CONTEMPORARY DATA ACQUISITION TECHNOLOGIES FOR LARGE SCALE MAPPING

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ABSTRACT

Unmanned aerial systems (UAS) have experienced a dynamic progress in the last years. Nowadays they are considered to be a challenge to conventional aerial photography when it comes to large scale mapping of limited areas. Considering the advancement of algorithms in conjunction to the increase of available computing power, a short review of the UAS technologies is considered useful and is attempted in this paper. A thorough analysis and experimentation with different processing algorithms is also conducted and presented. Optical and thermal images from both fixed wing and multi-rotor platforms over an archaeological excavation with adverse height variations are used as test dataset. Using commercial and freely available structure from motion and multiple view stereo software packages, digital terrain models and orthophotos have been produced and evaluated for their radiometric and metric qualities.

1. INTRODUCTION

The rapid development and spread of UAS technology during the past decade has resulted to the production of a massive number of image datasets. To overcome the data volume challenge as well as to add more flexibility during data acquisition, recently developed algorithms from the field of computer vision have been integrated with standard digital photogrammetric procedures (1). This has also served to efficiently process data produced using UAS as image acquisition platforms.

UAS can be remotely controlled, semi-autonomous, autonomous, or be driven by a combination of these capabilities. The flight trajectory of UAS depends on flight dynamics and flight management systems and display larger off nadir deviations in contrast with the traditional airborne blocks.

Kites, tethered balloons, airships, remote controlled airplanes and helicopters, multirotor and fixed wing systems are unmanned aerial vehicles appropriate for large scale mapping (2). Multirotor and fixed wing aircraft stand out from the others because of their recent upgrade to assisted or fully autonomous systems. Furthermore, the acquisition accuracy is increasing with these systems and they are becoming less weather dependent. Multirotor UAS are widely used for surveying smaller areas due to the fact that they can fly in lower flying heights but have shorter flying autonomy. They display greater stability in the wind and therefore the obtained images are suitable for photogrammetric use. Fixed wing systems stand out for their increased autonomy and the capability of covering wider areas, as a result of the larger flying height and the greater flying speed they can achieve. However, enough space is usually required for their takeoff and landing.

A significant difference between these two groups of systems is the capability of multi-rotor systems for obtaining oblique imagery.

Simple compact digital cameras are usually attached on UAS. However, they can also be equipped with thermal or infrared camera systems, airborne LiDAR systems, SAR or a combination thereof. In order to define the position and the orientation of the acquisition platform other navigation sensors are used, such as, miniature global positioning systems (GNSS) and inertial measurement units (IMU), compasses and barometers.

The goal of this study is the evaluation of digital terrain models and orthophotos produced using a rich optical and thermal data set using several commercial and freely available software for processing. These software include Agisoft Photoscan (http://www.agisoft.com/), PIX4D (https://pix4d.com/) and VisualSFM (http://ccwu.me/vsfm/) with SURE (http://www.ifp.uni-stuttgart.de/publications/software/sure/index.en.html).

2. TEST AREA AND DATA ACQUISITION

The datasets used for this study were acquired during an international field campaign organized by the Laboratory of Photogrammetry of NTUA for the documentation support of the archaeological excavation in Vassilika settlement in the archaeological site of Kymisalla in Rhodes (3). These test datasets contributed to the evaluation and comparison of the photogrammetric products that can be produced by different software.

Ground control points were measured using GNSS and Real Time Kinematic Method (RTK). They were signalised with a 20cm^2 black and white checkerboard pattern and were distributed in order to cover the entire area. Particularly, 15 points were used as control points and another 15 as check points. In Table 1 an overview of all the examined scenarios is presented regarding the acquisition equipment, the flying height and ground sampling distance.

Scenario	Type	# of images	UAS	Flying Height (m)	GSD (cm)
1	RGB	237	Octocopter	35	1
2	RGB	83	Swinglet Cam	60 & 90	2 & 3
3	RGB	101	Octocopter & Swinglet Cam	35, 60 & 90	1, 2 & 3
4	NIR	96	Swinglet Cam	90	3

Table 1: Overview of the datasets

2.1 UAS EQUIPMENT

An octocopter is a lightweight multi-rotor system with 8 rotors and has a maximum payload of approximately 1kg. The maximum duration of the flight is around 15 minutes and a compact digital camera Samsung NX1000 was integrated for the image capturing. The Swinglet Cam manufactured by Sensefly (https://www.sensefly.com/drones/swinglet-cam.html), is an electrically-powered fixed wing platform and has approximately 0.5kg weight. It is so lightweight that the user can launch it by hand and let it land on almost any surface without using any supporting system, such as a parachute. Its small impact energy also reduces significantly the risks of third-party collision damage. Its Canon Ixus 220HS compact camera records 12MP images. The mission planning has been automated for the application using e-motion software.

3. DATA PROCESSING

Conventional photogrammetry uses images from usually calibrated cameras and ground truth constraints to estimate the relative position of the cameras at the moment the images were acquired. Nowadays, computer vision techniques offer more flexible solutions and tend, thus, to fully automate these procedures using robust algorithms. The so-called structure from motion (SfM) algorithms use feature correspondences for camera pose estimation, while multi-view-stereo (MVS) methods take image pose as input and produce dense 3D models (4,5). Applying conventional photogrammetric procedures presupposes orderly taken near vertical images with standard overlap, usually around 60%-70% and almost straight flight lines. Images from UAS systems are usually unordered with larger overlaps and significant rotations. Thus, conventional photogrammetric workflows may often cause problems or even fail with UAS imagery although some manufacturers of digital photogrammetric workstations have developed special modules to compensate and orient such datasets (6,7). Therefore, modern image-based techniques are commonly used for processing such UAS data.

Various state of the art software are currently available, commercial and free. Pix4DMapper, Agisoft Photoscan, Acute3D ContextCapture and 123DCatch are just some examples of the most widespread available packages. VisualSFM is a commonly used open source algorithm interface implementing SfM. CMVS (8) and SURE (9) are tools used for dense matching. Apero/MicMac is an open source bundle adjustment software rather addressed to the scientific community (10). In this current study, data processing was performed with Pix4Dmapper, Photoscan and Visual SFM integrated with SURE tool. This enabled useful comparisons as to their performance and abilities.

The datasets from the two different platforms were processed with the above software with the scenarios presented in Table 1, using medium power computers (i.e. i5 or i7 quad core processors, 8GB-32GB RAM).

4. RESULTS AND DISCUSSION

In Table 2 the RMS errors of the control and check points for the 4 scenarios are presented. They are useful for drawing some conclusions for assessing the accuracy of Photoscan and Pix4DMapper software. It is observed that the RMS error is approximately up to 2.5 times bigger in Photoscan than in Pix4DMapper on average. However, both solutions present acceptable quality for the target scale of the final product. It should be stressed that since the imagery is highly overlapping and is of good quality, the increased number of GCPs does not improve the internal accuracy of the block and they are mainly used for georeference and the self calibration of the camera.

However, GCP usage is a biased estimate of the accuracy because both software use them for the georeference and will always optimize this value. On the contrary, checkpoints are a more objective assessment of accuracy because they do not take part during all the stages of the procedure.

As seen in Table 2, where the RMS values for the checkpoints are also presented, bundle adjustment is successfully performed in all cases. However, taking into consideration Pix4D results, it is concluded that the derived orientations (exterior and interior) of the images are more accurate in this case. The RMS errors in Pix4D range around the pixel size of the initial image. The altitude errors are larger in all scenarios using both Photoscan and Pix4D, but this is expected in photogrammetric image based adjustments.

	Photoscan						**Pix4D**					
	Control points			**Check points**			**Control points**			**Check points**		
	RMS_X	**RMS_Y**	**RMS_Z**	**RMS_X**	**RMS_Y**	**RMS_Z**	**RMS_X**	**RMS_Y**	**RMS_Z**	**RMS_X**	**RMS_Y**	**RMS_Z**
Sc. 1	0.020	0.016	0.014	0.035	0.030	0.036	0.012	0.011	0.009	0.023	0.022	0.029
Sc. 2	0.037	0.053	0.053	0.033	0.049	0.060	0.015	0.022	0.016	0.022	0.024	0.041
Sc. 3	0.022	0.032	0.026	0.025	0.027	0.043	0.011	0.015	0.013	0.016	0.026	0.024
Sc. 4	0.016	0.022	0.015	0.022	0.023	0.034	0.012	0.012	0.012	0.016	0.024	0.036

Table 2: Summary of RMS errors of the control points and the check points in Photoscan and Pix4D (in meters)

Dense point clouds resulting from Pix4D have large gaps within vegetation areas, however the point density in areas of rock and soil is better than that with Photoscan. On the other hand, the point clouds resulting from Photoscan have fewer gaps and describe better the vegetation areas. Photoscan produces larger number of point correspondences between the images. However, it is remarkable that in the fourth scenario, Photoscan produced 50% more points than Pix4D and the point density of the 3D model was much better, especially in areas where deficiencies occured using PIX4D . Generally, it is concluded that Agisoft Photoscan gives better results in vegetation areas and Pix4D in areas of rock and soil.

Point clouds were also produced using VisualSFM and SURE algorithm implementations. The workflow has as follows: a sparse point cloud is generated in VisualSFM and then image orientations are integrated as an input in SURE in order to build the dense cloud. It is remarkable in this test, that the generated point clouds contain higher number of correspondences compared to all scenarios. More particularly, in the third scenario, where images from different flying heights are combined in one project, almost 300.000.000 points (unfiltered point cloud) were produced using 101 images. This number is almost six and thirty times bigger from the corresponding in Photoscan and Pix4D respectively (Figure 1). The density of the point clouds is high and displays good both in vegetation areas and in areas of rock and soil.

Figure 1: Point clouds produced by Photosan (left), Pix4D (middle) and VisualSFM+Sure(right) in Scenario 3.

Orthophotos of all scenarios were produced using the commercial software using the corresponding GSD of the acquired images. In order to assess the accuracy of each method (Photoscan and Pix4D), we measured the offset between the orthophoto and the recorded locations of GCPs. The mean absolute total errors in Photoscan are higher than Pix4D and are two to three times larger from the GSD of the acquired images. In the fourth scenario, where NIR imagery is processed both software produced orthophotos with planimetric accuracy of 3cm. In the other cases the orthophotos produced with Pix4D are more accurately georeferenced (Table 3).

Scenario	**Mean absolute total error (Photoscan)**	**Mean absolute total error (Pix4D)**
1	0.027m	0.020m
2	0.063m	0.045m
3	0.038m	0.021m
4	0.029m	0.027m

Table 3: Offset between the mosaic and the GCPs

The output orthophotos of Photoscan have significantly more noise, especially around the edges. Blurred or misplaced parts also exist, decreasing thus the quality of the final product (Figure 2). Pix4D, on the other hand, displays better the vegetation areas. Its results have better radiometry as it blends better the images from different lighting conditions and flying heights. However, in the first scenario, a failure appears at the edges of the block. Using the VisualSfM and SURE procedure orthophotos were not produced, as the point clouds were not georeferenced.

Figure 2: Offset between the mosaics and the GCPs in Scenario 1 with Pix4D (left) and Photoscan (right).

5. CONCLUSIONS AND FUTURE WORK

UAV mapping is a flexible, easy and economical data acquisition method with extensive use in a variety of applications. Our test project has presented the efficiency of such methods in producing digital terrain models and orthophotos over an archaeological excavation. Both Pix4D and Photoscan software solutions are automated and addressed to non specialised users. In our dataset Pix4D produces orthophotos of better quality than Photoscan. Nevertheless, the derived products from both Photoscan and VisualSFM-SURE workflows are promising in the stage of image matching and dense point cloud generation. Their results, however, are within the expected accuracy.

The improvement of the stabilization systems, the integration of systems of obstacle avoidance and thus automated flight planning as well as the conjunction of the optical sensors with the GNSS systems are some of the sectors that the UAS industries are heading to. However, the biggest challenge for the spread of the UAS is the establishment of the harmonized flight regulations around Europe.

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