Research Journal of Agriculture and Forestry Sciences ISSN 2320– 6063
Vol. 13(4), 17-29, October (2025) Res. J. Agriculture and Forestry Sci.

Review paper

Applications of drone technology in the agricultural industry worldwide and in Africa: bibliographic review

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Available online at: www.isca.in, www.isca.me
Received 10th July 2025, revised 13th September 2025, accepted 1st October 2025

Abstract

With technological and technical developments, research on drones is intensifying more, and practical applications in many fields of human activity, especially in agriculture, have become more extensive. Currently, drone technology has matured, and drones are creating a new industrial revolution. It is estimated that the financial gains from the use of drones or UAVs (Unmanned Aerial Vehicles) in the agricultural sector will reach billions of dollars in the coming years. But the African continent is struggling to integrate into this process to take its share of this economic windfall that is developing. As farmers in the Global South struggle to adapt to climate change and other challenges, drones are expected to help all agricultural businesses and improve their efficiency and productivity. The objective of this work is to present the technology of drones on architectural, structural and conceptual level applied to sustainable and efficient agriculture and to emphasize the advantages of their uses in Africa and Benin. Also, operating principles coupled with a functional study of the technology of these unmanned vehicles are developed. Different applications of UAVs in the agricultural industry and their limitations are exposed. This work is part of a view to designing, sizing and producing drones for agricultural use within the limits of aviation safety and security regulations in Benin.

Keywords: Drone, UAVs, sustainable agriculture, functional study, food security.

Introduction

Drones are used in a wide range of civilian applications such as search and rescue, surveillance, firefighting, weather monitoring, surveying, electrical infrastructure monitoring, and urban planning and management. The increasingly productive and efficient agricultural world is integrating UAVs into all sectors of activity. This use has a significant impact on yield and good agricultural practices around the world. The use of drones in the agricultural sector offers great potential to address several major challenges: productivity, profitability, time saving, good agricultural practice while preserving the soil. Over the past five years, the total volume of investment in the agricultural sector has increased by 80%. The objective of these investments is to achieve productivity growth of at least 70% by 2050[1]. To meet the increased needs of Earth's population in view of the fact that cultivated area will decrease. The main applications of the drone in agriculture are irrigation, crop monitoring and protection, soil and field analysis, and animal control.

The issue of designing and building a drone dedicated to agriculture has evolved rapidly in recent years, given the demand and environmental sustainability concerns expected from agriculture. But unfortunately, at present, agricultural fields in Africa and Benin are facing problems not only of high-tech deficit in the production chain, but also with the shortage of labor due to climate change and losses of agricultural products due to pests and rural exodus. And negatively influence the requirements of precision in agriculture technologies. The new revolution in the fields of electronics and mechanics is introducing unmanned aerial vehicles (UAVs).

Drone technology combines the implementation of various mechatronic components such as flight controller (FC), brushless motors (BLDC), electronic speed control (ESC), global positioning system (GPS), telemetry radio link, and radio-controlled transceivers. It is controlled using a MAV link protocol which is an open-source point-to-point networking protocol that carries telemetry. Communication between the multi-rotor and the ground control station (GCS) is done using the MAV Link networking protocol. The drone can be controlled remotely by sending and receiving data via the MAV link protocol to the drone's control modules: the flight controller's autopilot and the APM Planner app. With the availability of the new technologies mentioned above, it is possible to observe water stress management of fields, crop management, crop harvesting and crop protection.

The objective of this work is to present the technology of drones on the architectural, structural and conceptual level applied to sustainable and efficient agriculture and to emphasize the advantages of their uses in Africa and BENIN. In addition, the operating principles coupled with a functional study of the technology of these unmanned vehicles are developed. Different applications of UAVs in the agricultural industry and their limitations are exposed.

This document also highlights drone technology and presents the various applications in the agricultural sector of drones available on the market for monitoring, observation, planting in order to achieve better crop quality and prevent soil degradation and various damages.

Methodology

Methodological approach: In this section, we use the systematic literature review (SLR) protocol which consists of defining the scope of study, collecting data, synthesizing and analyzing the results of the studies in this case in the field of drones in agriculture. We define keywords, understand the scope of the research, search in databases, select primary studies and carry out quality assessment, data extraction and synthesis. These search engines, Google, Google scholar, Science Direct, and Springer Link are prioritized among many others. These sources provide important information on the evolution of drone technology, their countless applications while clearly identifying their limits.

Documents identification resulted in approximately 100 research articles, scientific reports, and projects. We applied exclusion criteria to filter out relevant studies. These criteria are: 1-The abstract or title does not address drones. 2-The documents do not deal with drones, or are not mentioned in relation to the context of our study. 3- The document does not address the challenges related to the use of drones. 4- Duplicates that have already undergone the exclusion process. 5- Short and less illustrated versions of documents are excluded, and more detailed versions are considered.

Details of the SLR method: the six basic steps: The need for a research protocol for systematic literature review is to consider transparency, transferability, and workability, which are the characteristics that make a literature review systematic[2]. This helps minimize bias by conducting comprehensive literature searches. During this stage, the difficult question is to determine the scope of the research. Once the search field has been determined, it is helpful to formulate research questions and research boundaries to identify the appropriate research method[3]. The refined objectives of systematic literature review on the applications of drone technology in the agricultural industry are presented in the form of research questions as outlined below. Therefore, the refined research questions were the followings:
i. What is the state of the art of drone technology? ii. What types of drone applications in the agricultural industry have been highly successful and less studied? iii. What design approaches are common for evaluating drone technology? iv. What are the various recent areas of development of drone technology around the world? v. What are the current challenges that hinder the study and development of drones in Africa and Benin? Vi. What are the lessons learned and the way forward for a better adaptation of these technologies in Africa and Benin?

These are the research questions that the study will answer by following the structure of introduction - development - conclusion.

Types of drones and their classifications: Concept: Currently, when we talk about drones and their implementation, it is more essential to talk about a drone system. Because the drone is part of a system that is composed of one or more aerial vectors, one or more ground control stations as well as data links between the vector and the ground part. There can be land, sea, submarine and air drones. The definition encompasses many autonomous systems. If we restrict ourselves to aerial drones, we can classify them into different categories according to their wingspan, which are now very varied: from a few centimeters to several meters. Their shapes too, as well as their types of propulsion: some are equipped with jet engines, others with propellers, others use rotors, such as helicopter drones for example.

Classifications: The classification of drones is a very perilous exercise, insofar as it is different, depending on the country. However, aerial drones can be classified according to three criteria: cruising altitude, endurance in terms of flight time and their main dimension. In this context, the operational domain of drones can be broken down into three groups: i. tactical drones. ii. medium-altitude and long-endurance drones (MALE) allowing the use of a payload of around 100 kg. iii. high-altitude and long-endurance drones (HALE).

The tactical segment is itself broken down into six sub-groups: i. Micro Air Vehicle or MAV, which can be contained within a 30 cm sphere; ii. Mini Air Vehicle or MAV, which can be contained within a 70 cm sphere; iii. Very short-range drones (TCP); iv. Slow medium-range drones (multi-load multi-mission or slow MCMM); v. Fast low-altitude drones (fast MCMM); vi. Tactical maritime drones (TMD).

It may come as a surprise to distinguish micro-drones and mini drones into two segments, but the difference in scale between the two still imposes strong constraints on the choice of sensor materials and embedded systems. As a result, these two families are strongly differentiated by flight autonomy and the quality of the controls, however the miniaturization of electronic boards combined with the increase in the computing capacities of the mini-on-board systems tend to reduce these differences[4]. All of this is summarized in the Table-1.

This classification was made considering morphology.
Fixed Wing: These are unmanned aircraft with wings that require a runway to take off from the ground or a catapult. This type of UAV has high endurance as well as the ability to operate at high speeds. In addition, fixed-wing drones have the ability to

cover large areas on each flight and can carry more payload. However, they are more expensive than other types.

Table-1: Classification of drones[5].

Category	Acronym	Maximum take-off weight (kg)	Maximum Flight Altitude (km)	Endurance (h)	Example
Micro/ Mini Drones	MAV	0.10	0.25	1	Microbat
	Mini	<30	0.15 - 0.3	< 2	Alidin
Tactics Drones	CR (Close Range)	150	3	2 - 4	R-Max
	SR (Short Range)	200	3	3 -6	Phantom
	MR (Medium Range	150-500	3 - 5	6 - 10	Hunter B
	LR (Long Range	-	5	6 -13	Vigilente 502
	EN (Edurence)	500-1500	5 - 8	12 - 24	Aerosonde
	MALE	1000-1500	5 - 8	24 -48	Predator-IT
Strategic Drones	HALE	2500-12500	15 - 20	24 -48	Global Hawk
Specialized Drones	LET (Lethal)	250	3 - 4	3 - 4	Harpy
	DEC (Decoy)	250	0.05 - 5	<4	Nulka
	STRATO	-	20 - 30	>48	Pegasus
	EXO	-	>30	-	MarsFlyer

Rotary Wing: Rotary wing drones, also known as rotorcraft or vertical take-off and landing (VTOL), offer the benefits of regular flight in one location while maintaining the maneuverability attribute. These features are useful for many types of missions. However, they cannot fly at very high speeds or stay in the air for a long time. They are generally the most used drones in all kinds of applications, but especially in precision agriculture. A drone of this type can be:

Single rotor: These include main and tail rotors such as conventional helicopters.

Multirotor: This category includes rotary-wing drones with four or more rotors (quadcopter, hexacopter, octocopter. These aircraft are generally more stable in flight than unmanned helicopters.

Airships: This type of UAV is lighter than air, has high endurance, flies at low speeds, and is usually larger than other types. Their manufacturing characteristics allow them to stay in the air even in the event of a total loss of power, while being considered relatively safe in the event of a collision. Usually, they are not used in precision agriculture applications. No applications were found in the recent documents reviewed using this type of drone.

Flapping Wing: These drones are designed in small with flexible wings and that mimic the way birds and insects fly. They are not often used in agriculture, as they have a high energy consumption due to their size.

Architecture of a drone for agriculture: As discussed, the basic architecture of a drone, without considering payload sensors, consists of: (i) chassis, (ii) brushless motors, (iii) electronic speed control (ESC) modules, (iv) a control panel, (v) an inertial navigation system (INS), (vi) propellers, and (vii) a transmitter and receiver[6]. These different elements are illustrated in Figure-1[7].

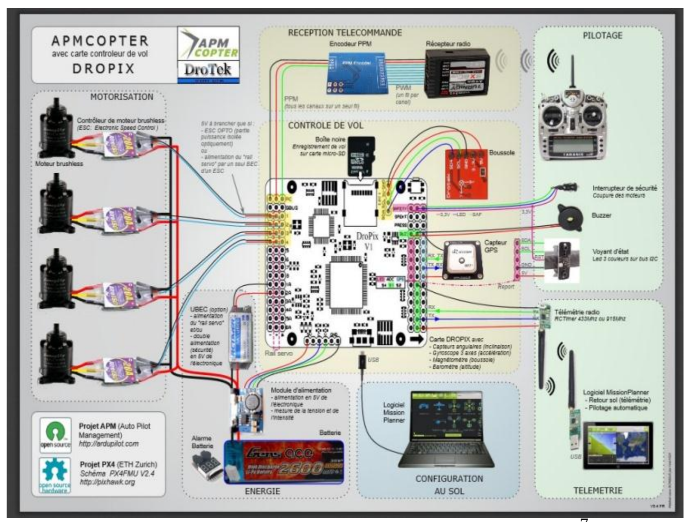

Figure-1: Conceptual architecture of a drone[7].

Prior to what follows, we present in Figure-2, the conventions of the rotational axes that will be used for all types of drones.

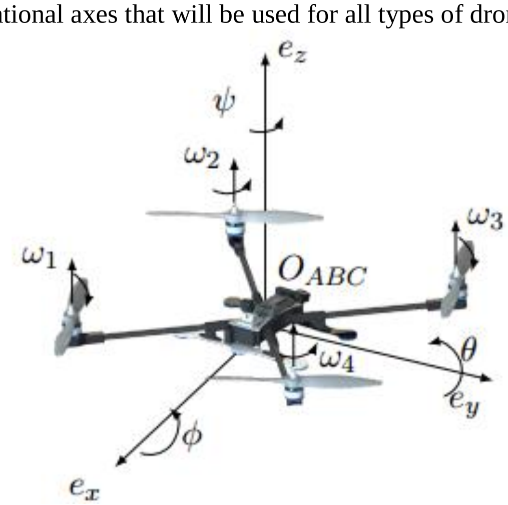

Figure-2: Axis of rotation convention[8].

The angle θ - indicates pitch, ф- roll and ψ- yaw. Each motor returns an angular velocity ω on each blade. Drones use fixed-height blades. See Figure 3 below.

Figure-3: Fixed height propeller[9].

The performance of the blades depends mainly on the thrust force (T) and torque (M), which are a function of the angular velocities of the propellers, among other things.

$$T = \rho C_T \left(\frac{N}{60}\right)^2 D_p^4 M = \rho C_M \left(\frac{N}{60}\right)^2 D_p^5$$ [10]

Where : $N[rpm]$is the rotational speed of the propeller, $D_p[m]$ the diameter of the propeller, $\rho[kg/m^3]$ air density, CT the drag coefficient which depends on the wings characteristic and CM, the lift coefficient which depends on the characteristic of the wing. The characteristics of the wing are its shape, thickness and wing. Drones used in agriculture can be classified according to their design feature.

Working principle: With mobile wing: In general, fixed-wing drones have a structure illustrated in Figure-4. With: **+ –** Four propellers, one of which is the main one, **X –** The most common construction, in which two propellers are at the head, **Y –** Three Y-shaped arms, where one or two arms can be leader, **V –** Very rare arrangement in which two propellers lead to outstretched arms, **H –** A very rare arrangement where the construction is based on the H with two propellers in the lead.

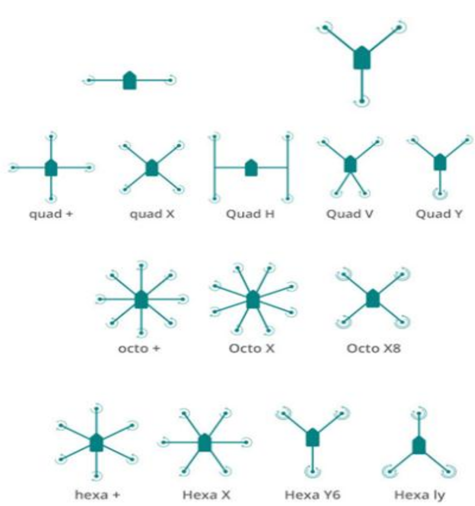

Figure-4: Structural architecture of fixed-wing drones[11].

Flight stability is ensured by the alternating reversal of the propeller rotation for mobile wing drones. The direction of the propeller blades is alternating in Figure-5. In hover, all engines run at the same speed. It should be noted that the object of our study is not the control of these parameters, namely pitch, roll and yaw.

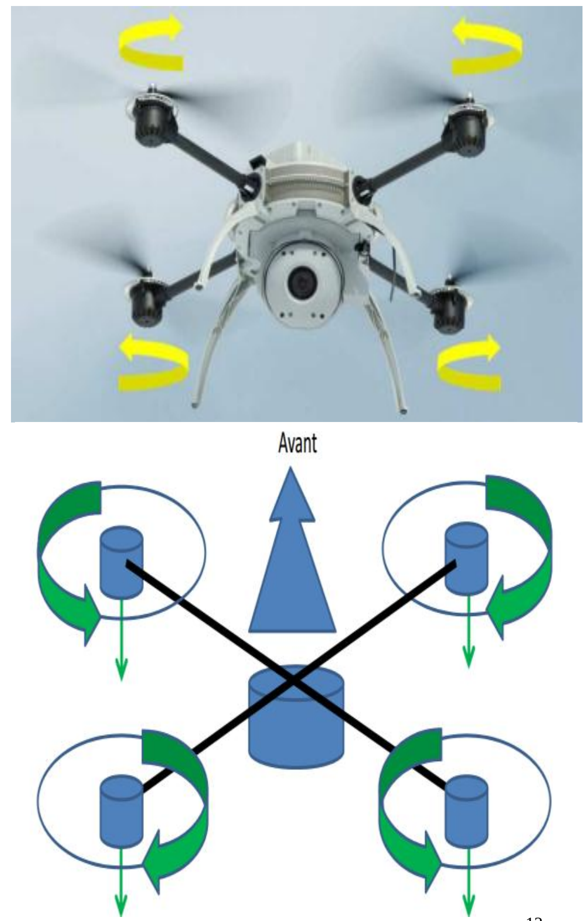

Figure-5: Hover propeller rotation indication[12].

Pitch: Forward/Backward and Roll: Right Left: To move forward, the front engines are slowed down. To reverse the rear motors are slowed down. To go to the right, the engines on the right are slowed down. To go to the left, the engines on the left are slowed down (Figure-6).

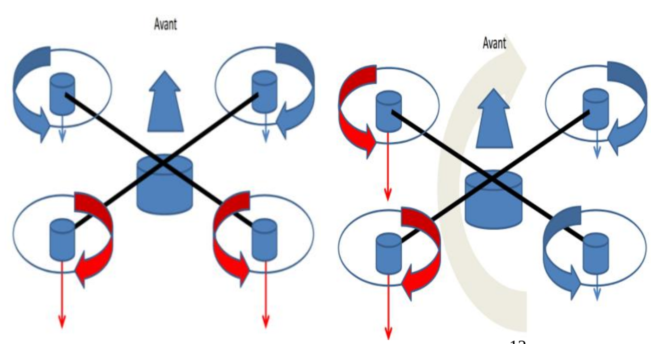

Figure-6: Pitch and roll movements[12].

Yaw: We increase the speed of a pair of propellers on the same axis.

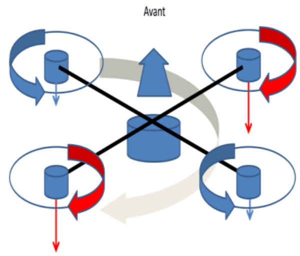

Figure-7: Yaw motion of the fixed-wing drone[12].

Fixed wing: The movable lift surfaces are the ailerons, elevator, and rudder (Figure-8 and 9)[13]. The ailerons cause a roll movement, the elevator a pitch movement, and the rudder a yaw movement.

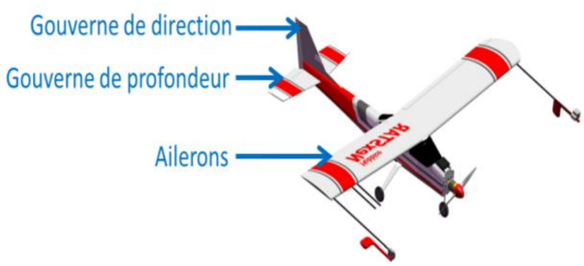

Figure-8: Attitude Variation Actuators.

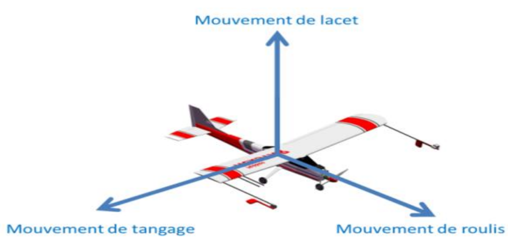

Figure-9: Roll, pitch and yaw movements.

Functional structure of drones: The drone moves in the air, it is subject to the wind, to variations in precision. The navigation electronics provide servo control. Trim variations (pitch, roll, and yaw) are measured using three piezoelectric gyroscopes. The altitude is measured by a pressure sensor. The geographical position with the help of a GPS. The functional architecture of navigation is illustrated in Figure-10.

Drone conceptual model: The main parts of a quadcopter: the frame connects all other components, it is in the shape of an X or + and must be solid, but also a light weight; rotors (coreless or brushless DC motors) that can provide the necessary thrust to propel the craft; an electronic variable speed drive to control each rotor separately according to specific needs; IMU sensors to measure vehicles altitudes; microcontroller - the "brain" of the quadcopter - an on-board processor that collects data, implements control algorithms, drives actuators and communicates with ground stations; propeller; the battery is the power source for the whole quadcopter; radio-controlled transmitter; in options : GPS, sensors, vision camera. The schematic structure of the quadcopter is shown in Figures-11[11].

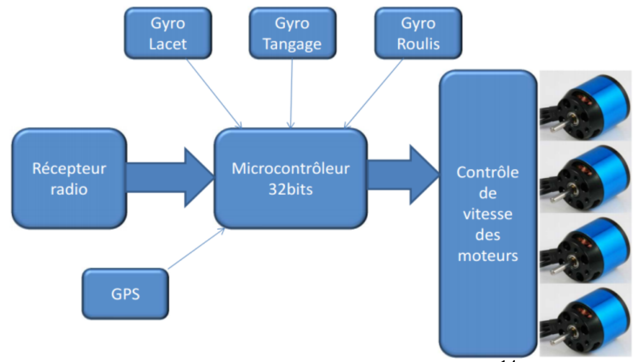

Figure-10: Block diagram of a drone[14].

The conceptual dynamic model is shown in Figure-12. The positions of a rotating body are determined using Euler angles: proper rotation φ, nutation θ and precession ψ. The angular velocities and angular accelerations that appear in Euler's equations are expressed in terms of these fundamental values, the positions of the principal axes being expressed in units of angle measurements and deviated from some initial positions. The relationships between the angles φ (roll), θ (pitch), and ψ (yaw), and their variations are complicated since these quantities are defined in different coordinates systems.

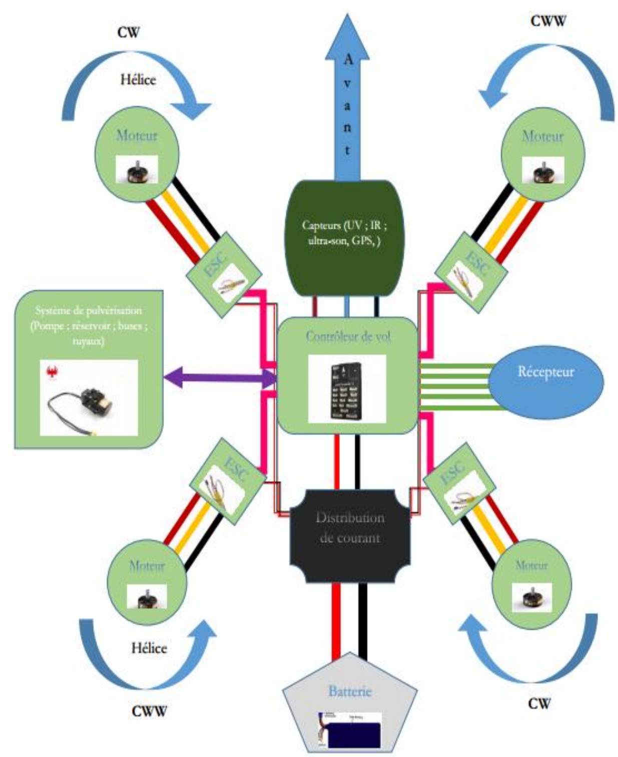

Figure-11: Conceptual diagram of a drone.

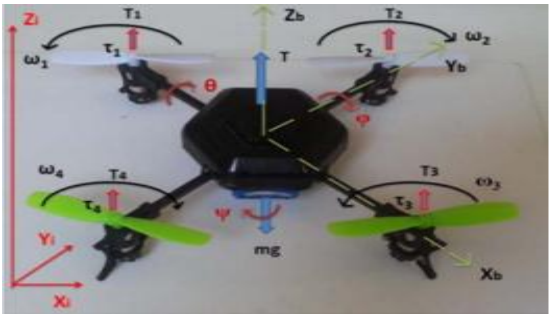

Figure-12: Conceptual dynamic model of Quadcopter[11].

Communication Protocol (MAV Link): The Micro Air Vehicle Link (MAV Link in short) is a communication protocol for unmanned systems (e.g., drones, robots). It specifies a complete set of messages exchanged between unmanned systems and ground stations. This protocol is used in major autopilot systems, mainly Ardu Pilot and PX4, and provides powerful features not only for mission monitoring and control of unmanned systems, but also for their integration to Internet. It is an open-source point-to-point networking protocol used to carry telemetry and to command and control many small unmanned aircraft. It should be noted that this technology has flaws that compromise the confidentiality, integrity and availability of communication between an unmanned aerial vehicle and a ground control station using the MAV Link protocol.

Applications of Drone technology in the agricultural industry: The use of drone technology over the past decade is on the rise, especially in agri-food sector[12]. Drones are remotely controlled by a ground operator or pre-programmed for specific routes[13] or both combined methods. There are several main benefits to using drones in farming operations. First, drones equipped with different types of sensors can carry out information gathering operations, protection monitoring and planting. The different applications of drone technology in the agricultural sector are outlined as follows:

Soil and field analysis: Drones can be used for soil and field analysis as shown in Figure-13. They can be used to produce accurate 3D maps that can be used for a preliminary analysis of soil and its properties. This is very important in planning seed planting methods. Even after planting, soil analysis by drone provides data for irrigation and management of nitrogen content in the soil. In addition, monitoring of agricultural land information is provided by drones.

Crop spreading: Drones can scan the ground and spray the right amount of liquid, soil modulation distance, and spray in real-time by uniform coverage. Efficiency is increased with a reduction in the amount of chemicals products entering in groundwater. In fact, experts estimate that aerial spraying can be done up to five times faster with drones than with traditional methods. The protection of the soil is ensured, because no machines are used to destroy the soil.

Figure-13: Soil Data Acquisition by drone[15].

Crop monitoring: One of the biggest obstacles to agriculture is the ineffective control of crops in large fields. The challenges of monitoring are compounded by the resurgence of unpredictable weather conditions that lead to a risk and cost of maintenance. Previously, satellite imagery offered the most advanced form of surveillance. But there were drawbacks. Today, drones are equipped with surveillance technology, creating time-series animations that can show the precise development of a crop and reveal production inefficiencies, allowing for a better harvest. Similarly, drones are used to estimate field biomass, forest cover, and leaf area index (LAI). Monitoring crop growth and maturity.

Planting: Drone planting systems achieve 75% absorption rate and reduce planting costs by85%[16]These systems grow pods with seeds and plant nutrients in the soil, providing to the plant all nutrients needed to keep it alive.

Irrigation and water stress detection: Drones equipped with hyper spectral, multispectral or thermal sensors can identify parts of a dry field so that water resources can be allocated much more economically, i.e. more water for dry areas and less for wetter ones. In addition, once the crop is growing, the drones allow the calculation of the vegetation index, which describes the relative density and health of the crop, and shows the heat signature, and energy quantity.

Nutritional stress and health assessments of crops: It is essential to assess crop health and detect bacterial or fungal infections on trees by scanning crops using both visible and infrared light; the devices embedded by the drone can identify crops that reflect different amounts of green light and infrared light. This information can produce multispectral images and indicate their health status. A quick response can save an entire orchard. In addition, as soon as a disease is discovered, farmers can apply and monitor the remedies more accurately.

Weeds identification in the middle of the field: Using NDVI sensor data and post-flight image data, maps of weeds can be created. This makes it easy for farmers to differentiate between areas with high weed intensity and areas of healthy crops that grow alongside them.

Cattle herd monitoring: Drones with thermal sensors are a solid option for monitoring herds from the air, observing if animals are missing, injured, or giving birth. Thus, drones offer ranchers a new way to keep an eye on their livestock at all times, leading to greater profits[17].

Crop Insurance Survey: Aerial imagery can be used to quickly classify surveyed areas into cropland and non-cropland, and to assess the extent of damage caused by natural disasters. Crop insurers and policyholders also benefit from readily available and easily repeatable drone imagery. In some industrialized countries, insurers plan to use drones to assess crop losses after natural disasters, allowing them to calculate payments more accurately and quickly. They can use the same data to build statistical risk management models, based on historical yield data, pest and weather conditions data. The drone's data can also be useful for early detection and prediction of pest infestations, data that insurance companies could share with farmers. Finally, drone data can be used to detect insurance fraud, preventing fraudsters from insuring the same piece of land multiple times or claiming damages where there is none[18].

Mechanical pollinator: In fact, robot bees may not help much with pollination, but drones could one day help real bees. A New York-based startup has developed a pollen discharge drone that helps pollenize fruits such as almonds, cherries, and apples. The company said it could increase field pollination rates by 25% to 65%. However, an external analysis confirmed that these figures were incomplete. Despite this, growers are optimistic about the usefulness of drones in orchards[18].

Most of the sensors used in the application of drone technology in agriculture are: Infrared (IR) sensors; Ultrasonic sensors; Red-green-blue (RGB) sensors; Stereo cameras; Laser Rangefinders (LRF); Ultra-wideband radar (UWB); Hyperspectral sensors; Magnetic sensors; Visible and near-infrared spectral range (VNIR); Air quality sensors. Some images of these sensors are shown in Figure-14. The different technologies that allow drones to fly and support different operations are listed in Table-2.

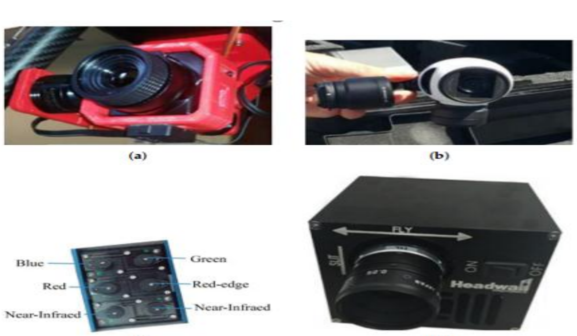

Figure-14: Examples of sensors used by drones in agriculture: a) thermal sensor; b) RGB sensor; c) multispectral sensor and d) hyperspectral sensor[6].

Table-2: Different technologies and sensors applied to support drone operations safely.

Prevention Technologies	Sensing technologies	Interdiction technologies	Investigative technologies
Feel and avoid	Radar detection	Filming	Digital Forensic Medecine
Anti-jamming	Visual Detection	Interference	
Geolocation	Acoustic Detection	Communicative	
Parachuting	Radio frequency detection		
	Multimodal Sensing		

Limitations of drone technology applications: Although the use of drone technologies in modern agriculture is expanding, several factors limit their wider use. Modern precision agriculture requires data-intensive procedures for the exploitation of the acquired images. Qualified personnel are usually required. This means that an average farmer may need training or even be forced to hire experts to assist him with image processing, which can be costly. This fact can slow down the adoption of UAV technologies by individual farmers with small farms[3]. The high investment cost of purchasing the unmanned aerial system is another prohibitive factor. Producers with larger cultivated areas and higher profit rates can use more sophisticated and expensive systems, although this is not the case for the majority of fields in Europe. The EU had 10.5 million agricultural holdings in 2016, two-thirds of which were smaller than 5 hectares, as shown by the Eurostat survey[19].

Other drawbacks stem from the limitations of drone technology. Most commercial drones have short flight times, ranging from 20 minutes to 1 hour, covering a very limited area per flight. Drones that can offer longer flight times are relatively expensive. Furthermore, the effective use of drones is subject to weather conditions. For example, on very windy or rainy days, flights must be postponed. Since the use of UAVs for agricultural purposes is considered commercial, UAV flights must also comply with related national legislation and regulations. It is also worth noting the difficulty of implementing legislation regarding drone piloting and operating procedures.

Advantages of using drones and their potential: One of the main advantages of drones is their flexibility of use: provided you have the necessary permits. The only major climatic constraint is the wind. They also have the possibility of carrying several sensors, some of which have a very high resolution, up to a centimeter. On the other hand, due to their flight altitude limit of 150 m, the width of the acquired ("swath") area does not exceed a few hundred meters, with images overlap of up to

80%. By way of comparison, the swath of an image acquired by satellite is of the order of a few hundred kilometers.

Table-3: Advantages/Limitations of Drone Technology.

Advantages	Disadvantages
Flexibility of intervention	Sensitive to wind
Flying under cloud cover	Small acquisition area due to low flight altitude
High resolution	(less than 150 m)
Possibility of embedding several types of sensors	Flights subject to air regulation
	High acquisitions recovery (until 80%)
	Images require post-acquisition processing (complexity for a group of farmers or a small cooperative)

The application of drones in various agricultural activities avoids one of the factors aggravating the dynamics of soil structure. The structure of the soil evolves under the effect of several types of processes, which can be classified into three groups: abiotic processes, such as cracking under the effect of freeze-thaw or wetting-desiccation alternations; biotic processes, resulting from micro-organisms, earthworms or roots on aggregation and porosity, and finally those linked to agricultural activity, which are fragmentation by tillage and compaction by agricultural machinery[20].

The compaction of cultivated soil is mainly the result of the rolling of agricultural machinery. Settlement produces a rut on the surface and, when severe, leads to a structural porosity close to zero. It modifiessoil properties: air permeability, hydraulic conductivity, resistance to penetration and shear strength. It also disrupts the growth and functioning of the roots and therefore the water supply and mineral elements to the plants. Finally, it modifies biological functioning of soil and the fluids circulation. For all these reasons, settlement can have a significant impact on yield. The ability to root also depends on the moisture of the soil interacting with the soil structure at the time of root growth. Therefore, the use of drones allows the application of an optimal number of inputs at the right time and in the right place to get better products. It enables data collection and mapping of farmland variability, data analysis, and farm management decision-making. It is based on the inferred results of analyses and finally controlled applications such as pesticide spraying and fertilizers.

The majority of recent work in agriculture uses multi-rotor drones. This is mainly because in most applications, the area considered is not very large. For this reason, there is no need to use drones that are high-speed and capable of covering large areas in a few flights, such as fixed-wing drones. Thus, rotary-wing aircraft are preferred because of the following advantages: Easy to use, relatively smaller speeds, ability to maneuver, relatively low cost.

These benefits give greater opportunities to collect crop information through imagery, which is the primary use of drones in vegetation monitoring. For relatively large surveillance areas, fixed-wing aircraft are preferred, which allows the entire area to be observed in a short time. The following table summarizes the advantages and disadvantages of each class.

Table-4: Advantages and disadvantages of fixed-wing and rotary-wing drones.

Fixed wing	Rotary wing
Advantages	Advantages
A larger payload capacity, higher top speed, longer flight times, and longer range compared to rotor systems with a similar battery capacity.	Manual takeoff, flight and landing are easy to learn and some models have obstacle avoidance technologies.
Useful for data collection over a large area	Low cost of many models on the market, as well as inexpensive units with greater payload and/or flight time.
Disadvantages	Disadvantages
Less maneuverable, it require more open space for landing and more skill for the pilot, and it tend to be several times more expensive than rotor systems of similar quality.	Shorter range and flight time compared to fixed wing.
	Fixed wings are the main disadvantages of rotorcraft.

Economic potential of agricultural drones: Although farmers have taken time to use drones in many areas of their business, drones occupy a significant place from the economic potential of human sectors, as illustrates Figure-15. The objective of efficient and effective agriculture is to apply an optimal amount of input at the right time and in the right place to obtain better products.

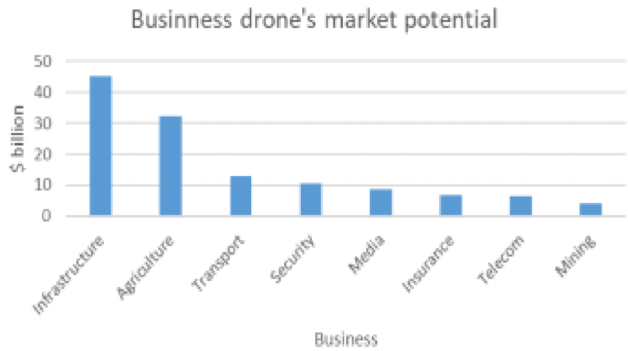

Figure-15: Potential of drones on the international market[21].

Results and Discussion

The use of drone in agriculture is at an early stage of development in Africa and Benin. We have to make significant efforts to raise awareness among farmers and other stakeholders in the agricultural sector for further use of drone technologies. While we are seeing some progress, it is still very derisory. The share of drone production in Africa is insignificant or even non-existent. As illustrates Figure-16 showing the production share of the world's top 20 companies in the field.

The main competitors in the drone sector are not from the African continent. However, encouraging actions are being carried out in Africa through training, the popularization of technologies and the desire to reduce the prevailing technological gap.

Functional analysis of the Drone system: This functional approach allows us to analyze our system to translate the needs expressed into functions. This analysis makes it possible to visualize the service functions that the system will perform as well as the constrained functions imposed by external environments for each life situation. The service function translates the expected action of the system during the life situation considered. The service function reflects the expected action of the system during the life situation considered. The constraint function is imposed on the system by each external environment.

Performance graph: diagram of the horned beast: Who does he serve? What does it work on?

Statement of functions: FP: Enabling users to operate remotely on farms, FC1: Adapt to all kinds of farms, FC2: Comply with aeronautical design standards, FC3: Resisting to environmental constraints, FC4: Be supplied with electrical energy, FC5: Spraying solids and liquids on farms.

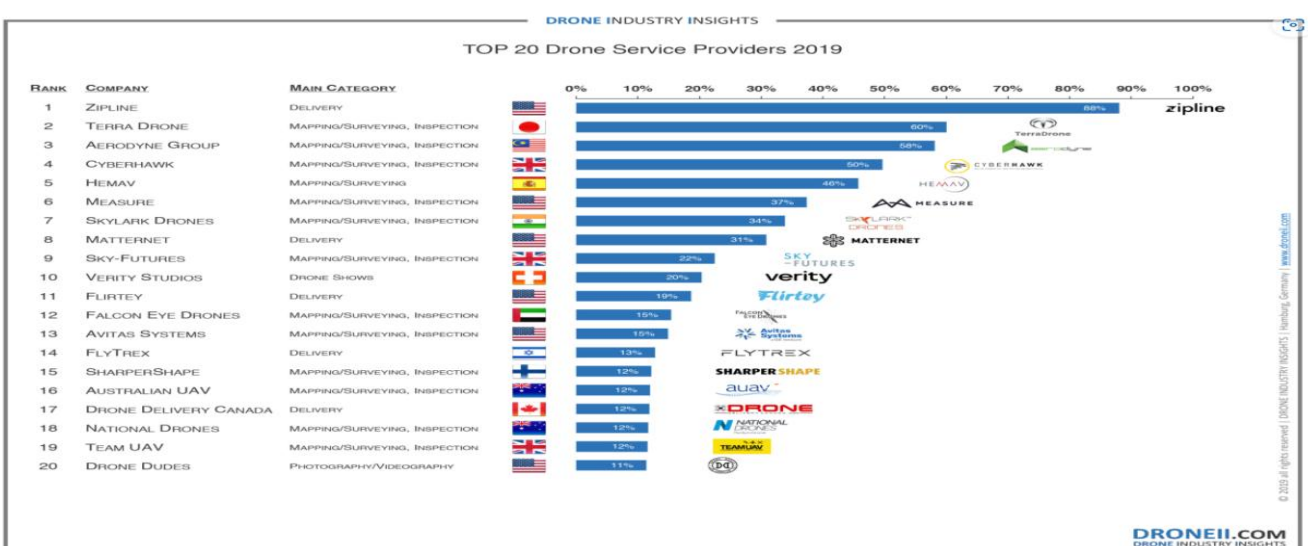

Figure-16: Rank of the top 20 companies in terms of drone production and marketing[22].

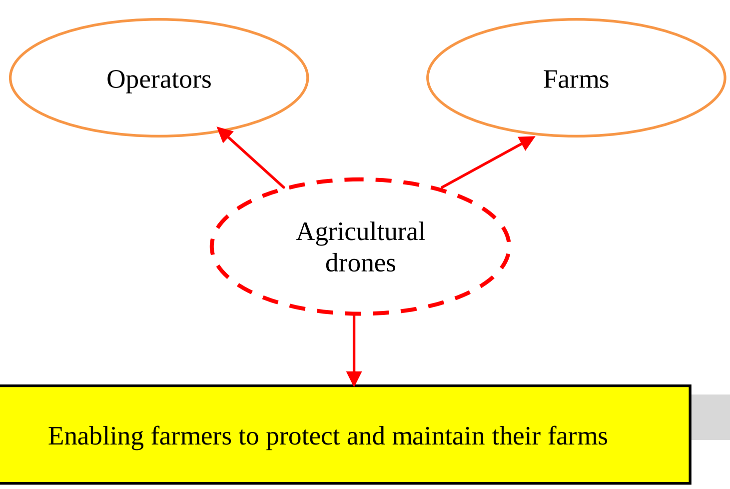

Figure-17: Horned beast diagram.

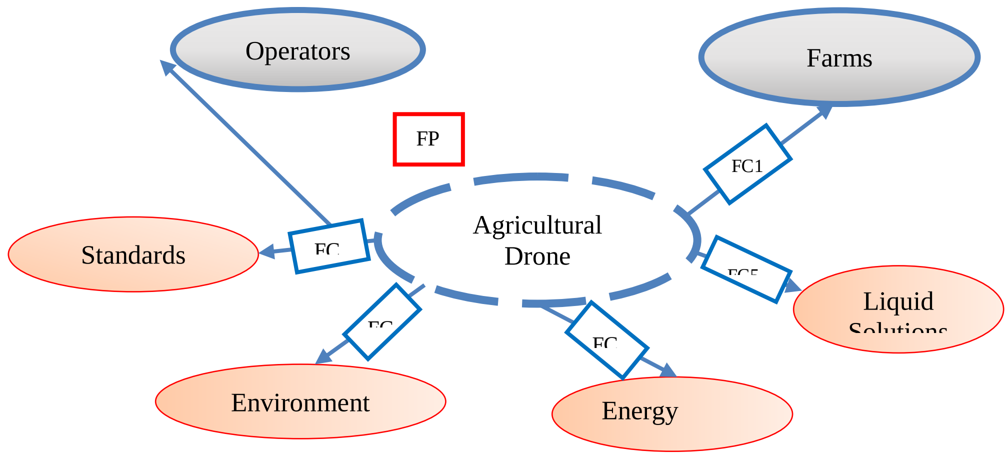

Figure-18: Octopus diagram.

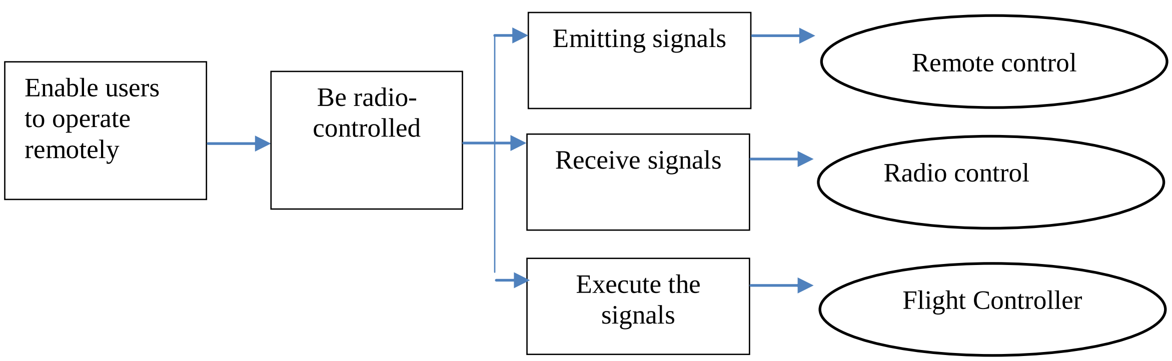

Figure-19: Main functions of control (FAST Diagram).

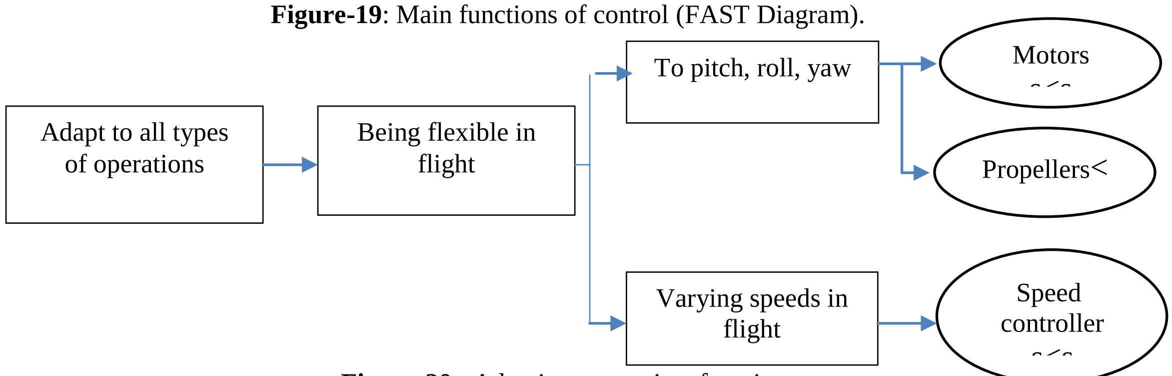

Figure-20: Adaptive constraints function.

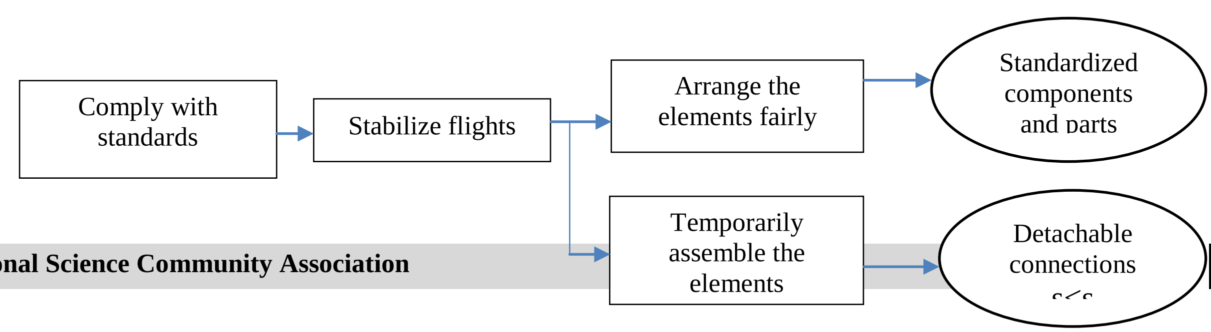

Figure-21: Normative constraints function.

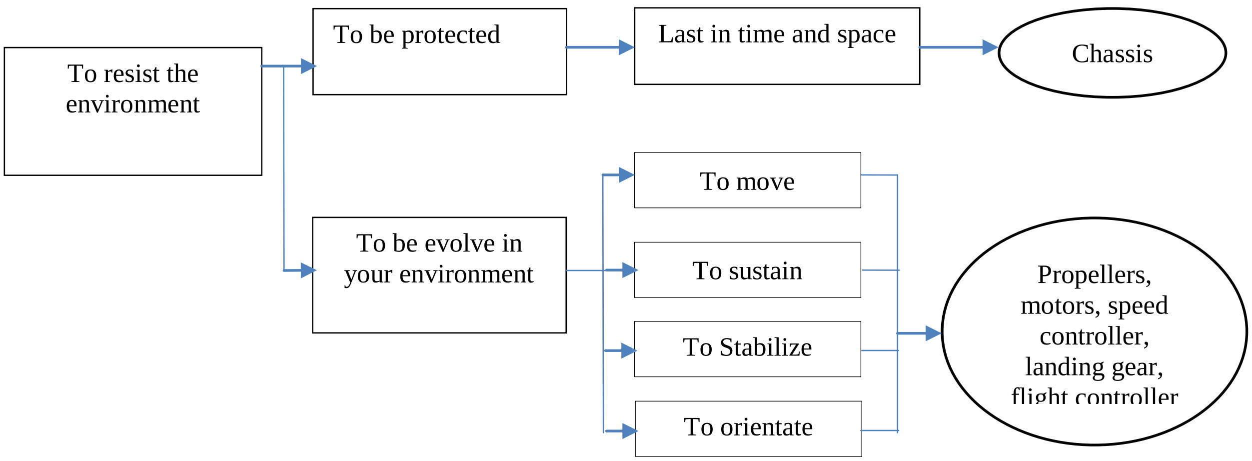

Figure-22: Environmental constraints function.

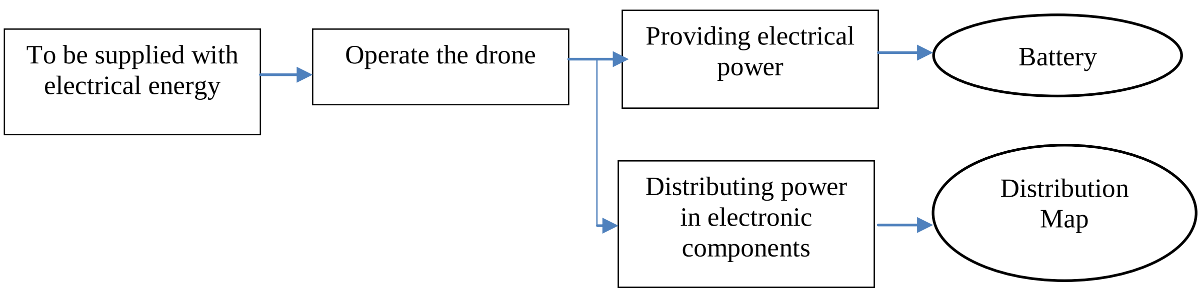

Figure-23: Power constraints function.

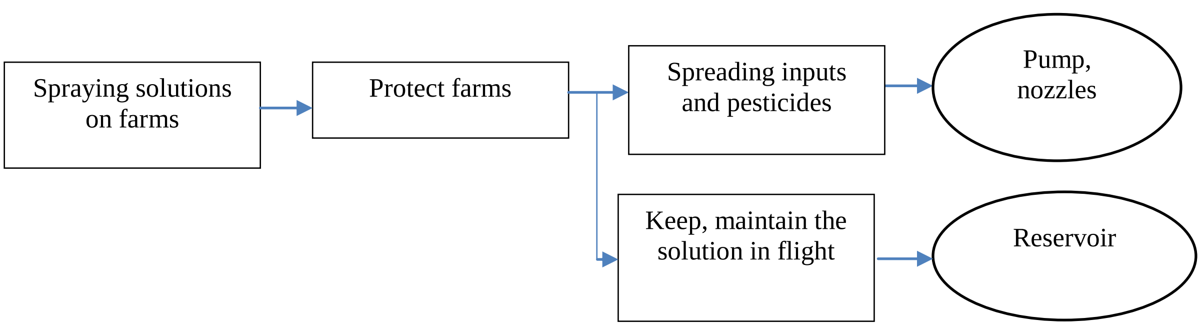

Figure-24: Exploitation constraints function.

Contribution of drones to development: The future of drones in Africa and sector: with a bit of hesitation, long after several other fields of human endeavors. Currently, farmers have begun to realize its importance. However, in Africa, in terms of research, various research works are underway in research institutes in Africa. i) At National University of Science, Technology, Engineering and Mathematics (UNSTIM) of Abomey through the National Higher Institute of Industrial Technology (INSTI) Lokossa under the public-private research a research project entitled 'Exploitation of drone technology in scientific research applied to the population' and financed by the National Fund for Scientific Research and Technological Innovation (FNRSIT). This project aims to develop techniques for design and production of agricultural drones for their integration into agricultural production chain in Benin and in the West African sub-region. ii) The Regional Research Centre for Integrated Development (RCID) and Charis Unmanned Aerial Solutions (Charis UAS); two organizations from Rwanda for the project optimize the use of nitrogen fertilizers in wheat crops. The drone Parrotwas used to take aerial images five times during the crop cycle. On each occasion, samples are taken from the micro-plots and sent to the laboratories of the Rwanda Agriculture Board (RAB). The aim is to calibrate an algorithm for wheat based on the correlations between cereal reflectance, dry matter and nitrogen content. This algorithm will allow extension agencies to use drone images to assess the nutritional content of wheat, and its nitrogen fertilizer needs, providing farmers with advice on the quantity of fertilizer and where to apply it[23].In short, these projects essentially aim to develop and promote the application of this technology in the agri-food sector and based on the monitoring of crops and soil health using different remote sensing sensor technologies; Hyper Spectral (HRS), Multi Spectral, Thermal and High Definition (RGB) cameras. These types of research projects are necessary for the use of this technology more effectively in the agribusiness sector in Benin and in Africa. iii) In addition, the first African Drone and Data Academy (ADDA) opened its doors since January 2020 in Lilongwe, Malawi. In 2022, the Academy is offering a free, two-year Master's program in Drone Technology in collaboration with the Malawi University of Science and Technology (MUST).

It also offers a curriculum that builds local capacity and an ecosystem that fosters sustainable business models for the use of drones in humanitarian and development missions. The academy equips graduates with the skills needed for jobs using drone applications ranging from agriculture, health, and natural resource monitoring. Recent data shows the role that investment in research plays in Africa's agricultural productivity. For example, over the past three decades, Africa's agricultural productivity has grown at a much higher rate (1.8%) than previously calculated.

Technical progress is the is the main driver of this growth. This observation reconfirms the critical role of research and development (R&D) in the productivity of agricultural sector. We wish that the use of drones would become more common in agricultural sector in Africa and in Benin.

Conclusion

Over the last decade, the latest technologies have been integrated into precision agriculture to improve productivity and ensure one of the principles of good agricultural practices. These technologies are useful where human intervention is not possible for spraying chemicals on crops and scarcity of labor. It also makes the spraying job easier and faster. The study contributed to describe the importance of drone use technologies for all sizes farms. It have shown the application of drone technology intervening at almost all stages of agricultural route: from sowing, seed protection, fertilization, weeding, pest diseases, water management and harvesting.

In perspective, this research consists of developing to design and sizing guidelines for the manufacture of drones whose applications in the agricultural sector will be multiple and within the reach of farmers in Benin and the West African sub-region. In addition, the integration of artificial intelligence into drone technology will allow drones to make decisions and be independent of human controllers. It can take years or even decades to see qualitative improvements thanks to drones. In any case, innovation is a key factor that must be focused on to get through the new industrial revolution.

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