THE USE OF DRONES AND SENSORS IN AGRICULTURE

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Abstract

This paper presents the possibilities and benefits of using drones in agriculture, especially in precision agriculture. In the first part of the paper, basic notions regarding drones in the agricultural context, legislative and flight safety aspects are presented, defined and clarified. In the second part of the paper, the most used sensors in agriculture are introduced, the benefits and the main stages of using drones in agriculture are presented, related to the life span of a crop and the duration of the agricultural year. This paper encourages and justifies the use of drones both in current agricultural operations and by applying photogrammetric methods and generating digital products such as orthophoto plans, thematic maps and digital terrain models.

Key words: *drone, sensors, agriculture, photogrammetry*

INTRODUCTION

Agriculture can be defined as the activity that deals with raising animals and cultivating plants and other life forms for the purpose of obtaining food, bio-fuel, medicinal products, and other products necessary for human living. The development of sustainable agriculture is important from a socio-economic point of view. The development of agriculture and the application of modern and efficient technologies generate an increase in food production, income, and living standards [4]. At the same time, it generates jobs and contributes to the reduction of social differences between rural and urban environments. Modern technologies for data collection, processing and analysis find their usefulness in more and more fields of activity, including agriculture. Among the modern technologies applicable in agriculture, we can mention photogrammetric methods, GIS-type products, remote sensing, and the use of drones [1,10]. They have the role of streamlining activities, reducing efforts, and costs and maximizing profitability. In addition, their application in precision agriculture generates higher production and increased crop quality [8].

Drones are one of the modern methods increasingly used in agriculture and offer the possibility of fast, safe, and cost-effective data collection, as well as operational use in agricultural activities. The use of unmanned aerial vehicles (UAV) leads to improved productivity and profitability of agricultural remote sensing operations [8,10]. The objective of this paper is to enable stakeholders to identify possible opportunities for the adoption, improvement, and application of drones in agriculture.

MATERIALS AND METHODS

Recently, drones have proven their usefulness and efficiency in more and more fields of activity [1], from agriculture to the organization of air shows. However, to fully understand the benefits, dangers, and responsibilities of using drones, both technical and legislative aspects must be defined and known.

Definitions

The term “drone” is used generically to define a remotely controlled vehicle. Thus, the detailed and correct definition of similar terms is required, as follows [3,5,7]:

• Drone – a vehicle that can move autonomously, without the intervention of the human factor (but they can be controlled remotely). Although drones can travel through air, water, or land, this article refers strictly to air travel.

• UAV (Unmanned Aerial Vehicle) – represents a narrowing of the types of drones and is limited to aerial vehicles that have the ability to travel autonomously or remotely controlled, without a pilot on board.

• UAS (Unmanned Aerial System) – includes all components of a flight system: drone, radio control, GNSS sensors, accessories used, the human factor (pilot and/or operator), photo/video cameras, additional loads, telemetry systems, software components, etc. Thus, UAV is a component of UAS.

Components

A UAS consists of several components and accessories (Figure 1), depending on the way of manufacture, the purpose of use or the field of activity. Thus, the most common components of a UAS, but not limited to these, are: the UAV itself (as an aircraft without a pilot on board, but with the ability to move autonomously or directed; radio control (as a tool for steering of the UAV by the pilot); photo/video camera, light filters, multispectral cameras, LIDAR, thermal imaging, etc. (if attached outside the manufacturing process); GNSS sensors; software component (any software product used to planning, conducting, controlling or supervising a flight); Pilot/operator (human or legal factor); Other components: telemetry elements, launch pads, night flight lights, FPV (First Person View) glasses, etc.

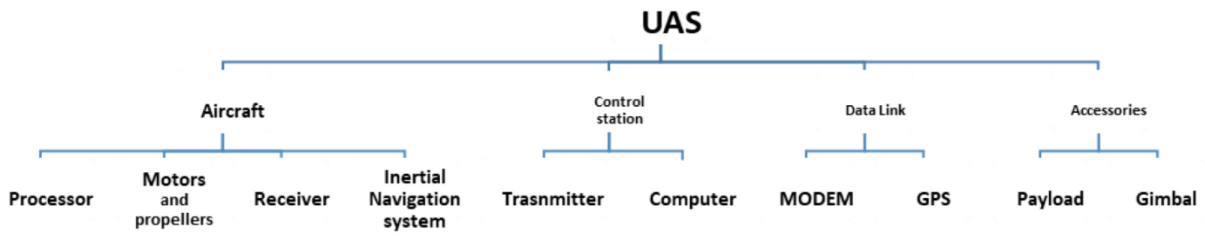

Figure 1. Subsystems of an unmanned aerial system [6,7]

Legislation

Along with the increase in the use of drones (by specialists, but also by the general population) the number of incidents and accidents caused by the irresponsible use of drones has also increased. Thus, the need to regulate their use arose and regulations were drawn up (at European and national level) with the aim of ensuring the protection of the population. The authorities involved in the development and implementation of these regulations are EASA (European Union Aviation Safety Agency) and AACR (Romanian Civil Aviation Authority). The level of risk in the use of drones is determined by the types of operations carried out (Table 1) and their classification [3,5,7].

Table 1. *Categories of operations*

Category	Risk	Details	Subcategory
Open	Low	Does not require a flight permit issued by the AACR; Supervision of operations is the responsibility of local authorities.	*A1* – operations near isolated persons are allowed. Overflying uninvolved persons must be avoided, and overflying crowds of people is prohibited; Flight within the visual line of sight (VLOS – Visual Line of Site); Maximum altitude 120 m.
			A2 – operations at a horizontal safe distance for non-involved persons are allowed; Flight within the visual line of sight (VLOS – Visual Line of Site); Maximum altitude 120 m.
			A3 – operations without non-involved persons. Flight within the visual line of sight (VLOS – Visual Line of Site); Horizontal safety distance 150 m from residential or commercial areas; Maximum altitude 120 m.
Specific	High	Requires obtaining a flight authorization before flying, unless the operation is covered by a standard scenario found in the annex to EU regulation 2019/947. Operations are overseen by the AACR.	*Assessing the risk of the intended operation* by applying the SORA (Specific Operations Risk Assessment) methodology or an equivalent methodology.
			Predefined Risk Assessment (PDRA – Predefined Risk Assessment) – it includes the most common scenarios, so that the flight guidance issued by EASA can be followed and applied.
Certificated	Major	Requires UAV certification; Requires pilot licensing; Requires obtaining a flight permit from the AACR.	*Type 1 operations*: international flight of certified cargo drones
			Type 2 operations: drone operations in urban or rural environments using predefined routes
			Type 3 operations similar to type 2 operations, but involves the presence of a pilot on board the drone

In addition to the category of operation to be carried out, the restrictions imposed by the class in which the drone was assigned must also be taken into account. EASA regulations provide for the classification and labeling of drones in the following classes: C0, C1, C2, C3, C4, private building).

Safety of the flight

Both for legislative reasons and to ensure the safety of people (involved and not in the drone flight), safety measures must be observed and good practice recommendations applied. These include the appropriate training of personnel, technical conditions, meteorological conditions and environmental conditions. A basic principle of flight safety is **MEUH** (Table 2) (**M**eteorology, **E**nvironment, **U**AS, **H**uman) [3,7].

Table 2. *UAV flight safety criteria*

Meteorology	It affects both the human factor and the capabilities of the equipment.	
	Wind	It influences flight by speed and direction. Special attention must be paid to updrafts and downdrafts that can form due to temperature differences or existing vertical walls.
	Temperature	It directly affects the lift of the drone. Low temperatures increase the density of the air and implicitly the lift of the drone, but decrease the performance of the batteries and implicitly the flight autonomy. Increased temperatures decrease the density of the air and generate additional effort on the engines, which leads to increased consumption and reduced flight range. The temperature also influences the capacity of the human factor.
	Precipitation	It varies according to form (rain, snow, hail, etc.), intensity, and duration. Precipitation also affects the pilot's ability to properly maneuver the drone, diminishes the degree of visibility and reduces the range of the radio control.
	Fog	It favors the formation of ice on the propellers, which can cause a reduction in lift and the drone to crash.
Environment	Flight environment, flight conditions, and restrictions.	
	Geosecurity areas	Areas where flying is not allowed or traffic are strictly regulated by the authorities.
	Altitude	The altitude of the flight area can affect the performance of the drone, especially through atmospheric rarefaction. Obstacles and bumps that can generate turbulence. They may cause the connection between the drone and the remote control to be interrupted, the drone to be lost or crashed.
	Terrain profile	Obstacles and bumps that can generate turbulence.
	Electromagnetic interference	They may cause the connection between the drone and the remote control to be interrupted, the drone to be lost or crashed.
UAS	The totality of the technical aspects and capabilities of the equipment	
Human	Human factor: pilot, observer, operator, people on the ground, people in the air. Evaluation of the pilot's state using the **"I'M SAFE"** methodology: **I**llness, **M**edication, **S**tress, **A**lcohol, **F**atigue, **E**motions [5,7]	

Sensors used in agriculture

One of the main factors that determine the usefulness of drones in agriculture is the sensors they are equipped with. There are several sensors that can be mounted on drones that can be successfully used in agriculture (Figure 2). Among them we mention [2,4,10] (Table 3):

• RGB sensors – represent digital cameras as they are known to the general public. They allow the acquisition of data from the visible spectrum (RGB – red, green, blue); they are relatively cheap sensors and are the starting point for farmers who start using drones for their activities.

• NIR sensors (Near Infrared sensors) – capable of acquiring images in a combination of NIR and RGB; they are more expensive than RGB sensors, but cheaper than multispectral sensors and do not have their accuracy either.

• Multispectral sensors – are typically cameras with 5-8 lenses, each capturing a different wavelength frequency, typically including visible RGB, NIR, and Red Edge (between Red and NIR).

• Thermal sensors – capture infrared data, generated by the temperature of monitored objects or surfaces.

• LiDAR (Light Detection and Ranging) sensors – used to capture detailed 3D models; they have the ability to penetrate vegetation, so they can be used to generate 3D terrain models or for volumetric biomass calculations.

Table 3. *Sensor agricultural applications*

	RGB	NIR	Multispectral	Thermal	LiDAR
Terrain Mapping	X	X	X		X
Soil Management	X	X	X		X
Crop Establishment	X	X	X		
Vegetation Health Monitoring	X	X	X	X	
Disease Detection	X	X	X		
Vegetation Growth and Yield Estimation	X	X	X		X
Irrigation Management	X	X	X	X	
Weed Detection	X	X	X		
Damage Assessment	X	X	X		
Holistic Crop Management	X	X	X	X	X

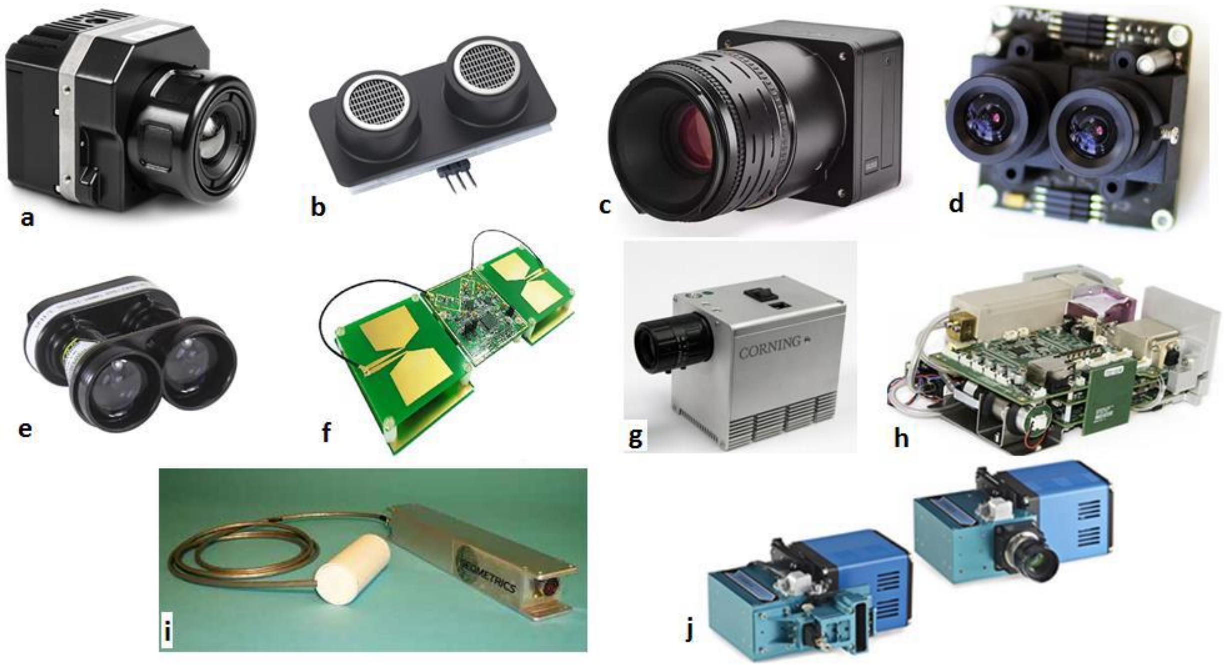

Figure 2. Examples of sensors: (a) infrared sensor, (b) ultrasonic sensor, (c) RGB camera, (d) stereo cameras, (e) laser telemeter, (f) ultra-wide band radar (UWB), (g) hyperspectral sensor, (h) magnetic sensor, (i) gas detector, (j) visible and near infra-red specter sensor (VNIR) [7]

RESULTS AND DISCUSSIONS

The benefits of using drones in agriculture

The use of drones in agriculture supports and encourages precision agriculture, i.e., the implementation of methods by which farmers efficiently manage crops and livestock. The basic principle is to apply exactly what you need, where you need it and how much you need it. Thus, the efficiency of irrigation, fertilization, and the use of pesticides is ensured, and at the same time, the increase in productivity, quality and yield is also ensured.

The main benefits are [4,10]:

• Eliminating uncertainty by receiving data almost in real time, which allows the rapid adoption of the best measures;

• Increasing yield by streamlining farm activities; at the same time, early identification of the crop health problems is possible, so that corrective measures can be adopted;

• Saving time – the use of drones ensures that data is obtained quickly, when and where it is needed, and farmers can focus on farm activities;

• Planning – reconnaissance flights and land mapping can be done throughout the year, so farmers have the opportunity to streamline and improve practical and farm management activities.

Limitations

The main limitations regarding the use of drones in agriculture are generated by the high costs of professional equipment and high-performance sensors. Cheap drones have a rather low level of stability and accuracy, so the results obtained are also of lower quality.

For the implementation of some strategies regarding the use of drones in agriculture, both legislative (flight restrictions, areas where flight is not allowed, certified pilot, insurance policy, etc.), financial and technical (maximum mass, flight autonomy, possibilities for planning flight routes, maximum flight altitude, sensors that can be used, the existence of real-time applications, etc.) aspects must be taken into account.

Among the limitations we can mention:

• connectivity limitations – in many rural areas, phone or internet signal is not available, which makes it difficult to use drones effectively;

• weather and environmental conditions – safe use of drones can only be done in favorable weather conditions;

• knowledge and skill – qualified and certified personnel is needed to operate drones.

Uses in agriculture

In agriculture, drones can be used in all stages of a crop's life, from spatial planning to harvesting [2,4]. Next, the main stages and ways of using drones in agriculture are presented.

Use before planting, for:

• *land mapping* (Figure 3) – by using RGB sensors, photogrammetric products can be generated, which can constitute the graphic basis for crop planning. These include the generation of digital models to assess the profile and slope of the land. Crop planning based on digital products is carried out much faster, and these can also constitute input data for the automation of agricultural equipment.

• *soil mapping* – data collection from the field can be done quickly using drones, thus optimizing soil management activities. At the same time, uncertainties regarding the condition of the soil can be eliminated or reduced and the time spent on the field is reduced. By using drones equipped with RGB sensors, soil data can be collected that highlights the degree of soil compaction, the level of erosion, etc. By using NIR or multispectral sensors, soil types and soil moisture levels can be identified.

Figure 3. Land mapping by drone [9]

Use immediately after planting, for:

• *crop surveillance* – by using drones, farmers can obtain almost real-time data on the rate and degree of crop development. Using RGB, NIR, or multispectral sensors, the vegetation level of crops can be determined and areas that need replanting can be identified. The data collected in this way can also constitute evidence in the case of claiming compensation from insurance funds.

Use during the season, for:

• *monitoring the level of vegetation, crop health and disease detection* (Figure 4) – a major advantage of using drones in agriculture is the ability to quickly and accurately monitor crop health, covering large areas of land with minimal effort (especially compared with classic surveillance methods). Early detection of potential diseases and affected crops allows for the adoption of documented corrective measures, thus limiting or even eliminating possible losses. Based on the data collected by drones and by applying specific algorithms, digital models of crops can be generated on which areas with potential problems or ailments can be highlighted. Crop health is the most monitored parameter, using RGB, NIR, or multispectral sensors. By using RGB sensors, crop variation can be determined based on the Visible Atmospherically Resistant Index VARI. NIR and multispectral sensors are capable of detecting and distinguishing crop stress levels based on the Normalized Difference Vegetation Index (NDVI). Cameras equipped with thermal sensors can also be used to detect the hydrological stress of crops by detecting plant temperature variations. In this way, possible irrigation problems can be detected and fixed.

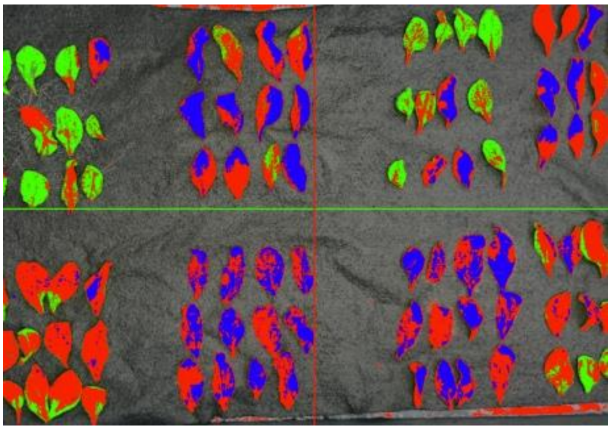

Figure 4. Disease detection by drone [11]

• *documented and applied decisions* – the data collected with the help of drones facilitates the adoption of documented decisions regarding the effective management of crops. For example, plans for fertilization or pesticide application can be generated based on crop health data. In addition, the use of drones in precision farming operations can reduce the consumption of substances and time, and reduce the risk of environmental pollution.

Use in the second half of the season, for:

• *estimating the level of vegetation and yield* – monitoring the growth rate and crop variation can provide useful information for estimating yield and financial indicators. The use of RGB, NIR or multispectral sensors allows the acquisition and analysis of data at different times of the culture. In this way, the efficiency of each stage can be evaluated (e.g., the efficiency of fertilization), unknown aspects can be eliminated and informed decisions can be adopted.

Use after the end of the season, for:

• *crop management* – the analysis of the collected multi-year data allows the identification of trends and anomalies for each crop or area. Through the analysis of multi-year data, farmers have the opportunity to identify deficient areas or crops, to adopt corrective measures, to apply land improvement, irrigation or drainage measures, etc. By knowing and understanding historical data, future crop decisions can be tailored.

Use throughout the year, for:

• *detection of weeds and pests* (Figure 5) – by using RGB, NIR, or multispectral sensors and applying specific algorithms, deficient areas (regarding the presence of weeds or pests) can be detected and mapped.

• *irrigation management* – in any crop, both irrigation and drainage systems must be managed efficiently. Detecting potential problems (water deficit or surplus) and timely intervention can save the crop and reduce financial losses. Thus, by using drones, data can be quickly collected on the basis of which decisions can be made. Also, by using drones for photogrammetric flights, digital models of the land can be generated and the slope of the land highlighted, areas at risk of flooding or erosion can be identified.

• *damage assessment and limitation* (Figure 6) – farms are subject to extreme weather phenomena. In the event of the occurrence of such phenomena, it is very important to assess the damage caused to farms, crops and livestock. Drones can help quickly obtain data on losses and indicate affected areas. Based on this data, farmers can assess losses, estimate the negative impact on yield and take documented measures.

Figure 6. Drone flight over flooded fields [12]

CONCLUSIONS

As in other fields, with the technological evolution drones have also found their applicability in agriculture. Their use presents major benefits in agricultural operations, especially in precision agriculture. Drones can be equipped with various sensors (RGB, NIR, multispectral, etc.) and can be successfully used in agricultural operations, and by applying specific algorithms (VARI, NDVI, etc.) detailed analyzes of crops (health status, grade of development, level of hydration, etc.). At the same time, by combining the use of drones with photogrammetric methods, orthophotoplans and digital models of the land can be generated, based on which surface surveys and future crop planning can be done.

The use of drones in agriculture presents some limitations and requires compliance with legislative restrictions and good practice rules.

The benefits of using drones in agriculture are both economic (quick and cheap data collection, increasing efficiency, reducing costs) and operational (ensuring staff safety, monitoring hard-to-reach areas, accuracy and quality of data collected).

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