Unmanned Aerial Vehicle (UAV) based mapping in engineering surveys: Technical considerations for optimum results

Stella Pytharouli[1], Jock Souter[2], Olympia Tziavou[1]

[1] Department of Civil and Environmental Engineering, University of Strathclyde, James Weir Building, 75 Montrose Street, Glasgow G1 1XJ, UK, (stella.pytharouli@strath.ac.uk)
[2] Survey Solutions Scotland, Bilston Glen Industrial Estate, 14 Dryden Rd, Loanhead EH20 9LZ, Scotland, UK, (jock.souter@survey-solutions-scotland.co.uk)

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ABSTRACT

Due to the wide availability of UAVs and their ease of use, the number of operators with limited surveying and photogrammetric knowledge is constantly increasing. At the same time, there are no easily accessible guidelines available regarding the choice of some of the parameters that greatly affect the quality of photos and consequently the orthomosaic obtained from a UAV e.g. overlap between photos, flight height, light conditions, specifications of the lens and camera, and weather conditions. As a result, if the user is not experienced or does not have a basic knowledge on surveying and photogrammetry (quite common considering the wide range of UAV user backgrounds), a poor quality orthomosaic is produced. This frequently leads to the misconception that a poor outcome is always due to limitations of the UAV technology. In this study, we discuss some of the main technical parameters, such as the effect of topography and UAV orientation on the overlap value, the camera calibration, number of control points and lighting conditions that need to be taken into account in order to utilize UAVs to their maximum potential.

I. INTRODUCTION

Over the last decades, extreme events connected to climate change, e.g., flooding, landslides etc., have considerably increased in numbers and seriously affected natural ecosystems, infrastructure and human life. Therefore, there is a growing need for the development of new or use of existing technologies, which will assist to the management of these effects, the minimisation of loss of properties and human lives, the protection of the environment and the design of sustainable and resilient infrastructure. The Unmanned Airborne (or Aerial) Vehicles (UAVs), or Unmanned Aerial Systems (UAS), or drones as they are commonly called, constitute a technology that can play a significant role towards this direction.

UAVs allow for the effective monitoring of large areas of land and existing infrastructure, within a few hours, a favourable characteristic, especially at cases where urgent intervention is required. The main principle is that a UAV takes aerial images over an area incorporated with spatial data based on GNSS to finally produce a high resolution 3D point cloud that can be used for a wide range of geological, civil/mining engineering applications and projects.

One of the most common uses of UAVs is 3-Dimensional (3D) mapping, with numerous applications in topographic surveys, photogrammetric solutions, progress monitoring, disaster analysis, archaeological mapping, agriculture and forestry (e.g., Remondino et al, 2011; Draeyer and Strecha, 2014). Applications related to monitoring of geological features in land and coastal study areas take advantage from the use of micro but integrated aerial vehicles supported by multisensory systems rather than employing greater platforms. This way the cost of field surveys is low while at the same time the captured detail of the aerial images is sufficiently high. Monitoring and 3D-mapping by micro-UAVs in geological applications focusing on surveying of geological structures and archaeological sites as well as on the detection of post-earthquake ground changes and displacements are described in several researches (e.g., Nagai et al, 2009; Jordan, 2015). In mapping of coastal areas the scale of detail can be at the level of 10 cm and may reach the level of 1 cm or better (e.g., Bemis et al, 2014).

This paper focuses on the use of UAVs for engineering mapping surveys and discusses the main parameters affecting the resolution of the images acquired by a UAV.

II. CHOICE OF FLIGHT PARAMETERS

For engineering mapping surveys, a spatial resolution of less than 10 cm is generally good. This translates to a requirement of maximum 10 cm/pixel, i.e. the Ground Sample Distance (GSD) should be 10cm/pixel or less. For a certain GSD, the flight height depends on the focal length F_L, the sensor width S_w and the number of pixels per photo width P_N (He et al., 2012).

$$F_H = GSD * F_L * \frac{P_N}{S_W} \quad (1)$$

where

F_H is the flight height (m)
GSD is the ground sample distance (m)
F_L is the focal length (mm)
P_N is the number of pixels per image width
S_w is the sensor width (mm)

From eq. 1 it is evident that keeping the flight height, number of pixels per image width and sensor width the same and increasing the focal length, results in a better GSD, i.e. spatial resolution.

Other factors to be accounted for are the flight time and the number of images required to cover a specific area. Both depend on the overlap percentage, i.e. the percentage of the same area on the ground covered by adjacent images as shown in Figure 1b. In general, an overlap value of more than 60% for the forward overlap and at least 20% for the side overlap is considered adequate in photogrammetry in order for an orthomosaic to be created. In practice, for UAVs, a higher overlap value, e.g. 80%-85%, would minimize the possibility of gaps in the orthomosaic and is recommended (Campbell and Wynne, 2011). However, it might not always be achievable due to camera triggering limitations and the flight parameters.

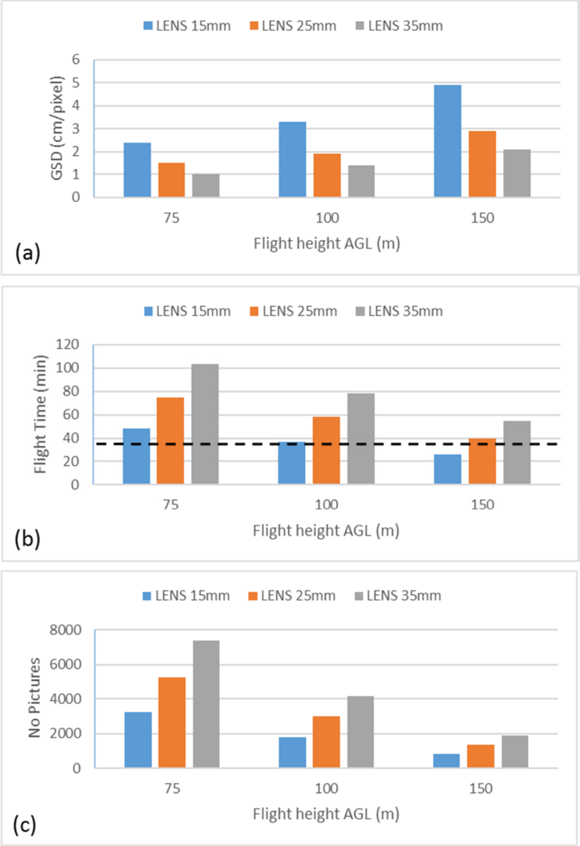

Figure 1. Change of (a) the GSD, (b) the flight time and (c) the number of acquired images with the flight height and the focal length (lens) for a survey area of 1km x 1km as obtained for the Sony A7R camera mounted on Trimble UX5 HP (fixed wing). The dashed horizontal line in (b) denotes the threshold of 35 mins which is the maximum time per flight for the UX5 HP (after Tziavou et al., 2018).

Figure 1 summarises how the GSD, the flight time and the number of acquired images change with the flight height and the focal length (lens) for an area of 1km x 1km. Numbers in Figure 1a and c have been calculated using eq.(1) –(8) in Tziavou et al. (2018) while Figure 1b numbers were calculated using the Trimble Flight Calculator (http://uas.trimble.com/calculator).

From Figure 1 it is evident that the focal length of the camera plays a significant role on the flight height as it can result in the same or even better resolution at twice the flight height to the one achieved by a lens with a smaller focal length (Figure 1a). Choosing a higher flight height reduces the flight time (Figure 1b) and the post-processing time since the number of acquired images covering the same area is significantly smaller.

When the camera and focal length (lens) do not change, the impact of the flight height on the image resolution, the flight time and number of images is more prominent. Figure 2(a) and (b) show the effect of the flight height on the change of the GSD, the number of images acquired and the flight time (calculated using the Trimble Flight Calculator) for a survey area of 1km2 and 0.01km2, respectively. The results refer to an Olympus E-PL7 camera with a 14mm lens, mounted on Trimble ZX5 (hexacopter). This allowed for a wider range of flight height values compared to those for the fixed wing.

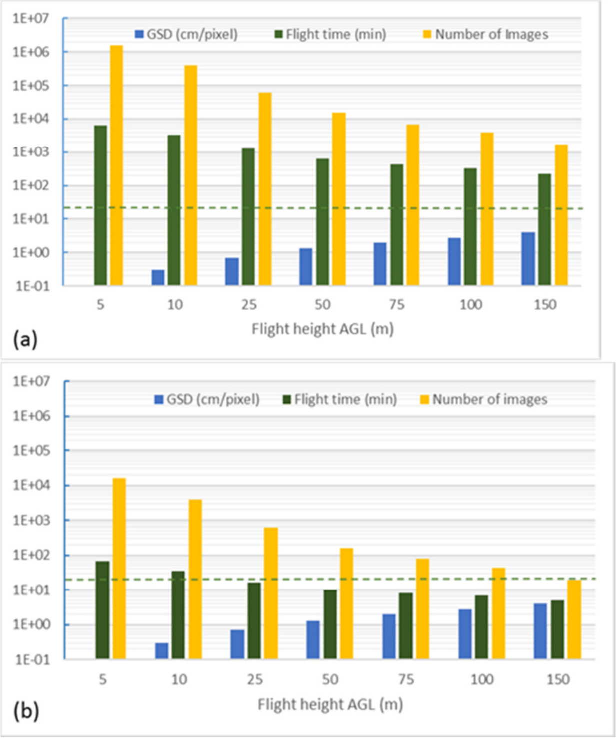

Figure 2. Change of the GSD (blue), the flight time (green) and the number of acquired images (yellow) with the flight height for an area of (a) 1km x 1km and (b) 0.1km x 0.1km. The focal length (lens) is 14mm and the camera used is the Olympus E-PL7 mounted on Trimble ZX5 (hexacopter). The dashed horizontal line denotes the threshold of 20 mins which is the maximum time per flight for the ZX5. Note that

the y-axis for both plots is in logarithmic scale (after Tziavou et al., 2018).

III. TECHNICAL CONSIDERATIONS

We show that for favourable weather conditions, the achieved resolution of the orthomosaic depends on the flight height and the sensor size and lens. The flight height is restricted by the type of the UAV, i.e. copter or fixed wing, the aviation regulations and the application itself. As shown in Figure 1a the flight height can be increased if using a lens with a bigger focal length or as derived from eq. 1, a bigger sensor size. The last two imply a high resolution camera which, on one hand, might conform with the resolution requirements of a project but on the other, results in increased cost and payload requirements.

For a flight height of more than 80m, a sensor size of 7360 pixels and a 15 mm lens can achieve a GSD better than 8mm/pixel, a value that is adequate for most engineering projects. If a lower height is adopted, for example when using a copter, another factor to be considered is the number of images acquired as it significantly affects the post-processing time. The latter depends on the processing software used and the camera. For the same processor and number of images, the camera also affects the processing time. For example, a 56MP camera will result in a significantly different, i.e. three times higher, number of pixels per image compared to a 16MP camera.

The number of ground control points (GCP) can significantly affect the accuracy of the orthomosaic (Tonkin and Mingley, 2016). The number of GCPs required depends on the topography and the method used to establish a GNSS position. For example, post-processing kinematic (PPK) and Real-time kinematic (RTK) only require one GCP. This is the minimum GCP number recommended to allow for the control of the height component of the GNSS measurements. The minimum number in all other cases is at least four or five per flight and their geometrical distribution should be suitable for the site topography (Tonkin and Mingley, 2016).

GCPs are also used for the calibration of the camera. The calibration of the camera models the lens distortion. In most cases, it is also important to calibrate for white balance. The latter does not affect the accuracy of the produced orthomosaic but it affects the true colours of the acquired images, which might be significant for specific projects, such as those related to geological mapping. The calibration of a camera for photogrammetric purposes has been extensively discussed in the international literature, e.g. Zhang, 2000; Wang et al., 2008; Balletti et al. 2014.

IV. USER ERRORS

As with every other technology, UAVs require sensible use. In many cases, the result of a UAV survey reflects user errors. One of the parameters that are controlled by the user and affect the quality of the orthomosaic is the forward and side overlap. The recommended value for the forward and side overlap is at least 80% for mapping surveys that require high accuracy (Gatewing, 2013). This might not be always achievable if the shutter speed of the camera is too slow for the chosen flight height and UAV speed. Also it can be compromised by not anticipating the effects of topography and the UAV orientation overlap. An example of the effect of topography on the overlap value is shown in Figure 3: the orthomosaic of a hill area. The black spots visible at the left of the image are areas that lacked sufficient tie points (i.e. common points among the images) for the images to be tied together. That particular area of the orthomosaic should depict a hill. In this case the overlap that was chosen by the user was 85% and the flight height 91m AGL. However, the topography was not flat (presence of a hill) and the take off point was not at the top of the hill but approximately at mid height. As a result, the effective overlap value for the area close to the top of the hill was much smaller (see Figure 4a) than 85%.

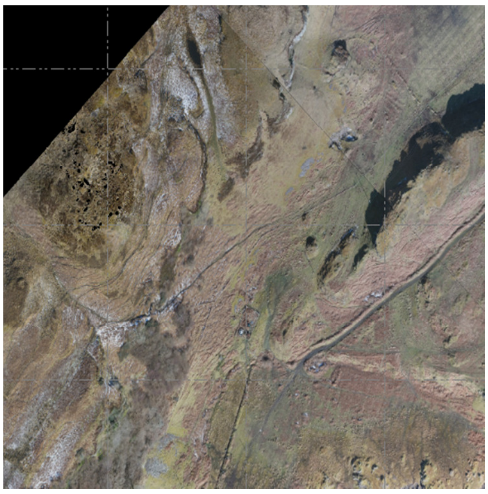

Figure 3. Effect of poor overlap on the orthomosaic of a hill area (after Tziavou et al., 2018).

The effect of the UAV orientation and how it compromises the overlap value is shown in Figure 4b. The pitch, roll and yaw values are known and provided by the inertial system. They help orientate the images correctly, however, that requires a high standards IMU. Even then, if the image isn't taken in the right orientation, e.g. due to excessive yaw because of unfavourable wind direction, no amount of re-orientation will make the photos overlap.

The wind direction is not the only meteorological factor affecting the quality of a UAV survey. A UAV flight should take place in good light conditions. Although the AutoISO can compensate for unfavourable light conditions, this function might be limited in some cameras. A detailed discussion on poor light conditions during a UAV flight and the resulted artefacts on the acquired images is presented in Whitehead and Hugenholtz (2014).

Another very common misconception is that the accuracy of measurements based on the images acquired by a UAV survey is equal to the value of the GSD. In a previous study we show that this is not true. The GSD value should be at least half the accuracy required by the project in order to minimize the ambiguity introduced by the pixel as discussed in Tziavou et al. (2018).

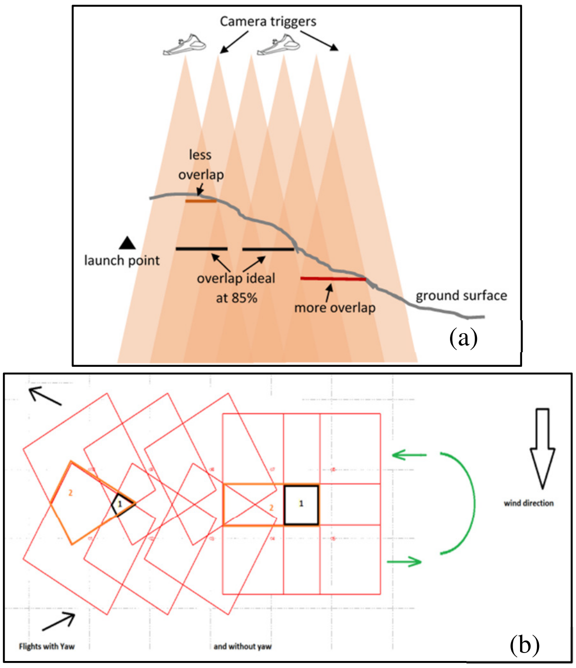

Figure 4. Overlap compromise with (a) topography. and (b) with yaw. In (a) the overlap value is the one specified by the user at the elevation of the launch point. At higher elevations, the effective overlap is less, at lower elevations the effective overlap is more. The change might be significant if the changes in the topography of the surveyed area are major. In (b) the size of the area that is overlapped for two cases, numbered 1 and 2, is shown for the same nominal overlap value for a flight with yaw (b-left) and without (b-right). Figures not on scale. (after Tziavou et al., 2018)

A UAV is a tool and as such it should be used for the right application. For mapping/monitoring of small areas, i.e. less than 10,000m^2, a VTOL (vertical take-off and landing) is more appropriate, while a fixed wing is more suitable for covering larger areas. Figure 5 shows how the survey of a small area, is affecting the shape of the flight lines for a fixed wing aircraft.

For the fixed wing aircraft (UX5 HP) the flight lines are not strictly straight above the area under survey as would have been in an optimum case (Figure 5-top). Instead, they are curved along at least half the length of the area of interest due to the turning circle required by the UX5 HP. This results in images that have a compromised overlap as shown in Figure 4b. On the contrary, Figure 5-bottom shows the flight lines for the ZX5 hexacopter (VTOL) over the same area. In this case, all flight lines are straight and parallel.

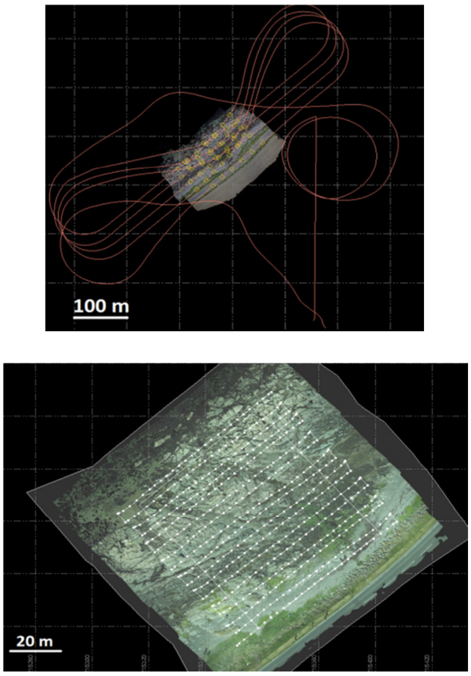

Figure 5. UAV survey at a shore along Scotland's west coast. Flight lines for (top) the UX5 HP (red lines) and (bottom) the ZX5 (white lines).

V. CONCLUSIONS

Unmanned Aerial Vehicles (UAVs) are a promising technology with great potential as a tool in engineering surveys. As every tool, it requires sensible use and more importantly, a good understanding of the surveying principles involved. This technology has already become the Holy Grail in mapping surveys, in many cases totally replacing terrestrial surveying equipment: its ability to cover large areas in very little time is a highly desirable characteristic in an era where quick and effective intervention has become the norm. We show that this comes at a cost; high resolution images require more expensive sensors or lower flight heights and computers with high processing capacity to allow for processing of large numbers of images. An engineering approach, such as a compromise between the flight height and the detail that can be derived from the orthomosaics, is required almost at all times, if, for example, cost and time are the driving parameters.

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References

Balletti, C., Guerra, F., Tsioukas, V., & Vernier, P. (2014). Calibration of action cameras for photogrammetric purposes. Sensors, 14(9), 17471-17490.

Bemis, S.P., Micklethwaite, S., Turner, D., James, M.R., Akciz, S., Thiele, S.T. and Bangash, H.A. (2014). Ground-based and UAV-based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology. Journal of Structural Geology, 69, 163-178.

Campbell, J. B., & Wynne, R. H. (2011). Introduction to remote sensing. Guilford Press.

Draeyer, B. and Strecha, C. (2014). White paper: how accurate are UAV surveying methods? Available at: https://support.pix4d.com/entries/40219303-How-accurate-are-UAV-surveying-methods (Accessed: 1 July 2016).

Gatewing (2013). Support Bulletin - Image Overlap Settings for Gatewing X100 and Trimble UX5 Aerial Imaging Solutions. Available at: http://surveypartners.trimble.com (Accessed: 12 August 2013).

He, J., Li, Y. and Zhang, K. (2012). Research of UAV flight planning parameters. Positioning, 3, 43-45.

Jordan, B.R. (2015). A bird's-eye view of geology: The use of micro drones/UAVs in geologic filed work and education. GSA Today, 25 (7), 50-52.

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M. and Sarazzi, D. (2011). UAV photogrammetry for mapping and 3D modeling-current status and future perspectives. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVIII-1/C22, 25-31.

Tziavou O., Pytharouli S. and Souter J. (2018). Unmanned Aerial Vehicle (UAV) based mapping in engineering geological surveys: considerations for optimum results Engineering Geology 232, 12-21 https://doi.org/10.1016/j.enggeo.2017.11.004

Tonkin, T. N., & Midgley, N. G. (2016). Ground-Control Networks for Image Based Surface Reconstruction: An Investigation of Optimum Survey Designs Using UAV Derived Imagery and Structure-from-Motion Photogrammetry. Remote Sensing, 8(9), 786.

Wang, J., Shi, F., Zhang, J., & Liu, Y. (2008). A new calibration model of camera lens distortion. Pattern Recognition, 41(2), 607-615.

Whitehead, K., & Hugenholtz, C. H. (2014). Remote sensing of the environment with small unmanned aircraft systems (UASs), part 1: A review of progress and challenges 1. Journal of Unmanned Vehicle Systems, 2(3), 69-85.

Zhang, Z. (2000). A flexible new technique for camera calibration. IEEE Transactions on pattern analysis and machine intelligence, 22(11), 1330-1334.