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sUAS and their application in observing geomorphological processes

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Abstract. Methodologies and procedures in processing gained data vary based on possibilities and needs of scientific projects. Technology moves ahead very fast. Application of different patents and remote control mechanisms has higher usage not only in military sector, but also in civil sector. These papers should help to get general overview in the choice of "small unmanned aircraft systems" (sUAS or commonly known as drones) for scientific purposes, for example remote sensing. Geomorphologic processes and the development of high mountain area are difficult for mapping and research with respect to accessibility of explored surface, slope of terrain, and mainly weather conditions that are rapidly changing. All high mountain areas in European countries are legislatively protected, and so various permissions and observation of strict procedures are needed, in order not to contaminate or not to have a negative influence on the environment. Nowadays several types of UAS and operating systems exist that could effectively help us in such protection, as well as in fully-fledged utilization when answering scientific questions.

Key words: Geomorphology. sUAS. Quadrocopter. Remote sensing. Alpine lake.

1 Introduction

Remote sensing of the Earth represents one of the crucial procedures which help us to understand its' substance. Throughout remote sensing we can observe "behaviour" of the environment we live in - changes of soil, vegetation, landforms, land uses, land management; what is the cause for these changes; and mainly what effects do have these changes on the environment (De Mûelenaere et al., 2011; Gong et al., 2015; Islam et al., 2015; Zucca et al., 2014). All these changes - whether natural or antrophogenic - can be effectively and easily monitored with the use of sUAS. For example, the use of this new and very popular technique can make research of vegetation changes (Cerdà, 1998; Zucca et al., 2014; Muñoz et al., 2014), landforms (De Sy et al., 2013), soil changes (Kiernan, 2015; Mohawesh et al., 2015; Gelaw et al., 2015), changes in fluvial systems (Poeppl et al., 2015; Smith et al., 2015) and land use (Zhang et al., 2015; Shelef et al., 2015; Parras-Alcàntara et al., 2013) easier in the way of getting data directly from the terrain. Our area of interest is the most important geomorphological-hydrological phenomena in the High Tatra Mts., deposition of Čierne Javorové pleso alpine lake. Alpine lakes play very important role in ecosystem services such as water retention and accumulation, local climate regulation, ecological, environmental and landscape aesthetic functions (Hreško et al., 2012). Throughout the monitoring of its' environs we can demonstrate effectiveness of remote sensing technology in praxes (hardly accessible, dangerous and legally protected areas).

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High capital cost for satellite, topographic and aerial photos force us to find cheaper technology – but of the same quality at the minimum – for scanning of landscape geomorphology. Quality of recording the earth's surface depends on many different factors when recording the landscape. Recording is used for the analyses of morphological processes, its dynamics, effects, force, hydrology, vegetation cover changes, etc.. Henry et al. (2002) described the way and the work methodology of mapping landscape structure with the use of individual flying machines. Also the illustration layout was made (Fig.1), ss we can see in the picture below. From photos gained in this way it is possible to create three dimensional (thereinafter 3D) models by fixing GPS points.

Work with 3D models of the terrain is commonly used in practice, but still there is a lot to improve on software and recording level. When using 3D model we focus on explored surface, let us say processes in progress and changes in the landscape. "Digital terrain data, gained in this way can be the material source for geomorphological research and monitoring. Multi-temporal data can potentially be very valuable for mapping geomorphological features and analyse their changes over time or for analysing effects of land management to landscape development (Anders et al., 2013)". That is the reason for collecting of data sets repeatedly, what is sometimes challenged by unfavourable weather conditions in high mountainous landscape. Here we would like to point out to a great progress in observing geomorphic processes where direct victims, observers or scientists are in peril of their life. Geomorphological hazards are understood here as "a probability of occurrence of the geomorphological processes endangering human interests in the affected area" (Minár, 2006). Millers (2012) suggested that we can prevent this by investing billion dollars into the research where UAS are used. And so, one of our objectives is demonstration of benefits in remote sensing with the use of sUAS (specifically DJI Phantom 1), such as its' accuracy in the terrain, easy access to hardly accessible areas and possibility to collect data even during the unfavourable weather conditions.

"Geomorphologists have to make choices and compromises because acquisition techniques of geometrical information are numerous, depending on the specific complexity of the targeted 3D objects and the requirements of the end user (Henry, et.al., 2002)". "Researchers are often forced to make a compromise between what is desirable for their project and what is actually possible (Whitehead et al., 2013)". Our second objective is collection of data (creation a photo documentation) needed before the direct entering the environment for the final statement whether it is relevant to start planned research or not. The same photos can be later used for the creation of more accurate DEM models (in comparison to DEM models derived on the basis of satellite, topographic and aerial photos) because of the higher accuracy of photos gained by the use of DJI Phantom and with the camera GoPro Hero3.

2 Material and methods

The study area

Mapping of the high mountain environment is grounded in accurate and effective use of all available means. We describe here the principle of the environment recording and work with particular types of sUAS in these papers. We have chosen the alpine lake in Čierna Javorová dolina valley in Slovakia (Central Europe) for direct representation of the methodology and its benefits. The valley is situated in the High Tatra Mts. that are located in the northern part of Slovakia and belong into the protected area of the Slovak national park (TANAP). One of the observed objects is Čierne Javorové pleso alpine lake (1,493 m) what signifies quite hard path to cover for a single researcher with the whole needed equipment. Moreover, when we take into consideration time factor, it is impossible to move all equipments to more locations if needed. Another problem is the fact that observed area is protected and it is inevitable to keep the environment in unaffected state which means total avoidance of any disruption (e.g. entering the alpine lake).

Observing of geomorphological phenomenons and processes

According to the problems stated above we had to find easier way for gathering data needed for research in high mountainous terrain. Based on the observation of alpine lake, we tried to improve and adjust the methodology of photogrammetric acquisition of data that will be applicable for the research before the sonar observation of the alpine lake. Sediment transfer and accumulation, observed in the terrain, were captured by recording, and then we made detailed photographic documentation. We used drone – DJI Phantom 1 quadrocopter in combination with waterproof camera GoPro Hero3 and mobile phone Nokia Lumia1020 for accurate watching the operation of the quadrocopter. DJI Phantom 1 contains remote control unit. It is easy to set up and fly also for new pilots. The flight time is 10 to 15 minutes and we prolonged it by using two batteries. We had more charged batteries to secure long flight time. For the controlling of the flight route we used Nokia Lumia 1020 so that we knew exactly where quadrocopter is, whether the object or phenomenon was captured well or whether the quadrocopter flies safely (danger of crash into the rocks). Camera GoPro Hero3 can be easily attached to quadrocopter. You can set up the frequency of snapshots or record a video. Data were taken in summer 2013 and winter 2014.

3 Results

After the study of relevant literature and our terrain research we present here concise survey of characteristics of UAS, and show possibilities of their use directly in terrain, where gaining high quality data is often challenged by exacting terrain and/or weather conditions.

3.1 Characteristics

"Two types of UAS are used for mapping relief and landscape field (Fig.2). Based on the configuration: rotary wing (helicopter) and fixed wing (airplane). These two are divided into five categories according to the weight. There is also specified a specific category of sUAS with the weight <25 kilograms, that is available for civil operation (Hugenholtz et al., 2012)". "These are powered aircraft that evolved from RC (thereinafter RC) and military 'drone' aircraft. They have integrated autopilot technology. which gives them semi- or fully-autonomous navigation, flight control and image acquisition capabilities (Hugenholtz et al., 2012; Stefanik et al., 2011)". "The sUAS have two control modes: remote control and autopilot control. Aircrafts are used mainly for accurate mapping of bigger fields and usually 3D landscape models are made after that. Aircrafts have accurate flight trajectory that is recounted by its own software, so that no problem occurs in

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photo-overlapping. Its flight height can be set manually and it ranges from 100m to about 800m. After it is set, the height is fixed during the whole time of flight (Hugenholtz et al., 2012)".

On the other hand, models with rotary wing are used for direct observing of processes in specific time, capturing of actual state and actual change of observed phenomenon from bird's-eye view. It means that quadrocopters are better used for detection of accurate point or its specific part from different perspective as detection from angle (Fig.3).

"Digital photogrammetry has been decreasing in costs. It is becoming accessible to a wider range of users who follow methods allowing non-metric cameras for the accurate calibration (Chandler, 1999; Chandler et al., 2002; Lane, 2000; Lane et al., 2003; Westaway et al., 2003)". Initial costs for purchasing cheaper machines are affordable for postgraduates and young scientists. Based on its affordability in the market, it is possible to work with software built in drones quickly, easily and without any flight training. A creating new software variation is necessary only in cases of specific projects with specific needs or if we want to assemble drone on our own. "It is possible to save 1/3 of market price when assembling multi-propeller copters. They are often difficult and costly to obtain. Price ranges from c. 1.500€ to about 100.000€ (Koh and Wich, 2012)". It is caused mainly because of the differences in duration of flight time, the speed of flight, used camera/recording machine and specific user demands. "These limitations imposed by battery life and the challenges of operating beyond line of sight impose limitations on the size of the area which can be covered by UAV surveys (Whitehead et al., 2013)". When talking about the range of controlling the quadrocopter, it is 300m.

3.2 Resolution of datasets

Mainly geomorphological projects cannot be done without aerial photos, mainly in its preliminary stage where decisions about the following steps are made and scientific questions and goals are reappraised. Depiction of GPS points from photos can be challenged in the future because of GPS deviation. In our area of the interest, Čierna Javorová dolina valley represents enclosed system and so the lower alpine lake is and the higher mountains surround it, the bigger deviations of cardinal points GPS device may show. It is caused by the less amount of satellites transmitting the signal that GPS devise receives. On the other hand, if something is captured authentically in the photo, it is needed only to recalculate measuring scale and then determinate cardinal point for the possible future comparison.

Recording by satellites and high flying aircrafts provides us with big 3D scene, several km^2 for one photo. Quadrocopter flies into much lower heights and scene captured by the camera narrows to only several tens of cm^2 up to hundreds of m^2. "Improvements in the cost and quality of compact and single lens reflex cameras and methods for their calibration (Clarke and Fryer, 1998; Chandler et al., 2005; Remondino and Fraser, 2006) encouraged a wide range of uses in geomorphology, for example monitoring river bed topography and plan form (Brasington and Smart, 2003; Chandler et al., 2002; Lane, 2000; Tamminga et al., 2015), gully erosion (Betts and DeRose, 1999; Marzolff and Poesen, 2009), in glaciology, for example the quantification of glacier surface change (Keutterling and Thomass, 2006), and also the quantification of soil erosion (Stojic et al., 1998; Lane et al., 2001; Brasington and Smart, 2003; Heng et al., 2010)".

"Satellite imagery, mainly used for government map updates, is appropriate for some types of measurements (Wainstein et al., 2008)". In some cases there are some limitations such as its cost, weather conditions or its resolution. Zooming of satellite photo makes photo quality lower while decreasing of flight level does not. This can be achieved by using the quadrocopter, so that harshness and accuracy of monitored phenomenon is increased. We can create detailed figures and maps of small measuring scales. In the following photos, high quality and very good resolution is visible (Fig.4: Scale 1:1 700), in contrary to zoomed satellite photo (Fig.5: Scale 1:2 260). Borders of particular herbal covers and its changes in the high mountain environment are separated straightforwardly. If any change of the soil type, physical or chemical structure appears, herbal cover is changing too (it's clearly visible in the Fig.4).

3.3 Ease of access

"The acquisition of the high quality terrain data still remains challenging in remote, hostile high alpine environments, where steep and unconsolidated slopes and poor satellite coverage hinder the application of ground surveys by GPS or total station. Other alternatives such as terrestrial laser scanning (TLS), airborne surveys are also restricted because of the high three dimensionality of mountainous landscape (Westoby et al., 2012)". Flying with the quadrocopter may be demanding on its operation. That is why we have used another technical aid, Nokia Lumia 1020. We have connected mobile phone with the GoPro camera through the WiFi, what enabled us to watch the whole operation of the quadrocopter's flight. This can prevent quadrocopter to crash into the rock. Another reason for such watching of the operation of quadrocopter is better control of the flight and so better recordings. It helps us to record exact area of monitored process and to control the flight height by the observer, so it is possible to approach observed process .

"Collecting of datasets may pose significant challenges in some glaciated areas where stable reference points are unavailable. Using remote sensing technology here has significant advances and it provides new options to researchers (d'Oleire-Oltmanns et al., 2012; Hugehnholtz et al., 2012)". "One of the most significant advantages of sUAS compared to aeroplanes is, that its owner does not need to have pilot licence for operating it, and its size is not bigger than radio-controlled models of aeroplanes and helicopter (Gallik and Bolešová, 2014).

"UAS enable us to effectively monitor ongoing processes such as ice flow, marginal recession or seasonal drainage on an ongoing basis (Whitehead et al., 2013)". In the photo from quadrocopter (Fig.4), shoreline (littoral zone) is clearly visible. According to colour scale it is possible to determine depth of the alpine lake in its constituent parts without any use of sonar technology that would have to be used when getting it into the alpine lake. As for shoreline and water surface that are changing in particular seasons (Hreško et al., 2012), not even the best quality sonar systems would provide information about these changes because they are limited in depth measuring. It is possible accurately to detect actual state of vegetation, what gives us depiction about sediments and its extension without any necessity to go through observed area several times and locate the area with other technical machines (e.g. GPS).

After the recording of the environment of the alpine lake, it is possible to use another special type of sUAS for the fully accurate depiction of the alpine lake bed, so called bait boat. It is remote-controlled boat equipped with sonar sensor which

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transmits data through Wi-Fi. It is possible to create 3D model of alpine lake bed in this way. Moreover, fine sonar technology can depict constituent sediment layers put on the bed. Disadvantage of this drone is its relatively high cost.

3.4 Weather conditions

One of the main advantages of using unmanned aircrafts is the analysis and the documentation of actual condition of environment and processes in progress. This way it is possible to record each geomorphological process individually, under what weather conditions it arose or what effects preceded its genesis.

"Although there exist various photogrammetric methods for 3D topographic modelling (Fraser and Cronk, 2009; Mathews, 2008; Remondino and El-Hakim, 2006)", when it is important to catch the effect of some processes in the mountainous landscape, using of the drone is better option. Our first decision was to make photos from one point (Fig.3), because Čierne Javorové pleso alpine lake is situated in enclosed valley with precipitous slopes that surrounds it. Since it is observing of water surface and its immediate environs, photo documentation from some angle gave us partly misrepresented information about changes in the alpine lake environs. It was because of the sun light reflecting from water surface and image of opposite slope (Fig.6). With the use of quadrocopter we have got optimal perpendicular look to the water surface of the alpine lake and image of sediment dispersion on its bottom (Fig.7). Shadows of surrounding peaks, based on the sun position and seasons, do not distract picture. Another advantage of the quadrocopter is its movement and stabilization in one point, that is easy to programme in case of expensive versions, what makes observer's work easier. It is also important to note that flight time ranges from 20 to 50 minutes, what depends on the quality of batteries and air temperature. Size of the quadrocopter is not crucial when observing in free space, but we had to make a right choice . It does not need to be too small, but it should have optimum size so it is easy for one person transfer.

Typical aerial photos acquired in our weather conditions are accurate, but there is quite big problem with shadow when detecting landscape components and landscape parts. That is why accurate area detection is not possible. These are places with poor visibility and places where the constant shadow in normal conditions is. As soon as we descend under the boundary of light and get into shadow places we can detect actual state of mountain rock-face, i.e. changes that are in process, rock fall in source areas of sedimentary rock. Then we are able to delimit steady places with almost no change – and if so, then in a very long time period (once in the geological period) – from zones that are rapidly destroyed.

sUAS, that has smaller size and weight, is highly dependent on favourable weather conditions. According to the Hugenholtz's (2013) study, they are inherently less stable than larger piloted aircraft. This instability of the platform changes the roll, pitch and yaw of the aircraft and it can affect accuracy of DTM. But in the case of the quadrocopter used for collecting photo documentation of ongoing processes, there still is benefit of changing the height of flight what enable us to departure from clouds.

Using drones for recording of the environment enables us to record landscape each day in case of good weather conditions. It is possible to observe various processes in different seasons of the year so we are able to determine actual and gradual landscape changes (Fig.8a) – winter – Scale: 1:1000, Fig.8b) – summer – Scale: 1:1000). Quadrocopter enables us to explore

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the landscape in real conditions, real time and space, and so secondary influences can be eliminated. "They can be easily and cheaply used before and after a natural event or also in order to offer a basis for understanding the evolution of the investigated process (Tarolli, 2014)".

4 Discussion

With the development and the progress of technology, limits of our knowledge are moving ahead. For today's conditions of the science knowledge, satellite and aerial photos do not suffice for accurate determination of the magnitude of geomorphic processes and phenomenon. Some people hold also the view that satellite photos taken from the Google Earth program which are free to download suffice for research, but in our opinion, these photos will not reach the level of the GoPro camera photo quality in connection with the quadrocopter. Many differences between the real state of observed phenomenon and available photos occur almost in all preliminary analyses, and only directly in terrain it is possible to state exactly whether our assumption was correct. The high quality of photo and good resolution are outcomes of flying and recording in lower heights.

Since our area of the interest belongs to the protected area of TANAP, the use of the quadrocopter is the best way to observe the area without any encroachment into the environment. After the pre-investigation stage of research we can decide whether there really is substantiated need to enter and affect such protected area. Via this papers we wanted to point to the protection of the environment by using remote sensing technology, mainly for immediate observation, transportation to the observed location and operation of sUAS, without harmful substances being released in the environment.

High-quality field research is hardly feasible without quality technical support. Each project, its realisation and procedures depend on exact measurements and gained data from the terrain. Observation of different morphodynamic processes in the high mountain landscape is exacting mainly because of rapidly changing weather conditions. Methodology of observing the field – environmental relief has made great progress in the last few years. Mainly in the way of remote sensing of the earth and the most modern technical aids used directly in the terrain, on which it was needed to use the laboratory in the past. UAS are the source of the new point of view on the observation of animate and inanimate components of the environment and gives higher scientific value of works where they are used. "An emerging technology - unmanned aerial vehicles - offers us a viable alternative to conventional platforms for acquiring high-resolution remote sensing data with increased operational flexibility, low cost and greater versatility. Usage of UAS transferred to civil and research applications where these tools are capable of acquiring high-quality geophysical measurements (Hugenholtz, 2012)". "Conventional applications of photogrammetry in geomorphology mainly involved piloted aircraft, but a number of other platforms have been tested, such as balloons (Boike and Yoshikawa, 2003), kites (Marzolff and Poesen, 2009), telescoping masts (Hauet et al., 2009) and small unmanned helicopters (Niethammer et al. 2009)".

All geomorphological processes are best determined via direct terrain research and measurements in landscape. "That is why application of the production of high-resolution topographic datasets is rapidly increasing in the geomorphic sciences (Bird et al., 2010; Butler et al., 2001; Fonstad and Marcus, 2010)". Satellite and aerial photos used in the scientific praxes, as we have stated earlier, will not achieve accuracy so that clear conclusions can be deduced. Based on this, it is possible only to point on the changes that have been happening during particular years of terrain recording sequence, made in one and multi-year repetition intervals. It is necessary to summarise digital data from different time and different technical devices so we could compare them. This process of working with different formats of photo-material could be made easier by selection of one quality technical device that will provide data from different time periods of the same format for easier work. We have made this by means of possible usage of the chosen quadrocopter in the terrain.

Because the price of some models is too high, it takes some time to reach the standard when it would be affordable also for economically weak countries. But still, this technology is much cheaper than the purchase of satellite photos needed for determination of landscape elements and phenomenon. After all, purchase of UAS can be funded by project.

Last but not least, we have created photo documentation needed for our research of the alpine lake. Based on the photos we are able to make all needed calculations, state the deposition level of the alpine lake or find the source of the deposited material. All of this was made without any disturbing encroachment into alpine lake environment.

5 Conclusions

The use of UAS technology for bearing out the hypothesis in the science projects still requires scrutiny and testing to fully understand the opportunities, limitations and drawbacks. sUAS make our work much easier, because we do not need to carry too much equipment, which is heavy and often take up too much space (the best example of this is the sonar technology for mapping alpine lake bed). This is great advantage mainly for scientists who need to get to hardly accessible terrain. Our area of interest is in protected area where scientific research needs to be permitted . As we have stated earlier in the papers, sUAS are small machines. We do not need any flying permit, because there is no encroachment into the environment, and so it is not necessary to spend too much time waiting for such permission.

Irreplaceable quality of using sUAS in high mountainous landscape is possibility of recording areas with poor visibility, constant shadow and what is more, it helps to lower inaccuracy of GPS coordinates of the point which we want to measure. With the use of the remote sensing technology for example in observing alpine lakes , it enables us to look on the water surface without any disturbing elements (e.g. sun light reflecting from the water surface, image of opposite slope on the water surface etc.). Via these papers, we pointed to possible and great use of the sUAS in locations with limited access and with limited conditions.

Author contribution

J. Gallik designed methods and procured all needed equipment J. Gallik and L. Bolešová collected all data in the terrain. J. Gallik processed them. L. Bolešová prepared the manuscript.

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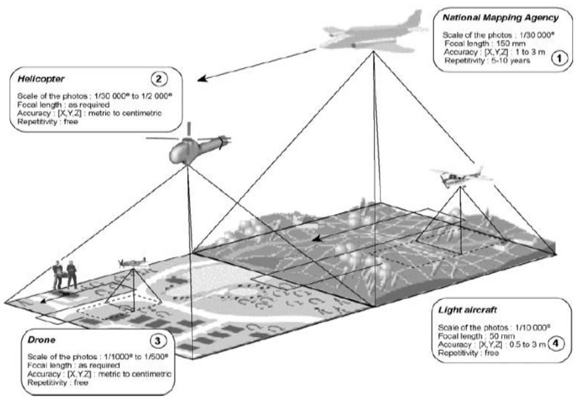

Fig.1: Sketch representing recording scale of Earth's surface (Henry, 2002).

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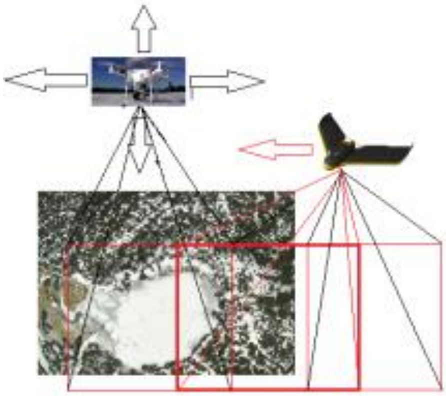

Fig. 2: Movement of the quadrocopter and fixed-wing UAS.

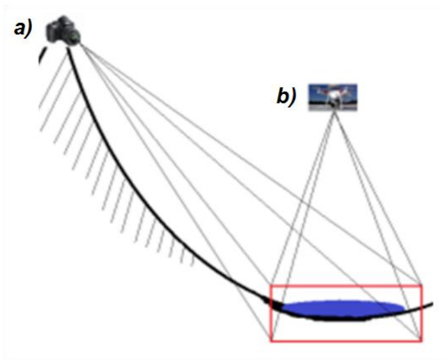

Fig. 3: a) Recording with the camera from angle; **b)** Recording of actual state of alpine lake with the quadrocopter perpendicular to the alpine lake.

Fig. 4: Quadrocopter photo - Čierne Javorové pleso alpine lake.

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Fig. 5: Zoomed satellite photo - Čierne Javorové pleso alpine lake (Google Earth, 2002).

Fig.6: Photo of Čierne Javorové pleso alpine lake from an angle, with reflected images of mountains surrounding it.

Fig.7: Photo of Čierne Javorové pleso alpine lake where disruptive, reflected images are missing.

Fig.8: Deluvio-fluvial sediments depositing Čierne Javorové pleso alpine lake in winter 2014 (on the left) and in summer 2013 (on the right).