HELIUM BALLOONS FOR 3D MODELLING: OFF TO A FLYING START?

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ABSTRACT:

Currently, the use of unmanned aerial vehicles (UAV) as a platform for aerial photography is becoming more and more common practice for 3D photo modelling applications. However, the use of these platforms has several drawbacks. Firstly, to recharge the UAV’s batteries a nearby electricity source is needed. This might cause problems when performing research in remote areas. Secondly, a skilled operator is required to control the UAV. Thirdly, there might be legal restrictions to the use of such an aerial platform in several countries. Finally, purchasing a UAV can form a big cost when performing a small project. To address these issues, the use of helium balloons as an alternative and low cost platform for aerial photography is proposed. To assess its efficiency, effectiveness and accuracy, several case studies are elaborated. In the first case study the accuracy of a 3D model created by laser scanning is compared with a 3D model created by helium balloon imagery (Ghent, Belgium). The second case study comprises a test of the performance of the system used at the lake of Vassivière (France). Finally, the helium balloons are deployed on the archaeological site of Edzna (Mexico). Here, a comparison is made between the accuracy of 3D models generated by UAV and helium balloon imagery. In conclusion, the advantages and drawbacks of the use of helium balloons as platform for aerial photography are listed. This allows potential users to make an informed choice between this and other platforms.

1. INTRODUCTION

Due to its low cost and ease of use, the technique of photo modelling has been adopted rapidly in academic practices. Photo modelling creates highly realistic and accurate 3D models which can be used for various goals, such as the reconstruction of archaeological objects (Howland et al., 2014). The workflow used in this paper encompasses both the Structure from Motion (SfM) and Multiview Stereo (MVS) processes, as elaborated by (Stal et al., 2012).

However, when spacious sites, complex structures or densely vegetated areas are modelled, the exclusive use of terrestrial imagery might be insufficient and result in incomplete data coverage. This will inherently cause gaps in the 3D models. This is why currently a lot of scientists are turning to unmanned aerial vehicles (UAV) to either supplement or replace their terrestrial recordings with aerial photographs. Moreover, UAVs allow the creation of digital elevation models (DEM) and orthorectified images, which give a geometrically correct overview of the study area (Hendrickx et al., 2011; Mancini et al., 2013; Zarco-Tejada et al., 2014). Two types of UAV are being deployed in such case studies, namely fixed-wing and copter UAVs. Fixed-wing UAVs are suitable for the reconstruction of large areas, as shown by (d'Oleire-Oltmanns et al., 2012). Copter UAVs are more fit for low altitude applications or when the flexibility of the platform is an important requirement (Taccola et al., 2014).

Nevertheless, these aerial platforms have some limitations of their own. Firstly, UAVs are powered by batteries and thus a nearby electricity source is needed in order to keep them running. When working in remote areas, this might cause problems, which can possibly be solved by providing solar chargers. However, the need for batteries also limits the time of flight of a UAV (copter type) to less than an hour, before having to change the batteries. This interruption of the data acquisition can cause gaps in the data when the progress of the acquisition is not thoroughly documented. Secondly, a skilled operator is required to control the UAV. The operator should know both how to fly the UAV and how to repair the UAV in case of an emergency. Otherwise, the project might have an unwanted delay when problems with the platform occur. Thirdly, there might be legal restrictions towards the use of UAVs in several countries. For example, Belgian law only allows the use of UAVs for test flights and scientific purposes under strict conditions and completely prohibits their use for commercial purposes (http://www.mobilit.belgium.be/). Furthermore, the Belgian regulation, but other counties as well, requires the possession of a certain permit or license in order to fly these platforms. Finally, purchasing a UAV might form a big cost for small scale projects, even though low cost possibilities are becoming more and more common on the market. Also, the technological complexity (especially in terms of indoor system maintenance) might scare off potential users to invest in this kind of platforms.

This is why researchers are looking into alternative platforms, such as poles, helium balloons or helikites (Verhoeven et al., 2009). Such platforms do not cope with the same limitations as UAVs and might provide an alternative or can be used in addition to them.

The most well-known application of helium balloons for scientific research to date is in weather- or atmosphere-related

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disciplines (Jarisch et al., 1997, Wilkerson et al., 2012). Their use for photogrammetry has also been documented by (Kersten et al., 2012). However, due to the emergence of UAVs they have been employed only occasionally for 3D modelling. The use of helium balloons as a platform for aerial photography is being discussed, amongst others, by (Jensen et al., 2007; Kako et al., 2012; Silva et al., 2014). (Johnson et al., 2014) demonstrate the use of these balloons in combination with photo modelling, reconstructing the topography of a fault zone.

This research paper proposes the use of helium balloons as a low cost and straightforward alternative for UAVs. The system is tested throughout several case studies in Ghent (Belgium), the Vassivière Lake (France) and the archaeological site of Edzna (Mexico), as described in Paragraph 1. The first case study consists of the initial tests of the helium balloons, comparing the results of this system with laser scanning and total station data. The second case study investigates its user-friendliness, advantages and drawbacks by employing it for the registration of a muddy, swamp-like area. The third and final case study takes place at an archaeological site, where the balloons are employed in addition to a UAV. The results, advantages and drawbacks of both methods are discussed. In Paragraph 2, the study areas are situated. In Paragraph 3, the different methodologies are elaborated, followed by the results in Paragraph 4. Paragraph 5 comprises a discussion. Finally, the research conclusions are listed in Paragraph 6 and the main advantages and disadvantages of the system are highlighted.

2. STUDY AREA

2.1 Ghent, Belgium

The first study area was situated at the Science campus of Ghent University (Ghent, Belgium) and took place in the summer of 2013 (Figure 1). The modelled object was a picnic bench.

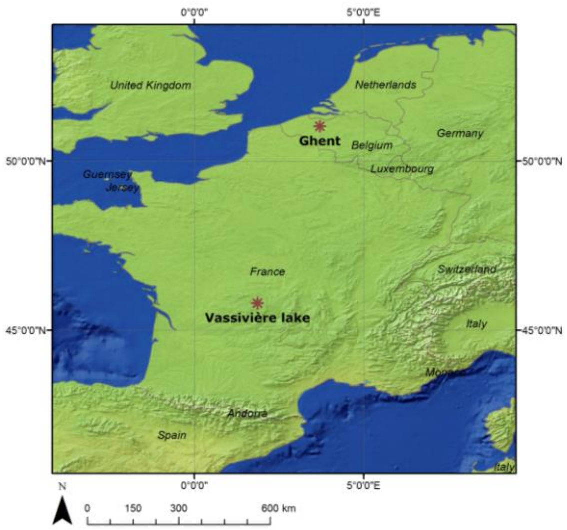

Figure 1. Location first and second study area (source shapefiles: http://www.naturalearthdata.com/)

2.2 Vassivière Lake, France

The second study area was selected as a function of the Erasmus Intensive Programme at the Vassivière Lake in October 2013 (Figure 1). The Programme unites students from ENSTA Bretagne, Ghent University and HCU Hamburg and introduces them to the use of terrestrial and hydrographical measurement techniques for 3D data acquisition at the lake.

The helium balloons were employed as an airborne platform for the registration of a muddy, swamp-like area.

2.3 Edzna, Mexico

Finally, the third study area was located at the Mayan archaeological site of Edzna (Yucatan peninsula, Mexico) and took place in November 2013 (Figure 2). The archaeological site was inhabited between 600 BC and 1450 and housed over 25,000 citizens at its peak. Nowadays, 16 structures are still visible and accessible for the general public. The most important structure, the Five-story building or Edificio de los Cinco Pisos, is located at the Great Acropolis and shows characteristics from the Puuc construction method, which can also be found at the sites of Uxmal and Chichen Itza.

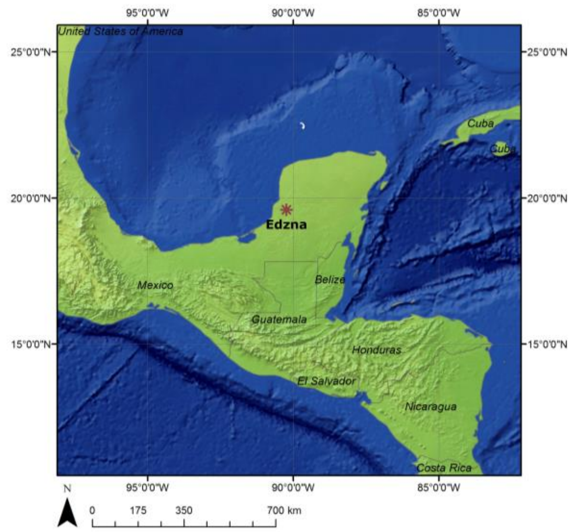

Figure 2. Location third study area (source shapefiles: http://www.naturalearthdata.com/)

3. MATERIALS AND METHODOLOGY

3.1 Ghent, Belgium

The initial tests with the system were performed at Ghent University, modelling a small picnic bench with total station, laser scanning and photo modelling simultaneously.

In this first stage of the research, two helium balloons were tied together and a wooden frame was created to attach the camera (Canon EOS 450D) to the balloons (Figure 3). The camera was equipped with a 10-22 mm lens, and had a resolution of 4272 x 2848 pixels and a 22,2 mm x 14,8 mm CMOS sensor. An infrared device was attached to the camera in order to allow automatic photographing. The helium balloons were controlled by two operators who used ropes in order to aim the balloons (and thus the camera) in a certain direction.

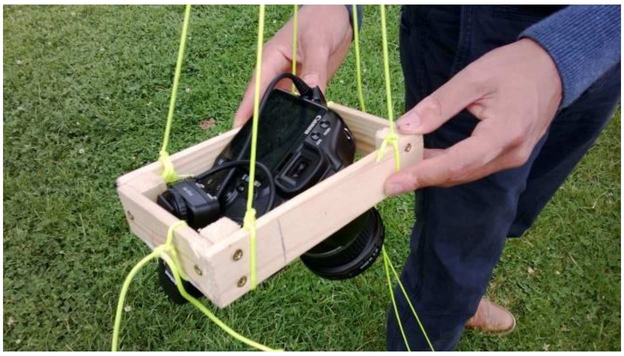

Figure 3. Wooden frame supporting camera

For the case study also a Leica HDS6100 laser scanner with eight black-and-white targets were used. The laser scanning targets were spread out evenly across the terrain, allowing an optimal registration of the point cloud (Figure 4). These targets, alongside twelve characteristic points on the bench and four ground control points, were measured in a local coordinate system using the total station.

Figure 4. Configuration of laser scanner and targets

A Pentax R-325(N) was employed for total station measurements. This device has an angular accuracy of 5” and a ranging accuracy of ± (5+3ppm x D). These measurements served as a basis for both georeferencing the laser scanning and photo modelling point clouds (based on the ground control points), and performing a quality assessment (based on the twelve characteristic points). The models were processed using Agisoft PhotoScan (photo modelling), Leica Cyclone (laser scanning) and Octopus (total station). The aerial photographs were supplemented with terrestrial pictures.

3.2 Vassivière lake, France

At the Vassivière Lake, the helium balloon system was updated using an improved wooden frame to attach the camera (Figure 5) and an app to gain automatic picture retrieval. Through this case study, the advantages and drawbacks of the system could be formulated and the system could be enhanced.

Figure 5. Helium balloons with updated frame

A muddy, swamp-like area was modelled by combining photo modelling (using the helium balloons) with total station measurements (Figure 6). In order to georeference the 3D model, standard pseudo-random targets provided by the photo modelling software (Agisoft PhotoScan) were spread out evenly and at different heights across the study area. A Trimble M3 total station was deployed, with an angular accuracy of 2” and a ranging accuracy of ± (2+2ppm x D). A Sony Nex-5R camera was attached to the helium balloons, equipped with a 16-50 mm lens and having a 4912 x 3264 pixel resolution and a 25.1 mm x 16.7 mm APS-C Exmor CMOS sensor. The pictures were taken using the Timelapse app, provided by Sony. The app allows the pictures to be taken during a certain time span and with a specific interval and thus replaces the need for an infrared trigger. The data were processed using Agisoft PhotoScan and Octopus.

Figure 6. Data acquisition at the Vassivière Lake

3.3 Edzna, Mexico

Based on the findings and conclusions of the experiments in Ghent and Vassivière, the available airborne platforms were optimized for the modelling of a Maya temple. Consequently, similar research was conducted at the archaeological site of Edzna in Mexico. The helium balloons were initially brought along as a backup system in case something went wrong with the UAV (Figure 7). The wooden frame was replaced by an aluminium one, allowing the camera to be aimed towards a certain point or in a certain angle. The pictures were taken using the Timelapse app as described above.

Figure 7. Deployment of helium balloons at Edzna

All structures on the site were modelled using both photo modelling, total station and GNSS measurements. The total station and GNSS measurements were used for georeferencing the 3D models in a local and absolute coordinate system. In order to do so, a network of first and second order ground control points was set out on the site. The total station measurements were carried out using a Trimble M3, the GNSS measurements were conducted with a Garmin Etrex handheld GPS with a 2-3 m accuracy in SBAS (WAAS) mode. A number of characteristic points was measured in order to allow a quality assessment afterwards, ranging from 21 points on the Moon temple to 75 points on the Five-story building. The focus of this quality assessment was on the Great Acropolis, comprising the Five-story building, Moon temple and North temple.

Both terrestrial and aerial photographic data acquisition was performed. Two airborne platforms were employed, namely a UAV (hexacopter) and the helium balloon system. In order to link the terrestrial to the aerial data, pictures were taken with an angle of 30°, 60° and 90° with respect to the ground. Sufficient overlap between consecutive images was also a prerequisite for qualitative and realistic 3D models.

Afterwards, the imagery was processed using Agisoft PhotoScan. A quality assessment was performed on the Moon temple (Figure 8). Hereby, the model generated through UAV imagery and the one generated through helium balloon imagery were compared. Normally, similar deviations can be expected for both methods in the quality assessment, as the same camera and technique were applied.

Figure 8. Moon temple

4. RESULTS

4.1 Ghent, Belgium

Two separate 3D models and an a-priori correct geometric framework were generated from the data. The accuracy of both models lay in the same range, as both models had a deviation below 1 cm when compared to the total station measurements. Both resulting point clouds were compared to one another using the M3C2 plugin in CloudCompare. The focus of this comparison was on the upward facing surfaces of the bench. The point clouds have a vertical offset of approximately 1-2 cm, as can been seen in Figure 9. This was probably caused by the way in which they were georeferenced.

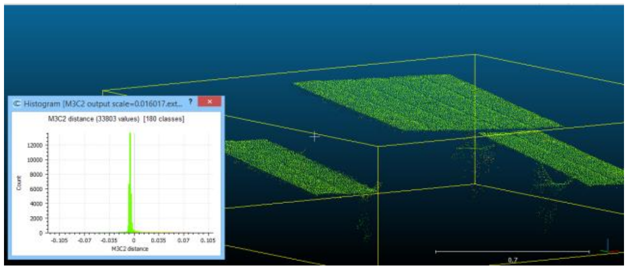

Figure 9. Comparison laser scanning and photo modelling point clouds in CloudCompare

Two problems occurred during the data acquisition. Firstly, the absence of a live view system hampered the user-friendliness of the system, as the operators were required to check the acquired imagery following every balloon flight in order to make sure that a certain level of overlap was obtained. Secondly, the windy conditions hindered a smooth balloon flight and the data acquisition had to be postponed, in anticipation of better weather conditions.

4.2 Vassivière Lake, France

After processing the total station and photographic data, the helium balloon system was thoroughly screened. The main advantages and drawbacks that were experienced during the field work are summarized in Table 1.

Advantages	Drawbacks
- Low cost - No legal restrictions - No batteries needed - Longer time of flight - Simple equipment (can be found anywhere) - No crashes	- Sensitive to wind - Need to access terrain - Minimum two operators - Hard to aim - Operators are in photos - Ropes might cause problems - Slow acquisition speed

Table 1. Advantages and drawbacks of helium balloons

In this case, the UAV was preferred above the helium balloons. This is mainly due to the fact that the UAV system is much easier to control. Furthermore, the camera can be aimed towards certain areas of interest and the acquisition speed with a UAV is reasonably faster. Nevertheless, the imagery that was obtained from the helium balloon sufficed for the creation of a qualitative 3D model of the study area (Figure 10).

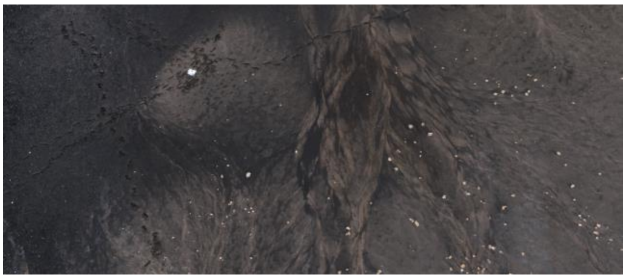

Figure 10. Point cloud representation of study area Vassivière Lake

4.3 Edzna, Mexico

Both helium balloon and UAV imagery were acquired at the archaeological site of Edzna. These data were processed as discussed in Paragraph 3.3. Afterwards, a quality assessment was performed on the Moon temple models. Arguably, this quality assessment should render similar results for both models, as they were generated using the exact same method. However, a small difference in accuracy could be noted when comparing the UAV model to the helium balloon model, as shown in Table 1.

	Mean absolute deviation		
	2D (m)	Z (m)	3D (m)
UAV	0.020	0.009	0.022
Helium balloon	0.028	0.020	0.034

Table 1. Mean absolute deviation in 2D, Z and 3D

The UAV model is slightly more accurate than the helium balloon model. Also, an offset can be noticed when comparing the two models in CloudCompare, using the same methodology as described in Paragraph 4.1. This offset has a Gaussian distribution, shown in Figure 11, which can also be explained by the georeferencing process.

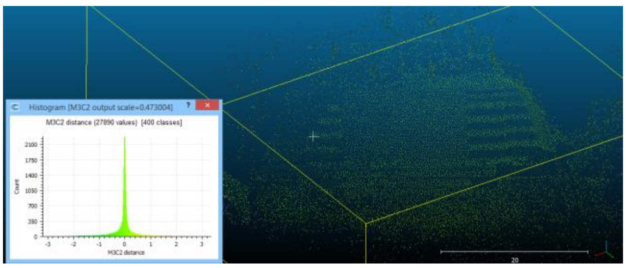

Figure 11. Comparison UAV and helium balloon point cloud in CloudCompare

5. DISCUSSION

It can be concluded that even though the system is clearly experienced as being easy to operate and low cost, it lacks certain qualities when compared to a UAV. The helium balloons can be a useful and alternative platform when necessary, but cannot replace the UAV when modelling large sites or complex structures. This is the result of certain drawbacks that need to be improved in order to be able to use the system to its full extent.

Firstly, the system is very sensitive to weather conditions such as wind. This also holds for a UAV, but to a much lesser extent. Calm weather conditions are thus a prerequisite for the system with the helium balloons to work. This cannot be guaranteed for all projects. When a certain project is situated in an especially windy environment (e.g. the beach), it is advised to use another 3D modelling system such as laser scanning. This was, among others, experienced during the picnic bench measurements in the first case study. Secondly, the operators need to physically access the terrain in order to control the helium balloons. This might cause problems when the site is inaccessible, which it might be due to various reasons: protection of the site, unhospitable environment, … Thirdly, at least two operators are required to conduct the image acquisition with the helium balloons. In order to assure or improve the system's stability, multiple operators might be necessary. This makes it a very labour-intensive acquisition method, whereas one operator suffices for controlling other platforms for aerial imagery, such as poles and UAVs. Moreover, even though the aluminium frame allows the operators to aim the camera in a certain direction, it is hard to estimate what part of the site the camera is capturing during the balloon flight. Even if a real-time monitoring system is implemented on the platform, the image acquisition will be difficult due to its motion sensitivity. After every flight, the camera needs to be checked and if the pictures do not cover the entire site, or if insufficiently overlapping or blurry images are present, the process will be done anew. Furthermore, it often occurs that the operators are visible in the images, as shown in Figure 12. This image is taken from the first case study, but similar images are also identified in the second and third case study. This might cause mismatching of images when they are processed afterwards. Either the images where operators are visible are deleted from the data set or the operators are masked in the images when processing these images in the photo modelling software. Finally, the ropes that control the helium balloons might cause problems. They might not be sufficiently strong and could snap during the image acquisition, which results in the loss of the camera, or they might get entangled during the process. This must be prevented at any cost in order to keep the duration of the whole procedure to a minimum and limit the project budget.

Figure 12. Presence of operator in images

It is important to note that the above factors are more important than the quality assessment when deciding whether or not to use this system, as they are more significant. The quality assessment does not give any information about the system of the helium balloons as such, but gives an indication of the accuracy of the photo modelling technique and the georeferencing process. The fact that the UAV model is slightly more accurate than the helium balloon model in the third case study, for instance, can be explained by two factors, being the optimization of the helium balloon model and the presence of blurry images in the helium balloon imagery. The first factor implies that the helium balloon model is georeferenced based on the optimization of the UAV model. If a different point set was used, the model might be more accurate. The second factor is caused by the use of the Timelapse app and the fact that the helium balloons are a volatile platform and thus very sensitive to windy conditions. This problem might be remedied by adjusting the shutter time of the camera.

6. CONCLUSION

Certain problems can arise when employing a UAV for the acquisition of aerial images, such as certain legal restrictions, the absence of a nearby electricity source and/or skilled operator. Moreover, the budget of the project can hold back researchers from buying such equipment.

In these cases, helium balloons are potentially a useful alternative and provide researchers with a valuable tool for aerial image acquisition. Even though they have only been used occasionally so far, helium balloons are able to overcome the abovementioned issues and have certain advantages of their own. The equipment is inexpensive, straightforward and universally available. No electricity sources are needed, as the system does not operate on batteries or any kind of fuel (except for the camera, which normally has long duration batteries). This also entails a longer time of flight, as the system can operate until the helium runs out. Furthermore, there are generally no legal restrictions to the use of helium balloons, as they remain within the direct control of the operators and thus do not hamper flights of aircrafts, which might be the case with UAVs.

However, there are certain drawbacks linked to the use of the helium balloons. Most importantly, it is very hard to aim the helium balloons towards a certain area of interest. Once the system is operational, the settings of the camera cannot be adjusted anymore and the overlap of the consecutive images cannot be analysed. Only when the helium balloons are pulled back to the ground level, an initial quality check can be conducted. This makes it a labour-intensive strategy. Due to its wind sensitivity, the system can be inoperable in certain environments. This can also cause the resulting images to be blurry or unfocused, which reduces the quality of the final 3D model or even obstructs the photo modelling process afterwards. Furthermore, the ropes that control the helium balloon can cause certain problems of their own. The first of these problems is the presence of the operators in particular images, which makes them unfit for further processing. The second problem is the possibility of the ropes to either snap or get entangled. The last difficulty with helium balloon is that the operators should also be able to physically access the terrain, which is not the case when using a UAV and which could be prohibited due to various reasons.

First-time users experienced this system to be less flexible and more cumbersome than similar airborne platforms. On the other hand, its low cost and simplicity were seen as the main advantages. Moreover, when comparing the results to other acquisition methods such as laser scanning and photo modelling through UAV imagery, no major anomalies were perceived. The described system thus is as accurate as these well-known 3D acquisition methods.

In conclusion, helium balloons are a promising and low cost alternative for UAVs, but their use should be limited to small scale projects in calm weather conditions. The problems that helium balloons might impose during the image acquisition make this a potentially labour- and time-intensive procedure and thus nullify the advantages that they have. It is important to clearly define the goal of the project and select a platform for aerial imagery on this basis.

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REFERENCES

d'Oleire-Oltmanns, S., Marzolff, I., Peter, K., Ries, J., 2012. Unmanned aerial vehicle (UAV) for monitoring soil erosion in Morocco. *Remote Sensing*, 4(11), pp. 3390-3416.

Hendrickx, M., Gheyle, W., Bonne, J., Bourgeois, J., De Wulf, A., Goossens, R., 2011. The use of stereoscopic images taken from a microdrone for the documentation of heritage: an example from the Tuekta burial mounds in the Russian Altay. *J. Archaeol. Sci.*, 38(11), pp. 2968–2978.

Howland, M., Kuester, F., Levy, T., 2014. Structure from motion: twenty-first century field recording with 3D technology. *Near East. Archaeol.*, 77(3), pp. 187-191.

Jarisch, M., Offermann, D., Riese, M., Wuebbels, D., 1997. Measurements of stratospheric trace gases by a balloon-borne infrared spectrometer in France. *J. Atmos. Sol-terr. Phy.*, 59(14), pp. 1747-1755.

Jensen, T., Apan, A., Young, F., Zeller, L., 2007. Detecting the attributes of a wheat crop using digital imagery acquired from a low-altitude platform. *Comput. Electron. Agr.*, 59(1-2), pp. 66-77.

Johnson, K., Nissen, E., Saripalli, S., Arrowsmith, J., McGarey, P., Scharer, K., Williams, P., Blisniuk, K., 2014. Rapid mapping of ultrafine fault zone topography with structure from motion. *Geosphere*, 10(5), pp. 969-986.

Kako, S., Isobe, A., Magome, S., 2012. Low altitude remote-sensing method to monitor marine and beach litter of various colors using a balloon equipped with a digital camera. *Mar. Pollut. Bull.*, 64(6), pp. 1156-1162.

Kersten, T., Botteri, A., Lutz, S., 1992. Photogrammetrie für Anwendungen in der Ingenieurgeologie. *Vermessung, Photogrammetrie, Kulturechnik*, 90(4), pp. 189-192.

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., Gabbianelli, G., 2013. Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: the structure from motion approach on coastal environments. *Remote Sensing*, 5(12), pp. 6880-6898.

Silva, B., Lehnert, L., Roos, K., Fries, A., Rollenbeck, R., Beck, E., Bendix, J., 2014. Mapping two competing grassland species from a low-altitude helium balloon. *IEEE J. Sel. Top. Appl.*, 7(7), pp. 3038-3049.

Stal, C., De Wulf, A., De Coene, K., De Maeyer, P., Nuttens, T., Ongena, T., 2012. Digital representation of historical globes: methods to make 3D and pseudo-3D models of sixteenth century Mercator globes. *Cartogr. J*., 49(2), pp. 107–117.

Taccola, E., Parra, M., Ampolo, C., 2014. The sanctuary of Punta Stilo at Kaulonia-Monasterace (Rc, Italy): preliminary results of the close range photogrammetric surveys 2012-2013. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, pp. 559-563.

Verhoeven, G., Loenders, J., Vermeulen, F., Docter, R., 2009. Helikite aerial photography – a versatile means of unmanned, radio controlled, low-altitude aerial archaeology. *Archaeol. Prospect.*, 16(2), pp. 125-138.

Wilkerson, T., Marchant, A., Apedaile, T., 2012. Wind field characterization from the trajectories of small balloons. *J. Atmos. Ocean. Tech.*, 29(9), pp. 1236-1249.

Zarco-Tejada, P., Diaz-Varela, R., Angileri, V., Loudjani, P., 2014. Tree height quantification using very high resolution imagery acquired from an unmanned aerial vehicle (UAV) and automatic 3D photo-reconstruction methods. *Eur. J. Agron.*, 55, pp. 89-99.