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Aerial robot for smart farming and enhancing farmers' net benefit

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ABSTRACT

The knitting of information and modern electronic technology with agricultural production system to determine, analyze and manage the critical temporal and spatial factors of farm for maximizing profitability, sustainability and environmental protection is need of hour. In this context, robot (Arial, Ground and Under-water) can play an important role. Aerial Robot is also commonly known as Unmanned Aerial Vehicle (UAV) or Drone. It may be boon for management of agricultural production as it can focus on small crop fields at lower flight altitudes than other regular aerial vehicle to perform site-specific farm management operation with higher precision. It can also address adverse crop and land prerequisites, where use of conventional machines is challenging, *e.g.* spraying under wet paddy field, tall crop sugarcane, pigeonpea *etc*. Embedding the available technologies and methods for meeting functional, operational and structural requisite, specifically for the crop and land environment with Arial Robot is of utmost importance. On the basis of system range, accuracy, resolution, and precision, sensitivity, linearity, offset, hysteresis and response time of different sensing and control technologies, e.g. optical, near infrared, thermal multi-spectral, hyper-spectral, Light Detection and Ranging, radio frequency and sonar .This paper presents an overview of research involving the development of UAV technology for agricultural production management. Technologies, systems and methods are analyzed for *in situ* integration under Indian farm conditions. The limitations of current Arial Robot for agricultural production management are deliberated, moreover forthcoming needs and suggestions for development and application of the technology in agricultural production management are projected.

Key words: Aerial spraying, Drone, Remote sensing, Sensor actuator network, UAV

The technological improvements in agriculture have brought about revolutionary change in agricultural production system. However, it is imperative to enhance input use efficiency for enhancing net profit from farming and mitigating the adverse effect on ecosystem. It is important to crystalize the innovative technologies in agriculture and subsequent modification as per local conditions for apt digestion to farm (Sinha 2017). It is also imperious to reduce drudgery in farming operation. The interweaving of information and electronic technology for agricultural production system to determine, analyze and manage the critical temporal and spatial factors of farm for maximizing profitability, sustainability and environmental protection is need of hour. Enhancing yield and simultaneously minimizing fertilizer and pesticide applications, needs high resolution data of fields for micro-level application. Conventionally, the estimate of various crop parameters such as biomass and nitrogen concentration are tedious and problematic. Remote sensing on satellite platform have been used agricultural management. However, attaining up-to-date data is expensive, of variable quality, and its processing is also intensive and complicated.

In the present era of agriculture system, amalgamation of sensors, satellites, digital technology, and robotics is indeed need for paving the way for precision, profitable and environmentally safe farming (Kushwaha *et al.* 2016). Harnessing the capability of robotics for coping with business competition, environmental challenges such as reducing the ecological footprint of agriculture, and increasing food production is an opportunity and robotics may be boon for achieving the target.

The UAV, a form of robot, had its developmental origin in military applications to take photography for aerial reconnaissance was the Radio plane in 1955 in the United States. Similar capabilities were developed by the French in the later 1950s, the Italians in the 1960s, and the Russians in the early 1970s. Radar and TV were flown on UAVs in 1941 in the United States, but only for guidance purposes. Imagery collected for reconnaissance became widespread from the mid-1960s to the mid-1970s during the Vietnam War. Many of the capabilities developed during this conflict had direct application to future civil sector UAVs and civil applications followed soon after. It was deployed for border infiltration monitoring, law enforcement operations, search and rescue operations, disaster management and

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aerial photography. Civilian applications of UAVs are relatively less, but growing rapidly. India has launched NETRA developed by DRDO with IdeaForge lightweight autonomous UAV for surveillance and reconnaissance operations equipped with thermal camera communication system. The NETRA has been deployed and utilized in Uttarakhand disaster, Nepal Earthquake, Chennai Flood, Pune landslide, Pathankot attack, Indore traffic management. In 1986 UAVs were tested for monitoring forest fires in Montana, while the Condor UAV was the first. By 1994, the Predator UAV was providing 30 cm resolution images (Osborne *et al.* 2002). The distinct features of drone were low cost, low elevation operation with staring and hover ability, light weight, ground station full control, efficient communication and operational ease may be harnessed for agricultural production, management and planning. The autonomous and stabilized flight of drone with inertial navigation sensors and even low cost multispectral or hyper spectral camera is able to geocode aerial photographs of high resolution 1 to 2 cm, a relatively better image resolution than that of any satellite-based images. In turn, this platform may be resourceful for generating reliable agricultural statistic of site and time specific. The data can generate firm base for precision agricultural technologies, *e.g.* variable rate application of fertilizer, pesticide, irrigation and other agricultural inputs. Apart from generating information of crop and land the UAV platform have potential for application of pesticides and fertilizers more judicious and safe manner. Tall crop canopy of sugarcane, pigeon pea, horticultural crops *etc.* has proven problematic for efficient spraying operation with conventional farm machines. In wet land condition, ground moving machines also induces adverse impact such as hardpan development. Impact assessment data through drone of natural clematises, *e.g.* drought, flood, hail storm *etc.* may be useful for crop insurance or policy planner as it can provide data more precise and reliable. The innovative UAV platform for farming may lure to rural youth which diminishing, as it having the comfortable working environment. It will also generate employment opportunity in rural sector which may address social balance. Fuji Heavy Industries RPH2 and Yamaha's RMAX (Yamaha Motor Corporation, Iwata, Shizuoka, Japan) commercial UAV initiated work for utilizing it for insect pest assessment in rice, soybean and wheat in 1986 (Tokekar *et al.* 2013).

Use of aerial robot in agriculture

Agricultural production matrix consists of several elements, *e.g.* soil (health, nutrition), water (quality and quantity), climate, weed, pest and their interactions. Precision is of utmost importance in agriculture for enhancing not only production, productivity but also increasing input utilization efficiency and ultimately bagging more benefit with safe bio system for future. It all require exhaustive and site-specific information for deducing knowledge base for further decision. The aerial color and color-infrared photography has long been used to monitor crop growth, these methods are being intensively studied for analyzing within-field spatial variability as the imagery has high spatial resolution and can be acquired during critical periods during crop growth. The data acquired from traditional aerial systems are expensive (Hunt *et al.* 2003). Unmanned airborne vehicles (UAVs), drones and radio-controlled model aircraft have potentially lower cost and can be flown at lower altitudes to increase spatial resolution (Hunt *et al.* 2005). The UAV platform has advantageous for agricultural management than conventional satellite imagery as: very high pixels resolution, independent of cloud cover factors during critical periods of growth and instant information communication. On the other hand, manned aerial or satellite surveillance system is the incumbent data source for whole field, but suitable for larger area at a time with intensive investment and complexity. However, UAV can be operated at lower height and can gather more precise information with lesser complexity. Visualizing its potential, first Japan Govt. deployed drones for pin pointing cause for dwindling of rice farmer in 1986. About 35% of Japan's rice fields' pest control are being accomplished with UAV. Now, Ministry of Agriculture, Forestry and Fisheries are focusing vigorously on use of drone in area of planting, weed management, fertilizing and pest control. The spectral reflectance and thermal emittance of soils and crops to their agronomic and biophysical characteristics may be exploited for non-destructive monitoring of plant growth and development and detection of many environmental stresses which limit plant productivity through remote sensing methods.

Crop scouting

Unmanned aerial system can be used for acquiring, processing, analysing and managing critical elements of agricultural production system. Traditionally crop scouting was done using visual inspection such as color estimation or mold localization, physical sensors like anemometers or thermometers, and more complex electronic sensors. The advantages of UAV over these traditional remote-sensing methods are capable of collecting very high-resolution imagery below the cloud level, with much more detail at lower upfront and operational cost. The UAV's equipped with visible-band, near-infrared, multi-spectral, hyperspectral scanning cameras can castoff proficient source of information for analysing crop growth, health status, maturity and morphology. The spectral signature can reveal whether individual plants are thriving or whether they are stressed by drought, nutritionally deficient, or under attack by insects or a virus. Narrower band indices such as the Photochemical Reflectance Index (PRI), Water Band Index (WBI), and Normalized Pigment Chlorophyll Ratio Index (NPCI) are examples of reflectance indices that are useful for diagnosing water and nutrient stress. Hyperspectral (reflectance for many contiguous narrow wavelength bands) approaches have been proposed and tested with varying degrees of success to detect water, nutrient and pest-induced stress in plants while minimizing unwanted signals from varying soil conditions or biomass amounts (Peña-Barragán *et al.* 2012) mapping invasive weed outbreaks in coffee plantations and vineyards, finding irregularities in the fertilization delivery system, analyzing variable soils and determining ripeness analysis have also been explored using UAV (Herwitz *et al*. 2004 and Johnson *et al*. 2001). Crop growth variability and its dependency on cultivator and plant treatment can also be detected by comparison of the multi-temporal crop surface model generated by very high-resolution Terrestrial Laser Scanning (TLS) (Hoffmeister *et al.* 2010). It has been tested for data acquired on a barley experiment field in Germany. UAV had been experimented for agricultural monitoring in Hawaii where high speed digital photography was used to predict coffee bean ripeness (Herwitz *et al.* 2004) and in California where digital photography and hyperspectral imagery were used to map crop vigor in vineyards (Johnson *et al.* 2003).

Fusion of low-cost multiple sensor data acquired through UAV within a machine learning framework can provide relatively accurate estimation of plant traits and provide valuable insight for high spatial precision in agriculture and plant stress assessment. The intervention has found that (i) the nitrogen concentration (Scharf P and Lory 2002) and chlorophyll (Chl) a content (RMSE of 9.9% and 17.1%, respectively) with fusion of biochemical variable estimation, multispectral and thermal data. However, RGB color information based indices and multispectral data fusion exhibited the largest RMSE 22.6%; the highest accuracy for Chl a + b content estimation was obtained by fusion of information from all three sensors with an RMSE of 11.6%. (ii) Among the plant biophysical variables, LAI was best predicted by RGB and thermal data fusion while multispectral and thermal data fusion was found to be best for biomass estimation. (iii) For estimation of the above-mentioned plant traits of soybean from multi-sensor data fusion, Extreme Learning Machine based Regression yields promising results of phenotyping of soybean (Maimaitijiang *et al.* 2017). The potential of UAV RGB imagery-derived spectral, structural, and volumetric information was found to be encouraging for high-throughput phenotyping and precision agro-ecological applications and management. UAV have also been used to sample pollen (Aylor *et al.* 2006), spore (Maldonado-Ramirez *et al.* 2005), and agricultural disease agents (Schmale *et al.* 2008). It also examined relationships of vegetation indices derived from UAV-based sensors with corn nitrogen status and soybean biomass, various rice nitrogen treatments and with wheat LAI (Hunt *et al.* 2005). UAV acquired images have been successfully employed for estimating the degree and extent of shrub utilization, for mapping grass species, for measuring shrub biomass, for aiding in vineyard management (Primicerio *et al.* 2012) and for mapping rangeland vegetation (Laliberte and Rango 2009), for detecting small weed patches in rangelands (Hardin *et al.* 2007), for documenting water stress in crops, for monitoring crop biomass (Hunt *et al.* 2005, Swain *et al.* 2010), for mapping vineyard vigour (Primicerio *et al.* 2012) and for examining the results of various nitrogen treatments on crops (Hunt *et al.* 2005, Swain *et al*. 2010). The precise estimation using remote sensing data with UAV platform for surface soil properties (Sullivan *et al.* 2005), water stress, vegetation cover (Laliberte *et al*. 2005), nitrogen content (Zhang *et al.* 2006), crop height, above ground biomass (Swain and Zaman 2012), crop yield, weed extent, and crop species (Pena-Barragan *et al*. 2008) had been reported. These data had also been used to monitor other biological parameters such as leaf chlorophyll content, and leaf nitrogen content over time.

It is crucial to discriminating between small weed and crop seedlings at early stages in the majority of fields as the spectral and appearance characteristics of the crops and weeds are similar (Peña-Barragán *et al.* 2012). A weed map can be created using thermal imaging or infrared cameras through which it becomes easy to distinguish between the regions of high-intensity weed growth from the healthy crops growing right along with them. Thus, processing of the images gathered can highlight differences between healthy and distressed plants. These UAV generated maps and images can be used to fend off weeds, insects, pests and diseases in the crops. The images obtained from the UAV borne cameras can differentiate between the weeds and plants and are also able to differentiate between healthy and unhealthy crops (Hoffmeister *et al.* 2010).

The traditional methods for soil monitoring and fertilizer application are taking ground samples manually from random locations and estimating the soil water status, nutrient deficiencies and pest infestation or by remote sensing through the satellites. Although ground-based or satellite imagery are more practical for the purpose of refining variable rate applications like Nitrogen, Phosphorus and Potassium but are time consuming, cost intensive and complex methods. UAV equipped with thermal imagers can be used for monitoring of the soil moisture content. The Variable Rate Application and anything that helps it get done more accurately saves money and increases crop yield. With the help of drone-generated variable-rate application (VRA) maps variable rate application can be implemented easily (Veroustraete 2015).

It has successfully used for managing multiple irrigation pivots in the widespread fields. When crops such as sorghum or jowar, corn start arrive at certain heights, mid-season observation of the nozzles and sprinklers for watering system supplies turns into a critical task (Chao *et al.* 2008). Drone technologies could potentially provide precise and site-specific information efficient irrigation. In turn water use efficiency will increase as well as reduce water losses significantly.

Drones can also be used for monitoring the activity and movement of animals. Using temporal sensors, an UAV is able to take body temperature readings for cattle to detect sickness at early stage. They can also be used for night time monitoring of the agricultural fields (Aleksandrs *et al.* 2013).

Images from drone surveys can be used to create detailed maps of forest cover and calculation of the tree height. They can also be used to identify forest fires. Drones

Fig 1 UAV based (a) surveying of farm, (b) mapping of plantation crop, (c) geotagged field mapping.

can also facilitate the detection and assessment of illegal deforestation, mining, fires and oil spills that threaten the livelihoods of forest communities. It can also identify camps, trails or boats of intruders such as illegal hunters, miners, loggers or fishermen, gathering evidence of illegal forest use without intercepting criminals directly (Koh and Wich 2012).

UAV based surveying and mapping: Site-specific management is intuitively appealing and profitable to agribusiness (Lambert and Lowenberg-Deboer 2000). Application of the balanced soft and hard PA technologies based on the need of specific socio-economic condition will make PA suitable not only for developed countries but also for developing countries (Mondal and Basu 2009). A three-dimensional representation of a field scene improves the presentation of crop information in GIS and also provide more information to support automated farming operations in agricultural fields (Rovira *et al*. 2005). The images from the drones using laser scanners and high-resolution cameras can be utilized for generating high definition, geographically accurate 3D elevation models and maps of the fields (Fig 1). The images captured are converted in point cloud form which in turn can be developed to create maps (Hunt *et al.* 2003 and Rovira *et al.* 2005). The drone maps as a zoned shapefile that can be integrated into precision agriculture system for variable rate application of inputs, *e.g.* nutrients and pesticides which in turn may reduce input cost as well as human resources and effectively maximize yields ultimately resulting in increasing net benefit of farmers. The drone-based aerial survey found to be effective in increasing planting efficiency and reducing significantly planting costs by Ipiranga Agroindustrial for sugarcane crop over 120 ha field. Ipiranga Agroindustrial used drone data to create an accurate contour map of a 120 ha field tracing the field's planting lines 75% faster compared to ground methods. The company imported the information into John Deere Autopilot in preparation for plowing the field. A bare geotagged field map could provide precise information of drainage and irrigation issues at early stage. The intervention could efficiently evaluate the operation of pivot irrigation system and to diagnose the problems of sunken tires or clogged nozzle. The ag-specific drone aerial real time data might be led to put to work in new and exciting ways, ranging from seed or plant stand counts, detecting crop damage to analyzing map for planning of farm operations such as irrigation, nutrient management, harvesting, human & machinery management and post-harvest strategies (Dronedeploy 2019). The geotagged map enables to pinpoint areas of a field that need exploration for either research or development work or remedial strategic planning or monitoring.

Crop insurance: Extreme weather conditions such as floods, droughts, heat waves, cyclones and hailstorms cause extensive crop damage. It is imperative need to develop a robust insurance system to insulate farmers from risks. Utility of aerial robot for transparent crop insurance in quick and efficient scientific estimation of damages due to unforeseen condition by decision makes or policy planners for rescuing farmers from breaking economic back bones may be proven boon. Herwitz *et al.* (2004) demonstrated the capability of UAV based imagery system for agricultural surveillance and decision support even presence of ground-obscuring cumulus cloud cover, when getting precise information from satellite was limited. Digital maps harnessed by UAV can exhibit precise spatial correlations and patterns that may be hard to perceive in spreadsheet-based reports. Moreover, the solution can be an incredible tool for collaboration among stakeholders in farm risk management, namely insurance providers, farmers and governmental agencies. MaVinci Sirius Pro unmanned vehicle was successfully used by an insurance company to estimate damage due to hail storm over the area of 267 ha under corn cultivation for in USA by mapping the area and image processing resulting ortho-mosaic, NDVI_rainbow, NDVI_heat and NDVI_gray images, using unmanned vehicle equipped with RTK GPS positioning system and near-infrared sensor imagery. It had been found that Drones with integrated GPS RTK technology could provide land spatial resolution up to 5 cm. The range of damage in wheat field was estimated with an accuracy of 99.5% and 99.3% using field global navigation satellite system (GNSS) measurements and classification of an ortho-mosaic generated from UAV-based imagery using structure from motion (SfM) techniques and 3D point clouds (Kuželka and Surový 2018). It was found that the reliable data of crop damage could be generated by the method for solving potential conflicts among agriculture stakeholders and the knowledge about crop damage dynamics could improve the management of both crops and stakeholders. Silicon Falcon Micro Aviation utilizing drone platform and using DroneDeploy software, helped tobacco farmer of Western Kentucky, USA for genuinely settling crop insurance claim in 2016. The intervention of Silicon Falcon Micro Aviation in settling the framers' loss due to heavy rains made agreed the insurance adjuster to increase the loss from 34 % to 47%, which was amounted to an additional ₹ 31000 more per ha above the original claim amount (Dronedeploy 2016). The wildlife induced damage of agricultural crops, use of an unmanned aerial vehicle (UAV) with an optical sensor was found efficient to the extent of more than 99% (Kuželka and Surový 2018). Skymatics had used drone-based imagery for transforming to precise information in 40 crops of 46 countries to assess crop damages from weather vagaries. The technology was found efficient, scientific, realistic and quick tool for protecting farmers burdens through truthful support from government or other stakeholders of insurance agencies (Rankine 2016). Utilizing UAV platform in the agricultural insurance and assessment sector, including in insurance claims forensics was found encouraging (Wadke 2017). The International Rice Research Institute (IRRI) together with a private partner, sarmap, had reported that the remote sensing and UAV platform had great potential for monitoring mapping and yield estimation of rice field of South Asian and Southeast Asian countries to reduce the vulnerability of smallholder farmers engaged in rice production during 2012-16 under the project entitled "Remote Sensing Based Information and Insurance for Crops in Emerging Economies (RIICE). The integrated system combining remote sensing, crop modelling, web geographic information system (GIS), smartphone, unmanned aerial vehicles (UAV), and Amazon Web Services (AWS) has generated promising results, with greater than 85 % accuracy, more than 24.5 million ha of rice have been monitored in 2016. Partnership and agreement with national and state governments have also been established on the use of the RIICE technology for food security and crop insurance policies with active role of German Development Agency (GIZ), Alliance, Swiss Re Group. The quick and realistic of flood maps and statistics generated for Cuddalore district in Tamil Nadu, India in November 2015 helped to identify the flood affected areas and facilitated relief and rehabilitation measures. It was proven boon to government for relief action in providing materials such as seeds and seedlings to 400 flood affected farmers in Cuddalore district (Gille *et al.* 2016). The technology was used to identify and disbursing insurance claims in record time of affected villages, and 200000 farmers from villages of Cuddalore, Tamil Nadu, India, Mindanao island of the Philippines, the Mekong River Delta of Vietnam and Cambodia (European Space Agency 2017). Drone data might also be advantageous for the early detection and prediction of pest infestations that insurance companies could share with farmers. The tool can be used to detect insurance fraud, preventing fraudsters from insuring the same piece of land multiple times, or claiming damage. University of Alberta researcher evaluated the high-tech, bird's-eye approach offered by Drones for estimation of crop loss of wheat, canola, barley, corn, potatoes and hemp over the area of 8094 ha through a crowdsourcing campaign for drone users online and found efficient method for insurance companies for accurate estimate of loss without any human subjectivity as well as for ensuring farmers to get fair compensation (Betkowski 2018). Agriculture Insurance Company (AIC) of India along with Skymet has conducted a few pilot studies in parts of Gujarat and Rajasthan to analyze drone feasibility for agricultural surveying, crop disease mapping for crop insurance claim settlement during 2016. The AIC has emphatically initiated research and development program for utilizing the cutting-edge technology, *e.g.* Mobile App, Remote Sensing, Technology, Unmanned Aerial Vehicle (UAV) or Drones for crop identification, acreage estimation, crop health monitoring, and yield estimation etc. in collaboration with various domestic and international organizations such as National Remote Sensing Centre (NRSC-ISRO), Skymet, Tamil Nadu Agriculture University *etc.* The mass media has also utilized it for assessment of drought conditions of Maharashtra as well as damage to wheat and mustered crop due to untimely rain and hail storm in Haryana.

Geo-fencing

Geo-fencing is a virtual boundary or region surrounding any geographical region. The major application of Geo-fencing is for security purpose; it sends a text whenever there is an invader in a Geo-Fenced region. Sometimes a lot of crops is damaged by attack of wild animals such as elephants, nilgai, mountain bull, birds *etc*. Geo-fencing can prove to be useful to fend off these animals' attacks by alerting the owner. It is also being widely used to track if UAV goes out of range or crosses a particular boundary (Sinha *et al.* 2016). If the UAV crosses the particular boundary then an alarm sound or a message is sent to operator (Pratyusha *et al.* 2015). Apart from its conventional uses; it can also be used in future to resolve the land issues among the farmers. Using geo-fencing; the net cultivated area can be increased by utilizing the land area that is wasted in making bunds for field separation. The geo-referenced cadastral map base and its linkage with different records could be helpful in policy planning of land reclaim strategy by precise assessment of land status, mid-term advisory dissemination to farmers about corrective measure for crop protection and input management.

Application of agricultural chemicals using UAV

UAVs may also be used for "search and destroy" pest control missions, identifying then wiping out particularly bothersome insects. The first aerial application of pesticide was used against the forest insect pests in Canada. They used calcium arsenate to protect forest stands from defoliation by the spruce budworm (*Choristoneura fumiferana*) (Randall AP 1975). However, the first Remote Controlled Aerial Spraying System (RCASS), an unmanned helicopter was developed in 1983 by Yamaha Motor Co., Ltd., Shizuoka, Japan (Sato A 2003) for pesticide dusting over crop, *e.g.* rice and soybeans. However, the stability and controllability of flight were not satisfactory to use in field. Subsequently, the R50 developed in 1990 had a payload limit of 20 kg with a laser-system for height control. It was found economical, environment-friendly, next-generation agriculture devices that are now being used primarily for crop dusting. However, there were several operational hitches experienced during field trials, primarily related with control system. Later on, the RMAX was developed during 1997 integrating efficient control system able to maintain stability, altitude free of field terrain limitations with higher payload of 30 kg. The R50 and RMAX operational for pesticide dusting for around 270,000 ha till 2000, including not only flat fields but also orchards and other crops grown on steep slopes (Sato 2003). The developed systems were complying the safety norms and flown at speed of 30 km/h at 3-5 m altitude found efficient in completing the chemical application either liquid or granular in one fifth time than the conventional method of application. Further, The RMAX Type II G and Type II were introduced in 2003 with functions that made them easier to fly, and the RMAX G1 that featured fully automatic flight geared towards industrial use was released in 2006. The 4-stroke FAZER model went on sale in 2013, followed by the FAZER R in 2016. The command area of aerial robot in Japanese Agriculture increased to 963000 ha per annum in 2012 which accounted to 50%-60% of total cultivated area; there were 2346 unmanned helicopters for agriculture and forestry and 14163 operators all around the nation with the working efficiency of up to 7-10 ha/h (He *et al.* 2017). Yamaha also developed KG – 135, YH300 and YH3 were developed for pesticide spraying over crop fields such as rice, soybeans and wheat (Sato a 2003). The continuous development of the technologies encompassed the application rate from the original application rate of 30 L/hm^2 to a lower application volume of 5 l/ha and finally to an ultra-low volume spraying of less than 1 l/ha with tank capacity from 5 to 30 liters equipped with GPS, DGPS, gyro control, laser sensor and anti-collision systems abled to operate at velocity of 65 m/s. Miller (2005) reported the effectiveness of using an UAV for dispersing pesticides to reduce human disease due to insects. The developments were using two stroke and four stroke liquid cooled engines for unmanned aerial vehicle.

In the recent last 10 years, agricultural UAV low-altitude and low-volume application developed exponentially in China mainly of two types: single rotor and multi rotor type. There were totally 178 types of agricultural UAVs operational in China, whose working efficiency up to 6-10 ha/h with 5-20 l liquid-tank and 5-20 m spraying swath (He *et al.* 2017). It has been found that the electric power system had characteristics of flexible operation, rapid rising and landing and 10-15 min flight duration. On other hand, the diesel power system UAV required a longer takeoff time and landing because of poor flexibility and large fuselage, however its flight duration could exceed 1 h. The multi-rotor UAV mostly adopts the electric power system, with less loading than single-rotor UAV, and the tank volume mostly ranges from 5 to 10 l. The multi-rotor system has the features of simply structure, convenient maintaining and high stability, and the spraying efficiency can reach 0.2 ha/min. There were manufacturers and over 169 types of agricultural unmanned aerial vehicles for chemical application in Chinese market, having already conducted the work of the control of pest and disease in the fields of paddy, wheat, corn, cotton and sugarcane and in the orchard. The real effect proves that the UAV pesticide application meets the requirement of practical level and it is in a rapid development stage (He 2013, Giles *et al.* 2016 and Li *et al.* 2016). Recently in 2017, the DJI Agras MG-1 is operational in China. It is an octocopter design UAV for precision variable rate application of liquid pesticides, fertilizers and herbicides capacity of 10 l operated by battery with endurance of 10 min covering 400-600 m^2/min. However, uneven crop coverage, overlapping of application and lower application at outer edge of field had been experienced with aerial robot spraying. Recently, a swarm of UAVs (Yao *et al.* 2016) were tried in a control loop of algorithm in order to eradicate the operational limitations of pesticides spraying with unmanned aerial vehicles. The process of spraying the pesticides on the crop was organized by the feedback coming from the WSNs deployed in the field (Costa F B S 2012). The communication with each one was done by a control loop to adjust the route of unmanned aerial vehicle to changes in the speed of wind and number of messages exchanged in between (Faiçal *et al.* 2014). It was proven efficient in minimizing the waste of pesticides (Kale *et al.* 2015). An automatic navigation UAV spraying system MSP430 (Xue *et al.* 2016) and a blimp integrated quad copter aerial automated pesticide sprayer (AAPS) were developed and tested (Vardhan *et al.* 2014). It was reported a development of a low cost user-friendly flexible pesticide spraying drone "Freyr" integrated with an android app. A step towards reducing the wastage of pesticides, use of an electrostatic sprayer introduced and with a hexa rotor UAV (Yanliang and Wei 2017). The spraying deposition and coverage over the field in multi spraying swath was studied using filter papers and water sensitive papers (Shilin *et al.* 2017) which revealed crop geometry and configuration as well as operational environment of the UAVs were critical steering factors for the quality of spray with UAVs. In light of these actualities, development of UAV system embedded with real time crop monitoring unit has been initiated.

Some initiative had been taken by Indian Council of Agricultural Research, India in developing drone assisted spraying system. Instability of UAV system was found core operational issue for operating at lower altitude and dynamic varying payload (Sinha *et al.* 2017). Telemetry control and fusion of sensor actuator networking was found of utmost importance for UAV safe operation. Amalgamation of

Fig 2 Spraying of chemicals using UAV in (a) Paddy, (b) Tea and (c) Banana field by UAV.

Real Time Kinematics GPS were found feasible solutions (Sinha and Gogoi 2017). Farmer of Chhattisgarh, India also assembled a Drone assisted spraying system and using for spraying pesticide and crop scouting. It had reduced the cost of production to 25-30% by early detection of pest and efficient spraying (Thakur P S 2016).

The high capacity and use of aerial platform may be exploited to combat disease epidemics and application of pesticides in difficult terrain. Also, it may be boon for difficult crop canopy (sugarcane, sorghum, pearl millet, pigeon pea etc.) or wet land conditions (paddy field), where ground moving machinery operation is not feasible or problematic (Fig 2). The aerial robot based spraying system enable farmers to apply protectants in time and safely. It will also reduce drudgery of farmers which is prominent even in simple conventional knapsack sprayer operation in form of higher heart rate and postural discomfort (Sinha *et al.* 2018).

Planning and management

The UAV platform may be new paradigm for policy planners and management personnels for estimating or forecasting crop yield, production or planning future strategies to combat adverse situation. Swain *et al.* (2010) used an unmanned helicopter for low altitude remote sensing to estimate yield and total biomass of a rice crop. It was found that the LARS – UAV platform could substitute for satellite based and costly airborne remote sensing methods for estimation of yield and biomass for rice. The time-series crop yield maps could be created that can be used alongside data related to socio economic conditions and management practices as well as biophysical farm conditions. The drones could be a great surveillance tool for examining Plantation Crops which are grown in difficult terrain and large area, regularly at a reasonable price with benefits of high spatial resolution at high accuracy, easy and quick to deploy on demand, no obstructions from clouds unlike earth-observation satellites. The real time data acquired by the UAV might be effective in monitoring the plant status and further decision for action plan for maintaining proper plant stand in tea garden to maximize harvest and net return by reducing input cost (Hazarika 2019). The aerial acquired image data and its analysis by using Arcsoft and GlobalMapper software based on Viola-Jones algorithm achieved accuracy of 96% in calculating number of oil palm trees and was found efficient, economically viable and rapid tool in monitoring for oil palm plantations in Indonesia (Sastrohartono *et al.* 2016). The UAV matrix, it would be possible to pin point causes of problems and surface up effective solutions for enhancing agricultural production, productivity and net benefit of farming community. The congregated data can be used to deduce statistical models for risk management. It might be powerful tool for early detection, prediction and forewarning of pest infestation and post-harvest management strategies planning. Time series acquired geotagged data and its analysis could be resourceful for generating knowledge base for disseminating prolific advisory to farmers.

Challenges of uses of aerial robot

Limitation of payload and battery life of UAV is hindering its rapid growth. The short flight range and low flight time limits economic viability of the technology for farming. High initial cost and a little knowledge base of acquired information analysis confining effacing use of UAV platform form farming. Apart from it, the rugged design for operating the system under extreme agricultural field condition has to be focused. Assured internet connectivity and assured energy source at farm field level are required for storing and precise processing of acquired data and for operation. An efficient network of development of skilled professional for operation, maintenance and useable information generation and dissemination to farmers in order to reap thoroughgoing, from use of aerial robotics at farm level. Use of renewal energy in application of ICT and robotics at farm level might be practical and safe option specifically in developing countries where assured grid power at farm level is tight (Sinha J P 2018). Currently, there is a lack of exiting low volume pesticide application technology outfit for spraying pesticides with UAV. The spray system configurations with UAVs have not yet been optimized to complement spray pattern based on the nozzle assortment, tank design, pesticide handling system. There are neither industrial standards nor scientific understanding that can offer guidance for optimizing operational parameters in close interaction of land and weather conditions with spray quality, efficacy and safety. Spray aerodynamics of single or multi rotor UAVs and the interactions with environmental factors, *e.g.* temperature, humidity, wind speed, crop geometry, still need to be understood. The radio frequency noise interferences in controlling the UAV had been found fatal. Without these may cause severe damages to adjacent crop and injuries to operators (Kushwaha *et al.* 2018). Risk assessment on driftable droplet based on field trials and drift reduction technology has important aspect to be considered for application of pesticide particularly with UAVs. While UAV's would help in making data collection easier, faster and cheaper; there are still some problems which are major bottlenecks in the use of UAV in agriculture. In order to construct robust crop yield maps, at least a couple of observations over the growing season are needed. However, UAV image quality is highly dependent on weather and environmental conditions at the time of flight and changing conditions like varying sunlight and cloud cover can make data harder to process. Radiometric correction protocols for satellite images are now commonly applied, and provide the basis for analysis-ready data and for correcting images for illumination change, atmospheric effect, viewing geometry, and instrument response characteristics (Lillesand *et al.* 2015). The techniques for processing aerial robot multi-spectral imagery are relatively new, the general problems we need to deal with are still very similar, although the scale is much smaller and the details of data are much higher. It had been found that inaccurate calibration panel measurements, inaccurate signal-to-reflectance conversion, and high variation in geometry between illumination, surface, and sensor viewing produced significant radiometric variations in at-surface reflectance estimates on UAV platform. Hence, critical factors should be considered for radiometrically correcting UAV multi-spectral imagery in order to analyze tree crops' biophysical properties and their temporal changes (Tu *et al.* 2018). Fragile drones can crash, collide with trees, or get damaged in the unpredictable conditions of tropical forests. Unless these conditions are controlled for, images cannot be compared over time. India's massive agricultural sector presents another obstacle to the widespread adoption of UAV imagery in crop insurance. While UAVs will help make data collection faster and cheaper, innovative business models will be required to make crop insurance work on such a massive scale. Therefore, introducing UAV imagery into Indian crop insurance won't always be easy. Drones and their cameras are too expensive and not every farmer can use them. They might be capable of autonomous flight, but they still require maintenance and skilled operators. And of course, there's uncertain government regulation. Commercialization of UAV technology requires collaborative and constructive marriage of all the stakeholders from governments, research institutions and industries. The professional and research organizations would play a critical role in developing human resources operation and maintenance.

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