UAVs FOR A COMPLETE TOPOGRAPHIC SURVEY

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ABSTRACT:

With the advancement of sensor technology, unmanned aerial vehicles (UAVs) or drones revolutionize several fields including topographic surveying, agriculture, recreation, emergency, rescue and so on. The autonomous flight modes available in current UAVs make it broaden to manoeuvring by an unskilled person. This, of course, causes to widely use the drone technology among different user communities. Of the revolutionized fields, topographic surveying is prominent because many low cost UAVs with on-board light weight optical payloads often deliver mapping products such as ortho-photos and DEMs with centimetre level accuracy (in XY and Z) that had been exclusively bounded to the expensive field surveying methods earlier. Though drones enables to obtain centimetre level geometric accuracy, the main drawback of the technology is inability to see underneath vegetation canopy which hinders applicability of drones for a complete topographical survey. In order to view beneath the tree canopies, UAV LiDAR is a solution but due to its high cost, it is still not popular among several communities who involve with land surveying. To measure underside vegetation, field surveying methods such as total stations and theodolites traversing are being mainly practised by the users. But it is also not a viable solution since it consumes much time and money. If remotely sensed data collection is able to capture landscapes that had been hampers by the canopies, definitely it will be a cost effective and a rapid solution. As such, oblique imagery (UAV) acquired in manual flight mode at very low altitudes is a good solution. The objective of the study is to develop a novel approach to generate UAV deliveries without vegetation canopy in vegetated areas.

First, autonomous flight mission is completed while maintaining 80% and 70% forward and lateral overlaps. For the terrain patches where they are covered by tree canopies, oblique imageries have been collected while operating the drone manually at low altitudes. Each UAV flight is separately processed and merged in to a single image to extract 2D maps without gaps beneath tree canopies. Re-sampling is fulfilled prior to stitching in order to gain a seamless product. Performed accuracy analysis confirmed that the developed approach is sufficient to produce DTMs and ortho-mosaics having average RMSE-XY 0.087m and RMSE-Z 0.177m at 4.0cm GSD which is really acceptable. Besides, there is not any significant accuracy variation between underneath canopy areas and open areas.

1. INTRODUCTION

1.1 Introduction

The history of Unmanned Aerial Systems (UAS) goes back over centuries and the hot-air balloons first used by Austrian people to send explosive war heads to Venice in 1849 is its starting point. As a tool to detect enemy territories, military people basically invest a lot to develop unmanned aerial vehicles and then the modern sensor system brought it up to the present condition. Thus we are now getting its benefit for humans' life activities (Santise, 2016). Nowadays, UAS has become a popular tool for many fields such as agriculture (Grenzdörffer and Niemeyer 2011), cadastral applications (Cramer et al., 2013; Cunningham et al., 2011; Barnes et al., 2014; Manyoky et al., 2011), geology (Eisenbeiss 2009), cultural heritage (Remondino et al., 2011; Rinaudo et al., 2012), archaeology (Chiabrando et al., 2011), disaster management (Molina et al., 2012; Choi and Lee 2011), damage assessments (Vertivel et al., 2015), coastal management (Delacourt et al., 2009) and so on.

However, the acquisition of high resolution data or dense data sets over the landscape is a requirement for many Earth science and mapping studies (Hackney and Clayton, 2015). With the advent of sensor systems UAS, i.e. a data acquisition system designed to operate with no on-board human pilot, are being promisingly used for surveying and mapping (Koeva et al., 2018; Nex and Remondino, 2014). Though the term UAS is commonly used, the other terms such as drones, Unmanned Aerial Vehicles (UAV), Remotely Piloted Aircraft Systems (RPAS) have been often used by the different user community. The UAV refers to the platform itself while the UAS refers to the entire system including platform, control unit together with the communication sub-system and the operator (Chio and Chiang, 2020; Nex and Remondino, 2014). Therefore the term UAS is more suitable to describe the technology. In fact, UAS has changed the way that the data has been collected in traditional land surveying methods such as theodolite, tacheometry, and total station traversing, and so on, and as well as in modern land surveying methods such as robotic total stations, RTK GNSS surveying, and so on (Wheeler, 2019). By the UAS photogrammetric surveying, the surveying crew, time

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and cost required for land surveying methods have been fully changed while preserving the product accuracy similar to the field surveying (Wheeler, 2019; Hackney and Clayton, 2015). The high accuracy, of course, is not practicable even with the digital aerial surveys due to the limitation of flying heights. Technically, UAVs can fly almost everywhere. Because of their high flexibility, location of the platform and their viewing angle can be altered within a short time (Watts et al., 2012). Even with the commercially available low cost UAS, flying at low altitudes is no longer an issue for photogrammetric user community. As such, imageries with high Ground Sample Distances (GSD) close to 1cm are achievable enabling users to accomplish remarkable positional accuracy without any effort. Though the available low cost drones are being used for topographic surveying, it is still debated which platform, hardware, and software should be best used for achieving the survey grade accuracy. Having sufficient number of accurate Ground Control Points (GCPs) and on-board Real Time Kinematic (RTK) positioning facility with accurate Inertial Measurement Unit (IMU), the expected accuracy can be achieved easily (Wheeler, 2019). In fact GCPs, it should be carefully selected and well distributed and should be visible in many images. Furthermore, the GCPs can be easily identifiable from the acquired images. On the other hand, with the UAS, recursive data acquisition that many studies are required can be achieved at any time. This of course cannot be achieved by super high resolution satellite images that have fixed temporal resolution. This is another factor to popularise the UAS. However the major disadvantage of UAS with optical payload is inability to view underneath vegetation canopies. This is the main reason that many surveyors still integrate expensive field surveying methods to the topographic surveying (Pueschel et al., 2008; Remondino et al., 2009). With the advent of light weight LiDAR (Light Detection And Ranging) sensors, UAS with LiDAR payloads are being used for topographic surveying (Nagai et al., 2004; Vierling et al., 2006; Wang et al., 2009; Berni et al., 2009; Kohoutek and Eisenbeiss, 2012; Grenzdoffer et al., 2012). This certainly helps to avoid drawbacks given by the optical payload. However, UAV LiDAR is still not popular among the community due to its high initial cost. As such, a remedy that allows to acquire the topography beneath the canopy with the usual UAS is required which is still not fully investigated. This paper addresses a way that one could follow to achieve the goal.

The structure of the manuscript is as follows: Section 02 presents a short summary of the study area and data. The methods are described in next section. The last two sections devote for presenting results and analysis and the conclusions.

2. STUDY AREA AND MATERIALS

The experiment took place in an irrigated area of Kaddaikaddukulam tank in Mullaitivu District, Sri Lanka (09°14′N 80°32′E). The area is primarily rural while containing lots of vegetation. The village next to the tank is partly covered by vegetation but exist various manmade structures, paddy fields, and so on (see figure 1). The manmade structures such as buildings, irrigation channels, culverts exist beneath the trees.

Planimetric coordinates of GCPs including topographic features have been surveyed by a RTK GNSS receiver (Topcon-GR5) while surveying elevation information by an auto level with respect to mean sea level (MSL). Due to canopy coverage, the features underneath the vegetation were surveyed by a Total

Station (Sokkia SET600S). Several cross checks were carried out to ensure that the measurements are free from biases. Except GCPs required for photogrammetric process, all other GCPs are considered as checkpoints and are used for the accuracy analysis. 28 GCPs were established using both RTK GNSS and Total station (depend on the canopy cover) and validated the accuracy of measurement with respect to known stations.
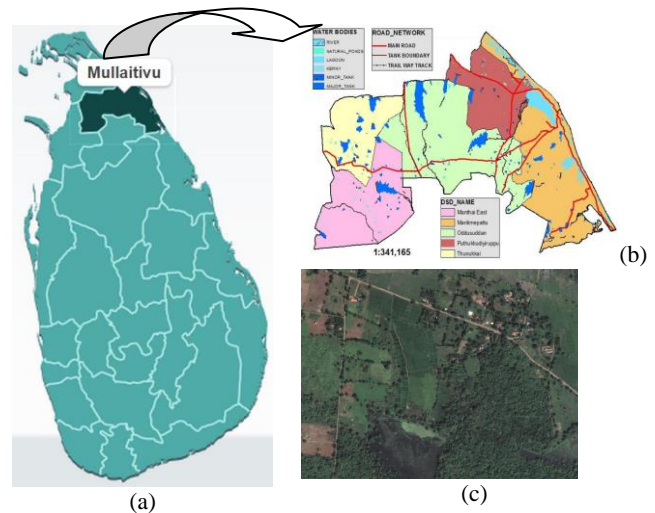

Figure 1: Study Area: (a) District Map of Sri Lanka, (b) Map of Mullaitivu portraying water features, and (c) Kaddaikaddukulam village

Phantom 4 Pro - DJI drone is used for image acquisition and 140-150m height above MSL was chosen as the flying height enabling to achieve nearly 4cm GSD. 80% forward and 70% lateral overlaps were maintained while carrying the 20-megapixel CMOS sensor. The extent of the entire surveyed area was 15 hectares which is covered by 635 images.

3. METHEDOLOGY

In this section, we describe the procedure followed for carrying out the study. A schematic overview is given in figure 2.

3.1 XY and Z Controlling

As mentioned in the section 2, the GCPs are established using RTK GNSS and Total Station traversing. Known points are used as the base stations for the GNSS survey and as well as the starting points for the traversing. The XY coordinates of each observation follows the SLD99 (national grid) coordinates while Z values follow the MSL heights. Though the locations of GCPs do not exactly follow a grid pattern due to the canopy coverage, a well spread location are chosen. After establishing the GCPs, prior to image acquisition, the spots that do not appear sharp features were painted by cross marks or located by pre-designed cross boards in order to gain an easy recognition with the image data. Further to that, we make sure to maintain sufficiently wide cross marks, larger than the GSD (4cm), in order to assign the GCP locations precisely in the processing step. Of the 28 GCPs, 15 GCPs were used for the photogrammetric product generation while rest is used for the accuracy analysis. Further to the checkpoints, surveyed features

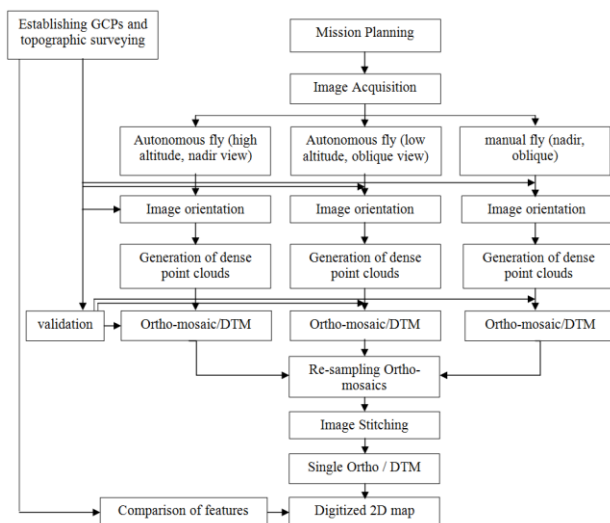including building corners, culvert or cannel edges or corners could be used as the checkpoints.

Figure 2: Schematic diagram of workflow

3.2 Image acquisition

The mission planning is carried out with the DJIFlightPlanner. Both autonomous (way point) flying and manual flying are used. To secure a maximum accuracy for 3rd dimension, double grid flight paths (two orthogonal paths) at 140m flying height is chosen for autonomous fly. At the places where isolate heavy canopies exist, autonomous flight mode is executed at low altitude (60m), while taking oblique imageries, to gain the maximum visibility beneath the canopy. In here, defined way points are used for deploying the drone. Besides, for the connected tree canopies, manual flight mode is employed while capturing the images both in nadir and oblique direction. A very low altitude (30m) is chosen in this case. These image acquisitions are carried out separately considering them as independent tasks for the easiness of subsequent processing.

3.3 Processing

Agisoft Metashape 1.7.3 is mainly used for the photogrammetric processing which basically relies on three stage SfM photogrammetry processing workflow. Initially, matching key points, automatic aerial triangulation and bundle block adjustment execute to create 3D point clouds. This of course is a sparse cloud which is geo-referenced respect to the assigned GCPs. The sparse points are then densified to generate a dense point cloud with the help of multi-view stereo images. As such, the process allows creating accurate products including a DSM and an ortho-photo in the last stage.

Having different GSDs, for the manipulation easiness, each independent acquisition is processed separately with the idea of merging them at the end.

3.4 Image stitching

Due to different GSDs of ortho-mosaics generated separately in the previous stage, the first step of creating a single mosaicked-

ortho is resampling each data set. The resolution of the largest ortho-mosaic is chosen as the base resolution and all other orthos are re-sampled to fit with the chosen one. Since orthos are already geo-referenced, each individual mosaic is properly registered on top of the base image where they should be. Assuming orthos portraying the underneath canopy are correct, their pixel values are used to replace the corresponding pixels belonging to the canopy areas of the base image. A single ortho-mosaic free from the vegetation is then obtained that can be used straightforward to extract boundary information of the landscape. Finally, manual digitization is applied to gain a complete 2D topographic map of the area.

The next step of the study is to compare the result with respect to field measurements.

4. RESULTS AND ANALYSIS

Some of the intermediate and final results together with their accuracy analysis are illustrated in this section.

4.1 Ortho-mosaics

Planimetric accuracy is analyzed based on the ortho photos. The figure 3 clearly showcases the ortho-mosaic generated from the autonomous image acquisition. The figure further shows the canopy areas of three selected land plots. As you can see, canopy coverage in the selected land plots is considerable, so that several boundary gaps would arise in the result of automated or manual feature extraction methods. This emphasises the removal of vegetation canopy for a continuous extraction of terrain feature. The generated ortho-mosaics of plot A, B and C illustrate in the figure 4 which portrays that the high vegetation canopy doesn't appear on those images ensuring the applicability to extract underneath topographic features.
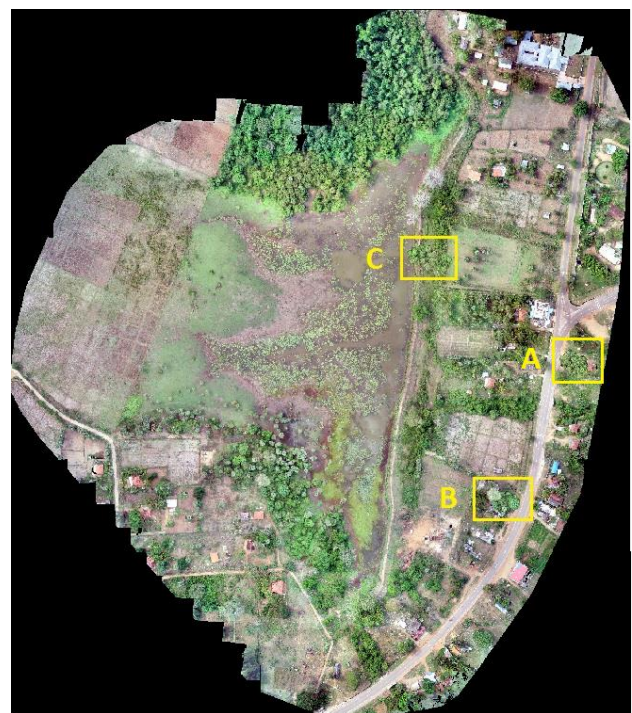

Figure 3: Ortho-mosaic of the study area (base image)

The above ground features such as buildings, fences, and ground level features such as irrigation cannels, culverts are nicely appearing in the underneath canopy mosaics (figure 4a,

c). However, some of the vegetation lower than to the flying height of the manual fly still remains (red arrow in figure 4b). In fact, these types of 2-3m elevated low vegetation is really hard to avoid by the drone surveying because very low altitude such as less than to 5m is still unable to achieve by the available drones due to safety reasons unless survey-grade micro drones are developed in the future. As such, terrestrial photography, for instance with the help of DSLR camera, would be a solution.

From the ortho-mosaics representing underneath canopy areas, the most important image subset is extracted while maintaining a slight overlap between the land plot and the base image which is then used for the image stitching. The resultant stitched image is shown in the figure 5 which clearly shows all topographic features within the land plots A, B and C.

The 2D topographic map is then extracted by manual digitization (figure 6) which is superimposed with the reference topographic map obtained by the field surveying.


(c)

Figure 4: Ortho-mosaic of underneath canopy - (a) plot A, (b) Plot B, and (c) Plot C

Since the objective is to assess the accuracy of stitched image, for the accuracy analysis, it is used only the surveyed checkpoints falls within the land plot A, B and C. Besides, to assess the accuracy of the outside the stitched areas, corresponding checkpoints falls outside to the plot A, B, and C are used. Both ± errors (see figure 7) indicates that there is no bias in the measurements and the product. Further to that, RMSE of the topographic features that falls within the land plot A, B and C are also computed.

(a)
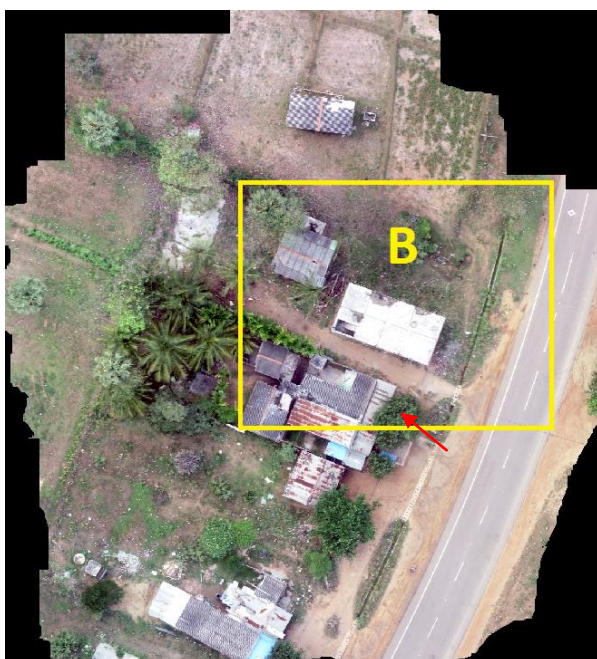
(b)

Figure 5: Ortho-mosaic after image stitching

The table 1 summarizes the planimetric accuracy of the stitched image within the land plots and outside the plots. The highest planimetric accuracy is given by the land plot A, B and C where low flying height is given. The RMSE of the topographic features is slightly higher than that of the checkpoints. Though the accuracy of field measurements was similar to the accuracy

of GCPs, digitization errors should contributed for this uncertainty. This of course is an acceptable factor.
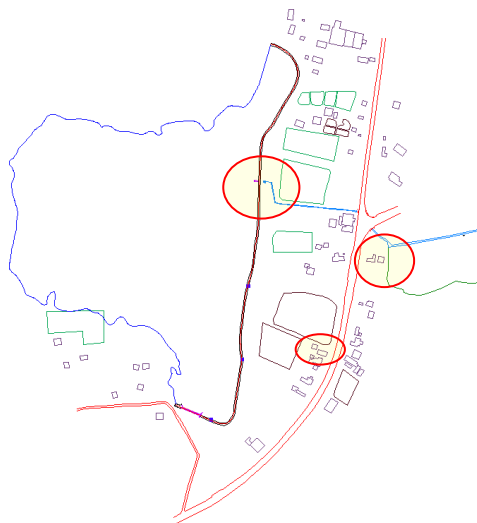

Figure 6: Extracted 2D topographic features by the manual digitization

Table 1: Summary of accuracy analysis - RMSE in XY plane (cm)

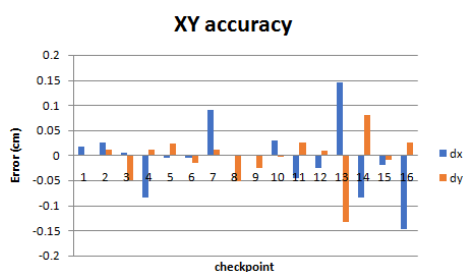| Point type	Within the Land Plot A,B,C	Outside the Land Plots
Checkpoints	8.03	8.46
Topographic features	8.92	9.75

Figure 7: XY errors at checkpoints

4.2 Elevation data

In addition to the planimetric accuracy analysis, Z values are also evaluated with respect to the field measurements. The obtained overall RMSE in Z direction is equal to 0.177 m. This is a quite large value when comparing to the XY error. A contour map (figure 8) is also generated in order to accommodate elevation of terrain and building locations.

Figure 8: Contour Map

The 3D surface model prior and after stitching the elevation show (figure 9) that the method also able to work with 3rd dimension as well. Similar to planimetric errors, both ± errors do exist for the Z direction (figure 10) as well.
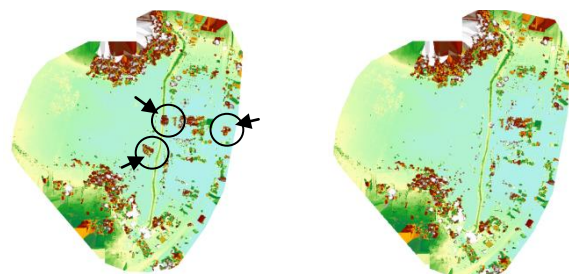

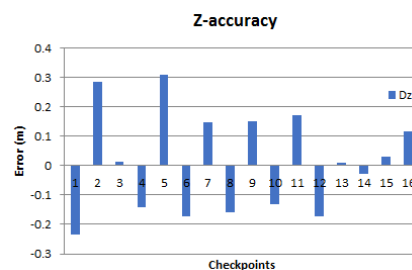**Figure 9:** DSM - (left) autonomous mode, (right) after replacing underneath elevation

Figure 10: Z errors at checkpoints

5. CONCLUSIONS

It is obvious that independent processing relevant to separate flying is easier to manipulate rather than a combined work. For the features in the final product, a seamless continuation is given even with the stitched image and thus the spatial accuracy within the stitched area and outside to the area deliver an almost similar accuracy. The medium high canopies elevated up to the 10m above the ground level can be viewed even by manual flying modes. The most critical case is to fly beneath the low elevated vegetation. In here, the most beneficial approach will be utilization of DSLR camera (or any appropriate terrestrial camera). This is not investigated yet and letting it to investigate as a future work. Manual and low altitude flight paths with and without oblique view can also be looked underneath canopies up to considerable extent. Irrespective to the nadir looking,

oblique and manually operated imagery will always give a similar accuracy.

Considering all, it can be concluded that, in near future, field surveying techniques would be replaced by the drone surveying and vegetation canopy would not be an obstacle any more.

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