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THE ROLE OF DRONES AS AN ENABLER FOR THE 4TH AGRICULTURAL REVOLUTION

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ABSTRACT

The domain of agriculture is constantly evolving in terms of means and tools used. The rapid evolution in Unmanned Aerial Vehicles (UAVs) and drone technology has facilitated a series of applications in the field of agriculture. The use of drones, combined with advanced ICT technologies as well as connected analytics methods, provides great potential in supporting and resolving some of the most challenging issues faced by the agricultural domain especially in real time data acquisition, monitoring and decision-making processes, triggering the so-called 4th agricultural revolution. The present paper provides an overview of the application of drones in the agriculture domain worldwide. Initially, the paper presents some introductory information concerning the technological evolution in the agricultural domain with special focus on the use of Unmanned Aerial Vehicles. It then conducts a research concerning different applications of UAVs in agriculture. It proceeds with discussing relevant existing research initiatives, highlighting the relevant advantages and the prospects in using drone technology in agriculture.

Contribution/Originality: This study documents the role of Unmanned Aerial Vehicles (UAVs) or drones in the Agriculture 4.0. The study summarizes, in a reader-friendly way, the contribution of drones to several aspects of the agriculture sector as well as commercial products and research projects in this domain.

1. INTRODUCTION

As it is well known, climate change has significantly intensified the food shortage at a global level. More than 815 million persons suffer from lasting hunger, with more than 60% of them residing in Asia. It is estimated that the global food production has to be increased at about 50% until 2050 in order to satisfy a global population of nine billion, while resources such as land and water become more and more scarce [1].

In this reason, farming communities as well as all organizations of the agriculture sector must adjust to various challenges imposed by climate change. The use of Information and Communication Technologies (ICT), aiming at supporting decisions based on specific, reliable and timely information, can play a significant role to this end. The introduction of emerging technologies in the agricultural domain is now more imperative than ever before, with the FAO (Food and Agriculture Organization) and the ITU (International Telecommunication Union) working together, along with other actors as well, towards jointly addressing these challenges through the use of sustainable ICT tools and methods.

The introduction or better the establishment of the use of ICT technologies in agriculture, has led to full digitalization of certain agricultural activities affecting tremendously the operations and the economies of agricultural communities at a global level, effects that can only be compared to the post World War 1 mechanization or the later introduction of biotechnologies and genetic modification. Thus, it is without doubt that the global agriculture has well entered the era of the so-called 4th agricultural evolution, an era characterized by the convergence of traditional farming processes to modern, technology-enabled and technology-assisted activities, leading to significant operational and economic shifting. Precision agriculture, enabled by technological advances such sensor technologies, the IoT paradigm, drone technologies, and robotics, combined with advanced data analytics techniques and big data management capabilities, now allow producers not only to monitor their crops and livestock in rea-time but also to take informed decisions on small-scale actions or large-scale strategy identification. The abundance of digital data on soil condition, crop progress or livestock status features enormous potential towards reshaping the agricultural industry, optimizing resource allocation, adjusting cultivation techniques, minimizing labor, thus eventually leading to more cost-efficient and growth-effective schemes.

One of the most important enablers of the 4th agricultural revolution, discussed above, is the introduction and extensive use of small, remotely controlled, unmanned aerial vehicles (UAV), widely known as drones, in the agricultural sector. Given their capabilities regarding information collection, drones emerge as a highly promising solution for the collection of precise data that can support strategic decisions and production design. Despite the existence of inherent restrictions, these tools combined with the associated networking and processing technologies, can assist in providing extremely useful data, which in turn can affect policies and decisions.

Drones are currently used in various domains, ranging from military missions or humanitarian aid, to crop destruction in agriculture. A recent report of PwCPwC [2] estimates the market value of agricultural drones to 32,4 billion dollars. The advantages offered when combining "eyes in the sky", with analytical tools, for converting data and images to useful information, have revolutionized traditional agricultural activities [3]. However, the warrantee of citizens' security and the protection of their privacy should be a guideline for the sustainable application of the aforementioned technologies [1].

The United Nations have experimented with aerial vehicles in various applications from humanitarian crises to agricultural production monitoring. The Worldwide Food Program, composed by the Belgian Government in order to develop drones for tackling with urgent humanitarian crises, is an indicative such example [4]. The ability of drones to collect fast data of high accuracy combined with the provision of a safer supervision and monitoring system in emergencies constitutes a main advantage in such field trials during humanitarian crises.

The FAO and Google [5] collaborated towards the implementation of remote supervision methods, where data are directly accessible and more accurate. Access to these high-quality data is the key for setting efficient policies and performing effective interventions towards the achievement of the Sustainable Development Goals until 2030 [6].

The use of drones in the agricultural domains expands at a fast pace with cultivation monitoring, on-time warning systems, destruction risk minimization, forestry, fishing, as well as protection of the wild fauna, being some indicative examples.

2. APPLICATION OF DRONES IN AGRICULTURE

2.1. Crops

Precision farming combines sensor data together with real time data visualization techniques for enhancing field productivity through spatial variability in a wider area. Data collected through drones consist valuable raw data that can then be utilized in agricultural analytic tools. Precision farming solutions employ drones for scanning ground areas and estimating their health conditions, for monitoring crop status, for providing input to watering scheduling tools, for fertilizing applications, for assessing crop yield and for providing useful data for weather condition analysis. Data collected through drones combined with other data sources and analysis tools can trigger a series of actions such as fertilizer application, crop harvesting etc. In detail, drones such as the DJI Agras MG-1 are especially designed for variable accuracy levels regarding the application of liquid pesticides, fertilizers and herbicides [7]. Moreover, other specialized drones equipped with UV, multispectrum and hyperspectrum sensors can be utilized, for the precise analysis of crop health and soil conditions. Finally, another use of drones in the area of agriculture, focuses on insurance purposes and assessments, including cases for compensation claims.

2.2. Disaster Risk Management

The FAO collaborates with various countries for the development of systems aiming at the use of drones as data collectors, for the support of Disaster Risk reduction efforts. The data collected, subsequently, feed modelling and analysis systems which in turn provide valuable predictions. Such type of information can provide local agricultural communities with reliable, high quality advice, and can assist governments towards better planning of disaster recovering schemes.

Drones used, for example, by the FAO in the Republic of the Philippines are equipped with photogrammetric tools, combined with navigation devices and can run soil analysis of up to three centimeters. Thus, they can be programmed to detect indicators such as the NDVI (Normalized Difference Vegetation Index), the degree of water concentration or the lack of certain nutrient substances in the crops. In a similar way, in the Republic of the Union of Myanmar, the FAO collaborates with the Ministry of Agriculture, Livestock and Irrigation, as well as the Myanmar Aerospace Engineering University and use modern geospatial technologies for enhancing the ministry's readiness and response levels to relevant disasters. This initiative, also, provides, useful information for mountainous hazards such as landslides and ground corrosion, which could be used for alerting on-time the agricultural communities as well as for helping them understand the risks and minimize the effects of each type of disaster.

2.3. Forestry

The OpenForests organization [8] performs mapping of forest areas, based on information collected by drones, thus offering a new capability, which could be used for the appraisal, monitoring and research of the considered areas. This mapping is conducted through the assembly of hundreds of drone collected photographs which are then combined in order to produce high resolution orthoimages. The use of drones supports forestry with a robust solution for the collection of reliable and timely information on everything related to this domain, ranging from carbon absorption measurements, to tree analysis, fauna tracking, bio-diversity monitoring at area level, etc. In this direction, Goodbody, Coops, Marshall, Tompalski and Crawford reported the useful use of unmanned aerial vehicles for the upgrade of forestry tools used in a small area of British Columbia in Canada [9]. In this report, the practical advantages of using such systems even under adverse weather conditions are also highlighted.

2.4. Fishing

Regarding the fishing domain, a continuously growing number of countries, such as the Republic of Palau, Belize, Jamaica, and Republic of Costa Rica, use drones for tracking illegal activities and outlaws. Moreover, the states of Texas and Nebraska mobilize drones for the enhancement of fishing assessment activities.

2.5. Wildlife Protection

Drones specially equipped with high resolution thermal cameras are used for tracking and monitoring of wildlife in certain areas. Furthermore, the tracking of thermal footprints is especially useful for monitoring and preventing illegal hunting activities. A characteristic example where drones were used in this context is the aversions of poachers threatening the Rhinoceros species, like African and Asian rhinoceros [10].

3. RESEARCH PROJECTS AND APPLICATIONS

3.1. Unmanned Aerial Systems in the Agricultural Domain: Regulations and Best Practices

In 2017, South Africa faced a condition known as "fail armyworm", when more than 100.000 hectares of maize were destroyed in Zambia. The Zambian Airforce rushed to assist the Ministry of Agriculture by using aerial vehicles targeting the harmful organisms, through the aerial application of pesticides in various "hot spots" throughout the country [11]. The national systems of timely warning and especially businessmen working in the agricultural domain are always in need of the most accurate as well as the most updated information regarding the areas and the resources they are concerned of. Agricultural airplanes are used for this purpose since 1920. Telemetry data from satellites are used more and more intensely for assessing the area, the expansion, and the health status of crops from above. During the last years, unmanned aerial vehicles or drones have been established as one of the most known and widely used technologies worldwide, with applications in a wide spectrum of professions, including the ones of agriculturists and agricultural infrastructure supervisors, as well as in the domain of humanitarian aid [12, 13]. Although drones are unlikely to completely substitute manned aircrafts or satellites, they do feature great advantages towards traditional telemetry methods. This technology is capable of collecting images of much greater analysis, under the level of clouds, with many more details than the satellite images usually available to analysts of developing countries. Moreover, they are easy to use and guide so that most mapping and data collection campaigns are performed autonomously, a fact that further boosts their deployment. Also, in this way, data collection and processing activities are rendered less expensive and more user friendly. The use of drones for monitoring poaching of endangered species, the illegal or not sustainable use of forest resources, even the land use in general is confirmed in many countries worldwide. International and national non-governmental organizations promote their use for the support of native populations and the collection of evidence on illegal activities in their territories. Drones are used in the areas of stock raising, fishing, topography, planning of land use and exploitation, humanitarian and emergency aid, assessment of available reserves, evaluation of crop damage, supervision of fixed and mobile assets, as well as in various other contexts. The obvious advantages of aerial agriculture stem from the drones' ability to cover fast large areas without harming the developing territory. This is extremely important in cases a fast response to diseases or parasites is needed. A specialized added value is the dispersion of chemical substances during spraying by drones to the bottom side of leaves from rotor wash. In the Republic of South Africa in 2014 mapping flights were conducted and the proper nutrients were applied using conventional methods immediately afterwards. High-resolution farm and vine mapping imagery was taken before the crops were sprayed with nutrients and at stages afterwards. Figure 1 shows improvement in the treated rows relative to the untreated ones [1].

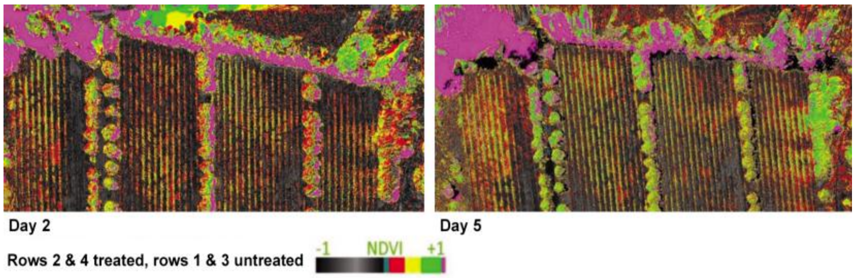

Figure-1. Image from drone before and after nutrients appliance highlighting nutrient value [1].
Source: Food and Agriculture Organization of the United Nations (FAO) [1].

On the other hand, several concerns are raised by governmental authorities against the unauthorized or illegal use of this innovative technology, regarding possible violations of civilians' private lives or military air space, potential drone crashes, as well injuries or material damages.

The consensus point regarding regulatory requirements and specifications, resides in the declaration and insurance of involved parties, which among other will hold a special license, with the exception of relatively safe flights, e.g. short-range flights far from residential areas.

3.2. Drone Technology as a Tool for Enhancing Agricultural Production

The drone technology as well as the advanced image data analyses enabled, feature the potential of becoming a bridge between technology-assisted agriculture and future needs [2, 14].

Several methods and tools, combining drones and advanced image analysis can be applied in the agriculture industry, the majority of which rely on drones as mobile, aerial platforms suitable for supporting advanced image collection techniques. Moreover, drones can be equipped with a wide range of visual data sensors and infrared cameras towards the identification of the Normalised Difference Vegetation Index (NVDI). The most frequent such application is related to the assessment of vegetable crops' health. Drone technology, as a platform for retrieving visual data brought NDVI mapping capability to an entirely new level of accuracy, rendering feasible the status monitoring of not only plants as a whole but of specific parts of these plants as well. This level of information granularity enables the timely tracking and identification of parasites, diseases and other harmful organisms. The advanced geospatial NDVI products can, also, be utilized in case of natural disasters or crop destruction for the exact assessment of damage levels by comparing the yield before and after the disaster, so as to render all losses obvious as shown in Figure 2. The aforementioned damage documentation, followed by the precise evaluation of reduction to the originally estimated performance could be well used for insurance purposes and procedures.

Figure-2. Analysis of the NDVI, allowing for the monitoring of maize crops [15].
Source: SmartAKIS-Smart Farming Thematic Network [15].

Another major application of drone technology in agriculture is crop spraying. Nowadays, a typical example of drone spraying involves of a tank full of over 10 liters of liquid pesticide, with the ability of spraying over a liter per minute, allowing for the coverage of a whole hectare in ten minutes. However, fully exploiting the motor technology as a spraying platform, spraying can be synchronized with monitoring, processing, and automated analysis in order to precisely address suffering areas or plantation, minimizing at the same time the overall use of chemicals in areas under consideration.

The full exploitation of the capabilities and solutions offered by the advanced image data analysis techniques calls for application and integration of these new technologies in the wide spectrum of agricultural business processes.

3.3. Reports, Mapping and Applications for Rice Crops

Rice production consists a prime focal example for the introduction and integration of ICT tools and solutions for monitoring, mapping and assessment of crops in countries of South Asia, towards the provision of increased food safety and enhanced well-being of farmers.

This Satellite-Based Rice Monitoring (SRM) approach encompasses telemetry methods, crop modelling tools and introduction of ICT tools for the provision of accurate and near real-time information on the production and development of rice crops, as well as on the damage caused by abiotic and biotic stress. The RICE technology provides precise and timely information regarding rice production levels, cultivated in village areas, including information on the season start and its variance based on the geographic anaglyph, the difference between the expected and the actual performance, and the effects of ay disaster in certain parts of the crop. It also, provides, accurate information for the implementation of effective crop insurance schemes in various countries.

The rice monitoring system assists the government and other related involved parties in accessing precise and updated information allowing for better management of the national production and distribution, resulting in minimizing the vulnerability of small farmers while at the same time maximizing food security. This information can assist governments and actors throughout the rice supply chain in better identifying and managing production related risks.

Exact and near real-time data on rice development can even help governments and other parties to adjust disaster management plans and policies and be better prepared for predicting natural disasters and coordinating relief strategies in case such disasters occur. High quality information retrieved through the use of RIICE technology could also be used for the development of more effective and more transparent plant insurance products towards the protection of small farmers, or for securing import and export processes [16]. Below in Figure 3 a Synthetic Aperture Radar (SAR) data process in an India area.

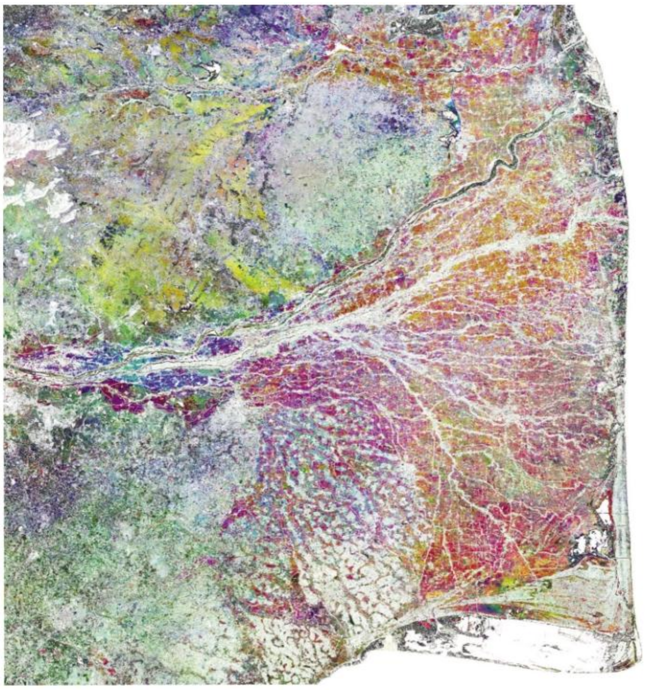

Figure-3. SAR data process in an India area [17].
Source: The European Space Agency [17].

3.4. Development and Evolution of Drones Used in Agriculture

Japan was a pioneer in the domain of unmanned helicopters for agricultural reasons, mainly since 1983 when the ministry of Agriculture, Forestry and Fishing asked for the development of remotely controlled aircrafts, capable of performing spraying of agrochemicals in crops. This project was undertaken by Yamaha, who although initially had focused on development only the motor for the helicopters, it then, recognizing the importance of providing a complete system of automatic aerial spraying, proceeded with the development of the entire system. The initial helicopter was based on the use of gyro sensors and was tested successfully, but his main drawback, the fact that it weighted over 100 kilograms, prevented its further exploitation. The evolution of this prototype was the R-50 model, which was the first unmanned aircraft globally used for crop spraying.

After the successful trial and establishment of the R-50 model, Yamaha continued working on the project of creating a fully autonomous helicopter which would not need human control. Thus, the Yamaha Attitude Control System (YACS) was developed and installed in the R-50 in 1955, together with advanced optic fiber sensors. In this way, the new version of the R-50 had now the ability to perform sprays in an area of rice crops in about 10 minutes, a significant downscaling from the 160 minutes previously needed.

In 1997, Yamaha presented the new unmanned aircraft RMAX, which in 2000 evolved as a commercial product, featuring the option of having automated pilot installed. The RMAX demonstrated two further models in 2000 and 2003 respectively, equipped with features that rendered flights even easier. In 2013, Yamaha presented the FAZER model, which was evolved in 2016 as FAZER-R, which is presented in Figure 4 and constitutes the most modern and reliable product of the company in the specific domain.

Figure-4. Yamaha [18].

Source: Yamaha [18].

Notably, in 2016 over 2800 unmanned Yamaha air vehicles were registered for agricultural purposes, conducting sprays in an area of over 1 million hectares per year, equivalent to almost 40% of the country's annual rice production [19]. Counting more than 25 years of development in Japan, the sector of unmanned vehicles is growing unceasingly encompassing novel advanced technologies.

3.5. Drones for the Estimation of Agricultural Damage

In many countries worldwide agriculture and livestock constitute the country's main industry and the main profession of the largest percentage of native population. These sectors are significantly vulnerable to natural disasters and entail great risk regarding their performance. Towards establishing an effective disaster risk management (DRM) scheme, and after the disastrous floods in Magway area in October 2016, the FAO investigated for the first time the use of drones for managing such situations. Drones can collect quickly precise data on the affected areas, which can then be processed and studied for providing effective relief measures.

The first pilot projects using drones for managing disasters, took place in Myanmar where areas of about 3600 hectares were photographed with the analysis reaching that of 5 centimeters. In this way, affected areas and the disaster intensity were quickly identified enabling the government to assess mitigation measures in an effective and rapid way. Through the analysis of high-resolution photographs collected by drones, the exact fertilizers, materials and resources can be identified quickly after the disastrous incident. A primary characteristic of drones, rendering them an obvious choice for assessing and tackling with disasters is their ability to approach remote and difficult to reach areas in urgent situations such as natural disasters where often humans cannot get close. For this purpose, wing drones engaged as shown in Figure 5.

Figure-5. Wing drone which used for mapping rural areas in the Republic of the Union of Myanmar [1].
Source: Food and Agriculture Organization of the United Nations (FAO) [1].

The specific drone technology used for managing crises was also integrated in crop assessment applications through the NDVI method, detailed in previous chapters. Nevertheless, the use of drones is effective in almost all kind of urgent situations, providing great flexibility and precision to operational design and critical decision support for dealing with hazardous conditions.

3.6. Forest Supervision Through the Use of Drones

The FAO in collaboration with the local authorities of Panama initiated research programs in the country targeting primarily at the supervision and registration of forest areas, covering large percentage of the country's land [20]. In the context of these projects, drone collected data can be used for diverse applications in response to a variety of requirements. These applications range from simple supervision of forests to urban or per-urban planning, fire detection, dynamic population growth, etc.

Through the images collected by drones and more specifically through their superimposing, stereoscopic data on the tree, crops and ground height can be calculated. This information can be later used for estimating area coverage, height and volume of crops as well as topographic information that could not be otherwise calculated.

Benefits by the use of drones in forest lands are multiple and already documented by communities in Panama, where these pilot projects were performed. Some of these reported advantages included the aversion and tracking of illegal timber activities, the monitoring and detection of fires, the proper and timely crop yield, as well as savings in water reserves. Finally, the use of air vehicles and innovative technologies positively transformed forest monitoring performed by community members. Through the new knowledge and equipment available, communities are now in position to access precise data that assist in managing their area and taking substantiated decisions. Figure 6 presents an example of forest area registration through drone collected images.

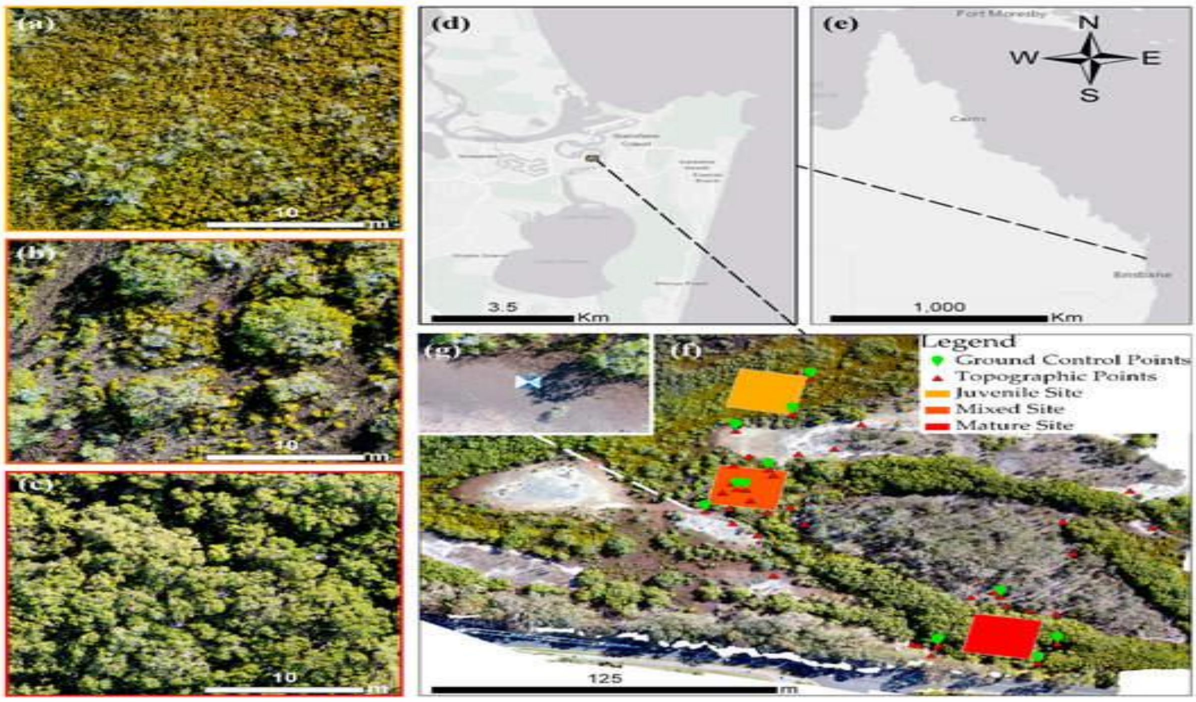

Figure-6. Example of forest area registration through drone collected images[21].
Source: Warfield and Leon [21].

3.7. Internet of Thing (IoT) and Drone Technologies in Agriculture

Monitoring remote agricultural areas and livestock is in most cases extremely difficult due to the lack of network infrastructure, highly unlikely to be also developed in the near future. Thus, data retrieval through Wireless Sensor Networks (WSNs) is quite difficult, raising network-equipped drones as a promising solution for fast and accurate data collection.

A relevant project involving data collection by wireless sensors through unmanned aerial vehicles was carried out in agricultural areas in China [22]. In these specific areas initially, there were no Wi-fi stations or wherever they existed, the signal was too weak to send or receive data. Therefore, their retrieval was a difficult and time consuming since it should be performed by the farmers themselves, resulting in the processing of outdated data and the inability to overview real time status conditions. Properly equipped drones, supporting Zigbee or Lora networks were deployed to address this problem, gathering data in every flight above the sensors and transmitting them to defined central nodes for further processing [22, 23]. An overview of the experimental setup used can be seen in Figure 7.

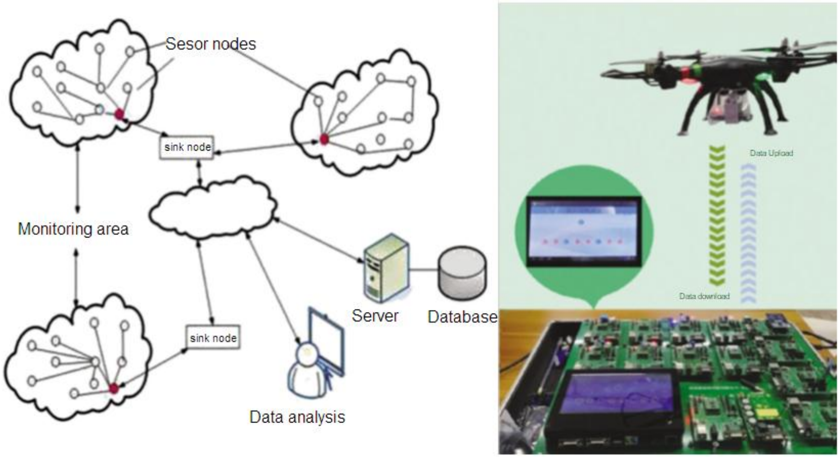

Figure-7. Drone data acquisition system [22].
Source: Zhang, et al. [22]

This architectural approach can be applied both in livestock and agriculture in extremely hard to reach areas without any existing network infrastructure. The main challenge faced in these cases is to devise a cost-effective yet high performance solution. Another challenge relates to weather conditions than can significantly deteriorate the abilities of drones or even destroy them altogether. Nevertheless, the use of drones together with wireless sensor networks is a promising alternative for achieving communication links in real time and reliable retrieve data in areas where the deployment of suitable network infrastructure is extremely problematic [22].

4. CONCLUSIONS

In the previous chapters an overview of drone use in certain areas of agriculture and livestock was performed, together with the presentation of characteristic use cases globally. Drones utilized can be classified in many categories depending usually on their size or the number of motors they carry. Each category has its own unique features and can deployed in various applications. For instance, a drone with embedded navigation wings has the advantage of greater autonomy and rigidity and can cover areas of larger surface. Their main weakness lies in the greater landing or takeoff areas needed. On the other hand, drones carrying multiple motors can achieve lower velocity and feature less autonomy, but are more flexible and can be mobilized in smaller and harder to reach areas.

Taking into account the previously discussed sectors as well as the available types of unmanned aerial vehicles some of the most common related uses of drones [24] include

- Spraying (pesticides, fertilizers, etc.).
- Photograph collection for the creation of 3D models.
- Data retrieval through specialized sensors and cameras.
- Monitoring of crops and fauna in specific areas.

The use of drones and the rapid development of communication and sensor technologies inaugurates the so-called 4th agricultural revolution, offering a variety of new abilities to all actors involved. However, certain restrictions such as air space regulation rules, privacy protection directives and technical hazards should be taken into consideration for enabling a truly wide and effective drone deployment.

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