UTILIZATION OF UNMANNED AERIAL VEHICLES IN PHOTOGRAMMETRY

Erik Bernát – Katarína Draganová

The aim of the article is to provide information about utilization of unmanned aircraft system for photogrammetric purposes. Basic principles of aerial photogrammetry, analysis of unmanned aircraft system and its application in photogrammetry are introduced. First part is devoted to utilization of unmanned aircraft system in comparison with commercial conventional aircraft. The photogrammetric system used for the realization of specific photogrammetric process from taking photos to data processing is also described. Consequently specific types of commercial aircraft and unmanned aircraft system used in aerial photogrammetry are listed. The inevitable part of theoretical preparation of data acquisition are cameras and sensors, programs for aircraft photo processing from unmanned aircraft vehicles and also other photogrammetric products used in aerial photogrammetry. Finally total expenses used for unmanned aircraft vehicle configuration, expenses for camera and other systems needed for successful action of aerial photogrammetry are analysed and compared with commercial aircrafts of same purpose.

K e y w o r d s: unmanned aerial vehicle (UAV), aerial photogrammetry

1 INTRODUCTION

Unmanned Aerial Vehicles (UAV) is a generic aircraft design to operate with no human pilot on board. The term UAV is used also terms like remotely piloted vehicle, remotely operated aircraft, remote controlled aircraft or unmanned aircraft systems and model aircraft are often used.

UAV has a long history in the different applications. The aerial photogrammetry is not an exception. Drones were highly used for such purpose in aerial photogrammetry during last decades.

Aerial photogrammetry is not a very popular form of photography. Basically, aerial photogrammetry is a division of aerial photography. With aerial photogrammetry, you combine aerial photography shots to create 2D or 3D models. Specifically, cartographers will combine the aerial shots, as long as the shots feature at least two difference angles of the same general area. This guideline will go over the uses of aerial photogrammetry and how the photographs for photogrammetry are obtained.

During the last years research focused on the use different unmanned aerial vehicles which are equipped of miniaturized georeferencing sensors such as GPS chip or inertial micro-electromechanical systems gave the possibility to pilot automatically the vehicle and to geo-reference acquired data.

Acquired datasets consists mostly in digital images, generally associated with a GPS position and sometimes attitude information.

Starting from this, it is possible using photogrammetric process to first get the orientation of the images and thus to extract digital terrain/surface model and Orthophoto.

The quality of the resulting 3D data will depend on geometric and radiometric image quality.

The goal of this paper is to describe advantages and disadvantages UAV and aircraft in photogrammetry, define UAV systems used in the photogrammetry and calculate cost on the UAV and aircraft in photogrammetry.

2 AERIAL PHOTOGRAMMETRY

Aerial photogrammetry is used to create topographical maps, which can be created by hand, but there are now computer programs that can be used to create them.

Aerial photogrammetry is very time consuming and costly to examine a very large portion of land by foot, which is why overhead shots are obtained by UAV or aircraft.

Aerial photogrammetry is often unable to capture shots of the entire land area.

Aerial photogrammetry is most popular in geography and cartography, engineering and urban planning, journalism, agriculture, surveillance and monitoring system, movie production and advertisement, tourism and protection of the natural environment - nature and wildlife.

2.1 Comparison of UAVs and aircrafts in photogrammetry

Aerial photos using commercial manned aircraft is most often done through photography from the aircraft. More convenient and often effective alternative is the use of helicopter where the camera is placed on the lower part of the helicopter.

UAV photogrammetry operates remotely controlled, semi-autonomously, or autonomously, without a pilot sitting in the vehicle.

The platform is equipped with a photogrammetric measurement system, video camera, thermal or infrared camera systems, airborne LiDAR system, or a combination thereof. UAV platform is not limited to a small or medium size.

UAV photogrammetry can be understood as a new photogrammetric measurement tool. UAV photogrammetry opens various new applications, combining aerial and terrestrial photogrammetry also from lower altitudes.

2.1.1 Advantages of UAVs

UAVs can be used in high risk situations without endangering a human life. In areas where access is difficult and where no manned aircraft is available or even no flight permission is given.

These regions are mountainous and volcanic areas, flood plains, earthquake and desert areas and scenes of accidents or for example in cloudy and drizzly weather conditions, the data acquisition with UAVs is still possible. Major advantage of using UAVs is also the attractive prices and lower operating costs than manned aircrafts have.

Supplementary advantages are ability for fast data acquisition, while transmitting the image, video and orientation data in real time to the ground control station. In addition to these advantages looking at rotary wing UAVs, the platform allows vertical take-off and landing. The use of VTOL (Vertical take-off and landing) systems permits the image acquisition while the camera is turning in vertical and horizontal direction.

2.1.2 Limitations of UAVs

For many UAVs small or medium format amateur cameras are usually used. In comparison to large format cameras, small cameras results in a reduced image quality. These payload limitations require the use of low weight navigation units, which implies less accurate results for the orientation of the sensors.

Cheaper UAVs are normally equipped with less powerful engines, limiting the reachable altitude.

Very important limitation is that UAVs UAVs cannot react like human beings in unexpected situations, e.g. unexpected appearance of an obstacle.

Low-cost UAVs are not equipped with collision avoidance systems, like manned aircrafts.

UAV is also dependant on the skill of the pilot to detect and follow the orientation of the UAV-system and this is basic reason there needs to be a well-trained pilot, due to security issues. The pilot should be able to interact with the system at any time and manoeuvres.

The largest hurdle to an operational UAV acquisition system is operating it safely within the airspace requirements put in place by CASA or other regulatory body. Commercial usage removes all the liberties hobbyists have in operating model aircraft and exposes the operators to liabilities due to failures. Extensive safety guidelines need to be followed and use is limited to non-urban environments where the airspace is uncontrolled. Training of the operators has to be carried out to exacting standards in order to meet approval requirements.

3 AIRCRAFTS, CAMERAS AND SOFTWARE PRODUCTS USED IN PHOTOGRAMMETRY

3.1 Aircrafts

There are many types of aircrafts and UAVs, which are or can be used in photogrammetry. Therefore only some of them with their brief specification are listed below.

3.1.1 Conventional aircrafts

Small types of aircrafts used in photogrammetry are for example: Cessna Stationair 206 G, Cessna 402B Businessliner, Aircraft Z – 37 A etc.

Every aircraft can be used for the needs of photogrammetric projects. All of airplanes can be equipped with different types of cameras and sensors according to the purpose of the photography.

All types of aircraft can be equipped with the most modern digital camera Microsoft Vexcel Ultracam – X or aerial survey camera ZEISS RMK TOP 15. System for navigational guidance along the planned route is called Mason; this program was completely created on the basis of long-time experience with aerial photography. The inertial navigational system Applanix POS AV 310 is installed for the direct measurement of parameters for outer orientation.

3.1.2 UAVs

In photogrammetry are mostly used following UAV configurations: UAV helicopter, multi-copter (quadrocopter, hexacopter, octocopter) and drone. Examples from these categories with their technical specifications are summarized and listed below.

Helicopter Aeroscout B1-100:

The autonomous industrial unmanned helicopter Scout B1-100 has been developed for professional airborne applications such as aerial mapping, airborne broadcasting, search & rescue, surveillance and inspection as well as law enforcement.

The helicopter provides a payload capacity of up to 30 kg.

The helicopter has been developed under severe safety policies, high engine power reserve capacities, mechanic robustness and environmental robustness against spray water.

The Aeroscout B1-100 provides easy transportability and maintainability through system modularity.

The helicopter can either be flown in conventional manual mode with high maneuverability or can be operated with its integrated INS/GPS automated flight control system.

Copter Aibotix X6:

Payload two - three kilograms and the size and weight results in enormous flight stability and even in strong wind impressive results are possible.

The six rotors and performance engines provide a massive thrust. The copter reached a climb rate of eight m/sec and a speed of 40 km/h. Even if one motor would fail the Aibot X6 has enough power to fly safely.

The innovative lightweight carbon fiber casing provides protection to the propellers when the UAV is flying close to objects. Bystanders and objects protected by the case from the rotating propellers. The intuitive

camera mount with automatic pitch and roll compensation provides steady and blur-free pictures and videos. You can change the settings during the flight and move from horizontal to vertical camera angle, because all type of copter have function vertical take off and landing.

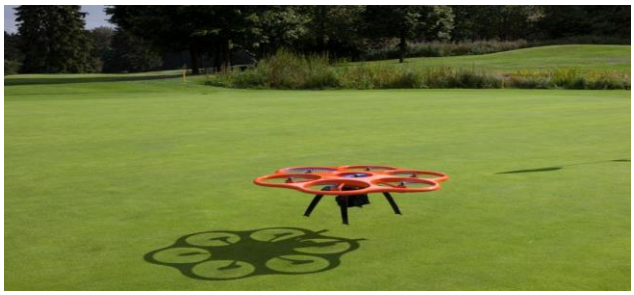

Figure 1: Aibotix X6 with camera

In the fact that the UAV goes out of range, you can use the coming home function. After activating the UAV automatically returns to the starting position.

It can control the copter by two people. One person controls the UAV and the other person the camera. As a result are impressive shots. This copter is equipped of sensor system based on methods of artificial intelligence and image processing for collision avoidance.

Drone Trimble UX 5:

Trimble UX 5 is the complete UAV photogrammetric mapping solution specifically designed for surveyors and geospatial professionals and to collect data with an unmanned aircraft for large projects.

Chief reason use drone trimble is to safely collect large amounts of accurate data in a short time. The Trimble UX5 can provide a safer method to collect data.

Flights are fully automated, from launch to landing, and require no piloting skills. The operator facilitates the aircraft's operating and built-in safety procedures can ensure safe and successful launches. Airframe of UAV is comprised of a carbon frame inside expanded polypropylene. Impact-resistant plastics and composite fibers are used for the aircraft components, including winglets and belly plate. This design and choice of materials results in a rigid aircraft with strong torsional stability and the ability to withstand rough landings.

Trimble UX 5 ensures optimal image quality along with maximum photogrammetric accuracy. The UX 5 camera has a large imaging sensor that captures very sharp, color-rich images, even in dark or cloudy conditions. The Trimble UX5 overcomes the limitations of traditional UAS landings with the addition of an advanced control method, is compact and allows landings in confined spaces.

3.2 Cameras and sensors

There are also many types of cameras and sensors, which can be used for aerial photogrammetry using UAVs.

Digital Camera VEXCEL UltraCAM-X:

UltraCamX has superior specifications and extended capabilities. Taking advantage of improved technology, UltraCamX employs 7.2 micrometer pixels and thus achieves an even larger image format at 14,430 x 9,420 pixels without sacrificing radiometric performance.

Some important specifications UltracamX are: Focal distance of panchromatic lenses is 100 millimetres; visual angle in vertical and cross direction is 55 degrees; capacity of on-flight storage devices is 1,7 TB.

Aerial survey camera ZEISS RMK TOP 15/30:

This camera is equipped with typical high-performance lenses with internal filters and significantly enhanced image quality and enables comprehensive image motion compensation by gyro-stabilized suspension mount. Stabilized camera axis is next typical attribute. Menu-driven central is controlled by a compact computer and logging of the mission data. This high quality camera is calibrated and certified by the German TUF office in Oberkochen.

Thermal Imaging Cameras Optris PI 400 / PI450

The infrared cameras optris PI 400 / PI 450 are the smallest thermographic cameras in their class. Being equipped with a measurement speed of 80 Hz and an optical resolution of 382 x 288 pixels they provide real-time thermographic images in high speed.

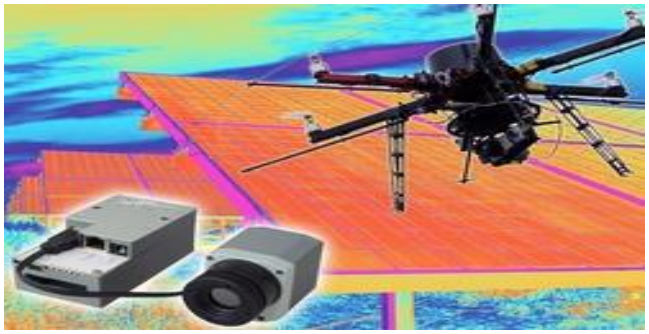

Figure 2: Termographic camera and hexacopter

The PI400 and PI450 are the newest models in the Optris PI series of thermal imaging cameras and really offer a step change in performance over other similar products. The higher resolution gives a higher quality image on the screen and enables the user to monitor the smallest of objects. Recording speed is 80 frames per second. These high-performance infrared cameras offer a temperature range of –20°C up to 900°C, with the model optris PI 400 being optionally upgradeable up to 1 500°C.

Areas of application optris PI 400 and PI 450 especially for surveillance and quality assurance in the automotive sector, in the plastics branch, and in the semi-conductor as well as photovoltaic industries. These cameras also play an important role in medical prevention where they detect slightest temperature differences. They can even highlight veins under the skin due to their brilliant optical resolution of up to 40 mK.

3.3 Software used in photogrammetry

Pix4D

This software is the fully automatic solution for advanced image processing of standard aerial pictures taken by UAVs and aircrafts. Pix4D develops advanced image processing algorithms to convert airborne imagery into georeferenced 2D orthomosaics and 3D surface models. With its advanced automatic aerial triangulation Pix4D enables civilian drones to become the next-generation mapping and surveying tool.

Full processing modes, features a fully automated workflow and can instantly be used by anyone as it is very intuitive and easy to use.

Aerogis

Is software of the German company GisCat. Competent software converts your digital metric or non-metric aerial photos into sophisticated digital products like ortho-mosaic images, detailed 3D-surface models and highest quality maps. GisCat and his Laser scanning and mobile mapping of the surface belong to the newest technologies for acquiring of spatial geodata.

Laser Scanning has finds its use especially in creating digital terrain and relief models, as well as use for it in city information systems and GIS and working schemes for engineering lines - communications, electric lines, telecommunications.

Advantages of laser scanning:
- high density of measured data in short time period
- possibility of use even in reduced visibility
- high accuracy of obtained data

Mobile mapping is a very quick, complex and economical method of geo information data acquisition together with actual images of mapped objects.

The system achieves reliable accuracy even when gathering data in densely built-up areas, city centers, tunnels and vegetation covered areas, where classic GPS technology fails. This system can be installed beyond UAV on a car, a boat, a helicopter or any moving vehicle.

Mobile mapping system is a technology appreciated and used for planning by road authorities, railway authorities, waterways, integrated rescue systems, environmental agencies, estate agencies, etc.

Mobile mapping has a wide range of application: mapping of street features - traffic signs, lamp posts, urban planning, illegal objects detection and mapping.

Icaros

Photogrammetry System of Icaros quickly and accurately processes aerial image data. Used for a different variety mapping and engineering applications, including disaster monitoring, agriculture and forestry analysis.

Icaros software is highly automated, meaning faster turnaround time from collection to orthophoto delivery, with minimal error.

Icaros is typical easy to use, ground-based flight planning software and creates a map of flight lines for pilots and navigators to follow during missions. Digital terrain models and 3D modeling give complete picture for continuous monitoring as well as identifying potential and existing hazards and risks.

Mapping is often costly and time consuming but Icaros is dedicated to providing duties, products and expertise that are cost-effective, simple to use and fast.

Icaros creates: Digital terrain model, Digital elevation model, Digital surface model

3.4 Photogrammetric products

Existing two software packages, which have been used for the generation of DSM data from UAV images:

3.4.1 Generation of digital surface models

LPS

The LPS matching strategy implemented is a combination of feature and area based matching. For the feature point matching, first interest points are extracted by cross-correlation.

Finally, as 3D reference information for the DSM generation, information on the accuracy of GCPs, check points and tie points can be selected as input information for the processing. The extracted DSM can be saved in various data formats - format IMG.

SAT-APP

For DSM generation, a image matching was used this method accommodate images from very high resolution.

The final DSMs are generated by combining the matching results of feature points, grid points and edges.

Matching is performed using cross-correlation and image pyramids.

If more than two images are available, procedure can use them simultaneously and the matching results are more robust. Image pair can be used as an approximation for the procedure.

Short procedure mainly contains a combination of feature point, edge and grid point matching. The grid point matching procedure can bridge-over areas with no or little texture through local smoothness constraints. The search for the match of a given grid point has a higher possibility of yielding an ambiguous match and even no matching candidate.

The software SAT-PP allows similar to LPS, the definition of excluded areas, while the adaptive parameters are generated automatically during the matching process.

NGATE and Match-T

NGATE is a tool that provides automatic generation of elevation models by multi-image-matching and correlation. This product combines area and feature based matching algorithms.

Match-T combines different matching techniques in a multi-image-matching approach.

3.4.2 Orthoimage and 3D visualization

Image data do not only allow one to extract surface models, one can, using the texture information, generate orthoimages and textured 3D visualization in combination with elevation data such as DSM and 3D-models.

An existing image can to produce a new image that conforms to specific geometric properties.

4. ECONOMIC ANALYSIS OF AERIAL PHOTOGRAMMETRY

The general trend in all industries is automation, the aerial photogrammetry industry is not an exception. The advent of digital cameras and powerful computing platforms has automated the image processing workflows. The advent small UAV has made the business of flying and capturing imagery automated as well.

There are several components to a UAV based photogrammetry platform. The UAV airframe is only a very small part of the equation, a lot of other pieces need to fall in place to allow a successful aerial photogrammetry project to take place commercially.

4.1 Octocopter Vulcan MANTIS Octo 1080 PRO

The Vulcan Mantis frame is aimed at professional applications such as aerial photography, building inspection, surveys, search and rescue etc. The raised front arm gives an unparalleled forward view for the camera with no props in the shot even during fast forward flight. Multicopter is great machine for the pilot for orientation in the air. This machine is an ideal tool for structural inspections, action videography, or any application requiring forward facing sensors. Flight characteristics are excellent, with no special setup needed in your flight controller.

Complete kit of octocopter includes:

Vulcan Mantis Octo 1080 Pro Frame with 350mm Landing Legs, Anti Vibration Mounting System, Rail Mount System, Vulcan Dual Side Battery Tray, Pro Flight Controller, On Screen Display, Data Link with 50 Waypoint Upgrade, 8 x Motor rings for Top Mounted Motors, 8 x Tiger MT3515 400Kv motors, 8 x JET HEliCopter 40A OPTO ESCs, 8 x 14 x 4.7 Carbon Fibre props, 1 x Dome cover, 1 x 250A Vulcan Power PDB, 1 x Vulcan Gel, 1 x ESC Tool and All necessary wiring and connectors.

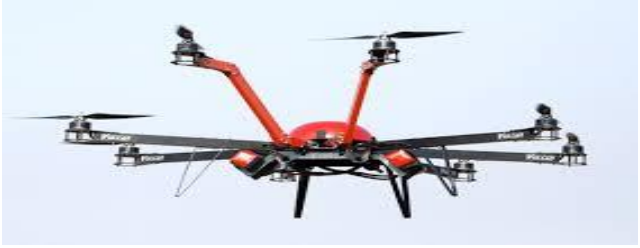

Figure 3: Vulcan MANTIS octo 1080 PRO

Photogrammetric kits for octocopter:
Camera Mounts with landing gear, System Stabilization of camera and Mini camera F 3230.

Complete purchase costs of the octocopter are 3 418 euro.

4.2 UAV drone 3DR Aero

The Aero Powered by the PixHawk controller, this Skywalker carbon tail-boom is perfect for long duration flights and medium payloads. Payload capacity of Aero is only 2kg. 3DR Aero is really fast and his maximum speed is 90 km/h. For communications with ground station, the Aero includes either a 900MHz or 433MHz wireless data link and system with transmitter are also available separately.

The Aero includes:

Ready-to-fly 3DR Aero aircraft, Pixhawk autopilot system, Digital airspeed sensor, 3DR Radio air and ground modules, 3DR GPS+Compass, 4S 6000 mAh LiPo power pack and balance charger, RC Tiger Motor 2820 830kv motor, Gemfan 11x7 propeller, Micro-USB ground station adapter, External LED indicator and USB port, 3DR Video/OSD System Kit and the FPV HD Monitor. Complete acquisition price of 3DR Aero is around 1 041 euro.

4.3 Aircraft - Piper Navajo Chieftain

The highly successful Navajo six - eight seat cabin class. Aircraft has been adapted to a number of commuter, charter, air taxi, light freight and executive transport roles, and has spawned a series of developments. The Piper Navajo was developed at the request of company founder William T Piper. The first prototype PA-31 was made on September 30 1964.

First flown in March 1968, first deliveries took place from 1970, and it remained in production until 1984. Meanwhile production of the PA-31-310 had ceased in 1983. Further developments of the Navajo, including the Chieftain, Mojave and Cheyenne, are described separately.

Configured to seat six (including pilot) in standard and executive layouts, and eight in commuter layout. Maximum take-off weight is 2 950 kg, max speed 420 km/h, service ceiling 27,300 ft. Purchase costs of this aircraft with thermovision camera PI 400 are min 253 873 euro.

4.4 Aircraft King Air 350i

The King Air 350i is new interior is the most comfortable and capable cabin ever offered in its class. King Air 350i can take more passengers farther on less fuel for consistent savings for your business. Cabin of Aircraft system can be configured for work or play. This King Air can be custom modified to fulfil a wide variety of long–distance, highly photogrammetric missions. Standard seating for nine passengers and storage for their baggage

At maximum weight, the twin–engine climb rate ascends to an extraordinary 2,730 feet per minute.

Figure 4: Aircraft King Air 350i

King Air offers unsurpassed interior styling and featuring plug-and-play access for laptops, smart phones and digital media players, the new high-definition cabin management system and LED lighting at each seat, what is ideal for photogrammetric services. The design of King Air consists of the high-strength aluminium alloy fuselage that contributes to unmatched fuel efficiency. Aircraft reduces the fuselage vibration-induced noise, setting new standards for a quiet cabin. The King Air 350i delivers truly inspiring performance with legendary Pratt & Whitney Canada engines. Max. take-off Weight 6,804 kg, Max Payload 1,134 kg, Maximum Speed 580 km/h. Complete price of aircraft with camera Vexcel ultracamX are around 3 116 360 euro.

5. CONCLUSION

Aim of this article was to highlight the possibility of unmanned system utilization in the aerial photogrammetry. In the introduction the basic principles of aerial photogrammetry and their uses in different sectors were introduced.

Next part was devoted to a short comparison of UAVs and conventional aircrafts used in aerial photogrammetry. Chosen UAV types, cameras and sensors of high quality, which are for the aerial photogrammetry necessary together with their technical and operational specifications were also overviewed. The final chapter includes economic aspects of aerial photogrammetry. The first part contains results of financial analysis of two unmanned aerial vehicles - octocopter and small UAV drone and the second part includes results of the economic analysis of two commercial aircraft. As expected the acquisition prices of UAVs are much more lower than in case of the conventional airplanes, which means that unmanned aerial systems seems to have a very perspective future in this area.

BIBLIOGRAPHY

[1] EISENBEIß, Henri. UAV Photogrammetry. Institut für Geodäsie und Photogrammetrie, Eidgenössische Technische Hochschule Zürich: Zurich, 2009. [online] [cit. 2014-05-01] ISSN 0252-9335. ISBN 978-3-906467-86-3. Dostupné na Internete: <http://www.igp-data.ethz.ch/berichte/Blaue_Berichte_PDF/105.pdf>.

[2] *Geodis*. [online]. [cit. 2014-05-03]. Dostupné na internete: <http://sluzby.geodis.cz/index.php>

[3] *Catalog. UAV shop.* [online]. 2014. [Cit. 2014-04-29]. Dostupné na internete: <http://www.uavshop.co.uk/catalog/index.php>.

AUTHOR(S)´ ADDRESS(ES)

Bernát Erik, Bc., Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Erbe142@gmail.com,
Ing. Katarína Draganová, PhD., Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, katarina.draganova@tuke.sk.