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Developing a Workflow for the Use of Unmanned Aerial Vehicles for Cadastral Mapping in Ghana

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Abstract
This paper proposes a generic workflow for using Unmanned Aerial Vehicles (UAV) to produce acceptable cadastral plans in Ghana. This was done by firstly verifying in the field UAV restricted zones specified by the Ghana Civil Aviation Authority (GCAA) and subsequently analyzing ground and aerial survey data from two sites within the Tema Municipality. The data analyzed consisted of one set of boundary coordinate data of the sites obtained from a static Global Navigation Satellite System (GNSS) survey and another set from on-screen digitization of site boundaries from aerials obtained from a Mavic Air UAV weighing 430 g with a camera resolution of 12 megapixels flying at altitudes of 40 and 60 m. A comparison of the two sets of boundary coordinates data showed differences under the limit of +/-3 ft specified by the Survey and Mapping Division (SMD) of the Lands Commission of Ghana. The paper thus outlines a generic workflow as follows: (1) Determining if selected site is within a flight restricted zone (2) Undertaking field reconnaissance to determine appropriate flight parameters and ground control point locations (3) Processing UAV imagery to obtain orthomosaics (4) Performing on-screen digitizing of site boundaries from orthomosaics and (5) Obtaining accurate boundary turning point coordinates from digitized boundary. The paper concludes that this approach if accepted may be used in obtaining multiple cadastral plans within built up areas from a single UAV flight and recommends that UAV and ground control data be submitted in Geotiff and Rinex formats respectively to facilitate checks by the Examinations Unit of the SMD.
Keywords: unmanned aerial vehicles, cadastral plans, ground control points, global navigation satellite system, orthomosaic
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1. Introduction

The Survey Act of 1962 of Ghana , Act 127 defines cadastral plans as plans purporting to show boundaries of land with accuracy and giving exact measurements by which the boundaries may be demarcated on the ground such maps or plans being made in conformity with the result of a survey carried out by an Official Surveyor or Licensed Surveyor to be certified by him and requiring whether made by an official surveyor or by a licensed surveyor to be approved by the Chief Survey Officer or any person appointed for that purpose (Fosu and Derby 2008).

Currently the predominant technique used for cadastral surveys in Ghana is either by static Global Navigation Satellite Systems (GNSS) or Total Station methods or a combination of both. Plans submitted for approval by the Survey and Mapping Division must include GNSS Rinex files showing processed baselines data from the surveyed parcel to two (2) government approved beacons. However, Mantey and Tagoe, (2019) have demonstrated that unmanned aerial vehicle (UAV) technology and data may be suitable for performing cadastral work in Ghana. Similarly, in other jurisdictions UAV technology and data has been found to be suitable for achieving desired positional accuracy for cadastral work in Manyoky *et al.* (2011) in Switzerland,

Zrinjski *et al.* (2019) in the Republic of Croatia, Yuwono *et al.* (2018) and Ramadhani (2016) in Indonesia, Mumbone (2015) in Namibia and Volkman and Barnes (2014) in Albania.

The main aim of this paper therefore is to propose a generic workflow that can be used for cadastral surveys using unmanned aerial vehicles while maintaining the accuracy requirements stipulated by the Survey and Mapping Division (SMD) of the Lands Commission of Ghana. Two residential plots within the Tema Municipal Assembly in the Greater Accra Region of Ghana subsequently referred to as sites 1 and site 2 in the text were chosen for the study. Site 1 with a size of approximately 0.455 acres is bounded by latitudes 005°39'19.37"N and 005°39'21.29"N and longitudes 000°01'39.55"W and 000°01'38.57"W while site 2 approximately 0.152 acres lies between latitudes 005°38'24.24"N and 005°38'25.45"N and longitudes 000°01'21.15"W and 000°01'20.52"W.

1.1 Types of Unmanned Aerial Types

A distinction is made between an Unmanned Aerial Vehicle (UAV) and Unmanned Aerial System (UAS) by Koeva *et al* (2016) as follows: A UAV is the aircraft itself that is intended to be operated without a pilot-on-board, whereas the UAS refers to the aircraft and other components such as navigation software and communication equipment. There are typically four main types of civilian drones on the market today powered by batteries and with propellers for propulsive power limited in range by battery life, payload, line of site, regulatory constraints and radio signal. These are broadly classified as follows: fixed wing, single rotor, multi rotor and hybrid (Anon, 2019).

2. Resources and Methods Used

The data collection and processing were carried out in four (4) distinct phases namely site selection, ground survey, aerial survey and data processing of both ground and aerial surveys. However, a desktop study was done to establish some necessary activities that should precede UAV field data collection.

2.1 Desk-Study and Field Verification of Restricted Flight Zones

Due to a sharp increase in drone use internationally, countries are incorporating drones and their operation into their aviation regulatory frameworks (Jones, 2019), thus in the operation of UAV's globally, it is expected that flight restrictions around specific installations are strictly adhered to. These are primarily areas of airspace in which potential hazard to aircraft exists and therefore the operation of civilian aircraft including UAV's is restricted. These restriction zones are embedded in software applications used for UAV flight operations and hence warnings and alerts are displayed to user. In some instances, the aircraft will automatically abort the mission and return to its home or take-off point. Per the Remotely Piloted Aircraft Systems Directives of 2018, Section 28.4 (i) of the Ghana Civil Aviation Authority (GCAA), flight restrictions are imposed in specific areas around aerodomes. In order to ascertain how these restrictions are enforced, a flight was attempted within the Airport Residential Area which is in a restricted zone as shown in Figure 1. The flight control software gave warnings and alerts and finally automatically force landed the UAV after it attained an altitude of 20 m.

2.2 Site Selection

One of the challenges faced by land surveyors in Ghana is having to deal with hostile and suspicious residents within the localities where the cadastral surveys are being performed. The researcher therefore chose a site that was easily accessible and where there was little or no risk of hostility. The other important limiting factor was to select a site that had no flight restrictions as stipulated by the Ghana Civil Aviation Authority (GCAA) and captured in the DJI Pilot Software. Figure 1 below shows flight restriction zones in the Greater Accra Region of Ghana, depicted by the two concentric circles and the coloured swath.

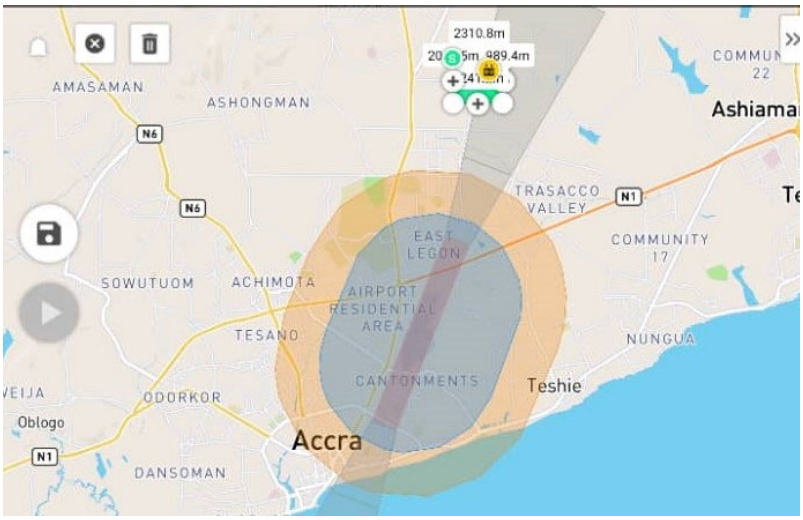


Figure 1: Restricted flight zones

2.3 GNSS Survey

A RUIDE R90T Global Navigation Satellite System (GNSS) dual frequency receiver (Figure 2) capable of making measurements to an accuracy of 5.0mm+0.5ppm RMS was used to establish boundary corner coordinates of the two sites. This survey was carried out using a static GNSS survey approach and referencing it to two (2) government approved control points as stipulated by the Survey and Mapping Division. The results of the survey are as shown in Table 2 under Results and Discussion. In addition, four (4) artificial ground control targets as shown in Figure 3 were observed on each site using the GNSS equipment and the resulting coordinates used in geo-refencing the images obtained from the UAV survey.

Figure 2: RUIDE R90T GNSS receiver

Figure 3: Artificial ground control targets

2.4 UAV Survey

A Mavic Air UAV (Figure 4) was used in obtaining imagery over the two (2) sites at two different altitudes- 40 m for Site 1 and at 60 m for Site 2. The specifications of the Mavic Air UAV are shown in Table 1. The flight planning parameters and flight details for both flights are further shown in figures 5a and 5b. Additionally, other relevant information regarding the flight was logged in a data sheet as shown in Figure 6.

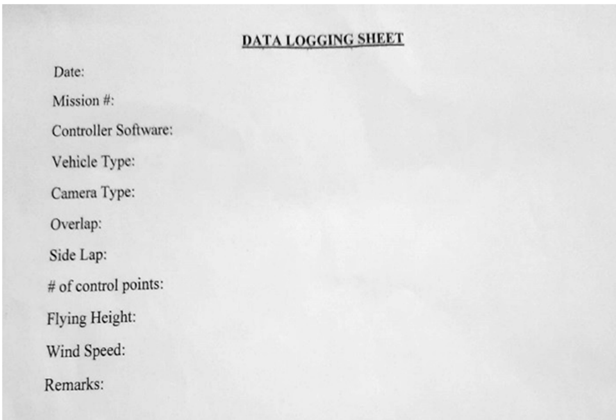
Figure 4: Mavic Air UAV with controller

Table 1: Specifications for Mavic Air UAV

General Specifications	Units	
	Imperial	Metric
Width	7.2 in	18.28 cm
Depth	6.6 in	16.76 cm
Height	2.5 in	6.35 cm
Weight	15.17 0z	430 g
Max Speed	42.5 mph	68.4 km/h
Sensor Specifications		
Resolution	12 megapixels	
Size	6.3mm x 4.7 mm	
Focal Length	24 mm	
Maximum View Angle	85°	

Figure 5a: Flight details for site 1

Figure 5b: Flight details for site 2


DATA LOGGING SHEET

Date:

Mission #:

Controller Software:

Vehicle Type:

Camera Type:

Overlap:

Side Lap:

# of control points:

Flying Height:

Wind Speed:

Remarks:

Figure 6: Sample data logging sheet

2.5 Wind Speed Measurement

In order to ascertain and investigate the effect of wind speeds and hence attempt to specify windspeed thresholds, a digital anemometer Digisense Model 20250-23 (Figure 7) was employed. The measurement of windspeed was deemed important for this work as the Mavic Air is one of the relatively lighter UAV's and so more susceptible to disturbances in strong winds. Wang et al (2019) summarizes the types of winds that have an influence on UAV in a low altitude environment as constant wind, turbulent flow, wind shear and propellor vortex. This research only measured directly the constant maximum wind speed.

Figure 7: Digital anemometer

2.6 Image Processing

The images were processed using the Agisoft Metashape Professional software going through the various processes of 1) aligning photos, 2) building dense clouds 3) importing ground control points 4) building meshes 5) building tiles models 6) building digital elevation models and finally 7) building orthomosaics. The processing process was largely automated in the sense that the processes listed above were achieved in the software by clicking appropriate menus. The georeferencing of images done after importing ground control points data could be described as semi-automated as it involved moving the imported ground control points to match exactly their locations in several images. The process of georeferencing sometimes called ground registration, aligns the columns and rows of image with a specific north and east ground coordinate system (Wolf and Dewitt, 2000).

2.7 On-Screen Digitizing

From the resulting orthomosaics, the boundaries of the study sites were digitized on-screen and the resulting boundary polygon exported into AutoCAD software. This allowed for a precise 2-D construction of the exported polygons to be plotted. The exact coordinates of the boundary turning points were thus obtained in the AutoCAD software environment and are referred to as UAV coordinates in Table 3.

3. Results and Discussion

From the on-site verification which showed that GCAA flight restriction was indeed enforced this research concludes that determining if a site is not encumbered by flight restriction is the first step that needs to be that needs to be considered in using UAV's for cadastral surveys.

Table 2 below shows the results of the static GNSS survey for Sites 1 and 2. These coordinates were obtained by processing the GNSS observations at the boundary turning points against government control beacons SGGA C2600 17 4 and SGGA C2600 17 6. The GNSS processing resulted in fixed solutions with horizontal root mean square values ranging between 0.028 - 0.073 ft.

Table 2: Boundary coordinate data for sites 1and 2 from GNSS survey

SITE 1				SITE 2			
Point Summary				Point Summary			
Name	Grid Northing (Ift)	Grid Easting (Ift)	Code	Name	Grid Northing (Ift)	Grid Easting (Ift)	Code
D1	358083.997	1253240.121		E1	353477.714	1255202.349	
D2	358122.388	1253338.152		E2	353478.381	1255272.650	
D3	357901.670	1253337.288		E3	353378.201	1255270.762	
D4	357898.577	1253239.904		E4	353377.000	1255203.110	
SGGA C2600 17 4	363758.751	1199747.949	CHK	SGGA C2600 17 4	363758.751	1199747.949	CHK
SGGA C2600 17 6	364495.947	1199762.427	BASE	SGGA C2600 17 6	364495.947	1199762.427	BASE

Figures 8 and 9 show portions of the orthomosaics with the on-screen digitized boundaries for sites 1 and 2. The orthomosaic generated from the UAV data for site 1 had a total size 11784 x 11672 pixels with a ground sample distance of 1.4 cm per pixel whereas that for site 2 was 10095 x 9551 with a ground sample distance of 2.09 cm per pixel. The Ghana Metre Grid was chosen as the output coordinate system for the UAV data processing.

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Figure 8: UAV data for Site 1

Figure 9: UAV data for Site 2

Since the UAV images were processed using the Ghana Metre Grid coordinate system, the coordinates obtained had to be converted from metres into feet to allow for comparison to be readily done with the GNSS survey which had been captured using the Ghana coordinate system in feet - the accepted norm for reporting coordinates and distances for cadastral maps. A comparison of the digitized boundary coordinates versus the coordinates obtained from the GNSS surveys is as shown in Table 3. As a general rule, the SMD specifies a tolerance of +/-3 feet between the coordinates presented by the licensed surveyor and the results obtained by the Examinations Unit after they have independently processed the GNSS Rinex data submitted by the licensed surveyor. This research therefore uses this same figure of +/-3 feet as a benchmark to conclude that the differences shown in the table above are acceptable.

Table 3: Digitized Boundary Coordinates versus GNSS Coordinates

SITE 1					
UAV Coordinates		**GNSS Coordinates**		**Coordinate Differences**	
Northing (Y ft)	**Easting (X ft)**	**Northing (Y ft)**	**Easting (X ft)**	**ΔN**	**ΔE**
358084.404	1253240.424	358083.997	1253240.121	0.407	0.303
358123.254	1253339.866	358122.388	1253338.152	0.866	1.714
357901.296	1253337.807	357901.670	1253337.288	-0.374	0.519
357898.118	1253239.748	357898.577	1253239.904	-0.459	-0.156
SITE 2					
UAV Coordinates		**GNSS Coordinates**		**Coordinate Differences**	
Northing (Y ft)	**Easting (X ft)**	**Northing (Y ft)**	**Easting (X ft)**	**ΔN**	**ΔE**
353478.057	1255202.611	353477.714	1255202.349	0.343	0.262
353477.924	1255273.428	353478.381	1255272.65	-0.458	0.778
353377.352	1255271.039	353378.201	1255270.762	-0.849	0.277
353377.832	1255203.997	353377.000	1255203.110	0.832	0.887

Figures 10 and 11 shows the digitized boundaries from the UAV data and boundaries from GNSS data overlaid over one another for both sites 1 and 2 plotted at a scale of 1:500

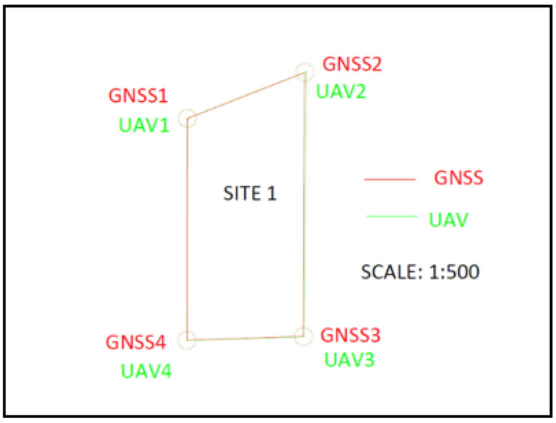

Figure 10: Overlay of boundaries for site 1

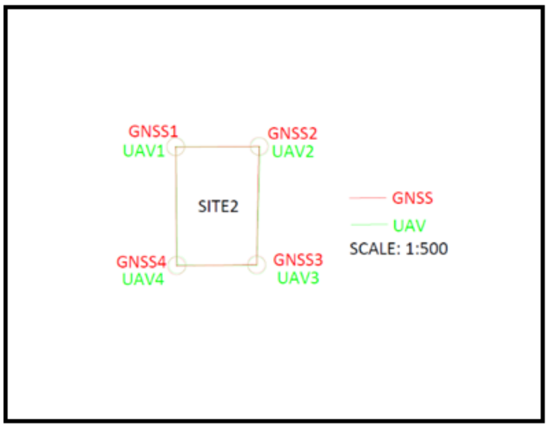

Figure 11: Overlay of boundaries for site 2

3.1 Generic Workflow
From the desk study, field survey and data processing a workflow as outlined below is suggested.

- Preparatory work and field reconnaissance work to determine:
  (i) Flying restrictions
  (ii) Suitable government control points, site GCP locations and decide on optimal flying height based on obstructing features within the project area.
- Select appropriate flight parameters for UAV mission. (eg. Side lap, Overlap, Tilt angle)
- Process UAV imagery using accurately surveyed ground control points for georeferencing
- Perform on screen digitizing of parcel boundaries that are visible from images
- Export digitized boundary polygons into an appropriate software (eg AutoCAD) capable of creating an accurate 2-D representation of digitized boundary from which turning point coordinates can be obtained.

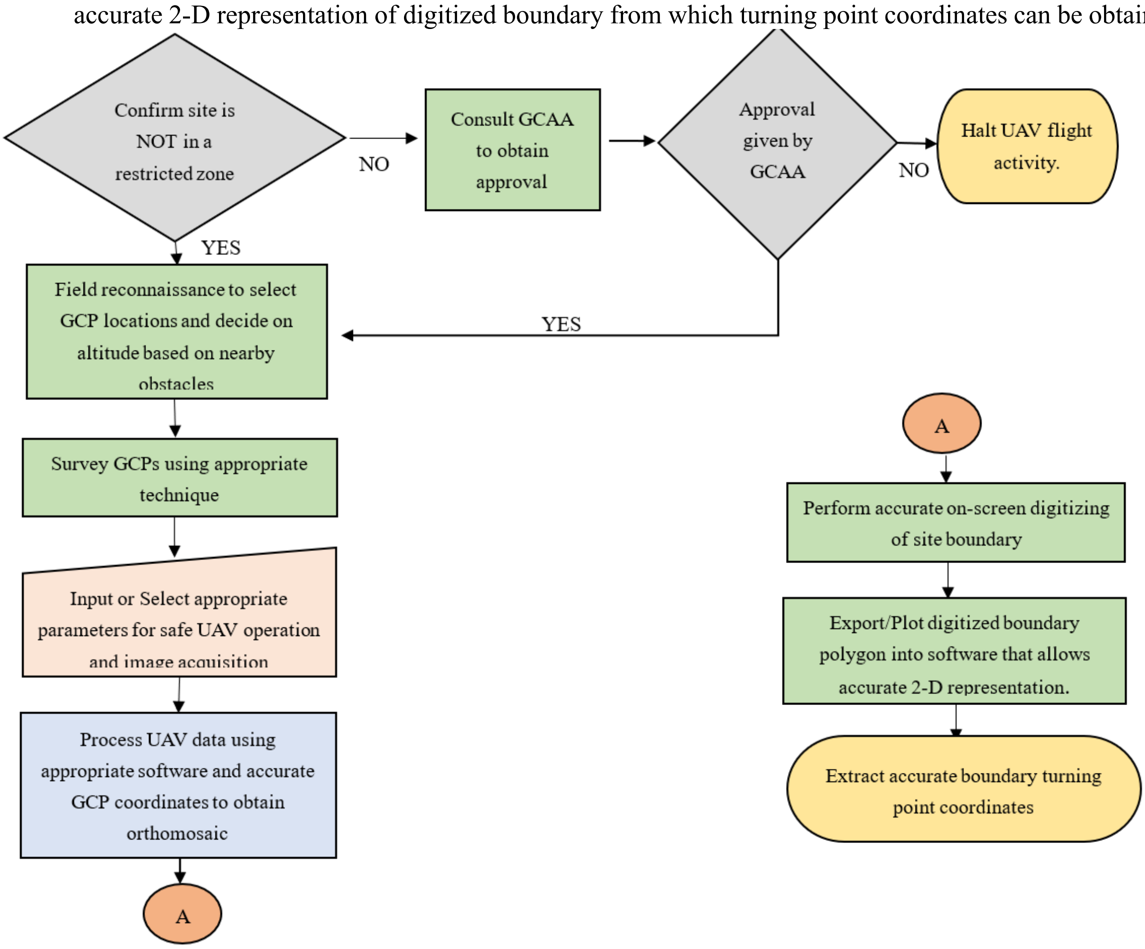

Figure 12: Flow chart of generic workflow

4. Conclusion and Recommendation

The paper outlines a generic workflow that can be used to surveyors in Ghana to produce cadastral plans to meet accuracy specifications stipulated by the SMD of Ghana.

A major advantage of the approach suggested in this paper is that with one flight and the resulting orthomosaic which has been georeferenced using ground control points surveyed by appropriate GNSS methods and checked by SMD, several boundaries can be digitized to meet cadastral accuracy specifications especially in developed and built-up areas. Another advantage is that imagery obtained can be added to boundary coordinate data so that the public can have a better appreciation and visualization of their boundaries as opposed to the existing system where certified cadastral plans only show boundary polygons obtained by GNSS methods.

In order to reduce distortions of features in images it is being advised that relatively light UAV's which weigh not more than 430 g should not be flown above an altitude of 60 m for the purpose of gathering data for cadastral surveys. Additionally, the camera on board the UAV must be capable of a resolution of 12 megapixels or better. It is also suggested that flying UAV's whose weights do not exceed 430 g should be avoided when constant maximum windspeeds are above 8m/s or approximately 30 km/h. This is because the Mavic Air UAV used for this research was seen to be shaking when a maximum windspeed of 7.8 m/s was measured during a flight. In proposing for the adoption of this UAV based workflow it is also suggested that the Examinations Unit of the SMD responsible for checking the accuracy of cadastral plans submitted by surveyors request the following:

1. all GNSS data in RINEX format relating to ground control points which have been used for georefencing.
2. digital copy of geo-refenced orthomosaic from which boundaries were digitized in geotiff format. This is because the geotiff format allows a raster image to be tied to a known model space or map projection (Mahammad and Ramakrishnan, 2003) thereby allowing for checks and verification to be done on submitted boundary coordinates from digitized polygons.

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