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UAV 3D Photogrammetric Mapping & GIS Development Case Study: Khartoum Railway Station

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Abstract: Aerial and satellite images are conventionally used as a main data source for image-based geospatial data collection, map production, and updating purposes. However, it can be time consuming and costly to obtain them. Recently, Unmanned Aerial Vehicles (UAVs) are emerging as suitable technology, which has the potential to provide information with a very high spatial and temporal resolution at a low cost. This paper aims to demonstrate and evaluate the potential of using UAVs for 3D photogrammetric mapping and GIS development as an affordable solution for many developing countries. Part of Khartoum railway station is used as a case study in which 127 images were collected with a DJI Phantom 4 at a flying height of 100 m. RTK-GPS and ground control points are used to improve the absolute accuracy of dereferencing. Two different software, namely, Pix4D and Photo scan are used to generate standard geospatial products such as Digital Surface Model (DSM), Digital Terrain Model (DTM), and orthophoto covering 0.225 km² with a spatial resolution of 3.61 cm. The final orthophoto with a positional accuracy of 2.4 cm was used to extract features for mapping purposes. General quantitative and qualitative control of the UAV data products and the final outputs were performed, indicating that the obtained accuracies comply with international standards. Moreover, possible problems and further perspectives were also discussed. The obtained results demonstrate that UAVs provide promising opportunities to create high-resolution and highly accurate orthophotos, thus facilitating map creation and updating. In addition, it demonstrates the capability of commercial photogrammetric software packages for automatic 3D reconstruction.

Keywords: *UAV, Photogrammetry, Digital Surface Model, Orthophoto, GIS Mapping.*

1. INTRODUCTION

Geospatial data plays an important role in an estimated 80% of our daily decisions [1], and in various urban planning activities. For example, in the context of the recently accepted Sustainable Development Goals, the UN emphasizes the need for high-quality and usable data, as “data are the lifeblood of decision-making” (IEAG 2014).

Moreover, there is an initiative from UN on Global Geospatial Information Management (UN-GGIM) which aims to promote the use of geospatial information to address key global challenges such as climate change and depleted resources. Unfortunately, the lack of funding is a major bottleneck in many developing countries and the required data are often unavailable or outdated [2]. To ensure the usability of spatial data as well as to provide a solid basis for informed decision-making and planning, map creation and updating is imperative.

Previous research has demonstrated the use of satellite and aerial imagery as means to extract information for creating and updating maps [3] as well as to provide input for urban models [4] and infrastructure management. Important features of the urban environment, such as roads and buildings, may then be digitized from the imagery either by experts [2] or by a wider public in participatory mapping exercises.

Over the past two decades, considerable research has also focused on automatic feature extraction from high resolution satellite and aerial images [5]. However, the temporal resolution of conventional sensors is limited by the restricted availability of aircraft platforms and the orbit characteristics of satellites [6].

Another Disadvantage is cloud cover, which impedes image acquisition through these platforms. Such limitations restrict the Use of satellites or manned aircrafts for map updating purposes, as it may increase cost and production time. In order to provide The high-quality and up-to-date geospatial information required to support urban governance and informed decision-making, land surveyors need to make use of the potential of new affordable, geo-spatial technologies and platforms. To be fair and without creating unnecessary bias, some sort of economy of scale needs to be understood and justified in terms of productivity and applicability.

A suitable example of such an emerging and innovative technology is Unmanned Aerial Vehicles (UAVs), which are proving to be a competitive data acquisition technique designed to operate with no human pilot onboard. Photogram metrically, UAVs can be viewed as one of the platforms for close range aerial mapping. Although the innovation parts in UAVs is at the platform level, its impact is very huge on the whole field of photogrammetry and the overall practice of surveying.

For example, it brought the practice of aerial photogrammetry to the level of engineering surveying with its many interesting and classical aspects such as the levels of details, accuracy, and the economy of scale at this particular level.

The term UAV is commonly used, but other terms, such as drones, Unmanned Aerial Systems (UAS), Remotely Piloted Aircraft (RPA) or Remotely Piloted Aerial Systems (RPAS) have also been frequently used in the geometrics community [7].

UAV refers to the aircraft itself which is intended to be operated without a pilot on-board, whereas UAS refers to the aircraft and other components that could be required such as navigation software and communication equipment etc.

According to International Civil Aviation Organization (ICAO) Standards [8], RPAS are a subset of UAS which are specifically piloted by a “licensed ‘remote pilot’ situated at a ‘remote pilot station’ located external to the aircraft”. RPAS refers to the entire system whereas RPA refers to the aircraft itself. The pilot's license should address legal, operational and safety aspects. In the geometrics community, the terms UAS and RPAS are often used interchangeably, and will be considered as synonyms in the current paper.

For photogrammetric applications, the payload of the whole UAV system is composed of a camera, Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU) [9]. The camera takes overlapping images as it flies over a study area. These images may be processed through a photogrammetric workflow to obtain a point cloud (or a Digital Surface Model), an orthophoto or a full 3D model of the scene.

An on-board GNSS device allows these data products to be georeferenced in a global coordinate system. However, in the context of low-cost UAVs, the metric accuracy of such GNSS is often limited.

Nevertheless, it provides an approximate solution for the orientation problem of the images. Therefore, supplementary Ground Control Points (GCPs) are usually acquired in the study area, in order to improve and maintain the accuracy of the image block orientation and derived mapping products, such as orthophotos as well as to facilitate its integration with other spatial data. In particular, the GCPs will be used to exploit the hidden relative accuracy of the image or block model in the context of a global and accurate coordinate system. This hidden accuracy is typically dictated by the high spatial resolution of the UAVs images.

These GCPs have to be carefully selected and well distributed, and they should be visible in many images, as well as easily identifiable in the images after the acquisition and measurable with accurate technology such as survey or geodetic grade GNSS. As a major observation UAVs data processing put a heavy emphasis on automated photogrammetric workflow such as image matching and sophisticated approaches for points transfer. As such, the future of UAVs development and deep market penetration is very much dependent on the research effort in digital and feature-based photogrammetry and the related fields such as computer vision and pattern recognition. In fact, UAVs can be seen as one of the main drivers that will push the development in digital photogrammetry to another level of maturity.

In this paper, the use of the UAV is demonstrated on part of Khartoum railway station. Four years ago, Sudan Railway Corporation (SRC) conducted a classical aerial mapping for a new track between Khartoum and PortSudan. Future works need to consider the use of UAVs in some sort of a modular approach to do similar work.

2. MATERIALS AND METHODS

The UAV used for this study is a quad copter DJI Phantom 4 shown by Fig. 1. Its properties are presented in Table 1.

Fig. 1. UAV DJI Phantom 4.

Table 1. UAV properties.

Model	DJI Phantom 4
Camera Model	FC330_3.6_4000x3000 (RGB)
Resolution	12 MP
Sensor width x height	6.317 [mm] x 4.738 [mm]
Focal length	3.61 mm
Pixel size	1.56 x 1.56 um
Lens FOV	94°
Photo Formats	JPEG, DNG
Maximum flight time	28 min
Geolocation	GPS/ GNSS

2.1 Study area

The area for the current study covers the main railway station located in Khartoum as shown in Fig. 2.

Fig. 2: Location of the Study area From a Google image.

Table 2. Boundaries of the study area.

Extent	D M S
Top	15 35'48'' N
Bottom	15 35'38'' N
Right	32 31'51'' E
Left	32 31'27'' E

2.2 Image Acquisition

Using Pix4D Capture software, the flight plan was defined above the study area. The camera was set at angle of 75 degrees to be able to capture side views of the existing buildings for 3D modelling. The UAV flew autonomously in a pre-defined flight plan at an approximate altitude of 100 m above ground using single grid mission in 19 flight lines (see Fig. 3), A total of 127 geotagged images were taken and with overlap of 80% forward and 75 % side lap. The duration of the flight over the study area, including take-off and landing, was approximately 20 minutes and the identification and marking of the GCPs in the images and image orientation, dense image matching and orthophoto creation took about 2 days on a decent laptop.

Fig. 3. Flight Plan (camera positions in red).

2.3 Image orientation

Acquired images were processed by two different software, namely, Pix4Dmapper and Photoscan photogrammetric software packages. Interior and exterior orientation were computed. These elements are very important for an accurate reconstruction from image and all photogrammetric products quality will rely on accurate image orientation. However, many affordable UAVs are equipped with cheap consumer grade camera to reduce their take-off weight and lower their price. These nonmetric cameras are not geometrically stable, which is a basic requirement for conventional photogrammetric mapping [10]. To resolve this problem, a self-calibration of the camera, which estimates the interior orientation and other camera parameters, was integrated into the bundle block [11].

In order to have accurately georeferenced products, high accuracy ground control points (GCPs) are needed. To this end, signalized and non-signalized ground control points were observed and used for indirect orientation for the block of images (see Fig. 4). Figure 5 shows the layout of 16 points which were accurately surveyed on the ground features with approximately 2 cm standard deviation Real-Time Kinematic Differential GPS (RTK-DGPS) in WGS84 UTM Zone 36 coordinate system. It should be noted that the ellipsoidal heights of the control points were used as vertical control since their relative geoid variation can be treated as a constant value [12].

In large areas, proper geoid corrections should be used to account for the undulation of the physical surface of the Earth. Out of the 16 points, 9 GCPs were selected as a control information for the indirect orientation process, which essentially amounts to the solution of a 3D similarity transformation, and 7 of them were reserved as check points for external accuracy assessment. It was ensured that each point got marked in at least 6 images.

Compact cameras are extremely sensitive to temperature differences, vibrations and shocks and these elements require a complete calibration for each flight. The two software packages include powerful camera auto calibration algorithms that take the full information of each pixel of the images to estimate the optimal camera and lens calibration parameters for each flight. This feature is critical to ensure high accuracy at any climate condition, without any manual and tedious user intervention involving checkerboard patterns that can be error prone steps. The two software packages are initiating a self-calibration process, which calculate photo interior orientation parameters. The calibration process started with parameters of an initial camera model and optimization of these parameters with respect to the relative geometry of the images as well as the distribution of the ground control points.

Fig. 4. RTK-DGPS observations.

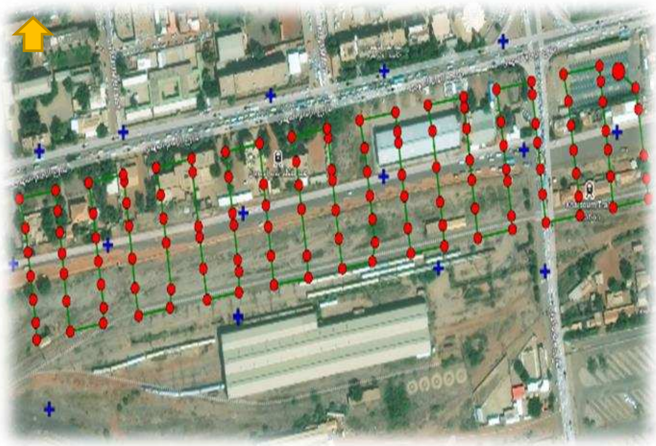


Fig. 5. Distribution of GCPs Points (in blue).

2.4 Dense image matching

After images orientation with sparse matched points, the dense matching process was initiated to generate the dense point cloud. The employed software packages use a patch based approach. This process led to the generation of millions of points that were interpolated into DSM.

2.5 DSM & Orthophoto Production

The 3D points generated in previous steps were interpolated and formed a triangulated irregular network which resulted in a Digital Surface Model (DSM). From this DSM, the ortho-rectification process was performed. The task of ortho-rectification is to produce an orthogonal projection from the originally taken images. Since the DSM is already in the target projection, a reprojection of original image pixels onto the reference plane is possible. This reprojection is normally done per DSM-mesh and in order to retrieve a more appealing ortho image, some texture and color balancing gets applied.

2.6 Orthophoto Quality Assessment

The quality of the image orientation and orthophoto were analysed both qualitatively and quantitatively. Possible deformations of the orthophoto include radiometric errors caused by imperfect image blending and radiometric differences between the individual UAV images. Deformation could also be visible due to the imperfections in the DSM, causing faulty ortho-rectification of the individual images. Through visual inspection, deformation and artefacts are identified and presented.

2.7 Feature extraction & GIS Mapping

The final orthophoto and the DSM are very useful for manual or semi-automatic feature extraction for map creation or updating using GIS software [13]. The main use of the orthophoto in this paper is to help extract spatial data which was used to create a map for the study area.

3. RESULTS

3.1 Pix4D Orthophoto and quality assessment

3.1.1 Qualitative assessment

Fig. 6 shows the resulted orthophoto with the following specification:

- GSD: 0.033 m

- Spectral resolution: RGB

- Radiometric resolution: 8 bit

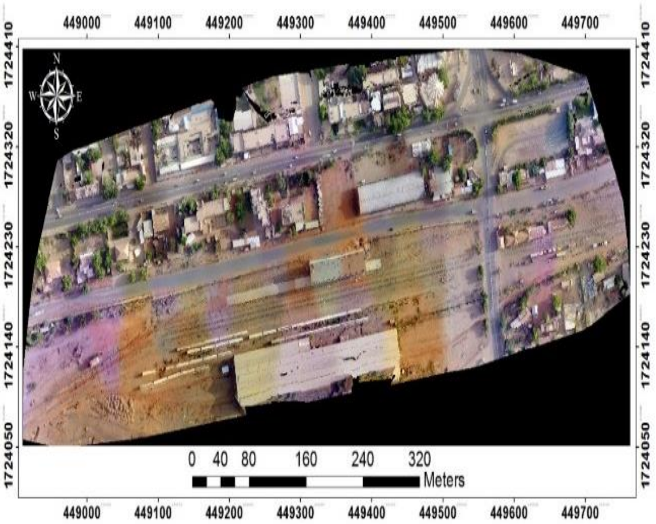


Fig. 6. The produced Orthophoto.

After visual inspection, the quality of orthophoto and its features have a good visibility and object can be detected very well, which is a good result. All rooftops were ortho-rectified to their correct positions and no wall can be seen in the final result. However, some minor deformations were detected in the study area. Those include: façade visibility, moving object, rounding of some roof buildings, standing objects such as light poles and pylons.

3.1.2 Quantitative Assessment

The quantitative assessment of the orthophoto consists of two aspects: (I) the accuracy at the measured control points, (II) the geometric accuracy of the lengths of selected objects that were measured on the orthophoto as well as on the ground.

The same control points utilized to verify the image orientation step yield an RMSE of 1.4 cm in X and 1.9 cm in Y, corresponding to a planimetric accuracy of 2.4 cm. The result shows that the level of detail and the radiometric quality of the orthophoto is completely comparable to the quality of the input images. According to the ASPRS [14], the obtained error meets the requirements for the horizontal accuracy class of 3.1cm.

The second part of the quantitative assessment consisted in analyzing the geometric accuracy of the produced orthophoto on an object level using the length. A number of permanent objects were actually measured in the field as well as on the orthophoto (see Fig. 7). Results indicate that measurements in the orthophoto replicated the field measurements to an error of less than 1.25% of the actual dimensions (see Table 3).

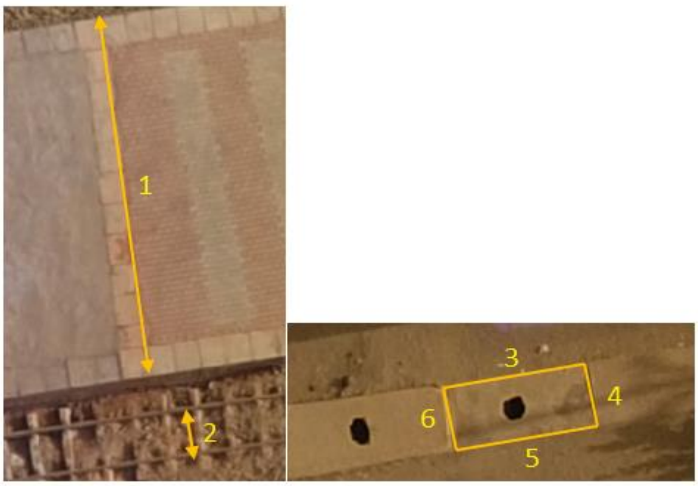


Fig. 7. Lengths used for Comparison.

Table 3. Comparison between GCPs Orthophoto measurements and field Measurements.

Object	L Field (m)	L GCPs Ortho(m)	Error (m)	Error (%)
1	8.95	8.94	0.01	0.112
2	1.20	1.20	0.01	0.826
3	3.5	3.49	0.01	0.286
4	1.58	1.57	0.01	0.637
5	3.54	3.52	0.02	0.562
6	1.6	1.62	0.02	1.234

3.2 Comparison between Pix4D and Photoscan

This section provides a comprehensive comparison between different aspects of the two software that were acquired during the course of this work (see Table 4). The images acquired by UAV are suitable for proceeding by different software packages, the images were processed using Pix4d mapper and Photoscan photogrammetric software packages. Both of them have strengths and weaknesses. The most important differences between the two software packages are shown in the following table:

Table 4. Comparison between Pix4D and Photoscan.

Comparison Type	Pix4d Mapper	Photoscan
Images deployment at world map	Automatically	No
User Usage	Easier	Easy
Processing speed	Fast	Faster
Software Visualization	Better	Good
Mosaic editing	Yes	No
Network Processing	No	Yes
Cloud Processing	Yes	No
Video animation Trajectory Creation	Yes	No
GCPs automatic marking	Yes	No
Track and detect markers	No	Yes
Processing Options Templates	Yes	No
Python Scripting	Doesn’t Support	Support
Orthophoto ghosting producing	Yes	No
Merging chunks	Slow	Fast
Trial version	25 days	30 days
Hardware requirements	Lower than	High
Documentation and report	Better	Good

3.1.3 Results comparison

a) Coverage area: The resulted area from Photoscan is larger than the resulted area from Pix4d by $0.015 km^2$, this difference happened because Pix4d tries to make a geometrical representation for the study area by excluding the areas of low overlap that can affect the results (see Fig. 8)

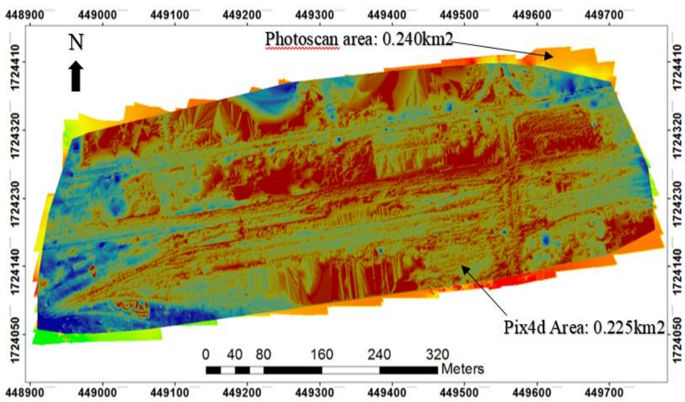


Fig. 8. Coverage area.

b) Geolocation: Table 5 shows the results of the onboard GPS for the average error of the camera positions and both software provide more or less very similar results. Once again, both software provide similar level on internal accuracy (see Table 6) as well as external accuracy (see Table 7).

Table 5. Average camera location error comparison.

Comparison	Pix4d mapper	Photoscan
X error (m)	0.767514	0.764013
Y error (m)	3.234481	3.22211
Z error (m)	38.566396	38.5211

Table 6. Control points

Comparison	Pix4d mapper	Photoscan
X error (m)	0.014046	0.0110994
Y error (m)	0.018920	0.0109328
XY error (m)	0.016483	0.0155796
Z error (m)	0.024858	0.00216947
Total error (m)	0.018	0.0157299
Error (pixel)	1.008	0.239

Table 7. Check points.

Comparison	Pix4d mapper	Photoscan
X error (m)	0.029111	0.0315771
Y error (m)	0.044369	0.0275245
XY error (m)	0.023564	0.0418893
Z error (m)	0.076455	0.076929
Total error (m)	0.080004	0.0875945
Error (pixel)	0.913	0.255

c) Processing time comparison: As shown in Table 8 there is 1h: 0m: 5s difference in processing time between the two software packages.

Table 8. Processing time.

Comparison	Pix4d mapper	Photoscan
Time for Point Cloud Densification	53m:19s	58m:42s
Time for Point Cloud Classification	13m:55s	1m:07s
Time for 3D Textured Mesh Generation	14m:09s	9m:16s
Time for DSM Generation	25m:41s	3m:06s
Time for Orthomosaic Generation	29m:52s	12m:26s
Time for DTM Generation	10m:09s	2m:50s

The comparison results indicate that Photoscan is faster than Pix4D.

d) DTM: DTM quality mainly depends on the dense cloud classification accuracy, Pix4d automatic classification is better than Photoscan, also it is much easier to perform manual classification than Photoscan. Figs 9 and 10 show the railway store building area, the building dense cloud points were assigned as buildings, the two software packages interpolated the ground elevations of the building area from the neighbouring ground points.

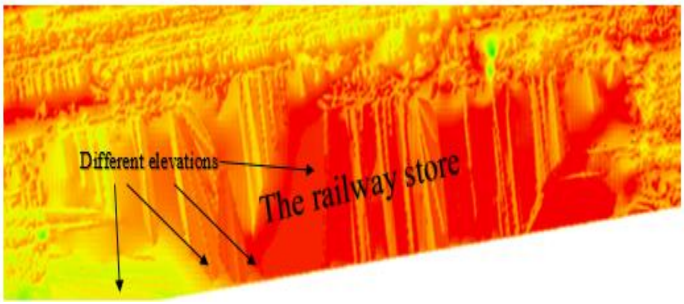


Fig. 9. Pix4D DTM for the railway store area.

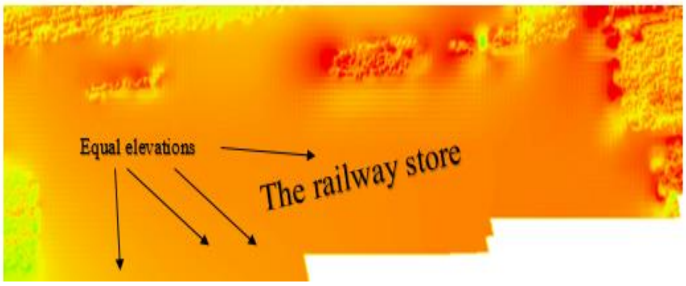


Fig. 10. Photoscan DTM for the railway store area.

The differences in the resulted elevations indicate that the two software packages are using different interpolation methods.

e) DSM: There are many distortions at the boundary of the study area that affecting DSM generation, these distortions happened due to insufficient overlap between images (see Figs 11, 11, and 13).

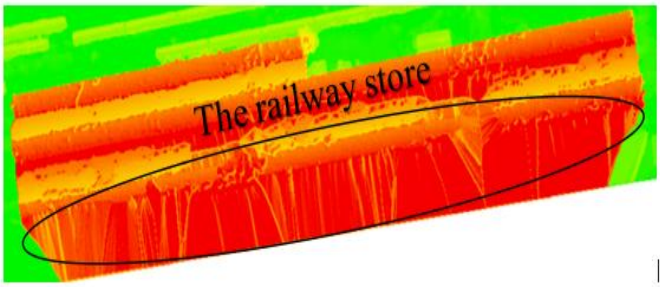


Fig 11. Photoscan DSM for the Railway Store Building.

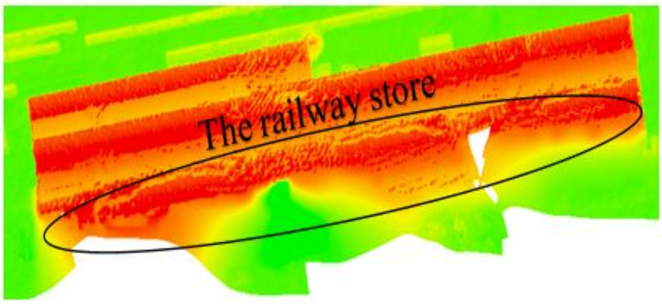
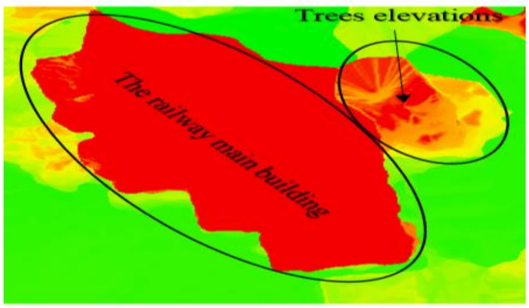
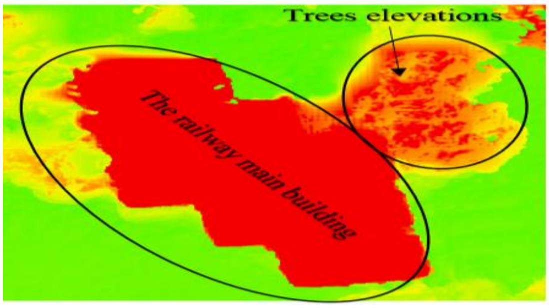


Fig. 12. Photoscan DSM for the Railway Store Building.



(a) Pix4D



(b) Photoscan

Fig. 13. DSM for the railway main building area.

The above differences in elevation indicate that Photoscan is better than Pix4d in DSM generation.

f) Orthomosaic: The generated mosaic from Photoscan is better than that generated from Pix4d, it has a better reconstruction for light poles, trees and buildings in the study area sides, and also it doesn't produce any moving objects ghosts as shown in Figs 14 and 15.

(a) Photoscan (b) Pix4D

Fig. 14. Orthomosaic façade Visibility.

(a) Photoscan

(b) Pix4D

Fig. 15. Orthomosaic ghosts and Reconstruction Errors.

3.3 Map creation

The obtained orthophoto was used to create a topographic map (using a scale of 1:2500) for the study area (See Figs 16, 17, and 18). The map includes 12 layers with the following names:

- Manholes
- Light poles
- Camera poles
- Vegetation
- Curve stone
- Asphalt
- Railway
- Buildings
- Drainage water
- Soil mounds
- Out of service train
- Soil

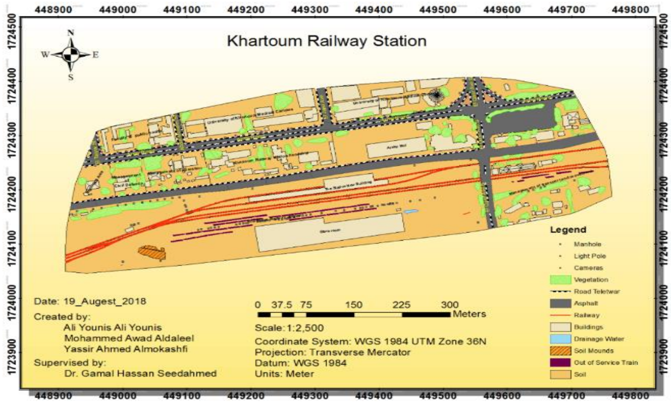


Fig. 16. Topographic map for the Study Area.

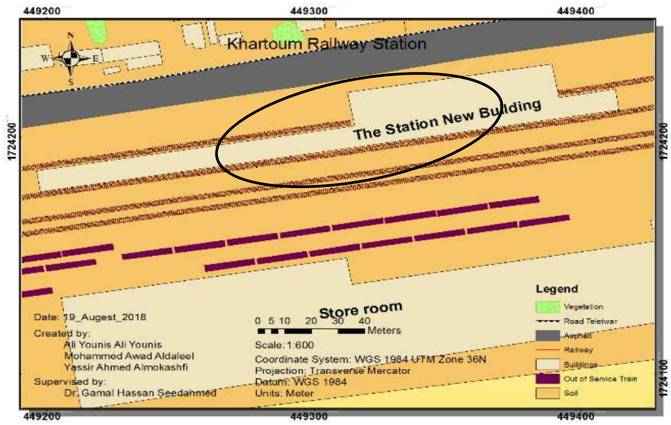


Fig. 17. Map for the Railway Station new Building Area using Scale 1:600.

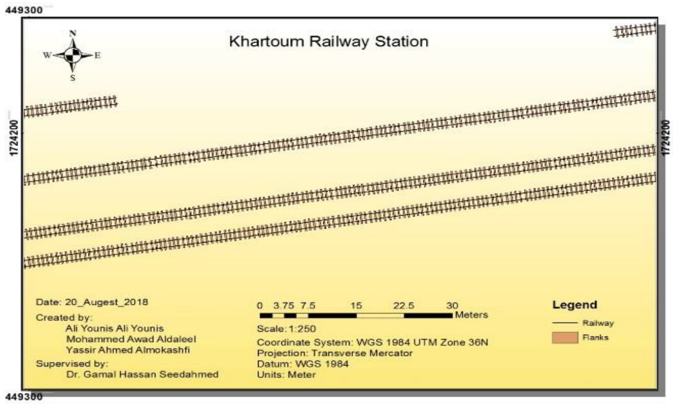


Fig. 18. Map for the Railway Near the new Railway main Building using Engineering Scale 1:250.

4. DISCUSSION

The results indicate that using an Unmanned Aerial Vehicle, with proper training and techniques, it is possible to obtain high-quality photogrammetric products comparable to ground surveying equipment. Comparing to the time and cost it would have taken to produce such data using traditional equipment (total station, aircraft, etc.), UAV is a more promising alternative for photogrammetric surveying.

However, the obtained quality of UAV photogrammetric products depended on many elements which needed to be taken care of at every step. The final orthophoto visual errors were due mainly to DSM deformation. This deformation was caused by lack of images or overlap during image acquisition, hence the generated points cloud was not dense enough to perform the geometric reconstruction of objects. However, these deformations were not too much in this work, and some of them were easily removed using mosaic editor. As a lesson learned, the first step of flight planning and image acquisition needs to be done accurately so that the final result will be high quality.

GCP quality can be influenced by the precision of the surveying equipment used, their distribution throughout the study area and positioning error introduced when manually marking GCPs in the UAV images is performed. Errors incurred in any of these elements will have an impact on the accuracy of the final product.

The two software packages comparison results indicate that there is no best software to produce photogrammetric products from UAV images processing, any software has its strengths and weaknesses, software with best performance could be selected based on the object of interest, geometric and visual accuracy of 3D reconstruction, resolution and scale of interest, software and hardware capabilities, and the budget.

5. CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This work demonstrates that UAVs provide promising opportunities to create a high resolution and highly accurate orthophoto, thus facilitating map creation and updating. Through an example in Khartoum railway station, the photogrammetric process of obtaining an orthophoto from the individual UAV images is explained. A number of factors that influence the quality of the orthophoto are highlighted as well as possible strategies which can be adopted to mitigate these imperfections.

This study shows that due to the high resolution of the UAV orthophoto, new features can be easily extracted and various outputs can be produced. UAV based mapping offers a completely new paradigm of what is considered to be land surveying. Surveyors can map huge areas of land, and make technical and business decisions later, focusing on anything from which survey maps to produce to the question of resolution and level of detail. Furthermore, if at later stage a more detailed survey map is required, one can extract additional measurements from existing close-range aerial images without having to do any more field work.

The important role of GCPs on increasing the accuracy of the obtained orthophoto is also demonstrated here. As reported, the geolocation accuracy without external GCPs is relatively low. This can be resolved through the collection of additional high-quality GCPs in the field, which require extra time for collection and insertion in the software. Therefore, small-scale UAVs are currently more suitable for map creation and updating projects over a limited study area and incremental map creation and updating. However, rapid developments in both UAV platforms, increasing the area covered per flight and improving the accuracies of the on-board GNSS, as well as photogrammetric software will likely facilitate the processing of larger projects in the foreseeable future.

The software packages comparison results of this study demonstrate the capability of commercial photogrammetric software packages for automatic 3D reconstruction of different features.

RECOMMENDATION:

- Use double grid flight plan to capture images, and make comparisons between the two flight plans products.
- Use total station to create a map for the study area, and make accuracy comparisons between the two maps.
- Use several photogrammetric software packages such as drone deploy, photo modeller, 3D survey, SURE …etc. and make comparisons between them.
- Use mobile mapping techniques to survey the study area, and combine its data with the UAV data to produce a true 3D city model.
- Explore feature-based photogrammetry as a ground control information for the orientation of the UAVs images [15].

6. REFERENCES

[1] Heipke, C. Woodsford, P. A. and Gerke, M. 2008. Updating geospatial databases from images. In: Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences: 2008.

[2] Ottichilo, W. and Khamala, E. 2002. Map Updating Using High Resolution Satellite Imagery-A Case of the Kingdom of Swaziland. International Archives of Photogrammetry and Remote Sensing, 34(6/W6), pp. 89-92.

[3] Alexandrov, A., Hristova, T., Ivanova, K., Koeva, M., Madzharova, T., & Petrova, V. 2004a. Application of Quick Bird satellite imagery for updating cadastral information. In The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVPart B2, 2004, (pp. 386-391).

[4] Herold, M. Goldstein, N.C. and Clarke, K.C. 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. Remote Sensing of Environment, 86(3), pp. 286-302.

[5] Liu, H., and Jezek, K. C. 2004. Automated extraction of coastline from satellite imagery by integrating canny edge detection and locally adaptive thresholding methods. International Journal of Remote Sensing, 25(5), pp. 937–958.

[6] Turner, D. Lucieer, A. and Watson, C. 2012. An automated technique for generating georectified mosaics from ultra-high resolution Unmanned Aerial Vehicle (UAV) imagery, based on Structure from Motion (SFM) point clouds. Remote Sensing, 4(5), pp. 1392–1410.

[7] Nex, F., and Remondino, F. 2014. UAV for 3D mapping applications: a review. https://www.researchgate.net/publication/260529522

[8] International Civil Aviation Organization Standards http://www.icao.int/Meetings/UAS/Documents/Circular%20328_en.pdf

[9] Colomina, I. and Molina, P. 2014. Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing, Volume 92, pp. 79-97.

[10] Barnes, G., Volkmann, W., Sherko, R., Kelm, K., World, T., & Washington, B. (2014). Drones for Peace: Part 1 of 2 Design and Testing of a UAV-based Cadastral Surveying and Mapping Methodology in Albania Paper prepared for presentation at the "2014 WORLD BANK CONFERENCE ON LAND AND POVERTY" Copyright 2014 by Grenville Barnes, Walter V, 1–28.

[11] Seedahmed G., T. Schenk, and D. Merchant, (1998). Experimental Results of Digital Camera Calibration. *ISPRS, Intern. Archives*, vol. 32, part 3/1, pp. 91-96, Columbus, Ohio, USA.

[12] Seedahmed G. (2017). A Methodology For Checking The Validity of An Existing Contour Map Using RTK-GPS and GIS. University of Khartoum Engineering Journal, Vol. 7(1): pp: 1-7.

[13] M. Koeva, M. Muneza, C. Gevaert, M. Gerke, F. Nex. 2016 Using UAVs for map creation and updating. A case study in Rwanda. Article in Survey Review, DOI:10.1080/00396265.2016.1268756

[14] American Society for Photogrammetry and Remote Sensing (ASPRS). December 2013. ASPRS Positional Accuracy Standards for Digital Geospatial Data. Photogrammetric Engineering and Remote Sensing.

[15] Seedahmed G. (2004). On The Suitability of Conic Section in A Single-Photo Resection, Camera Calibration, and Photogrammetric Triangulation. Ph.D. Dissertation, Dept. of Civil & Environmental Engineering & Geodetic Science, the Ohio State University, Columbus, Ohio, USA, 138 p.