COMPETITIVE ANALYSIS OF UNMANNED AERIAL SYSTEMS IN AEROPHOTOGRAMMETRY

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ABSTRACT

In the past decade we have witnessed the accelerated development of unmanned aerial systems and photogrammetry sensors. For that reason, its role in modern aerophotogrammetry is becoming even more significant. Today, there is a large number of easily available unmanned aerophotogrammetric systems with sensors of satisfactory quality, and lower cost of acquisition and use, in comparison to standard manned aerophotogrammetric systems.

This paper contains a competitiveness analysis conducted in order to compare the application of unmanned aerial systems in aerophotogrammetric survey and classic manned aerial systems which still have a dominant role and represent a standard in this field.

By comparative analysis of those two systems, their similarities and differences, advantages and disadvantages, all based on specific examples, their characteristics and technical capabilities, applied technologies and procedures, prices and end result, a conclusion was drawn in order to answer the question whether unmanned aerial systems can take primacy in aerophotogrammetry.

Keywords: Aerophotogrammetry, Unmanned aerial systems, Manned aerial systems, Photogrammetric sensors

INTRODUCTION

Manned systems have been the backbone of aerial photogrammetry for over 70 years. Due to the extremely high costs of acquisition and operation, aerial photogrammetry surveys were mainly carried out by the government, much less often by the private sector. With the development of unmanned systems, aerial photogrammetric survey has become available to a much wider range of users. New unmanned aircrafts, new sensors of smaller sizes, with ever-increasing possibilities of application, rapidly began to emerge.

The time has come to ask the question of what the future holds for aerial photogrammetry: is the technology of unmanned aerial photogrammetry systems sufficiently advanced and ready to take over from manned aerial photogrammetry systems?

A comparative analysis, by means of description of both technologies, will answer the question of where aerial photogrammetry is today, and more importantly, where will it be in the near future.

There are many combinations of manned aircrafts and photogrammetry sensors in use today, as well as a large number of unmanned aerial photogrammetry systems. The two specific aerial photogrammetric systems, manned and unmanned, which are analysed and compared in this paper, were chosen based on the author's career experience.

AEROPHOTOGRAMMETRY

Photogrammetry is the science of obtaining reliable information about properties of physical objects and surfaces without direct contact with the object of measurement and of interpreting of the obtained data. Its methods of geodetic survey of large areas are incomparably efficient. Information about measured objects is obtained by use of sensors that register electromagnetic radiation, most often in the form of a photographic image, but other types of sensors, such as lasers, can be used as well.

Aerophotogrammetry is a branch of photogrammetry with the sensor located in the aircraft and the survey is performed from the air. It deals with survey at distances (altitude) of several thousand meters with an accuracy of tens of centimetres. It is used in geodesy to create orthophotos, digital terrain models, topographic maps, etc [1]..

MANNED AEROPHOTOGRAMMETRY SYSTEMS

A manned aerial photogrammetry system consists of a specially modified aircraft that has a factory or retrofitted opening in the floor, an aerial photogrammetry sensor with a special stand that is placed above the opening in the floor of the aircraft, and a control station that connects the aircraft and the sensor, through which the survey process is managed, and the pilot is instructed.

Aerial photogrammetry cameras have the same basic features as standard cameras, but are much larger, heavier, automated, and specially designed for use in aircrafts. Cameras are used at heights of several kilometres in a very challenging environment that involves sudden changes in temperature and strong vibrations during operation. Despite this, high quality survey results are required from these cameras. Due to the large distance from the recording object, the lenses are much larger than those of regular cameras. The shutter speed needs to be significantly faster and the exposure much shorter. Cameras must have special stands that neutralize vibrations and compensate for the aircraft's flight speed during survey. All this results in a very high price. Due to the high purchase price, but also high reliability in exploitation, these cameras have a service life that is measured in decades.

DESCRIPTION OF MANNED SYSTEM PIPER SENECA V EQUIPPED WITH LEICA ADS80

The Piper Seneca V aircraft (Figure 1) is a twin-engine aircraft equipped with turbocharged piston engines, all-metal construction and retractable landing gear [4]. The aircraft is intended for aerial photogrammetric survey of the terrain.

Figure 1. Piper Seneca V, YU-VGI [2].

It is equipped with an aerial photogrammetric camera Leica ADS80 (Figure 2) that works as a scanner – recording is continuous. This means that one flightline is one photo. This technology (pushbroom) enables much simpler processing of the survey results. There is a pilot and a sensor operator in the aircraft. The operator manages the surveying process and controls the operation of the camera through the control station. The pilot controls the aircraft according to the flight plan and makes corrections during the flight in accordance with the given flightlines.

Figure 2: Leica ADS80 camera [3].

A description of the manned aerial photogrammetry system used in the Military Geographical Institute - "General Stevan Bošković", Belgrade provides in Table 1.

Table 1: Piper Seneca V specification [4].

Aircraft type:	Airplane
Aircraft weight:	1.457 kg
Wingspan:	11,9 m
Propulsion:	2 turboprop engines with a power of 220 hp each
Fuel consumption:	79 l/h
Range:	1.534 km
Air speed:	Up to 370 km/h
Maximum flight height:	7.000 m above the ground
Takeoff:	Hard surface runway
Landing:	Hard surface runway
Equipment:	- Leica ADS80 - GNSS Receiver

UNMANNED AERIAL SYSTEMS

Unmanned Aerial System consists of unmanned aircraft, a control station on the ground and a data link between the control station and the aircraft.

The generally accepted term for an airplane that does not have a pilot in the aircraft is UAV (Unmanned Aerial Vehicle). The basic division of unmanned aircraft is based on whether they are lighter or heavier than air and whether they are self-propelled or wind-powered. Unmanned aircrafts heavier than air are divided into aircrafts with flexible (soft) wings, hard wings, and rotary wings. They can also be self-propelled or wind-powered.

Historically, lighter-than-air and wind-powered flexible-wing UAVs were once dominant, but today they have been supplanted and are much less commonly used commercially.

Self-propelled fixed-wing unmanned aircrafts may have propellers driven by an electric or internal combustion engine, or may be jet-powered. These aircrafts have wings shaped in such manner to generate lift when the aircraft is moving forward at sufficient speed.

Unmanned rotary-wing aircrafts are principally self-propelled. They are called copters. They have the ability to take off and land vertically, as well as to hover in place. Copters can have one, two, four or more rotors driven by a drive shaft.

According to take-off weight, unmanned aircrafts can be micro (up to 100 grams), small (up to 150 kilograms) and large (over 150 kilograms).

Control station on the ground - GCS (Ground Control Station) is the brain of the system. It is used for operating and control of the unmanned aircraft, directly or by means of predetermined flight plan.

Link for data exchange - Data Link is used for establishing communication between the control station and the unmanned aircraft. This connection is used to control the aircraft in flight. It is possible to upload a flight plan to the aircraft before the flight, send the telemetry data of the aircraft to the control station during the flight, as well as send the recording results in real time during the flight or after the flight has been finished. Communication is realized via radio link.

UNMANNED AERIAL PHOTOGRAMMETRY SYSTEMS

An unmanned aerial photogrammetric system is a remotely controlled, semi-automatic or automatic aerial platform equipped with a photogrammetric sensor (camera, multispectral camera, thermal camera, lidar, or a combination of two or more sensors). The difference between an unmanned aerial system and an unmanned aerial photogrammetry system is the sensor carried by the unmanned aircraft.

Effective application of unmanned aerial photogrammetry systems in photogrammetry depends on achieving the ideal compliance of the unmanned aircraft as a platform and the sensors it carries. Higher quality photogrammetric sensors weigh more than amateur sensors and require larger and stronger, and therefore more expensive, unmanned aerial vehicles to carry them. Today there are unmanned aircraft with a payload of over 100 kilograms and large enough to carry a professional aerial photogrammetry camera used in manned aircraft, but the cost of acquiring and using such an unmanned aircraft is similar or even exceeds the cost of using a classic aerial photogrammetry manned platform. In order for unmanned aerial photogrammetry systems to be competitive with manned aerial photogrammetry systems, they must have the same or better quality of survey results at much lower costs. For this purpose, it is necessary to find the optimal ratio between the capabilities and the price of the unmanned aerial vehicle and the photogrammetric sensor.

The growing and faster development of unmanned aerial vehicles has encouraged the development of ever smaller and lighter photogrammetric sensors while maintaining the quality of imaging. Thus, Sony developed the DSC-RX1 digital camera (Figure 3), the world's smallest camera with a full-size sensor. This camera weighs only 500 grams. When it comes to thermal cameras, the company "Flir" achieves excellent results in reducing the weight and dimensions of digital thermal cameras.

Figure 3: Sony RX1 camera [5].

A considerable challenge for unmanned aerial photogrammetry systems are Lidar (Light Identification Detection And Ranging) sensors or, in other words, laser scanners. Even though sensors of reduced mass and dimensions are developed in order to enable unmanned aircrafts to carry them, nevertheless, the quality-price ratio of the obtained results is not yet competitive with the existing sensors on manned aircraft.

DESCRIPTION OF THE GEOSCAN 201 UNMANNED SYSTEM

The Geoscan 201 system consists of an aircraft, a control station, a radio link between the control station and the aircraft, and a launch pad for the aircraft to take off. The control station (laptop computer) contains the control software. The flight is performed automatically. The operator at the control station is there only to monitor the aircraft's telemetry and recording characteristics. In case of unforeseen circumstances, the operator can take manual control of the aircraft at any time. It receives real-time data on the flight and on every shot taken. A description of the unmanned aerial photogrammetry system Geoscan 201 provides in Table 2.

Table 2: Geoscan 201 specification [6].

Aircraft type:	Flying wing
Aircraft weight:	8,5 kg
Wingspan:	222 cm
Propulsion:	Electric motor
Flight duration:	Up to 180 minutes
Airspeed:	64 – 130 km/h
Maximum flight altitude:	4.000 m above the ground
Minimum flight altitude:	100 m above the ground
Takeoff:	Launch pad
Landing:	Parachute
Equipment:	- Sony DSC RX1R camera - GNSS receiver
Communication:	Radio link
Maximum wind strength:	10 m/s measured on the ground
Temperature range:	Between -20 °C and +40°C

The aircraft used in the company "Evrogeomatika" d.o.o. based in Belgrade (Figure 4) allows the use of one to three sensors. A SONY RX1 camera is installed as standard. Photo resolution is 24,7 MP. It features a Carl Zeiss lens and a full-size (35 mm x 26 mm) sensor.

Figure 4: Geoscan 201 [7].

Depending on the needs, a video camera, a multispectral camera, an infrared camera, or some other sensor can be installed in the remaining sensor slots. The sensors are connected to the autopilot on the aircraft, which regulates their operation depending on the present recording parameters. All sensors are powered by the aircraft battery.
In the right wing of the aircraft there is a Topcon dual-frequency GNSS receiver with a speed of registering signals from satellites up to 10 Hz. This receiver is what provides the geodetic component to this system, and it makes it possible to obtain data with centimetre horizontal and height accuracy. After fieldwork is completed, after one or more flights,

the autopilot and camera data from each flight are processed in photogrammetric processing software.

COMPARATIVE ANALYSIS OF MANNED AND UNMANNED AEROPHOTOGRAMMETRIC SYSTEMS

The specific characteristics of two aerial photogrammetry systems, manned and unmanned, on the basis of which the possibilities and competitiveness of these systems can be analysed presents in Table 3.

Table 3: Comparative systems analysis

	Piper Seneca V Leica ADS80	**Geoscan 201 Sony RX1**
System price	≈ 1.000.000 € - aircraft ≈ 1.000.000 € - sensor	≈ 50.000 €
Crew	Pilot Operator	Operator (on the ground)
Flight cost	≈ 1.500 €/h	≈ 0.1 €/h
Surveying resolution 3 cm		
Area size	-	≈ 15 km^2
Surveying resolution 10 cm		
Area size	≈ 600 km^2	≈ 42 km^2
Surveying resolution 40 cm		
Area size	≈ 2.400 km^2	-

The first thing that comes to attention is the cost of the manned aerial photogrammetry system. Having in mind the cost of the aircraft and of sensors, it is clear that this system requires a large initial investment. On the other hand, an unmanned aerial photometric system is 40 times cheaper and therefore available to a much wider group of users.

Another component which affects the cost of using the system is the training and wages for those engaged in surveying. A qualified professional pilot who is required to operate an aircraft must undergo very demanding and expensive training. The pilot and aerial photogrammetry operator work in a dangerous and unnatural environment, which affects their salary. An airplane burns large amounts of fuel during flight. In contrast, the unmanned aircraft operator training is far simpler and cheaper, the workplace is much safer, and the salary costs are much lower. The electric motor that drives the unmanned aircraft is powered by a battery that is charged from the power grid before flight, so flight costs are negligible.

In terms of applicability, the situation is also very different. Unmanned aerial photogrammetry systems can fly at much lower altitudes than manned systems. The advantage is a higher image resolution, but the downside is a much smaller survey area that can be covered in one flight. The maximum flight height of the Geoscan 201 system of 4.000 meters above the ground is impractical for the purposes of aerial photogrammetry. Namely, the Sony RX1 sensor is not capable of taking high-quality shots at that height due to its technical characteristics (primarily focal length). The distortion of the footage is too great. Sensors on manned aerial photogrammetry systems are designed to work at high altitudes and enable large surveying areas in one flight.

We can directly compare the potential of the two systems by analysing the only comparable example in the table - the surveying resolution of 10 cm. The manned system can cover an area 14 times larger during one aerial photogrammetric survey. This difference is still 3 times smaller than the difference in the purchase price of the system.

This means that using several unmanned aerial photogrammetry systems can further neutralize the advantage of the manned system.

CASE STUDY

In order to obtain valid study results, a case study is introduced, and its data analyzed. An area of 25 square kilometers between the city of Ruma and the village of Voganj was used for purpose of providing a case study (Figure 5). This area was chosen since one year apart aerial photogrammetric survey was carried out both with an aerial photogrammetric system Piper Seneca V and with an unmanned aerial photogrammetric system Geoscan 201. For the purposes of the land consolidation project in the cadastral municipality of Voganj, the company "Evrogeomatika" d.o.o. performed an aerial photogrammetric survey of this area on April 10, 2018. On April 16, 2019, the Military Geographical Institute - "General Stevan Bošković" carried out an aerial photogrammetric survey of the same area as part of the IPA 2014 project "Special measures for reconstruction after floods and flood risk management - Serbia". A comparative analysis of the surveying results is given in Table 4.

Figure 5: Case study area [8].

Table 4: Comparative analysis of the surveying results

Area size ≈ 25km^2	Piper Seneca V Leica ADS80	Geoscan 201 Sony RX1
Date	16.04.2019.	10.04.2018.
Flights	1	2
Flight altitute	2.000 m	400 m
Surveying time	≈ 20 min	≈ 160 min (100+60)
Surveying resolution	20 cm	4 cm
Images obtained	8	3.940 (2.466+1.474)
Single image size	≈ 4,5 GB	≈ 11 MB
Total images size	38 GB	41 GB

Based on the technical characteristics of the manned aerial photogrammetry system Piper Seneca V, it is clear that one flight is more than enough for surveying this area. The plane took off from Belgrade, arrived at the assigned area, performed aerial photogrammetric survey of 8 flightlines according to the predetermined flight plan, after which the plane returned to Belgrade. Since the aircraft departed from Belgrade, it had enough time to reach the required flight altitude before arriving at the surveying location. On the other hand, the unmanned aerial photogrammetry system Geoscan 201 was transported by road vehicle from Belgrade to the given location. Based on the surface area and the defined flight altitude, for safety reasons, it was decided to perform two surveying flights. After the first flight, the recording data was downloaded, the battery was replaced, and the second flight was carried out. At the beginning of both flights, the aircraft had to spiral up to the set flight altitude first, and only then start recording, which consumes a lot of time and aircraft's battery.

The Leica ADS80 sensor on the manned aerial photogrammetry system is equipped with a push broom imaging technology, which means that each flightline is a single shot. Therefore, the number of obtained images is 8. The Sony RX1 sensor of the unmanned aerial photogrammetry system makes individual images. It is noticable that the total size of data obtained with both surveying methods is similar. During the processing of the data obtained from the manned aerial photogrammetry system, it should be kept in mind that it is a small number of a large size images. This increases the processing time and requires higher hardware capabilities of the processing computer. The data of the unmanned aerial photogrammetry system is characterized by a very large number of small-sized images, which speeds up the processing time and reduces hardware requirements. Data can be divided into smaller blocks and thus processed.

The same detail is displayed on Figure 6, captured by manned and unmanned aerial photogrammetry systems. Based on this example, it is clear that the image quality surveyed by the unmanned aerial photogrammetry system is much better at smaller scale. This is a great advantage in the further application of the surveying results, especially in urban areas or areas of special interest. But on the other hand, as seen in Figure 5, a large percentage of the surveyed area consists of fields and uninhabited areas. This is the case in most aerial photogrammetry surveys. The technical capabilities of unmanned aerial photogrammetry systems exceed the requirements related to the quality of data recorded in these areas, while the time and resources required to image these areas with unmanned aerial photogrammetry systems are impractically extensive.

Figure 6: Church in vilafe of Voganj. left image taken with Leica ADS 80 sensor [8];
right image taken with Sony RX1 sensor [9];

ADVANTAGES AND LIMITATIONS OF THE APPLICATION OF UNMANNED AERIAL SYSTEMS IN PHOTOGRAMMETRY

The main advantage of unmanned aerial systems compared to manned aircraft is the possibility of use in dangerous situations, such as natural disasters (volcanoes, floods, etc.), riots and war environment, without risking the lives of the operators. Due to their construction and size, they can be used in inaccessible areas. Due to the low flight height, they can be used under clouds or under the restricted flight zone.

Modern unmanned aerial photogrammetry systems have the ability to process data in real time. The size of the images is much smaller compared to professional aerial photogrammetry cameras, so it is possible to transfer data during the flight from the aircraft to the control station via radio link.

Copters have the possibility of vertical take-off and landing and hovering in place, which has a great application in engineering photogrammetry in the creation of detailed and precise 3D models. In close-up photogrammetry, it is possible to combine aerial photography with terrestrial photogrammetry using identical sensors to obtain images of the same quality, which facilitates further processing.

The basic limitation of unmanned aerial photogrammetry systems is the payload, which is determined by the mass, dimensions, and engine power of the unmanned aircraft. This is why amateur digital cameras or sensors are generally used in these systems, being much lighter than professional sensors. This affects the surveying quality, especially at higher flight altitudes. What's more, a much larger number of images are needed to cover the same area compared to classic aerial photogrammetry systems.

Insufficiently defined legal regulations in many countries cannot be ignored, since it is a considerable limitation of unmanned aerial systems. It is generally not required for unmanned aircrafts to use automatic identification devices or automatic mid-air collision avoidance devices as is the case with manned aircrafts. In order for efficiency to stand out, the optimal flight height of an unmanned aerial photogrammetry aircraft is several hundred meters. Those heights are mainly intended for flights of manned aircrafts, which can make the use of unmanned aircrafts very dangerous depending on the legal regulations, i.e., its deficiencies.

Flight autonomy is much lower when it comes to unmanned aircrafts compared to manned aircrafts. It depends on the unmanned aircraft drive type. Unmanned aircrafts can have an electric motor, in which case a larger battery capacity increases the weight of the battery,

consequently the weight of the aircraft itself, reduces the payload, i.e., reduces the flight autonomy. Unmanned aircrafts powered by internal combustion engines need to overcome the heaviness of the engine itself, along with the weight of the fuel, which again increases the total weight, reduces the payload, that is, reduces the flight autonomy.
The maximum range of an unmanned aircraft represents another limitation. The range of an unmanned aircraft may be greater than the range of the radio link with the control station. In this case, the flight of the unmanned aircraft can be continued without radio communication with the control station in automatic mode, which represents a great risk, or the range of the unmanned aircraft must be reduced in order to be within the range of the radio communication.

CONCLUSION

Ten years ago, it was unthinkable to question the competitiveness of unmanned aerial photogrammetry systems with manned systems. The best-case scenario was to use unmanned systems as a supplement to classic aerial photogrammetry, that is, as a substitute for supplementary terrestrial measurements by classic geodetic methods.
The situation is completely different now. Advances in technology have increased the capabilities, reliability and affordability of unmanned aerial systems, while the costs of acquisition and use have been reduced. Today, unmanned aerial photogrammetry systems are much more competitive with classic manned systems. They succeed in fulfilling their mission, to achieve the same or higher quality recording results with lower costs.
Where unmanned systems still lag behind manned systems is the ability to survey large areas. There is often no need for high image resolutions, especially in unpopulated areas, which make up most of any countryside. Here, the higher surveying resolution is not an advantage, but a limitation. When surveying monotonous surfaces, for example forests, a large number of images with practically the same content make photogrammetric processing difficult.
Based on all arguments listed in this paper, we may conclude that nowadays the best results can be achieved by using both systems, having the advantages of each contribute to the overall result. By combining manned and unmanned aerial photogrammetry systems, a greater coverage of imaging is obtained where it is needed (unpopulated areas) as well as a higher resolution of imaging (inhabited areas, rail and road infrastructure). This approach greatly facilitates further processing and gives much greater possibilities for the application of final products.
In order for unmanned aerial photogrammetry systems to become competitive with manned systems, they still have to come close to their technical capabilities. The most significant limitation is the available battery technology for electrical energy storage. The ratio of battery weight to the amount of electricity it can store is still not optimal. The next revolution in electricity storage technology is required. Photogrammetric sensors must continue the trend of reducing dimensions and weight while maintaining or improving their characteristics. Unmanned systems technology is rapidly approaching manned systems and will undoubtedly become the new standard in aerial photogrammetry in the near future.

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