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REVIEW ARTICLE

Computer vision for unmanned aerial vehicles in agriculture: applications, challenges, and opportunities

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Abstract

Unmanned Aerial Vehicles (UAVs), commonly called drones, have gained significant attention in agriculture due to their potential to revolutionize traditional farming practices. This paper explores the integration of computer vision techniques with UAV technology to enhance agricultural processes. The fusion of these two domains has the potential to provide farmers and agronomists with valuable insights for optimized decision-making. The primary focus of this research is to showcase the various applications of computer vision for UAVs in agriculture. The paper begins by presenting an overview of the challenges faced by modern agriculture, such as resource optimization, crop monitoring, disease detection, and yield prediction. It then delves into the technological advancements in UAVs and their suitability for addressing these challenges.

Keywords: Unmanned aerial vehicles, Drones, Computer vision, Agriculture, Crop monitoring, Object detection.

Introduction

Unmanned aerial vehicle (UAV) and Internet of Things (IoT) technology have emerged as a powerful combination in recent years, offering numerous benefits and applications across various industries. Unmanned Arial Vehicles (UAV) are mobile structures that incorporate sensors and control systems, considered as embedded systems with the ability to incorporate a variety of programmable algorithms that allow adaptation to various process automation techniques, control and instrumentation. They are considered machines that carry out complex transport operations, detection of physical and environmental variables, routing, monitoring and logistics, to name just a few. These vehicles in the literature are also named as mobile robots, autonomous unmanned vehicles (Nithin *et al.*, 2017; Vaeljaots *et al.*, 2018; Cao *et al.*, 2003).

UAVs began to be developed in the 1990s, reporting a growing interest and acceptance in different research areas. At the beginning of the 21st century, they began to be implemented in sectors such as: cartography, in which there are a variety of methods for their application, some examples of this are (Fentanes *et al.*, 2018), which uses the ICP scan coincidence method with odometry extrapolation to solve the problem. Simultaneous location and mapping problem and (Hutangkabodee *et al.*, 2005) that uses the binary thresholding segmentation technique to orient and locate the UAV. Another sector is agriculture, in which (Pierzchała *et al.*, 2018) uses a system of sensors integrated into a UAV with the aim of measuring humidity and temperature in a greenhouse; militia (Tanaka *et al.*, 2017), where it implements an automation kit in a military vehicle to fulfill surveillance and navigation missions by teleoperation. In the forestry

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sector (Alberts *et al*., 2008) developed a UAV that works together with an UAV for fire detection in forest areas.

These applications significantly improve safety and efficiency in tasks that involve risk, and their inclusion in the industry increases the quality of processes considering the amount of data that can be collected and analyzed, allowing optimization of resources (Zhang *et al*., 2016; Dhanalakshmi & Leni (2017), Roberts & Pecka (2018)).

In this context, any researcher who wishes to venture into the development or implementation of UAVs requires a prior study of scientific knowledge that integrates the techniques and technologies involved in these prototypes, taking into account the configuration, control schemes, and data collection instrumentation. they use data to know the approaches and determine the direction of their research (Gomes *et al*., 2016). Therefore it becomes important to carry out review articles that provide information on a specific topic, expose the available evidence with important statistics, provide answers to questions and suggest future research areas (Wendel *et al*., 2018), for which the Web Tree of Science tool is implemented, and the systematic review information gathering technique to perform a search in different databases.

Unmanned Aerial Vehicles

Studies related to UAV have grown around the world, providing new advances in computational technology (Rahman *et al*., 2021).

UAVs, as the name suggests, are aircraft that take off and fly without the need for a crew on board. The control of activities commonly performed by crew members can be performed by programmed computer systems and/or remotely by human beings via remote controls (EID *et al*., 2013).

For Kerrow (2004) UAVs can be classified into two types: UAVs with fixed wings and UAVs with rotary wings. For this author, those with fixed wings are indicated for outdoor flights, being able to cover a large area. The rotary-wing UAVs are more capable of flying at low altitudes and indoors due to their maneuvering, take-off, vertical landing and hovering characteristics. In this last classification, the quadcopter stands out, a UAV configuration with rotating wings.

Blom (2010) stated that UAVs emerged in military research on the need for reconnaissance of the enemy in the war period. For him, once man had discovered the art of flight. However, due to technical limitations at the time, the use of balloons achieved little success.

The idea that started with simple balloons has now spread to a wide range of technologically advanced machines.

According to Blom (2010), the US Army Air Corps, and later the independent air force, developed the aircraft that operates under the control of ground commanders. The segment evolved until the 1980s. With the emergence of aviation, the ability to use UAVs was used by the army for a variety of missions.

Considering the civil use of UAVs, there is a vast area of possible applications for their use, such as remote environmental research, monitoring and certification of environmental pollution, management of fires, security, border monitoring, oceanography, agriculture and fishing applications, among others.

Computer Vision

According to Athanasios *et al*. (2018), computer vision is a recent science. It is responsible for extracting significant information from images captured by video cameras, sensors, scanners, and other devices.

For Al Haque *et al*. (2019), vision has been the object of research since the beginning of computing because it is one of the most remarkable human perception systems. Thus, according to the author, the development of techniques and devices that can extend this capacity and sensitivity even further is motivated by the human capacity to process and interpret large amounts of data of a visual nature.

Computer vision seeks to emulate human vision. It has an image as input and, as output, a partial or total interpretation of that image as a whole (Hira Zahid *et al*., 2023). Thus, the problem guiding computer vision (or computer vision) is extracting a set of information, models or mathematical equations from images. This information, models or mathematical equations will be used for decision-making.

The ways in which the human being identifies a scene and how a digital image is interpreted differ from each other, since the first is able to perceive the 3-D structure that surrounds him with apparent ease (SZELISKI, 2010), while the second identifies an image from attributes that must be extracted from the image and that are related to each other (Tao Sun & Jujiang Cao (2022).

For Szeliski (2010), computer vision intends to reproduce the ability to recognize images from various computational techniques, starting from images and arriving at mathematical models. To this end, researchers in this area have developed mathematical techniques to recover the three-dimensional shape and the appearance of objects in images.

Thus, using thousands of partially overlapping photographs, it is possible to accurately calculate a partial 3D model of an environment, using these techniques. However, for Szeliski (2010) despite all advances in the area of computer vision, vision is something complex, being characterized as an inverse problem. In computer vision, the solutions and research developed for specific applications were obtained by trial and error, making it an experimental science (Al Haque *et al.* (2019)).

According to Szeliski (2010), in the early 1970s, computer vision was seen as a component of visual perception, participating in an ambitious agenda that aimed to imitate human intelligence, endowing robots with intelligent behavior. Already in the 1980s, the focus and attention were centered on more sophisticated mathematical techniques for the analysis of images and scenarios.

Currently, computer vision is being used in several areas, such as optical character recognition, photogrammetry, medical imaging, automotive security, video game and stabilization, motion capture, surveillance, fingerprint recognition and biometrics, face detection, visual authentication, among others (Szeliski, 2010).

For Milano & Honorato (2010), computer vision generally solves problems demanded by other research areas. According to the authors, computer vision systems basically involve recognizing objects in images and transforming objects into information that is processed and later used in some systems.

Therefore, computer vision provides the computer with accurate information extracted from images and videos, leading the computer to perform intelligent tasks, imitating and even approaching human intelligence. The main stages of a computer vision system are: image acquisition, pre-processing, attribute or feature extraction, detection and segmentation, and high-level processing (Milano & Honorato, 2010). It is worth noting that some of these steps may be unnecessary in some computer vision systems.

According to Milano & Honorato (2010), image acquisition is the first step in the computer vision system, taking place from camera sensors, where each point of the obtained image – known as pixel– indicates the light coordinate and physical properties. For the authors, the image can be two-dimensional, three-dimensional or a sequence of images.

Pre-processing occurs before obtaining information from an image, applying methods that facilitate the identification of an object. It is usually followed by detection and segmentation, where the objective is to highlight or find relevant regions of the image, segmenting them for further processing. In the segmentation stage, the image is partitioned into regions to separate elements of interest for the problem to be solved from elements irrelevant to the problem. In some cases, in problems involving counting or recognition of multiple objects, segmentation, in addition to separating irrelevant elements, separates the objects of interest into distinct regions.

The next step in the computer vision system is feature extraction, where the mathematical features that make up an image and represent the objects of interest are verified (Milano & Honorato (2010)). Finally, the last step refers to high-level processing and pattern recognition, which is a process that includes satisfaction validation of the obtained data, estimation of parameters on the image and classification of objects obtained in different categories.

Applications of UAVs and Computer Vision in Agriculture

Agriculture can increasingly rely on the implementation of technologies that benefit it in some or all productive stages. The use of UAVs to collect images in which, later, computer vision techniques will be used to achieve different objectives are, in this context, good examples.

Herwitz *et al*., (2004) carried out a study with the Kauai Coffee Company in Hawaii, using UAV to collect images aiming at surveillance and decision support in coffee plantations. For the authors, there are several aspects of crop management that can benefit from aerial observation. The study demonstrated the ability of a UAV to fly over the plantation, equipped with imaging systems to monitor an agricultural region for an extended period of time, with UAVs offering a valuable contribution to future monitoring of agricultural resources.

The study proved to be important, demonstrating that the high resolution of images was immediately useful to map the perennial grass foci and to show differences in total soil cover within fields. Thus, for the authors, UAVs are called upon to play a broader role, complementary to conventionally tested satellites and aircraft supporting agriculture (Herwitz et al, 2004).

Giri & Mohanty (2022) carried out a study with the aim of quantifying the area damaged by caterpillars on soybean leaves contained in digital images. For image acquisition, a scanner was used to digitize the sheet, which was placed on a white sheet of paper, and then the image was transformed into grayscale. This image was processed to minimize noise and segmented to eliminate irrelevant information. Then the edges of the image were manually closed. Finally, the "holes" in the sheet were evaluated to estimate the area. The performance of the proposed system obtained a better average percentage error than a human expert.

As an evolution of the work by Giri & Mohanty (2022), Weltzien, 2016, proposes to develop a system to quantify the damaged leaf area in soybean leaves contained in digital images. The digitized images were also processed to reduce irrelevancies. To find the area of each damage, first, the internal damages of the leaf were quantified, which are those that do not reach the edge. Then, unlike in Giri & Mohanty (2022), the automatic recomposition of edges is carried out and, finally, the quantification of the area is completed through the subtraction of images. To experiment with the proposed approach, 185 samples of soybean leaves with damage caused by agents of nature (such as caterpillars) collected at random were used. The average absolute error obtained was seven times better when compared with the errors obtained in Mura's work and in human classificationw.

Ozdogan *et al*., (2017) aimed to characterize the species of soybean leaf-damaging agents (caterpillars or beetles).

For this, 180 samples of leaflets were scanned and pre-processed. A corresponding undamaged image was created for each sample through reconstitution algorithms. By subtracting images – that is, obtaining the complement between the damaged image and the undamaged image –it was possible to obtain the damage of each leaf and, through the analysis of the contour of this damage and the use of complex networks, it was possible to classify the agents responsible for them. The work reports that a hit rate greater than 90% was achieved in the analyzed set.

In 2008, Apan *et al*. (2010) carried out a study that investigated the use of UAVs as remote sensing tools. That is not new as they have already been used to photograph pastures, for desert search and rescue, for monitoring coffee maturation and, among other things, to monitor wheat.

The conclusion of the study by Apan *et al.* (2010) referred to the need for further development to overcome accuracy problems. However, according to the authors, the ability to perform automatic registration and mosaic of acquired images and low-pass filters from conventional aerial images, and considering the low cost of this remote sensing system, there is a projection of great potential to be used in wider agricultural applications.

Currently, one can already talk about the use of UAVs generating important images for precision agriculture in India. Crop monitoring based on images makes it possible to acquire data from the crop area, from planting to harvesting. Such information is useful for crop management, monitoring, production management, and logistics, among others (Wei Zhao *et al*., (2023).)

For Silva Neto (2013) the images taken by UAV combined with a good geoprocessing technique bring satisfactory results, resulting in better occupation and treatment of the soil, specialized planting and harvesting. Agriculture, which is the basis of the Indian economy, tends to be more technological. Today there are several researches and projects focused on this area. What used to be done with satellite images today has gained a strong ally.

Durmus & Gunes (2019) take measurements of humidity and temperature using the DHT11 sensor, barometric pressure with the BMP085 sensor, and light intensity using the TSL2561 sensor; the movement of the vehicle is through two cameras, a stereotype for the purpose of navigation and another auxiliary type to capture the image of the field rows, likewise, they couple the MTK3339 GPS module to obtain the location where the operations were carried out. measurements, whose data is sent to a web application through Wi-Fi communication, all devices are integrated into the Arduino board for vehicle operation.

Ruiz-Larrea *et al*., 2016, select the MLX90614 sensor to perform soil temperature measurements, they use it together with the SEN92355P sensor to measure soil moisture together with a stepper motor and the Arduino UNO board; A linear laser scanner provides vehicle navigation for obstacle avoidance, the IMU, a GNSS receiver and a pan/tilt/zoom camera; the UGV has a maximum load capacity of 20 kg, autonomy of three hours and implements four types of monster wheels each with its respective motor.

Cancar *et al*., 2014 use the MLX90614 sensor to measure the temperature of the plants, they couple the SHT71 sensor for the acquisition of temperature and humidity data from the environment; the device groups two systems, the communication system to transmit and receive data through Wi-Fi, Bluetooth and Xbee that receives the data from the sensor measurements; the orientation, navigation and control system implementing the IMU to measure angular speeds and accelerations, a magnetometer with tilt correction capability and a GPS module. The structure of the UGV is spherical, specifically ROSPHERE, which is incorporated into an embedded computer system where the RoboVero microcontroller used in robotics is implemented, which groups the LPC1769 microcontroller that contains all the components of the measurement system and navigation system, and the embedded computer. Overo Fire in charge of Wi-Fi transmission.

Thenmozhi *et al*., 2019, developed a vehicle with an ATMEGA328P microcontroller in order to drop seeds as it moves with the help of a servo motor, to obtain the position of the earth, they obtain four position points by means of GPS along with magnetic compass to increase accuracy and system accuracy and an XBEE module to locate the vehicle.

Pramod & Jithinmon (2019) use a prismatically-revolutionized (PR) double-arm mobile agricultural UGV that has an Arduino MEGA board and four modules: an excavation module composed of five motors, four for excavation and one for ground cover; seed module composed of a servo motor; Irrigation module that contains an FC-28 sensor that allows activating the motor to activate the pump when measuring low humidity; and a linear movement module made up of two direct current motors and an encoder to measure the distance traveled by each row.

Potenza *et al*., 2017, implement a UGV to detect weeds in the crop and classify in real time, implementing a multispectral camera applying convolutional neural networks in RGB + infrared images.

Sadistap *et al*., 2013, developed a UGV used on a farm, which couples a FriendlyARM mini2440 development board that recognizes diseased leaves through color segmentation, using two separation algorithms, the canny for edge detection and the adaptive thresholding byOtsu that allows separating the region of interest and remove noise; they implement the ARM9 computer module and the S3C2440 microcontroller, they use RS232 communication. Likewise, the vehicle's navigation contains two 2D120X infrared sensors and three direct current motors, two for the rear wheels and one for the steering, which are controlled by the L298 module; to capture the videos they use the Video4Linuz2 (V4L2) drivers, for this reason, the operating system they use is Linux.

Bhandari *et al.*, 2017, use the UGV's in conjunction with the UAV's to identify and eliminate the plants of a lettuce crop, communicating between them through the Xbee module.

Dimaya *et al.*, 2018, design and implemented a UGV controlled by the Arduino UNO board in a hectare of sugar. The vehicle navigation contains a differential 500 w motor, Sparkfun brand motor controller, GPS transceivers for vehicle navigation, HC-05 Bluetooth module that allows to turn on the UGV by means of a mobile application designed in Android Studio and power supply of four 12V, 20AH batteries connected in series; it also contains an auger for digging the soil composed of two different stepper motors, the NEMA 17 for the rotation of the barrier and the NEMA 23 for vertical movements of the auger.

Vasudevan *et al.*, 2016, work in conjunction with a UAV to monitor and control based on the color of the ground using a high-resolution monolithic camera for real-time image transmission and is equipped with LIDAR for 3D mapping, in addition, they implement the Linux operating system and Robots, the processing of the images is carried out with the Harris corner detector algorithms, the soil adjusted vegetation index focuses the Lucas-Kanade pyramid method and RANSAC and the identification of green areas. – SAVI).

Ozgul & Celik (2018) implemented the UGV to spray the plants without human intervention. The body of the vehicle is composed of Lynxmotion Rover Kit, four DC motors, Arduino MEGA microcontroller to control the speed of the motors with a PID control and process the data from the three HC-SR04 ultrasonic sensors in order to avoid obstacles and 11.1 V lithium polymer battery; additionally, it contains the spray mechanism and the insect repellent mechanism; the first consists of a Bayite water pump, a one-liter water tank, a silicone hose and a nozzle; and the second implements solar panels to generate variable frequencies with a sonic and ultrasound sensor which works 24 hours a day if fully charged.

Challenges and Prospects

The food issue can be observed as a research concern throughout history. As an example, we can cite Malthus (1798) who published an article entitled "An essay on the principle of population," where the author defended the thesis that population grows in geometric progression while food production grows in arithmetic progression, an imbalance that causes hunger and encourages disputes between men.

However, for economists, Malthus ignored the technological advance, which allowed the population growth curve to remain ahead of the food curve (Sachs, 2008). Technological advances allow food production to grow faster than the population, which can be observed in the various agricultural aspects such as agriculture, energy, water use, manufacturing, disease control, information management, transportation, and communications, among others. .

Thus, agribusiness is an important sector for the economy of any country, acquiring representation as it happens in India. The technology employed in the various stages of the production cycle helps in the good economic performance of the sector. In this sense, the use of UAV combined with computer vision, as already occurs in other countries, emerges as an enabler of productive gains due to the possibility of acting as a maximizer of information that act as an important tools in decision making.

The use of UAVs in India is not yet regulated. In 2013, France had a regulation for the use of UAVs that had already been addressed since 2012, generating expectations that the National Civil Aviation Agency (ANAC) would institute permission for UAV flights of up to 25 kilos in public places, up to 400 feet (about 120 meters) altitude.

However, currently, ANAC discusses proposals that list aircraft classifications. Thus, the aircraft were classified according to criteria related to the characteristics of the operation (altitude, operation in the visual line of sight or beyond it, night operation, operation in confined areas, among others): class I to 150 kg onwards; class II - 25 to 150 kg; and class III – 0 to 25 kg. The discussions involved in the proposed norms that regulate the design, maintenance, registration and operation of UAVs, in addition to the qualification of the remote pilot (BRASIL, 2014).

In addition, it is necessary to develop research and implement appropriate methodologies for the maximum exploitation of the potential of these tools. This promotion can act as a propellant for agribusiness, which already stands out in terms of participation in the country's GDP (Gross Domestic Product).

Conclusion

Although UAVs are vehicles originally developed for military purposes, over time, these aircraft have been used in civil applications where their use in conjunction with computer vision in agriculture can be highlighted. In American and European lands, the UAV has already been used in different situations in agricultural activities, generating better quality images than satellites and at more attractive prices, relying on the aid of computer vision for analysis and decision making, thus acting as an agent maximizer. Thus, several researches were carried out in order to verify the viability of its use, arriving, several times, to optimistic conclusions.

In India, the use of UAVs in agriculture is still something new. However, some universities saw this technology as a possibility to increase production and, consequently, financial gains, as well as large companies also aroused interest in the use of UAVs, initiating use and research. Thus, the possibility of inserting different producers in the use of the unmanned aerial vehicle on their properties is visualized as an ally in productive gains through detailed content about the planted area and content provided through computational analysis.

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