Unmanned Aerial Vehicle Applications In Agriculture

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Abstract. Agriculture becomes extremely important as a main source of food production to feed the population in this planet. On the other hand, agriculture provides a lot of benefits to the country such as food and non-food product, transportation and balancing the environment. The demand for food security creates pressure to the decision maker to ensure our world has sufficient food for the entire world. Thus, the usage of the unmanned aerial vehicle (UAV) is an alternative to manage a farm properly to increase its yield. In order to promote the use of UAV in agriculture to support its sustainability, this paper provides an understanding towards the usage of UAV and its applications in agriculture. The objective of this paper is to review the usage of UAV in agriculture applications. Based on the literature, we found that a lot of agriculture applications can be done by using UAV. In the methodology, we used a comprehensive review from other researches in this world. As a result, from the revision, we found that different sensors give different analysis to the agriculture applications. Thus, the purpose of the project needs to be investigated before using the UAV technology for better data quality and analysis. As a conclusion, a suitable sensor and UAV need to be identified before using UAV to gather accurate data and precise analysis.

1. Introduction

Agriculture can be defined as cultivation of animals, plants, fungi and other life forms for food, fiber, biofuel, medicinal and other products used to sustain and enhance human [1]. It is the most comprehensive word used to show the many ways crop plants and domestic animals contribute in order to sustain the global human population especially in providing food and also other products [2]. Agriculture development is important especially for social and economic benefit, where agriculture increases food production, increases net income and improves family productivity, reduces income imbalance between rural agricultural employment and urban income of factory workers, and improves

farmers' living condition [3]. Malaysia has introduced Agrofood Policy 2011-2020, as a continuity from Third National Agriculture Policy (DPN3). This policy aims to outline a strategic planning to improve in the food value chain as well as increasing food production in sustainable manner [4]. From the latest knowledge and technologies in agriculture development, Department of Agriculture (DOA) will then spread the knowledge to farmers and give proper training to improve the workforce in agriculture sector [5].

Government have initiatives to improve development in agriculture by using technologies. One of the technologies is unmanned aerial vehicle (UAV) or also known as drone. It was first introduced in military for their surveillance during war. However now there are wide applications such as the forestry industry [6] rangeland and ecology research [7] as well as agriculture [8, 9, 10, 11, and 12]. Small or medium sized plantation or farm are suitable to use UAV for data collection and field monitoring effectively. UAV could be one of the solutions in getting higher resolution at a reasonable price, using high-end systems, fulfilling the requirements of the spatial, spectral, and temporal resolution needed, real-time processing capability as well as reducing the influence of environmental conditions [13, 14, 15, 16 and 6]. UAV can provide high resolution imagery in contrast with satellite imagery, which has certain date and day to obtain the image. This paper discusses the definition of UAV, Precision Agriculture, the usage of UAV in agriculture fields, and how to improve agriculture development via using UAV technology.

1.1 Unmanned Aerial Vehicle (UAV)
Unmanned Aerial Vehicle is a low-cost alternative in sensing technology and data analysis technique in the recent years. Basically, remote sensing using electromagnetic energy to determine the properties of targeted object from a distance and has the advantages of extensiveness, non-invasiveness, timeliness, and flexibility. However, remote sensing measures soil properties in the farm is far from actual data due to the complex natures of remote sensing, agricultural production and soils [17]. According to [17], some early studies using multispectral satellite images for soil surveys and soil mapping were done, however the images were generally unable to provide quantitative information concerning specific soil properties. Thus, UAV can be an option to collect accurate data in the field. It had been identified as a potential technology that can generate high spatial resolution imagery (< 1m) and at temporal frequency appropriate for timely responses in the production of actionable information about crop and field status [18]. The small UAV belongs to Low Altitude Remote Sensing (LARS), which is less as costly compared to traditionally manned aircraft is probably one of the main reason why the UAV industry had been exceeding the market demand [19].

The advantages of UAV are, it can capture the images of the farmer's crop with a variety of camera filters that can provide the farmers with multiple spectral imaging, allow the image processing and analysis which gives better information on their crop's health and at the same time identifying areas of the crops that require specific forms of attention. The small UAV can be easily flown and maintained with little training, making it a great option for farmers looking to advance their farming by merging agriculture with the technology of remote sensing [20]. UAV can be categorized in two types which is fixed wing and multirotor. It is a potential substitute for satellite-based remote sensing and it had been identified to generate high spatial resolution imagery and temporal frequency appropriate for timely responses in the production of actionable information about crops and field status [18]. Table 1 shows the comparison between multirotor and fixed wing UAV.

Table 1. Comparison between multirotor and fixed wing UAV [21]

Type	Pay-load	Flight time	Benefits	Limitation	Examples
Multirotor UAV	0.8–8.0 kg	8 – 120 min	• Applicable with waypoint navigation • Hovering capabilities • Can hold range of sensors from thermal, multispectral to hyperspectral cameras	• Payload may limit battery usage and flight time	DJI Inspire, Mikrocopter ARK OktoXL 6S12, Yamaha RMAX
Fixed wing UAV	1.0–10 lg	30 – 240 min	• Better flight time • Multiple sensors can be mounted • Limited hovering capacity	• Lower speed is required for image stitching	Landcaster Precision Hawk, senseFly eBee

1.2 Sensor and type of UAV

Good imagery depends on the type of UAV, sensor types and flight plan [22]. The type of UAV and sensors depend on the applications. Table 2 shows the different type of sensors used in agriculture. The applications of UAV will lead the type of the sensors. For example, to detect disease the suitable sensor is multispectral because it has many bands that can detect the sensitivity of the symptom. However, for agriculture mapping the RGB camera should be enough for data collection.

Table 2. Different types of sensors used in plant phenotype characterization

UAV and Sensor type	Applications	Photo	Ref.
3DR Iris+ (a) and DJI Phantom 2 (b), camera gimbal and GoPro camera	Agriculture field monitoring, autonomous navigation		[20]
Turnigy 9XR Octocopter UAV, Digital camera (RGB)	Basal Stem Rot (BSR) disease in oil palm		[23]
Sensefly eBee UAV, 16-megapixel digital camera	Mapping changes to land cover, transmission of infectious diseases		[24]
(HiSystems GmbH Mikrokopter, Germany, RGB camera	Develop a new estimation technique for disease severity		[25]
Microdrones MD4-200, A Tetracam ADC Lite digital camera	NDVI and grain yield, aerial biomass and nitrogen content		[26]

All aspects need to be considered before flying any UAV applications. In addition, geometric correction and geocoding are also important in producing an accurate weed map [27]. This is considered high accuracy for site-specific application. The accuracy of the geo-referencing of the images depends on the altitude of the UAV. The spectral and spatial resolution of the images depends on the sensors carried by the UAV. It is not necessary to use expensive sensors to map an area because it can be done using a typical digital camera such as a Canon 550D 15 Megapixel, DSLR (Digital Single-Lens Reflex), with a Canon EF-S 18-55 mm F/3.5 – 5.6 IS lens [28]. However, to detect the occurrence of specific diseases, pests and weeds, it is necessary to use a multispectral or thermal sensor camera [9]. The type of sensor should be matched to the type of information to be collected. The sensors can collect higher spatial resolution imagery than satellite sensors and at a lower cost [29].

1.3 Precision Agriculture

Precision agriculture (PA) concept was established in the late 1970s where the global positioning system (GPS) was developed and this system provides its own potential to determine accurate position (latitude, longitude and altitude) anywhere and at any time [30]. It is a holistic farm system to monitor and manage the field by using many components such as high-resolution data and high technology to maximize the output and minimize the input [20]. Furthermore, precision agriculture also referred to the application of "the right input, at the right place, at the right time with the right amount" [31] by using an integrated agricultural management system incorporating several technologies. The technological tools often include the GPS, geographical information system (GIS), yield monitor, variable rate technology (VRT), and remote sensing. Over the years, remote sensing approaches place remote sensors on towers over the crop field (thermal imagery, multi and hyper-spectral cameras, fluorometers) where the fixed positions were the main limitation for data collection [32].

These technologies can maximize the crop output of the farmers [20]. Satellite Imaging has been used before in crop monitoring, however there are several problematic issues on the satellite usage such as the prohibitive cost, the low image resolution, and its low sampling frequency [20]. Precision farming, PA, site-specific crop management (SSCM) or even site-specific farming basically use sensors that are capable of detecting field variability, such as VRT and grain yield monitor have been used in combination with high position accuracy GPS. The main concern of PA is to provide an alternative and realistic ways in order to promote a healthier environment for humans and in the meantime to reduce and optimize the usage of potentially harmful compounds [33] by using the spatial analysis like GIS tools. The flow of GIS tool purpose in agriculture is shown in figure 1.
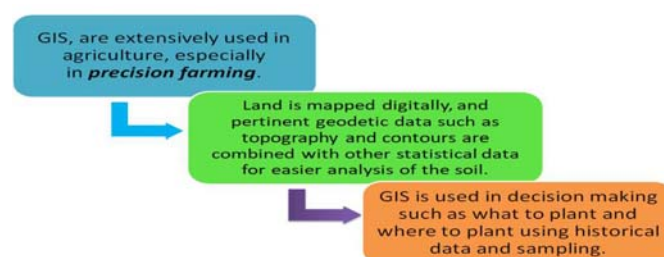

Figure 1. GIS flow for decision making in agriculture application.

The main key point of PA refers to the way farmers manage their crops to make sure there is continuous supply of water and fertilizer, and maximizing its productivity, quality and yield. In addition, it also involves minimizing pests, unwanted flooding and disease to the crops area. The invention of highly technical images had also lead in practicing agriculture by using information technologies with the approaches of looking at the whole system [34]. According to [35], most of the farmers face huge financial loss due to wrong weather prediction and poor irrigation method for crops. Some of the major problems faced by farmers was lack of knowledge on soil content, types of soil, lack of knowledge on

which fertilizer is suitable for certain areas and the correct amount of irrigation according to the areas. Thus, the usage of UAV will allow farmers to constantly monitoring their crops' condition by air to find problems quickly and at the same time reduce time consumed for ground-level spot checks. For instance, a farmer might find through time-lapse UAV photography that part of their crop is low in nutrient or not well irrigated in some areas that are difficult to access quickly.

Precision agriculture can reduce the cost of input such as the fertilizer, herbicides, and pesticides and at the same time maximize the output. For a farmer, knowing the health and current state of the year's crop is essential for effective crop management and this is where the main role of PA especially the usage of UAV take place [20]. The aim of these PA is parallel with the Fourth Industrial Revolution that brings technological revolution that will fundamentally alter the way we live, work and relate to one another. The First Industrial Revolution used water and steam power to mechanize production. The Second and Third used electric power to create mass production and used electronics and information technology to automate production respectively. Now a Fourth Industrial Revolution is building on the Third, the digital revolution that has occurred since the middle of the last century. The Fourth revolution is characterized by a fusion of technologies that is blurring the lines between the physical, digital and biological spheres [21].

However, there is some policy requirements before the UAV can be departed. It is the policy of the Department of Civil Aviation, Malaysia (DCA) that UAVs operating in Malaysia must meet or exceed the safety and operational standards as those for manned aircraft. Thus, UAV operations must be as safe as manned aircraft, for example the UAV operations must not present or create hazard to person or property in the air or on the ground. UAV must not present or create a hazard to persons or property in the air or on the ground greater than that attributable to the operations of manned aircraft of equivalent class or category. Moreover, without obtaining prior relevant DCA approval, UAVs shall not be flown [36]. Standard and operating guideline of the UAV in Malaysia is not yet well established although the DCA office had release a minimum requirement for the safety such as the weight of the instrument should not be more than 2 kg of the total carried weight, unless obtained required official approval from the DCA office. The rules were more for the public safety and there is no guideline for agriculture practices.

2. Application of UAV in Agriculture

This paper reviewed the UAV applications and the sensors usage in the applications. There are many agriculture applications that use UAV technologies nowadays such as AeroVironment [37], X-Copter [38], VIPtero [39], Fieldcopter [40] and senseFly eBee. The imagery from the sensors contain different types of format that need to be processed using the correct software. Mosaic and orthorectification are a technique to combine each piece of the photos, which are captured using UAV to produce a complete set of maps. ENVI 4.5 (Exelis Visual Information Solutions Inc., Boulder, CO, USA) and ArcGIS 9.3 (ESRI Inc., Redlands, CA, USA) are the common softwares used for orthorectification and geo-referencing the image. One of the applications using UAV in Sydney for surveillance and management of aquatic weeds [37]. They used rotary UAV, which was cost-effective and very suitable for surveillance and management in aquatic weed. They collected the data and weed experts analyzed the data and produced a map. They used Support Vector Machine (SVM) in image processing analysis. It shows that SVM was successful in identifying the weeds in natural environments.

Oil palm is the golden crop in tropical region especially Malaysia. The number of oil palm trees in the area is important information to predict the yield, monitoring the oil palm growth and increase their productivity [41]. In South-East Asia especially Malaysia, Indonesia and Thailand where oil palm (*Elaeis guineensis*) are mostly planted. The oil from oil palm is the most consumed vegetable oil in the world about 35% compared to other oil crops such as soybean and sunflower. The demand from the consumer for vegetable oil had converted most area into plantation area for oil palm. The oil palm needs proper management for planting operations on a daily basis such as weeding, pruning, harvesting and manuring [42]. Unmanned aerial vehicle is a flight with no pilot on-board and controlled by a remote or autonomous self-control. The UAV is used to capture geospatial orthophotos to monitor oil palm growth

from the early planting and identify which points at the plantation area is fertile to plant crop. Therefore, UAV is used to get the information quickly [43]. A system to detect palm oil nutrient stress had been developed and UAV images used to detect the oil palm rods [44, 45]. From the orthophoto, user can match with other maps that has agriculture elements. The UAV captured the images and then images were analysed to observe the growth in the oil palm plantation [43].

The UAV used in oil palm plantation to capture images that were processed with photogrammetry software. The photogrammetry software then were created orthomosaics of the interest zones and obtains an automatic census of the palm by using GIS software. The DJI Phantom 2 Vision+ can be controlled using mobile app iOS operating system. The Pix4D mapper Capture was used to mosaic the oil palm plantation to monitor the whole area in a faster way [46].

Rubber plantations (*Hevea brasiliensis*) have increased rapidly in tropical and non-tropical regions a few years ago in order to meet the demand for natural rubber [47]. According to report by Food and Agriculture Organization (FAO) in 2010 the rubber plantation has increased by 25% for past two decades [48]. The expansion of rubber industry has created problems between the production, forest management and conservation [49, 50, 51, 52, 53, and 54]. A better understanding of its management can aide a proper decision making for its management [55]. Drone used in precision agriculture has a lot of benefits to farmers which allows them to save their money in managing their crop by increasing the yield and the productivity [56]. The drone can be used to count the plants, nutrient applicator sprayer, mapping and NDVI plant health indexing [57, 58].

The application of UAV in rice is really important in classification, phenological behaviour, yield estimation and triggering various researchers in deriving a rice database at global, national and regional scales [38]. [39] developed a UAV for rice monitoring and management. It is known as X-Copter and can carry about 30 kg payload and fly for more than an hour. The interesting part of their research is the X-Copter, which not only capture the images but apply fertilizer in real time. This is a very good opportunity for farmers to apply precise input. In Italy, the first research using UAV in vigor mapping was based on Normalized Differentiated Vegetation Indices (NDVI) known as "VIPtero" [59]. It is a six-rotor aerial platform and flies autonomously. Multispectral camera and spectroradiometer been used for capturing and sampling the data respectively. "VIPtero" produced high-resolution imagery up to 5 cm per pixel. It definitely helps in vineyard management and is very suitable for precision agriculture in medium size.

Meanwhile, for large area rice mapping generally performed at low spatial resolution due to insufficient availability of high temporal data [59]. Image fusion or blending algorithms that combs high and low spatial resolution images is commonly applied in order to obtain the temporal data at high spatial resolution. Moreover, from the studies that were done by [60] one of the methods suggested is using spectral features along with phenological behaviors, this is because when using spectral features alone the grassland and other crops can be misclassified as rice due to similar spectral properties with rice. By combining the spectral features with phenological behavior, different crop type has different seasonal behavior that is captured through phenological behavior. This method is usually done by calculating, integrating, averaging, differencing or taking the maximum value of annual NDVI [61] found out that there is a high correlation between uncalibrated RGBVI (UAV-based RGB images) and calibrated NDVI images from their findings also, RGBVI could serve as a strong predictor for qualitative differences in crop growth for any captured growth stage.

AeroVironment is one of the UAV applications in agriculture using solar-powered and PathFinder Plus [37]. It is a high-altitude flying UAV with both multispectral imaging and hyperspectral imaging systems. It has been demonstrated in Kauai Coffee Plantations with a focus on surveillance of large rangelands. Another research has been done in a coffee plantation in Indonesia that used UAV with RGB digital camera [62]. The research investigated the usage of RGB camera as low-cost system for assessing Chlorophyll a and b, Carotenoid, and Nitrogen in coffee plantation with the combination ground sensor such as spectrometer (Ocean Optic USB2000, VIS–NIR series of portable spectrometer (Ocean optics, USA) and SPAD-502 Chlorophyll meter. Despite using spectrometer and SPAD-502 Chlorophyll meter in estimating Chlorophyll a and b, Carotenoids, and Nitrogen, they successfully

measured the Chlorophyll a and b, Carotenoid, and Nitrogen in coffee plantation without any multispectral camera. They also developed, modified, and compared the VIs with the previous research.

3. Advantages and Limitations

UAVs are capable of capturing imagery at high risk situations. They can be flown below clouds and in light rain [9]. They are not limited by physiological conditions that would affect human pilots of light planes. Field Copter is a UAV that can carry multispectral sensors for soil and crop analysis [40]. It is capable of flying and capturing imagery in more than 70% weather conditions compared to satellite imagery. There are numerous advantages and benefits using UAV in various applications. However, it depends on the aircraft, sensor types, mission objectives and their platforms [63]. All these aspects need to be considered before implementing any UAV applications. The advantages of UAV in various aspects such as it can be used in high risk situations at low altitude, in cloudy and drizzly weather conditions, not burdened with the physiological limitations and economic expenses, real-time capability and the ability for fast data acquisition, can fly below the clouds, imagery is available 'on-demand', cost effective, images are geo-referenced, enabling direct links with GIS packages, low maintenance and safety.

The limitations of the UAV are the weight and dimension of the sensors of low-cost UAV. The small or medium amateur format chosen are normally less stable and not accurate. Low-cost UAV have limitations in reaching a certain altitude due to a less powerful engine [52]. There are some problems that need to be considered when using UAV, such as the path-planning system does not use professional pilot, the high-speed ultra-low situation, data downloading function during real-time application, the size and payload to avoid bottleneck and the software for its automatic processing [64].

4. Conclusions

The production of agriculture is very important for food security in the world. The field management can be improved by using the UAV and increase the yield of productivity in order to feed the increasing population in the world. The sensor and type of UAV depends on the objectives of the research. The usage of the UAV cannot solve all the problems in the field but it can help some specific issues in agriculture. The integrated technology will help farmers in field operations. This paper only reviewed some of the researches in agriculture that used UAV and more study need to be investigated in the future such as image processing, cost of the UAV and the accuracy of data.

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