Information & Security

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vol. 46, no. 2 (2020): 127-140
https://doi.org/10.11610/isij.4609

Published since 1998 ISSN 0861-5160 (print), ISSN 1314-2119 (online)

Research Article

Possibilities for Using Unmanned Aerial Vehicles to Obtain Sensory Information for Environmental Analysis

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ABSTRACT:

This article presents some possibilities for obtaining sensory data from the environment (such as meteorological data, pollution level, night vision, etc.), using unmanned aerial vehicles. Attention is paid to some specific requirements to UAVs used as flying platforms for sensory data acquisition. The process of creating a prototype of a system for collecting and transmitting data in real time from the site of a crisis event using UAVs is analysed. The authors propose to use a specialised neural network tuned to identify half-hidden (half-buried by disaster) people when analysing images received from UAV-borne sensors.

ARTICLE INFO:

RECEIVED: 31 MAY 2020
REVISED: 08 JUL 2020
ONLINE: 12 Aug 2020

KEYWORDS:

UAV, sensors, drones, information, environmental analysis, crises

Introduction

Unmanned aerial vehicles (UAVs), so-called drones, have become increasingly popular in recent years due to some major advantages: high functionality, determined by the wide range of applicability, variety of sizes, characteristics, relatively easy to manufacture and low price, opportunities for technological development - increasingly powerful electric batteries, high precision flying, built-in intelligence and more.

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According to Gartner's forecasts, sales of UAVs are expected to reach 11.2 billion dollars by the end of 2020, with significant growth (about 30%) in industrial inspection drones (oil, energy, gas, transport, infrastructure). and others.). And according to a study by Business Insider Intelligence,[13] drone production in the United States in recent years is growing at a significant rate and in 2023 alone is projected to reach nearly 1 million units, and for the rest of the world – about 1.5 million (see Fig. 1).

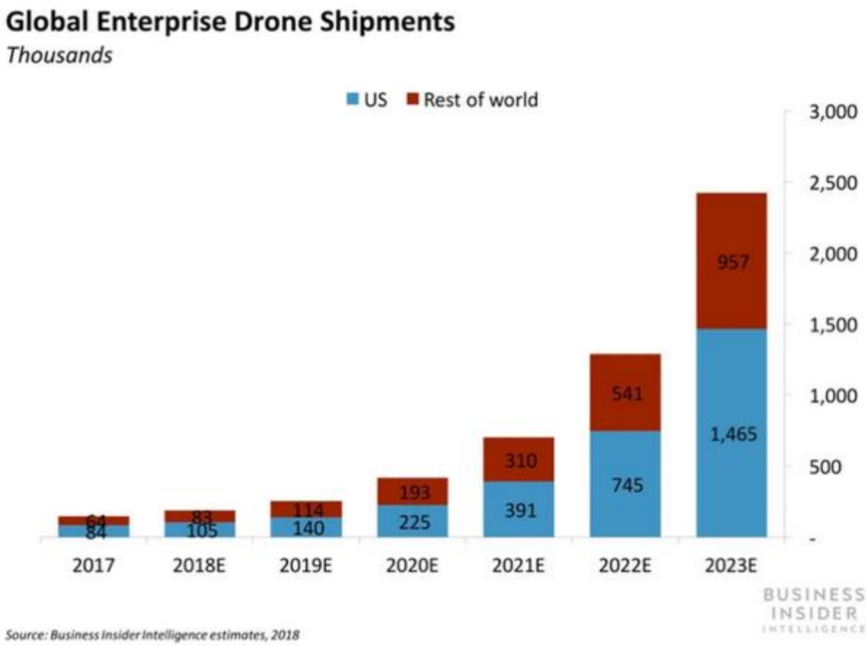

Figure 1: Increasing drone production in the United States compared to the rest of the world.[13]

The use of commercial drones could reach $ 82 billion and 100,000 jobs in the United States by 2025, according to AUVSI. BI Intelligence expects drone sales to reach $ 12 billion in 2021. And not a small part of that will come from the sale of personal drones used to create movies, photographs, games and more. From their research it can be seen that the most used are drones for taking photos (42.9%), as well as for real estate (20.7%), Utilities (10.9%), in construction (8.6%) and in agriculture (8.0%).[13]

1. Analysis of the technological development of UAVs and requirements for collecting sensory information

The development of technologies in the production of drones has increased significantly in recent years, in line with the increased application, demand and minimization of production costs and ease of operation of these devices. They are widely used for aerial photography and video, surveillance, geographical mapping, freight transport, crop treatment, for express delivery of consumables in life-saving operations, for exploration of inaccessible disaster areas, obtaining information in life-threatening environments, in conducting of military operations, games, etc.

With the improvement of electric batteries, modern UAVs have been given a big boost for longer stays in the air, and the miniaturization in electronics and the development of sensor technologies have made them smaller, more precise and more manoeuvrable, which has given them incredibly new opportunities for application. And recently, with the development of artificial intelligence, there is an opportunity to create intelligent flying devices that can make their own decisions on choosing the optimal route, avoiding obstacles, radio detection, situation analysis and much more.

Recently, intensive work has been done on the creation of intelligent sensors, in which the data collection system itself (camera, etc.) has built-in applications for preliminary image analysis and immediate determination of target objects to which specialized sensors should be directed. for closer monitoring.

The possibilities for using unmanned aerial vehicles for obtaining sensory information in site analysis are determined not only by the technical parameters and their capabilities, but also by the characteristics of the sensors, cameras and other devices used for this purpose. For the successful application of drones for these purposes, it is necessary to solve the following more important tasks:

- Selection of a suitable flight platform / design;
- Providing communications and management;
- Providing the information itself - selection of appropriate sensors.

Flight platform requirements

The requirements to the flight platform are based on the need to provide conditions for collecting the necessary information. In the course of the analysis the following requirements are formulated:

- *Sustainability.* This class includes resistance to environmental influences such as sun, dust, wind, moisture; Resistance to electromagnetic influences; Mechanical stability and service life (wear resistance).
- *Load capacity*. The load capacity must be sufficient to ensure the ability to transport the equipment on board the aircraft.

- *Flight duration.* This requirement stems both from the need to cover a sufficiently large surveillance perimeter and from the need to ensure a safe distance for the operating personnel.
- *Extensibility (universality).* Refers to the capabilities of the platform to expand/adapt to specific needs by installing different types of equipment. This requirement includes physical capacity, mechanical conveniences and interfaces (control, data, power).
- *Speed range.* The requirements regarding the speed of movement in different operating modes are contradictory. On the one hand, the higher the maximum speed, the faster the data collection capability will be provided, and on the other hand, the lower the minimum speed, the better the chance of accurate positioning and collection of some specific data (e.g. for gas leaks and others).
- *Ease of use.* The platform must be easily retractable and deployable, serviced and repaired, take off and land without special requirements for terrain or fixtures.
- *Price* for operation and acquisition.

Communication requirements

Communication modules and interfaces are used both for control and for receiving data from the mounted sensors in real time. The main requirements for them are:

- *Transmission speed.* The higher it is, the greater amount of sensor data per unit time will be possible to transmit. For example, when transmitting high-definition video streams, the required speed can reach 20 Mbit / s.
- *Connection distance.* The greater the distance provided, the wider perimeter for sensing and data collection will be covered by the aircraft.
- *Power consumption.* The lower the power consumption, the more energy will remain available for the other modules.
- *Dimensions and weight.* The lower size and weight of the communication modules allow for the integration of additional equipment.

When choosing communication means, it is necessary to make a compromise between the above requirements. High speeds and long transmission distances are achieved by increasing the power of the transmitters, which leads to an increase in their power consumption, size and weight of the devices.

Sensor requirements

The requirements for sensors mounted on aircraft platforms are related to the limitations in terms of weight, size, energy consumed and shape.

Both the platform and the sensors are also exposed to environmental influences and mechanical shocks, which is why they must be resistant to such impacts. The sensors must have a long service life, high accuracy, short response time - from setting a measurement task to obtaining the result.

2. Prototype of the system for collection and transmission of data in real time from the place of crisis event

One of the goals is to develop a prototype of system, able to collect and transmit environmental sensory data from the zone of a crisis event. Based on the requirements formulated above, a suitable platform, communication system and sensors must be selected to be integrated into a single highly configurable solution.

Selection of the flying platform

The designs of the known flying platforms can be divided according to the principles of obtaining vertical lift, into two main types:

- platforms receiving lift by using wings;
- platforms receiving lift through propellers.

During the study, it was found that there are hybrid flight platforms that combine the advantages of the above platforms by changing the mode of operation. During take-off and high-precision shooting they can hang in place, during movement they can use the lifting force of the wings to achieve higher speed and lower aerodynamic drag (see Fig. 2).

Figure 2: Drone VTOL DeltaQuad Pro with flight distance - 150 km and single charge flight - 160 min.

A comparison of the properties of the aircraft platforms with the requirements for speed range, ease of operation and flight duration is given in Table 1.

Table 1. A comparison of the properties of the aircraft platforms with the requirements for speed range

№	*Flight Construction*	*Max. speed*	*Min. speed*	*Ease of use takeoff / landing*	*Flight duration (typical)*
1.	Obtaining lift through wings	**high** *	high	Low (needs space or landing system)	**20-240 minutes**
2.	Obtaining lift through propellers	low	**low**	**High - vertical takeoff / landing**	15-40 minutes
3.	Hybrid	**high**	**low**	**High - vertical takeoff / landing**	25-120 minutes

* - where the value is an advantage over the set criteria, the font is bold.

Communications

The protocols and modulations used determine the properties of the communication channels. The requirements for the communication channels are determined by their purpose. Based on their purpose, we can distinguish two main types of communication channels:

- Management channels;
- Video streaming channels.

If the requirements for these two types of channels are compared, it can be seen that they are divergent, and for this reason, they often have to be implemented independently of each other. The control channels must ensure high reliability of the long-distance connection in both directions. This implies encryption of information and requires the use of digital data. The transmission rate is usually low and is determined by the operator's limited ability to generate information. In the opposite direction flows telemetric information about the state of the aircraft systems and control information about the execution of commands. In this group are also the channels providing transmission of information from sensors such as gas analyzers and others. For the channels providing video transmission, the requirements are different. They must provide one-way transmission of information at high speed, as the video information tolerates the presence of errors in its reception. For this reason, analog drones often use analog video transmission systems. Their advantages are the simplicity of their design and the smooth degradation of the quality of the transmitted picture, which gives the operator an idea of the state of the video channel. When implementing a professional surveillance solution, the use of analog video channels is unacceptable, as there is no possibility to encrypt the information. The digital channels for transmitting video information make it possible to combine several receivers in order to realize spatially spaced reception. The basic version of such a system includes two receivers configured with an omnidirectional and a directional antenna, respectively. The omnidirectional antenna provides reception from all directions as long as the aircraft is close to the operator. After moving the aircraft away in a certain direction, the directional antenna is used to provide stronger signal.

Used antennas and polarization

When transmitting signals from the flight platform, there may be various obstacles in the path of the radio waves. The reflections from these obstacles create interference, as the signals arrive at the receiving antenna with a different delay. These effects have been found to be significantly attenuated when circular polarization is used.[6, 9, 14] This can briefly be illustrated using the polarization loss factor (PLF).[16] If the transmitting and receiving antennas are linear polarized and relatively (from each other) rotated at angle ϕ, then the power received (PR), compared to the power received when there is not mismatch (P_0) is:

$$PR = PLF*P_0, \text{ where } PLF = \cos^2(\phi) \qquad (1)$$

When a circular polarized signal is reflected from a perfect reflecting surface, its polarization is inverted.[17] So, the PLF for such signal becomes 0, which means it is cancelled. In practice, the reflecting surfaces do not always produce perfect reflection so in these cases the reflected signals are not 100%, but significantly reduced. Some systems employ both right-hand circular polarization (RHCP) and left hand CP (LHCP) antennas to utilize the reflected signals as well, but these are considered out of interest for the purpose of this research.

The circular polarization of the signals gives another advantage - the amplitude of the received signal emitted by a non-directional antenna depends less on the position in the space of the aircraft. Some designs of omnidirectional circular polarized antennas are presented on Fig. 3. Tests have demonstrated that the second design has superior characteristics (lower parasitic emission with the opposite polarization).[10] In practice it is hard to recommend it without having antenna test equipment, due to its high sensitivity to the manufacturing tolerances, exhibited during the tests.[10] The 'Antena Pro Pagoda 2.1' is among those recommended by the designer manufacturers.[21]

Increasing the amplitude of the received signal can be achieved by using directional antennas on the ground (Fig. 4).

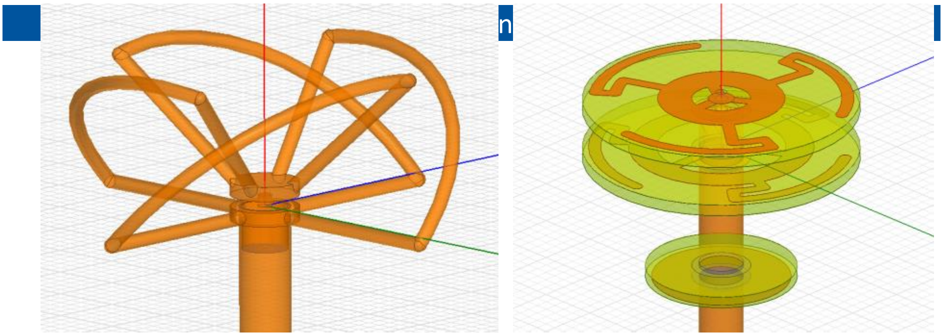

Figure 3: Designs of non-directional antennas with circular polarization.[10]

At short distances, the circular polarized antennas can be used in conjunction with linearly polarized antennas, and it should be noted that the amplitude of the received signal decreases by approximately 50% (PLF=$\cos^2(\pi/4)$) compared to the use of antennas with the same polarization.[11] Increasing the amplitude of the received signal can be achieved by using directional antennas on the ground. A directional antenna with a helical construction is selected as suitable for the proposed prototype. In Fig. 4 a) and b) the construction and directional pattern of such an antenna are shown.

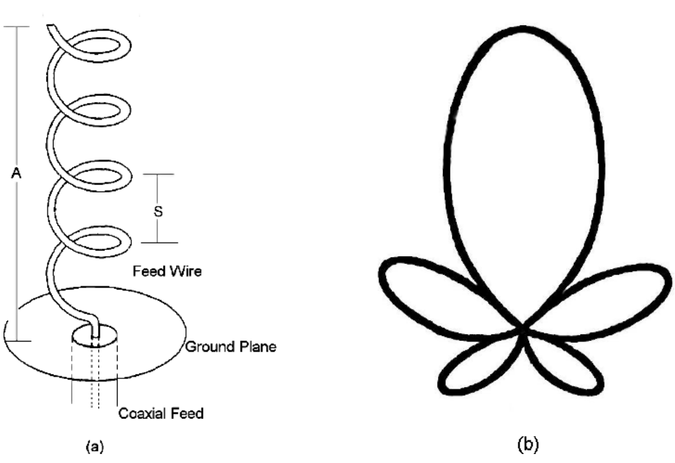

Figure 4: Helical directional antenna with circular polarization.[7]

The point-to-point direct transmission wireless technologies have a limited range. By increasing the transmission power and the use of directional antennas, this range can reach practically about 20-30 km in conditions of direct visibility. In the general case, there may be obstacles that significantly reduce these distances. This requires the data collection and transmission system to have more connection options. A second set of transceivers can provide data transmission over 4G and 5G networks to mobile operators.[8] In cases where these networks are also unavailable, a third scenario is possible - by connecting to fixed networks (see Fig. 5).

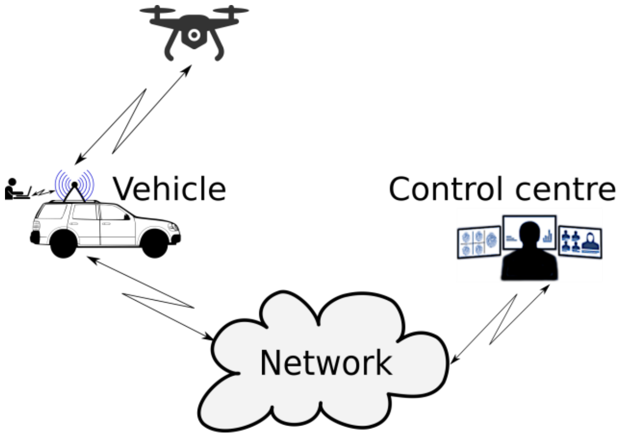

Figure 5: Option of using a fixed network for transmission of sensor data.

The data transmission platform (the UAV) is connected to a relatively nearby mobile vehicle (the SUV on the picture). There is an operator in the vehicle. The operator can work independently or transmit the information via a fixed or radio relay network to a control centre for further processing and decision making.

Sensors

To assess the state of the environment in case of disasters and accidents, it is necessary for the flight platform to be able to analyse basic parameters of the environment such as:

- temperature;
- atmospheric pressure;
- humidity;
- presence of smoke and dangerous gases;
- radiation background;
- electromagnetic radiation, etc.

In addition, it is necessary to have video information in the visible and infrared range. The video information can be used both directly by the platform operators and after subsequent digital processing.

The environmental sensors usually communicate via serial lines using I^2C, SPI, CANBUS and RS232 physical interfaces. The update speed is low, which enlightens the requirements to the downlink. For such data, often the radio transmitters offer low speed TTL-level RS232 interfaces, so the sensors must be first connected to an onboard processing unit to convert and, if necessary, encapsulate the data (when a single channel is available) for transmission.

The imaging sensors (those producing 2D/3D data) like video, infrared, LiDAR and synthetic-aperture radar (SAR) require much higher bandwidth. They usually are coupled with processing boards to convert the raw data from the sensor to an endpoint in a general-purpose computer interface like USB2/3 or Ethernet to connect to the drone onboard computer. The real-time video information is then packetized in standard or custom payload RTP packets and sent to the high-speed radio interface via an Ethernet interface. The radio interface can provide additional encapsulation adding forward error correction data and encryption.

Digital processing of video information

With the development in the field of fuzzy classifiers, it has become possible and accessible to recognize different classes of objects in the received stream of video information. This functionality has many applications, and for the purposes of this study, two main ones have been selected:

- Counting of sites of a given class in the area;
- Finding the location of objects of a given class in the area.

In the event of a disaster, it is important to identify people who may need help.

In FIG. 6 and 7 an image of an earthquake site, taken using a drone [15] before and after the classification of the detected objects using a neural network is shown.

Figure 6: Video frame, taken by a drone after an earthquake in Nepal.

Figure 7: A trained neural network has been used to recognize objects.

So far, the experiment was conducted with a neural network, trained to analyse only human images and some images of animals. Bochkovskiy, Wang, and Liao describe in detail the design of the used neural network.[18] Its topology was not customized. With specific training, the performance might be improved towards discovery of buried and half-hidden (half-buried by disaster) people using images from IR-cameras and more. It should be mentioned, that despite the state of the art NN topology, for realtime detection it still requires huge amount of processing power. The feasible available commercial solutions include the Nvidia Jetson™ boards [19] and Intel Movidius Myriad X.[20] This type of processing can still be done on the ground unless requirements changes for enhanced autonomy AI impose mandatory onboard processing.

Modern sensor technologies provide great opportunities for monitoring, mapping, object detection, and a number of other applications. However, for their operation, three key components are needed: highly secure wireless communication, allowing integration of sensors and transmission of large amounts of data in a short time, storage space for huge amounts of data (in the order of terabytes) and high computing power for their processing.

One possible approach to solving these problems is to process the images from the sensors at the base station (in the SUV in Fig. 5) or even in the drone itself (primary processing), so that useful information can be sifted out of the unnecessary and transmitted only through the communication system, or any changes made to it.

Some research and development projects offer solutions to theoretical and practical problems in the field of GIS technologies,[4] communication networks for information exchange,[1, 3] cyber security,[5] integrated information systems,[2] etc., some elements of which can be integrated into the developed visual-sensory system for obtaining information from the environment.

Conclusion

UAVs equipped with sensors for visual and other information are gaining popularity not only for military purposes but also for civilian use. Within the research project (on which the authors are working) for obtaining such information from the area by ground, water and unmanned aerial vehicles, it is planned to develop a visual-sensory system for obtaining information in real time with analysis and visualization of operational important information and its transmission to a crisis management centre. The project is relevant in the assessment and prevention of natural disasters, accidents, fires, explosions with explosives and more. Much of the information is obtained from drones equipped with specialized environmental sensors, IR cameras and other sensors with which the received data will be processed before being sent to the crisis centre – one part in UAVs and another – at the base station.

Acknowledgments

The present research has been conducted in the frames of “Acquisition of visual-sensory information by land, water and unmanned aerial vehicles and its presentation on a large screen in a crisis management centre” project supported by the Bulgarian Defence Institute, 2018-2021.

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