Digital Preservation of Cultural Heritage Sites using Unmanned Aerial Vehicle - A Case Study*

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Abstract

In the past, preservation of cultural heritage sites was primarily undertaken using techniques such as painting, photography, using still cameras, and lithography to extract two dimensional (2D) records. The advent of aerial and terrestrial photogrammetry, laser scanning, and Global Navigation Satellite Systems (GNSS) technologies has made it possible to digitally preserve cultural heritage sites through the creation of Digital Surface Models (DSM), orthophotos and 3D realistic models that are true to scale. The introduction of Unmanned Aerial Vehicles (UAVs) technology has proven to be a source of 3D data capture for cultural heritage sites for preservation and geo-spatial analysis of these sites. In Ghana and many developing countries, these heritage sites are not well maintained, neither have they been digitally preserved. The main reasons why these sites are not preserved is because most of the modern techniques of preserving cultural heritage sites are expensive and time consuming. There is therefore the need to adopt a low-cost but relatively fast technique such as UAV technology for collecting geographically referenced 3D data for the preservation of cultural heritage sites. This research applied UAV technology to digitally preserve Fort William in Anomabo, Ghana by creating a 3D Model, Digital Surface Model and Orthophoto. This research recommends that the UAV technology should be adopted to digitally preserve cultural heritage sites.

Keywords: Unmanned Aerial Vehicles, Global Navigation Satellite Systems, Heritage Sites, Orthophotos

1 Introduction

Cultural heritage is the legacy of a society that is inherited from past generations, maintained in the present and passed on for the benefit of future generations (Anon, 2018a). Cultural heritage can either be tangible or intangible. Tangible cultural heritages are physical artefacts or objects such as castles, forts and artefacts that are significant to archaeology, architecture, science or technology of a specified culture (Wendland, 2004). Intangible cultural heritages on the other hand consists of non-physical attributes of a particular culture such as oral traditions, performing arts, rituals and festivals (Sullivan, 2016). The preservation of cultural heritage is necessary to validate memories of the past, provide data for research and education, restoration in case of damage and to increase awareness of tangible cultural heritage (Rüther, 2002). In the past, the preservation of cultural heritage sites was primarily undertaken using techniques such as painting, photography using still cameras and lithography to extract two dimensional (2D) records (Raof *et al*., 2015). Today, technologies such as aerial and terrestrial photogrammetry, laser scanning and Global Navigation Satellite Systems (GNSS) have made it possible to digitally preserve cultural heritage sites through the creation of 3D realistic models that are true to scale, Digital Surface Models (DSM) and orthophotos (Choroma´ nski *et al*., 2019). The advent of Unmanned Aerial Vehicles (UAVs) technology is a source of 3D data for the digital preservation of cultural heritage sites as it compliments earlier technologies. The Ghana Museums and Monuments Board (GMMB) is the legal custodian of the country's tangible cultural heritage (Anon, 2018b). The Board is responsible for the preservation of cultural heritage sites, especially those enlisted by United Nations Educational, Scientific and Cultural Organisation (UNESCO) as World Heritage sites. Many World Heritage sites in Ghana are hardly or not digitally preserved at all. This is because most of the modern techniques of preserving cultural heritage sites are expensive. There is therefore the need to adopt a low-cost, efficient and relatively fast technique such as UAV technology for the preservation of cultural heritage sites. This research therefore seeks to apply the UAV technology for the digital preservation of a World Heritage Site using Fort William in Anomabo as a case study.

1.1 Brief History about Fort William

In 1753, the British Parliament voted enormous sums of money for the construction of a new trading fort in Anomabo, now part of the Central Region of Ghana (Anon., 2018b). It was completed by 1757 and was erected on an eroded shelf of hard rock close to a sandy beach indentation with a sheltered anchorage (Anon, 2018b). Earlier, in 1674, the English had built a small fort, named Fort Charles, after the reigning monarch King Charles II. The English demolished Fort Charles in 1731, to prevent its capture and use by another European country. The French, however, rebuilt a fort where

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Fort Charles once stood. Regretting the loss of their Anomabo fort, the English hastened to then build a new one Fort William (Anon, 2018b). The fort was probably christened Fort William by 19th century commander Brodie Cruickshank in honor of King William IV, upon the completion of another one storey apartment. Fort William was constructed almost entirely with local materials, and is considered one of the handsomest and best built of the Coast. However, nowhere else does the original structure of a fort include a large prison specifically built to hold slaves awaiting transport overseas. Fort William had a superior stock of cannons; yet it was attacked by the French in 1794 and besieged by the Asante's on 15th June, 1806 a day after which it capitulated. Once a rest house and a post office, became a state prison until 2001(Anon, 2018b). Fort William now serves Anomabo as a community library.

1.2 Unmanned Aerial Vehicle (UAV)

The UAV is an acronym for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled (*i.e*. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans in their embedded systems, working with onboard sensors and Global Navigation Satellite Systems (GNSS). UAVs are currently used for a number of applications including but not limited to surveying and mapping, precision agriculture, monitoring and inspection, advertising, emergency response and disaster management, defense, urban planning, healthcare, waste management, weather forecasting, mining and telecommunications (Anon, 2018c). The acronym UAV has been expanded in some cases to UAVS (Unmanned Aircraft Vehicle System). The Federal Aviation Administration (FAA) has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other elements beside the actual air vehicles. The term UAS, however, is not widely used as the term UAV has become part of the modern lexicon (Anon, 2019).

1.3 UAV Platforms and Classifications

UAV could be classified according to their physical features, the ranges they can travel and their endurance in the air. In respect of physical features, UAVs could be classified into rotary wing, fixed wing or hybrid Vertical Takeoff and Landing (VTOL) drones. The rotary-wing drones could either be single-rotor, coaxial, quadcopter or multi-rotor. The fixed wing drones are either gliders or high wings. The hybrid VTOL drones have a combination of the rotary-wing and fixed wing features. Some fixed wing drones currently in operation are Mavinci Sirius, Aeromao, Pteryx, Sensefly, Gatewing, SmartPlanes *etc.* Some operational rotary-wing drones are DJI Phantom 4 series, DJI Matrice series, Falcon, Parrot and DJI Inspire series. Hybrid VTOL types of drones include; Deltaquad, Atmos, ALTI, Wingtra, Heliplane, Nimbus, Swift020, UMS Skeldar, Schiebel, UAVOS and Threod. Based on the UAVs travel range and endurance, they are classified into; long endurance long-range UAVs, medium endurance medium-range and Low endurance short-range UAVs. Long endurance UAVs could have 24 hours or more flight time and can also fly for a long distance, from 1500 km to 22000 km (Anon, 2008). Global Hawk, Herron and GNAT are examples of these type of UAVs. The medium endurance UAVs usually have the endurance between 5 to 24 hours. Some common UAV types of this category are the Predator, Hunter and Shadow 600. This type of UAVs can have an endurance of up to 40 hours. Low endurance UAVs can operate for less than 5 hours and used for short missions. Typical examples of this type are; the Pointer, SilentEye, DragonEye, Dragon Warrior, Desert Hawk; and Outrider (Anon, 2008). The various types of UAVs have payloads capable of carrying small to medium size digital cameras and video recorders. These cameras can either be normal RGB digital cameras capable of acquiring high resolution photos which can then be mosaicked into orthophotos (Fonstad *et al.,* 2013; Hugenholtz *et al.,* 2013), or hyper-spectral cameras capable of assessing local water stress (Zarco-Tejada *et al*., 2012; Pádua *et al*., 2017) or agricultural and forestry health (Saari *et al*., 2011). These payloads are however restricted to 7 kg under the regulations of the Civil Aviation Authority in Ghana.

1.4 Global Navigation Satellite Systems

UAVs are embedded with Global Navigation Satellite Systems (GNSS) to establish the flight paths, establish current position relative to the Pilot and execute all necessary actions to correct any deviation in position (Walter *et al*., 2008). GNSS is a global term referring to all satellite navigation systems, which include GPS (USA), GLONASS (Russia), Galileo (Europe), Beidou/BDS (China), IRNSS/NavIC (India) and QZNSS (Japan) (Khojasteh *et al*., 2016; Grejner-Brzezinska *et al*., 2005). The GNSS antenna is usually mounted on the UAV to receive location and time data from GNSS satellites (Velaga *et al*., 2012). This data is then transferred unto the autopilot, avionics or navigation systems of the UAV, and can also be used to determine velocity (Sabatini *et al*., 2013). GNSS has the limitation of needing to be within line of sight of at least four satellites in order to provide reliable navigation. In poor signal conditions it is ideal to combine the GNSS with an Inertial Navigation System (INS), which uses rotation and acceleration to calculate a relative position which accurately navigates the UAV during loss of GNSS signal. The GNSS can in turn provide an external reference to the INS that helps to reduce the effect of bias errors (Zhu *et al*, 2018).

2 Resources and Methods Used

2.1 Resources

Anomabo is the study area. It is located in the Central Region of Ghana and lies between latitudes 5°10' N and 5°25' N and longitudes 0°50' W and 1°12' W. Anomabo forms part of the Mfanteman Municipal Assembly in the Central Region. The equipment resources used were: DJI phantom 4 UAV for capturing of aerial photographs (Fig. 1); South Real Time Kinematic (RTK) GNSS Receiver set (Fig. 2); and Ground Control Point (Target) (Fig. 3).

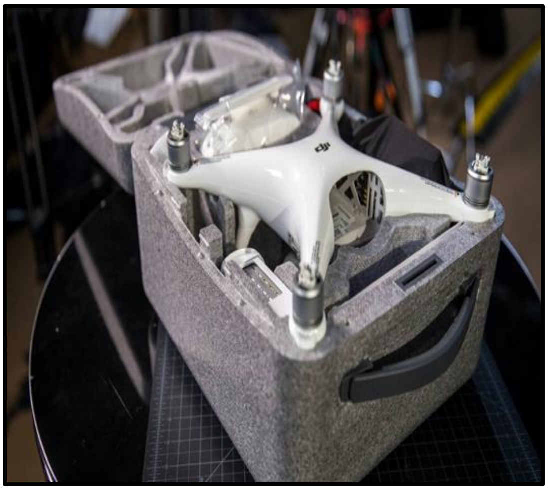

Fig. 1 DJI Phantom 4 UAV

Fig. 2 South RTK GNSS Receivers

Fig. 3 Ground Control Point (Target)

2.2 Methods Used

Flow chart of the methods used is as shown in Fig. 4.

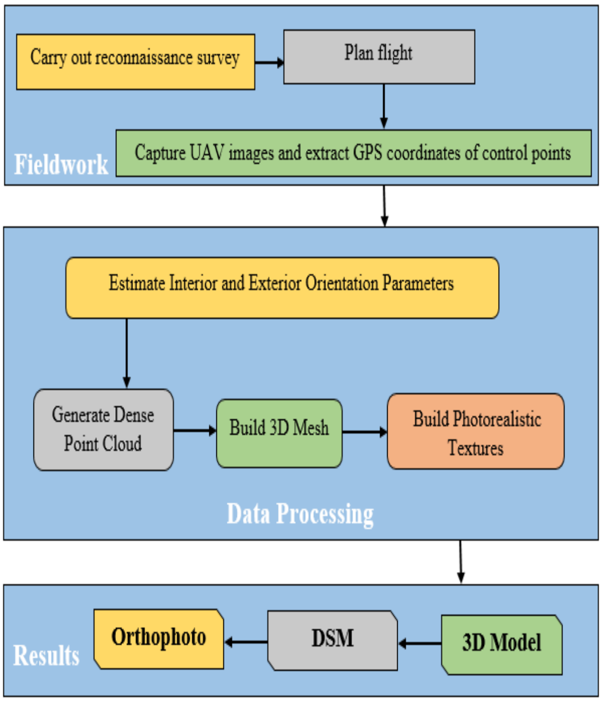

Fig. 4 Flow Chart of the Methods Used

2.2.1 Reconnaissance and Flight Planning

First, reconnaissance survey was conducted to gain preliminary information about the study area and to lookout for suitable positions devoid of shade and destructions to fix Ground Control Points (GCPs). Fig. 5 shows the distribution of GCPs. Flight was planned using the Drone Deploy software. The area of interest (AOI), the required ground sample distance (GSD), image scale, and the flying height were set. The DJI Phantom 4 UAV can be operated in either autonomous or manual mode. The autonomous mode was used because it defines fixed image scale and regular overlaps. The onboard GNSS/INS navigation device is usually exploited for the autonomous flight (takeoff, navigation and landing). The area of interest (AOI) is defined on graphical interface using a tablet with the flight planning software installed. The general flight planning procedure employed on the field include: creating a new mission on the tablet device with installed software to define the area of interest to be surveyed, flying height (mission altitude) is set, position for takeoff and landing is clearly defined, image overlap and side lap are set to 80% and 60% respectively and angles of camera is also set to 60, 75, 80 and 90 degrees for respective flights.

Fig. 5 Distribution of Ground Control Points

2.2.2 Data Collection

Eight Ground Control Points (GCPs) were established and fixed temporarily on the ground (Fig. 5). The GCPs were positioned to ensure even distribution within the site. The GCPs were surveyed with a South RTK GNSS receiver to get the Eastings and Nothings of each Point in UTM 84 zone 30N coordinate system (Table 1). The accuracies of the GCPs were determined (Table 2). The differences in the Eastings and Northings from the GCPs were all within the tolerance of +/- 0.9114 m set by the Survey and Mapping Division of Ghana (Table 2). The UAV was then calibrated and prepared for flight. The frame, motors, propellers, battery, sensors and availability of signals were all checked before takeoff. Waypoints for the flight plan was uploaded onto the tablet.

Table 1 Coordinates for Ground Control Points

Point ID	Eastings (m)	Northings (m)
GCP 1	708483.776	572228.087
GCP 2	708458.453	572212.338
GCP 3	708452.194	572248.510
GCP 4	708485.802	572275.962
GCP 5	708514.419	572274.689
GCP 6	708521.894	572241.856
GCP 7	708528.717	572211.044
GCP 8	708480.152	572169.554

2.2.3 Data Processing

Agisoft Photoscan Professional Software was used for the processing of the data. First, all images captured by the UAV were imported from the UAV camera onto the computer. During processing, there is the need to determine the interior and exterior orientation of the multiple overlapping images to orient the images. Interior orientation was to determine camera geometry, and exterior orientation was to determine both the relative positions between images and the position of images in 3D space (Fryer, 1996; Youcai and Haralick, 1999). A step wise processing of the images was carried-out: that is, aligning photos, building of dense point cloud, building mesh, building texture, and building DEM, 3D model and orthomosaic. Photo alignment was done to produce a sparse point cloud. Sparse point clouds represent 2D coordinates. With the existence of the sparse point cloud, a mathematical algorithm applies interpolation to densify 2D coordinates of points to 3D coordinates. Texturing was done to create a 3D model for easy visualisation. Meshes (Triangular Irregular Network) were then created. Surface reconstruction was done to smoothen the meshes and also to close holes in the 3D model generated. A 3D model, a DSM and orthophoto of Fort Williams were then generated. Fig. 6 shows the dense point cloud. Fig. 7 and Fig. 8 show 3D Mesh and solid model of Fort William respectively.

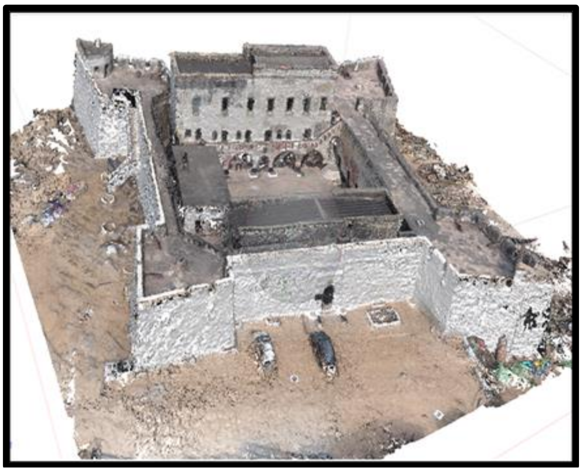

Fig. 6 Dense Point Cloud

Table 2 Accuracy of GCPs

Point ID	Eastings Residuals ($\Delta\mathbf{X}$) (m)	Northings Residuals ($\Delta\mathbf{Y}$) (m)
GCP 1	0.656	-0.163
GCP 2	-0.167	0.084
GCP 3	-0.318	0.042
GCP 4	0.182	0.388
GCP 5	0.205	0.364
GCP 6	0.444	0.098
GCP 7	0.459	-0.043
GCP 8	-0.702	0.126
Number of GCPs	8	8
Mean error	0.1919	0.0432
$RMSE_x$: $RMSE_y$ $RMSE_x = \sqrt{(\Sigma(\Delta\mathbf{X})^2/n)}$ $RMSE_y = \sqrt{(\Sigma(\Delta\mathbf{Y})^2/n)}$	0.4381	0.2079
$RMSEr = \sqrt{(RMSEx^2+RMSEy^2)}$	0.1967	

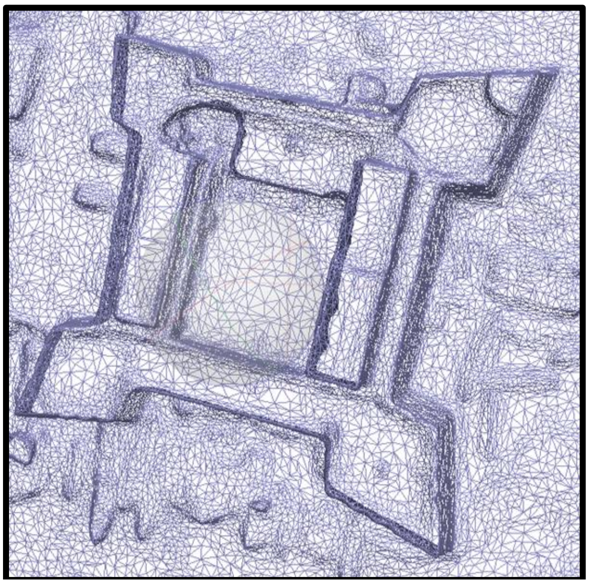

Fig. 7 3D Mesh of Fort William

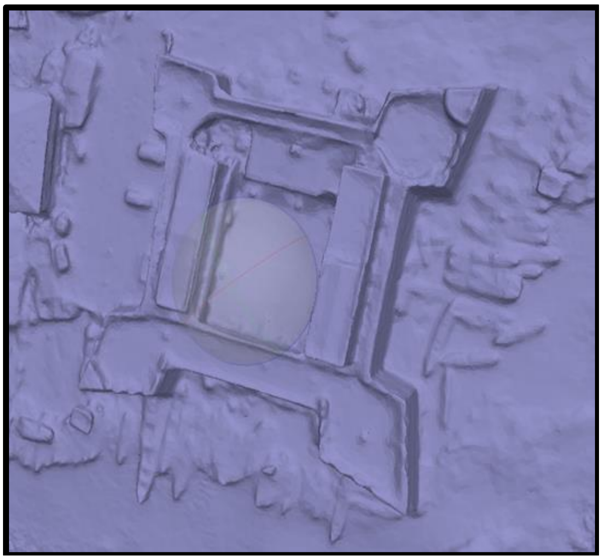

Fig. 8 Solid Model of Fort William

3 Results and Discussion

3.1 Results

UAV technology (DJI Phantom 4) has been used to produce 3D textured model, 3D model, Digital Surface Model and Orthophoto of Fort William all shown in Figs. 9, 10, 11 and 12 respectively. These models would be very useful in the preservation of Fort William in Anomabo.

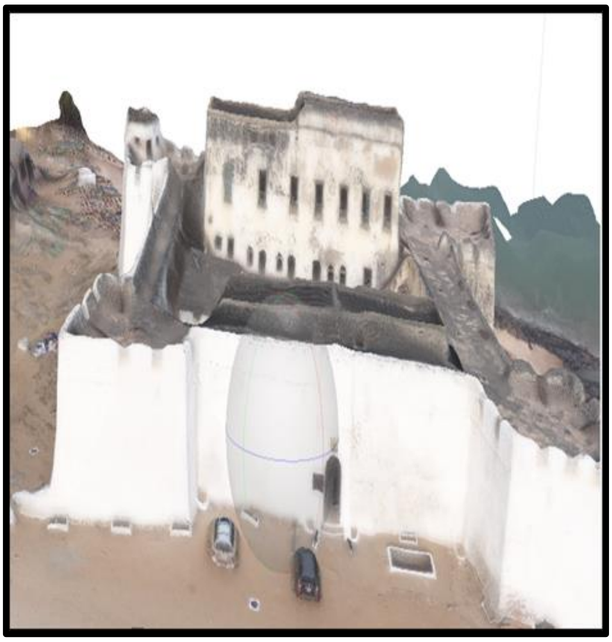

Fig. 9 Generated 3D Textured Model

3.2 Discussion

A 3D model, Digital Surface Model and orthophoto generated for cultural heritage sites are very useful for their preservations. The UAV technology provides a real-time capability, fast image acquisition and low-cost technique as compared to most of the modern techniques of preserving cultural heritage sites. This makes it a suitable method for low budget projects. The UAV approach however requires skilled and certified experts to fly and process the data.

Fig. 10 3D Model of Fort William

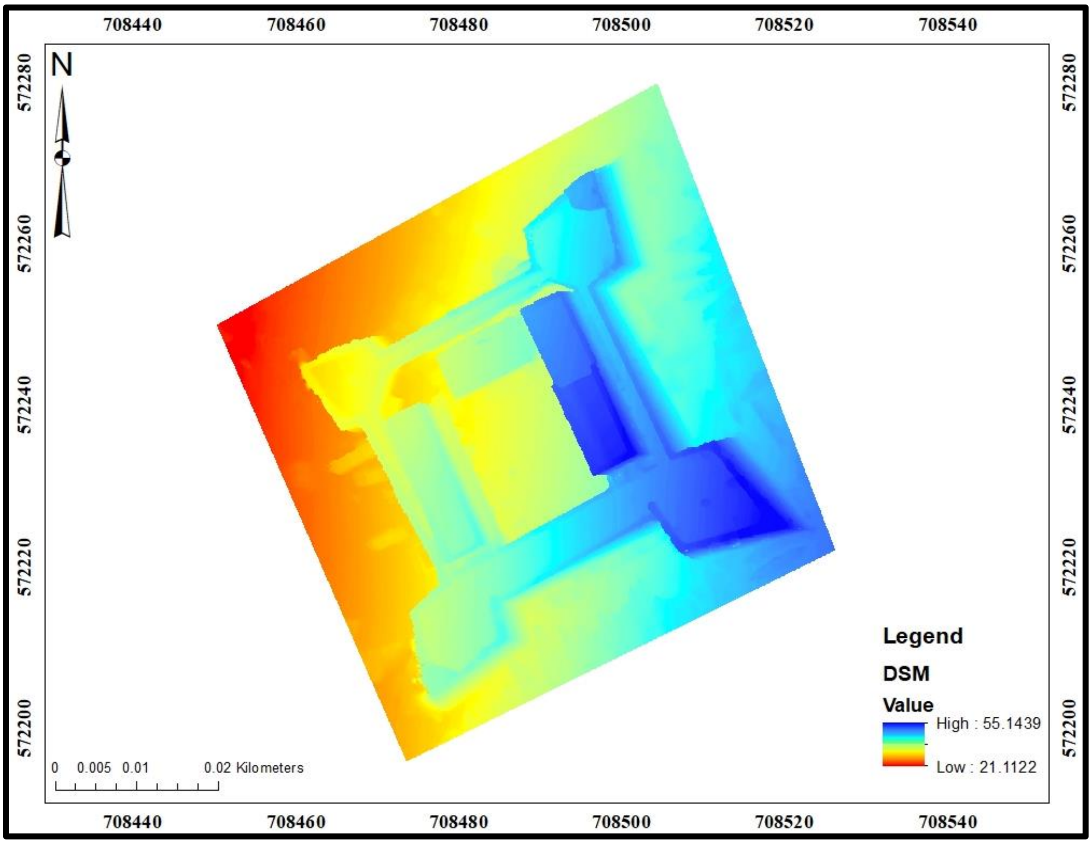

Fig. 11 Digital Surface Model of Fort William

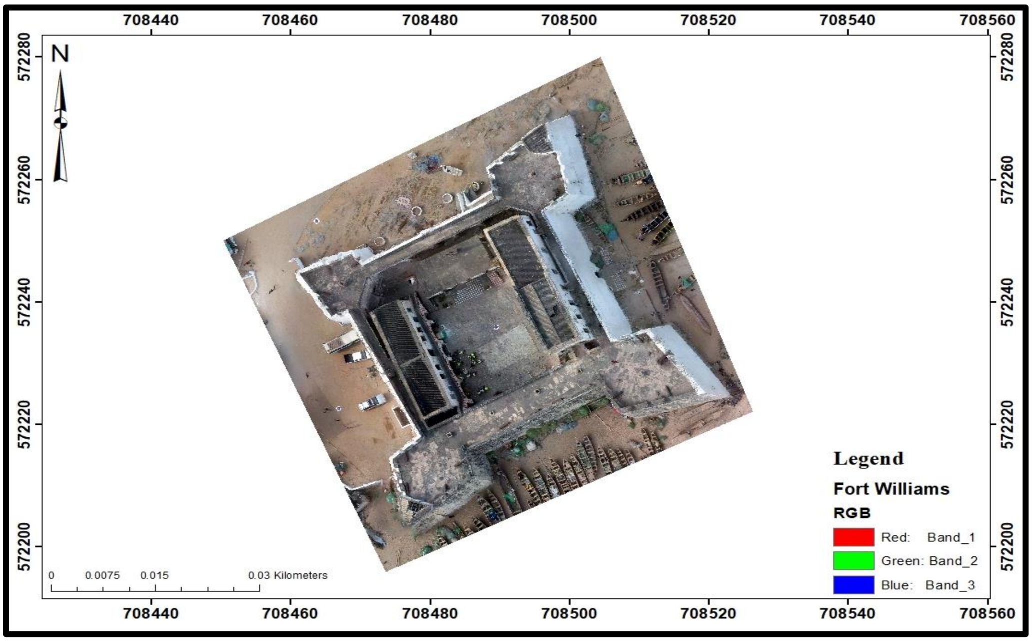

Fig. 12 Orthophoto of Fort William

4 Conclusions and Recommendations

4.1 Conclusions

In conclusion, a 3D Model, a Digital Surface Model and orthophoto of a cultural heritage site in Anomabo has been successfully generated using UAV technology for preservation purposes. The photogrammetric approach using UAV technology to generate 3D models is a low-cost but relatively fast technique compared to other modern techniques of preserving cultural heritage sites such as laser scanning and terrestrial photogrammetry. This makes it a much suitable method for low budget projects.

4.2 Recommendations

This paper recommends that a similar approach be adopted to preserve other heritage sites in the country. This research further recommends that the UAV technology should be incorporated with Close Range terrestrial photogrammetry to provide more interior information for digital preservation.

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