Current status and future trends of precision agricultural aviation technologies

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Abstract

Modern technologies and information tools can be used to maximize agricultural aviation productivity allowing for precision application of agrochemical products. This paper reviews and summarizes the state-of-the-art in precision agricultural aviation technology highlighting remote sensing, aerial spraying and ground verification technologies. Further, the authors forecast the future of precision agricultural aviation technology with key development directions in precision agricultural aviation technologies, such as real-time image processing, variable-rate spraying, multi-sensor data fusion and RTK differential positioning, and other supporting technologies for UAV-based aerial spraying. This review is expected to provide references for peers by summarizing the history and achievements, and encourage further development of precision agricultural aviation technologies.

Keywords: precision agricultural aviation technology, remote sensing, aerial spraying, ground verification

Introduction

Precision Agricultural Aviation (PAA) Technologies (PAAT) have rapidly developed in recent years attracting the attention by the government departments and farm users as an effective means to reduce pesticide residues and adverse environmental impacts while enhancing the pesticide effectiveness. There are a number of technologies that assist aerial applicators including global positioning systems (GPS) and geographic information systems (GIS), soil mapping, yield monitoring, nutrient management field mapping, aerial photography, and variable-rate (VR) controllers, as exhibited in Figures 1 and 2. Additionally, new nozzle types like pulse width modulation (PWM) and variable-rate nozzles can be integrated into these other systems enhancing application efficiency. Further, ground verification technologies, which include prediction models of droplet deposition and droplet detection sensors, allow for quick confirmation and optimization of PAATs. A decade has passed since development of the first VR, aerial application systems which provide applicators the ability to precisely apply products such as cotton growth regulators, defoliants, and insecticides using prescription maps developed using remote sensing and GPS/GIS technologies. Precision Agriculture (PA) technologies benefit the agricultural aviation industry through time and money savings. Airborne remote sensing allows for a new revenue source to agricultural aviators through remote sensing (RS) missions that would coincide with aerial spray applications. Remote sensing systems provide precise images for spatial analyses of plant stress due to water or nutrient status in the field, disease, and pest infestations. However, natural variations in biological characteristics, presence of disease and insects, and the interactions among these factors combine to influence crop quality and yield. Spatial statistics can often increase understanding of the field and plant conditions. Through image processing, remote sensing data are converted into prescription maps for variable-rate aerial application[1]. Ground verification technologies are an indispensable means of characterizing spray droplet deposition data which can be used to modify and optimize the setup and operation of aerial spray systems. Therefore, remote sensing, aerial spraying and ground verification technologies all combine to develop PAATs for use in agricultural protection and production practices. The research status and progress of PAATs are reviewed and summarized, with the three main components of remote sensing, aerial spraying and ground verification technologies highlighted. Based on the reviewed literature, trends in each component forecast are focused on key development directions in the areas of real-time image processing, variable-rate (VR) spraying, multisensor data fusion and real-time kinematic (RTK) differential positioning with the goal of promoting the further development of PAATs.

Figure 1. Precision agricultural aviation technology

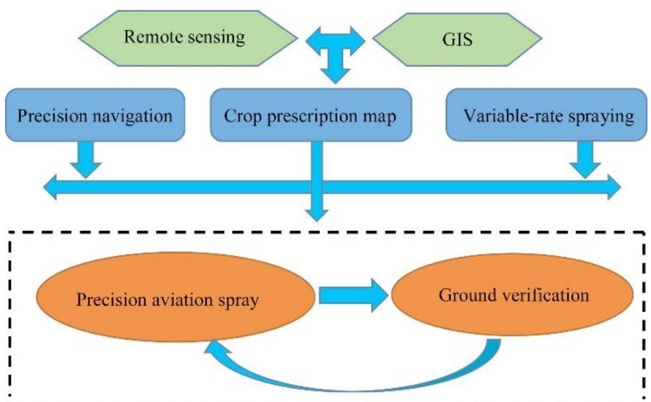

Figure 2. The composition of PAATs

1. Remote sensing technologies for PAA

The rapid acquisition and analysis of crop information is a prerequisite, and forms the basis, for carrying out precision agricultural practices proving the key to breaking the bottleneck restricting the development and application of precision agriculture[2]. With an increasing population and a commensurate need for increasing agricultural production, there is an urgent need to improve management of agricultural resources. Remote sensing is being used with GPS, GIS, and VR technologies to ultimately help farmers maximize the economic and environmental benefits of crop pest management through precision agriculture[3]. RS technology has been advanced rapidly becoming one of the most important directions in the development of PAAT[1] in recent years, providing imagery data for crop diseases and insect pests at different spatial, spectral and temporal resolutions, ultimately providing guidance in aerial application decisions. The existing agricultural RS technologies are divided into satellite, aircraft and unmanned aerial vehicle (UAV) platforms, each of which is discussed in the following sections.

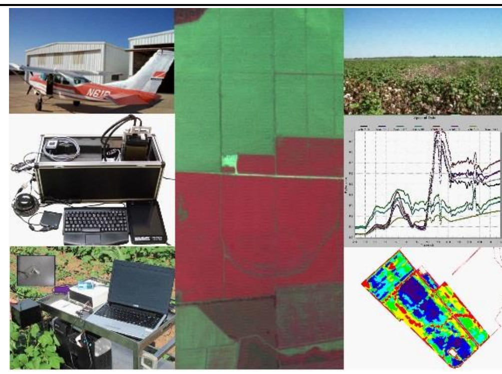

Figure 3. Airborne remote sensing

2. Aerial spraying technologies

Agricultural aerial spraying, which falls into both manned and unmanned platforms, is a critical agricultural aviation service providing efficient and effective application for crop pest control allowing for rapid response to sudden pest outbreaks of pests and the ability to apply crop production and protection products in terrain difficult for ground based systems, such as rice. Additionally, unmanned agricultural aviation spraying has the advantage of low labor operational costs with no damage to crops or soil physical structure due to wheel or track damage. Therefore, aerial spraying technologies has been widely used and promoted in agricultural production [4-6].

a. P-20 UAV spraying on wheat by XAIRCRAFT Co., LTD

b. HY-B-15L UAV spraying on cotton by Shenzhen Hi-tech New Agriculture Technologies Co., LTD

c. 3WQF125-16 UAV spraying on cole by Quanfeng Aviation Plant Protection Technology Co., LTD

d. TXA-Xiangnong UAV spraying on rice by Guangzhou Tianxiang Aerospace Science and Technology Co., LTD

Figure 4. Four working UAVs for different crops

3. Ground verification technology for PAA

As an important part of PAAT, ground verification technology (GVT) is indispensable for obtaining droplet deposition data following aerial spray applications and is used to optimize spraying system setups and operational parameters. Droplet trajectories and depositional distributions are difficult to predict aerial spray applications as a result of the complexity of the operational environment and the variability of operating parameters. GVT are used to measured and examine droplet deposition patterns and explore the influence of the UAV and spray system operating parameters to provide improved operational guidance and spray system setups. GVTs used in precision agricultural aerial spray applications include theoretical models and measurement of spray deposition.

4. Future development of PAATs

As precision agriculture continues to grow, and demand for food and ecological security will continue to rise and more operators will become familiar with these technologies to meet this growing demand. Research continues to be conducted to enhance these technologies and create new technologies for accuracy and efficiency.

5. Real time image processing

Real time image processing is needed to bridge the gap between remote sensing and variable-rate aerial application. Data analysis and interpretation is one of the most important parts of precision aerial application. Whether collected from airborne images, ground-based sensors and instrumentation systems, human observations, or laboratory samples, data must be analyzed properly to understand cause-and-effect relationships. To develop appropriate prescription maps for variable-rate aerial application, the findings from hyperspectral or multispectral remote sensing images in near real time has been a challenge. The ultimate goal is to develop a user-friendly image processing software system, aiming to analyze the data rapidly from aerial images so that variable-rate spraying can occur immediately after data acquisition.

5.1. Variable-rate technology

Variable-rate spay technology is the core of precision aerial spraying. There is limited application for turn-key commercial Variable-rate technology (VRT) devices due to their perceived high cost and operational difficulty. An economical and user-oriented system is needed that could process spatially distributed information, and apply only the necessary amounts of pesticide to the infested area efficiently and to minimize environmental damage. Additionally, nozzles are designed to produce optimal droplet size spectra for mitigation of off-target drift and to provide maximum application efficacy. These desired size ranges require the nozzles to operate within proper boundaries of their design pressure. Variable rates called for by the aerial application system might operate these nozzles outside their optimal pressure ranges making their valid use questionable if a wide range of flow rate is required. This would not be a problem for “on-off” variable control.

5.2. Multisensor data fusion technology

A key step in successful precision system development is creation of accurate prescription maps for aerial application. Creation of these maps can be assisted by multisensor, multispectral, multitemporal and even multi-resolution data fusion utilizing GIS techniques. The data fusion will be based on new methods for the fusion of heterogeneous data: numerical or measurable (radiometric, multispectral, and spatial information) and symbolic (thematic, human interpretation and ground truth) data. The multisensor data fusion scheme needs to be fully integrated into the system through GIS.

5.3. RTK positioning technology

GPS is one of the most important parts of agricultural aircraft. Inertial navigation provided only by inertial measurement unit (IMU), is unable to provide hover and route planning accurately. The hover and route planning of agricultural aircraft (or UAV) is essential for precision aerial spraying operations, not only saving labor costs to a large extent, but also improving the accuracy and efficiency of spraying operations. At present, the RTK positioning technology and product has not really applied in agricultural aircraft (or UAV) due to its high price for aerial spraying operation, which will result in the safety and accuracy of aerial spraying difficult to ensure. Therefore, with the rapid development of micro-electronic technology, RTK technology costs will gradually decline, and RTK technology will be one of the most important technologies in the field of agricultural aviation in the future.

5.4. Multi-aircraft cooperative technology

With the extensive implementation of precision agricultural aviation applications, information detection and pesticide spraying of aircraft have different requirements, and single aircraft is difficult to effectively accomplish various tasks at the same time[7]. In order to make up for the shortcomings of single-aircraft operations, researchers have begun to follow with interest the multi-aircraft cooperative technology. Multi-aircraft cooperative operation is based on single-aircraft operation, to achieve intelligent networking of multi aircrafts. Each single aircraft is required to be able to coordinate the task for the whole so as to effectively cover a large area and conduct information interaction and collaboration. With technological advances in Internet of Things (IoT) and big data, multi-aircraft cooperative operation will be a greater extent to save labor costs and improve the efficiency of precision aviation operations.

5.5. Supporting technologies for UAV-based aerial spraying

In recent years, UAV-based aerial spraying operation has become one of the most important components of agricultural aviation applications as its large-scale application. As UAV-based aerial spraying application with high-degree atomization of spray liquid, droplets easy to drift and other characteristics, in order to ensure the effective application of UAV-based aerial spraying, supporting technologies for UAV-based aerial spraying such as R&D technologies for nozzle, chemical agent and adjuvant, etc., which have a huge research potential. In which, these nozzles may include the electrostatic nozzle, the adjustable spray nozzle for droplet size and spray flow and others, chemical agent for aerial spraying by UAV may include the ultra-low-volume liquid, the nano-biological agent and others, chemical adjuvant for aerial spraying by UAV may include the modified vegetable-oil adjuvant, the organosilicone adjuvant and others. The development and application of these technologies will provide a strong guarantee for precision agricultural aviation application by effectively reducing drift and loss of droplets and promoting the absorption of the active ingredients in crop.

6. Summary

PAAT will result in more judicious use of pesticides while maintaining efficacious application and protecting the environment from adverse impacts. Large farms will benefit greatly from the use of these technologies. Small farmers could use precision agriculture technologies using a cooperative system to deal with urgent areawide pest management issues. PAAT will also allow for the targeting inputs to specific areas of fields, enabling farmers to remain successful in an increasingly competitive industry. Furthermore, it is anticipated that within the next 5-10 years, a number of breakthroughs will be made expanding the basic theories of PAAT and related equipment research such as real-time image processing and VRT, along with agricultural aviation policy. This will lead to increased guidance and support for PAATs and an increase in the number of alliances and associations related to agricultural aviation pushing PAAT into the future to support the needs of modern agricultural production.

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