Scanning the Issue

Cyber Threats Facing Autonomous and Connected Vehicles: Future Challenges

S. Parkinson, P. Ward, K. Wilson, and J. Miller

Vehicles are currently being developed and sold with increasing levels of connectivity and automation. As with all networked computing devices, increased connectivity often results in a heightened risk of a cyber-security attack. Furthermore, increased automation exacerbates any risk by increasing the opportunities for the adversary to implement a successful attack. In this paper, a large volume of the publicly accessible literature is reviewed and compartmentalized based on the vulnerabilities identified and mitigation techniques developed. This review highlighted that the majority of studies are reactive, and vulnerabilities are often discovered by friendly adversaries (white-hat hackers). Many gaps in the knowledge base were identified. Priority should be given to address these knowledge gaps to minimize future cyber security risks in the connected and autonomous vehicle sector.

Learning Roadway Surface Disruption Patterns Using the Bag of Words Representation

L. C. González, R. Moreno, H. J. Escalante, F. Martínez, and M. R. Carlos

Accurately classifying roadway surface disruptions, such as potholes and bumps, plays a crucial role in enhancing quality transportation and road safety. A novel data collection process was conducted in real-life environments where smartphones were freely placed at five user-surveyed locations, within a fleet of cars and trucks. Accelerometer data are represented with a novel technique inspired in the bag of words representation. The authors exhaustively evaluated the performance of six classifiers in various data sets, most of them resembling actual data sets used in similar projects. Experimental results reveal that the representation technique boosts the classification performance considerably when compared with state-of-the-art solutions, reducing in one order of magnitude the false positives/negatives rate and surpassing the classification accuracy for about 10% in a multi-class data set.

A Generalized Method to Extract Visual Time-Sharing Sequences From Naturalistic Driving Data

C. Ahlstrom and K. Kircher

Drivers typically look forward about 80% of the time and, when looking away, he/she is unwilling to do so for more than about 1.5 s. This means that if the sought information cannot be obtained within this time frame, the information intake has to be divided into several glances back and forth between the road view and the target of interest. Here, the authors present a new method to automatically extract such visual time-sharing sequences directly from eye tracking data. Grouping glances to the same target, such that one extracted glance sequence describes one distinct information intake event, adds an additional layer of information to glance analyses in traffic and expands the widely used concept of visual time-sharing to a greater range of targets. The new approach provides a mean to extend glance analyses to include information about tactical glance behavior, especially when more detailed environmental information is available.

Estimation of Performance Metrics at Signalized Intersections Using Loop Detector Data and Probe Travel Times

Q. Gan, G. Gomes, and A. Bayen

A simple but practical approach that uses both loop detector data and probe travel times is introduced for computing the vehicle hours traveled (VHT), average delay, and level of service (LOS) for signalized intersections. The goal is to improve upon the state-of-the-practice method outlined in the highway capacity manual (HCM) by incorporating additional travel time measurements from probe vehicles or vehicle reidentification systems. The test results suggest that the proposed methodology requires either a large population size or a high penetration rate to produce reliable estimates of VHT, delay, and LOS. Results also show that the proposed methodology only requires 7% of the penetration rate to outperform the HCM methodology.

Adaptive Compensation of Traction System Actuator Failures for High-Speed Trains

Z. Mao, G. Tao, B. Jiang, and X.-G. Yan

An adaptive failure compensation problem is addressed for high-speed trains with longitudinal dynamics and traction system actuator failures. Considered the time-varying parameters of the train motion dynamics caused by time-varying friction characteristics, a new piecewise constant model is introduced to describe the longitudinal dynamics with variable parameters. For both the healthy piecewise constant system and the system with actuator failures, the adaptive controller with the adaptive laws is designed, in the presence of the system piecewise constant parameters and actuator failure parameters.

Throughput of Infrastructure-Based Cooperative Vehicular Networks

J. Chen, G. Mao, C. Li, A. Zafar, and A. Y. Zomaya

A cooperative communication strategy utilizing vehicle to infrastructure communications, vehicle-to-vehicle communications, mobility of vehicles, and cooperations among vehicles and infrastructure is proposed to improve the throughput of vehicular networks with a finite vehicular density. A closed-form expression of the achievable throughput is obtained,

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which reveals the impact of some major performance-impacting parameters. Simulations are conducted to validate the accuracy of the analytical results and show that the proposed cooperative strategy can significantly improve the achievable throughput of vehicular networks even when traffic density is rather low.

Ant Colony Optimization for Simulated Dynamic Multi-Objective Railway Junction Rescheduling

J. Eaton, S. Yang, and M. Gongora

Minimizing the ongoing impact of train delays has benefits to both the users of the railway system and the railway stakeholders. However, the efficient rescheduling of trains after a perturbation is a complex real-world problem. The complexity is compounded by the fact that the problem may be both dynamic and multi-objective. The aim of this paper is to investigate the ability of ant colony optimization algorithms to solve a simulated dynamic multi-objective railway rescheduling problem and, in the process, to attempt to identify the features of the algorithms that enable them to cope with a multi-objective problem that is also dynamic. Results showed that, when the changes in the problem are large and frequent, retaining the archive of non-dominated solution between changes and updating the pheromones to reflect the new environment play an important role in enabling the algorithms to perform well on this dynamic multi-objective railway rescheduling problem.

Road Recognition From Remote Sensing Imagery Using Incremental Learning

J. Zhang, L. Chen, C. Wang, L. Zhuo, Q. Tian, and X. Liang

Considering the growing amount of remote sensing imagery and the constantly changing nature of the road structure, a road recognition method from remote sensing imagery is proposed by using incremental learning. The definition of saliency feature is extended to most significant characteristics of roads compared with surrounding background. A road network is achieved by computing multiple saliency features. An incremental learning algorithm is introduced to recognize the types of roads from remote sensing imagery. The experimental results demonstrate that the proposed method has a higher road recognition rate as well as less recognition time.

An Optimization Approach for Localization Refinement of Candidate Traffic Signs

Z. Zhu, J. Lu, R. R. Martin, and S. Hu

This paper proposes the localization refinement approach for candidate traffic signs. Previous traffic sign localization approaches, which place a bounding rectangle around the sign, do not always give a compact bounding box, making the subsequent classification task more difficult. The localization was formulated as a segmentation problem, and prior knowledge concerning color and shape of traffic signs is incorporated. The proposed approach is evaluated on the German Traffic Sign Detection Benchmark as well as a newly launched Chinese Traffic Sign Detection Benchmark. This newly created benchmark is publicly available and goes beyond previous benchmark data sets: it has over 5000 high-resolution images containing more than 14 000 traffic signs taken in realistic driving conditions. Experimental results show that the proposed localization approach significantly improves bounding boxes when compared with a standard localizer, thereby allowing a standard traffic sign classifier to generate more accurate classification results.

Reusability of the Output of Map-Matching Algorithms Across Space and Time Through Machine Learning

M. Hashemi

The spatial–temporal pattern in projection vectors produced by map-matching algorithms is detected and validated via machine learning. Projection vectors showed a strong spatial–temporal pattern in Chicago, IL, USA, which was captured best via a local nonlinear regressor, k-nearest neighbors, and helped double the positional accuracy of unseen GPS points. While a global non-linear regressor, multi-layer perceptron, was able to slightly improve the positional accuracy of GPS points, the linear least squares had an exacerbating effect on the positional accuracy.

A Low-Cost Lane-Determination System Using GNSS/IMU Fusion and HMM-Based Multistage Map Matching

M. M. Atia, A. R. Hilal, C. Stellings, E. Hartwell, J. Toonstra, W. B. Miners, and O. A. Basir

A low-cost real-time lane-determination system that fuses micro-electromechanical systems inertial sensors, standard GPS, and commercial road network maps is investigated. The system does not depend on visual markings or high-precision GPS technology (e.g., real-time kinematics), and it does not need explicit lane-level resolution maps. High-resolution estimation of the vehicle's position, velocity, and orientation is implemented by fusing inertial sensors with GPS in a loosely coupled mode using extended Kalman filter. A curve-to-curve road-level map matching is implemented using a hidden Markov model followed by a least-square regression step that estimates the vehicle's lane. The system includes a lane-change detector based on inertial sensors and the filtered vehicle's state. The system has been realized in real time and tested extensively on real-road data. Experiments showed robust map matching in challenging road intersections/forks/joins and a 97.14% lane determination success rate.

Reduction of Air Traffic Complexity Using Trajectory-Based Operations and Validation of Novel Complexity Indicators

T. Radišić, D. Novak, and B. Juričić

Airspace capacity is limited primarily by the saturation of the air traffic controller's capacity, whose workload increases as the air traffic complexity increases. Implementation of trajectory-based operations (TBO) has been proposed as a way to reduce workload, but few studies have examined how TBO affects air traffic complexity. This paper compares air traffic complexity experienced by ten air traffic controllers in a real-time simulation environment involving conventional operations and TBO. An analysis of subjective complexity scores collected in real time showed that the TBO significantly reduced complexity when at least 70% of aircraft were flying according to TBO and when the airspace was occupied simultaneously by more than 15 aircraft. Subjective complexity scores were tested for correlation with 20 commonly used and 7 novel TBO-specific complexity indicators. A predictive linear model was created combining two of these novel indicators with four already in use, and it generated better predictions of complexity in TBO environment than older models.

Predictive Energy Management Strategy for Fully Electric Vehicles Based on Preceding Vehicle Movement

S. Zhang, Y. Luo, J. Wang, X. Wang, and K. Li

An energy-efficient and terrain-information-and-preceding-vehicle-information-incorporated energy management strategy is proposed for fully electric vehicles (FEV) equipped with in-wheel motors. The Bayes network model is applied to predict the movement of a front vehicle during each control cycle based on vehicle-to-vehicle communication, and the velocity and the motor torque distribution of the FEV are optimized by a nonlinear model predictive controller to reduce energy consumption. The proposed controller achieves the energy-saving performance by including in the cost function the motor energy consumption in each control cycle, while the safety objective is accomplished by keeping a suitable relative distance from the preceding vehicle. The simulation results show that this method has a better energy-saving performance than the control method without using the preceding vehicle movement information.

Real-Time Feedback Impacts on Eco-Driving Behavior and Influential Variables in Fuel Consumption in a Lisbon Urban Bus Operator

C. Rolim, P. Baptista, G. Duarte, T. Farias, and J. Pereira

The impacts of real-time feedback were assessed in driving performance of drivers from an urban bus operator. Data on seven driving indicators were collected over a period of three years with an on-board device. The impact of bus type and age as well as drivers' experience were accounted for in the analysis. Additionally, the most influential variables on fuel consumption were analyzed by applying a statistical model.

Simultaneous Optimization of Airspace Congestion and Flight Delay in Air Traffic Network Flow Management

K.-Q. Cai, J. Zhang, M.-M. Xiao, K. Tang, and W.-B. Du

Air traffic flow management (ATFM) aims to facilitate the utilization of airspace and airport resources and is critical in air transportation systems. This paper addresses the problem of alleviating the airspace congestion and reducing the flight delays in ATFM simultaneously. The authors formulate this problem as a multi-objective air traffic network flow optimization (MATNFO) problem. In this MATNFO model, comprehensive ATFM actions are taken into account. Meanwhile, a systematic approach, namely, the route and time-slot assignment (RTA) algorithm, is developed to solve the MATNFO problem. The idea of divide-and-conquer is embedded in the algorithm by sequentially applying both the route searching module and the time-refinement module. Furthermore, for the sake of efficiency, a pre-selection operator is proposed as one heuristic strategy to identify promising solutions and reduce the search space by defining a sector equilibrium metric. Experiments show that the RTA is competent for a high-quality real-time air traffic network flow assignment.

Statistical Anomaly Detection in Human Dynamics Monitoring Using a Hierarchical Dirichlet Process Hidden Markov Model

T. Fuse and K. Kamiya

This paper defines an anomaly detection problem of human dynamics monitoring with time-series gridded population data. The authors discussed the characteristics of the problem and categorized it to a semi-supervised anomaly detection problem that detects contextual anomalies behind time-series data. This paper also develops an anomaly detection method based on a sticky hierarchical Dirichlet process hidden Markov model, which is able to estimate the number of latent states according to the input data. Results of the experiment with synthetic data showed that their proposed method has good fundamental performance with respect to the detection rate. Through the experiments with real gridded population data, anomalies were detected when and where an actual social event had occurred.

Moving-Object Detection From Consecutive Stereo Pairs Using Slanted Plane Smoothing

L. Chen, L. Fan, G. Xie, K. Huang, and A. Nüchter

In this paper, the authors have proposed a novel and efficient stereo-moving-object detection method, which obtains pixel-level results of moving targets at 20 Hz. The proposed method achieves accurate detection results in challenging scenarios and is independent of dense optical flow calculation. The states of moving objects, including location, direction, and velocity, are also obtained simultaneously as further byproducts. The proposed work is the first approach that introduces superpixel boundary classification into moving-object detection, which ameliorates the shadow effect. Additionally, their method is not object-type-specific. Detection results in several videos also show the robustness of dealing with various kinds of targets. In future work, the authors will focus on large-scale mapping coupling with moving-object detection for autonomous driving, especially by using low-cost cameras and embedded computing.

Personalized Prediction of Vehicle Energy Consumption Based on Participatory Sensing

C.-M. Tseng and C.-K. Chau

The advent of abundant on-board sensors and electronic devices in vehicles populates the paradigm of participatory sensing to harness crowd-sourced data gathering for intelligent transportation applications, such as distance-to-empty prediction and eco-routing. While participatory sensing can provide diverse driving data, there lacks a systematic study of effective utilization of the data for personalized prediction. There are considerable challenges on how to interpolate the missing data from a sparse data set, which often arises from participatory sensing. This paper presents and compares various approaches for personalized vehicle energy consumption prediction, including a black-box framework that identifies driver/vehicle/environment-dependent factors and a collaborative filtering approach based on matrix factorization. Furthermore, a case study of distance-to-empty prediction for electric vehicles by participatory sensing data is conducted and evaluated empirically, which shows that their approaches can significantly improve the prediction accuracy.

Energy-Efficient Train Control by Multi-Train Dynamic Cooperation

X. Sun, H. Lu, and H. Dong

Regenerative braking technology has been widely used by subway trains, where regenerative braking energy (RBE) will be generated during train braking processes. An RBE usage method is proposed for subway trains, in which train braking processes are predicted based on the field data of the train control system, and the braking information will be obtained in advance. The RBE will be calculated and then part or all of it will be distributed to neighboring trains in the same or adjacent power supply sections. For each adjusted speed profile of the neighboring train, a power process will be normally introduced. A simulation case of the Yizhuang Line in the Beijing subway is studied, and the simulation results show that the proposed method can use the RBE efficiently.

Maritime Traffic Probabilistic Forecasting Based on Vessels' Waterway Patterns and Motion Behaviors

Z. Xiao, L. Ponnambalam, X. Fu, and W. Zhang

In this study, the authors propose a novel knowledge-assisted methodology for maritime traffic forecasting based on a vessel's waterway pattern and motion behavior. The vessel's waterway pattern is extracted through a proposed lattice-based DBSCAN algorithm that significantly reduces the problem scale. The vessel's motion behavior is quantitatively modeled for the first time using kernel density estimation. By incorporating both the vessel's waterway pattern and motion behavior knowledge, their solution suggests a set of probable coordinates with the corresponding probability as the forecasting output. The proposed forecasting algorithm is capable of accurately predicting maritime traffic 5, 30, and 60 min ahead while its computation can be completed in milliseconds for a single-vessel prediction. Owing to such a high computational efficiency, an extensive predictive analysis of hundreds of vessels has been reported for the first time in this paper.

Spatio-Temporal Analysis of Passenger Travel Patterns in Massive Smart Card Data

J. Zhao, Q. Qu, F. Zhang, C. Xu, and S. Liu

Metro systems have become one of the most important public transit services in cities. It is important to understand individual metro passengers' spatio-temporal travel patterns. More specifically, for a specific passenger questions include: What are the temporal patterns? What are the spatial patterns? Is there any relationship between the temporal and spatial patterns? and Are the passenger's travel patterns normal or special? Answering all these questions can help to improve metro services, such as evacuation policy making and marketing. Given a set of massive smart card data over a long period, how to effectively and systematically identify and understand the travel patterns of individual passengers in terms of space and time is a very challenging task. This paper proposes an effective data-mining procedure to better understand the travel patterns of individual metro passengers in Shenzhen, a modern and big city in China. First, the authors investigate the travel patterns at the individual level and devise the method to retrieve them based on raw smart card transaction data, then use statistical-based and unsupervised clustering-based methods, to understand the hidden regularities and anomalies of the travel patterns. From the statistical-based point of view, the authors look into the passenger travel distribution patterns and find the abnormal passengers based on empirical knowledge. From an unsupervised clustering point of view, the authors classify passengers in terms of the similarity of their travel patterns. To interpret the group behaviors, the authors also employ the bus transaction data. Moreover, the abnormal passengers are detected based on the clustering results. At last, the authors provide case studies and findings to demonstrate the effectiveness of the proposed scheme.

Deep CNNs With Spatially Weighted Pooling for Fine-Grained Car Recognition

Q. Hu, H. Wang, T. Li, and C. Shen

Fine-grained car recognition aims to recognize the category information of a car, such as car make, car model, or even the year of manufacture. In this paper, the authors propose a spatially weighted pooling (swp) method, which considerably improves the robustness and the effectiveness of the feature representation of most dominant deep convolutional neural networks (DCNNs). More specifically, the swp is a novel pooling strategy, which contains a predefined number of spatially weighted masks or pooling channels. The swp pools the extracted features of DCNNs with the guidance of its learned masks, which measures the importance of the spatial units in terms of discriminative power. By applying their method to several fine-grained car-recognition data sets, the authors demonstrate that the proposed method can achieve better performance than recent approaches in the literature.

Integrated Cooperative Adaptive Cruise and Variable Speed Limit Controls for Reducing Rear-End Collision Risks Near Freeway Bottlenecks Based on Micro-Simulations

Y. Li, C. Xu, L. Xing, and W. Wang

This paper developed a control strategy of an integrated system of cooperative adaptive cruise control (CACC) and variable speed limit (VSL) to reduce rear-end collision risks near freeway bottlenecks. A microscopic simulation test bed was first constructed, in which the realistic PATH CACC models and surrogate safety measures of the time exposed time-to-collision and time-integrated time-to-collision were used. A feedback control algorithm was then developed for the proposed vehicle-to-infrastructure system of CACC and VSL. The proposed integration system with a 100% CACC penetration rate can reduce the rear-end collision risks by 98%.

The average travel time was also decreased by 33%, compared with the manual vehicles without any control. Moreover, the penetration rate of CACC has a significant impact on safety performance. The VSL control plays an important role in reducing rear-end collision risks when the penetration rate of CACC is low.

A Real-Time Passenger Flow Estimation and Prediction Method for Urban Bus Transit Systems

J. Zhang, D. Shen, L. Tu, F. Zhang, C. Xu, Y. Wang, C. Tian, X. Li, B. Huang, and Z. Li

Bus service is the most important function of public transportation. Besides the major goal of carrying passengers around, providing a comfortable travel experience for passengers is also a key business consideration. To provide a comfortable travel experience, effective bus scheduling is essential. Traditional approaches are based on fixed timetables. The wide adoptions of smart card fare collection systems and GPS tracing systems in public transportation provide new opportunities for using the data-driven approaches to fit the demand of passengers. In this paper, the authors associate these two independent data sets to derive the passengers' origin and destination. As the data is real time, the authors build a system to forecast the passenger flow in real time. To the best of their knowledge, this is the first paper that implements a system utilizing smart card data and GPS data to forecast the passenger flow in real time.

Sampling-Based Path Planning for UAV Collision Avoidance

Y. Lin and S. Saripalli

The ability to avoid collisions with moving obstacles, such as commercial aircraft, is critical to the safe operation of unmanned aerial vehicles (UAVs) and other air traffic. This paper presents the algorithm design and experiment implementation of sampling-based path planning methods for a UAV to avoid a collision with moving obstacles. In detail, the algorithms include a method based on the closed-loop rapidly exploring random tree algorithm and three variations of it. The variations are: 1) simplification of the trajectory generation strategy; 2) utilization of intermediate waypoints; and 3) collision prediction using a reachable set. The experimental validation includes software-in-the-loop simulations, hardware-in-the-loop simulations, and real flight experiments. It is shown that the algorithms are able to generate collision-free paths in real time for the different types of UAVs among moving obstacles of different numbers, approaching angles, and speeds.

Safe Optimization of Highway Traffic With Robust Model Predictive Control-Based Cooperative Adaptive Cruise Control

C. M. Filho, M. H. Terra, and D. F. Wolf

A robust model predictive controller (RMPC) has been developed for cooperative adaptive cruise control systems with the objective to guarantee that a minimum safety distance is not violated due to uncertainties on the preceding vehicle behavior. A formulation for a safe lower bound clearance between vehicles inside a platoon is also proposed. Simulation results show the performance of the approach compared with a non-RMPC when the system is subject to both modeled and unmodeled disturbances.

Reinforcement Learning-Based Variable Speed Limit Control Strategy to Reduce Traffic Congestion at Freeway Recurrent Bottlenecks

Z. Li, P. Liu, C. Xu, H. Duan, and W. Wang

The reinforcement learning is incorporated in variable speed limit (VSL) control strategies to reduce system travel time at freeway bottlenecks. The controller included two components: a Q-learning (QL)-based off-line agent and an online VSL controller. The VSL controller was trained to learn the optimal speed limits for various traffic states to achieve a long-term goal of system optimization. The results showed that the proposed QL-based VSL strategy reduced system travel time by 49.34% in the stable demand scenario and 21.84% in the fluctuating demand scenario.

Graph Theoretic Approach to the Robustness of k-Nearest Neighbor Vehicle Platoons

M. Pirani, E. Hashemi, J. W. Simpson-Porco, B. Fidan, and A. Khajepour

In this paper, a set of graph theoretic conditions for the robustness of k-nearest neighbor vehicle platoons to disturbances and time delay have been derived and analyzed. In particular, a necessary and sufficient condition for the platoon to have non-expansive H_∞ norm for velocity tracking dynamics has been provided by introducing a specific arrangement of reference vehicles. The effect of such arrangement of reference vehicles on H_∞ norm of network formation dynamics has also been investigated. Furthermore, the effect of the communication delay on the stability of velocity tracking dynamics and network formation dynamics has been addressed. The results show that there is a tradeoff between robustness to time delay and robustness to disturbances. These results are also showing fundamental limitations in the conceptual design level of such networked control systems.

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