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Application of drone in agriculture: A review

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Abstract
The population is increasing tremendously and with this increase the demand of food. The traditional methods which were used by the farmers were not sufficient enough to fulfil these requirements. Thus, new automated methods (Drone technology) were introduced. These new methods satisfied the food requirements and also provided employment opportunities to billions of people. Drones technologies saves the excess use of water, pesticides, and herbicides, maintains the fertility of the soil, also helps in the efficient use of man power and elevate the productivity and improve the quality. The objective of this paper is to review the usage of Drones in agriculture applications. Based on the literature, we found that a lot of agriculture applications can be done by using Drone. In the methodology, we used a comprehensive review from other researches in this world. This paper summarizes the current state of drone technology for agricultural uses, including crop health monitoring and farm operations like weed management, Evapotranspiration estimation, spraying etc. The research article concludes by recommending that more farmers invest in drone technology to better their agricultural outputs.

Keywords: Drone, crop health monitoring, evapotranspiration, spraying

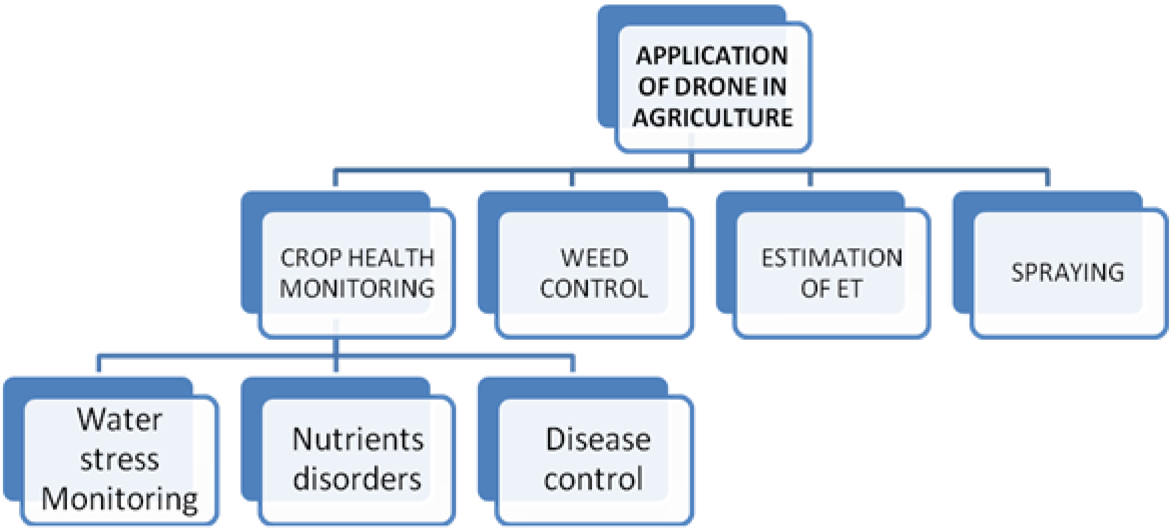
Introduction

As much as India depends upon the agriculture, still it is far short from adapting latest technologies in it to get good farm. Developed countries have already started use of UAV's in their precision agriculture [1, 2], photogrammetry and remote sensing [3, 4]. It is very fast and it could reduce the work load of a farmer. In general, UAVs are equipped with the cameras and sensors for crop monitoring and sprayers for pesticide spraying. In the past, variety of UAV models running on military and civilian applications [5]. A technical analysis of UAVs in precision agriculture is to analyze their applicability in agriculture operations like crop monitoring [6], crop height Estimations [7], pesticide Spraying [8], soil and field analysis [9]. However, their hardware implementations [10] are purely depended on critical aspects like weight, range of flight, payload, configuration and their costs.

Drones have long been thought of as expensive toys. One area that has seen little attention from drones, perhaps to its detriment, is the agricultural sector. Drones can fly autonomously with dedicated software which allows making a flight plan and deploying the system with GPS and feed in various parameters such as speed, altitude, ROI (Region of Interest), geo-fence and fail-safe modes. Drones are preferred over full size aircrafts due to major factors like combination of high spatial resolution and fast turnaround capabilities together with low operation cost and easy to trigger. These features are required in precision agriculture where large areas are monitored and analyses are carried out in minimum time. Using of aerial vehicle is possible due to miniaturization of compact cameras and other sensors like infrared and sonar.

The Japanese were the first to successfully apply UAS technology to agricultural chemical spraying applications in 1980's [11], and crop dusting in the 1990's. As of 2001 1,220 units of Yamaha unmanned helicopters had been sold and were in use in Japan [12]. Over 2,000 Yamaha RMAX unmanned hellos spray about 2.5 million acres a year, covering about 40% of the country's rice paddies in Japan [12]. U.S. is behind Japan in UAV agricultural applications, and advocates have to navigate through a minefield of privacy and legal issues in order to legally implement them into society. Although the use of UAVs in agriculture has been steadily increasing, such growth is hindered by many technical challenges that still need to be overcome. Among those applications, stress detections and quantification is arguably the one that has received the greatest amount of attention, most likely due to the potential positive impact that early stress detection can have on the agricultural activity. As a consequence, a large amount of data has been generated and a wide variety of strategies have been proposed, making it difficult to keep track of the current state of the art on the subject and the main challenges yet to be overcome. In this context, the objective of this article is to provide a comprehensive overview of the application of Drone (UAVs) in agriculture to monitor and assess plant stresses such as drought, diseases, nutrition deficiencies, pests, and weeds etc.

Crop monitoring for insects, nutrients, disease, water-stress, and overall plant health is an important aspect of precision agriculture operations. This has been carried out by examination from the air or on the ground traditionally, but these methods are limited by cost of operation and availability. Imagery created using light aircraft usually has higher resolution, is cheaper and more up to date, but it is still relatively expensive per acre. Small UAV or UAS can be used to acquire temporal/spatial data with a resolution of centimetres, and can fly consistently with repeatability of route and altitude to continuously cover the crop's fields. The acquisition of the images by UAVs is manageable and not as influenced by cloud cover. As indicated, UAS has been used in many areas in agriculture, although they still have many limitations and challenges to overcome. This paper summarizes major UAS applications and technologies for agriculture, and discusses the challenges of using UAS in an agricultural context.



Crop health monitoring

Drones can be used for monitoring the conditions of crops throughout the crop season so that the need-based and timely action can be taken. By using different kinds of sensors pertaining to visible, NIR and thermal infrared rays, different multispectral indices can be computed based on the reflection pattern at different wavelengths. These indices can be used to assess the conditions of crops like water stress, nutrient stress, insect-pest attack, diseases, etc. The sensors present over the drones can see the incidence of diseases or deficiency even before the appearance of visible symptoms. Thus, they serve as a tool for early detection of the diseases. In this way, drones can be used for early warning system so that timely action can be taken by applying the remedial measures based on the degree of the stress. UAVs (Drone) are capable of observing the crop with different indices [13]. The UAVs are able to cover up hectares of fields in single flight. For this observation thermal and multi spectral Cameras [14] to record reflectance of vegetation canopy, which is mounted to downside of the quad copter. The camera takes one capture per second and stores it into memory and sends to the ground station through telemetry.

The data coming from the multispectral camera through telemetry was analysed by the Geographic indicator Normalized Difference Vegetation Index (NDVI) [15] represented in equation.

$$NDVI = (R_{NIR} - R_{RED})/ (R_{NIR} + R_{RED})$$

R_{NIR} = Reflectance of the near infrared band.
R_{RED} = Reflectance of the red band.

Normalization difference vegetation index is a simple metric which indicates the health of green vegetation. The basic theory is chlorophyll strongly reflects near infrared light (NIR, around 750nm) while red and blue are absorbed. Chlorophyll reflects strongly which is why plants appear green to us but reflection in NIR in even greater, this plays a very important role and helps in rendering precise data for analysis. The calculations gives the values -1 to +1; near to 0 (ZERO) indicates no vegetation on the crop and near to +1 (0.8 to 0.9) means highest density of green leaves on the crop [12]. Based upon these result farmers easily identify crop health condition also monitoring crops. Based upon these results, farmers easily identify the field where can spray the pesticides. Drones can be used for monitoring the conditions of crops throughout the crop season so that the need-based and timely action can be taken. The quick and appropriate action can prevent yield loss. This technology will eliminate the need to visually inspecting the crops by the farmers. They can monitor the horticultural crops or other crops present in remote areas like mountainous regions. They can also monitor the tall crops and trees efficiently, which are otherwise challenging to scout physically by farmers.

Water stress monitoring:

The characterization of water stress on crops is a complex task because the effects of drought affect (and can be affected by) several factors [16]. Variables derived from thermal images often rely on very slight temperature variations to detect stresses and other phenomena. As a result, thresholds and regression equations derived under certain conditions usually do not hold under even slightly different circumstances. For example, different genotypes of a given crop may present significantly different canopy temperatures under the same conditions due to inherent differences in stomatal conductance and transpiration rates [17, 18, 19].

Researchers used various types of sensors and model to identify water stresses:

Using multispectral or hyper spectral images and the vegetation indices (NDVI, GNDVI, etc.) used in References [16, 20] are the result of spectral transformations aiming at highlighting certain vegetation properties. Using multispectral or hyper spectral images and the photochemical reflectance index (PRI) used in References [17, 20, 21] is a reflectance measurement sensitive to changes in carotenoid pigments present in leaves. Using thermal infrared imagery and the difference between the canopy and air temperatures (T_c - T_a) used in Reference [18]; some studies use the canopy temperature directly [16, 22]. Using thermal infrared imagery and the crop water stress index (CWSI), used in References [18, 19, 21] is based on the difference between canopy temperature and air temperature (T_c - T_a), normalized by the vapour pressure deficit (VPD) [21]. A related variable, called Non Water Stress Baseline (NWSB), was also used in some investigations [23].

The rationale behind this is that water stress induces a decrease in stomatal conductance and less heat dissipation in plants, causing a detectable increase in the canopy temperature [16, 24]. Red-Green-Blue (RGB) images have been employed sparingly, usually associated with multispectral or thermal images for the calculation of hybrid variables such as the Water Deficit Index (WDI) [24]. Chlorophyll fluorescence, calculated using narrow-band multispectral images, has also been sporadically applied to the problem of water stress detection and monitoring [20, 25].

Nutrient status and deficiency monitoring:

Plants need the appropriate levels of nutrients in order to thrive and produce a strong yield. The appropriate levels of nitrogen will ensure strong growth of vegetation and foliage, appropriate levels of phosphorous are required for strong root and stem growth and appropriate levels of potassium are necessary for improving of the resistance to disease and also to ensure a better quality of crop. If soil lacks any of these nutrients, the plant will become stressed and will struggle to thrive. NDVI Index mosaics offer the possibility to identify exactly which areas of the crops are stressed or struggling and to target directly these areas. The NIR/multispectral imagery provided by the UAVs can identify these management zones long before the problem become visible to the naked eye. This means that these management zones can be targeted before crop development and yield is affected.

Currently, the most common way to determine the nutritional status is visually, by means of plant colour guides that do not allow quantitatively rigorous assessments [26]. More accurate evaluations require laboratorial leaf analyses, which are time consuming and require the application of specific methods for a correct interpretation of the data [27]. There are some indirect alternatives available for some nutrients, such as the chlorophyll meter (Soil-plant analyses development (SPAD) for nitrogen predictions [28], but this is a time consuming process [29] and the estimates are not always accurate [30]. Thus, considerable effort has been dedicated to the development of new methods for the detection and estimation of nutritional problems in plants [31].

Nitrogen is, by far, the most studied nutrient due to its connection to biomass and yield. Potassium and sodium [32] have also received some attention. Multispectral images have been the predominant choice for the extraction of meaningful features and indices [33, 34], but RGB [35] and hyper spectral images [33] are also frequently adopted. Data fusion combining two or even three types of sensors (multispectral, RGB, and thermal) has also been investigated [35].

The vast majority of the studies found in the literature extracts vegetation indices (VI) from the images and relates them with nutrient content using a regression model (usually linear). Although less common, other types of variables have also been used to feed the regression models, such as the average reflectance spectra [32], selected spectral bands [34], colour features [36], and principal components [37]. All of these are calculated from hyper spectral images, except the colour features, which are calculated from RGB images.

Diseases monitoring

Crop diseases can be devastating and classified as fungal, bacterial or viral. Drones equipped with Infrared cameras can see inside plants [38], giving a clear image of the condition thereof. If a farmer can detect an infection before it spreads, preventative measures can be taken - like removing the plant - before the infection spreads to neighbour plants. Image-based tools can, thus, play an important role in detecting and recognizing plant diseases when human assessment is unsuitable, unreliable, or unavailable [39], especially with the extended coverage provided by UAVs. RGB [39, 40] and multispectral images [41, 42] have been preferred methods for acquiring information about the studied areas, but hyper spectral [43, 44] and thermal images [43, 44] have also been tested. The latter is employed mostly to detect water stress signs potentially caused by the targeted disease.

Weed Control

Weeds are not desirable plants, which grow in agricultural crops and can cause several problems. They are competing for available resources such as water or even space, causing losses to crop yields and in their growth. Yield losses due to weed in India: Rice (10-100%), Wheat (10-60%), Maize (30-40%), Sugarcane (25-50%), Vegetables (30-40%), Jute (30-70%), Potato (20-30%) etc. [45]. The use of herbicides is the dominant choice for weed control. In conventional farming, Farmers uprooted weeds after post emergence and the most common practice of weed management is to spray the same amounts of herbicides over the entire field, even within the weed-free areas. However, the overuse of herbicides can result in the evolution of herbicide-resistant weeds and it can affect the growth and yield of the crops. Using hyperspectral images to discriminate between the spectral signatures of some weeds with different resistances to glyphosate [46]. Using RGB sensors to classify various weed species [47]. Researchers used drone with hyper spectral sensors to monitor weed as a function of the plant canopy chlorophyll content and leaf density [48]. In addition, it poses a heavy pollution threat to the environment. To overcome the above problems site specific weed management is used to achieve this goal, it is necessary to generate an accurate weed cover map for precise spraying of herbicide. Drone 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.

Agro-drone application for weedicide spray useful for pre-emergence & post emergence weed control. Spraying is possible in any field condition (muddy, weeds, insects etc.) also in sunny and drizzling condition. Weedicide application through drone is efficient and optimizes uses of weedicide. It is simple to use and easy to carry and maintain. Operate remotely that is very safe for health.

Drone for Evapotranspiration (ET) estimation

Evapotranspiration (ET) is an important process by which water is transferred from the land to the atmosphere by evaporation from the soil and by transpiration from living plants. Estimates of potential ET are used by professionals in the fields of hydrology, agriculture, and water management. Estimating evapotranspiration has been one of the most important researches in agriculture recently because of water scarcity, growing population, and climate change. Many kinds of unmanned aerial vehicles are used on different research purposes for ET estimation. Typically, there are three different UAV platforms, aircraft, fixed-wings, and quad copter. Aircraft is usually expensive, but it can fly longer and carry heavy sensors. Compared with aircraft, fixed-wings and quadcopter are less expensive. Fixed-wings can usually fly about 2 hours, which is suitable for a large scale of field. Quadcopter can fly about 30 minutes, which is used for short flight mission in a small scale of field. Being used as a remote sensing platform, UAVs also arouse new research problems, such as drone image processing, and flight path planning. A fixed-wing UAV to collect thermal data to estimate ET with two source energy balance models [49]. Evapotranspiration in a peach orchard estimated by using very-high-resolution imagery from an UAV platform (S1000, DJI, Shenzhen, China) [50]. A TIR camera (A65, FLIR Systems Inc.) and a multispectral camera RedEdge (MicaSense, Seattle, WA, USA) are also mounted on the drone. Multispectral and thermal images were collected by using an airborne digital system for estimation of evapotranspiration, developed by Utah State University [50]. The spectral bands for these cameras are, Red (0.645 μm - 0.655 μm), Green (0.545 μm – 0.555 μm), Blue (0.465 μm – 0.475 μm) and Near-infrared (NIR) (0.780 μm – 0.820 μm). A Thermal CAM SC640 (FLIR Systems Inc.) is also mounted on the aircraft to collect thermal infrared (TIR) images; the wavelength range is 7.5 μm – 13 μm. Compared with other satellites based remote sensing methods, UAV platform and light weight sensors can provide better quality, higher spatial and temporal resolution images [51].

Spraying

Indian agriculture needed production and protection materials to achieve high productivity. Agriculture fertilizer and chemical frequently needed to kill insects and the growth of crops. Drones can be used to spray chemicals like fertilizers, pesticides, etc. based on the spatial variability of the crops and field. The amount of chemicals to be sprayed can be adjusted depending upon the crop conditions, or the degree of severity of the insect-pest attack. The integration of UAV with sprayer system results a potential to provide a platform to pest management and vector control. This is accurate site specific application for a large crop fields. For this purpose heavy lift UAVs [52, 53] are required for large area of spraying. Researcher proposed the Quad copter (QC) system which is low cost, and lightweight, also known as Unmanned Aerial Vehicle (UAV) [54]. These quadcopter is small size, and this system can be used for indoor crops as well as outdoor crops. Quadcopter is an autonomous flight for spraying pesticides and fertilizer using the android device. Between the quadcopter and android device communication is done by Bluetooth device in real time operation. This system is used to reduce agriculture field related problems, and also increases the yield of agriculture. The efficiency of the spraying system which is mounted to the UAV increases through the PWM controller [55, 56] in the pesticide applications. A blimp integrated quad copter aerial automated pesticide sprayer (AAPS) was developed for pesticide spraying based on the GPS coordinates in lower altitude environment [57]. To, overcome this low cost user flexible pesticide spraying drone "Freyr" was developed which is controlled by an android app [58]. A laboratory and field evolutions are analyzed for discharge and pressure rate of the liquid, spray uniformity and liquid loss, droplet density and sizes of a developed hexa copter mounted sprayer [59]. To reduce the wastage of pesticides an electrostatic sprayer introduced and designed on electrostatic spray technology with a hexa rotor UAV [60]. The WHO (World Health Organization) estimates there are more than 1 million pesticide cases every year. In that more than one lakh deaths each year, especially in developing countries due to the pesticides sprayed by a human being. The pesticide affects the nervous system of human and leads to disorders in the body. A remote controlled UAV (Unmanned Aerial Vehicle) is used to spray the Pesticide as well as fertilizer to avoid the humans from pesticide poison [61]. Crop dusting: Drones able to carry tanks of fertilizers and pesticides to spray crops with far more precision than a tractor. This helps reduce costs and potential pesticide exposure to workers who would have needed to spray those crops manually [62]. Pesticide application by drone can be used in all situations, especially in the places where labours are hard to find, environmental pollution can be reduced when it sprayed from lower altitude also it has a great potential to enhance pest management for small as well as the large crop field to entail highly accurate site-specification application [63]. Some scientist studied the impact of UAV (UAV N-3) spraying parameters at different working height and varying concentration of spraying pesticide on the wheat canopy and the prevention of powdery mildew in Asian countries [64]. This ultimately increases the efficiency of the chemicals applied, thereby reducing their adverse impacts on the environment by decreasing the soil and water pollution. Thus, it can lead towards sustainable agriculture. Drones spray chemicals at a faster rate as compared to other methods. It can also result in the saving of the amount of chemicals applied, which can reduce input cost. A major economic input for any agricultural season is the application of fertilizers (e.g., nitrogen, phosphate, potash), and micronutrients (e.g., sulphur, magnesium, zinc). Fertilizer is applied by on-ground equipment (tractor powered sprayers or pressurized irrigation systems) [65] or by manned aircraft [66]. The latter is the most preferred by producers with multiple and large land units. They generally use a single application rate for all fields being sprayed because changing wind speed and direction conditions during fertilizer application and the elevation of the aircraft make more precise application impossible. Ground equipment application is used as a complement to aerial spraying to maintain stable crop nutrient status across the irrigation season. UAV estimation of crop nutrient status can directly benefit the application rate recommendations by producer or agronomist consultant by including the entirety of the field. Research efforts indicate that it is possible to perform the monitoring with scientific UAVs and specialized camera sensors such as optical and thermal cameras [67, 68] along with specialized optical filters such as Red Edge or hyper spectral cameras [69, 70, 71]. Accelerometer and Gyroscope Sensors were used for spraying fertilizer and pesticide; it has ability to reduce time and human efforts [72].

Table 1: References dealing with the application of drones in various cases

Application	Sensor/ model used	Reference
Water Stress Monitoring	Multispectral or Hyperspectral sensors and NDVI, GNDVI and PRI model Thermal infrared sensor and Canopy temperature, canopy temp.-Air temp. (T_c - T_a) RGB Sensor & WDI	[16, 20, 17, 20, 21] [27, 28, 29, 30, 33] [24]
Nutrient Disorders	RGB, Multispectral and Hyperspectral sensors	[33, 34, 35]
Diseases Monitoring	RGB sensor Multispectral images sensor Hyperspectral and thermal sensor	[39, 40] [41, 42] [43, 44]
Weeding	Hyperspectral sensor RGB sensors	[46, 48] [47]
Evapotranspiration	Multispectral and thermal sensor	[49, 50]
Spraying	GPS sensor Accelerometer and Gyroscope Sensors	[57] [72]

Conclusion

Drones have great potential to transform Indian agriculture. With the advancement of technology in the future, the production of drones is expected to become economical. The modern youth are not attracted towards farming due to hard work and drudgery involved in it. The implication of drones may fascinate and encourage the youth towards agriculture. Drones provide real time and high quality aerial imagery compared to satellite imagery over agricultural areas. Also, applications for localizing weeds and diseases, determining soil properties, detecting vegetation differences and the production of an accurate elevation models are currently possible with the help of drones. Drones will enable farmers to know more about their fields. Therefore, farmers will be assisted with producing more food while using fewer chemicals. Nearly all farmers who have made use of drones have achieved some form of benefit. They can make more efficient use of their land, exterminate pests before they destroy entire crops, adjust the soil quality to improve growth in problem areas, improve irrigation to plants suffering from heat stress and track fires before they get out of control. Therefore, drones may become part and parcel of agriculture in the future by helping farmers in managing their fields and resources in a better and sustainable way.

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