A photogrammetric approach for map updating using UAV in Rwanda.

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***Abstract*— Geospatial data is an important asset for development planning in every country. Rwanda is experiencing a steady period of growth in terms of both population and economic development, which emphasizes the need for regularly updated maps so that development can be planned in effective way. The existing basemap produced from the 2008 orthophoto campaign - which has been used to guide all country development planning - is outdated. This can result in unreliable decisions, hence an update is necessary. Conventional methods for spatial data acquisition are aerial photogrammetry and terrestrial surveying. They are, however, time consuming and costly. A new approach is needed for rapid spatial data collection at a low cost. This study will present how this can be achieved using Unmanned Aerial Vehicles (UAVs); a new remote sensing tool capable of acquiring airborne images which has the potential to provide information with a very high spatial and temporal resolution at a low cost. The main objective of this study was to use UAV imagery to produce a high quality orthophoto to update geospatial data. In order to achieve this, a DJI Phantom 2 Vision Plus quadcopter was used to collect 954 images at a flying height of 50 m. Using adequate photogrammetric software, an orthophoto of 3.3 cm GSD covering 0.095 km^2 was produced. With appropriate ground control points, an absolute positional accuracy of 7.9 cm RMSE was achieved. Features of interest were digitized using ArcMap at 1/1000 scale and updated in the existing basemap. This study has demonstrate that UAV is a useful platform for obtaining high-resolution aerial images for basemap updating at a sustainable cost.**

***Keywords*— Basemap, orthophoto, orientation, photogrammetry, UAV.**

I. INTRODUCTION

Rwanda is experiencing a steady period of growth in terms of both population and economic development, which raises the need for regularly updated spatial data so that development can be planned and monitored in an effective way. Aware of this, in the summers of 2008 and 2009 a traditional aerial photography mission was performed with a digital photogrammetric camera over the territory of Rwanda. All post-processing procedures were done. As a result, elevation data was generated and an accurate orthophoto was produced for the whole country, and used to digitize detailed spatial datasets (basemap, cadastral, etc.) which were used to guide development in different planning sectors of economy.

The problem is that now, seven years down the line, many changes have happened; reality on the ground has changed substantially. Therefore, an update is needed not only to prevent inaccurate decision making by the public sectors who depend on this data, but also to keep an accurate, consistent and fit for purpose database reflecting current reality. To better achieve this, more recent and accurate aerial imagery is preferred (Heipke, Woodsford, & Gerke, 2008)

However, data collection and updating is an extensive process that needs continuous investment. Lack of funds in most developing countries is a major bottleneck for surveying and mapping activities which prevent them from having updated and precise data as needed (RCMRD, 2001). The costs of producing conventional aerial photographs and digital orthophotos and the performance of terrestrial surveys can amount to several thousand or even millions of dollars and can use up a significant amount of time and project budget. For this reason, research on how spatial data can be acquired and updated quickly through a low cost solution is needed.

High quality aerial imagery can be acquired using conventional platforms such as satellites and aircraft but their temporal resolution is limited by the restricted availability of aircraft platforms and orbit characteristics of satellites (Turner, Lucieer, & Watson, 2012). This limits their use for map updating purposes, as it will increase cost and production time. Recently, UAVs have been introduced in mapping activities and have been linked with low cost production of accurate and high quality spatial data in a short time (Nex & Remondino, 2013). This study will evaluate how it can be used to resolve the above mentioned problems. To achieve this three objectives were fixed: to produce an orthophoto from UAV images, to perform quantitative and qualitative control of the produced orthophoto and finally to extract 2D features for basemap updating.

II. MATERIAL & METHODS

The UAV used for this study is a quadcopter DJI Phantom 2 Vision+ shown by Figure 1. Its properties are presented in Table 1.

Figure 1: DJI phantom 2 Vision +

Source: www.dji.com

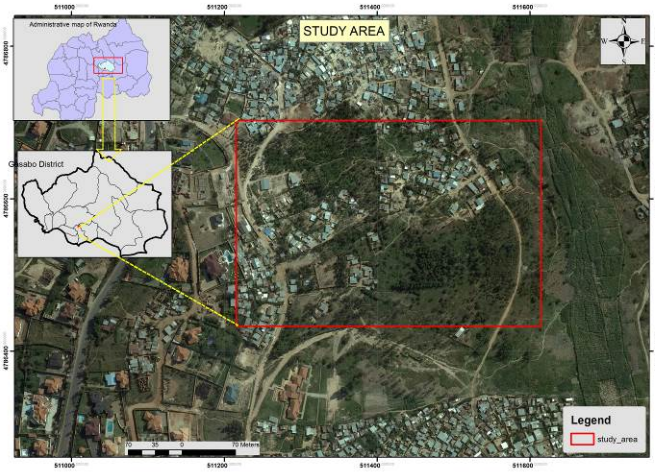
Table 1: UAV properties

Model	DJI Phantom 2 Vision +
Camera	PhantomVisionFC 2000
Resolution	16 MP
Sensor width & height (mm)	6.48525 & 4.86394
Image width & height (pixels)	4608 & 3456
Pixel size	1.4 µm
Focal length (mm)	5
Flight time	25 min
Geolocation	On-board GPS

A. Study area

A study area located in Kigali City, Gasabo District, Remera sector, Nyarutarama cell was chosen. This study area, as presented by Figure 2, shows slum characteristics. One of the main conditions was to show the need of update. This was characterised by the fact that there has been changes from the time the orthophoto was taken (2009) up to now. This has been achieved by comparing features using old orthophoto and Google Earth imagery (updated in 2015). New features such as houses and roads can easily be detected.

Figure 2: Study area



B. Image Acquisition

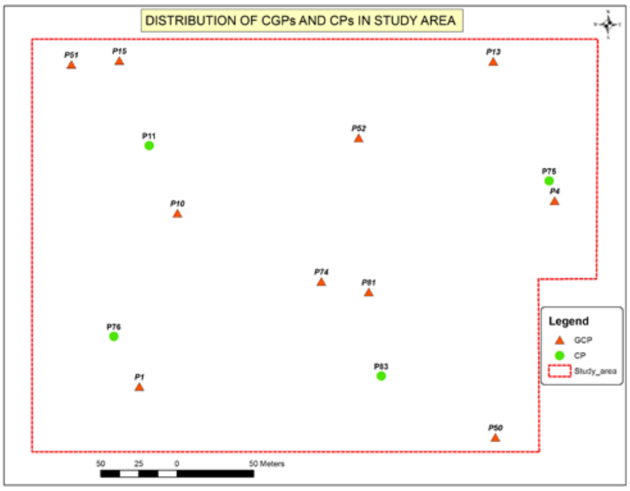
Using Pix4D Capture software, the flight plan was defined above the study area. The UAV flew autonomously in a pre-defined flight plan at an approximate altitude of 50m above ground. A total of 954 geotagged images were taken in nadir perspective and with overlap of 85% forward and 75 % side.

C. Image orientation

Acquired images were processed using Pix4Dmapper photogrammetric software. 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 non-metric cameras are not geometrically stable, which is a basic requirement for conventional photogrammetric mapping (Barnes et al., 2014). To resolve this problem, a self-calibration of the camera, which estimates the interior orientation, was integrated into the bundle block adjustment (Nex & Remondino, 2013).

In order to have accurately georeferenced products, high accuracy ground control points (GCPs) are needed. Figure 3 shows the layout of 14 points which were accurately surveyed on the ground features with approximately 2 cm standard deviation Real-Time Kinematic (RTK) DGPS in the local coordinate system (TM_Rwanda). Out of the 14 points, 10 GCPs were selected for exterior orientation process and 4 Check points for accuracy assessment. It was ensured that each point got marked in at least 6 images. To further test the usability of the UAV, it was analyzed which accuracy can be obtained without any GCPs, but using only the on-board GPS for image orientation. This can be useful in quantifying the geolocation error in a situation where it is not possible to collect GCPs. In order to check this, all GCPs were introduced in the image orientation as check points.

Figure 3: GCP distribution in study area



D. Bundle Block Adjustment

The first step within the bundle block adjustment workflow was to identify tie points, i.e. individual image points which refer to the same object point in the scene. To this end, interest point extractors and descriptors, like the combined approach from the Scale Invariant Feature Transform (SIFT) (Lowe, 2004) were applied. The fact that SIFT is both scale and rotation invariant made it very well suited for this task. In addition, corresponding points were matched in feature space, not in image space, hence, it enables to use arbitrary arrangements of images, without any pre-knowledge on their orientation. After some initial relative orientation of the image sequence, a bundle block adjustment (BBA) is applied, and the GCPs – if available – are introduced as constraints in order to stabilize the image block geometry and to locate it in the right datum. Even if GCPs are not available, the approximate geolocations of the camera during exposure as obtained from the on-board GPS can be used for the same purpose, but with much lower accuracy and reliability. The six elements of exterior orientation per image, i.e. the location of the optical centre and rotation of the optical axis were computed in this process.

As mentioned before, it was advised to include camera interior orientation parameters as unknowns into the BBA. Besides the focal length and principal point location, the parameters of lens distortion were estimated. This is helpful to increase the reliability and accuracy, but on the other hand, the high correlation between depth and focal length renders this procedure sensitive especially in flat terrain.

E. Dense image matching

The result of the bundle block adjustment (i.e. image orientation) is a tie points cloud and optimized internal and external camera parameters. There are several approaches to dense image matching (DIM). One group of methods works on optimizing disparity maps in stereo pairs, such as those based on the Semi-Global Matching (SGM) carried out by Hirschmuller (2008). Another idea is to densify the initial tie point cloud using all images simultaneously. A well-known method for that was presented in Furukawa et al., (2010). In the employed software, Pix4Dmapper, the densification approach is pursued.

F. 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 orthorectification process was performed. The task of orthorectification 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 colour balancing gets applied.

G. Orthophoto quality assessment

Using above mentioned check points the quantitative quality of orthophoto was checked. As the use of UAV is progressively increasing, and there is an interest of using geotags from the GPS on board the UAV without relying on ground checked coordinates. Therefore, the positional accuracy of two orthophoto of the same data, with and without GCPs was compared. Thus the result will help to estimate to which extent and application each orthophoto could be used.

Concerning qualitative assessment it will address the general and features appearance in the orthophoto. Radiometric errors which were mainly caused by bad image blending will be checked. Deformation could also be visible due to imperfections in the DSM. Using visual inspection, deformation and artefacts will be detected and their respective cause was discussed as well as how they can be corrected.

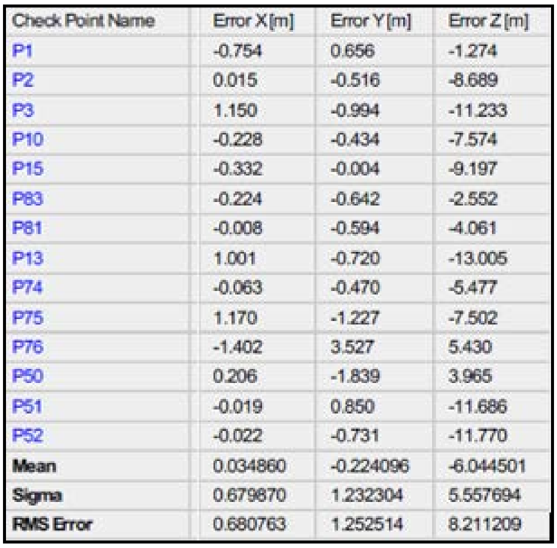
H. Feature extraction

The main use of the orthophoto in this project is to help extract spatial data which was used to update the existing basemap. After orthophoto quality assessment and correction, the next step was to design the feature extraction guide, which guided in the extraction process and provided clearly defined rules of digitization. Due to the size of study area, objects of interest was detected and digitized on large scale and generalization will be applied before being updated in small scale basemap. However, due to high level of details of produced high resolution orthophoto, where even small objects were detected, new datasets can also be created depending of their future use in development planning (drainage, footpaths, etc.). After digitization, their spatial accuracy was checked by comparing digitized and known coordinates from ground and finally the RMSE were calculated and analysed in Excel. In the end, their quality will be documented to facilitate future use and easy interpretation using ArcGIS metadata editor's ISO 19115(2003) template before being updated in the basemap.

III. RESULTS

A. Image orientation

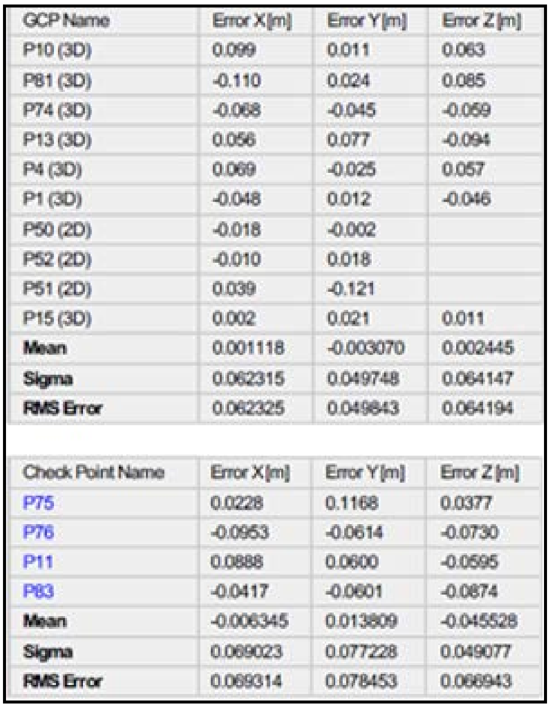
Figure 4 : Geolocation result with image geotags only



Check Point Name	Error X [m]	Error Y [m]	Error Z [m]
P1	-0.754	0.656	-1.274
P2	0.015	-0.516	-8.689
P3	1.150	-0.994	-11.233
P10	-0.228	-0.434	-7.574
P15	-0.332	-0.004	-9.197
P83	-0.224	-0.642	-2.552
P81	-0.008	-0.594	-4.061
P13	1.001	-0.720	-13.005
P74	-0.063	-0.470	-5.477
P75	1.170	-1.227	-7.502
P76	-1.402	3.527	5.430
P50	0.206	-1.839	3.965
P51	-0.019	0.850	-11.686
P52	-0.022	-0.731	-11.770
Mean	0.034860	-0.224096	-6.044501
Sigma	0.679870	1.232304	5.557694
RMS Error	0.680763	1.252514	8.211209

As Figure 4 shows, image orientation with geotags only resulted in low accuracy geolocation, especially in height. This is due to use of only the GPS on board the UAV. However, this result is promising as it can be used for some mapping applications which require less than 1.5 m of accuracy. For this project expected for 1/1000 scale, this accuracy is not enough. The limited accuracy is primarily due to the low accuracy of the navigation-grade GPS units used to record camera position at the time of image capture. The second contributing factor to this can be lack of precise time synchronization between the camera acquisition and GPS receiver. For Z, the possible error can come also from the GPS of UAV which cannot take the height with accuracy but also the contributing cause can be the extracted value from DEM (5 m), which may not be accurate enough.

Figure 5 : Geolocation with Ground control point results



GCP Name	Error X [m]	Error Y [m]	Error Z [m]
P10 (3D)	0.099	0.011	0.063
P81 (3D)	-0.110	0.024	0.085
P74 (3D)	-0.068	-0.045	-0.059
P13 (3D)	0.056	0.077	-0.094
P4 (3D)	0.069	-0.025	0.057
P1 (3D)	-0.048	0.012	-0.046
P50 (2D)	-0.018	-0.002	
P52 (2D)	-0.010	0.018	
P51 (2D)	0.039	-0.121	
P15 (3D)	0.002	0.021	0.011
Mean	0.001118	-0.003070	0.002445
Sigma	0.062315	0.049748	0.064147
RMS Error	0.062325	0.049843	0.064194

Check Point Name	Error X [m]	Error Y [m]	Error Z [m]
P75	0.0228	0.1168	0.0377
P76	-0.0953	-0.0614	-0.0730
P11	0.0888	0.0600	-0.0595
P83	-0.0417	-0.0601	-0.0874
Mean	-0.006345	0.013809	-0.045528
Sigma	0.069023	0.077228	0.049077
RMS Error	0.069314	0.078453	0.066943

With GCPs, the accuracy has changed significantly (Figure 5). The model was geolocated accurately in terms of 6 cm in x, 4 cm in y and 6 cm in z. This will help to reach required accuracy for this project.

B. Orthophoto and quality assessment

The previous steps resulted in a high quality orthophoto shown by Figure 6 with the following specification:

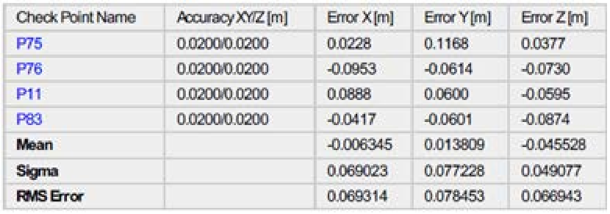
- GSD: 0.033 m
- Spectral resolution: RGB
- Radiometric resolution: 8 bit

Figure 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 orthorectified to theirs 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. These errors are very small and hardly detectable.

C. Quantitative assessment

Figure 7: Accuracy assessment of the check points in Pix4D (above) and on orthophoto (below).

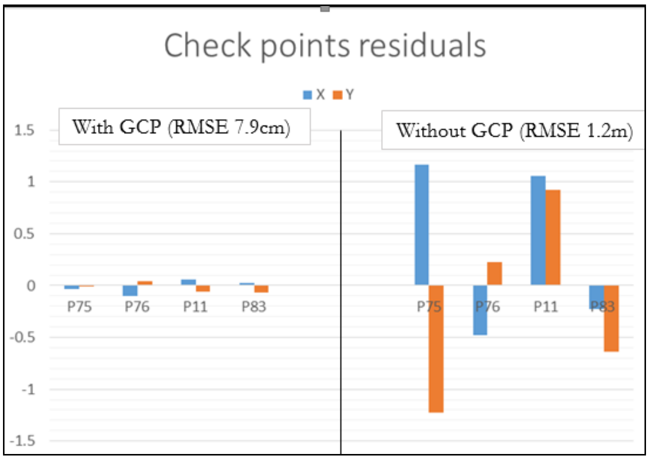


Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]
P75	0.0200/0.0200	0.0228	0.1168	0.0377
P76	0.0200/0.0200	-0.0953	-0.0614	-0.0730
P11	0.0200/0.0200	0.0888	0.0600	-0.0595
P83	0.0200/0.0200	-0.0417	-0.0601	-0.0874
Mean		-0.006345	0.013809	-0.045528
Sigma		0.069023	0.077228	0.049077
RMS Error		0.069314	0.078453	0.066943

Check points	dX	dX2	dY	dY2
P75	-0.032	0.001	-0.009	0.000
P76	-0.099	0.010	0.043	0.002
P11	0.058	0.003	-0.058	0.003
P83	0.026	0.001	-0.070	0.005
	-0.012		-0.024	
	mx	0.061	my	0.050
RMSE	0.079			

From Figure 7, the result of manual checking of horizontal accuracy on orthophoto accuracy did not change too much compared to image orientation. This means that the intermediate steps of dense image matching, DSM and Orthophoto production did not change significantly the accuracy of check points. However, a slight change is visible in P75 and may have been caused by its location which is very close to GCP 4 and may have been under its influence. In this work the orthophoto was accurately georeferenced with RMSE of 7.9 cm. This accuracy is enough for this work as the minimum required was 12.5 cm for 1/1000 scale (ASPRS, 2015). This result may have been influenced by some factors like visual perception limitation while detecting GCP, precision of DGPS used which is estimated to be around 2 cm.

Figure 8: RMSE Comparison of on-board GPS and GCP in final orthophoto



The vertical accuracy obtained without ground control points was around 1.25 m (Figure 8). This is due to the use of only geotags from consumer grade GPS on-board of UAV for image orientation. This accuracy is a bit high in general mapping activities but can be useful in mapping which doesn't require high accuracy work (tourism, navigation, etc.). As UAVs may be used for rapid mapping applications in areas with hazardous or limited human accessibility where it's not easy or impossible to take ground control points, knowing this range will help to estimate how accurate their model is. Similar accuracy using on board GPS was reported for example 1 m (8cm GSD) by Skarlatos et al., (2013), 90 cm accuracy (Haitao & Lei, 2010), 2-8 m for 130–900 m flying altitude was reported by Küng et al., (2012), 2-4 m with 50-100 flying height by Eugster & Nebiker, (2007).

Now that absolute position accuracy achieved, it's good to perform geometrical accuracy assessment. This will help to confirm if produced orthophoto will achieve its primary purpose of identifying objects and measuring their size. This is also a good possibility to check if the produced size of image pixels (GSD) matches the data product specification and keeps uniform scale. As Figure 9 shows, objects on field were measured using a tape and compared to the digitized size on the orthophoto (results are reported in Table 2).

Figure 9 : Measurement in orthophoto (m): Parking border on left and concrete slab on right

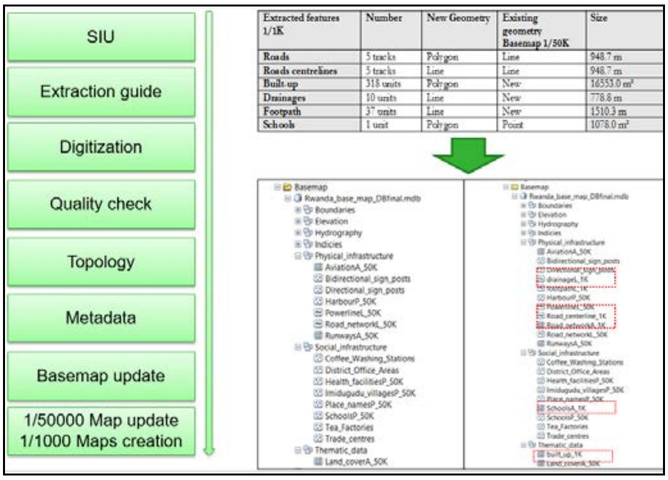
Table 2 : Geometric accuracy checking overview

Object	**Measurement on field**	**Measurement on orthophoto**	**Difference**	**Percentage(error)**
Parking border	56.200 m	56.221m	0.021m	0.03
Concrete slab	0.700 m	0.704m	0.004m	0.57
Concrete slab(Length)	1.820 m	1.822m	0.012m	0.66

D .Basemap updating and map production

As the quality of orthophoto was checked and yield an excellent result, the next steps was basemap updating. Through cartographic process, (Figure 10), the extraction guide with rules to guide digitization were designed. Digitization was done on a scale of 1/1000. Digitized datasets quality was checked and the RMSE was 8 cm. Finally, the topology control and metadata creation (ISO 2003 Template) was conducted before being updated in basemap (Figure 11). As the produced datasets were on 1/1000 scale, generalization were applied to fit 1/50000 scale of basemap. Finally, large scale maps were produced from produced datasets. Among them topographic maps (Figure 12) and cadastral maps (Figure 13).

Figure 10 : Basemap updating results



Extracted features 1/1K	Number	New Geometry	Existing geometry Basemap 1/50K	Size
Roads	5 tracks	Polygon	Line	948.7 m
Roads centrelines	5 tracks	Line	Line	948.7 m
Built-up	318 units	Polygon	New	16553.0 m²
Drainages	10 units	Line	New	778.8 m
Footpath	37 units	Line	New	1510.3 m
Schools	1 unit	Polygon	Point	1078.0 m²

Figure 11: Map update 1/50000 (before and after: inserted)

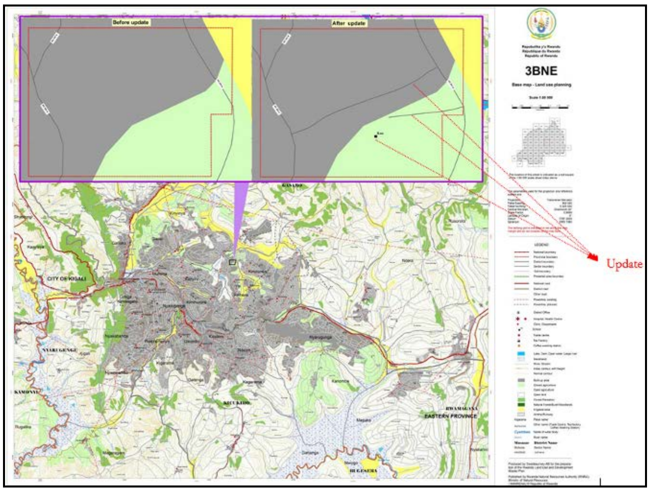
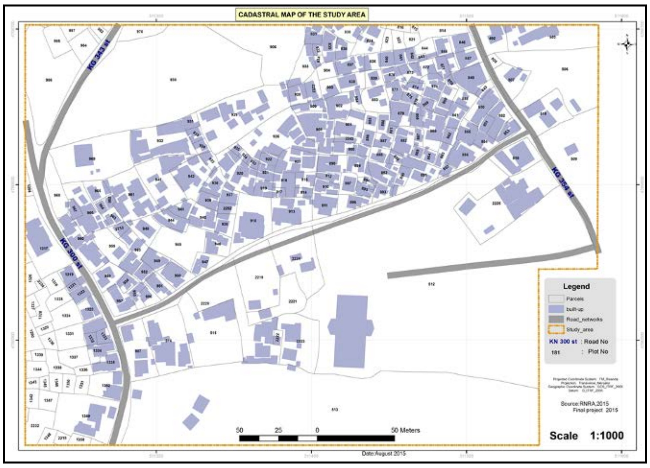


Figure 12 : Topographic map (1/1000)

Figure 13: Cadastral map



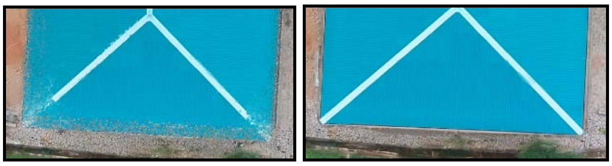
IV: DISCUSSION

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.

The quality of orthophoto also showed dependency on the used algorithms. For example, in the previous version of Pix4D (1.4), DSM interpolation were done using triangulation and the result presented noise around roof edges (Figure 14). However, in newly released Pix4D 2.0, the introduction of Inverse Distance Weighting interpolation has improved the roof corners which were sharper but sometimes rounded. This proves that quality of the DSM and orthophoto can depend on the software used and the built-in algorithm.

Figure 14: Comparison of roof edges (left: Triangulation, Right: Inverse Distance Weighting)



Another orthophoto aspect which was checked is its georeferencing accuracy, where a comparison was made between using only on-board GPS and including GCPs for image orientation. As proved in this work, the result of direct georefencing from UAV on board GPS has resulted in low accuracy (1.2 m). This is understandable as they are using the consumer grade GPS which can be influenced by its low accuracy and lack of precise time synchronization between camera acquisitions and GPS receiver. This proves that for better accuracy, there is still a dependency on ground control points. GCPs will determine the georeferencing accuracy of final products, hence their acquisition need to be done accurately. Their quality can be influenced by the precision of the surveying equipment used, their distribution in the study area and positioning error while being introduced in photogrammetric project. Any error incurred in any of these elements will have an impact on the final results.

Finally, as all these problems above were corrected, it resulted in orthophoto with high spatial resolution and centimeter level accuracy. This orthophoto can be used as reliable source for feature extraction and various map creation and updating and other multiple spatial planning activities. In this work, creation of large scale datasets and respective maps was done accurately. This confirms that private and government institutions can use UAV to create multipurpose spatial databases and to keep updating them as needed, which will help to achieve their everyday planning activities.

V. CONCLUSION AND RECOMMENDATIONS

The main objective of this project was to create a high quality orthophoto from images taken from UAV and later to perform features extraction for basemap updating. Through photogrammetric processing it has been possible to obtain very high resolution orthophoto which were used to produce datasets, updated in basemap which can be used also in various planning activities. However, the results will depend on knowledge and qualification of the specialist on how to plan and conduct all steps. Many elements needs to be taken into account: flight planning, the sensor used, image processing techniques and algorithms.

This work has proved that UAVs can be an excellent tool for capturing imagery with high resolution in order to produce products with high accuracy. However, there are still some limitations which require further research for improvement. Small image footprints make that a large number of images will be needed for coverage. As the size of the area covered increases, the number of images also increases and this aspect will lead to enlarging the processing time. UAVs are therefore more suitable for acquiring imagery over small areas. For large areas, it is still needed to use traditional aircraft. The other problem is dependency on the accuracy of the ground control points. As reported, the geolocation without ground control points is still low which makes that ground reality is needed for better accuracy. This will take extra time for collection and insertion in software.

Acknowledgment

We thank Pix4D for providing us with the research license of Pix4dmapper. All image orientation and dense matching tasks for this research were performed with Pix4dmapper.

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