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UAV for Agrochemical Application: A Review

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Abstract

Unmanned aerial vehicles (UAVs) are tools for mechanized agriculture: they are used to alleviate maladies in a variety of fields through commercial, scientific, agricultural, and infrastructure enhancement. The purpose of the paper is to illuminate knowledge on mechanized agriculture using unmanned aircraft systems for pesticides and fertilizer application in obstacle rich farm. Various journal papers were reviewed to ascertain the state-of-the-art in agricultural unmanned aerial vehicles. X-rayed are unmanned aerial vehicle agrochemicals spraying architecture and efficacy, deployment and control strategies, obstacle sensing and avoidance systems, development/studies, and the limitations of the technology. The review shows that great strides have been made to develop agricultural unmanned aerial vehicles that can autonomously identify obstacle type, realize desired avoidance actions, and carry out variable rate agrochemical application. It is however noted that studies should continue on developing protocols and standard operation procedure, more human friendly interface platform, power technology, higher payload, real time quality imagery and robust mechanical features as well as enhanced sense and avoidance technology to meet the requirement of agricultural unmanned aerial vehicle for real time autonomous actions, flight endurance, low speed and low altitude. The paper therefore addressed the lack of awareness and absence of dedicated education on precision agriculture in the farming sector that has since ensured that its adoption level as a preferred system of farming remains very low in Nigeria despite the many benefits of unmanned aircraft vehicle farming technology.

Keywords: Unmanned aerial vehicle; mechanization; obstacle avoidance; variable rate application.

1.0 INTRODUCTION

On the front burner of discourse on Nigerian economy is the diversification of the nations' mono-economy away from oil. In the forefront of alternative choices is agriculture but agriculture as is currently practiced accounts for 70 percent of extreme poverty in the land. Hence the desire for paradigm shifts in deploying agricultural solution as the most sustainable candidate for wealth creation and national economic growth. Mechanization of agriculture is one sure way of rendering farming attractive and profitable for the youths that have jettisoned it.

It therefore follows that resolving the profitability and the drudgery issues of the current farming scenario is core to the solution. A more efficient use of agricultural inputs, i.e., water, nutrients and chemicals for crop production and protection, can improve crop yield, both in quantity and quality as well as reduce the environmental impact of production [1]. Site Specific (SS) management applies inputs by variable rates, considering the existing variability of soil and vegetation within the field, thus using resources more efficiently.

Unmanned aerial vehicle (UAV), commonly known as drone, and defined as "an aircraft that is equipped with necessary data processing units, sensors, automatic control, and communications systems and is capable of performing autonomous flight missions" [2], has a long history dating back to early 20th century, but it was not until the 21st century that the technologies required to thrust it into widespread usage converged [3]. It was then that technological theories that were originally unrelated became more closely integrated and unified to produce the UAVs of today flight missions and sophistications. One of those tasks is its application to agriculture away from military engagement in the areas of remote sense, imaging and the aerial spraying of farms where ground spraying machines and systems are constrained by "topography, later stage of crop growth, poor field adaptability and operational results" [4]. According to [5], UAVs are suitable for agricultural fields because such areas are often vast- making ground scouting difficult, and sparsely populated- hence injury and privacy

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risks are not as important as in urban settings. UAVs are now in addition to being used to spray plants with plant protection products and to spread fertilizers are also used to sow seeds and plant plants [6].

Remote sensing generally considered one of the most important technologies for precision agriculture, smart or auto farming has continued to grow in leaps and bounds with few hitches bordering essentially on evolving sensor miniaturization technology and autonomous operations [7] to meet the demand of UAV limiting factors of size, weight and power (SWaP). On the other hand, the application of UAVs to crop spraying in precision agriculture rarely meet its objectives of the right place and right quantities. Under adverse weather conditions the speed and direction of the wind impair the effectiveness of the spraying of pesticides in a target crop field. It is believed that large amount of all the pesticide used in the world drifts outside of the target crop field [8]. Again, it was observed that the UAV's operating precision is not high enough near the plants due to low accuracy flight control. Other problems include crop areas not covered in the spraying process and the overlapped of spraying areas [9].

Hence UAVs though extensively used in agriculture, its efficiency in the application of agrochemicals is below expectation compared to ground systems and the risk of pesticide pollution exists. To the authors in [8] this is mainly because the autonomy of many Ag UAV system is limited as most of them are operated through remote control and therefore subject to human skill and idiosyncrasy. Notwithstanding [10] insists that in recent time, these low cost, low maintenance aerial vehicles are being utilized in precision agriculture from overall monitoring of crop fields to spraying of pesticides and fertilizer. This and many other controversies underscore the need for updated review of literature on current status of UAVs for agrochemical application in precision agriculture.

2.0 PRECISION AGRICULTURE

2.1 UAV in Precision Agriculture

UAV technologies- advanced electronics, global positioning systems (GPS) and remote sensing have enabled the effective application of farm inputs based on variations in soil, nutrition, and crop stress [11] to support the four pillars of precision agriculture which are "to apply the right practice, at the right place, at the right time and with the right quantity" [7]. The key to the achievement of these objectives is the deployment of UAV in agriculture for real-time capture and flow of information in many areas of farming operations such as spraying and fertilizer application, seed planting and weed recognition, continuous pest and disease control (PDC), artificial pollination, irrigation assessment, mapping and crop forecasting [12].

Precision agriculture has continued to harness the capability of robotics in coping with business competition, negative ecological effect of agriculture, and to increase food production thereby becoming a boon for achieving target [13]. Multispectral and hyperspectral imaging sensors on UAVs help the farmers to manage the crops, soil, and irrigation and to fertilize more productively. The data collected from the imaging sensors are consolidated in image classification software which process the data into meaningful and useful information [14].

Not only is the use of aerial system necessary to ensure precision in agriculture for optimum utilization of inputs and efficacy, but it is also a times the only mechanized means to overcome obstacles limiting ground operations and access, such as terrain, soil compaction, swamp and to offer protection to man from the collateral effect of the application of harmful agrochemicals by the traditional method. Furthermore, unlike most conventional ground equipment, aircraft do not damage crops, and do not create wheel tracks in the farm [15]. However, piloted aircrafts which are used to carry out spraying and aerial imaging on large fields in short time are not relatively cheaper and readily available in all areas [16]. Hence it is noted that UAV is used for spraying under wet paddy field, tall sugarcane crop, pigeon pea, small farms and as scarecrows against bird invasion in rice paddies etc [13]. Further, most agricultural UAVs now cost less than US$10,000 [17]. More importantly, UAVs do not need specially prepared permanent or temporary airfields as do piloted aircrafts. Again, UAVs can obtain quality images at lower altitudes whereas satellites and aircrafts operate at high altitudes for imaging with higher complexities and cost. Similarly, UAVs unlike the satellites, can photograph from different angles and the images captured are more detailed [18]. With satellites, the resolution unit of images is in meters whereas UAV imaging has a higher resolution in centimetre-level [19]. UAVs are therefore considered to have high efficiency, low labour intensity, and low comprehensive cost [20]. Consequently, the Ag UAV terrain is now characterized by enhancements in various areas of farming such as soil and field analysis, seed planting, spraying, mapping, irrigation, and real-time livestock monitoring [21].

Despite the inimitable profile of UAVs in agriculture, its use in agriculture is not ubiquitous because according to [17] there still is no standardized operation procedure for its use in agriculture compared to other agricultural technologies as it is a relatively new area. Scepticism exists as per the effectiveness of the pictures taken because of the inability of UAVs to fly in diverse weather conditions like rain or high wind, which affects the quality of images. Another worrisome factor is the price of data elaboration which at times is higher than the UAV airframe [22]. Above all, the low spectral and radiometric resolutions obtained by low-cost compact cameras commonly used to meet the size, weight, and power (SWaP) limitations of UAVs do not render it amenable to in-depth analysis for radiometric and geometric calibration even with its higher spatial resolution. The spectral resolution is related to the wavelength detected by the sensor and the number of spectral ranges or bands. In attempt to achieve better results sensors are therefore embedded in cameras which make UAVs more expensive [23] relative to other farm machinery.

2.2 UAV Agrochemical Spraying in Precision Agriculture

Traditional applications of agrochemicals in developing countries on crops to control pests and weeds by knapsack spraying systems do not consider substantial variation in plant population, canopies and weed density [24]. Excessive application is therefore common resulting in health as well as environmental hazard. For example, Nigerian cowpea cannot access the international commodity market because of allegation of over application of inorganic substance to control the pest maruca vitrata from damaging crops in the field [25]. On the other hand, inadequate application limits crop yield. Utmost efficiency in the application of Plant Protection Products (PPP) in tandem with field conditions to avoid environmental pollution and save cost is therefore important. In view of this objective, real time monitoring of crop health through chlorophyll content-based vegetation indices using UAV is implemented in Variable Rate Technique (VRT).

Further, the use of hand pump by farmers to spray pesticides on crops takes too much time to spray and do not uniformly apply the pesticides. But by using UAV spraying, work is done in less amount of time when compared to using manual means [26]. It is also estimated that UAV spraying is five times faster than conventional tractor and machinery equipment [27]. Moreover, the conventional sprayers used by farmers have health impacts on the operators who are often advised by medical practitioners to take some diary product after spraying to mitigate the health threat. It is also noted that conventional land- spraying machines are not convenient for spraying in crops like rice, cotton, and sugarcane as well as orchards due to crop growth stages and poor efficiency. UAV will uniformly spray fertilizers and pesticides without damaging the crops while saving spraying time thereby minimizing drudgery in agriculture, increase efficacy, save resources and human life [27].

3.0 AGRICULTURAL UNMANNED AERIAL VEHICLES

3.1 Architecture

A UAV is made of light composite materials to reduce weight, increase position-changing capability and are therefore easy to transport [22]. They come in different forms and for different purposes due to significant efforts being made to increase their flight duration, the payload, and their tolerance to various weather conditions. The result is different UAV configurations with different sizes, duration of autonomy and attitude. Pedestrian classification of UAVs is by use such as photography, aerial mapping, surveillance, cinematography, agricultural etc. UAVs are categorised by type such as multi-rotor, fixed-wing, single rotor, and fixed wing multi rotor hybrid each with its own capabilities on altitude, control range, flight endurance and air speed [21].

In [28] UAV are classified by their drive as electric where electric batteries or solar where solar cells are the source of energy and internal combustion engines where they are driven by gasoline, kerosene or methanol-fuelled combustion engines. On commercially available bases Tsouros et al [7] classified UAV into five: Fixed wing, rotary wing, blimps, flapping wings and para-foil wings out of which they found only the first two applicable to agriculture. Other key criteria used to distinguish among aircrafts are the size and flight duration to obtain four categories: “High Altitude Long Endurance (HALE) UAV, Medium Altitude Long Endurance (MALE) UAV, Regular use UAVs and Small and portable UAVs” [22]. On their part and for agricultural purposes Vroegindeweij *et al* in [29] categorized UAVs into three as Fixed Wing, Vertical Take-Off, and Landing (VTOL) and Bird/Insect. For Kim *et al* [12] primary type of Ag UAV airframes is fixed wing which is typically larger and used for spraying over a large area and rotary- wing which are classified into helicopter and multi-rotor types.

Helicopter and Octocopters are used for spraying because of their larger payload capacities while the smaller quadcopters and hexacopters with smaller payload capacities are used essentially for reconnaissance and mapping [12]. According to Banjo and Ajayi in [21] there is also hybridization of airframes which resulted in higher flying altitude, wider control range, increased speed, and longer flights time. Some of the capabilities achieved by hybridization are at variance with the demands on Ag UAVs of low altitude, low speed while others agree with its applications demand of longer flight time and wider control range. For instance, pesticide spraying, and fertilizer application airframe needs to be of higher payload weight and able to support longer flight endurance [11].

It is noted in [7] that rotary-wing aircraft are preferred because they are easy to operate, of slower speeds, have ability to maneuver and relatively low cost. Though most take-off and landing phases of UAVs with fixed-wing platform are manual, except those with autopilot [23], it is preferred in cases where the monitoring area is relatively large to enable the monitoring of the entire area in a short time [30]. In contrasting by power source of Ag UAV, [13] observed that the electric power system has characteristics of flexible operation, rapid rising and landing with some 10-15 min flight duration. On the other hand, the diesel-powered UAV system required a longer take-off time and landing because of poor flexibility and large fuselage but enjoys a flight duration which could exceed 1 hour. The multirotor UAV mostly adopts the electric power system, with less loading than single-rotor UAV and tank volume which ranges from 5 to 10 l.

Further, in reviewing basic dynamic modelling of agricultural UAV Kim et al [12] chose two airframes common to agriculture – the fixed wing and the quadcopter and asserted that it is impossible for fixed wing to fly below a certain speed, climb vertically or descend and to hover while flying because it must maintain the lift force to remain in air. On the other hand, the quadcopter with these capabilities is equipped with four armed motors with two turning in clockwise and the other two in counter clockwise directions.

The configuration of a quad copter is divided into plus (+) model and cross (X) mode basically. In considering the air maneuverability of the two models resulting from their response to the pitch and roll controls, the cross model is found to be very popular in agriculture and more stable compared to the plus model [30]. In addition, the cross wings type does not obstruct camera view.

The deployment of UAV platforms for aerial spraying started in 1983 when the first remote controlled aerial spraying system (RCASS) was built, followed in 1990 by R50 helicopter with a payload limit of 20kg and laser system for height determination. However, the two were limited by issues of stability and controllability of flight and other operational hitches [13]. Today, typical Ag UAVs for spraying is equipped with modern on board and ground equipment. In [15], the equipment necessary for aerial spraying are outlined to be: Autopilot, which allows the performance of agricultural work in automatic mode assisted by the satellite navigation system GPS, special sprayer with rotary nozzles, equipment for scanning of the cultivated area and flat ground of about 150m x 15m with open approaches- though they can take off from crops during germination and from harvested crop. Further, UAV is equipped with a radio-controlled braking and taxiway systems for its exact movements on the ground and 4 flight control systems (barometric, GPS, ultrasonic and laser-guided), which guarantees high safety of flight and quality of the spray on the field.

Generally, the sprinkling system is attached to the lower region of the UAV which has a nozzle beneath the pesticide tank to sprinkle the pesticide downward. It is made of two modules- the sprinkling system itself and the controller. The sprinkling system contains the spraying content (pesticides or fertilizers) and a nozzle to produce atomized rain for spraying. The controller is used to activate the nozzle of the sprayer. A pressure pump pressurizes the pesticide to flow through the nozzle.

3.2 Deployment Strategies

Task allocation is a key factor in pesticides spraying process using unmanned aerial vehicles (UAVs) and maximizing the effects of pesticide spraying is the goal of optimizing UAV pesticide spraying. The leaf area index (LAI) is the proportion of leaf area to ground area and it changes from portion to portion [31]. Hence the need for initial imaging and mapping to determine the requirement for product mixes. Deployment of UAV for the application of agrochemicals therefore starts with crop monitoring using multispectral camera which is mounted in UAV. The camera takes pictures to analyses the geographic and agronomic indicators which enable the farmers to decide on the field to spray the pesticides. The UAV sprinkling system auto navigate with the GPS coordinates, to spray the pesticides on the infected areas where no crop is identified if herbicide or infected crop if insecticide, fungicide, or liquid fertilizer thereby reducing the wasting of water and chemicals [30].

With advances in sprayers' technology, UAVs deployment strategies have continued to improve to ensure efficacy and precision of spraying using Ag UAVs. Such advances are found in the configuration and methods of UAV employment for spraying operations.

3.2.1 Configurations

UAV can be deployed on a single, multiple or as a swam for agrochemical spraying. Recently, most agricultural UAVs are multi-copter type UAVs, while the fixed-wing type or helicopter type UAV that was used in the past is gradually disappearing [32]. The reason for the increase in multi-copter type UAV is that the structure is simple, the noise and vibration are small, and it is easy to move and store by folding the frame. It also has the advantage of not requiring a large space for take-off and landing. The multi-rotor airframe, however, has a problem of low payload and flight time. One of the ways to solve this problem is to use multiple UAVs.

Multi-UAV application consists of many UAVs for precision agriculture tasks [33]. In practice a large field is divided into subareas corresponding to the number of UAVs. Multiple UAVs working in a cooperative manner can then be used to provide powerful capabilities that a single UAV cannot offer [34]. Therefore, for larger and highly complex applications and tasks which are either beyond the capabilities of a single UAV or cannot be performed efficiently if only a single UAV is used, multiple UAVs can be used together in the form of a swarm or a fleet [35].

Further, in the light of limited UAV flight time and payload the multiple UAV deployment approach for agrochemical application has become strategic on large and multiple fields. The multiple UAV deployment strategy must however ensure that the control objectives of formation control, obstacle avoidance, movements and path following are satisfied [36].

Furthermore, Ju and Son [36] opined that instead of homogeneous robotics, collaboration, and cooperative control among heterogeneous agricultural field robots are required for the definitive automation and “robotization” of agriculture. A heterogeneous multi-robot system can overcome the limitations of existing homogeneous multi-robot systems because “the advantages of each robot type are utilized while its disadvantages are compensated” [37]. For example, if a UAV identifies and shares information about areas where fruits are moderately ripe while performing remote sensing in an orchard, a mobile UGV manipulator can harvest them faster and more accurately.

3.2.2 Spraying Method

In conventional farming, the most common method of weed management is blanket spraying of herbicides whereby the same type and concentration of herbicides is sprayed over the entire field of different types of weed and density and even on weed-free areas. Blanket spraying results to waste of scarce resources by the overuse of herbicides, the evolution of herbicide-resistant weeds that can affect the growth and yield of the crops, poses a heavy pollution threat to the environment and increases the cost of operation. To overcome the above problems, site-specific weed management (SSWM) which refers to the spatially Variable Rate Application (VRT) of herbicides rather than spraying them in the whole field is used [7]. To achieve this goal, it is necessary to generate an accurate weed cover map for precise spraying of herbicide.

UAV generated maps and images are 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 [38]. Biomass is the most common crop parameter, which together with information related to nitrogen content (photochemical reflectance index (PRI), water band index (WBI), and normalized pigment chlorophyll ratio index (NPCI)) are used to determine the need for additional fertilizer and the design of mitigation actions [13]. Also, Pest and Disease control (PDC) is site-specific in precision agriculture. First signs of the disease in plants appear in a change of chlorophyll, the green pigment involved in photosynthesis. With the help of infrared images, diseased plants are noticed in time to prevent crop damage. Normalized Difference Vegetation Index (NDVI) are used to identify areas of poor soil fertility and poor plant health [38]. UAVs are then used for targeted spraying as well as for accurately monitoring the progress of the intervention.

However, in adverse weather conditions the speed and direction of the wind hampers the effectiveness of pesticide spraying in a target crop field. In [39] the authors propose a methodology based on Particle Swarm Optimization (PSO) for the fine-tuning of control rules during the spraying of pesticides in crop fields. This methodology achieved good results by taking account of the weather conditions reported by a Wireless Sensor Network (WSN).

3.3 Control Strategies

Controls provide countermeasure against the exigencies of flight environment such as wind, storm, obstacles and to achieve the flight mission. For each aircraft, whether fixed or rotary wing, there will be compatible software or application to plan and execute missions, such as eMotion 2 for eBee, the Mission Planner for X8 and the application DJI-Phantom for Phantom 2 [23]. However, the off-the-shelf systems are site and environment specific without the ability for all purpose and all-encompassing view of farming systems [16]. Hence some items must be evaluated before the flight: area, potential hazards from and for flight, flight planning, preparation, and configuration of equipment, checking equipment and realization of flight and data collection [40].

The UAV is controlled by the radio channel (RC) transmitter and receiver [41]. In its most modern form and general use in spraying a computer with GPS and digital map of the farm controls the operation of the spray gun while the flight of the UAV is programmed in congruence with the area to be covered [11].

Control strategies is reviewed under the type of control, control hardware and algorithms so as to effectively cover the three layers of the UAV system: “the spatial foundation system, the ground infrastructure system and the remote sensing data storage system” [42]

3.3.1 Types of control

Control type could be either manual, semi-autonomous or autonomous. In manual control computer, GPS and digital map of the farm are used to control the UAV spraying operation by the operator [11]. Most Ag UAVs operations are done through this manual remote control thereby rendering the outcome susceptible to the skill of the operator [20].

The semi-autonomous and autonomous are of variable rate application (VRA) methods. The first case is map based whereby the operation requires the creation of a prescription map as well as GPS to enable the UAV to configure appropriately the requirement for each area. In that case the pilot controls the operation through remote teleoperation. The second case is autonomous and hence does not require map nor GPS rather the sensor system determines the need of each area or sub area and distributes the input proportionally in real-time [33]. Fully autonomous system is responsible for all the operations.

3.3.2 Control Hardwares

The UAV control hardware platform includes Pixhawk, Ardupilot, Naza and Multiwii and the computing platforms Arduino, Raspberry Pi, Orange Pi, Odroid, Nvidia Jetson etc. [12] The control system process information from sensors on the flight environment and communicate same to the ground control station (GCS) [7]. For instance, the Pixhawk 2.4.8 flight controller can control fixed-wing aircraft, multi-rotor helicopters, as well as traditional helicopters with, two-way telemetry, supporting 8 RC channels with 4 serial ports [43].

Sensors are cameras of one form or the other embedded in the aerial system to collect the information needed. The sensors send the data to the flight controller which runs an algorithm for processing of the image data of scanned surrounding for onward transmission to the ground control station (GCS).

Communication systems such as MAVLINK facilitate communication with the UAV computing or control platform. It transmits the directions, position of the global navigation satellite system (GNSS), and speeds of the UAV to the ground control station (GCS) applications such as Mission Planner and Qgroundcontrol [12]. Other physical communication system that exist are ZigBee and radio-frequency modules transmitters.

Others control hardware includes GPS, machine vision payload, ground control station, current sensors, air speed sensors, LiDAR instruments etc. Possible types of hardware components and peripherals used in UAVs are shown in Table 2 below.

Table 2. Hardware components and peripherals (courtesy of [30]).

Components	For
Accelerometer	Acceleration
Gyroscope	Rotational motion
Magnetometer	Magnetic field
Wireless sensor network (WSN)	Sensing environmental conditions
Inertia measurement unit (IMU)	Angular rate and forces
Global positioning system (GPS)	Geo location of an object
Camera	Visual images
Multispectral Camera	Images at specific frequencies
Hyper spectral camera	Images at narrow spectral bands
Thermal Camera	Low light imaginary
Video Camera	Electronic motion of objects
Laser scanner 2D	Captures shape of the object
Telemetry	Live data from UAV
Altimeter	Altitude
Air Pressure Sensor	Gases or liquids pressure
Brushless DC BLDC	Motion control
Electronic speed control ESC	Regulates the speed of BLDC
Microsoft Kinect	Motion sensing

Components	For
Barometer	Atmospheric pressures
Solar	Energy source
PWM controller	Pulsing signal
Digital Temperature	Temperature detectors
Humidity indicator	Moisture in air
Water sensitive paper	Assessing spray coverage
Filter papers	Separate fine substances
Anemometer	Speed of wind

3.4 Control Algorithms

The Proportional Integral Derivative (PID) with Linear Quadratic (LQR) and LQR plus are controlling algorithms designed to improve the automatic flight missions [44]. Commercial software includes APM Mission Planner V to plan and control the UAV flight, Agisoft® Photoscan to produce orthophoto and QGIS 2.0 to do spatial analysis [45]. OPTIC is a ground station software which receive data from wireless sensor network (WSN) by deploying four algorithms: genetic algorithm (GA), simulated annealing (SA), hill climbing with next ascent (NAHC) and particle swam optimization (PSO) to determine appropriate action [33].

UAV control algorithm are categorized as linear, non-linear, and learning by Kim et al in [12]. They observed that linear and non-linear control systems are based on linear quadratic (LQ) models while learning based controls are based on a type of fuzzy logic that learns using data obtained from flight and do not require dynamic models. In this class is the reinforcement learning whereby the UAV selects the actions based on its past experiences (exploitation) and by new choices (exploration). Example is the Autonomous Mental Development (AMD) algorithm [46,47] that simulate the mental development process of human being. In this case deep learning using convolutional neural network (CNN) algorithm comes into play [48]. Another of such learning techniques is artificial neural network (ANN) a processing algorithm or a hardware whose functioning is inspired by the design and functioning of a human brain too.

Whereas linear and non- linear models are commonly used in agricultural mapping because it provides robust and steady state tracking, uncertainty remains about the stability and robustness of the learning-based approach though experimentally validated [49]. In [50] ANNs and support vector machines (SVMs) are jettison by the authors because all the models developed based on these techniques are limited to site-specific applications where they are trained, and their parameters are tuned. They therefore implemented genetic programming (GP); a machine learning method inspired by the genetic algorithm (GA) to estimate soil moisture at different soil levels. In contrast to ANN and SVM output, which is a trained network, the output of GP is a trained equation that researchers can simply use.

Swam control is a technology that controls multiple UAVs using one operator or program while task allocation is the subdivision of tasks and paths involving the mapping of the field. Its configuration can be centralized, decentralized, or distributed [39]. The technique of UAV swam control is evolving using linear and nonlinear controls based on K-means algorithm (K-means clustering) to prevent collisions and another to map allocated areas [6]. Hence UAVs on commercial activities are launched in hundreds or even thousands in the sky simultaneously and synchronize in a swarm [51] without ado.

In [39] the authors proposed an evolutionary algorithm to fine-tune sets of control rules, to be employed in a simulated autonomous UAV. The proposed architecture employs an UAV, which has a spray system coupled to it that communicates with a wireless sensor network (WSN), which send feedback on the weather conditions and how spraying is falling in the target crop field. Based on the information received, the UAV appropriately applies a policy to correct its route.

3.5 Obstacle Detection and Avoidance

As UAV operates in D-cube (Dangerous-Dirty-Dull) situations [40] it is necessary to evaluate the area and observe some safety factors for the aircraft operation, for the operator and for the people involved around the operation before performing any flight. These include weather conditions; wind speed; presence of objects, poles, trees, electric transmission towers; appropriate flight locations (away from airports and areas with high population density), landing and take-off places; ground conditions and other limiting factors related to the specific laws of each country that should be observed [47].

In [52] Wang *et al*, proposed a classification of farm obstacles that are replete in Ag UAV operating environment based on size and distance. They came up with four classes based on size (micro, small and medium, large, and non-fixed) and three based on distance (short-range, middle, and long-range obstacles). Following which they zone the UAV flight environment into execution, warning, and safe zones. They then asserted that what exist in most farm flight environment are mostly micro-sized and non-characteristic obstacles. Different OA actions include optimize OA paths, response time, adjustment of flying speed, height and altitude, re-planning of flight path after obstacle avoidance etc.

A typical Nigeria farm holding is characterised by small size, fragmentation, multiple farmlands, undulating, fallow, beast, human and meandering boundary. The flying environment is replete with forested areas, tall trees, electric poles and wire, farm structures, birds and some reflecting objects, wireless networks including hot and stormy weather. Moreover, Ag UAV are usually about 1m to 1.5m above the ground when in operation on a farmland and therefore faced with some ground operation obstructions such as small trees in the middle of the farm, stacking poles, robes, molehills, undulation terrain, out-growths etc. In addition, the spraying farm environment often has flying dust and flying liquid that smudge it and rule out the use of visual obstacle avoidance systems. The need for an autonomous system to manage these complex and constantly changing aerial farm environments are therefore important. The obstacle avoidance methods of many Ag UAV systems after detecting obstacle include on-site suspension, planned travel route and autonomous obstacle avoidance. Leonetang, in [53] however, noted that autonomous actions that requires the UAV to evade the algorithm and to regenerate the route is at the expense of the battery life which may no longer have the capacity to tackle further obstacle on regeneration of the route

The survival of flying air vehicles therefore depends on precise sensors' feedback [54]. Hence Wang et al in [52] expound that an agricultural unmanned vehicle obstacle avoidance (Ag UAV OA) system is the core intelligent unit which enables a UAV to autonomously identify obstacles and effect the specified avoidance action. It is an inbuilt capacity for sensing and avoidance (S&A) of threat [49]. To these end, radar, laser, and ultrasonic ranging as well as monocular and binocular vision are deployed as tools for sensing or detecting obstacles. Further, in sensing depth especially of frontal obstacles, studies have been on mimicking biological systems such as motion parallax, monocular cues and stereo vision [55].

Sensor fusion which is a process by which data from multi-sensor UAV are brought together for computations is used in a multispectral remote imaging in precision agriculture to capture both visible and invisible images of obstacles, crops, and vegetation. [56]. Sensor integration allows the combination of data derived from two or more devices with the aim of reducing the uncertainty of the observations obtained separately from each source [57].

Initially there were two main sense and avoid (S&A) technologies- Radar that sends out radio waves and measures their reflections from obstacles and Light Detection and Ranging LiDAR optical sensor that uses laser beams instead of radio waves to provide detailed images of nearby features [58]. Today many variants of controls and obstacle detection and avoidance devices adorn the UAV shelves and aircraft market that virtually solve the initial problems of bulky, heavy, low energy efficiency and high cost of the earlier version of sensors. This includes Real-time kinematic (RTK) sensors, Ultrasonic sensors, Laser sensors, Infrared sensing technology, Structured light, Time of flight (TOF) ranging, Millimetre-wavelength radar, Monocular visual ranging, and Binocular stereo vision [52]

The sensors are further supported by various algorithms to achieve real time perception of obstacles, rapid analysis, and actionable interpretation of images. The OA algorithms are divided into three approaches [47] to include a geometric relationship, real time planning and decision making. In [59], an online, collision-free path generation and navigation system for swarms of UAVs was proposed. The proposed system used geographical locations of the UAVs and successfully detected static and dynamically appearing moving obstacles to predict and avoid various types of collisions. Further, the simultaneous localization and mapping (SLAM) technology which maps in real time, recognizing own position and identifies obstacles while autonomously traveling or performing tasks is awesome sauce [12].

Notwithstanding, Corrigan in his paper [49] observed that the challenge of these technologies is accuracy as measurements must constantly be taken as the UAV moves through its space and assimilated to update the models and account for the noise introduced by both the movement of the device and the inaccuracy of the measurement method. This task is achieved by using measured values to update the model state variables. Kalman Filter is deployed in estimating the states of the systems from the sensor data as well as the variables that are not directly observable so as to minimize the noise [60].

The obstacle avoidance methods of many Ag UAV systems after detecting obstacle include on-site suspension, planned travel route and autonomous obstacle avoidance. Leonetang, in [53] however, noted that autonomous actions that requires the UAV to evade the algorithm and to regenerate the route is at the expense of the battery life which may no longer have the capacity to tackle further obstacle on regeneration of the route

4.0 DEVELOPMENT/STUDIES ON THE USE OF AGRICULTURAL UNMANNED AERIAL VEHICLES FOR AGROCHEMICALS APPLICATION

In recent times advances have continued to be made in Ag UAV pest control operations with various biosensors that monitor plant growth and detect plant diseases including the replacement of manual weeding by the laser weeding technology, where a mobile focused infra-red light disrupts the cells of the weeds [31] and the discrimination of Cynodondactylon in cover crops that enabled targeted control to be applied on the parasitic Cynodondactylon growing in vine yard cover crops with an UAV [22].

In [61], an experiment was conducted to investigate the sprayer performance of a commercial UAV, equipped with different types of nozzles, and compare with the sprayers usually used on small size mountain vineyards (i.e., a knapsack sprayer and a sprayer gun) which showed that the working capacity of the UAV was 2-fold that of the sprayer gun and 1.6-fold that of the knapsack sprayer. Droplet coverage, density and size were however variable and affected by the position of the targets (water sensitive papers) and the type of sprayer used. Uneven crop coverage, overlapping of application and lower application at outer edge of field had been experienced with aerial UAV spraying. Hence in [62] the study on nozzle selection suggests that selecting a nozzle with a small atomizing particle size for UAV could improve the control effect of plant hoppers. Meanwhile, a swarm of UAVs [63] were also tried in a control loop of algorithm in order to eradicate the operational limitations of pesticides spraying with unmanned aerial vehicles. On their part, Berner and Chojnacki [28], observed that the efficacy of the spaying is subject to the behaviour of the UAV airframe in terms of the speed, flight altitude and other factors such as weather, type of pesticide, temperature, and terrain. The droplet drift and deposition of pesticides on plants with the use of UAV is the combined effect of the jet of liquid being sprayed and the stream of air generated by the rotors. Because the rush of air from the rotor changes due to the changing load of the UAV as it discharges the spraying mix content of the tank there is a difference in the concentration of droplets in the air stream between the start, along and end of spraying operation. Hence the quality of UAV spraying may not meet that of manned aerial and ground systems [11].

However, in [64] the author provided a water level sensor to monitor the status of the tank so that if the pesticide level reaches below the threshold, say 25ml the operator is notified by sending a buzzer control signal to the controller who on receiving the signal will land the quadcopter for refilling thereby maintaining minimum fly weight differential that may affect the efficacy of spraying between the start and the end of the field.

In [15] Genadiy Y, et al observed that Efficiency of aerial spraying directly depends on the design features of the aircraft. The lift in helicopter is created by dropping vertically down a large mass of air which undoubtedly increases the wing bearing capacity. The downwash flow improves the evenness of the chemical distribution on the surface of the target so treated. Its covers both sides with the pesticides, which is especially important in the treatment of gardens and vineyards where pests of fruit crops usually nest on the underside of the leaf.

Some agricultural spraying unmanned helicopters now have plant protection parameters as shown in Table 1 [43]

Table 2: Plant Protection Parameter (QF170-18L Agri-Spraying Helicopter)

Items	Index
Length of spraying rod	140m
Spraying height (above crop)	1-3m
Nozzle number	6pcs
Spraying flow rate	3.0-4.4litre/min
Agrochemical tank volume	18.0 Litre
Spraying time per flight	4-9min
Spraying width	6-8m
Covering area of one flight	1.0-1.2 hectare

Areas of ongoing and further development include sensors for harvesting, extending mapping beyond topology to learning and recognition to achieve real time monitoring. Dispersion of UAV technology to small farms in developing countries is necessary for enhanced precision and efficiency in small holder farms that account for over 70 percent of world food and fibre production. The problem of spray drift is managed by proper selection of suitable medium to coarse nozzles while spraying at optimum height of 2 to 3 meter above the crop. Vortex generation studies are also ongoing.

5.0 CHALLENGES/LIMITATIONS OF UAVS' ADOPTION FOR AGROCHEMICALS SPRAYING.

The following empirical studies lay credence to the controversy surrounding the profitability of precision agriculture as a boon to farming industry beyond it environmental benefits:

A report on Economic and Environmental Benefits / Risks of Precision Agriculture and Mosaic Farming by Brennan et al [65] explored the profitability of spatially variable nitrogen fertiliser management for a grains-based farm, near Moree, in the north-east Australian wheat belt to show that in some years there was substantial economic returns and in others the cost of the investment in the PA technology outweighed the benefit, even with perfect information. They, therefore, suggest that any proposed application of PA technology to spatially variable input management should start with a thorough investigation into the nature of the biophysical response surface. They opined that in an environment where the consequences of climate-driven temporal variability exceed those of spatial variability, there is little value in applying spatially variable rates unless seasonal adjustments are also made. This assertion is confirmed by the work of Knight and Malcolm [66] who used a farm in the Victorian Mallee over the period 1998 – 2005 to analyse whole-farm profitability and risks of investing in Precision Agriculture and Site-Specific Crop Management System. The case study farm comprised 1400 hectares, with 900 hectares of cereals cropped each year. The investment in Zone Management technologies did not meet the required return on capitals. A comparison using certain and uncertain seasonal knowledge assumptions indicated that seasonal variation has a much bigger impact on gross margins than spatial variation. They therefore concluded that Investment in GPS guidance technology can be a worthwhile investment, provided the benefits per hectare are adequate and the capital cost is spread over sufficient hectares.

In their article on the Economics of a Precision Agricultural Sprayer System, Batte and Ehsani [67] provided preliminary estimates of the magnitude of private benefits for a precision guidance system combined with auto-boom control for agricultural sprayers (precision spraying) system. The result shows that even when considering only private benefits of input savings, the value derived from a precision spraying system can be substantial. These benefits increase proportional to the cost of the spray material being applied and with the number of annual applications and the driver error rate for the non-precision system. Further, because most of the costs of the precision spraying system relate to the fixed investment, these costs diminish per acre as farm size increases. Hence, the precision spraying system will make most sense economically for larger farms who make several applications annually of relatively expensive spray materials.

In another study Richards et al [68] analyzed alternative spatial nitrogen application in economic terms and compared it to the costs of precision farming hardware, software, and other services for cereal crops in the UK. They found that at current prices the benefits of variable rate application of nitrogen exceed the returns from a uniform application depending upon the system chosen for an area of 250 ha. The benefits outweighed the associated costs for cereal farms in excess of 80 ha for the lowest price system to 200 – 300 ha for the more sophisticated systems. They further observed that the scale of benefits obtained depends upon the magnitude of the response to the treatment and the proportion of the field that will respond. In their work, “Sequential Adoption and Cost Savings from Precision Agriculture” Schimmelpfenning and Ebel [69] posited that precision agricultural (PA) technologies can decrease input costs by providing farmers with more detailed information and application control. They asserted that VRT contributes additional production cost savings when added to soil mapping, but not when done with yield mapping alone.

In an attempt to contribute to a better understanding of the impact of precision agriculture through the use of unmanned aerial vehicles (UAV)/remotely piloted aircraft systems (RPAS) and normalized difference vegetation index (NDVI) techniques using small Mediterranean farms as a case study, Loures *et al*, [70], considered three parameters (seeding failure, differentiated irrigation and differentiated fertilization) to determine not only the ecological benefits of these methods, but also their economic and productivity aspects. The results obtained based on these methods, proved that an efficient combination of UAV/RPAS and NDVI techniques allows for important economic savings in productivity factors, that promotes sustainable agriculture both in ecological and economic terms. Additionally, they argued, that contrary to what is generally defended, even in small farms, as the ones assessed in this study (less than 50ha), the costs associated with the application of the aforementioned precision agriculture processes are largely surpassed by the economic gains achieved with their application, in addition to the environmental benefits introduced by the reduction of crucial production inputs as water and fertilizers.

Maikaensam and Chanthharat [71] carried out a field survey and analysis to illustrate the effectiveness of UAV use for rice production in Central Thailand. The results revealed that the use of UAV has a greater effectiveness compared to conventional methods. Application of a UAV reduced the loss of production by 10-15%, water volume for chemical mixing by 10 times, and the use of chemicals by 40%. According to the fine size of the droplets, it can spray chemicals effectively, which prevented insects by up to 90%, and can spray equally across the field thereby enhancing the quality of rice that results to increase its selling price.

Applied to Nigerian situation in which farm holding is characterised by small size, fragmentation, multiple farmland: with more than 70 percent farm size less than 1ha the economy of scale, prerequisite for viable PA is lost. However, when contiguous fields with the same crop are considered, it is possible to obtain fields of over 15 ha extent in which similar crop management are followed as found in rice fields in Ebonyi and Abia States and other Northern States of the country. Such fields can be considered for the purpose of initiating the implementation of precision farming. Similar implementation can also be carried out on the state and cooperative farms including corporate large farm holdings such Dangote, Bua, Michelin Plantations, Presco Oil palm plantations etc. There are opportunities for implementing precision agriculture for crops like, rice, beans, oil palm, rubber, cocoa grains etc. The only limiting factor is that assessing the spatial variability within farms fields is new to most agriculturalists. Education and training programs in SSM are grossly lacking and will need to be developed in both the public and private sector [72]. The Nigeria-Brazil led bilateral agricultural development program under the “The Green Imperative” programme of the Federal Government of Nigeria with funding base of US $1.2 billion from the Development Bank of Brazil (BNDES) offers great opportunity for the proposed agricultural drone study academy project in Nigeria [73]. A typical example of such academy is the University of Philippines Los Banos which uses free satellite images from NASA and European Union to monitor farming areas, to determine crop status and crop health as well as estimate actual damage by natural disasters. The academy also produces a high resolution map that shows the extent of flooding across major rivers in the country using aircrafts equipped with LiDAR to scan and reflect the earth surface and its features to a sensor. The twin objectives of the academy are to convince more young people to venture into farming and environmental protection and to build more mature technologies for the future- the robots of tomorrow; to secure production and preserve natural resources [74].

The merit of the available Ag UAV technologies has been highlighted to include low cost, low elevation operation with staring and hover ability, light weight, ground station full control, efficient communication, operational ease, and low labour intensity [20]. These attributes enable Ag UAVs to find application in various agricultural operations such as mapping, spraying, crop monitoring, irrigation, planting, pest and disease control, artificial pollination, and livestock production systems [21].

Gaps to bridge are found in the areas of:

i. Airframe technology- cost, payload, and fight endurance,
ii. In sensors- direct imaging sensors of less cost, size and weight,
iii. In reliability- mechanical, electronics and interference,
iv. In commercial off the shelf (COTS) and low-cost sensors in geomatics for rapid remediation,
v. In operation- autonomous take-off and landing, automated computation of flight paths, integrated spray and remote sensing algorithm to achieve intelligent operation of spraying and
vi. In power- longer life, hybrid and light weight energy source.

Currently the battery and flight time limitation are being managed using lithium-ion batteries with capacity larger than the conventional type which proportionately increases the weight problem. Improving battery maintenance management and developing optimized hybrid power cells are recommended [12]. Swarm deployment using multiple UAVs, to share operation time, is another approach to limited flight time management. Improved ergonomics and user-friendly interface at the level of ground control station (GCS) is also needed to fast track diffusion of UAV techniques beyond the UAV experts to permeate the substrata of the farming communities that need it for performing daily farm tasks.

Whereas there are UAV legal framework stipulating rules and regulation on legal weight, speed, maximum altitude, age and certification of pilot, there is no Standard Operating Procedure (SOP) document on the use of agricultural UAV. Currently, South Africa leads in Sub Sahara Africa as the first country to implement and enforce a comprehensive set of legally binding rules governing UAVs in July 2015. A total of 15 countries have published dedicated UAV regulations by 2016. Nigeria is one of the countries with legally binding rules on use of UAVs [75]

6.0 CONCLUSIONS

The review shows that spray systems have been successfully developed for UAV application platform and that the integration of the spray system with the UAV results in an autonomous variable rate application of agrochemicals that can be used for pest management and control. In general, Ag UAVs are equipped with cameras and sensors for crop monitoring, flight control, obstacle avoidance and sprayers for the most efficient economic, social and environmentally sustainable application of plant products and protection materials towards profitable and drudgery free farming.

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