UAV Technology Versus PNG's Conventional Surveying Methods in Cadastral Survey Applications

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Abstract

Surveyors in Papua New Guinea (PNG) are challenged by the country's difficult terrain which forces them to look for innovative ideas and emerging high-in-the-sky technologies that could reduce the field exposure time while upholding the accuracy specified for such surveys. One of those emerging survey technologies that a handful of surveyors are using in PNG is the Unmanned Aerial Vehicle (UAV), commonly known as Drone. This study was specifically carried out with its objectives set to assess the accuracy and efficiency of UAV against total station (TS) and Global Positioning System (GPS) or Global Navigation Satellite System (GNSS) to find out if UAV can meet the cadastral survey specifications set as standards for such surveys in PNG grounds. Based on the results obtained from the research, it was concluded that UAVs, with proper high-definition (HD) cameras/sensors, and enough lighting at a reasonably lower height with associated lower ground sampling distance (GSD) and proper coordination of ground control points (GCPs) can deliver accurate cadastral survey data to sub-centimeter or even to millimeter level. UAV not only meet the country's cadastral survey requirements but is also an efficient equipment that reduces field exposure or data collection time to a fraction of an hour, reduces field surveyors down to 1 or 2, and thus, reduces redundant costs and labor associated with TS and GNSS receiver which are PNG's conventional survey methods.

Keywords: *Accuracy, Cadastral, Efficiency, GNSS, Total Station, UAV*

1. Introduction

Papua New Guinea's development is dragged by many factors and one of the reasons can be its rough and dangerous terrains which are difficult to explore. This imposes surveyors a great challenge to define the wild terrain using the conventional survey methods used in the country which requires surveyors to be physically on the field/ground for data collection. Although the use of total stations and GPS or GNSS receivers is widely accepted in PNG for cadastral surveys, they are sometimes unfavorable in some conditions. When surveying crowded urban areas, total stations would require point-to-point visibility and GNSS receivers would require enough satellite reception which is not that easy to meet resulting in time loss, increased cost, and intense labor (Mantey & Tagoe, 2019). These surveying techniques and instruments that require surveyors to be physically on-field for data acquisition expose the surveyors to hazardous areas like difficult terrain, dense vegetation, and inaccessible areas and sometimes lead to disagreements and 'violent landowner actions' due to misunderstanding. Thus, the safety of the surveyor is at risk most times.

Apart from the low-cost DRONES that are used for photo/video shots for fun and leisure, survey-grade UAVs for photogrammetric surveys are currently not common in the country and are mostly used in the mines for stockpiles, dumps, heave, mud, etc. scans, and mine as-built survey (Gerea, 2020). Some UAVs are in Forestry (PNG Forest Authority, 2019), Agriculture sectors, and other aerial photogrammetric applications. Few people are using UAV to carry out aerial/photogrammetric surveys for engineering applications like road detail surveys to create DTM/DSM, Aerial photogrammetry for photomosaic maps, and for cartographic and GIS applications in the country.

2. Location of the study area

The study area is located at East Taraka and PNGUoT campus, Lae Urban District, about 6 Kilometers north of Lae City (Top Town), Morobe Province in Papua New Guinea. The study area is approximately enclosed within the latitude of 06° 39' 25" S and 06° 40' 54" S and the longitude of 146° 59' 18" E and 147° 00' 19" E (Extracted from Google Earth 2022 – on WGS 84).

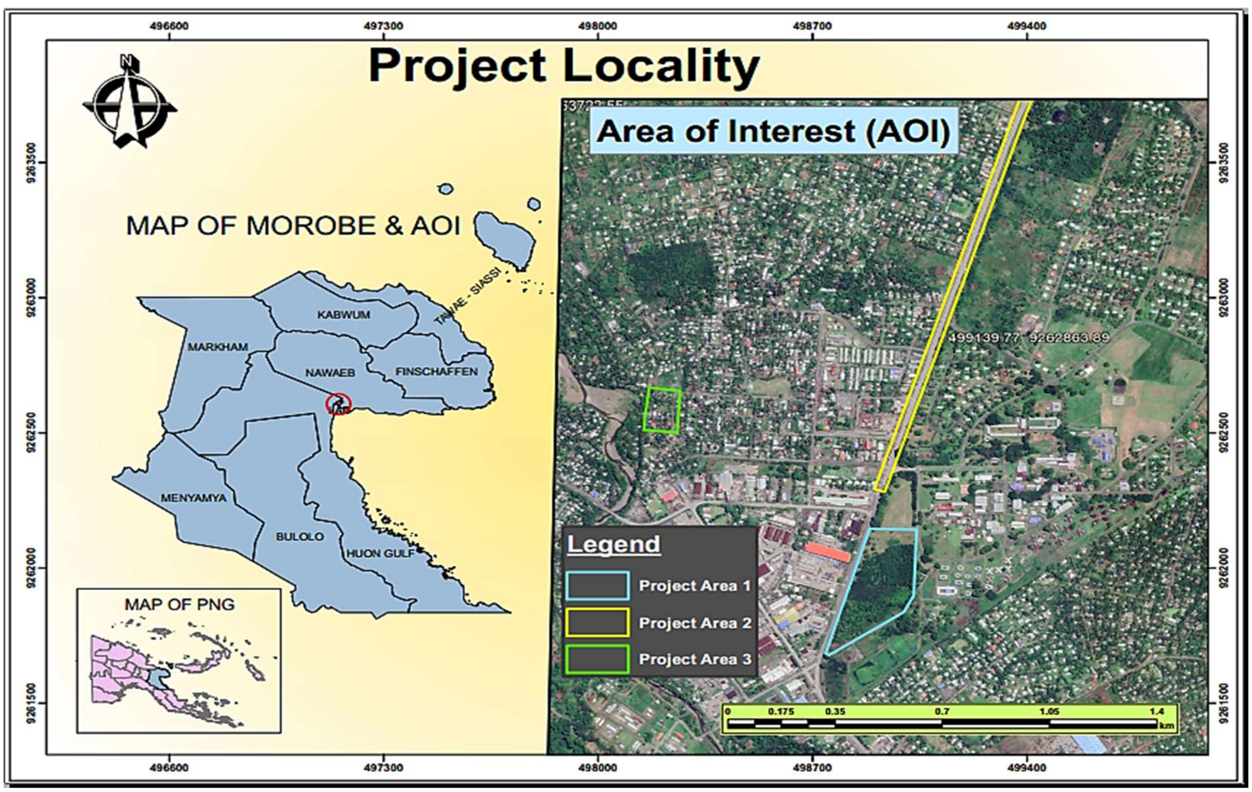

Fig. 1 Locality map of the study area

Three different sites were selected to carry out the data collection for comparison and analysis for research purposes. One, along the western boundary of the university and Independence Road (yellow polygon), the second one within and at the bottom edge of the university boundary (cyan polygon), and the last one in the densely populated/town area, East Taraka settlement, as enclosed in green in figure 3.2 below. Those three different sites were surveyed using three different survey equipment, total station, GNSS receiver, and UAV. Each site was selected to carry out a different type of cadastral survey. This means three different types of cadastral surveys were carried out using three different survey equipment at three different locations respectively.

3. Materials and Methodology

The research project consists of three phases, performing three different cadastral survey types using three different survey equipment, UAV, GNSS, and Total Station. All practices in data collection were done by the country's survey Direction (SD 1990) and this includes the standard practices from datum adoption and positional accuracy to equipment setup, to field observation methods, and all the accuracies and precisions required for such surveys were all given sufficient attention. Three different sites were selected for the study as shown in the map/AOI shown below (Figure 2). All sites were surveyed with TS, GNSS, and UAV respectively.

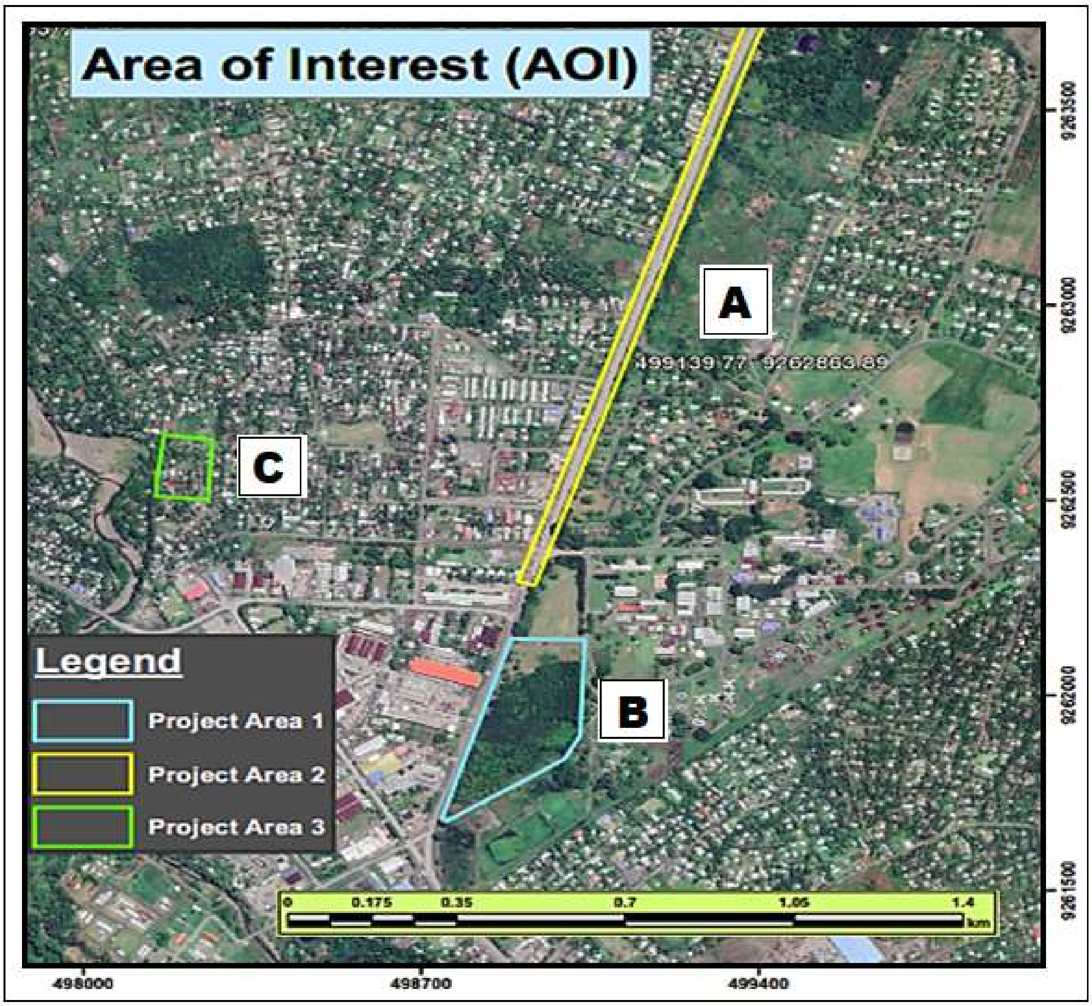

Fig. 2 Areas of Interest at Lae PNGUoT Taraka campus and east Taraka settlement, (A) for an identification (ID) survey to check for encroachment of UoT campus boundary and road Easement, (B) for a boundary survey for customary land registration and (C) for Identification (ID) Survey and topo survey of dense urban areas that could impose some sort of challenge.

3.1. Phase 1 – Plane Survey with Total Station (Sokkia Set 5x)

For the ID survey for encroachment, a total of five control stations were placed along the road, three old cement pegs (OCPs) were found through identification, and a detailed topography survey was done for the 1.4km road length and the infrastructures built thereon the 30m road easement. For the boundary survey for customary land registration, a total of eight (8) boundary cement pegs were placed around the property boundary and were coordinated by adapting data from two PSMs (PSM 3374 & PSM 13040). Finally, for the ID and topo survey of the densely populated area, a total of 5 OCPs were found and a detail/topo survey was carried out for the 2.3ha area.

3.2.Phase 2 – GNSS observations (Topcon HiPer RS/VR)

The datum stations used for the survey using total stations (PSM 3374 & PSM 13040) were also occupied as base stations for the GNSS Survey. The control stations and cement pegs, which were pre-coordinated by the total station from the first phase, were then observed using a GNSS receiver for a minimum of 30 minutes for static point positioning. A few of the baselines were not fixed and thus, were observed again for about 2 to 3 hours for enough satellite reception and corrections and then post-processed in magnet tool software. All data were processed and coordinates were prepared on AGD66 (in line with existing data) and the elevations were derived using the PNG08 geoid model. After all coordinates were prepared and reduced to plane coordinates (from reduced terrain distance and grid bearing), a GNSS RTK topo/detail survey was carried out. The points picked up by RTK GNSS were also reduced to the plane surface using Magnet Office software.

3.3.Phase 3 – UAV Photogrammetric Survey (DJI Phantom 4 RTK)

Deploying the UAV for the photogrammetric survey was the third and final phase. The UAV survey in cadastral applications was the major target for the project and was given careful attention in flight mission planning, the establishment of the Ground Control Points (GCPs), the deploying of the UAV, and the post-processing of the UAV images captured. The flights for all sites were pre-planned and the UAV was deployed autonomously from take-off to landing. All images were captured with an overlap of 80% which was a bit higher than the recommended overlap for higher accuracy which is ≥70% (Kateryna, 2016). The flight speed was maintained at 9m/s, which was the default speed. All flights made were at a height ranging from 60-80m with associated Ground Sampling Distance (GSD) of 1.5 to 2.5cm/px.

The same control points that were established and coordinated earlier using Total station and GNSS static observation respectively were used as GCPs. In addition to the GCPs and for check purposes, several control stations and coordinated cement pegs were also captured as checkpoints and were not used in geotagging during post-processing. Throughout the survey using each of the equipment for each of the sites, the number of human resources, the total field survey, and office processing time were also recorded and noted during the data collection and processing period.

4. Results and Discussions

Every survey procedure carried out in this research abided by the standard practices outlined in the survey direction (1990) from Datum Positional accuracy check and adoptions, to control station network establishment and the associated accuracies, office calculations, reductions and transformations and all other necessary tasks engaged. The results and discussions here are based on real-time numerical values that were observed from the field data collection. The main focus of the study was to assess the accuracy and efficiency of UAV against total station and GNSS Receivers in numerical terms thus are discussed in this section.

4.1 Conventional Equipment Analysis – Total Station vs GNSS Receiver

For the total station, the main control stations were established with an overall linear misclose of 13mm resulting in a linear accuracy of 1: 170 000. The GNSS coordinates (E&N), were observed with Topcon Hiper SR and were fixed with a mean positional uncertainty of 7mm and 9mm respectively (for all vector lines). Least square adjustment was made and loop closure for all vectors was computed with a mean residual of 25mm in eastings, 28mm in northings, and 46mm in elevation. Stations with unprocessed, unfixed, or vectors with higher residuals were reoccupied and observed for one to three hours for a fixed position with favorable accuracies. Thus, the difference in bearings and distances measured from the total station and GNSS receivers were about 5mm to 23mm on average and as low as 1 to 2mm for a few lines. For the bearing, GNSS deviated from that of the total station by 11 to 50 seconds (0° 00’ 11”/ 0°00’ 50”) on average. As can be seen from Table 1 below, the deviation of GNSS data when compared against the existing/old Cadasta is within 11-15mm in distance which also portrays how accurate and useful GNSS receivers can be for cadastral surveys in PNG. For the difference in distance and bearing between the boundary cement pegs from the boundary survey for land title, some differences are very low but one or two are a bit higher by a few centimeters because boundary pegs were placed where they were supposed to be. Thus, few were under the canopy and thus the accuracy dropped by a few centimeters which can be considered a setback for the use of GNSS for cadastral boundary placement and observations. The accuracy in distance measurement using GNSS RTK was surprisingly high because the RTK pickup data were brought to the plane surface through a transformation in the Magnet Office software.

4.2 UAV Internal Accuracy Analysis (DJI Phantom 4 RTK)

To assess how accurate a UAV, with its internal accuracy, can measure features/objects, a water pump block pre-surveyed by total station and a GCP board with known dimensions of 60cm x 60cm that were captured during the flight at 80m and 60m respectively and were measured on the orthomosaic in Autodesk Civil 3D. UAV can measure unobstructed objects down to a level of about 6mm (0.006m) error compared to the true value at a height of 60m and about 10 to 30mm (0.01-0.03m) error at a height of 80m. It was observed that the lower the flight height and the lower the GSD, the higher the accuracy in Object/Feature measurement and vice versa for survey-grade UAVs (Figure 3).

4.3 UAV Vector Measuring Accuracy

The UAV survey data (images) were processed in Agisoft Metashape and georeferenced using five ground control points (GCPs) in post-processing for every survey carried out while the other stations/cement pegs were used as checkpoints for data validation purposes. To extract the vectors between the points for the UAV surveyed points, the orthomosaic in TIFF format from Agisoft Metashape was imported to Autodesk Civil 3D, and lines were drawn from the centers of visible GCP points after being zoomed out to about millimeter levels. The vector measurements between visible points (GCPs & Check Points) for the UAV survey were then compared against the values from vector measurements/observations of the same lines by total station and GNSS receiver as presented in Table 1 below.

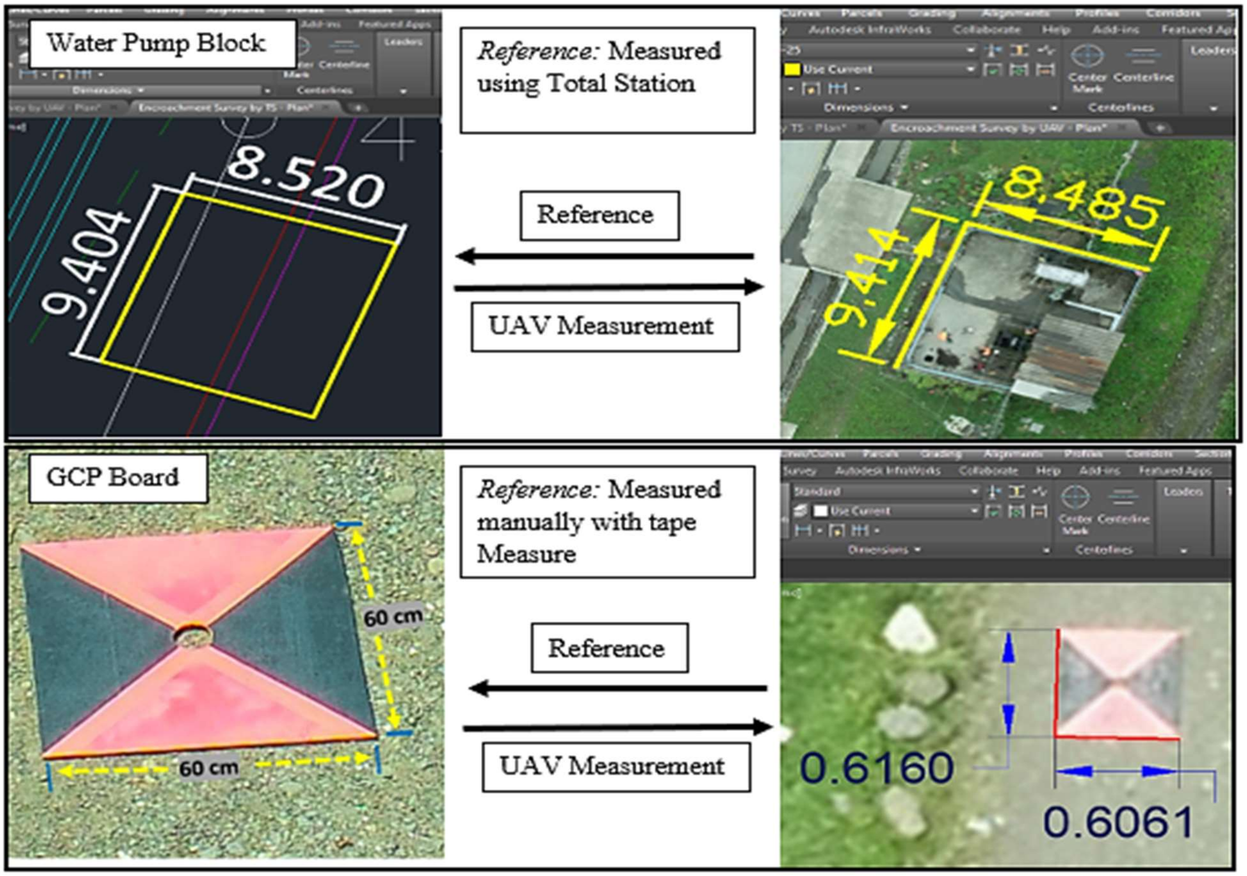

Fig. 3 UAV Object/Feature Measurement Accuracy

From the vectors' accuracy analysis and the results presented in Table 1 below, at an average (13 vectors/lines), UAV measured distances deviated from that of the total station by **21mm** (0.021m) and **33 seconds** (0°00'33") in bearings. When measured against that of the GNSS receiver, at an average (13 vectors/lines), UAV measured distances deviated from that of GNSS by **25mm** (0.025m) and **44 seconds** (0°00'44") in bearings. The distance measurement error, when compared against pre-surveyed lines with total station and GNSS, can drop as low as 2mm to 3mm with proper GCP coordination and georeferencing when post-processing aerial data. The average deviation of 21mm and 25mm in distance and 33seconds and 44seconds in bearing is within the country's tolerance of 30mm (0.03m) linear error and 1minute 30secods (0°01'30") in bearing set as standard for Urban class one surveys as specified in the Survey Direction 1990.

Table 1. Difference in Vector Between UAV against Total Station and GNSS Observations

1. Boundary Survey for Encroachment - Control Stations								
	UAV vs Total Station				*UAV vs GNSS Receiver*			
Line	*Δ Dist (m)*	*Δ Bearing*			*Δ Dist (m)*	*Δ Bearing*		
CS 44 - CS 1	*0.007*	0°	0'	10"	*0.002*	0°	0'	23"
CS 1 - CS 2	*0.002*	0°	0'	01"	*0.005*	0°	0'	03"
CS 2 - CS 3	*0.066*	0°	0'	23"	*0.067*	0°	0'	28"
CS 3 - CS 4	*0.052*	0°	0'	22"	*0.050*	0°	0'	19"

CS 4 - CS 5	*0.029*	0°	0'	06"	*0.036*	0°	0'	08"
2. Boundary Survey for Land Title – Boundary Cement Pegs								
Line	*UAV vs Total Station*				*UAV vs GNSS Receiver*			
	Δ Dist (m)	*Δ Bearing*			*Δ Dist (m)*	*Δ Bearing*		
CP01-CP02	*0.011*	0°	01'	26"	*0.012*	0°	01'	54"
CP02-CP03	*0.02*	0°	01'	03"	*0.041*	0°	01'	42"
CP03-CP04	*0.036*	0°	0'	10"	*0.066*	0°	0'	54"
CP04-CP04	*0.036*	0°	0'	30"	*0.013*	0°	0'	57"
CP05-CP06	*0.021*	0°	0'	10"	*0.004*	0°	0'	46"
CP06-CP07	*0.003*	0°	2'	28"	*0.029*	0°	01'	59"
CP07-CP08	*0.005*	0°	0'	03"	*0.001*	0°	0'	18"
CP08-CP01	*0.001*	0°	01'	34"	*0.026*	0°	01'	44"
3. Topo Survey of Densely Populated area – Old Cement Pegs' (OCP)								
Line	*UAV vs Total Station*				*UAV vs GNSS Receiver*			
	Δ Dist (m)	*Δ Bearing*			*Δ Dist (m)*	*Δ Bearing*		
OCP1-OCP2	*0.006*	0°	24'	53"	*-0.009*	0°	10'	25"
OCP2-OCP3	*0.006*	0°	10'	54"	*-0.008*	0°	01'	15"
OCP3-OCP1	*0.034*	0°	14'	20"	*0.023*	0°	17'	07"

4.4 UAV Relative Position/Point Measuring Accuracy

The main interest of the research was to find the accuracy of point positioning by UAV and thus, the checkpoints were the ones assessed for overall positional accuracy. Ground control points are what geo-references/geotag the images captured on the default GPS module of the UAV and adjust, correct, and transform the point's positions on the image. Thus, improves the accuracy of the data captured. However, checkpoints do not affect the images but are captured to validate the accuracy of the survey data. Checkpoints are just like any point on the map and how they relate to the pre-measured/true values portrays the accuracy of the UAV survey. Thus, to check for the positional accuracy of this research, only check points' coordinates were compared against that of TS and GNSS. To extract the coordinates of the checkpoints for the UAV survey, again the ortho-mosaic in TIFF format from Agisoft Metashape was imported into Autodesk Civil 3D, and point marks were drawn from the centers of visible checkpoints after being zoomed to about a millimeter level and as tabulated as follows.

Table 2. Positions/coordinates of Check Points – Total Station (TS), GNSS receiver, and UAV

1. Boundary Survey for Encroachment - Control Station as Checkpoint									
ChkPt	***Coordinates from TS***			***Coordinates from GNSS***			***Coordinates from UAV***		
	E	**N**	**RL**	**E**	**N**	**RL**	**E**	**N**	**RL**
CS 3	498980.720	9262733.703	59.432	498980.717	9262733.697	59.283	498980.702	9262733.784	59.256
2. Boundary Survey for Land Title – Boundary Cement Pegs as Checkpoint									
ChkPt	***Coordinates from TS***			***Coordinates from GNSS***			***Coordinates from UAV***		
	E	**N**	**RL**	**E**	**N**	**RL**	**E**	**N**	**RL**

CP02	498916.837	9261938.623	NA	498916.818	9261938.609	53.855	498916.8494	9261938.63	53.6521
CP03	498924.710	9261904.429	NA	498924.705	9261904.439	53.649	498924.729	9261904.417	53.398
CP04	498921.540	9261760.591	NA	498921.504	9261760.572	52.631	498921.567	9261760.618	52.427
CP06	498674.278	9261542.278	NA	498674.154	9261542.264	50.258	498674.28	9261542.267	50.048
3. Topo Survey of Densely Populated area – Old Cement Pegs' (OCP) from Cadasta as Check Point									
ChkPt	***Coordinates from TS/from CADASTA***			***Coordinates from GNSS***			***Coordinates from UAV***		
	E	**N**	**RL**	**E**	**N**	**RL**	**E**	**N**	**RL**
OCP1	498103.651	9262415.846	53.723	498103.616	9262415.819	45.354	498103.592	9262415.814	53.734
OCP2	498108.329	9262410.505	53.597	498108.316	9262410.523	45.321	498108.252	9262410.515	53.686
OCP3	498109.454	9262430.474	53.662	498109.513	9262430.501	45.411	498109.441	9262430.485	53.719

The following table presents the differences in position/coordinates of the UAV surveyed point were, compared to the coordinates of the total station and GNSS receivers.

Table 3. Positional deviations of UAV points compared to the total station and GNSS receiver

1. Boundary Survey for Encroachment - Control Station as Checkpoint						
ChkPt	***UAV against TS***			***UAV against GNSS***		
	Δ E	**Δ N**	**Δ RL**	**Δ E**	**Δ N**	**Δ RL**
CS 3	0.018	0.081	0.176	0.015	0.087	0.027
2. Boundary Survey for Land Title – Boundary Cement Pegs as Checkpoint						
ChkPt	***UAV against TS***			***UAV against GNSS***		
	Δ E	**Δ N**	**Δ RL**	**Δ E**	**Δ N**	**Δ RL**
CP02	0.012	0.007	NA	0.031	0.021	0.253
CP03	0.019	0.012	NA	0.024	0.022	0.251
CP04	0.027	0.027	NA	0.063	0.046	0.204
CP06	0.002	0.011	NA	0.126	0.003	0.210
3. Topo Survey of Densely Populated area – Old Cement Pegs' (OCP) as Checkpoint						
ChkPt	***UAV against TS***			***UAV against GNSS***		
	ΔE	**ΔN**	**ΔRL**	**Δ E**	**Δ N**	**Δ RL**
OCP1	0.059	0.032	0.011	0.024	0.005	NA
OCP2	0.077	0.010	0.089	0.064	0.008	NA
OCP3	0.013	0.011	0.057	0.072	0.016	NA

According to Table 3, when the positions of the checkpoints were extracted as coordinates and checked against the coordinates pre-surveyed using total station and GNSS receivers, it was realized that the position of a UAV point can differ from that of a total station observed position by an average of 28mm (0.028m) in easting, 24mm (0.024m) in northings and about 8.3cm in elevation. UAV coordinates differ from that of GNSS established points at an average of 52mm (0.052m) in eastings, 26mm (0.026m) in northings, and 0.189m in elevation. From those results, it can be seen that UAV positions deviated from that of total station by fewer values (better) than that of GNSS receiver and this is because Total Station coordinates were used to provide positions for the GCPs and were used in geotagging the UAV aerial data when post-processing. It can be observed that the difference in UAV point positioning against the total station and GNSS receiver can drop as low as 2mm to 5mm if appropriate measures are taken in carrying out the UAV survey.

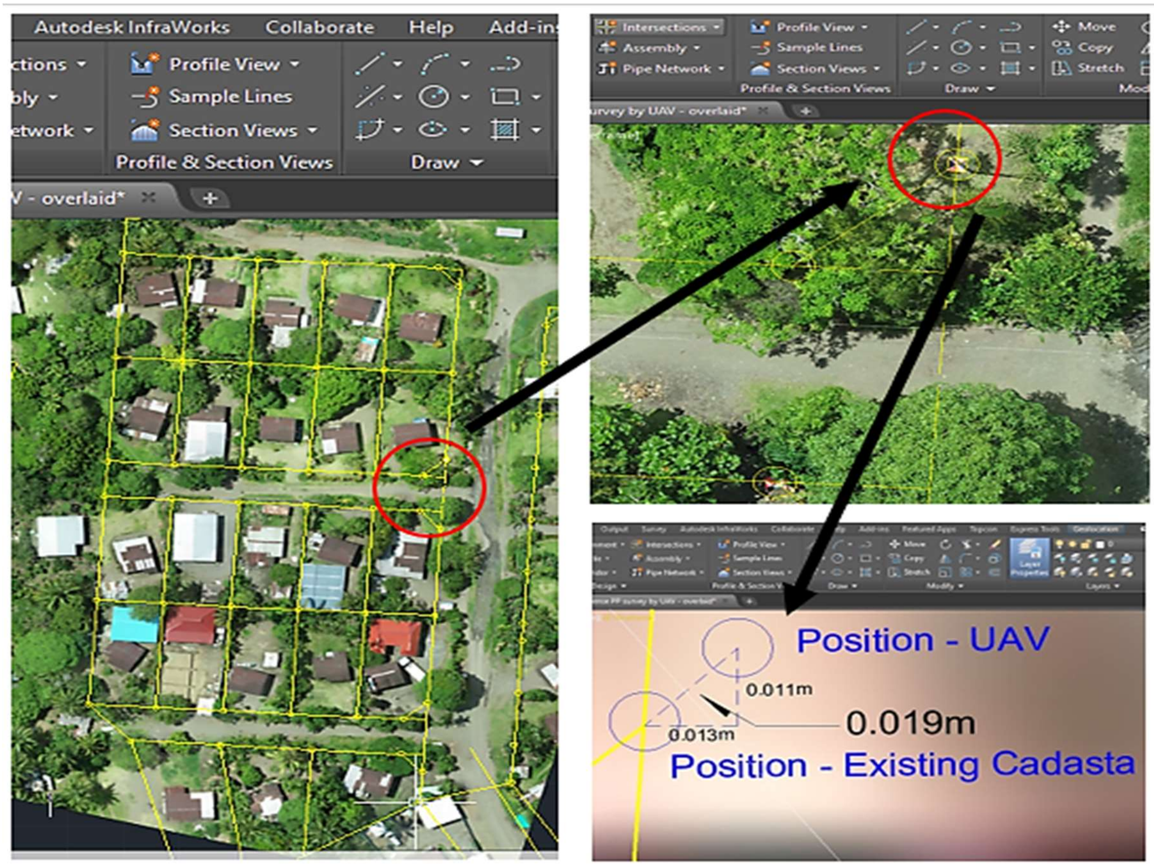

Fig. 4 Superimposing Orthomosaic from UAV onto Existing cadastral plan – UAV Positional accuracy measurement.

When compared against existing Cadasta by superimposition or overlaying cadasta with the Orthomosaic as illustrated in Figure 4 above, Easting and Northings positioned by UAV can deviate from the true value by as low as 13mm and 11mm respectively.
It is outlined in the country's survey direction that, for an urban class 2 and 3 survey, "the position of any internal boundary is to be determined to a precision of ±0.5m by any method used (Survey Direction 1990)." If this is the tolerance for such cadastral surveys, UAV is way accurate in determining the positions as all deviations are way below that specified tolerance.

4.5 UAV efficiency analysis against Total Station and GNSS Receiver

Accuracy measurement alone cannot promote the use of equipment. How effective the equipment is, how fast it can carry out tasks saving time and cost, and how much labor or human resource is involved in getting the work done, also needs to be considered for any survey equipment introduced/available. Thus, for this research, for equipment efficiency assessment purposes, the human resources needed, the total field data collection time, and the office data processing time were monitored for each survey equipment used for the research. The results, as portrayed by the following graphs from those two assessments, gave a clear indication of how effective equipment can be or how laborious and time-consuming survey equipment can be.

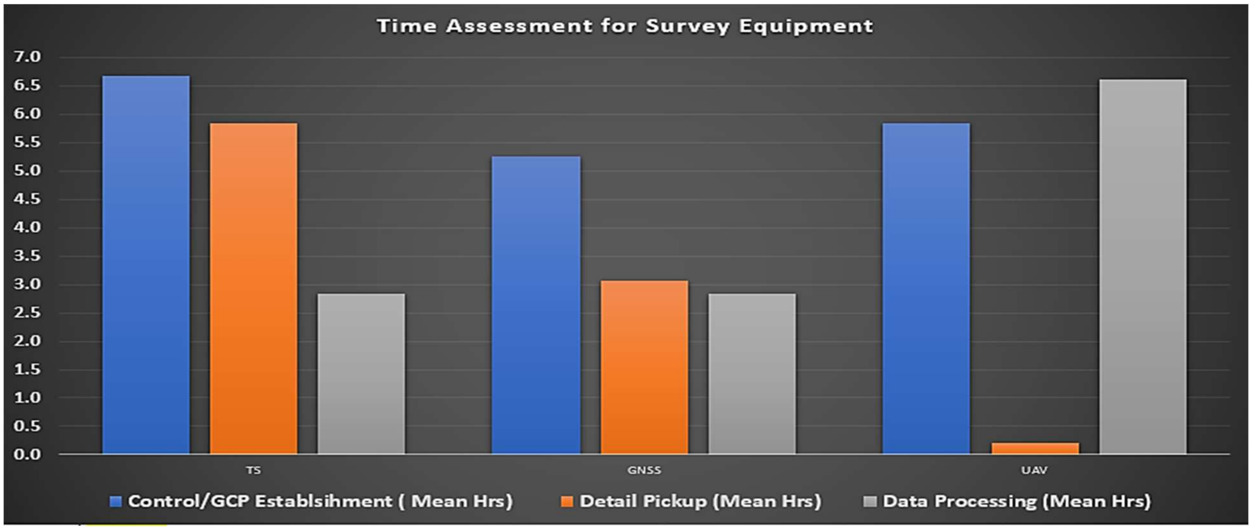

Fig. 5 The mean hours for data collection using each survey equipment

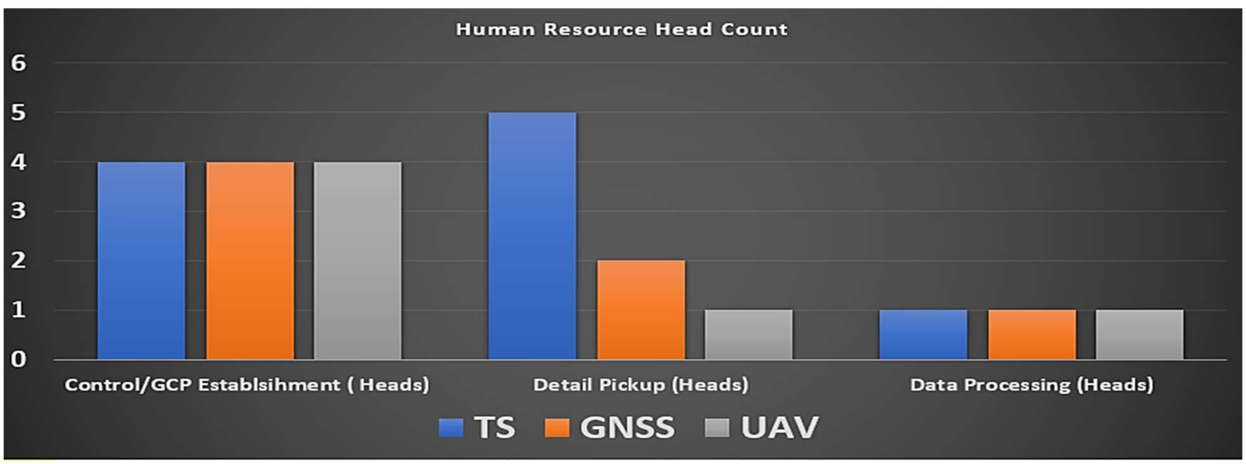

Fig. 6 The total number of Human resources involved in the data collection

From Figure 5, it can be seen that for the total station, the field exposure time for control establishment and detail survey was way more than the office/processing time while for the GNSS receiver, the field exposure time was less than that of the total station. The detail pickup part of the data collection using GNSS (RTK) reduces the time for the total station by almost 50% while the processing time is almost the same. For the UAV, the field exposure time for GCP establishment is almost the same as that of Total station and GNSS but when it comes to the detail pickup part of the survey, UAV takes only about 3.5% (reducing 96.5%) field exposure time taken for total station and about 6.5% (reducing 93.5%) field exposure time of GNSS RTK pickups. However, the processing time is way higher, almost 440% or 4.4 times more compared to that of the total station and GNSS receiver.

From Figure 6, it can be seen that for total station, GNSS, and UAV, it would require almost equal amount of people for the control/GCP establishment but for detail pickup, total station is more laborious compared to GNSS and UAV which would require 2 and 1 human resource respectively.

For UAVs with RTK that do not require GCPs, the time and human resources needed for GCP establishment as displayed would go down to zero, making UAV way more efficient in data collection in a fraction of the time compared to total station and GNSS receivers. UAV would require only one person to carry out a whole survey project.

5. Conclusion and Recommendations

It can be concluded that UAVs, with proper HD cameras/sensors, and enough lighting, at a reasonably lower height of 60m to 80m with GSD ranging from 1.6cm/px to 2.2cm/px, proper coordination of GCPs taking into consideration the appropriate reductions and transformations either from total stations or GNSS receivers, can deliver accurate cadastral survey data to sub-centimeter or even to millimeter level. Thus, yes, UAV can meet the cadastral survey specifications outlined in the country's survey Direction 1990 in terms of its accuracy and it can be used for cadastral surveys in the country. UAV does not only meet the country's cadastral survey requirements but is concluded to be the most efficient equipment in the market reducing field exposure and data collection time to a fraction of an hour and reducing field surveyors down to 1 to 2 surveyors and thus reducing redundant costs and labor associated with a total station and GNSS receiver which are PNG's conventional survey tools.

Long-introduced and widely used equipment in the surveying profession like Global Navigation Satellite Systems (GNSS) receivers or its combination with total station is not even legally recognized in PNG's legal documents about the profession due to the legal documents not being reviewed and updated. Emerging technologies in the country like UAVs are slowly becoming favorable to many surveyors in the country but the existing Survey Direction and Survey Co-ordinations do not recognize the use of such emerging technologies which are unmanned and 'High in the sky technology' in the different categories of cadastral Surveys; Urban and Rural. Emerging technologies like Unmanned Aerial Vehicle (UAV) that diminishes the exposure of cadastral surveyors to hazardous areas through distant data acquisition, fast and efficient, produce additional mapping data such as high-resolution orthoimages, coordinated point clouds, three-dimensional (3D) models of structures, elevation models, DSM/DTM etc. needs to be accepted and legally recognized by the country and be used for its cadastral surveys for the overall good of the Surveying Profession. The conventional method of cadastral surveying and mapping where just line maps are used to define the spatial dimensions of land tenure has been used for centuries with very little to no change. This kind of spatial data presentation strips away the contextual background with the picture of the topographical features and the terrain details which cannot be easily interpreted or perceived by non-technical people or clients (Barnes et al., 2014). Relying on cadastral maps which describe property boundaries by just lines is inadequate. It would be ideal for Cadastral maps with digital formats, presenting a georeferenced photogrammetric aerial perspective that is easily perceived and understood by the landholders without any mapping skills. Surveyors are exposed to a huge number of difficulties from the difficult terrain of PNG and also from the underdeveloped minds of native land owners which would result in a lot of energy, time, and money loss, being injured or properties and survey equipment being damaged by natural or human frustrations. If there's one thing surveyors look for in survey equipment for cadastral applications, it would be Accuracy and Efficiency and UAV could be the answer.

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