Autonomous Soaring Algorithm for Small Unmanned Aircraft Systems, pp. 1123-1130

Rosales, Jesus New Mexico State University
Guijarro Reyes, Gabriel Alexis New Mexico State University
Sun, Liang New Mexico State University
Garcia Carrillo, Luis Rodolfo New Mexico State University
Gross, Andreas New Mexico State University

An autonomous flight control algorithm is proposed for a fixed-wing unmanned aircraft system (UAS) to carry out waypoint navigation tasks while exploiting thermals to cut down on energy consumption. The main components of the flight control algorithm are a waypoint navigation system that is coupled with an altitude controller, a thermaling flight controller, and a gliding flight controller that is combined with a proportional-integral controller to maintain a desired heading angle. The flight control algorithm is tested using a three degrees-of-freedom point mass model for a notional fixed-wing aircraft model. The flight control algorithm is demonstrated to perform satisfactorily. The aircraft reaches all of the desired waypoints and exploits thermals to save energy.

12:40-13:00 FrB1.6

Autonomous Flight through Cluttered Outdoor Environments Using a Memoryless Planner, pp. 1131-1138

Lee, Junseok University of California, Berkeley
Wu, Xiangyu University of California, Berkeley
Lee, Seung Jae Seoul National University
Mueller, Mark Wilfried University of California, Berkeley

This paper introduces a collision avoidance system for navigating a multicopter in cluttered outdoor environments based on the recent

memory-less motion planner, rectangular pyramid partitioning using integrated depth sensors (RAPPIDS). The RAPPIDS motion planner generates collision-free flight trajectories at high speed with low computational cost using only the latest depth image. In this work we extend it to improve the performance of the planner by taking the following issues into account. (a) Changes in the dynamic characteristics of the multicopter that occur during flight, such as changes in motor input/output characteristics due to battery voltage drop. (b) The noise of the flight sensor, which can cause unwanted control input components. (c) Planner utility function which may not be suitable for the cluttered environment. Therefore, in this paper we introduce solutions to each of the above problems and propose a system for the successful operation of the RAPPIDS planner in an outdoor cluttered flight environment. At the end of the paper, we validate the proposed method effectiveness by presenting the flight experiment results in a forest environment. A video can be found at www.youtube.com/watch?v=3av5xEuKg2w&ab_channel=HiPeRLab

FrB2	Kozani
Control Design V (Regular Session)	

11:00-11:20	FrB2.1

Autonomous Collaborative Transport of a Beam-Type Payload by a Pair of Multi-Rotor Helicopters, pp. 1139-1147

Horyna, Jiri	Czech Technical University in Prague
Baca, Tomas	Czech Technical University in Prague
Saska, Martin	Czech Technical University in Prague

Collaborative payload carrying by multi-rotor Unmanned Aerial Vehicles (UAVs) is presented in this paper. We propose a unique control strategy for a pair of UAVs operating with a beam-type payload that is independent of precise localization techniques or unconventional sensor equipment, allowing the system to be operable outside of the laboratory environments. The designed control system comes out with the dynamics of the coupled system, which corresponds to a bicopter aerial vehicle. Such a configuration allows for the use of estimation and control methods typical for a conventional multi-rotor aerial vehicle. The proposed master-slave control system consists of a feedback controller and an MPC reference tracker on the side of the master agent. The slave agent serves as an actuator under command of the master. In addition to the control, a system for payload detection and localization is presented. We fuse the data from RGB and depth cameras to provide sufficient conditions during payload grasping. A state machine was designed to synchronize the master-slave collaborative operations, including payload grasping or response to failure.

11:20-11:40	FrB2.2

A Comparison of LiDAR-Based SLAM Systems for Control of Unmanned Aerial Vehicles, pp. 1148-1154

Milijas, Robert	University of Zagreb
Markovic, Lovro	University of Zagreb
Ivanovic, Antun	University of Zagreb
Petric, Frano	University of Zagreb
Bogdan, Stjepan	University of Zagreb

This paper investigates the use of LiDAR SLAM as a pose feedback for autonomous flight. Cartographer, LOAM and HDL graph SLAM are first introduced on a conceptual level and later tested for this role. They are first compared offline on a series of datasets to see if they are capable of producing high-quality pose estimates in agile and long-range flight scenarios. The second stage of testing consists of integrating the SLAM algorithms into a cascade PID UAV control system and comparing the control system performance on step excitation signals and helical trajectories. The comparison is based on step response characteristics and several time integral performance criteria as well as the RMS error between planned and executed trajectory.

11:40-12:00	FrB2.3

Low Level Controller for Quadrotors, pp. 1155-1161

Rodriguez-Cortes, Hugo	CINVESTAV-IPN
Tlatelpa-Osorio, Yarai E.	CINVESTAV-IPN
Ramirez-Rodriguez, Jose Miguel	CINVESTAV-IPN

The current trend for quadcopter's control design aims to ensure the asymptotic/exponential stability of the position errors. This approach, attractive from the control theory point of view, has little impact on real quadrotor applications. Quadrotor applications include a human pilot or a set of positioning sensors with very low bandwidth; then, they rely on a robust low-level controller. In real quadrotor applications, the low-level controller commands, at least, the quadrotor angles around its longitudinal and vertical axis, the angular velocity around the vertical axis, and the vertical speed. This paper proposes a low-level controller using robust control techniques to track the input commands from a pilot or a high-level controller that uses positioning systems with low sampling time.

12:00-12:20	FrB2.4

Controlling a Formation of a MARV in Backward Movements with an UAV for Inspection Tasks, pp. 1162-1170

Bertolani, Diego Nunes	Federal Institute of Espírito Santo
Bacheti, Vinicius	Federal University of Espirito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

This work aims to show an application in inspection tasks in which an unmanned aerial vehicle (UAV) navigates while in a formation with

a multi-articulated robotic vehicle (MARV), this last one executing backward movements. This application illustrates a situation in which the MARV needs a top view of the environment, in order to avoid contact with any obstacle or a risky situation for the load, which in this case is the trailer or trailers being pushed (the MARV corresponds to a tractor pushing one or two trailers). Besides taking care of the control of the MARV-UAV formation, the proposed system also controls the backward movement of the MARV to avoid emph{jackknifing}, the shock between the trailers or between the trailer and the tractor, while the multi articulated robot follows the path. Successful experiments show navigation with the multi articulated robot pushing one and two trailers. An inspection task demonstration shows the ability of the UAV to detect obstacles for the MARV, since the ground vehicle does not have sensors to accomplish that.

12:20-12:40 FrB2.5

High-Fidelity Modeling and Control Design for a Cooperative High Altitude Long Endurance Aircraft Landing System, pp. 1171-1178

Rodrigues Della Noce, Eduardo	German Aerospace Center (DLR)
Kalra, Arti	German Aerospace Center (DLR)
Coelho, Andre	German Aerospace Center (DLR)
Muskardin, Tin	German Aerospace Center (DLR)
Kondak, Konstantin	German Aerospace Center (DLR)

High Altitude Long Endurance (HALE) aircraft can take flight to altitudes as high as 20 km and can stay there for long periods of time. In this article, the viability of landing such an aircraft on a mobile platform using a cooperative control strategy for motion synchronization is examined. Time domain system identification is applied to create a model of the Elektra 2 Solar HALE aircraft, which was found to be high fidelity by the Federal Aviation Administration (FAA) standards. An analysis is made to evaluate the feasibility of autonomously landing the HALE Unmanned Aerial Vehicle (UAV) on top of a ground vehicle with a roof-mounted landing platform. Controller synthesis is done for the individual vehicles as well as the cooperative landing control, leading to an examination of the overall system stability and performance, using both deterministic and stochastic methods.

12:40-13:00 FrB2.6

Pilot-Assist Landing System for Hover-Capable Fixed-Wing Unmanned Aerial Vehicles in All Flight Regimes, pp. 1179-1186

Hernandez Ramirez, Juan Carlos	McGill University
Nahon, Meyer	McGill University

This work presents an integrated guidance and control system designed to assist a remote human operator during the landing operation of a hover-capable fixed-wing aircraft. These platforms are capable of both conventional, steady flight and thrust-borne maneuvering, but are challenging to pilot. The proposed pilot-assist system is valid for both flight regimes, including transitions between them, and enables the pilot to intuitively adjust the landing approach, reposition if necessary, and select between conventional and vertical landing. The control system is constructed around a nonlinear SO(3) attitude control system, together with a nonlinear position controller valid for all flight regimes. A guidance algorithm is developed around the control system that translates pilot inputs into references in an intuitive manner. System performance is verified through numerical simulation using a high-fidelity model of an agile fixed-wing aircraft. Results show the proposed system enables a remote operator to safely land the aircraft while retaining high level authority during the procedure.

FrB3 Edessa

Neural Networks (Regular Session)

11:00-11:20 FrB3.1

Neural Network Techniques to Solve a Model-Free Scheme for Flow Angle Estimation, pp. 1187-1193

Lerro, Angelo	Politecnico Di Torino
Brandl, Alberto	Politecnico Di Torino
Gili, Piero	Politecnico Di Torino

In the area of synthetic and smart sensors for flow angle estimation for UAS applications, model-based, data-driven and model-free approaches represent the state-of-the-art techniques to estimate the angle-of-attack and angle-of-sideslip. Thanks to sensor fusion techniques, a synthetic sensor is able to provide estimation of flow angles without any dedicated physical sensors. A model-free approach, based on a set of nonlinear equations, demonstrates good performances when used with flight simulated data. As shown in this work, an iterative solver could not be adequate dealing with real flight data affected by common instrument uncertainties. In order to cope with real flight data, two deterministic solvers can be adopted that are based on neural techniques: pre-trained multilayer perceptron and generalised radial basis function neural networks. The neural networks considered in this work are trained with batch and sequential algorithms. All solvers are tested with noise-free and noisy signals simulating real flight instrument noise. The aim of the present work, in fact, is to provide a preliminary benchmark between the aforementioned solvers when used to solve the proposed nonlinear scheme for flow angle estimation dealing with instrument noise.

11:20-11:40 FrB3.2

Thrust--To--Weight Ratio Optimization for Multi--Rotor Drones Using Neural Network with Six Input Parameters, pp. 1194-1199

Mogorosi, Tony Oliver	Botswana International University of Science and Technology

Jamisola, Rodrigo S. Jr. — Botswana International University of Science and Technology
Subaschandar, N. — Botswana International University of Science and Technology
Mohutsiwa, Lucky Odirile — Botswana International University of Science and Technology

This study analyzes the thrust--to--weight ratio of a multi-rotor drones with respect to six different parameters using neural network. The parameters are the model weight, number of propellers, frame size, propeller diameter, propeller pitch and number of blades. An online calculation tool called eCalc is used to collect data to build a neural network model.The model has an accuracy of 97% when compared to an eCalc computed data. From this model, we optimize the thrust--to--weight ratio using gradient descent method initialized from the collected eCalc data. We ran another optimization computationby fixing two parameters to satisfy available components in the market. Optimization results are showed and analyzed.

11:40-12:00 FrB3.3

A Neural Autopilot Training Platform Based on a Matlab and X-Plane Co-Simulation, pp. 1200-1209

Pinguet, Jérémy — Safran Electronics & Defense
Feyel, Philippe — Safran Electronics and Defense
Sandou, Guillaume — École Supérieure D'électricité

The main objective of this paper is to describe a tool for the aircraft autopilot deployment only based on a flight database. Flight simulators such as X-Plane turn out to be powerful and efficient tools for creating such database and controller experimentation. The paper outlines the development of a co-simulation framework between Matlab and X-Plane using the User Datagram Protocol (UDP). The flight data collected during a first step are then used for the training of neural controllers. The approach is based on the neural network imitation ability to learn the piloting skills implicitly stored in the dataset. Also, in order to include fault-tolerant control, a Neural Multiple Model Adaptive Control (NMMAC) based on previously learned networks is implemented. This architecture consists of a bank of local controllers and a switching logic using a bank of estimators. As an illustration of the proposed platform, it is assumed that the airspeed is unmeasured for the flight director. A neural guidance autopilot based NMMAC is therefore performed on different airspeed values. Experiments show that the designed neural autopilot can successfully track both heading and altitude reference signals, while the method is not restricted to this scope.

12:00-12:20 FrB3.4

Neural Network Based Algorithm for Multi-UAV Coverage Path Planning, pp. 1210-1217

Sanna, Giovanni — Politecnico Di Torino
Godio, Simone — Politecnico Di Torino
Guglieri, Giorgio — Politecnico Di Torino

This paper discusses the Complete Coverage Path Planning (CCPP) of a complex-shaped areas executed by a fleet of AI-driven UAVs. Decision-making is delivered by a balanced “explicit vs implicit" programming. The algorithm relies on a mixed-use of decentralized Artificial Neural Networks (ANN) which confers elementary cognitive skills to each UAV, and a modified version of the famous A* pathfinder. The neural network training session imitates Human Priors in a multi-class classification, which completely bypasses common drawbacks such as the need for large databases or high computational resources. The case study focuses on complex urban areas, for which the grid resolution of the traditional approaches can't model the problem with sufficient accuracy.

12:20-12:40 FrB3.5

Adaptive Tracking Control for a UAV with Neural Adaptive Compensation Using SMC, pp. 1218-1224

Rossomando, Francisco — CONICET - Universidad Nacional De San Juan
Rosales, Claudio — CONICET - Universidad Nacional De San Juan
Soria, Carlos — CONICET - Universidad Nacional De San Juan
Gandolfo, Daniel Ceferino — CONICET - Universidad Nacional De San Juan
Carelli, Ricardo — CONICET - Universidad Nacional De San Juan

This article presents a novel adaptive controller developed for trajectory tracking tasks in UAVs. The controller is based on a parametric adaptive control law combined with the identification of the non-modeled dynamics by a neural network by using a sliding surface. A stability analysis was made by using Lyapunov theory. The proposal was validated through several simulations where the adaptive features of the controller were proved.

12:40-13:00 FrB3.6

Nonlinear Adaptive Control of Unmanned Aerial Vehicle Using Echo State Neural Networks, pp. 1225-1232

Duggan, Christopher — California State Polytechnic University, Pomona
Bhandari, Subodh — California State Polytechnic University, Pomona

This paper presents the use of Echo State neural Networks (ESN) for nonlinear adaptive control of a fixed-wing unmanned aerial vehicle (UAV). Both offline and online trained ESNs are investigated. Flight test data and simulated data are used to train the ESNs offline. The first offline trained ESN is used to estimate the inverse transformation function required for feedback linearization, specifically for the lateral-directional case. The second ESN is trained to estimate error in the output of the first ESN. The estimated error from the second ESN is used to make real time controller corrections as well as update the weighting parameters of the output phase of the first ESN, and thus allowing the controller to adapt in flight. Simulated results show that including online adaptive control improves performance in the

presence of noise and disturbances.

FrB4	Naoussa
Safety, Security and Reliability (Regular Session)	

11:00-11:20 FrB4.1

Emergency Landing Decision Method for Unmanned Aircraft, pp. 1233-1239

Ramirez Gomez, Aitor — Aalborg University
la Cour-Harbo, Anders — Aalborg University

This paper describes a framework to generate a computationally low-cost decision function to automate emergency landings for drones. Specifically, this function makes a choice of which is the most suitable location to land an unmanned aircraft from a given list of candidate ground locations. The candidate ground locations are described by a distance metric from the aircraft to the landing location and by a probability safety measure associated to how safe it is to land in that particular location. In addition, an urgency level, associated with the current healthy status of the unmanned aircraft, and a tuning parameter that models its robustness are included in the decision function. These four parameters are assumed to be given and to have some particular properties, which are described further in the paper.

11:20-11:40 FrB4.2

Collision Severity Evaluation of Generalized Unmanned Aerial Vehicles (UAVs) Impacting on Aircraft Engines, pp. 1240-1247

Sivakumar, Anush Kumar — Nanyang Technological University
Che Man, Mohd Hasrizam — Nanyang Technological University
Liu, Hu — Nanyang Technological University
Low, Kin Huat — Nanyang Technological University

This paper is devoted to investigating the collision severity of generalized UAVs impacting aircraft engines. The peak impact force and fracture of the CFM56 engine blades were evaluated using FEM and Explicit Dynamics simulations on ABAQUS. In this study, Multiple Linear Regression (MLR) analysis was performed to obtain appropriate dimensions for the modelling of quadcopter UAVs. Maximum Take-off Mass (MTOM) values of 0.5kg, 1kg, 2kg were assigned based on dimensional analyses from 39 commercial UAVs. For the simulation, parametric variations in MTOM, aircraft speed of UAV, and rotational speed of engine fan blades were adopted. Results indicated that contact forces to the blades due to collision were more severe with UAV MTOM of 1 kg and above. This was prominent in the most severe case, with the UAV camera having a head-on collision with a fan blade. However, it was notable that simulations were case-dependent as the UAV trajectory and point of collision varies for each scenario. Further studies are required to consider the influence of various UAV trajectories and component level sizing on the engine collision severity.

11:40-12:00 FrB4.3

Impact Probability Maps Computation and Risk Analysis for 3D Ground Infrastructures Due to UAV Operations, pp. 1248-1257

Levasseur, Baptiste — ONERA
Bertrand, Sylvain — ONERA

This paper proposes a methodology for computing the probability of impact on 3D infrastructures (eg. buildings) in the event of an Unmanned Aerial Vehicle (UAV) failure during a flight. This information is essential in risk analysis, whether for the preparation of a mission or for the definition of safety rules by regulatory authorities. Generation of impact probability maps on the infrastructures is based on Monte Carlo simulations involving a dynamic model of a fixed-wing UAV. Two cases are considered to represent different types of structures. The first corresponds to the presence of an infinite vertical plane, a textbook case allowing thresholds to be set conservatively. The second corresponds to a box placed on the ground that can generically encompass many types of infrastructures at risk. Generated probability maps of impact on the infrastructures are given and analyzed for these two cases. The evaluation of the kinetic energy of impact, a fundamental element in the evaluation of damage to buildings, is also addressed.

12:00-12:20 FrB4.4

Safety Challenges for Integrating U-Space in Urban Environments, pp. 1258-1267

Gutierrez, Daniel — Technological Institute of Galicia Foundation
Ventas García, Enrique — Technological Institute of Galicia Foundation

As the drone market keeps growing, it is essential to build a regulatory and safety framework to ensure a safe, efficient and secure management of an increasing number of Remotely Piloted Aircraft Systems. In that sense, Europe launched U-space initiative to enable the integration of thousands of drones into the skies. However, Unmanned Aerial Systems technology and their framework need to reach higher level of maturity to face the safety challenges arising from their implementation. The objective of this paper is to assess the State-of-the-art of the U-space and Air Traffic Management regulatory framework in Europe, describe the main challenges that need to be addressed to ensure a safe and efficient integration of drones into the European airspace and, propose the next steps to define concrete actions and solutions to face them. The analysis concludes that the current framework is not mature enough to address some of the emerging challenges identified, especially regarding the application of safety assessment methodologies in urban environments, where dense unmanned traffic and low-level operations generate a disruptive scenario. To face them, it is key to create safety metrics and operational insights using data from high-fidelity large-scale simulations followed by controlled flight demonstrations in sandbox

environments. In addition, systems safety assessment methodologies should follow an iterative approach that assigns different assurance levels to each service depending on their criticality. Future work should include the use of resilience engineering techniques to mitigate the risks linked to autonomous systems and a balanced usage of Artificial Intelligence, which benefits at medium/long term will overcome the initial safety challenges.

12:20-12:40 FrB4.5

Investigating Malware-In-The-Loop Autopilot Attack Using Falsification of Sensor Data, pp. 1268-1276

Jares, Garrett — Texas A&M University
Valasek, John — Texas A&M University

The proliferation of unmanned air systems (UAS) in recent years has provided advanced capabilities in many fields and industries. However, this widespread usage of UAS has also introduced many cyber threats. One of the primary threats faced by UAS is the threat of hijacking by cyber attack. This paper seeks to investigate and understand this threat by implementing and validating a cyber hijacking attack on a UAS using a software-in-the-loop simulation. The relevant control theory necessary to develop the attack is explained and demonstrated on a generic linear second-order system, and the attack is implemented in a Gazebo simulation and demonstrated on a quadcopter using the ArduCopter autopilot. This simulation permitted evaluation of the attack throughout several experiments. The experiments allowed for evaluation of the attack under multiple different flight conditions. Simulation results presented in the paper demonstrate that the attack poses a legitimate threat to UAS. The attacker demonstrates successful performance when the vehicle is attempting to hold position, but demonstrates only marginal control over the vehicle when it is attempting to fly to a desired position.

12:40-13:00 FrB4.6

Cyber-Security through Dynamic Watermarking for 2-Rotor Aerial Vehicle Flight Control Systems, pp. 1277-1283

Kim, Jaewon — Texas A&M University
Ko, Woo-Hyun — Texas A&M University
Kumar, P. R. — Texas A&M University

We consider the problem of security for unmanned aerial vehicle flight control systems. To provide a concrete setting, we consider the security problem in the context of a helicopter which is compromised by a malicious agent that distorts elevation measurements to the control loop. This is a particular example of the problem of the security of stochastic control systems under erroneous observation measurements caused by malicious sensors within the system.

In order to secure the control system, we consider dynamic watermarking, where a private random excitation signal is superimposed onto the control input of the flight control system. An attack detector at the actuator can then check if the reported sensor measurements are appropriately correlated with the private random excitation signal. This is done via two specific statistical tests whose violation signifies an attack.

We apply dynamic watermarking technique to a 2-rotor-based 3-DOF helicopter control system test-bed. We demonstrate through both simulation and experimental results the performance of the attack detector on two attack models: a stealth attack, and a random bias injection attack.

FrC1 — Macedonia Hall

Estimation and Bio-Inspired (Regular Session)

14:00-14:20 FrC1.1

Analysis of Forces Involved in the Perching Maneuver of Flapping-Wing Aerial Systems and Development of an Ultra-Lightweight Perching System, pp. 1284-1290

Perez Sanchez, Vicente — Universidad De Sevilla
Gómez Tamm, Alejandro Ernesto — Universidad De Sevilla
Garcia Rubiales, Francisco Javier — Universidad De Sevilla
Arrue Ulles, Begoña Chiquinquira — Universidad De Sevilla
Ollero, Anibal — Universidad De Sevilla

Trying to optimize the design of aerial robotics systems, this work presents an optimized low-weight landing system for flapping-wing aerial robots. The design, based on the use of low-sized neodymium magnets, intends to provide that these aerial robots have the capability of landing in restricted areas by using the presented solution. This capacity will increase the application range of these robots. A study of this situation has been done to analyze the perching maneuver forces and evaluate the system. The solution presented is low-weight, low-sized, and also relatively inexpensive. Therefore, this solution may apply to most ornithopter robots. Design, analysis of the implied forces, development and experimental validation of the idea are presented in this work, demonstrating that the developed solution can overcome the ornithopter's payload limitation providing an efficient and reliable solution.

14:20-14:40 FrC1.2

Estimation of the Distance from a Surface Based on Local Optic Flow Divergence, pp. 1291-1298

Bergantin, Lucia — Aix-Marseille Université
Raharijaona, Thibaut — Université De Lorraine
Ruffier, Franck — Aix-Marseille Université

Estimating the distance from a surface is a well-known problem for all kinds of applications involving robots moving in an unknown environment. For flying robots this issue is often coupled with weight constraints, from which the importance of carrying out the estimation of distances with minimalistic equipment. In this study, we present a method to exploit the optic flow divergence cue in order to assess the distance from a surface by means of an Extended Kalman Filter. First, we demonstrated mathematically that the optic flow divergence can be assessed by computing the subtraction between two local optic flow magnitudes. Then, we tested this method on a test bench consisting of two on-the-shelf optic flow sensors performing a back-and-forth oscillatory movement in front of a static or moving panorama. Our findings showed that the optic flow divergence measured as a subtraction of two local optic flow magnitudes was in line with the optic flow divergence computed theoretically under two different lighting conditions. Thus, we were able to use the optic flow divergence measured to assess the distance from the panorama, both when static and when in movement, for low (120 lux) and bright (974 lux) illuminance respectively. Future work will focus on the implementation of this method on a micro-flier to estimate the height of flight from a surface, with little mass and computational power.

14:40-15:00 FrC1.3

Feedforward Formation Control Based on Self-Organized Body-Schema, pp. 1299-1307

Franco-Robles, Jesus — XLIM Research Institute, University of Limoges
Escareno Castro, Juan Antonio — XLIM Research Institute, University of Limoges
Soto-Guerrero, Daniel — XLIM Research Institute, University of Limoges
Labbani-Igbida, Ouiddad — XLIM Research Institute, University of Limoges

In this paper we propose a new architecture of the self-organized body schema (SO-BoS) system capable of learning the configuration space of three rotorcrafts relative to a single sensor space. The SO-BoS cortical map architecture represents the posterior parietal cortex where sensory-motor of the human posture is synthesized (circular-reaction); we inspired on such process to control the displacement in formation of three rotorcraft UAVs. The SO-BoS-based feedforward control drives the aerial robots formation towards the desired position while avoiding obstacles and inter-agent collisions. The proposed strategy is a promising approach for aerial vehicles systems due to the plasticity resulting from the learning-babbling stage. A numerical result section is given to provide the inherent discussions to assess the effectiveness of the proposed intelligent navigation scheme.

15:00-15:20 FrC1.4

Mutli-UAV Method for Continuous Source Rate Estimation of Fugitive Gas Emissions from a Point Source, pp. 1308-1313

Hollenbeck, Derek — University of California, Merced
Chen, YangQuan — University of California, Merced

A multi unmanned aerial vehicle (UAV) based method for making continuous source rate estimations is proposed. The multi-UAV method utilizes the signal processing, spatial interpolation, and data-driven techniques to apply centroidal Voronoi tessellations (CVT) based coverage control. The method uses low frequency modes from dynamic mode decomposition (DMD) as the CVT density kernel. The method also employs an ordinary kriging estimation variance based entropy as a regularization term to improve exploration behavior. A 3D short time-scale plume simulation model (POSIM) is used to test the continuous source rate estimation performance.

15:20-15:40 FrC1.5

A Flow Disturbance Estimation and Rejection Strategy for Multirotors with Round-Trip Trajectories, pp. 1314-1320

Byun, Jaeseung — University of California, Berkeley
Makiharju, Simo — University of California, Berkeley
Mueller, Mark Wilfried — University of California, Berkeley

This paper presents a round-trip strategy of multirotors subject to unknown flow disturbances. During the outbound flight, the vehicle immediately utilizes the wind disturbance estimations in feedback control, as an attempt to reduce the tracking error. During this phase, the disturbance estimations with respect to the position are also recorded for future use. For the return flight, the disturbances previously collected are then routed through a feedforward controller. The major assumption here is that the disturbances may vary over space, but not over time during the same mission. We demonstrate the effectiveness of this feedforward strategy via experiments with two different types of wind flows; a simple jet flow and a more complex flow. To use as a baseline case, a cascaded PD controller with an additional feedback loop for disturbance estimation was employed for outbound flights. To display our contributions regarding the additional feedforward approach, an additional feedforward correction term obtained via prerecorded data was integrated for the return flight. Compared to the baseline controller, the feedforward controller was observed to produce 43% less RMSE position error at a vehicle ground velocity of 1 m/s with 6 m/s of environmental wind velocity. This feedforward approach also produced 14% less RMSE position error for the complex flow as well.

FrC2 Kozani

See-And-Avoid Systems (Regular Session)

14:00-14:20 FrC2.1

Monocular Vision-Based Obstacle Avoidance Scheme for Micro Aerial Vehicle Navigation, pp. 1321-1327

Karlsson, Samuel — Luleå University of Technology
Kanellakis, Christoforos — Luleå University of Technology
Sharif Mansouri, Sina — Luleå University of Technology

Nikolakopoulos, George | Luleå University of Technology, Sweden

One of the challenges in deploying Micro Aerial Vehicless (MAVs) in unknown environments is the need of securing for collision-free paths with static and dynamic obstacles. This article proposes a monocular vision-based reactive planner for MAVs obstacle avoidance. The avoidance scheme is structured around a Convolution Neural Network (CNN) for object detection and classification (You Only Lock Once (YOLO)), used to identify the bounding box of the objects of interest in the image plane. Moreover, the YOLO is combined with a Kalman filter to robustify the object tracking, in case of losing the boundary boxes, by estimating their position and providing a fixed rate estimation. Since MAVs are fast and agile platforms, the object tracking should be performed in real-time for the collision avoidance. By processing the information of the bounding boxes with the image field of view and applying trigonometry operations, the pixel coordinates of the object are translated to heading commands, which results to a collision free maneuver. The efficacy of the proposed scheme has been extensively evaluated in the Gazebo simulation environment, as well as in experimental evaluations with a MAV equipped with a monocular camera.

14:20-14:40 FrC2.2

Flight Test Validation of Adaptive Collision Avoidance Algorithms Using Multiple Unmanned Aircraft, pp. 1328-1336

McKinnis, Aaron | University of Kansas
Hauptman, Dustin Hauptman | University of Kansas
Keshmiri, Shawn | University of Kansas
Ewing, Mark | University of Kansas

With the advent of the unmanned aerial systems (UAS) era, it is of grave importance that research be conducted into the reliable and safe operation of UAS in urban areas, where aircraft are flying over people and properties in spatially constrained environments. A large focus in recent years has been on adaptable collision avoidance systems, that are capable of avoiding fixed and moving obstacles in the modern day skyline. This paper presents flight test validation of an adaptive collision algorithm known as morphing potential field algorithm. The morphing potential field algorithm has been modified to allow implementation of more advanced guidance logics such as L2+ guidance. The aim is to validate the morphing collision avoidance path planning algorithm in a complex scenario, where multiple aircraft are, including two fixed-wing and two rotor-wing aircraft replicating obstacles. Aircraft were intentionally put in collision course with each other and obstacles. Validation flight test were successfully conducted to assess performance of morphing potential field navigation algorithms and also to quantify the impact of possible communication delays on the safety of collision avoidance methods for high speed and high inertia aircraft.

14:40-15:00 FrC2.3

Multi-Camera Multi-Target Drone Tracking Systems with Trajectory-Based Target Matching and Re-Identification, pp. 1337-1344

Sie, Jun Liang Niven | National University of Singapore
Srigrarom, Sutthiphong | National University of Singapore

This paper presents the integrated use of multiple cameras to detect, track and localize multiple moving objects, especially drones, in real-time by computer vision. The algorithm of the integrated system incorporates target tracking, localizing and identifying schemes, with the ability to use multiple cameras from different viewing angles and simultaneously track moving objects in the cameras' frames. Moving objects are detected by hybrid detection (motion-based blob detection appearance-based detection), and movements are predicted with Extended Kalman Filter. For motion-based detection, the trajectories of the tracked objects are analyzed using trajectory features variable. For appearance-based detection, motion is tracked with Yolo V3 detection algorithm. The integrated target identification algorithm matches and reidentifies targets between frames (intra-camera) and among cameras (inter-camera). This algorithm subsequently cross-correlate every tracked object in the different camera frames, and pair all the tracked targets to each other so that the cameras track the same objects for subsequent 3D localization. We tested our multi-cameras system to track multiple aerial and ground targets, andwere successful in the re-identification of targets in real time.

15:00-15:20 FrC2.4

Vision-Based Sense and Avoid with Monocular Vision and Real-Time Object Detection for UAVs, pp. 1345-1354

Leong, Wai Lun | National University of Singapore
Huang, Sunan | National Universtiy of Singapore
Wang, Pengfei | National University of Singapore
Ma, Zhengtian | National University of Singapore
Yang, Hong | National University of Singapore
Sun, Jingxuan | National University of Singapore
Zhou, Yu | National University of Singapore
Abdul Hamid, Mohamed Redhwan | National University of Singapore
Srigrarom, Sutthiphong | National University of Singapore
Teo, Rodney | National University of Singapore

The use of unmanned aerial vehicles (UAVs) or drones have become ubiquitous in the recent years. Collision avoidance is a critical component of path planning, allowing multi-agent networks of cooperative UAVs to work together towards common objectives while avoiding each other. We implemented, integrated and evaluated the effectiveness of using a low cost, wide angle monocular camera with real-time computer vision algorithms to detect and track other UAVs in local airspace and perform collision avoidance in the event of a

communications degradation or the presence of non-cooperative adversaries, through experimental flight tests where the UAVs were set on collision courses.

15:20-15:40 FrC2.5

LiDAR Simulation for Performance Evaluation of UAS Detect and Avoid, pp. 1355-1363

Riordan, James — University of the West of Scotland
Manduhu, Manduhu — University of the West of Scotland
Black, Julie — University of the West of Scotland
Dow, Alexander — University of the West of Scotland
Dooly, Gerard — University of Limerick
Matalonga, Santiago — University of the West of Scotland

The solution to mitigating risks associated with beyond Visual Line of Sight (BVLOS) operations of Unmanned Aerial System (UAS) generally focuses on the use of advanced Unmanned Traffic Management (UTM) systems. However, this solution does not take into account other uncooperative objects in the airspace. A more robust approach is to have UTM integrations coupled with onboard machine vision which is tied to automated collision avoidance systems. Future BVLOS regulations in urban situations may require robust embedded software that is capable of detecting air collision hazards in real-time at near and far ranges as uncooperative small aircraft and other unpredictable small objects with fast-changing and unscheduled trajectories pose significant hazards to UAS. This work presents the concept and initial prototyping of a Digital Twin to evaluate the capability of UAS mounted LiDAR to detect small-object air collision risks. A Digital Twin of the Port of Hamburg is augmented with typical port and harbour aerial hazards such as birds, drones, helicopters, and low flying aircraft. The use case scenarios are created in Maya and Unity, with Optix ray tracing of typical LiDAR imaging configurations used to replicate the cause and effect relationship between different LiDAR specifications and their response to small flying objects. Our results demonstrate the inhomogeneous point clouds generated at different spatial-temporal parts of the LiDAR scanning cycle and field of view. These results confirm the challenges of detecting small uncooperative objects by LiDAR.

FrC3 Edessa

Swarms I (Regular Session)

14:00-14:20 FrC3.1

Distributed Event-Based Sliding-Mode Consensus Control in Dynamic Formation for VTOL-UAVs, pp. 1364-1373

Alvarez Muñoz, Jonatan Uziel — EXTIA
Chevalier, Jérémy — EXTIA
Castillo Zamora, Jose de Jesus — IPSA & CentraleSupelec
Escareno Castro, Juan Antonio — XLIM Research Institute, University of Limoges

The present work deals with consensus control for a multi-agent system composed by mini Vertical Takeoff and Landing (VTOL) rotorcrafts by means of a novel nonlinear event-based control law. First, the VTOL system modeling is presented using the quaternion parametrization to develop an integral sliding-mode control law for attitude stabilization of the aerial robots. Then, the vehicle position dynamics is expanded to the multi-agent case where a cutting-edge event-triggered sliding-mode control is synthesized to fulfill the collective consensus objective within a formation context. With its inherent robustness and reduced computational cost, the aforementioned control strategy guarantees closed-loop stability, while driving trajectories to the equilibrium in the presence of time-varying disturbances. Finally, for validation and assessment purposes of the overall consensus strategy, an extensive numerical simulation stage is conducted.

14:20-14:40 FrC3.2

Self-Organized UAV Flocking Based on Proximal Control, pp. 1374-1382

Amorim, Thulio G. S. — Universidade Federal Da Paraiba
Nascimento, Tiago — Universidade Federal Da Paraiba
Petracek, Pavel — Czech Technical University in Prague
De Masi, Giulia — Technology Innovation Institute
Ferrante, Eliseo — Technology Innovation Institute
Saska, Martin — Czech Technical University in Prague

In this work, we address the problem of achieving cohesive and aligned flocking (collective motion) with a swarm of unmanned aerial vehicles (UAVs). We propose a method that requires only onboard sensing of the relative range and bearing of neighboring UAVs, and therefore requires only proximal control for achieving formation. Our method efficiently achieves flocking in the absence of any explicit orientation information exchange (alignment control), and achieves flocking in a random direction without externally provided directional information. To implement proximal control, the Lennard-Jones potential function is used to maintain cohesiveness and avoid collisions. Our approach may be used independently from any external positioning system such as GNSS or Motion Capture, and can therefore be used in GNSS-denied environments. The performance of the approach was tested in real-world conditions by experiments with UAVs that rely only on a relative visual localization system called UVDAR, proposed by our group. To evaluate the degree of alignment and cohesiveness, we used the order metric and the steady-state value.

14:40-15:00 FrC3.3

Virtual Structure Formation Flight Control Based on Nonlinear MPC, pp. 1383-1390

Rosa, Victor Stafy Megda — Universidade De São Paulo
Morgado Belo, Eduardo — Universidade De São Paulo

A formation flight controller for unmanned aerial vehicles (UAV) capable of obstacle avoidance is designed in the framework of nonlinear model predictive control (MPC). The controller considers both input and state constraints. The formation flight controller is designed in a distributed way; each aircraft holds one. The formation architecture is based on the virtual structure approach. The objective function for each UAV is based on the tracking error and the relative distance to obstacles and other vehicles of the formation. The costs related to obstacle and inter-vehicle collision avoidance are added as penalties. Inter-vehicle collision avoidance is ensured using a priority strategy. The optimization problem is solved using sequential quadratic programming (SQP), which has better convergence. A simulation in a 3-D environment provided the results needed to evaluate the performance of the algorithm.

15:00-15:20 FrC3.4

Safe Tightly-Constrained UAV Swarming inGNSS-Denied Environments, pp. 1391-1399

Dmytruk, Andriy — Czech Technical University in Prague
Nascimento, Tiago — Universidade Federal Da Paraiba
Ahmad, Afzal — Czech Technical University in Prague
Baca, Tomas — Czech Technical University in Prague
Saska, Martin — Czech Technical University in Prague

A decentralized algorithm for flocking of Unmanned Aerial Vehicles (UAV) in environments with high obstacle density is proposed in this work. The method combines a local planning loop with bio-inspired swarming rules for navigating a compact UAV flock in a real workspace without relying on external infrastructures, such as motion capture system and GNSS. The group stability and coherence are achieved by employing a purposely designed onboard UVDAR system for mutual localization of teammates in local proximity of each UAV. The required robustness and scalability of the multi-UAV system are therefore achieved without any need for communication among the swarm particles. Such minimal sensory and communication requirements have allowed the system to become a backup technique for centralized multi-robot systems in case of communication and GNSS dropout. The proposed approach has been verified in numerous simulations and real experiments inside a forest that represents one of the most challenging environments for deployment of compact groups of aerial vehicles.

15:20-15:40 FrC3.5

Expanding Domains for Multi-Vehicle Unmanned Systems, pp. 1400-1409

Giles, Kathleen — Naval Postgraduate School
Davis, Duane — Naval Postgraduate School
Jones, Kevin — Naval Postgraduate School
Jones, Marianna — Naval Postgraduate School

In this paper, we present a modular multi-vehicle hardware and software architecture that expands swarm system capability into multiple domains and vehicle types. The Swarm Brick electronics stack integrates into various air and ground-based vehicles. The redesigned playbook style behavior architecture demonstrates reusability across missions and dissimilar platform types. This dual-track approach aims to advance swarm system scalability by further shifting the role of the operator from controller to supervisor. We discuss results of demonstrations conducted with the upgraded heterogeneous, multi-domain swarm system during simulation and live-fly field exercises.

FrC4 Naoussa

Technology Challenges (Regular Session)

14:00-14:20 FrC4.1

Computationally Efficient RGB-T UAV Detection and Tracking System, pp. 1410-1415

Xing, Daitao — New York University
Tsoukalas, Athanasios — New York University Abu Dhabi
Giakoumidis, Nikolaos — New York University Abu Dhabi
Tzes, Anthony — New York University Abu Dhabi

In this work, we propose a long-term UAV detection and tracking system from RGB-Thermal (RGB-T) sequences. The system consists of a high resolution daylight visible camera and a thermal camera mounted on a UAV (airborne), for the detection of flying intruders. The framework is composed of the detection and tracking modules. The primary detection module based on the YOLOv4 method is optimized for small UAV detection and works both on the RGB and Thermal domains. To alleviate the issue of temporarily losing the intruder, we employ a discriminative correlation filter based object tracker, which is initialized with the output of the detection module and tracks the target at a higher speed. The dimensionality reduction is applied to the features for tracking to improve the performance. Meanwhile, we utilize the infrared signal as a spatial regularization term of the tracker to suppress the boundary effects that stem from circular convolution, leading to a more robust appearance model and tracking performance. The tracker is efficiently optimized via the Alternating Direction Method of Multiplier (ADMM). We evaluate our method on multiple visual and thermal tracking benchmarks, as well as field tests with a prototype platform. The experimental results demonstrate that our system can achieve accurate, robust and continuous detection and tracking of UAVs under complex circumstances.

14:20-14:40	FrC4.2

Air-Ground Cooperative Exploration of 3D Complex Environment with Maximized Visibility and Obstacles Avoidance, pp. 1416-1421

Wu, YuXuan	Beijing University of Chemical Technology
Wang, Jing	North China University of Technology
Zhou, Meng	North China University of Technology
Dong, Zhe	North China University of Technology
Chen, YangQuan	University of California, Merced

Unmanned aerial vehicles (UAVs) can provide vision at high altitude. In this paper, multi-UAVs and ground vehicle are utilized to explore a complex environment with obstacles. The desired UAV formation is proposed around ground vehicle to provide wider vision. The Interfered Fluid Dynamical System (IFDS) method is utilized to guide UAVs avoid obstacles, while the desired formation need be maintained. Then formation control scheme of multi-UAVs is updated to combine with IFDS method according to original formation and obstacles avoidance. Simulation results shows that multi-UAVs can avoid obstacles and maintain the desired formation around ground vehicle during exploration.

14:40-15:00	FrC4.3

Asymmetric Quadrotor Modeling and State-Space System Identification, pp. 1422-1431

Leshikar, Christopher	Texas A&M University
Ninan, Nidhin	Texas A&M University
Eves, Kameron	Texas A&M University
Valasek, John	Texas A&M University

This paper synthesizes an analytical nonlinear parametric state-space model of an asymmetric quadrotor Unmanned Air System, and validates the model using a non-parametric model synthesized from measured inputs and outputs from flight logs of the actual vehicle. The offline system identification process is conducted using the Observer Kalman Identification algorithm, which produces a linear discrete-time state-space model. This model is then converted to a continuous time model for comparison to the linearized analytical model. Several dynamic modes, which are difficult to model, are given as motivation for the system identification. The Developmental Flight Test Instrumentation 2, a custom flight test instrumentation system is used for data logging and is designed to run on an Ardupilot autopilot stack. This software is released as open-source. Results presented in the paper demonstrate that the linear model, synthesized using system identification, compares well to the linearized analytical model.

15:00-15:20	FrC4.4

Low Electromagnetic Interference Design and Simulation of Lithium Battery Powered UAV, pp. 1432-1438

Ge, Jiahao	Beijing Institute of Technology
Liu, Li	Beijing Institute of Technology
He, Yuntao	Beijing Institute of Technology
Cao, Xiao	Beijing Institute of Technology

Electromagnetic Interference (EMI) is the main disturbance source of magnetic compass. On the basis of EMI analysis, a low EMI design method of lithium battery powered UAV is proposed and verified through virtual trajectories. The EMI modeling is based on the electric circuit analysis of lithium battery powered UAV and the power supply principle of lithium battery. On the one hand, the low EMI design is carried out by optimizing the inclination angle of lithium battery. On the other hand, trajectory planning using kinodynamic RRT* algorithm is chosen as the verification method to reveal the effect of reducing EMI during flight. The results show that the average EMI of lithium battery can be reduced by more than 95% through the proposed method.

15:20-15:40	FrC4.5

A Study on Software Bugs in Unmanned Aerial Systems, pp. 1439-1448

Taylor, Max	The Ohio State University
Boubin, Jayson	The Ohio State University
Chen, Haicheng	The Ohio State University
Stewart, Christopher	The Ohio State University
Qin, Feng	The Ohio State University

Control firmware in unmanned aircraft systems (UAS) manage the subsystems for in-flight dynamics, navigation and aircraft sensors. Computer systems on-board the aircraft and on gateway machines can now support rich features in the control firmware, such as GPS-driven waypoint missions and autonomy. However, the source code behind control firmware can harbor software bugs whose symptoms are detectable only during flight. Often, software bugs in UAS have serious symptoms that lead to dangerous situations. We studied previously reported bugs in the open-source repositories of ArduPilot and PX4, two widely used control firmware for UAS, and characterized their root causes, severity and position in the firmware architecture. Even though both platforms have employed rigorous software engineering practices, bugs were common and often had severe symptoms (e.g., crashes.) In particular, bugs associated with mishandling aircraft sensor readings were the leading cause for bug-induced crashes. Finally, we used simulation to study the symptoms of sensor bugs and found that source code repositories under reported their frequency and impact. Our study motivates multiple research directions on software reliability in UAS firmware.

FrD1	Macedonia Hall
Manned/Unmanned Aviation and UAS Testbeds (Regular Session)	

16:00-16:20	FrD1.1

OpenUAS Version 1.0, pp. 1449-1458

Johannsen, Chris	Iowa State University
Anderson, Marcella	Iowa State University
Burken, William	Iowa State University
Diersen, Ellie	Iowa State University
Edgren, John	Iowa State University
Glick, Colton	Iowa State University
Jou, Stephanie	Iowa State University
Kumar, Adkyaksh	Iowa State University
Levandowski, John	Iowa State University
Moyer, Evelyn	Iowa State University
Roquet, Taylor	Iowa State University
Vande Loo, Alexander	Iowa State University
Rozier, Kristin Yvonne	Iowa State University

The future of fixed-wing autonomous aircraft operations depends on the availability of an appropriate UAS testbed. The testbed must be accessible: relatively inexpensive and easy to come by, without requiring long shipping delays from small international companies. It must be reconfigurable to accommodate the vast range of different sensor packages, payloads, use-cases, and flight characteristics needed to accommodate a broad variety of autonomy operations. It must be easy to fix or find replacement parts that will inevitably break during rigorous testing and it must accommodate safety analysis on-board with a deep understanding of the aircraft's design. Yet no previous fixed-wing UAS meets this need. Therefore, we contribute the first completely open-source (in both hardware and software) fixed-wing UAS, designed for reconfigurability and accessibility of broad audiences from researchers to high school students.

16:20-16:40	FrD1.2

Design Optimization of Wingtip Devices to Reduce Induced Drag on Fixed-Wings, pp. 1459-1465

Makgantai, Boitumelo	Botswana International University of Science and Technology
Subaschandar, N.	Botswana International University of Science and Technology
Jamisola, Rodrigo S Jr.	Botswana International University of Science and Technology

The current study investigates drone wing parameter optimization based on aerodynamic performance, lift-to-drag ratio (L/D), and endurance. Optimized aircraft have better performance, i.e., more range, good payload capabilities, and higher maneuverability. Wingtip devices for large aircraft flying at subsonic speeds at high Reynolds number have been extensively analyzed. In this study we analyse the performance differences of these wingtip devices on Unmanned Aerial Vehicles (UAVs) due to the fact that they operate at very low speeds and high Reynolds number. Computational Fluid Dynamics (CFD) analysis was conducted for both aircraft and drone wings. The first set of simulations performed was for an aircraft swept-back wing. It was designed using sections of a two-dimensional aerofoil NACA 0015. Another set of simulations was for a drone moderate-tapered-wing design using sections of NACA632615 aerofoils. The analysis was carried on three wingtip devices: blended winglets, drooped wingtip, and spiroid winglets. The results were compared and analysed between the performance of these winglets on an aircraft wing and a UAV wing.

16:40-17:00	FrD1.3

Design and Characterization of a Multi-Domain Unmanned Vehicle Operating in Aerial, Terrestrial, and Underwater Environments, pp. 1466-1471

Canelon, Dario	University of Minnesota
Westlake, Samuel	University of Minnesota
Wang, Youbing	University of Minnesota
Papanikolopoulos, Nikos	University of Minnesota

In this paper, we demonstrate and validate the flight characteristics of a multi-domain unmanned platform capable of locomotion in the air, water, and land domains. The OmnibotV2 uses four flight motors in a quad-copter configuration for flight, a dual screwdrive system for land and water locomotion, and optionally features a buoyancy control unit for water operations. Experiments were performed to measure how maximum battery voltage, temperature, and motors of different torque-speed characteristics affect the performance of the platform in flight. The screwdrive locomotion was also characterized on land, on the water surface, and under the water. Transition between the water's surface and the air was validated as was the use of the flight propulsion for moving along the water surface. A streaming camera unit as well as other additions were integrated with a view towards eventual applications in environmental monitoring.

17:00-17:20	FrD1.4

A 3D Printing Hexacopter: Design and Demonstration, pp. 1472-1477

Nettekoven, Alexander — The University of Texas at Austin
Topcu, Ufuk — The University of Texas at Austin

3D printing using robots has garnered significant interest in manufacturing and construction in recent years. A robot's versatility paired with the design freedom of 3D printing offers promising opportunities for how parts and structures are built in the future. However, 3D printed objects are still limited in size and location due to a lack of vertical mobility of ground robots. These limitations severely restrict the potential of the 3D printing process. To overcome these limitations, we develop a hexacopter testbed that can print via fused deposition modeling during flight. We discuss the design of this testbed and develop a simple control strategy for initial print tests. By successfully performing these initial print tests, we demonstrate the feasibility of this approach and lay the groundwork for printing 3D parts and structures with drones. A video for one of the initial print tests can be found at https://youtu.be/tEooDpE2TyE.

17:20-17:40 — FrD1.5

The Polish Perspective of Using Unmanned Aerial Vehicle Systems in International Firefighting and Crisis Management Missions - Legal and Technological Analysis, pp. 1478-1487

Balcerzak, Tomasz — Lazarski University
Jasiuk, Ewa — Lazarski University
Fellner, Andrzej — Silesian University of Technology
Feltynowski, Mariusz — The Main School of Fire Service

The subject of using UAV (Unmanned Aerial Vehicle) in extinguishing activities during large-scale forest fires is described in the scientific literature. For example, the Web of Science service for the period 1990-2018 recorded 308 publications related to UAV and forest fires. These are mainly analyzes and studies on remote fire detection, monitoring, mapping, architecture and technology integration.

There is a noticeable growing interest of researchers in the subject of using machine learning to detect and predict the spread of fires using unmanned aerial vehicles. At the same time, analyzes are carried out on the ad-hoc creation of local data networks using drones or drones as an element of the Internet of Things (IoT). In the operational context, concepts and solutions such as water transfer and extinguishing with UAV are only being tested.

Another important challenge is that current firefighting civil aviation regulations only allow firefighting manned aircrafts to operate between first and last flight due to safety concerns for pilots, limiting the operation time to an average of 12 hours, which leads to many fires reactivating at night.

There are many initiatives around the world to convince the international community about the rightness of using unmanned aerial vehicles in international firefighting and crisis management missions. However, there are too few initiatives aimed at issuing relevant legal provisions in this area.

FrD2 — Kozani

UAS Communications (Regular Session)

16:00-16:20 — FrD2.1

Teleoperated Aerial Manipulator and Its Avatar. Communication, System's Interconnection, and Virtual World, pp. 1488-1493

Verdìn, Rodolfo Isaac — Center for Research in Optics, A.C
Ramírez, Germán — Center for Research in Optics, A.C
Rivera Quezada, Carlos Arturo — Center for Research in Optics, A.C
Flores, Gerardo — Center for Research in Optics, A.C

The tasks that an aerial manipulator can perform are incredibly diverse. However, nowadays the technology is not entirely developed to achieve complex tasks autonomously. That is why we propose a human-in-the-loop system that can control a semi-autonomous aerial manipulator to accomplish these kinds of tasks. Furthermore, motivated by the growing trend of virtual reality systems, together with teleoperation, we develop a system composed of an aerial manipulator model programmed in PX4 and modeled in Gazebo, a virtual reality immersion with an interactive controller, and the interconnection between the systems above via the Internet. This research is the first part of a broader project. In this part, we present experiments in the software in the loop simulation. The code of this work is available on our GitHub page. Also, a video shows the conducted experiments.

16:20-16:40 — FrD2.2

RF Detection and Classification of Unmanned Aerial Vehicles in Environments with Wireless Interference, pp. 1494-1498

Swinney, Carolyn J. — University of Essex
Woods, John C. — University of Essex

Unmanned Aerial Vehicle (UAV) detection and classification methods include the use of audio, video, thermal, RADAR and radio frequency (RF) signals. RF signals have the ability to detect UAVs at longer ranges but interference from other signals in the same frequency band such as Bluetooth and Wi-Fi at 2.4GHz is a known limitation. The experiments in this paper evaluate the effect of real world Bluetooth and Wi-Fi signal interference on UAV detection and classification, using transfer learning via Convolutional Neural Network (CNN) feature extraction and machine learning classifiers Logistic Regression (LR) and k Nearest Neighbour (kNN). 2 class UAV detection, 4 class UAV type and 10 class flight mode classification are evaluated with graphical representation from the time and frequency

domain. Flight modes evaluated included mode 1 - switched on and connected to the controller, mode 2 - hovering and mode 3 - flying. Results show that Bluetooth signals are more likely to interfere with detection and classification accuracy than Wi-Fi signals but that accuracy can be maintained at over 96% by using frequency domain features with LR as the classifier. Time domain features were shown to be less robust than frequency domain features when interference signals were introduced. In the presence of Bluetooth or Wi-Fi signals, 2 class UAV detection produced 100% accuracy, 4 class UAV type classification produced 99.9% (+/- 0.1%) and 10 class UAV flight mode classification produced 96.4% (+/- 0.5%) accuracy. Overall we have shown frequency domain features extracted from a CNN to be more robust than time domain features in the presence of interference and that high accuracy can be maintained using LR as a classifier with CNN derived features.

16:40-17:00 FrD2.3

System Requirements Specification for Unmanned Aerial Vehicle (UAV) to Server Communication, pp. 1499-1508

Purucker, Patrick — University of Applied Sciences Amberg-Weiden
Schmid, Josef — University of Applied Sciences Amberg-Weiden
Hoess, Alfred — University of Applied Sciences Amberg-Weiden
Schuller, Björn — University of Augsburg

Within this paper, requirements for server to Unmanned Aerial Vehicle (UAV) communication over the mobile network are evaluated. It is examined, whether a reliable cellular network communication can be accomplished with the use of current Long Term Evolution (LTE) network technologies, or, if the 5th Generation (5G) network is indispensable. Moreover, enhancements on improving the channel quality on the UAV-side are evaluated. Therefore, parameters like data rate, latency, message size and reliability for Command and Control (C&C) and application data are determined. Furthermore, possible improvements regarding interference mitigation in the up- and downlink of the UAV are discussed. For this purpose, results from publications of the 3rd Generation Partnership Project (3GPP) and from surveys regarding UAVs and mobile networks are presented. This work shows that, for C&C use cases like steering to waypoints, the latency and the data rate of the LTE network is sufficient, but in terms of reliability problems can occur. Furthermore, the usability of standard protocols for computer networks like the Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) is discussed. There are also multimodal implementations of these protocols like MultiPath TCP (MPTCP) which can be adapted into the UAV's communication system in order to increase reliability through multiple communication channels. Finally, applications for Long Range (LoRa) direct communication in terms of supporting the cellular network of the UAV are considered.

17:00-17:20 FrD2.4

Towards SORA-Compliant BVLOS Communication, pp. 1509-1519

Andersen, Frederik Mazur — University of Southern Denmark
Terkildsen, Kristian Husum — University of Southern Denmark
Schultz, Ulrik Pagh — University of Southern Denmark
Jensen, Kjeld — University of Southern Denmark

With the advances in drone technology, the demand for long-distance drone flights Beyond Visual Line of Sight (BVLOS), is increasing. A prerequisite to BVLOS flights is reliable communication between Unmanned Aerial Vehicle (UAV) and Ground Control Station (GCS). Moreover, BVLOS operations can require multiple pilots during the flight, for example at takeoff and landing, who can take manual control if necessary. This necessitates a means to handover control between multiple pilots during the flight. This paper will explore options for line-of-sight radio links, for reducing the required bandwidth by optimizing the communication between the UAV and GCS, and for supporting multiple pilots. A MAVLink library to optimize the communication between the UAV and GCS has been designed and implemented. The library successfully reduced the communication from 11440 bytes/s to 951 bytes/s. A component for pilot handover has similarly been designed and successfully tested in real-world conditions. The LOS radios selected have been used successfully together with the MAVLink library in real-world SORA-approved BVLOS operations at a maximum radio LOS distance of 1375 m.

17:20-17:40 FrD2.5

On the Evaluation of Access-Point Handovers for UAVs in Long-Distance Missions, pp. 1520-1529

Alves Fagundes Junior, Leonardo — Universidade Federal De Viçosa
Souza, Vitor Barbosa — Universidade Federal De Viçosa
Brandao, Alexandre Santos — Universidade Federal De Viçosa

Unmanned Aerial Vehicle (UAV) systems are being increasingly used in a broad range of applications requiring extensive communications either to interconnect the UAVs with each other or to connect them with Ground Control Stations (GCS). Due to the complexity and difficulty of performing long distance experiments with these robots, simulation becomes a viable and necessary alternative. However, focusing either on the modeling of UAV operations or communication dynamics, available simulation tools are not able to capture the complex interdependencies between these two aspects, especially in applications where extensive communications are required. The main contribution of this work is the modeling and implementation of strategies for enhancing connectivity of a UAV performing long-distance navigation tasks, taking into account applications' requirements. The proposed strategies aim at assessing the impact of frequent handovers between wireless access points in terms of packet loss and available bandwidth. The first strategy prioritizes maintaining a connection until the signal-to-noise ratio (SNR) observed by the robot reaches a predefined threshold. For this, it is assumed that the data to be transmitted is small enough so that the robot may change its modulation to obtain smaller bandwidths while improving connection time. The second one prioritizes bandwidth availability, thus, it always searches for a network that is able to offer data rates higher than a minimum threshold. A hybrid model is validated by considering the characteristics of each individual strategy. The capabilities of the simulation tool designed for this work are illustrated through some case-study scenarios.

FrD3	Edessa
Swarms II (Regular Session)	

16:00-16:20	FrD3.1

Formation-Containment for a MAV Fleet UnderPerturbations Via Adaptive Sliding Mode Approach, pp. 1530-1537

Katt, Carlos	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey
Castillo, Pedro	Unviersité De Technologie De Compiègne

In this paper, a formation-containment control scheme using a class of adaptive sliding mode for a fleet of micro air quadrotors is proposed. The system consists of a virtual leader and a set of modeled leaders and followers. The virtual leader establishes the trajectory of the fleet. The proposal uses two layers to solve the formation-containment problem. First, the leaders accomplish the time-varying formation relative to the state of the virtual leader, then the followers converge to the convex hull spanned by the leaders. An adaptive sliding mode controller is proposed to deal with external disturbances, which affect the desired relative positions while tracking a time-variant trajectory for a full micro quad-rotor dynamic model. The advantage of the proposed method relies on its adaptive gain that provides robustness and maintains the trajectory as uncertainties/perturbations appear. Simulation results demonstrate the benefits and viability of the proposed control strategy.

16:20-16:40	FrD3.2

Cooperative Navigation and Visual Tracking with Passive Ranging for UAV Flight in GNSS-Challenging Environments, pp. 1538-1547

Causa, Flavia	University of Naples Federico II
Opromolla, Roberto	University of Naples Federico II
Fasano, Giancarmine	University of Naples Federico II

This paper discusses an approach conceived to improve navigation performance of small Unmanned Aerial Vehicles (UAVs) in GNSS-challenging environments by exploiting cooperation with other aircraft flying in better GNSS coverage conditions. Cooperation is realized by exchanging navigation data (i.e., GNSS observables when available) and exploiting a monocular camera system for relative vision-based tracking. Cooperative measurements are used within an Extended Kalman Filter, developing a solution potentially ready for real-time applications. The visual algorithm exploits both Deep Learning-based detectors and standard machine vision techniques to provide not only accurate line-of-sight but also distance estimates, and it is designed to deal with targets placed both above and below the horizon. The two algorithmic blocks are integrated in a closed loop fashion since navigation estimates are used in feedback to support visual processing. An experimental flight test campaign is carried out using two quadcopters to assess attainable navigation performance in terms of attitude and positioning. Results compare filter performance when using line-of-sight only with the case of using line-of-sight and ranging measurements altogether. They demonstrate that reliability and integrity of visual algorithms are good enough for the navigation filter needs, and that metric positioning error is achieved within GNSS-challenging areas by using the proposed cooperative strategy. The added value of range estimation strongly depends on the formation geometry and the GNSS coverage conditions.

16:40-17:00	FrD3.3

A Review of Consensus-Based Multi-Agent UAV Applications, pp. 1548-1557

Lizzio, Fausto Francesco	Politecnico Di Torino
Capello, Elisa	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino

In this paper, a review of distributed control for multi-agent systems is proposed, focusing on consensus-based applications. Both rotary-wing and fixed-wing Unmanned Aerial Vehicles (UAVs) are considered. On one side, methodologies and implementations based on collision and obstacle avoidance through consensus are analyzed for multirotor UAVs. On the other hand, a target tracking through consensus is considered for fixed-wing UAVs. This novel approach to classify the literature could help researchers to assess the outcomes achieved in these two directions in view of potential practical implementations of consensus-based methodologies.

17:00-17:20	FrD3.4

Unified Control Solution for Mobile Robot Formations, pp. 1558-1564

Rosales, Claudio	CONICET - Universidad Nacional De San Juan
Rossomando, Francisco	CONICET - Universidad Nacional De San Juan
Salinas, Lucio Rafael	CONICET - Universidad Nacional De San Juan
Gimenez, Javier	CONICET - Universidad Nacional De San Juan
Carelli, Ricardo	CONICET - Universidad Nacional De San Juan

This paper presents a unified control for a formation of mobile robots in positioning, path following, and trajectory tracking tasks. The control is based on a kinematic model of the formation in combination with a dynamic compensator based on a neural sliding mode control to guarantee a good tracking of reference velocities. Stability analysis of the complete system is given by using the Lyapunov theory. Finally, the control scheme is validated through simulations.

17:20-17:40	FrD3.5

Robust Observer-Based Leader-Following Control for a Class of Nonlinear Multi-Agent Systems: Application to Fleet of UAVs, pp. 1565-1572

Vazquez Trejo, Juan Antonio	University of Lorraine
Rotondo, Damiano	University of Stavanger
Adam-Medina, Manuel	National Center for Research and Technological Development
Theilliol, Didier	University of Lorraine

This paper presents the design of a robust observer-based control for a class of nonlinear multi-agent systems. The leader-following consensus problem is solved in order for all the agents to follow the trajectory of a virtual leader in spite of a nonlinear input which depends on the local and neighboring agents. The main contribution of this paper is to guarantee the stability and robustness of the estimated states and the synchronization error for each agent. Linear matrix inequality (LMI)-based sufficient conditions are obtained for computing the controller and observer gains. The effectiveness of the proposed approach is shown considering a formation control problem in a fleet of unmanned aerial vehicles under a simulation setting.

FrD4 Naoussa

Airspace Control and Management (Regular Session)

16:00-16:20 FrD4.1

Modeling, Design and Manufacturing of Delta-Wing UAV, pp. 1573-1579

Srour, Ali	Paris Saclay
Noura, Hassan	Islamic University of Lebanon

The article presents the mathematical modeling of a Fixed-Wing Unmanned Aircraft Vehicle (UAV) which is the Delta-Wing. To obtain the model, Newton Euler formulas are used for both lateral and longitudinal axes. The characteristics of the aircraft from aerodynamic coefficients, inertias and operating regions are obtained by the simulations on XFLR5 software in a way that matches the prototype. There is huge interest among researchers in this type of UAVs for its advantage of more lift and less drag. Thus, a Full functional Delta-Wing UAV is designed for the purpose of experimentation and implementing new control strategies in the future. The design fabrication takes into consideration winglet effect in aerodynamic properties especially roll and yaw stability.

16:20-16:40 FrD4.2

Ring Formation Maneuvering with Double Integrator Dynamics, pp. 1580-1586

Tran, Dzung	Air Force Research Laboratory
Casbeer, David	Air Force Research Laboratory
Garcia, Eloy	Air Force Research Laboratory
Weintraub, Isaac E.	Air Force Research Laboratory
Milutinovic, Dejan	University of California, Santa Cruz

Conventional leader-follower formations restrict the follower to a single desired position relative to the leader. To give the follower more flexibility in motion and to replicate typical human pilot operations, in this paper we propose a control architecture allowing the follower to converge to a ring, which is a set of desired points, relative to the leader. The follower is considered subject to a point-mass aircraft model, which can be transformed into the double integrator kinematics. For that reason, the nonlinear backstepping method is first utilized to design the controller for the double integrator kinematics with input saturation constraints being taken into account. The controller is then converted into control variables for the point-mass model. The stability of the proposed architecture is analyzed. Finally, a numerical example is presented to illustrate the efficacy of the proposed controller.

16:40-17:00 FrD4.3

RflySim: A Rapid Multicopter Development Platform for Education and Research Based on Pixhawk and MATLAB, pp. 1587-1594

Wang, Shuai	Beihang University
Dai, Xunhua	Central South University
Ke, Chenxu	Beihang University
Quan, Quan	Beihang University

In this paper, we propose and open a rapid development platform--RflySim based on Pixhawk/PX4 and MATLAB/Simulink for UAV education and research. This platform adopts model-based development ideas and uses software-in-the-loop simulation and hardware-in-the-loop simulation to accelerate physical deployment. With that, beginners and developers can directly use MATLAB/Simulink to design low-level controllers (such as attitude control, position control) and high-level applications (such as decision-making, autonomous flight), and then deploy them into a multicopter autopilot system with no need to access the C/C++ underlying code. Three demonstrations are presented to verify the ease of use and the high efficiency of the proposed platform.

17:00-17:20 FrD4.4

Enhancing SkyVision: Integrating UAS Flight Information with ATC Data, pp. 1595-1604

Lamping, Anthony	University of Cincinnati

Ouwerkerk, Justin	University of Cincinnati
Barnes, Evan	University of Cincinnati
DeGroote, Nicholas	University of Cincinnati
Wessels, Austin	University of Cincinnati
Brown, Bryan	University of Cincinnati
Cohen, Kelly	University of Cincinnati

The SkyVision system was developed by the State of Ohio and the Air Force Research Laboratory (AFRL) to promote the research and development of Unmanned Aerial Systems (UAS) technologies. With the goal and vision to deliver a ground-based detect and avoid (GBDAA) capability, SkyVision leverages Air Traffic Control (ATC) level radar data through the Federal Aviation Administration's (FAA) Standard Terminal Automation Replacement System (STARS). This paper details the research and development of a set of subsystems that integrate into SkyVision to provide the system with UAS flight information, seeking to enhance the system, enabling safe beyond visual line of sight (BVLOS) UAS operations throughout the nation.

17:20-17:40 FrD4.5

A Lifting Wing Fixed on Multirotor UAVs for Long Flight Ranges, pp. 1605-1610

Xiao, Kun	Beihang University
Meng, Yao	Beihang University
Dai, Xunhua	Central South University
Zhang, Haotian	Beihang University
Quan, Quan	Beihang University

This paper presents a lifting-wing multirotor UAV that allows long-range flight. The UAV features a lifting wing in a special mounting angle that works together with rotors to supply lift when it flies forward, achieving a reduction in energy consumption and improvement of flight range compared to traditional multirotor UAVs. Its design considers aerodynamics, airframe configuration and the mounting angle. Its optimization model is built according to the classical multirotor theory and the fixed-wing theory, as the aerodynamics of its multiple propellers and that of its lifting wing are almost decoupled. The performance of the UAV is verified by experiments, which show that the lifting wing saves 50.14% of the power when the UAV flies at the cruise speed (15m/s).

17:40-18:00 FrD4.6

Lane Geometry, Compliance Levels, and Adaptive Geo-Fencing in CORRIDRONE Architecture for Urban Mobility, pp. 1611-1617

Tony, Lima Agnel	Indian Institute of Science
Ratnoo, Ashwini	Indian Institute of Science
Ghose, Debasish	Indian Institute of Science

Integrating Unmanned Aerial Vehicles (UAVs) into airspace requires a reliable framework which is robust and scalable. CORRIDRONE is one such architecture that generates corridors for point-to-point traversal of drones. This work presents details about its central features like adaptive geo-fencing, drone compliance levels, and corridor geometry. Adaptive geo-fencing guarantees vehicle safety when multiple vehicles of different hardware and software capabilities are sharing the same airspace. Compliance levels, defined based on these capabilities of the UAVs, are an essential measure for determining geo-fence bounds. The lane geometry of CORRIDRONE is designed considering the aerodynamic aspects like downwash, which ensures in-flight stability of the UAVs. These features confirm safe transit of the vehicles and also ensures efficient operation of the system. The flexibility to accommodate multiple UAVs of varying compliance levels highlight the robustness of the proposed framework.

FrPS Foyer, Mezzanine Level

Poster Papers Session (Poster Session)

09:00-09:15 FrPS.1

A Dual Frequency Blade Antenna Enabling UAV-Based Operations in ADS-B and 5G Environments, pp. 1618-1623

Arpaio, Maximilian James	Alma Mater Studiorum, University of Bologna
Fuschini, Franco	Alma Mater Studiorum, University of Bologna
Masotti, Diego	Alma Mater Studiorum, University of Bologna

Driven by the recent enhancements provided by Automatic Dependent Surveillance-Broadcast (ADS-B) and the latest developments in 5th Generation (5G) networks supported by Unmanned Air Vehicles (UAVs), this paper describes the design of an “all-in-one” SMA coaxial fed compact blade antenna with dual frequency characteristics for broadband applications on board of UAVs. A single antenna element is designed using CST Microwave Studio software which shows a dual frequency broadband characteristic, when compared to traditional blade antennas, covering the 1.030 – 1.090 GHz and the 3.4 – 3.8 GHz ranges thanks to an oblique side and a ‘C' shaped cavity within the radiation element. The designed antenna is simulated on an ideal ground plane first and then extended to a bent ground plane. The results are compared and discussed in terms of return loss, bandwidth, gain and radiation pattern. These results show a lightweight antenna with a low profile and a simple structure that can find numerous applications in various airborne wideband communication systems, suiting future UAV-based networks for 5G and beyond while being perfectly compliant with the ongoing ADS-B based Detect-

And-Avoid (DAA) technologies for integration of UAVs in Unmanned Aerial Traffic Management (UTM).

09:15-09:30 FrPS.2

A Multi-Layer Software Architecture for Aerial Cognitive Multi-Robot Systems in Power Line Inspection Tasks, pp. 1624-1629

Silano, Giuseppe — Czech Technical University in Prague
Bednar, Jan — Czech Technical University in Prague
Nascimento, Tiago — Universidade Federal Da Paraiba
Capitan, Jesus — Universidad De Sevilla
Saska, Martin — Czech Technical University in Prague
Ollero, Anibal — Universidad De Sevilla

This paper presents a multi-layer software architecture to perform cooperative missions with a fleet of quadrotors providing support in electrical power line inspection operations. The proposed software framework guarantees the compliance with safety requirements between drones and human workers while ensuring that the mission is carried out successfully. Besides, cognitive capabilities are integrated in the multi-vehicle system in order to reply to unforeseen events and external disturbances. The feasibility and effectiveness of the proposed architecture are demonstrated by means of realistic simulations.

09:30-09:45 FrPS.3

A Vision-Based Algorithm for a Path Following Problem, pp. 1630-1635

Terlizzi, Mario — University of Sannio
Silano, Giuseppe — Czech Technical University in Prague
Russo, Luigi — University of Sannio
Aatif, Muhammad — University of Sannio
Basiri, Amin — University of Sannio
Mariani, Valerio — University of Sannio
Iannelli, Luigi — University of Sannio
Glielmo, Luigi — University of Sannio

A novel prize-winner algorithm designed for a path following problem within the Unmanned Aerial Vehicle (UAV) field is presented in this paper. The proposed approach exploits the advantages offered by the pure pursuing algorithm to set up an intuitive and simple control solution. A path for a quad-rotor UAV is obtained by using the drone downward facing camera images to implement an Image-Based Visual Servoing (IBVS) approach. Numerical simulations in MATLAB® together with the MathWorks™ Virtual Reality toolbox demonstrate the validity and the effectiveness of the proposed algorithm. The code is released as open-source making it possible to go through any part of the system and replicating the obtained results.

09:45-10:00 FrPS.4

Appraisal of Autonomous Swarms through Analysis of Observed Behavior, pp. 1636-1641

Helble, Sarah — Johns Hopkins Applied Physics Laboratory
Guinn, Andrew — Johns Hopkins Applied Physics Laboratory
Blake, Joshua — Johns Hopkins University Applied Physics Laboratory

Swarms of autonomous vehicles are capable of performing complex missions in a variety of applications. Functions inherent to these missions include obstacle avoidance and collaboration with other swarm members. The logic for guiding autonomous agents through these functions can result in unanticipated emergent behaviors. Commanders of complex autonomous missions need a way to gain confidence in a swarm's behavior and detect adversarial behavior at runtime without inhibiting operations. The research described in this paper explores using measurements and analysis of external, observable characteristics, such as location data, to detect adversarial behavior in a simulated homogeneous swarm for a set of well-defined use cases. Initial results using directional and positional entropy of individual agents and the DBSCAN clustering algorithm demonstrate that measurements of external characteristics are a promising addition to a commander's toolset. Further research should be performed to determine the applicability to a broader set of use cases.

10:00-10:15 FrPS.5

Assisted Canopy Sampling Using Unmanned Aerial Vehicles (UAVs), pp. 1642-1647

La Vigne, Hughes — Université De Sherbrooke
Charron, Guillaume — Université De Sherbrooke
Hovington, Samuel — Université De Sherbrooke
Desbiens, Alexis Lussier — Université De Sherbrooke

Recently, Unmanned Aerial Vehicles (UAVs) carrying canopy sampling tools have been demonstrated. They present serious advantages in terms of safety and reach, but their time efficiency and ease of use could still be improved. Three main challenges were identified when using such tools: the selection of accessible branches, the lack of precision caused by the pendulum movement of the sampling tool, and the necessity to have two operators. In this paper, we address those issues by presenting the foundation of an architecture to provide sampling assistance on deciduous trees that makes UAV sampling more efficient and easy to use. The UAV is equipped with a DeLeaves

canopy sampling tool, an RGB-D camera, and an onboard computer. Computer vision was used to detect and localize branches. Sampling assistance was used to limit the tool's oscillation and reduce the pilot's workload, allowing him or her to control both the UAV and the tool. This assisted canopy sampling solution allowed a sampling phase time of 34 seconds on average on mature deciduous trees, thus reducing the time required by 7 times.

10:15-10:30	FrPS.6

Flight Plan Management System for Unmanned Aircraft Vehicles Using Blockchain, pp. 1648-1652

Yaguchi, Yuichi — University of Aizu
Wakazono, Takuya — University of Aizu

Current unmanned aerial vehicle (UAV) traffic management systems are almost exclusively centralized and require a large amount of network traffic and data storage because the estimated amount of data required in the future will be quite large and difficult to achieve. In this paper, we present a distributed autonomous flight plan management system for data and network traffic regionalization in each UAV. Our approach is applied to blockchain technology for reservation systems, octree for airspace indexing, and probabilistic road maps with an A* algorithm for the replanning system. We evaluated this system by load testing based on future estimates and the results demonstrate that our approach is capable of handling estimated future flight plans.

10:30-10:45	FrPS.7

Impedance-Based Control for Soft UAV Landing on a Ground Robot in Heterogeneous Robotic System, pp. 1653-1658

Kalinov, Ivan — Skolkovo Institute of Science and Technology
Petrovsky, Alexander — Skolkovo Institute of Science and Technology
Agishev, Ruslan — Skolkovo Institute of Science and Technology
Karpyshev, Pavel — Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry — Skolkovo Institute of Science and Technology

In this paper, we present a new method for soft landing of an unmanned aerial vehicle (UAV) on a ground robot based on impedance control. It is applied for a heterogeneous robotic system aimed at warehouse stocktaking automation. We describe the operating and mathematical principles of the impedance control for the landing system of the UAV and present the results of the real-world experiments. We evaluate the softness of landing using force sensors attached to each of four legs of the drone by measuring the impact force during the contact. Experimental results revealed that proposed landing impedance control decreased the impact force by 60%. The proposed approach can also be applied for delivery drone landing on the moving truck, cargo ship, or uneven terrain providing low risk of crash accident.

10:45-11:00	FrPS.8

Near-Optimal Coverage Path Planning of Distributed Regions for Aerial Robots with Energy Constraint, pp. 1659-1664

Khanam, Zeba — University of Essex
McDonald-Maier, Klaus — University of Essex
Ehsan, Shoaib — University of Essex

Unmanned Aircraft Vehicles (UAVs) have gained immense popularity for area coverage having applications such as environmental monitoring, demining, search and rescue, among others. Most of the existing studies exploring area coverage have considered only a single region, however, few recent studies have considered coverage of multiple distributed regions. One of the limitations which UAV suffers while covering distributed multiple regions is energy constraints where complete area coverage is not possible. From a strategical point of view, we propose a novel algorithm which solves a variant of the area coverage problem where the UAV aims to achieve near-optimal area coverage due to path length limitation caused by the energy constraint. In this paper, a preliminary study is conducted by first formulating the problem and later on presenting a solution. The solution has been partitioned into two inter-dependent sub-problems: i) inter-region coverage, ii) intra-region coverage. The performance of the algorithm has been evaluated by analysing its properties over an exhaustive set of test case scenarios and comparing it against two state-of-the-art area coverage approaches.

11:00-11:15	FrPS.9

Neural Networks Algorithms for Ornithopter Trajectory Optimization, pp. 1665-1670

Pérez-Cutiño, Miguel Angel — Universidad De Sevilla
Rodríguez, Fabio — Universidad De Sevilla
Pascual Callejo, Luis David — Universidad De Sevilla
Díaz-Báñez, José-Miguel — Universidad De Sevilla

Trajectory optimization has recently been addressed to compute energy-efficient routes for ornithopter navigation, but its online application remains a challenge. To overcome the high computation time of traditional approaches, this paper proposes algorithms that recursively generate trajectories based on the output of neural networks. To this end, we create a novel data set composed by energy-efficient trajectories obtained by running a competitive planner. We present two methods to compute low-cost trajectories: a classification approach to learn maneuvers and an alternative regression method that predicts new states. Both approaches are tested inseveral scenarios, including the landing case. The effectiveness and efficiency of the proposed algorithms are demonstrated through simulation, which show that neural networks can beused to compute the flight path of the ornithopter in real time.

11:15-11:30	FrPS.10

Performance of Sliding Mode and Consensus-Based Control Approaches for Quadrotor Leader-Follower Formation

Flight, pp. 1671-1676

Wu, Falin — Beihang University
He, Jiaqi — Beihang University
Zhou, Guopeng — Beihang University
Li, Haolun — Beihang University
Liu, Yushuang — Beijing System Design Institute of Electro-Mechanic Engineering

Quadrotors are making a difference to numerous civilian and military applications. There are various approaches to realize formation flight control. In this paper, a comparison between sliding mode and second-order consensus approaches for quadrotor leader-follower formation flight was conducted. Sliding mode and second-order consensus algorithms were employed to design the formation controller for steady formation flight. Both leader and the follower quadrotors are controlled by proportional integral derivative controllers. The leader follows the desired trajectory while the followers follow the instruction calculated by the formation controller. Simulations are carried out to analyze the effect of these two approaches. The result indicates that the followers can follow the leader's trajectory and keep the formation fairy well under the control of both approaches. However, the sliding mode approach can achieve faster position convergence effect, while the secondorder consistency approach has better disturbance suppression performance in case of disturbance.

11:30-11:45 FrPS.11

Region Coverage Flight Path Planning Using Multiple UAVs to Monitor the Huge Areas, pp. 1677-1682

Yaguchi, Yuichi — University of Aizu
Tomeba, Tomoki — University of Aizu

The development of a coverage flight planner for multiple multicopters used in a wide-area survey, such as inspecting the storage site of radioactive decontaminated soil or searching for victims in disaster response, is proposed. For these multiple multicopter application cases, effective coverage flight path planning with no collisions is needed. In this paper, we developed two parts of the system where the region is separated by two approaches and quasi-optimal flight paths for each region. As a result, each of the two region divisions showed a good equally divided region, and a flight path designed on the two region divisions was also efficiently generated. Flight tests of two multicopters with the generated paths were also conducted.

11:45-12:00 FrPS.12

Time Cooperation Method for Multiple UCAVs Based on Hybrid Non-Uniform Adjustment, pp. 1683-1688

Bi, Wenhao — Northwestern Polytechnical University
Li, Chong — 28th Research Institute of China Electronics Technology Group
Zhang, An — Northwestern Polytechnical University
Gao, Fei — Northwestern Polytechnical University

The time cooperation technology has important influence on multiple unmanned combat aerial vehicles (multi-UCAVs) cooperative attacking, which improves the operational effectiveness of UCAVs conspicuously. In this paper, a novel time cooperation method based on hybrid non-uniform adjustment is proposed to solve the time collaboration problem of multiple UCAVs. The hybrid non-uniform cooperation method construct the time coordination mode combining maneuvering coordination and speed coordination, adopting the non-uniform cruising rate along the whole route. The simulation results verify the method proposed in this paper has a larger adjustment range and higher adjustment accuracy compared with the existing time collaboration methods.

ICUAS '21 Key Word Index

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