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Orchard spraying systems for unmanned aerial vehicles: A review

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Abstract
Mango is the most important commercial grown fruit crop and world's mango production is averaging about 22 million metric tons per year. India is largest fruit producer after china. However, the country having advantages over mango producing countries, but productivity continues to be low. To increase the overall plant health and fruit yield as well as to protect the tress from harmful fungal diseases, spraying is necessary for mango orchard. As mango is important fruit crop of Konkan region and its spraying operation is done conventionally, the operation is time consuming. UAVs are commonly used for spraying orchards. In conventional method of spraying results in excessive application of chemicals and less uniformity which further leads to more production cost. Application of pesticides with the help of UAV could have advantage of spray over crops and covering large areas quickly. UAV fly at proper height can increase pesticide penetrate effectively. This paper presents details study about development of orchard spraying system for unmanned aerial vehicle which can reduce spraying cost and loss pesticide.

Keywords: UAV spraying application, development, Spray drift, UAVs performance, Factor affecting, Conclusion, References

1. Introduction

Precision agriculture is an agriculture production system based on the information technology which is based for the purpose of determine, analyze and manage of the factors such as temporal and spatial variability in the field to obtain maximum profit, sustainability and environmental protection. Mango (*Mangifera indica* L.) is the most important fruit of India and is known as "King of fruits". Indian mangoes come in various shapes, sizes and colours with a wide variety of flavour, aroma and taste. The Indian mango is the special product that substantiates the high standards of quality and bountiful of nutrients packed in it. In India, mangoes are mainly grown in tropical and subtropical regions from sea level to an altitude of 1,500 m. Mango is important fruit crop of Konkan region grown on 1.10 lakh ha productive area was under mango cultivation having annual production of 2.6 lakh metric tons. In crop and fruits production system pesticides are applied in agricultural fields to protect crops and fruits. The crop yield is generally reduced by 40 per cent mainly due to attack of pest, disease and weed and farmers have adopted many chemical control for controlling them. Pests are prominent issues in crop production. According to the data released by FAO, about 30% of the crop loss worldwide is caused by weeds, diseases and insect pests annually. Chemical spraying remains the most effective method for pest control (Guo *et al*. 2019) [7]. Indian farmers use conventional methods to spray pesticides in the field which leads to excessive use of chemicals, less spray uniformity, low deposition, higher cost of spray operation and environment pollution (Haung *et al*.,2009) [12].

There are too many technologies involved in today's agriculture, out of which spraying pesticides using UAVs is one of the emerging technologies. In the recent years, the development of Unmanned Aerial Vehicles (UAVs) supported the of precision agriculture (Huang 2013) [13]. Field operations over smaller field can especially benefit for use of UAVs. UAV or commonly known as drones, are beginning to emerge as an incredible solution for many of the challenges. UAV platforms has given a new solution for crop management as well as monitoring, especially where small farm areas have to be monitored (Kumar *et al*.2020) [18]. Also this technology perfect for agriculture, because these are mainly vast in rural areas, where privacy and safety issues regarding the drones are less of concern than in many other UAV applications.

2. Review of Literature

2.1 UAVs spray application

Ru *et al*., (2011) [32] conducted research on aerial spray application using helicopter. The aerial spraying was enabled with electrostatic technology. It had coverage of about 12 droplets/cm^2 when charging voltage was 10 kV. Droplet distribution uniformity was improved and droplets drift decreased 38%. Qiu *et al*., (2013) [28] studied the relationship between spray deposition characteristics, flight height and flight velocity of an unmanned helicopter. These experiments were carried out in the wheat field at flying height of 0.8 m above the crop canopy. They found that flight height and flight velocity of unmanned helicopter had significant effect on the deposition concentration. Meivel *et al*., (2016) [22] developed quadcoptor UAV based fertilizer and pesticide spraying system. Remote controller was used to spray the pesticide as well as fertilizer to avoid the humans from pesticide poison. Also this model was used to spray the pesticide content to the areas that cannot accessible easily by humans. This developed quadcopter UAV based fertilizer and pesticide spraying system used liquid pump motor with tank at flow rate, maximum spraying the height and flying speed were 1 l/m, 4 m and 5 m/s respectively. The quadcopter was used multispectral camera to capture the remote sensing images which are used to identify green fields. The pay load lifting capacity of these quadcoptor is 8 kg. Kim *et al*., (2019) [17] studied application and control of unmanned aerial vehicles in agriculture. These UAVs highly capable and their use has expanded across all areas of agriculture, including pesticide and fertilizer spraying, seed sowing, and growth assessment and mapping. Accordingly, the market for agricultural UAVs is expected to continue growing with the related technologies. In that research they consider the latest trends and applications of leading technologies related to agricultural UAVs, control technologies, equipment, and development.

2.2 Spraying platform for UAVs

Yanbo *et al*., (2008) [51] developed of an unmanned aerial vehicle-based spray system for highly accurate site-specific application. These spray system was specially designed for the UAV with the triggering of the sprayer being controlled by the UAV's GPS system. The UAVs used were Vertical Take-Off and Landing (VTOL) unmanned autonomous helicopters, SR20 and SR200. The SR20 and SR200 utilize the same control and communication systems. SR200 was developed to carry a low-volume spray system to apply crop protection materials. Huang *et al*., (2009) [12] conducted research on spray system for unmanned aerial vehicle platform. They developed spray application system of Rotomotion's SR200. The SR200 was Vertical Take-Off and Landing (VTOL) unmanned autonomous helicopter powered by two stroke gasoline engine. It has a main rotor diameter of 3 m and a maximum payload of 22.7 kg. An additional UAV helicopter, Rotomotion's SR20, which was battery-powered and has a main rotor diameter of 1.75 m used to develop control software familiarity as well as test and troubleshoot operational software interface and routines. This UAV was especially good for vector control (< 50 µm droplet size) with a number of micronair ULV-A+ nozzles (2, 3 and 4) in the PWM control stage of spray pump speed. Zhu *et al*., (2010) studied that pulse width module (PWM) controller for aerial spraying which was fitted on UAV for precise spraying. TL494 frequency pulse width modulator which produce fixed frequency with 12-bit data acquisition board and software was used. A PWM controller was connected to the guidance system and control commands sent between UAV helicopter and ground control station via a wireless telemetry system. Rotomotion SR200 model 1.75 m rotor diameter and 4.5 kg payload was used. The spraying system consisted micron air ultra-low volume (ULV) nozzle, a tank having size of 9.5 x 12 x 15.8 cm and 12 V DC compact pump for pumping the liquid. Ru *et al*., (2011) [31] studied that design and investigation of ultra-low volume centrifugal spraying system on aerial plant protection. The rotary wing was 3m, weights 95 kg and operating speed was 3 km/h. Air atomization system includes a frame connected with the remote control helicopter, electric centrifugal nozzle, pesticide tank, pump, infusion pipeline and so on. The observation was taken the droplets diameter 80-150 µm, spraying volume 1.2 -2 L/min, and motor speed 3000-12000 rpm. Then the test on rice is carried out using this system matched with Eagle3. They observed that when the rice area is 40,000 square meters, spray time is 36 min, 60 liters of pesticides consumed. Huang *et al*. (2013) [13] conducted research on spraying platform for modified non-military Yamaha UAV for controlling pest in rice, soybean, wheat crops. The developed unmanned aerial vehicle was equipped with GPS and 22.7 kg payload capacity, maximum altitude of 1500 m for 5 hours of flying endurance. Harsha *et al*., (2014) [9] conducted research on automated aerial pesticide sprayer. The developed automated aerial pesticide sprayer was basically a combination of blimp on a quad copter frame. The designing of automated pesticide sprayer considering frame characteristics, electronic speed controller, software and control design, propeller characteristics and blind design. It covers larger areas to field while spraying pesticides in short of time when compared to manual spraying. Kale *et al*., (2015) [15] developed agricultural drone for spraying pesticide and fertilizer. It includes of electronic speed controller, DC power brushless (BLDC) motor, DC water pump, accelerometer sensor, gyroscope sensor, Li-Po battery and atmega328 micro flight controller. Atmega 8-bit flight controller supported six pulse width module (PWM) channels which was programmable. LiPo battery of 3000 mAh and 25 ^{O}C was used. Xue *et al*., (2016) [48] studied unmanned aerial vehicle based automatic aerial spraying system. The spraying system was equipped with a flight controller, gyro-scope, GPS receiver, image transmitter, telemetry transmitter, altimeter, heading sensor, and spray system The system not only used for highly integrated but also ultra-low power MSP430 single-chip micro-computer with an independent functional module. Zhang *et al*., (2017) [56] developed a six-rotor unmanned aerial vehicle (UAV) electrostatic spraying system for crop protection. The electrostatic spray system consisted of a diaphragm liquid pump, a spray container, a pipe, a nozzle mast, an electrostatic nozzle and a high voltage electrostatic generator. Spraying system of a six-rotor UAV with a 10 L loading capacity was designed using Dajiang flight control system. Rasi *et al*., (2020) [29] developed of an unmanned aerial vehicle for agricultural spraying in Brazil. They studied configurations as a platform for agricultural sprayers, with a hopper with a capacity of 100 kg, which can perform better maneuvers than conventional agricultural aviation, for precision spraying on small and medium Brazilian properties agricultural. These UAV consisted MP 2128g Micro Pilot flight control board and RC, BEC, Battery eliminator circuit, the receiver of the remote radio control signal, BW water bomb with a brushed engine. Also the propulsion system consists of an air-cooled Simonini Mini 3 two-stroke Otto cycle engine, with a pulley and V-belt speed reduction system, a 24 V DC electricity generator, built-in starter, and rated power of 33 Hp

2.3 Performance of UAVs

Giles and Billing (2014) [8] evaluated pesticide spraying in rice crop by using spraying system for RMAX unmanned helicopter for spraying pesticides in the rice field. The RMAX unmanned helicopter was including the different rotor diameter 3.1 m, vehicle length 3.6 m and height 1.1 m. They powered by a two stroke 13.6 kW liquid cool engine as well as controlled through 72 MHz radio link Transmitter. The spraying system was fitted to UAV and consist of an electrically powered diaphragm pump as well as flat fan nozzles having flow rate of 1.3 to 2.0 l/min. The experiment was conducted on 0.61 ha area of vine grapes. The result of the experiment was observed that UAV could achieve 2.0 to 4.5 ha /h field capacity at an application rate of 14 to 39 l/ha.

Ru *et al*., (2015) [31] evaluated aerial sprayer and observed that when flight altitude was 2 m then the droplet deposition better in case of non-electrostatic spray in comparison with 1 m and 3 m flight height. Number of droplet deposited on water sensitive paper was 56 cm^2 in non-electrostatic spray. While in electrostatic spray droplet deposition was increased by 35.4, 26 and 9 cm^2 in top, middle and bottom of the plant canopy, respectively. They found that the droplet size of electrostatic spray was in the range from 80 to 200 µm. Chagling *et al*., (2016) [5] reported that effect of flight parameters of 3WQF80-10 single rotor diesel plant-protection UAV model. The droplets deposition as well as downwash air flow were measured at different height, different directions and different crosswind speed. The result found that at the height of 3.0 m, velocity of 5.0 m/s and crosswind speed 1.2 m/s, the flight direction had an impact on droplets distribution. At the height of 2.0 to 3.5 m, velocity of 5.0 m/s, crosswind speed 8.0 m/s, and the coefficient of variation (R^2) was 0.9178 found at the bottom part which indicated that droplets distribution became more uniform with the increase of height. Yanliang *et al*., (2017) [52] Compared their developed a six rotor UAV electrostatic spraying system with non-electrostatic sprayer. They found that electrostatic spray had more concentrated droplet deposition and less drift. At top of the sample for electrostatic spray the average droplet deposition was around 16.1 droplets/cm^2 and at middle it was 28 drops /cm^2 which was more than for the non-electrostatic spray Yallapa *et al*., (2017) [50] evaluated a developed drone mounted sprayer for pesticide application and evaluated in the field of groundnut and paddy. The average field capacity was found to be 1.15 ha/h, respectively when forward speed was 3.6 km/h and height of spray was 1.0 m above crop canopy. Spray uniformity increased with increase in height of spray and working pressure. Spray droplet size was found be 345 µm. Tang *et al*. (2018) [36] conducted the experiment with using of multi rotor unmanned aerial vehicle (ZHKU-0404-01) to study the effect of flight height, operational speed and tree shape on droplet deposition. They conducted Experiment with flying height of 1.2 m and flight speed of 3.5 m/s. The statistical analysis showed a significant difference in droplet density and coverage rate in the upper and lower layer of inverted triangle shaped trees canopy.

2.4 Drift characteristics of UAVs

Xue *et al*., (2014) [47] studied drift and deposition of ultra-low altitude and low volume application in paddy field. They conducted field trials to evaluate various techniques for measuring spray deposition and aerial drift during spray application in paddy field. They applied spraying agent containing fluorescent dye Rhodamine-B by an unmanned aerial vehicle (UAV) which flew at a height of 5 m, speed of 3 m/s, and wind speed of 3 m/s. They observed that average deposition on the upper layer accounts for 28% of that total spraying and deposition on the under layer accounts for 26% of that total spraying. Also droplets drift data showed that drift of non-target area took up 12.9% of the total liquid spray. The 90% drifting droplets were located within a range of 8 m of the target area, the drift quantity was almost zero at a distance of 50 m away from the treated area. Ru *et al*., (2015) [31] conducted study on electrostatic aerial sprayer XT8D UAV. The result showed that for non-electrostatic spray deposition of droplet effect is better when flight height was 2 m as compared to height of 1 and 3 m the number of droplet deposited on water sensitive paper reaches to 56 per square centimeter, electrostatic spray makes droplet deposition increases and coverages increased by 35.4, 26 and 9 per square centimeter the target canopy, middle and lower layer respectively. They concluded that when height was 1, 2 and 3 m there was no significant difference between electrostatic and non-electrostatic spray, up to 3 m height, the mean droplet drift distance was 12.1 15.8 and 18.6 m, respectively and mean drift amount was 5.88, 10.31 and 14.98 µg/cm^2, respectively for the flight heights. Brown *et al*., (2018) [1] studied that measurement of pesticide drift from an unmanned aerial vehicle application on vineyard. They measured spray drift from 0.84 ha aerial pesticide application of imidacloprid performed by a Yamaha R-Max II UAV over a Napa Valley vineyard. They collected downwind deposition samples, in-swath deposition samples, and downwind air up to 48 m downwind of the application field. They concluded that in-swath deposition samples approximately 57% of the target rate, while downwind samples indicated that drift deposition decreased to approximately 0.4% at the 7.5 m downwind distance and 0.03% at the 48 m downwind distance.Hunter *et al*., (2019) [14] studied coverage and drift potential associated with nozzle and speed selection for herbicide applications using an unmanned aerial sprayer. The author observed that highest coverage was achieved with an application speed of 1m/s and ranged from 30% to 60%. Also coverage consistently decreased as application speed increased across all nozzles, with extended-range flat-spray nozzles declining at a faster rate than air-induction nozzles, likely due to higher drift. They were measured drift potential of UAV-applied pesticides using extended-range flat spray, air-induction flat-spray, turbo air-induction flat-spray, and hollow-cone nozzles under 0, 2, 4, 7, and 9 m/s perpendicular wind conditions in the immediate 1.75 m above the target were conducted in the absence of natural wind. Wen *et al*., (2019) [45] investigated drift and movement of droplets with respect to flight speed and altitude of a quadrotor UAV. The quadrotor flying at 2 m/s with boom height of 0.25, nozzle spacing of 0.4 m at 1 m height. The quadcopter operating with pressure 1 MPa, flow rate of 4 L/min, spray angle of 110°. They used 0.3, 0.4 and 0.5 m as the distance between the nozzles to find out effective nozzle position. The author found out 0.4 m to be the appropriate distance in order to reduce the drift. The capacity of medical kit tank of drone is 10L. The test wind speed used in the experiment was 0.4 m/s.

2.5 Factor affecting on UAVs
Zhang *et al* (2012) [60] evaluated the spray droplet deposition on rice field at different flight speed 1.5, 2.0, and 2.5 m/s and flying height 1, 2, 3 and 4m. In that trial they were using WPH642 unmanned helicopter which was equipped with infrared thermal imaging system. They found was flying speed 1.5 m/s and flying height 2 m suitable for this experiment. Xue *et al*., (2014) [49] investigated that to evaluate various techniques for measuring spray deposition and aerial drift during spray application to paddy field. The application of a spraying agent containing the fluorescent dye Rhodamine-B was applied by an unmanned aerial vehicle (UAV) which flew at a height of 5 m, a speed of 3 m/s, and wind speed of 3 m/s. They obtained results that downdraft produced by a helicopter rotor increased the penetrability of crops, there is a higher deposition on the upper layer and the under layer than the traditional spraying. The average deposition on the upper layer accounts for 28% of the total spraying, the deposition on the under layer accounts for 26% of the total spraying. Chen *et al*., (2016) [2] conducted a field experiment by using HY-B unmanned helicopter having 10 kg payload capacity on rice field. They found suitable flight parameters as flight height of 2 m and average speed of 2 to 3 m/s.

Qin *et al*., (2016) [26] carried out research on droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. It observed that when the spraying height was 1.5 m and the spraying velocity 5 m/s, the droplet deposition in the lower layer was maximized, and the droplets exhibited the most uniform distribution. droplet size distribution is of great importance to control the spray process because the droplet size is one of the most important parameters for spray technology. Qin *et al*., (2018) [25] conducted research on droplet deposition and efficiency of fungicides sprayed with small UAV against wheat powdery mildew. They observed that impact of spraying height on the distribution of droplets on the wheat upper layer was quite significant, when the spraying height was 5.0 m and the spraying speed was 4 m/s, the coverage rate of droplets on the wheat lower layer was the largest, as it was 45.6% of that on the upper layer, the droplets distribution was the most uniform, and the coefficient of variation was 33.13%. Wang *et al*., (2018) [44] evaluated drift and deposition of pesticide applied by UAV on pineapple plants under different meteorological conditions. They conducted deposition and spray drift test using a QuanFeng120 UAV in a pineapple field under various different meteorological conditions. The results showed that with the changes of UAV operating height and wind speed, the start position of the in-swath deposition area changed 4 m in the extreme situation. They concluded that the percentage of the total spray drift was from 15.42% to 55.76% and the position of cumulative spray drift that accounted for 90% of the total spray drift was from 3.70 m to 46.50 m relative to the flight line.

3. Conclusion
It was concluded from review that spraying operation with the help of unmanned aerial vehicle depends on forward speed, spraying height, UAV platform (type of UAV, number of rotors, payload capacity and endurance time). The reviewed literature summarized as the unmanned aerial vehicle technology for pesticide application was highly efficient, effective and reduce time compared to traditional spraying methods. These review also revealed that suitable flight parameters as flight height of 2 m and average speed of 2 to 3 m/s as well as 2 m height and 2 m/s speed effective for pesticide application. Single rotor unmanned aerial vehicle and multirotor unmanned aerial vehicles were used for the aerial spraying application by various researchers. LiPo (Lithium polymer batteries) and BLDC motor (Brushless direct current motor) were widely used in unmanned aerial vehicle for spraying operation. In multirotor unmanned aerial vehicle spray droplet size was found be 345 µm and in ultra-low volume centrifugal spraying system on aerial plant protection droplets diameter 80-150 µm, spraying volume 1.2-2 L/min and motor speed 3000-12000 rpm. After reviewing the above literature UAVs was available to apply pesticide on the field crops. Therefore, it is important to work on the orchard spraying system for unmanned aerial vehicles. To complete the tasks, it is important to work on available unmanned aerial vehicle and finding the drawbacks of available UAVs for developing and testing orchard spraying system for UAVs in laboratory as well as field conditions. The above findings were useful for development of orchard spraying system for an unmanned aerial vehicle.

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