Suitability of Unmanned Aerial Vehicles for Cadastral Surveys*

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Mantey, S. and Tagoe, N. D., (2019), "Suitability of Unmanned Aerial Vehicles for Cadastral Surveys", *Ghana Mining Journal,* Vol. 19, No. 1, pp. 1 - 8.

Abstract

Cadastral surveys in Ghana often employ well known surveying equipment such as Total Station and GNSS receivers or a combination of both. These survey techniques are well-established and widely accepted. However, there are limitations in certain areas. In situations where difficult terrain and inaccessible areas and dense vegetation are encountered or when surveyor's life may be at risk, Unmanned Aerial Vehicles (UAVs) could be used to overcome the limitations of these well-established survey instruments. This research used high resolution images from UAV (DJI Phantom 4) to survey plots within the University of Mines and Technology land area. Coordinates of the boundary points were extracted using Agisoft Photoscan. GNSS receivers were also used to survey the land and the same boundary point coordinates obtained and compared. This enabled the establishment of accurate ground control points for georeferencing. The coordinates obtained from both UAV and GNSS Surveys were used to prepare cadastral plans and compared. The difference in Northings and Eastings from UAV and GNSS surveys were +0.380 cm and +0.351 cm respectively. These differences are well within tolerance of +/- 0.9114 m (+/-3 ft) set by the Survey and Mapping Division (SMD) of the Lands Commission for cadastral plans production. This research therefore concludes that high resolution images from UAVs are suitable for cadastral surveying.

Keywords: Unmanned Aerial Vehicles, Drones, Global Navigation Satellite Systems, Cadastral Surveys

1 Introduction

Defining land ownership requires the use of cadastral maps. A cadastral map consists of cadastral units each of which represents a single registered plot of land (Williamson, 1997). Cadastral maps are often produced using land survey techniques which often employ well known surveying equipment such as Total Stations and Global Navigation Satellite Systems (GNSS) or combination of both. These techniques are well established, however, they are sometimes unfavourable in some conditions. When surveying a very large area, the cost involved could be prohibitive and time consuming. In crowded urban settings where subdivision surveys are normally conducted, there are challenges because these tools require point-to-point visibility and enough satellite reception. Sometimes, the safety of personnel carrying out the survey is also jeopardised. Some challenges associated with land boundaries such as litigations are sometimes easily and clearly pointed out on high resolution images which are captured using Unmanned Aerial Vehicle (UAV). UAV also called a drone is an aircraft system with no human being on board (Saripalli *et al*., 2003; Valavanis, 2008; Anon., 2017). UAV Surveys can solve some challenges associated with land surveying techniques (Eisenbeiss, 2011; Everaerts, 2008) and also create alternatives for cadastral surveying (Darwin *et al*., 2013). The study area is located between longitudes 2°0′45.76"W and 2°0′42.51"W and latitudes 5°17′49.48"N and 5°17′47.52"N within Tarkwa Nsuaem Municipality which was created from the former Wassa West District under Legislative Instrument (LI) 1886 in 2007. It shares boundary with Prestea Huni-Valley to the North, the South by Ahanta West, the West by Nzema East and the East by Mpohor Wassa East. The Municipality has a total land area of 2354 sqkm, and has Tarkwa as its capital (Anon., 2012).

1.1 Cadastral Surveys

Cadastral surveys are carried out to produce cadastral maps. Cadastral map is the spatial representation of cadastre records, which is defined as the records showing the extent, value and ownership (or other basis for use or occupancy) of land (Williamson, 1997). Cadastral map is also the basis for planning economic and social development (Kavannagh and Glenn Bird, 2000). Cadastral map is one of the most important elements of the society, therefore the accurate cadastral information is needed to foster development (Kavannagh and Glenn Bird, 2000).

1.2 Well-Established Surveying Techniques

Total Station and GNSS receivers are well-established equipment mostly used in land surveying techniques. Total Station and GNSS receivers are widely accepted and are still in use for data acquisition for cadastral mapping purposes. When two control points are known in the area, the collection of survey data can be carried out using Total Station. Whatever the method, the provision of control points, includes the measurement of two entities (Distance and Angle) (Kavannagh and Glenn Bird, 2000). The measurement results can be

*Manuscript received March 9, 2019
Revised version accepted June 21, 2019
https://dx.doi.org/10.4314/gm.v19i1.1

recorded into the internal memory for further processing. GNSS receivers on the other hand, has been used primarily as a means of densifying geodetic control networks, or establishing such networks in areas where they had not previously existed. While GNSS receivers appears to be an attractive alternative for surveying at the parcel level, there are few studies that have tested the cost-efficiency of a GNSS methodology compared with other approaches (Barry and Coakley, 2013). Mostly using GNSS receivers and Total Stations for cadastral surveys is often labour intensive and sometimes exposes surveyors to hazardous environments. Alternative methods of cadastral survey such as the application of UAVs are suggested to minimise the exposure of surveyors to hazardous environments while maintaining accuracy and standards.

1.3 UAV Surveys

UAV Surveys require a proper mission planning for a successful flight. Planning the mission is determined by a number of factors, *i.e.* the desired ground resolution, the focal length and resolution of the camera and the flying height (Lee, *et al.*, 2015; Manyoky *et al.*, 2011). The simple calculations that integrate these factors to create flight plans with corresponding spatial resolution of digital maps is commonly expressed as the Ground Sampling Distance (GSD). GSD is the dimension of a square on the ground covered by one pixel (p) in the image and is a function of the resolution of the camera sensor, the focal length (f) of the camera and the flying height (H = the distance between camera and ground). From simple geometry the following ratio holds: GSD/p= H/f or H = GSD (f/p). The pixel size (p) of the camera sensor is usually computed from the technical specifications of the camera. Commonly, the dimensions of the sensor are specified both in linear units (*e.g.* 17.3 x 13.0 mm) as well as in number of pixels (*e.g.* 4000 x 3000 pixels). Pixel size is simply determined by dividing the linear units by the number of pixels. In UAV surveys, it is essential to capture imagery with sufficient stereo overlap to generate 3D models (Manyoky *et al.*, 2011; Merz and Chapman, 2011). Once a flying height has been determined it is necessary to compute the distance between each exposure position, the spacing between flight lines and the overlap (Witayangkurn *et al.*, 2011).

1.4 Major Components of UAV

A basic flight control system for these UAVs contains an Inertial Measurement Unit (IMU) linked to a processor that manages power distribution to the motors to stabilise flight. Most flight control systems also include; a magnetometer, a barometer as well as a Global Navigation Satellite System (GNSS) receiver to support three dimensional navigations of the UAV. A typical UAV consists of airborne components (vehicle, camera, battery, gimbal, *etc*.) and the ground-based components (base station and a radio control (RC) transmitter to remotely control the UAV (Ferruz *et al.*, 2011; Manyoky *et al.*, 2011). Although it is possible for the flight controller to control the UAV autonomously, it is generally a good idea to have a RC transmitter so that you can control the UAV if something goes wrong or just use the RC transmitter to fly manually (Ferruz *et al.*, 2011; Lippiello and Siciliano 2012). All three of the basic components; the vehicle, base station and RC transmitter, are equipped with appropriate telecommunication devices which facilitate the transfer of data and instructions from and to the UAV. Although most UAVs have the inherent capability to execute automated flights from take-off to landing without any manual operator input or any connection to the ground components, few are configured to actually function without prior establishment of a live link to either RC transmitter or base station. The RC transmitter constraint is implemented mainly as a safety precaution to ensure that manual control of the UAV can be resumed if needed at any given point during a flight (Ferruz *et al.*, 2011; Manyoky *et al.*, 2011).

2 Resources and Methods Used

2.1 Resources

The UAV used for this study is the DJI Phantom 4 Drone (Fig. 1) with the following specifications indicated in Table 1. In addition to the DJI Phantom 4 Drone, printed targets or Ground Control Points (GCP) were also used (Fig. 2). The GCPs or printed targets were carefully designed so that the most exact centre of the marker could be determined with a very high degree of accuracy. Furthermore, South S86 GNSS receiver (Fig. 3) was also used to determine coordinates on GCPs to provide photo control. The GNSS receiver was also used to survey all the boundary of the land parcel. The GNSS unit has static horizontal and vertical accuracies of 3mm+0.5ppm Root Mean Square (RMS) and 5mm+0.5ppm RMS respectively. The centering position of the GNSS receiver was given an error margin of ±2 cm due to the fact that error of the exact centre is not the same as that of the UAV.

Fig. 1 DJI Phantom 4 UAV

Table 1 Specifications of Phantom 4 UAV

Model	DJI Phantom 4
Camera	Phantom VisionFC 4000
Still camera resolution	12 Mega pixels
Max image size	4000x3000
Operating range	5000
Max video resolution	4K
Smart rating	100
Focal length (mm)	3.6125
Flight time	28 min
Positioning system	On-board GPS/GLONASS

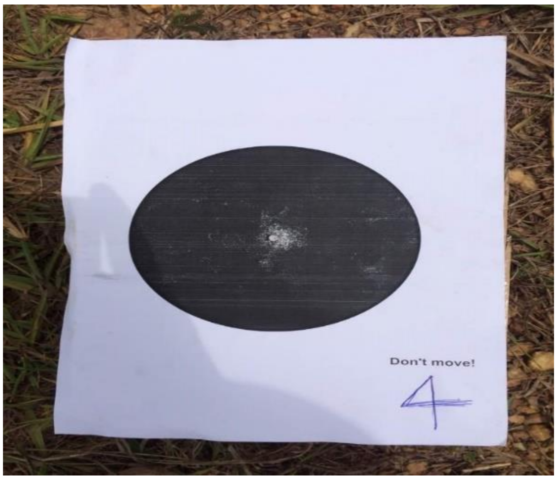

Fig. 2 Ground Control Point (Target)

Fig. 3 South S86 GNSS Receiver

2.2 Methods

The method used in this study involves fieldwork and office work: The fieldwork consists of two sections. The UAV data acquisition and GNSS surveys. Fig. 4 shows the work flow for UAV and GNSS/GNSS procedure.

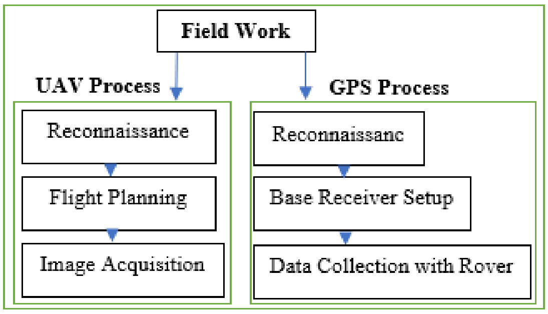

Fig. 4 UAV and GNSS Survey Fieldwork Procedure

Reconnaissance was carried out and suitable areas pre-marked immediately before flying, by placing the printed targets of appropriate shape and colour in a more or less even distribution across the mapping space or they can be naturally occurring features. Whether pre-marked or not, the printed targets were surveyed to determine their precise coordinates in a defined spatial reference (Table 2). The following inputs were required before flight; a polygon marking the outline of the area to be mapped and waypoints; flying height (altitude above ground level); camera geometry (focal length and sensor dimensions); longitudinal (forward) (%) and lateral (side) overlap (%). Flight plans can be edited either in the graphical or the tabular sections of the monitor. Using DroneDeploy software, the flight plan of the area was defined and the images were captured. The GNSS survey fieldwork also involved comprehensive planning and reconnaissance survey to primarily determine suitable existing control points in the study area. The selected control points should be accessible and visible from the skies. Furthermore, the area to be mapped must be determined. The GNSS Base receiver is set-up on a ground control point and the configuration checked. The Base receiver is also centered over the existing control points using a precise optical plummet. The height of the antenna is measured and recorded in a field book, together with the station name, the date and time, and other pertinent information. The GNSS Rover receiver is mounted to collect data of boundary points (Table 3) within specified time, applying all the necessary checks and configurations.

Table 2 Coordinates for Ground Control Points

Point ID	Eastings (m)	Northings (m)
GCP 1	609433.836	585529.464
GCP 2	609400.960	585539.047
GCP 3	609422.035	585587.920

Table 3 Coordinates of Boundary Points from GNSS Surveys and Control Stations

Point ID	Eastings (m)	Northings (m)
SGW D904/13/24	610770.394	585868.636
BP 1	609461.300	585536.442
BP 2	609414.687	585551.483
BP 3	609468.098	585570.660
BP 4	609433.443	585584.723
SGW D904/13/25	610592.417	585747.415

Office Work: The office work is done immediately after the field data acquisition. The office work for the GNSS surveys were as follows: The GNSS survey data of the boundary points were downloaded on a desktop computer and processed using appropriate software. This ensures that a back-up copy of all raw data is maintained for security reasons. All data collected and stored in the receiver relate to the World Geodetic System of 1984 (WGS84) reference ellipsoid. It is recommended that the data be processed in WGS 84 and converted to the local datum once processing is completed.

However, these transformations require some knowledge of the relationship between the two systems. The differential correction process may be conceptually divided into the following steps: specifying and preparing the base data file(s); entering the reference position of the base station; specifying and preparing the rover data file(s); differentially correcting the data, outputting the results; and transforming the results to local datum. The data collected and processed as described above are of little value to the property and land registration system unless they are presented in graphical format. This formatting represents the final step, and one of the most critical, in the proposed GNSS methodology, since it ensures that the data obtained from GNSS receiver are compatible with the traditional measurement process currently utilised for parcel mapping.

2.2.1 Drone Data Processing

The images captured were processed using Agisoft photoscan 1.2 pro software. Image Orientation was carried out. Image orientation (bundle block adjustment) consists of Interior orientation and Exterior Orientations (Jaramillo, 2000). Interior orientation (IO) involves the determination of the interior geometry of the camera (Camera is pre-calibrated) (Table 4).

Table 4 Camera Information

Camera Model	Resolution	Focal Length	Pixel Size	Pre-calibrated
Phantom VisionFC 4000	4000× 3000	3.6125	1.55 ×1.55 µm	Yes

The exterior orientation on the other hand comprises of both relative orientation (which includes Tie points extraction, matching and bundle adjustment) and absolute orientation (*i.e.* determining the position of images in the 3D ground coordinate.

2.2.2 Orthophoto Quality Assessment

The positional accuracies were determined by comparing the Northings and Eastings coordinates from the UAV and the GNSS (Table 5). Both coordinate components had errors in the same interval. The mean errors obtained were 0.053 cm and 0.041 cm (Table 5) with a standard deviation of 0.122. The spatial distribution of errors from the orthophotos showed random behavior. These results are within acceptable accuracy requirements (Barry and Coakley, 2013).

Table 5 Discrepancies of GCPs as Measured with GNSS and UAV

Points	Northings	Eastings
BP1/DP1	+0.211	+0.191
BP2/DP2	+0.007	-0.082
BP3/DP3	-0.076	-0.037
BP4/DP4	-0.089	-0.041
Total Error	**+0.053**	**+0.031**

3 Results and Discussion

3.1 Results

The coordinates processed from both UAV and GNSS Surveys were used to produce cadastral plans of the study area. Cadastral plans for both UAV and GNSS were superimposed (Figs. 7 and 8). The green lines represent the boundary for UAV and the red lines represent the boundary for the GNSS. Fig. 5 and Fig. 6 show cadastral plans from UAV and GNSS respectively. Fig. 7 shows the overlay of cadastral plans from UAV and GNSS Surveys while Fig. 8 shows the overlay of GNSS and UAV Cadastral Plans on the orthophoto of the study area.

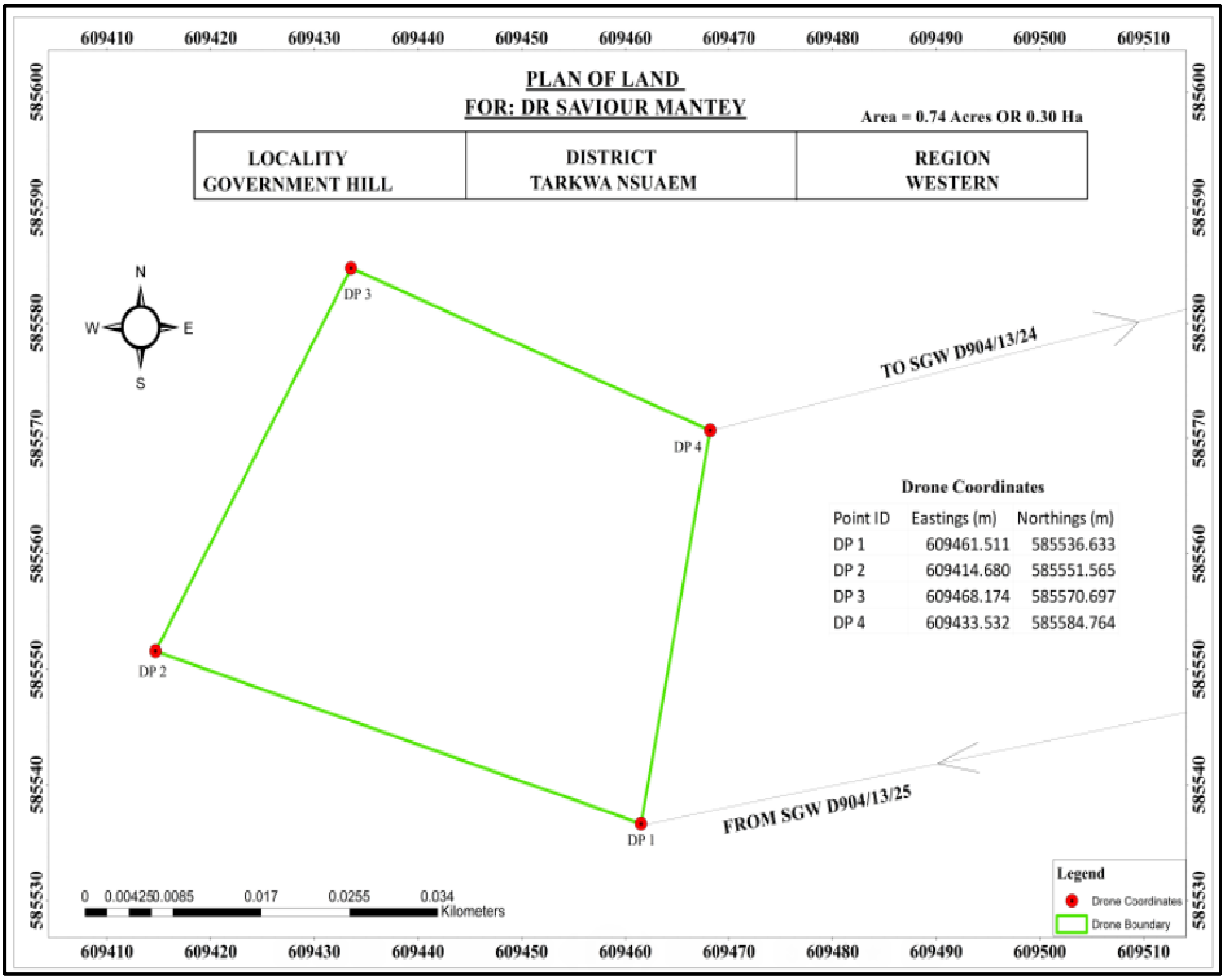

Fig. 5 Cadastral Plan from UAV Surveys

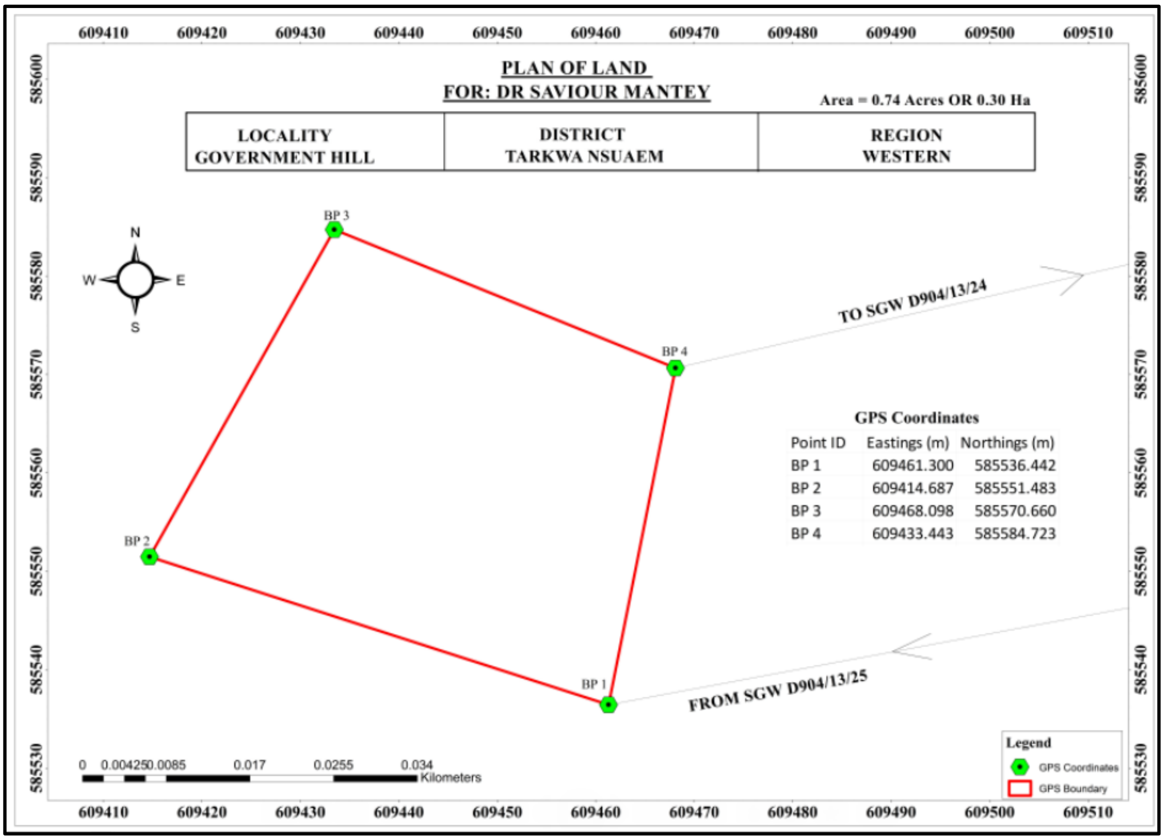

Fig. 6 Cadastral Plan from GNSS Surveys

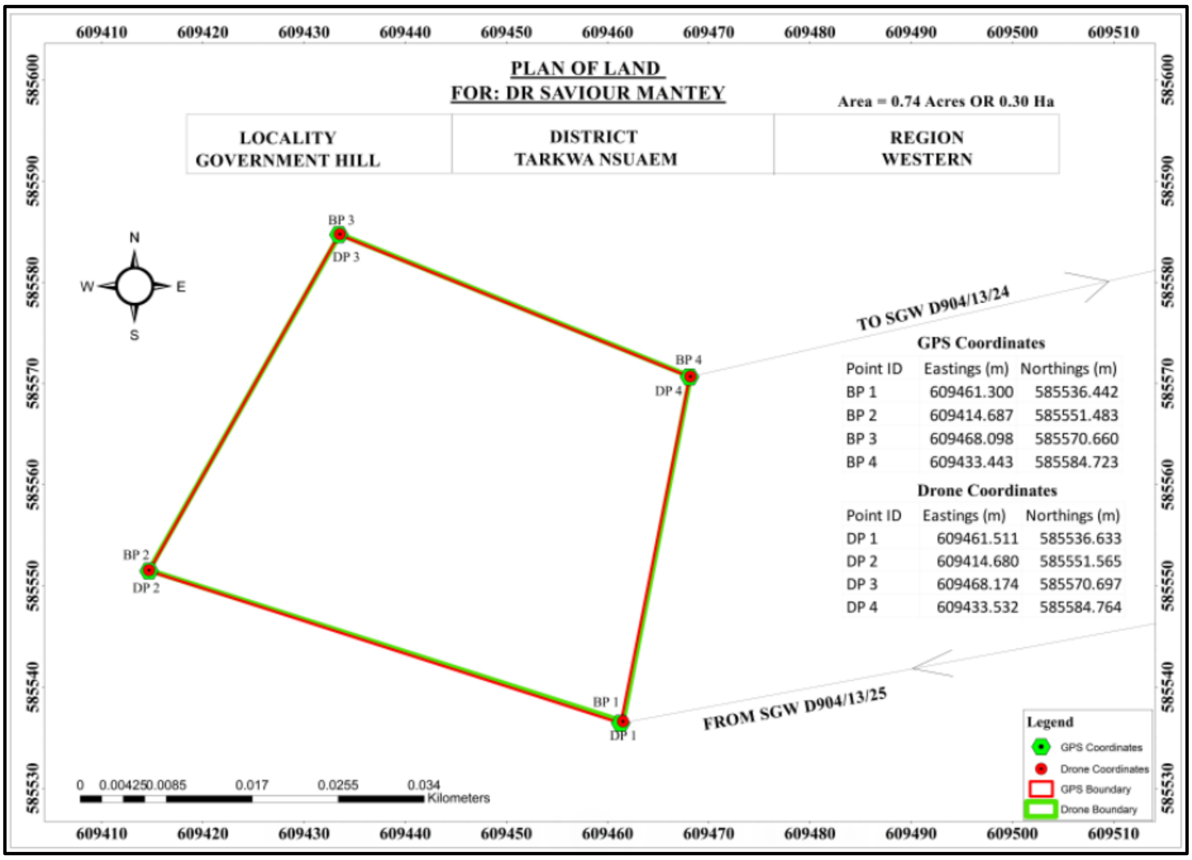

Fig. 7 Overlay of Cadastral Plan from UAV and GNSS Surveys

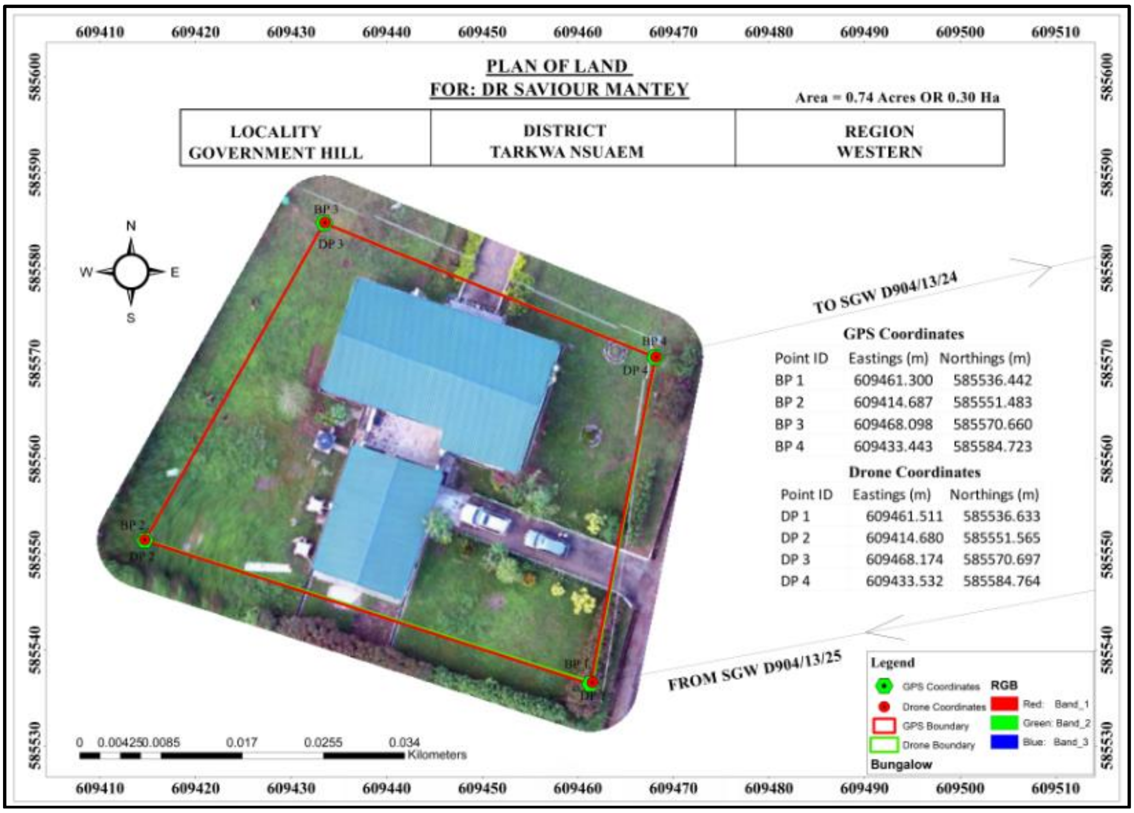

Fig. 8 Overlay of GNSS and UAV Cadastral Plans on Orthophoto of Study Area

3.2 Discussion

The cadastral plans produced for the UAV is assessed based on the differences between the coordinates for the boundaries and also the discrepancies of the GCP as measured in the photogrammetric software for the assessment of the quality of the orthophoto and also the deviation of the plan of the UAV from the cadastral plan produced from the GNSS. The cadastral surveying system gives preference to the survey records of parcel boundary positions over physical locations of landmarks on the ground. Cadastral plans provide information with the coordinates of the landmarks and site plans within a particular national geodetic coordinate reference system in a country. In case of lost or disputed boundary of a land parcel, it is this record or register that takes the precedence over marks on the ground.

4 Conclusions and Recommendations

4.1 Conclusions

Both UAV and GNSS Surveys were confirmed to be comparable in terms of accuracy and completeness. The difference in Northings and Eastings from UAV and GNSS surveys which were +0.380 cm and +0.351 cm respectively were well within the tolerance of +/- 0.9114 m set by the Survey and Mapping Division (SMD) of the Lands Commission for cadastral plans production. This research therefore concludes that high resolution images from UAVs are suitable for cadastral surveying. The preference of UAV systems is the capability to quickly observe large areas at low flying altitude while still conforming to accuracy requirements of cadastral surveying. In areas where accessibility is difficult, UAVs offer a valuable alternative to GNSS Surveys.

4.2 Recommendations

For large areas where it is expensive and time consuming to apply Total Station or GNSS survey techniques, the UAV could be deployed to achieve the same results. Also, when safety of surveyors is at risk the use of UAV is suitable.

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