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Drones in sustainable agricultural systems: A literature review

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***Abstract*—The article focuses on the application of 5G technology in drones to improve sustainable agriculture. It highlights the use of drones equipped with cameras, taking advantage of 5G networks to cover large areas and access remote areas, enabling more effective monitoring of fields and crops. Extensive research was conducted in eight digital libraries, where 186 relevant studies were initially found. After detailed analysis, 25 studies were selected that met the research criteria. It was observed that precision agriculture presents a wide variety of techniques and tools, with a diversity of cameras and sensors currently in use. These tools have practical applications ranging from assessing evaporation and soil moisture to monitoring crop nutrients and crop yields. The study identifies several challenges that need to be addressed, such as integrating data from different sources and optimizing algorithms for more accurate analysis. However, precision agriculture presents itself as a valuable tool with the potential to positively transform agricultural practices, fostering sustainability and efficiency in the sector.**

***Keywords*—agricultural systems; drones; efficient agriculture; sustainability; 5G technology**

I. Introduction

Since World War I, the military has used drones for remote surveillance. Over the last decade, these technologies have evolved, and farmers have begun to use them to monitor their fields and promote sustainable agriculture initiatives. It is estimated that by 2030, between 80% and 90% of the drone market will go to agriculture. Currently, unmanned aerial vehicles are experiencing a significant increase in their use and development, being increasingly used in daily civil and commercial activities, not only in the military field. In this context, these devices continue to acquire greater complexity in their programs, "learn" more and have access to a variety of tools and applications [1].

These advances allow the implementation of more accurate control methods, which represents continuous development in this field. In particular, guided landings and runway monitoring are crucial for all commercial flights and need significant improvements. These improvements are essential for gifts to perform their tasks correctly, protecting the vehicle, its components and the data collected [2].

To address the problems raised, a review of the literature was carried out to collect and analyze research regarding the use of drones with 5G intelligence.

In summary, performing search processes in these libraries (Scopus; ACM Digital Library; Science Direct, and IEEE Xplore) found 186 studies (published articles), that were deleted anomalous and repeated records leaving a total of 161, of which it was verified that 25 coincide with our needs (This means that they are related to the topic under discussion and meet the inclusion requirements).

Finally, the selected documents are analyzed and classified to answer the following questions:

RQ1: What are the benefits of using 5G drones for agriculture?

RQ2: How do drones connect to 5G networks and technologies currently available?

RQ3: What are the advantages of 5G technology in drone farming versus 4G networks?

RQ4: How can drones help reduce the use of chemicals in agriculture?

RQ5: What are the challenges of implementing drones in agriculture using 5G technology?

II. Background

More than 51,000 unmanned aerial vehicles, 11,000 jobs, and an economic impact of more than 1.2 billion euros in 2035. These are the figures handled by the Ministry of Public Works on the drone industry in Spain, collected in the Strategic Plan for the Development of the civil drone sector 2018-2023 presented this Monday by Minister Iñigo de la Serna, see Fig. 1.

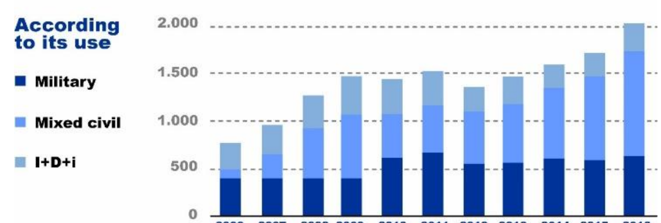

Fig. 1 Evolution of the number of drone models according to their global scope.

Agriculture is an evolving industry and 5G technology is changing the way producers work and manage their crops [3]. With high speeds, low latency, and the ability to connect multiple devices and sensors [4]. In addition, one of the most important benefits that 5G technology brings to agriculture is the possibility of performing "precision agriculture" [4]. It allows farmers to instantly monitor crop conditions such as soil moisture and temperature [5], [6], [7]. Collecting data to optimize irrigation, fertilizer, and pest control, resulting in more efficient use of resources and increased productivity, see Fig. 2.

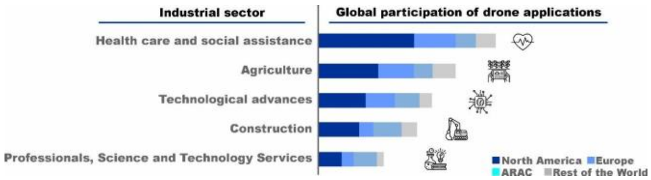

Fig. 2 Enterprise Drone Applications.

As he points out [6], "Agricultural drones, also known as Unmanned Aerial Vehicles (UAVs), have proven to be crucial tools in farm and crop management". Its ability to capture high-resolution data, monitor the condition of fields, and apply agricultural inputs accurately has led to notable improvements in the efficiency and sustainability of agriculture [8].

5G technology stands out as a key enabler to take sustainable agriculture and drone operational efficiency to a new level [6]. As stated, "5G connectivity promises ultra-fast data transmission speeds, low latency, and unprecedented massive network capacity". This results in unmatched communication between drones and ground-based monitoring systems [9], [10], [11], allowing for greater automation, real-time decision-making, and accurate management of agricultural resources [12].

In this article, we seek to identify advances in the use of UAVs as an effective and accurate agricultural tool and determine the future of this technology in this area of research, a thorough literature review and systematic mapping of relevant research is undertaken to explore the increasingly important role of drones and 5G technology in building sustainable agricultural systems [13], [14].

The implementation of drones in sustainable agricultural systems presents several challenges and requirements that must be considered. It is important to note that collaboration between farmers, technology companies, academic institutions and government entities is essential to overcome these challenges and harness the full potential of drones in sustainable agriculture.

- Costs.
- Technology.
- Training.
- Rules and regulations.
- Data integration.
- Privacy and security.
- Scalability.

III. METHOD

A. *Description of research questions*

The purpose of this article is to discuss knowing 5G technology used in drones and applied in sustainable agricultural systems. This allows for greater and better surveillance of fields and crops. Related questions were asked according to the research:

RQ1: What are the benefits of using 5G drones for agriculture?

RQ2: How do drones connect to 5G networks and technologies currently available?

RQ3: What are the advantages of 5G technology in drone farming versus 4G networks?

RQ4: How can drones help reduce the use of chemicals in agriculture?

RQ5: What are the challenges of implementing drones in agriculture using 5G technology?

B. *Definition of search criteria*

Primary study research is divided into two research steps. In step one, the search chain is established considering the most relevant terminology related to the topic under study. step two, the electronic databases necessary to perform the search will be selected.

Three keywords were used in the research questions derived from key documents, and from an interview with experts in the field of agriculture. Each of these keywords represents a category that contains its respective related terms, see Table I.

TABLE I
CATEGORIES OF KEYWORDS AND THEIR RELATED TERMS, OWN ELABORATION.

Reference	***Category***	***Related terms***
C1	Technology	Drones and agriculture
C2	Sustainability	Sustainable agriculture
C3	Agriculture	Agricultural systems

To generate the final search string, the Boolean operators "AND" and "OR" were used to combine the related terms in the three categories (C1, C2 and C3), as shown below:

(technology AND drones AND agricultural) AND (sustainability OR sustainable agriculture) AND (agricultural AND agricultural systems).

The list was then narrowed to focus the search [15], [16], [17], resulting in a database covering the most relevant educational technology conferences and journals. The following electronic databases were selected:

- ScienceDirect
- Scopus
- IEEE Xplore
- ACM Digital Library

Each selected database search engine uses different mechanisms and criteria. Therefore, the search string was adapted to each database, to perform an advanced search in titles, abstracts, and article keywords, thus obtaining a first set of primary studies, see Table II.

TABLE II
SEARCH CHAIN BY DATABASE.

Databases	*Search string*	*Articles*
ACM Digital Library	("technology")+("drones")+("agriculture") ("sustainability")+("sustainable agriculture") ("agriculture")+("agricultural systems")	4
IEEE Xplore	(technology OR drones OR agriculture) (sustainability AND sustainable agriculture) (agriculture and agricultural systems)	5
ScienceDirect	TAK ((technology or gifts and agriculture) Y (sustainability or sustainable agriculture) AND ("agriculture" or agricultural systems)	7
Scopus	TITLE-ABS-KEY ((technology or agricultural drones) Y (sustainability or sustainable agriculture) AND ("agriculture" or agricultural systems)	9
TOTAL		25

C. Concepts of exclusion criteria and inclusion

The following exclusions (E) and inclusion criteria (I) were established to eliminate and/or add articles to the analysis as follows:

I1: Articles published in the last five (10) years (2013 - 2023).

I2: If several articles are related to the same study, only the most recent one is selected.

I3: If an article describes more than one study, each study is evaluated individually.

I4: If there are short and complete versions of the same study, the latter is included.

E1: Technical reports and documents that are available in the form of abstracts or presentations (grey literature) and secondary studies (reviews and systematic mapping).

E2: Articles in languages other than English or Spanish.

E3: Articles that do not present studies related to education.

E4: Articles that do not present studies related to computer science and related.

Once the inclusion and exclusion criteria are defined, the abstracts and titles of the papers are reviewed considering those most relevant to the article. Then, they are read, analyzed, and categorized completely, extracting the most important data.

IV. ANALYSIS AND RESULTS

The section presents the results of the research article. The main objective is to give an overview of how drones are being used as a technological strategy for agricultural systems and sustainability based on 5G technology.

In Figure 3 you can see how the steps listed in the statements are executed A, B, and C. Firstly, when exploring the selected databases, 186 articles were obtained, of which 27 records with little information were eliminated, which resulted in a total of 159 articles.

Of these, it was found that 24 of them are housed in multiple databases, so duplicates were also eliminated, leaving only one copy of each article in the records. For the next step, 135 articles remain to be examined. Next, the incorporation and discard criteria (I1 + E1 + E2) are applied to the 135 articles, such as those published in the last five (5) years, discarding records that do not correspond to published articles, books, and the written in languages other than English or Spanish, leaving a total of 132 articles.

It is intended to explain current and future advances in the use of unmanned aerial vehicles in precision and efficient agriculture. In any case, this machine continues to develop, and its application has expanded to cover various fields of human knowledge, in science and engineering, and especially in the topic of precision agriculture of which we speak.

These are unmanned aerial vehicles that have no military application, which can be: commercial drones used to sell photogrammetry, multimedia, and other services; amateur drones used as a hobby; drones used by governments, national armies, firefighters, drones used in rescue operations [18].

The drone controls its flight plan and the technicians, although they cannot directly control the command center, can decide what actions to take. This system is the most used in precision agriculture and photogrammetry. They are the most used because they are extremely stable and can perform simple maneuvers and many maneuvers, in addition to flying statically in the positions we indicate [19].

In a special section of this document, 5 detailed questions give answers to the results obtained. Here, the questions are designed to explore, analyze, and comprehensively understand the information presented in the results, thus providing a structured guide.

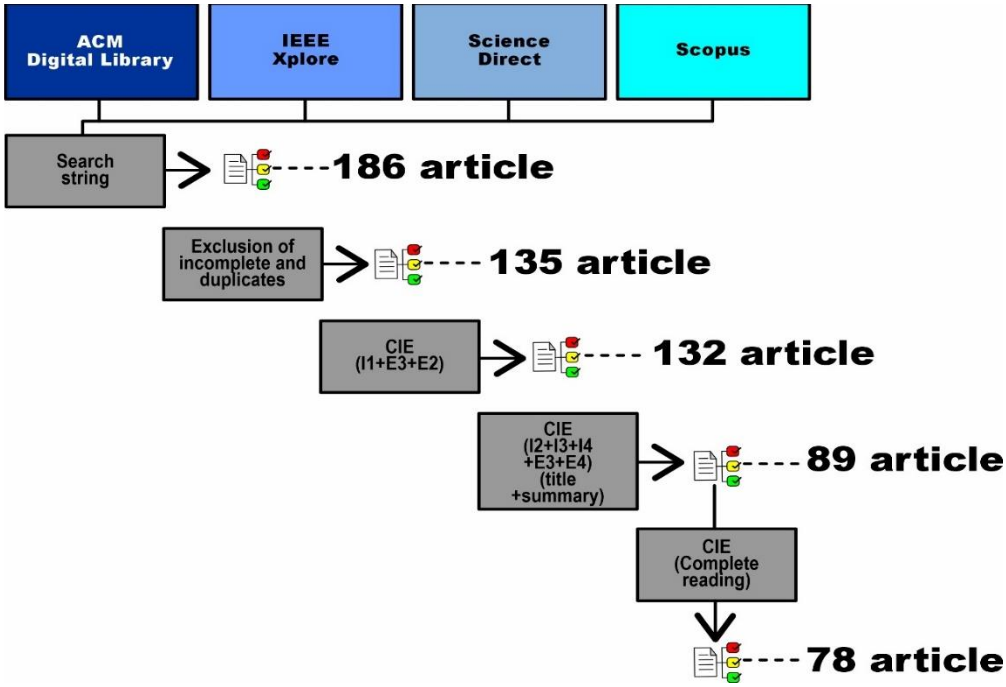

Fig. 3 Overview of the article filtering process.

A. *RQ1: What are the benefits of using 5G drones for agriculture?*

One of the main benefits that 5G technology is bringing to agriculture is the possibility of implementing "precision agriculture". Connected sensors and devices allow growers to monitor in real-time the condition of crops, such as soil moisture, temperature, and air humidity. This allows them to make decisions based on data to optimize irrigation, fertilization, and pest management, resulting in more efficient use of resources and greater productivity, see Table III.

TABLE III
BENEFITS OF USING DRONES WITH 5G TECHNOLOGY.

Benefits	***Articles***
Precision agriculture	[22], [23], [24]]
Sensors and connected devices allow producers to monitor in real time.	[25], [26], [27]
Good fertilization	[20], [21]
Pest management	[20], [28]
A higher connection speed	[25], [27]
Increased capacity to connect multiple devices simultaneously.	[20], [28]
Zero latency	[20], [21]

A higher connection speeds. 5G connectivity offers unprecedented data communication power, with more transmission channels. Not only this, but these are wider than those of 4G. Increased ability to connect multiple devices simultaneously.

Zero latency. This is the time it takes a connected device to request a server action and get a response. It is estimated that 5G networks have a latency of one millisecond, in contrast to the 200 milliseconds of 4G [20], [21].

B. *RQ2: How do drones connect to 5G networks and technologies currently available?*

The drone connects to the 5G network via the built-in modem and 5G antenna. This high-speed, low-latency connection allows instant data transmission and remote control of drones, see Fig. 4.

Fig. 4 Drones are used in agriculture, and multi-rotating (Quadro copter).

There are different types of agricultural drones in the international market. Multirotating quadcopters (30-minute flight time, 65-hectare flight coverage) and fixed-wing aircraft (30–90-minute flight time, 120-3800 ha flight coverage) are the most commonly used in this area, as we can see in Figure 4. An important aspect is the sensor used. The sensors that capture RGB and NIR color images do not need to be manufactured or adjusted for agriculture.

Fig. 5 Images according to camera types and spectra (RGB and NDVI).

Figure 5 shows these two types of images [12], [29]. The images had to be geolocated to be able to locate them accurately and overlay them to create a map of the plantation. The brands used for the mentioned sensors are found in Canon, Sony, Go-Pro, and many more. Cameras that operate in digital agriculture are manufactured with suitable lenses and sensors, which increase in price due to the technology being more optimized. There is a wide variety of cameras suitable for agriculture such as the Parrot Sequoia Plus and the Micasense Red-Edge. They are optimized and lightweight cameras that are specially manufactured for operation with agricultural drones. On the other hand, there is an important aspect and that is the location on the ground: drones are equipped with a built-in GPS that makes it easier to locate the drone during flight time. Currently, the device achieves an accuracy of +/- 3 m. Drones are used in agriculture, and multi-rotating (quadcopter).

In the products of these regular flights, there are maps captured by commercial drones that are NDVI or similar. The NDVI is an index that generalizes the health status of the captured plants. If the NDVI percentages are close to 1.0, the vegetation is expected to be healthy; as for values close to 0.0, the captured map shows clear ground or extensive vegetation. Different cameras provide varying NDVI values for the same time of flight and the same field, which could cause errors to the consumer. However, cameras with agricultural technologies can provide a standard NDVI compared to other agricultural cameras with different technologies such as satellites, see Fig. 6.

With the increasing availability of thermal proximity sensors, UAV cameras, and Foucault covariance radiometers, it can be assumed that the information produced by these sensors is interchangeable or compatible [30]. This assumption is often maintained for estimating agricultural parameters such as soil cover and temperature, energy balance components, and evapotranspiration. However, environmental conditions, calibration, and terrain configuration may affect the relationship between the measurements of each of these thermal sensors.

With reductions in water availability in much of California due to drought and competing water use interests, it is important to optimize irrigation management strategies. According to [31], satellite-derived evapotranspiration (ET) maps and the proportion of actual ET to reference (f RET) based on Earth surface temperature (LST) images are very useful remote sensors to control crop water use and stress in vineyards. Similarly, and with higher resolution, we can establish that the evapotranspiration maps resulting from the application of drone flights and specialized sensors are very useful for efficient agriculture.

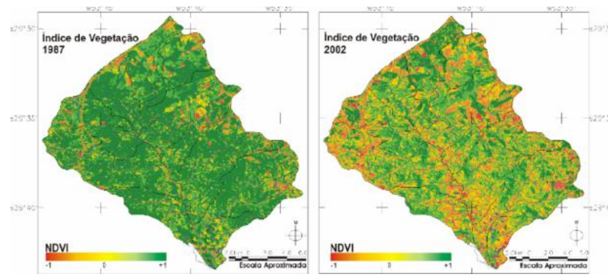

Fig. 6 NDVI comparison (smaller row) between the Red, Green, Blue, and long-pass Normalized Difference Vegetation Index filters (left column) and the RED and NDVI spectral filters (right column).

C. *RQ3: What are the advantages of 5G technology in drone farming versus 4G networks?*

Zero latency. This is the time it takes a connected device to request a server action and get a response. It is estimated that 5G networks have a latency of one millisecond, in contrast to the 200 milliseconds of 4G, see Fig. 7 and Table IV.

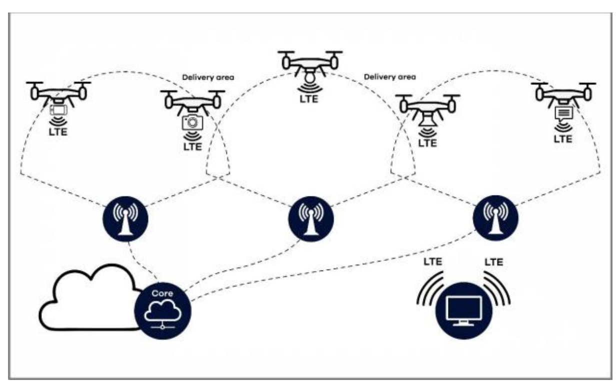

Fig. 7 Official Telecommunications Engineers Association, 2020.

TABLE IV
4G VS 5G.

4G	*5G*
They can operate in the bands of 800 Mhz;1,8 GHz: and 2,6 Ghz in Spain (CNAF)	Order download speeds of approximately 10 Gb/s
They can operate in the bands of 800 Mhz;1,8 GHz: and 2,6 Ghz in Spain (CNAF)	Above latency less than 1 millisecond
Use multiple access based on OFDMA and SCFDMA digital transmission techniques	700 Mhz band. Minimum speed 100 Mb/s.
Latency (data transfer delay) can be up to 5 milliseconds	Bands 1500 and 3500 Mhz. BW possible:100,90 and 80 Mhz. For urban areas thanks to "Smart cells". Speeds 1 to 3Gb/s
Can operate in FDD and TDD modes	Band 26 GHz. BW possible:400 or 500 Mhz. Shorter range and is possible for "hotspots". Speeds up to 10 Gb/s

An important aspect of these new networks is the ease of interconnection between LTE (4G) and 5G-NR (New Radio) networks, where 5G modems can simultaneously access LTE and NR carriers. The latter is known as option 5G-NSA (Non-StandAlone), see Fig. 7.

D. *RQ4: How can drones help reduce the use of chemicals in agriculture?*

The main task of the drones is to monitor agricultural plots. To do this, the drone captures images that, after proper computer processing, can provide precise data on different aspects, such as:

- The water stress of crops.
- Nutritional deficiencies of plants.
- The incidence of pests, diseases, and weeds in crops.
- The state of development and phenology of plants.

This data can be carried on a pen drive to the on-board computer of the tractor. In this way, the farmer can apply doses of agrochemicals (such as fertilizers, pesticides, and herbicides) much more adjusted to the needs of the crop and only where necessary[32], [33]. This optimization in the use of agrochemicals saves money and time, as well as benefits for the environment.

Agricultural drones allow farmers to access a wealth of data, which can be used to improve decision-making and increase the profitability of the farm. With the help of drones, data can be collected on crops, livestock, soil quality, nutrient levels, climate effects, and rainfall. With all the data a very precise overview of the state of the crop is obtained, as it is based on detailed and very reliable data [13], [14].

E. *RQ5: What are the challenges of implementing drones in agriculture using 5G technology?*

Today, the agricultural industry faces a powerful challenge. According to the Food and Agriculture Organization of the United Nations (FAO), the world's population will need 70 percent more food in 2050 than it did in 2009. Experts believe that increasing the productivity of the field depends on technology. Specifically, 5G innovation.

Agricultural innovation based on 5G still has challenges to overcome, such as the lack of coverage in rural areas. However, its rapid evolution brings closer and closer its application to agriculture, where it represents a real revolution [6], [12], [27].

When considering the integration of drones into sustainable agricultural systems, connectivity and communication protocols are key aspects that need to be addressed, especially in regions with telecommunications coverage limitations. The transition to advanced technologies such as 5G and comparison with IoT protocols can provide valuable insights to improve efficiency and sustainability in agriculture.

Communication challenges in remote agricultural regions: In many agricultural regions of the world, telecommunications coverage is limited, which can make it difficult to transmit data from drones and other IoT devices.

Transition to advanced communication technologies, such as 5G: Transition to advanced communication technologies, such as 5G, can improve connectivity in remote agricultural areas, enabling faster and more reliable data transmission from drones and other IoT devices.

V. CONCLUSIONS

The literature review on drone technology for sustainable agricultural systems, with a particular focus on 5G connectivity, reveals an emerging landscape of advanced technologies with the potential to significantly transform agriculture. The application of drones in modern agriculture has proven to be a versatile tool, providing solutions ranging from crop monitoring to the precise application of inputs.

The connection through 5G technology quickly helps not only the transfer of data between drones and cloud systems, but also helps farmers make decisions quickly and accurately. Employing the ability of drones to collect real-time data on crop status, soil quality and other crucial parameters, farmers can optimize input use and minimize waste, increasing farm efficiency and sustainability. agricultural production. Efficient collection of information and its immediate transmission to cloud analytics systems offer unprecedented opportunities for informed decisions in real time.

However, despite promising prospects, it is important to address potential challenges, such as data security and the infrastructure needed to support 5G connectivity in rural areas. In addition, continued collaboration between industry, farmers, and regulators is required to ensure the effective and ethical implementation of these technologies.

Data collection by drones in existing agricultural systems is of utmost importance to maximize their value. Farmers can use software and data analytics platforms to interpret the information collected by drones and optimize their farming practices.

Drones can generate detailed maps of agricultural fields, helping farmers identify specific patterns and areas that require attention. With 5G connectivity, this data could be quickly transmitted to Geographic Information Systems (GIS) in the cloud, facilitating faster and more accurate analysis.

Drones can be used to accurately apply fertilizers, pesticides, or irrigation in specific areas of the field. 5G connectivity could improve the ability of these drones to receive and process information in real time, allowing more precise and efficient adjustments in the application of inputs.

Many agricultural drones are equipped with autonomous flight systems that allow them to follow pre-programmed routes and perform specific tasks without constant human intervention. 5G connectivity could improve communication and coordination between multiple drones, which would be especially useful on large farms.

5G connectivity facilitates fast and efficient data transmission to the cloud. This allows data collected by drones to be processed in real-time or later in advanced analysis systems, which can provide farmers with valuable information for decision-making.

Ultimately, the convergence of drones and 5G in sustainable agriculture opens new opportunities to improve operational efficiency, reduce environmental impact, and contribute to the development of smarter and more sustainable farming practices.

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