Smart Agriculture 2

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Unmanned Aerial Systems in Precision Agriculture

Technological Progresses and Applications

Springer

Smart Agriculture

Volume 2

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ISSN 2731-3476 ISSN 2731-3484 (electronic)
Smart Agriculture
ISBN 978-981-19-2026-4 ISBN 978-981-19-2027-1 (eBook)
https://doi.org/10.1007/978-981-19-2027-1

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

Chapter 1
Applications of UAVs and Machine Learning in Agriculture

Sri Charan Kakarla, Lucas Costa, Yiannis Ampatzidis, and Zhao Zhang

Abstract Farmers across the world are looking for more efficient ways to collect data about various plant physiological factors. This data collection is conventionally done using manual methods, which are time-consuming and labor intensive. Remote sensing technologies (aerial and ground based) combined with machine learning techniques can be used for high-throughput phenotyping and provide critical information for precision crop management. In this chapter, different types of unmanned aerial vehicles (UAVs) equipped with various types of sensors are presented. The advantages and disadvantages of each type of UAV and sensing system are discussed for precision agriculture applications. Furthermore, an overview of artificial intelligence algorithms is presented with examples of their usage in precision agriculture. Machine learning, which is an application of AI, is used to process and analyze data generated by these remote sensing systems. These algorithms are used for their capabilities to process complex big data to estimate plant needs and predict production.

1.1 Introduction

Unmanned aerial vehicles (UAVs) have become a great tool for various agricultural applications that helps growers across the world. UAVs are currently used for applications such as plant health and stress monitoring, pest and disease detection and management, plant phenotyping and yield estimation, etc. When compared to conventional methods and strategies, UAV based agricultural applications are

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Z. Zhang et al. (eds.), *Unmanned Aerial Systems in Precision Agriculture*,
Smart Agriculture 2, https://doi.org/10.1007/978-981-19-2027-1_1

efficient, require less labor, and can cover large areas. UAVs are now commonly used in remote sensing applications for precision agriculture. With the integration of spectral sensors to the UAVs, they can sense beyond the human vision. For examples, UAVs are being used to detect and differentiate diseases that have similar visual symptoms at the early stage [1, 2]. Scouting of plants for disease detection is an essential component of integrated pest management. Visual/manual scouting is labor-intensive, expensive, requires expertise in pest identification, and the observations may be subjective and biased in terms of disease identification [3–5]. Accurate disease identification at the beginning of an outbreak is essential for the selection of effective active ingredients in spray treatments and reduces the dosage required with significant environmental and economic benefits. Diseases are currently detected in the field by visual scouting of plants and fruits. However, diagnosis based on visual symptoms is difficult due to the inability to differentiate among similar foliar symptoms of diseases. Initially, symptoms for these diseases may appear alike requiring additional confirmatory tests in a lab that could delay the diagnosis by hours or even days. UAVs equipped with sensors like hyperspectral camera can significantly reduce the time taken for this process and can also be cheaper than the traditional process [6, 7].

Tree height and canopy size measurements are other applications of the UAVs. Traditional sensing technologies for evaluation of field phenotypes rely on manual sampling and are often very labor intensive and time consuming, especially when covering large areas. Additionally, field surveys for pest and disease detection, plant inventory, and plant health assessments are expensive, labor intensive and time consuming. Small UAVs equipped with RGB (Red, Green, Blue), and multispectral sensors have recently become flexible and cost-effective solutions for rapid, precise, and non-destructive high-throughput phenotyping. UAVs equipped with RGB cameras combined with cloud-based web applications integrated with deep learning networks allow growers to constantly monitor crop health status, estimate plant water needs, detect diseases and pests, and quantify pruning strategies and impacts. UAVs equipped with LiDAR sensors are also used to monitor landscape and terrain changes in forests. There are several artificial intelligence and machine learning algorithms and platforms that have been developed in recent years that use post processed UAV data to present growers with various crop parameters, such as health conditions, canopy size and density. They can also be used to generate different maps (e.g., weed intensity, soil, and yield). In addition, UAVs can be used for spraying applications. They can be used for site specific spraying where the UAV based imagery data identifies a high-risk area affected with a disease and the UAV is programmed to be able to travel to the high-risk location and spray that specific area.

1.2 Types of UAVs

Unmanned aerial vehicles can be classified into different types based on their aerodynamic features. The four major types are (Fig. 1.1 and Table 1.1): multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL).

1. Multi-rotor UAVs: These are the most commonly used UAVs by professionals and hobbyists. They are widely used for applications like aerial photography, aerial mapping, and recreational sports. These types of UAVs are the cheapest option available in the market currently. They can be further classified into different types based on the number of rotors on the UAV: (i) Tricopter (3 rotors); (ii) Quadcopter (4 rotors); (iii) Hexacopter (6 rotors); and (iv) octocopter (8 rotors). Generally, the payload capacity increases with the number of rotors the UAV is equipped with. Compared to the low cost as the advantage, multi-rotor UAVS have several disadvantages. They have limited flight time and endurance when compared to the other types of UAVs. This is due to the fact that they need to consume a lot of energy to remain stable in air fighting against gravity and winds. The average flight time for multi-rotor UAVs ranges around 20–40 min.
2. Fixed-wing UAVs: The design of these types of UAVs are akin to regular airplanes with wings. In contrast to the multi-rotor UAVs, they do not require a lot of energy to stay in the air as they take advantage of the aerodynamic lift provided by its structure. Due to this, they can fly for a longer time compared to the multi-rotor UAVs. The average flight time for fixed-wing UAVs can last around 1–2 h. A disadvantage of these types of UAVs is that they usually need a lot of space for takeoff and landing. They also lack the ability to hover and are considered to be more complex and difficult to manipulate/operate than multi-rotor UAVs, requiring professional training. These types of UAVs also typically cost more than the multi-rotor UAVs.
3. Single-rotor UAVs: This type of UAVs looks very similar to helicopters in their design and structure. They are usually equipped with a large rotor on its top and a small rotor on its tail to control the direction of heading. These UAVs are usually powered by gas engines and therefore can fly for longer time when compared to multi-rotor UAVs (powered by rechargeable batteries). The downside of this type of UAVs is the operational dangers that comes with its large sized and more powerful rotors. They are also more difficult to fly than multi-rotor UAVs, and professional training is required. They usually cost even more than the fixed-wing UAVs but compensate for this price difference with a higher payload carrying capacity than fixed-wing UAVs.
4. Hybrid VTOL UAVs: This type of UAVs combines the advantages of fixed-wing and multi-rotors UAVs with vertical takeoff and landing capabilities. These UAVs are relatively new in the market and there are limited options available. They have a long flight time and can carry larger payloads, but the efficiency of these UAVs needs to be tested and evaluated.

Fig. 1.1 Different types of UAVs

Table 1.1 Different types of UAVs with price points and payload capabilities

Type of UAV	Price	Payload capabilities
Multi-rotor	Starts from $100	• Can hold up to 4 sensors at once • Depends on the number of gimbal spots available but can also mount using self-made mounts
Fixed wing	Starts from $1,000	• Usually, can carry 1 to 2 sensors at once • Sensors already come preinstalled in the UAV
Single rotor	Starts from $10,000	• Mostly used for spraying applications
Hybrid VTOL	Starts from $8,000	• Usually, can carry 1 to 2 sensors at once • Comes with preinstalled sensors

Types of Sensing Technologies:

1. RGB sensors

The RGB sensors are commonly referred to as visual or color cameras. They are widely used in a huge number of common devices such as cellphones, tablets, digital cameras, etc. These sensors measure the reflectance in the red, green, and blue spectrums and provide the users with a visible image. When UAVs equipped with RGB cameras are flown over large areas, they collect thousands of images, which are then stitched together using photogrammetry software to produce a map of the entire field. These maps can be used for several agricultural applications (e.g., to develop plant inventories, estimate plant leaf density and plant canopy volume) [8, 9].

2. Multispectral sensors

Multispectral sensors are an advanced version of RGB sensors, which can provide data beyond what the naked human eyes can see, and thus can capture information beyond the human vision. They provide reflectance data from the near infrared (NIR) spectrum in additional to the red, green, and blue spectrums that are usually captured by the RGB sensors. These data can be used for the calculation of several vegetation indices (VIs), among which the mostly used is the normalized difference vegetation index (NDVI). In agriculture, NDVI is measured on a scale from 0 to 1, with 0 being a stressed and 1 being a healthy plant. NDVI is being widely used by researchers to identify plant stress, predict crop yield, etc. The following is the formula to calculate NDVI:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

where Red and NIR are the spectral reflectance measurements in the red and near-infrared regions, respectively.

3. Hyperspectral sensors

The hyperspectral sensor is one of the most complex spectral sensing technologies being used in agricultural applications. It is not being as widely used as the other spectral sensors, due to very high cost of equipment and complex operating procedures. Contrary to the RGB and multispectral sensors, hyperspectral sensors collect reflectance data in continuous scans along a spectrum, usually ranging from 400 to 2,400 nm. While multispectral sensors collect reflectance data over discrete broader bands (e.g., 4–10 bands), hyperspectral sensors collect reflectance data from much narrow bands (e.g., 4–20 nm). Researchers have been using hyperspectral sensors combined with machine learning (ML) algorithms to correlate the collected reflectance data with various agricultural parameters. For example, hyperspectral sensors are being used to detect, identify, and distinguish plant diseases with similar visual symptoms, which can be a very complex task for RGB and multispectral cameras [2, 10–12].

4. Thermal sensors

Thermal sensors measure the energy radiated by an object at a wavelength (ranging from 7,000 to 12,000 nm) corresponding to its surface temperature. They can provide the users with surface temperature of various objects present in a field. Thermal cameras are widely used for precision irrigation applications. They can also be used with ML to detect leaf wetness [13] and fruits on trees [14].

5. LiDAR sensors

Light detection and ranging (LiDAR) sensors measure the distance to objects around them by illuminating the target with laser light and calculating the time required for the light to return to the sensor. LiDAR sensors have been used historically to map

Fig. 1.2 Different types of sensors outfitted to UAVs

digital elevation and surface models of the earth's surface. In agriculture, LiDAR sensors are being used for 3D modelling of the farms and farm buildings. They can also be used to measure various parameters such as crop height, crop density, canopy size, etc. Garcia et al. [15] used LiDAR data to model forest canopy height and Sankey et al. [16] used LiDAR and hyperspectral fusion for topography modelling in southwestern forests of USA, which can help monitoring landscape changes. LiDAR sensors can be used both on ground and air-based platforms for various applications (Fig. 1.2).

1.3 Examples of UAV-Based Agricultural Applications

1. Weed Mapping: Weed mapping is one of most popular applications of UAVs in precision agriculture. Weeds are undesirable plants that can grow near agricultural crops and can lead to various issues. They are competing with the crops for water, nutrients, and space, causing crop growth issues and resulting in yield loss. Since weed control is closely related to crop yield, it is very important to eliminate weeds in an agricultural field. Weed control is usually done by the use of herbicides. The most conventional spraying strategy in farming is

to spray herbicides uniformly over the entire field (blanket application), even where there are no weeds. However, this strategy may not be efficient in terms of cost and time, and also the overuse of herbicides can result in the evolution of herbicide-resistant weeds and can affect the growth and yield of the crops. In addition, indiscriminate herbicide spraying causes environmental issues (e.g., soil and water contamination) and agrochemical residues on food products. To overcome these problems, through precision agriculture practices, site-specific weed management (SSWM) is used [17]. SSWM refers to the spatially variable application of herbicides rather than spraying them in the whole field. In this context, the field is divided into management zones that each receives a customized management, as usually weed plants spread through only few spots of the field. To achieve this goal, it is necessary to generate an accurate weed cover map for precise spraying of herbicide. UAVs can gather images and derive data from the whole field that can be used to generate a precise weed cover map depicting the spots where the chemicals are needed: (a) the most; (b) the least; or (c) not at all.

2. Plant growth monitoring: UAVs are most frequently used for monitoring the growth of vegetation and providing yield estimates. For a grower to systematically monitor the progress of crop growth, there is a lot of human effort and time involved which makes it almost practically impossible. This problem is compounded by presence of diseases and pests in the fields which makes even more challenging to track the crop growth. In addition, under extreme weather conditions (e.g., rain), growers have challenges to get access to crop fields. Regular collection of information and visualization of crops using UAVs provides increased opportunities to monitor crop growth and record the variability observed in several parameters of the field. The information acquired by the UAVs can be used for the creation of three-dimensional digital maps of the crop, and for the measurement of various parameters, such as crop height, plant inter- and intra-row distance, leaf area index (LAI), etc. UAVs offer the potential to systematically collect crop information, therefore farmers can optimize crop management, such as use of inputs (e.g., nutrients, water), timing of harvest, pest and disease control, or even identify possible management errors.

3. Crop health and disease monitoring: UAVs are also used to monitor vegetation health. Crop health is a very important factor that needs to be monitored, as pests, diseases and improper/insufficient nutrients in crops can cause significant economic loss due to the reduced yield and lowered crop quality. Crops should be monitored constantly to early detect the pests and diseases and avoid spreading throughout the field. Traditionally, this task is performed by human experts who visually inspect the crop. However, this can be very time consuming, as it can require months to inspect an entire field preventing the potentials of "continuous" monitoring. Furthermore, several diseases have similar visual symptoms, which makes it difficult even for the experts to accurately detect and distinguish diseases in early stages. To overcome this challenge, remote sensing technologies, such as multispectral and hyperspectral sensors, combined with ML algorithms have been used to detect and distinguish diseases that have similar