

A Comparative Analysis of Volumetric Stockpile from UAV Photogrammetry and Total Station Data

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Abstract

The efficacy of volume determination in various fields of survey; mining, quarry, hydrographic and engineering fields can't be overemphasized. Conventional surveying method using Total station has been the natural panacea for volume determination in surveying, despite its lengthy and laborious data collection, and quite risky at site. Although, UAV (Unmanned Aerial Vehicle) has been an alternative in surveying, but there have been doubts about its efficiency and accuracy. This project compares the applications of two novel surveying technologies for volume estimation and also compares volumes computed by various software vendors. For this purpose, an appropriate stockpile was chosen, two sets of observations were taken. First, the stockpile was mapped by a UAV flight, and secondly the stockpile was measured using a Total station. The results have been analyzed with respect to different volumes, software, discrepancies between surfaces and project time. After detailed analysis and comparison, it was found that TIN and DEM modelling yields better and accurate results than gridding modelling, making Surfer software not ideal for volume computation, also observed that ArcGIS and AutoCAD Civil3D software is ideal for vector volume measurement, while Agisoft gives a better result for raster volume measurement. Also realized was that for this project Total station volume differs with that of the UAV with 3%. also, this project indicates that using conventional surveying methods such as total station surveying volume estimation is more time consuming and the results are more generalized than using UAV technology where capturing thousands of surface points (i.e. point cloud) takes just seconds. The results show a promising future for UAV in volume estimation.

Keywords — UAV, TST, Stockpiles, Volume, Ground Control Points (GCPs), Photoscan.

1. INTRODUCTION

Currently, Unmanned Aerial Vehicle (UAV) have become an alternative for different engineering applications, especially in surveying [5]. One of these applications is the capturing datasets for volume computation of volumes of stockpile material, but there are questions about its accuracy and efficiency.

Data capturing is one aspect and then also data processing is another area which is necessary to yield accurate results. The method of calculation for volume as evolved from the exigent manual process to a more computerized and automated process using the Digital Terrain Model (DTM). Various methods are employed in surface modelling which includes Triangulated Irregular Network (TIN) and grid modelling. Several software vendors' employs various techniques in volume estimation. Hence, a comparison will be carried using different software packages namely; ArcGIS, AutoCAD Civil3D, Agisoft and Surfer.

The goal of this project was to compare the accuracy and efficiency of the Total station method and that of the UAV. With the growing need for accuracy in volume measurement, there is a tremendous need to determine which instrument can capture accurate field data and also which software could perform better with accurate results. Looking at the Total Station and the UAVs for volume measurement, there is a need to wonder which of this equipment is more accurate and efficient?

The main problem of this project was to determine which methods between UAV and TST was more accurate and efficient for carrying out volume measurement of stockpiles materials. As these questions were answered, there was a remarkable potential for utilization of this technology in sectors such as engineering, agriculture, hydrography, mining, etc. Therefore, the study aimed to compare the accuracy and effectiveness of Total station and Unmanned Aerial Vehicle (UAV) in stockpile volume measurement and determination.

The followings objectives were the focus of the study.

- i. To establishment site control.
- ii. To capture field data using UAV.
- iii. To capture field data using Total station.
- iv. Analysis of UAV and Total station data.
- v. Computation of data from the UAV and Total station using various software.
- vi. Comparative Analysis of the end-result of both methods.

Reviews of previous works on this study examined the most appropriate case studies on volume measurements. "Reference [6] designed a number of studies to test the performance of close range

photogrammetry when applied to volume calculations”. A preliminary study was performed in a lab setting in which an artificial object of a conical shape with a volume of 364.2cm^3 was photographed using a Sony F828 digital camera. The photos were then processed using PhotoModeler 5.0 to generate a 3D point cloud of the object. Software packages Surfer 8.0 and NetCad generated volume calculations of 359.5cm^3 and 359.7cm^3 respectively. It concluded that an error of 1.28% was acceptable for most practical purposes.

Another lab study using the same methodology only on a cube with dimensions of 10-cm resulted in a photogrammetric accuracy of 99.99%. Upon completion of the lab studies, the methodology was taken to the field in order to assess the ability on a natural hill. The author used both classical and photogrammetric techniques for volume calculation and then compared the two results. The hill had dimensions of 6m wide 9m long and 3m tall. Thirty-four test targets were placed in a well-distributed pattern on the hill and coordinates were measured using a Topcon total station instrument. The volume of the hill was calculated as 29.9m^3 using the GNSS approach. Photogrammetric processing resulted in a volume calculation of 28.8m^3 a difference of 3.7%. It was concluded that “the photogrammetric method, when compared to the classical method, had more than 21.43% advantage in terms of time-saving, more than 10.62% in accuracy, and more than 33.33% in cost saving”.

Also, “Reference [4] assessed the accuracy of volume estimation of a stockpile by surveying a stockpile using a UAV before and after a portion was excavated. Photogrammetric operations were applied to the UAV images before and after the excavation in order to produce two DTMs”. The study utilized 10 GCPs and a GNSS survey-using RTK was performed. The total stockpile volume for the first flight was determined to be $10,202.66\text{m}^3$ and $8,681.05\text{m}^3$ for the second resulting in a percent difference of 2.6 and 3.9 respectively from the GPS based estimations. The removed gravel estimated at $1,521.44\text{m}^3$ from the UAV survey differed by 2.5% from the volume estimated from the haul ticket of $1,483.44\text{m}^3$. It was concluded that UAVs could be a valuable tool for geomatics but more research into the accuracy, limitations, cost efficiency and operationalization was needed.

“Reference [1] carried out a comparison of TST and Laser scanner in the volume computation of a stockpile material. a pile of sand (size around 400

m^3) were surveyed twice: once with a laser scanner – Leica HDS 3000 – and once with a total station – Leica TPS1200”. The data of the measurement were computed with three different software products: Geo, Geograf and Cyclone. It further stated that the accuracy of volume determination depended on the ratio between the surface area (S) and the volume (V), (S/V. This meant that the smaller the ratio the better

the accuracy of volume determination. With small volumes, changes in the determination of the surface had strong influence in the accuracy of the volume determination that were up to 20m^3 . So a pile should be measured which is bigger than 20m^3 to make sure that the results can be transferred to bigger piles. In each software product, a DTM was created and the volume about a reference plane was computed. The results of the different methods – laser scanner and tacheometry, as well as the results of the different software were compared between the different methods. The results of the computations showed that there was no difference between the programs Geo and Geograf, but the result of Cyclone diverged from the other [2].

Lastly, “Reference [3] estimated the volume of a stockpile using and comparing TST and a Topcon Imaging station. They performed the scanning method with two different densities which were 0.3m density and 0.1m density. This study only focused on volume calculation using IS and TST and the data process used IM and 12D software”. The study recommended the comparison of stockpile volume calculation using AutoCAD Land Desktop and Surfer software of the same stockpile by using the grid method, composite and end-line volume. For the imaging station there was a 0.05 percent difference from the actual volume. In contrast to the conventional method, the percentage was 5.34 percent different from the actual volume. By using scanning method, the percentage showed that the scanning method were more accurate during stockpile volume calculation as the results were approximately the actual volume. This also far exceeded the speed and accuracy of conventional methods.

II. MATERIALS AND METHODS

A. Study Area

The project site was Dockins Stones, a chippings commercial company located at Abak road, approximately 1km from Ekom Iman Junction, Uyo, Akwa Ibom State, Nigeria. Dockins Stones lies between Longitudes $04^{\circ}59'58''\text{N}$ and $05^{\circ}00'00''.28''\text{N}$ and between Latitudes $07^{\circ}50'44''\text{E}$ and $07^{\circ}50'49.20''\text{E}$.

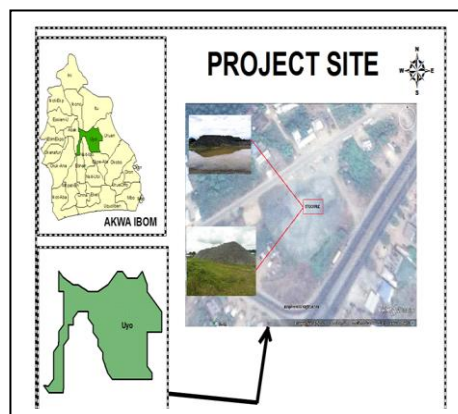


Fig. 1: Study Area (Stockpile Site)

A. Methodology

The process adopted during this study is as shown in Fig. 2 below.

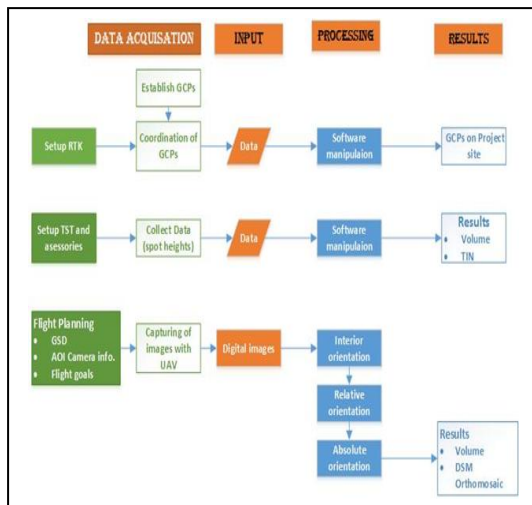


Fig. 2: Flowchart of Methodology

a). Instrumentation/Software

The materials and instruments utilized in this study were chosen because of their ability to aid in the accomplishment of the project goals. These included the following;

- i. UAV system (DJI Phantom 4 Pro)
- ii. Total station and accessories (Sokkia)
- iii. GNSS receiver (Hi-Target) for GCPs coordination
- iv. 100m linen tape
- v. PPC
- vi. Hammer, nails and cutlass
- vii. Paint and brush
- viii. Field book and writing materials

Ground control points utilized were self-made to fit the purpose of the study. The following materials were used in the preparation of the GCPs viz., PPC, a circular-shaped material about 5cm, paint and brush (Fig.3). These targets were designed on standard 0.5m by 0.2m sheets of PPC and secured to the ground with nails driven through them with the aid of a hammer. The GCPs were numbered individually and a total number of 21 GCPs were utilized in this study as shown in Fig. 4.



Fig. 3: Sample of Emplaced GCP No.21 on the Site



Fig. 4: GCPs around the Study Area

Software used were carefully selected for this study. This was done to detect the nuances between them and also see which gave a more accurate result. The sophistication of the software aided greatly in data processing as well as its analysis. The primary software used included Agisoft Photoscan, ESRI ArcMap, Surfer, AutoCAD Civil3D; others included, Microsoft Excel, Notepad, Microsoft Word.

b). Field Methods

The two methods employed for data acquisition were, first ground survey with a total station, and secondly, aerial survey with a UAV, and these were carried out through the following processes.

1. Reconnaissance

Reconnaissance was an essential stage in this study. It was sub-divided into two namely:

- a) Field reconnaissance: this involved going to the project site to determine the area of the project site, also consider the numbers of GCPs necessary to cover the Area of Interest (AOI).
- b) Office reconnaissance: After the field reconnaissance, the information obtained was used in the design of the flight plan needed for the execution of the UAV and also the necessary numbers of GCPs to be produced for the project.

2. GCPs Placement and Coordination

Ground Control Points (GCPs) were placed at random but in a dense manner around the stockpile, bearing in mind avoidance of clustering of the GCPs. At the study site, however, due to the soggy nature of the land, 21 GCPs were placed. Ground control points data were collected using two GNSS Hi-target Receiver (Fig. 5). First the controller was powered on and configured to collect data in RTK mode and all the GCPs were surveyed. Time was allowed for the GPS to gather a good amount of satellite reception to improve the PDOP (positional dilution of precision).

All data was collected using the World Geodetic System 1984 (WGS84) datum.



Fig. 5: Coordination of the GCPs with GNSS Receiver

3. Data Collection

This project utilized one primary site containing a gigantic stockpile(chippings) suitable for 3D reconstructions and volume estimation. All measurements were carried out on the same day, Sept 25, 2018. Data was collected both with a UAV and TST, thus, will be discussed under the following sub-headings viz.,

a). Data collection using UAV

Data was collected using the DJI Phantom 4 Pro V2 UAV system and flight plan was designed with flight planner app Pix4Dmapper, allowing quick, precise and automatic image capturing. All that was left for the operator was to select the AOI, on Google Maps, camera model, photo size, resolution, flight altitude. The software uses these parameters to compute a full flight plan consisting of waypoints as shown in Fig. 6. A live camera stream was broadcast to a Samsung S6 via the Pix4Dmapper app. The flight plan was set with 1.36cm/pixel ground resolution and 80% end lap and 60% side lap of the images. The values for the overlap were bigger than the theoretical ones. This was due to the necessity of great amount of tie and matching points to be detected in the images for image correlation and stereo-modelling. The result was one flight in both directions for 15min. The average flying height was 50m above the ground.

The UAV images were obtained by the late hours of the morning, 11:45am. The weather condition at the time of flighty was sunny, with a light breeze, with no precipitation during flight time. The DJI Phantom 4 Pro flight resulted in 257 geotagged images.

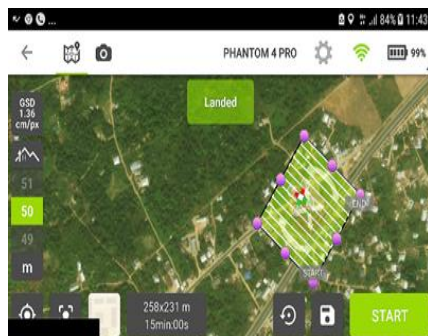


Fig. 6: Flight Planning Interface with the Pix 4D App

b). Data collection using TST

After execution of aerial survey, the TST was employed to obtain spot heights around the stockpile material. This was carried out using the SOKKIA TST and its accessories. The TST was set up on one of the GCPs, and necessary temporary adjustments were performed to bring the instrument to its appropriate working condition. After orientation of the instrument, spot heights were taken around the stockpile.

Observations was carried first by taking spot heights (of approximately 2m) around the stockpile base, then to the middle of the stockpile material and finally to the top of the stockpile material. During observation, the height of the reflector was always taken into cognizant, as it could constitute an erroneous outcome if ignored or wrongly inputted into the system. So as to eliminate error due to changes in target height, a reflector height of 2.00m was maintained during the course of observation.

For the base of stockpile, a total of 32 observations were obtained, while at the top and middle of the stockpile, a total of 45 observations were taken, which sums to a grand total of 77 observations (see Fig. 7). The group of points were documented manually into the field book. These observations were taken between the hours of 11:35GMT to 12:45 GMT.



Fig. 7: Data Acquisition using Convention Survey Method

4. Data Processing and Manipulation

Data processing was carried out in two phases, one being for the UAV data and the other for the TST data.

a). UAV Photogrammetric Data Processing

UAV image processing was performed by the software package called Agisoft Photoscan version 1.2.5, a trial version of 30days. Fig. 8 below depicts the photogrammetric data processing workflow of Agisoft Photoscan.

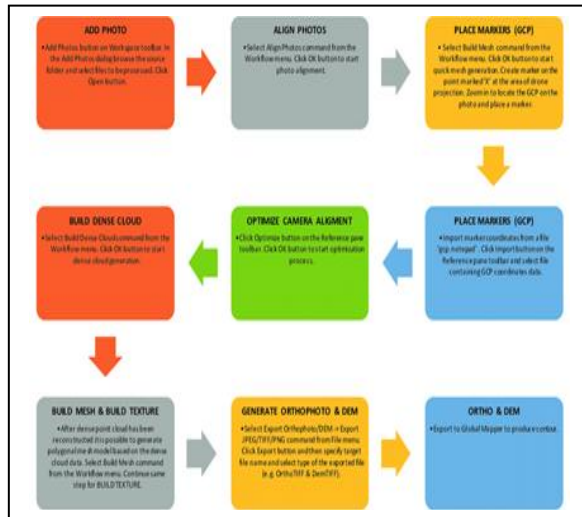


Fig. 8: Workflow of Image Processing in Agisoft Environment

- i. Manual Filtering: Images close or around the AOI was filtered from the 257 images obtained during data capture and a total number of 48 were used.
- ii. Add Photo: Image processing began with importing photos into Agisoft Photoscan environ. This was accomplished by using the 'Add Photos' tool. All photos (48 images), were imported into one chunk. The time taken for this process was 2sec. Also the added photos coordinate system was set to WGS84/UTM zone 32N using the "Convert Tool". The image of the Added photo is as shown in Fig. 9.

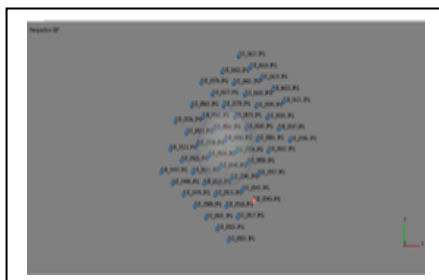


Fig. 9: Added photos

- iii. Image Quality: Once all the images were added up, the image quality of the added photos was estimated. The quality of images ranged from 0.844346 to 0.906621.
- iv. Align Photos: The next step was alignment of the photos. At this stage Photoscan finds the camera position and orientation for each photo and builds a sparse point cloud model. Also after the alignment of the photos, the coordinates of the photos were converted from WGS84 geographic coordinate to UTM projected system. The time taken for this process was 21min 40sec.

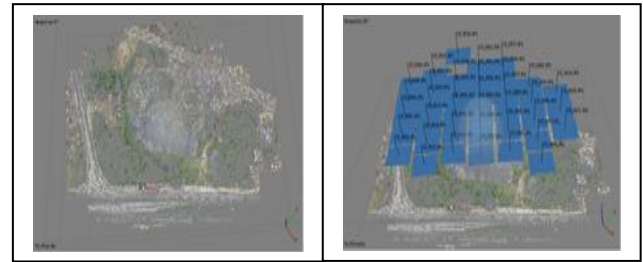


Fig. 9: Photos aligned without and with camera positions

- v. Quick Mesh Generation: Upon completion of the photo alignment process, the next step was to generate a mesh. Processing times ranged for approximately 6sec.
- vi. Place Markers(GCPs): Markers were used for setting up a coordinate system, photo alignment optimization, measuring distances and volumes within the scene as well as for marker based chunk alignment. Marker positions were defined by their projections on the source photos. The more photos were used to specify marker position, the higher was accuracy of marker placement. To define marker location within a scene it should be placed on at least 2 photos. After completion of the mesh, the GCPs points were imported into the environment, then 16 markers were placed and adjusted on the aligned photos, with its right labels. This process took 5min.

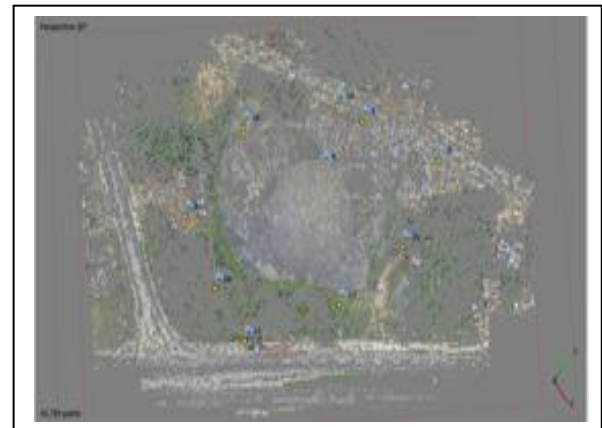


Fig. 10: Placed Markers(GCPs)

- vii. Optimization of Camera Alignment: PhotoScan estimates internal and external camera orientation parameters during photo alignment. The time taken for this process was 2sec. The error obtained was 0.472293(m) and 0.588(pix).
- viii. Build Dense Cloud: The next step was to generate dense point cloud. At this stage, Photoscan finds the camera position and orientation for each photo and builds a sparse point cloud model [7]. The time taken for this process was 5min 34sec., while points

generated were 9,989,658 points. Medium quality setting was used to obtain more details and accurate geometry. Next was to classify the dense cloud, this was carried out to separate the ground and non-ground points. The time required for this process was 2min 25sec.



Fig. 11: Dense Cloud Model

- ix. Build Mesh and Build Texture: After, the completion of the dense cloud, the next step was to build mesh and build texture of the dense cloud model. Processing times ranged for approximately 7min 5sec.



Fig. 12: 3D Model

- x. Generation of DEM and Orthomosaic: Upon completion of the mesh, the next step was to generate a DEM. The time taken for this process was 4min 25sec. Also, the next step followed was to generate an Orthomosaic. Processing times was 02min 10sec.
- xi. Volume Estimation: Finally, for volume estimation using Agisoft, each object must be isolated, this was accomplished by using the 'clip' tool to remove the entire scene except the object to be measured. Once volume was estimated using the UAV data in the Agisoft environment, for comparison sake, the DEM was exported and saved, which was further imported into the ArcGIS environ where contours and volume were obtained also.

b). TST Data Processing

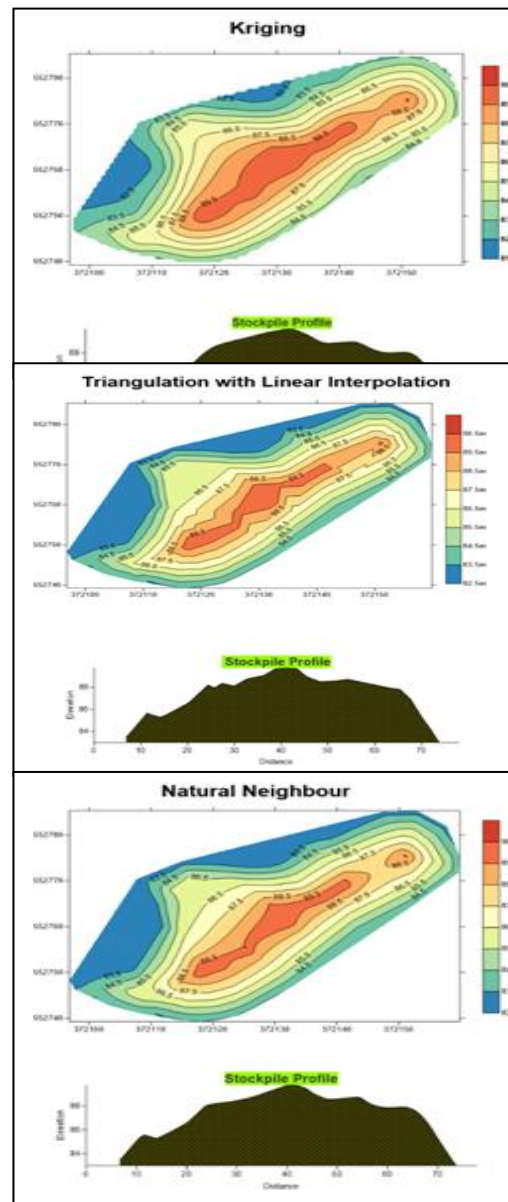
The TST data acquired was manually inputted into the computer. The data was inputted and saved in MS Excel and Notepad environment respectively, also the spot heights were saved separately i.e. top and base of stockpile. The TST data was plotted, and volume was estimated using the following software: Surfer 12, AutoCAD Civil 3D, and ArcGIS 10.4.1 respectively. This enabled comparison to be performed.

i. Using Surfer 12

The steps taken in volume estimation using Surfer software were:

- Gridding
- Contours Generation
- Volume measurement.

Fig. 13 below show the different methods of gridding used.



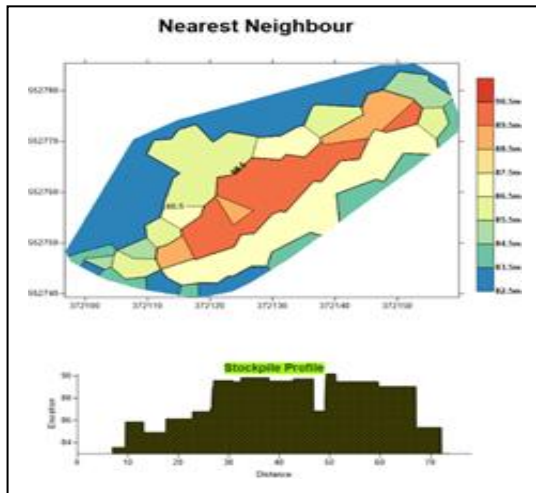


Fig. 13: Contour of Stockpiles in Surfer Environ using different Gridding Methods

ii. Using AutoCAD Civil 3D

The steps employed in volume estimation with AutoCAD Civil 3D software were:

- Import points
- Delineation and TIN generation
- Volume Determination.

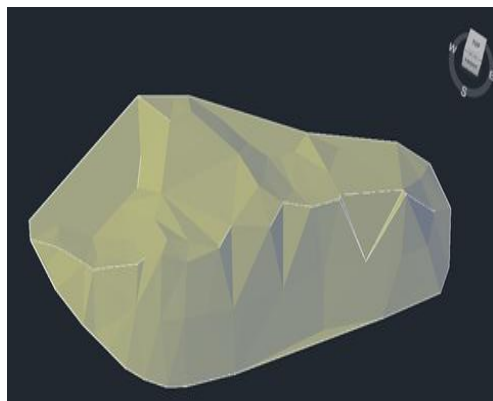


Fig. 14: Conceptual view of TIN generated in AutoCAD Civil3D

iii. Using ArcGIS

Below were the steps taken in volume estimation using ArcGIS software;

- i. Add and plot data
- ii. TIN Generation: To estimate volume, TIN model of the plotted points were generated using the ArcToolbox | 3D Analyst Tools | TIN | Create TIN.
- iii. Volume Estimation: After TIN model production. Volume was estimated in the ArcGIS environ using three (3) different volume computation methods which included surface volume, surface difference and cut and fill.

On completion, the plotted spot heights points of the TST is as shown in Fig. 15.

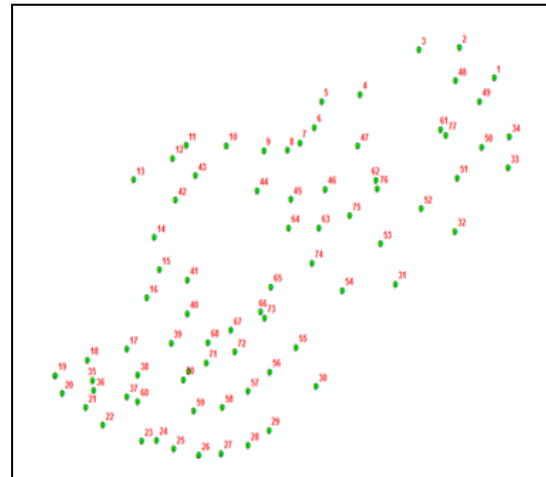


Fig. 15: Plotted Spot Heights of the TST Data

III. RESULTS AND DISCUSSIONS

A. Results and Analyses of Volumes

Due to the different conditions in the methods of the creation of TIN, grids by the various software, there were realistic differences in their respective volumes. These are discussed and analyzed below. The volumes extracted from the various methods were presented differently.

a). Volume obtained from TST Data

i) Using Surfer software

Table I: Volume from the Gridding Methods

| Gridding type | Volume (m ³) |
|---|--------------------------|
| Kriging | 4663.096 |
| Triangulation with Linear Interpolation | 4506.828 |
| Natural Neighbor | 4497.029 |
| Nearest Neighbor | 4730.951 |

ii) Using AutoCAD Civil 3D software

Table II: Volume of TST Stockpile Data in Civil 3D

| Volume type | Volume (m ³) |
|--------------------|--------------------------|
| Cut and fill (TIN) | 4539.28 |

iii) Using ArcGIS software

Table III: Volume of TST Stockpile Data in ArcGIS

| Volume type | Volume (m ³) |
|--------------------|--------------------------|
| Surface volume | 4863.492 |
| Cut and fill(TIN) | 4539.305 |
| Surface difference | 4539.279 |

b). Volume obtained from UAV Data

i) Using Agisoft software

Table IV: Volume of UAV Stockpile Data in Agisoft

| Volume type | Volume (m ³) |
|---------------|--------------------------|
| Polygon shape | 4707.895 |

ii) Using ArcGIS software

Table V: Volume of UAV Stockpile Data in ArcGIS

| Volume type | Volume (m ³) |
|------------------|--------------------------|
| Zonal Statistics | 5202.719 |
| Surface volume | 5194.212 |

c). Analysis of Project Time

The entire project from start to finish took approximately 2 hours, both for the TST and UAV. For the UAV bulky time was consumed during image processing, while in the case of TST, more time was spent during data collection. The study time for both UAV and TST are given in details in table VI and VII.

Table VI: Project Time for UAV

| Process | Time |
|--|-------------|
| Data Collection | 15min |
| Add and Align Photos | 21min 40sec |
| Build Dense point cloud & classification | 7min 59sec |
| Build Mesh & Texturing | 7min 5sec |
| Total | 51min 44sec |

Table VII: Project Time for TST

| Process | Time |
|-----------------|----------------|
| Data Collection | 1hr 10min |
| Data processing | 2min 4sec |
| Total | 1hr 12min 4sec |

d). Comparison of Results from Different Software

TST data: Volume was obtained from Surfer, ArcGIS and AutoCAD Civil 3D software. For ArcGIS, using “surface volume”, its value was about 324m³ different from the other methods (cut & fill, and surface difference method). From Fig. 16 below, the values gotten from AutoCAD Civil 3D, ArcGIS (cut & fill, and surface difference method) seems close with decimated differences not greater than 0.1m. While Surfer (all methods used) gave values not close to that of ArcGIS nor AutoCAD Civil 3D. This attested to earlier results, that surface modelling through TIN yielded more accurate volumes than grid modeling [2].

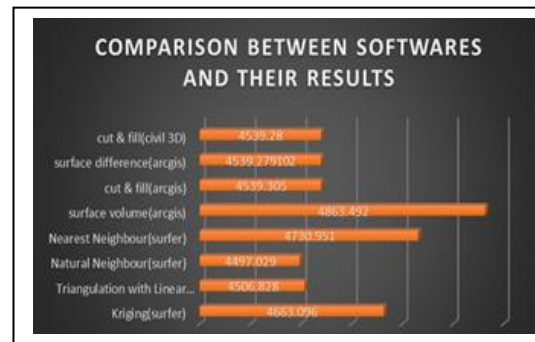


Fig. 16: Comparison between software and Volume Results of TST Data

UAV Data: Volume estimation was carried out using ArcGIS and Agisoft software. The difference between the volume calculated by ArcGIS and that calculated by Agisoft was about 494m³. Fig. 17 depicted the differences between the volumes. It was observed that the large difference between the results of Agisoft and ArcGIS was as a result of the inability of ArcGIS to interpolate the planar height necessary to compute column. This was confirmed by extracting the base height used by Agisoft which was 83.385m to ArcGIS environ and the resultant volume estimated using the Surface Volume method was 4699.625m³.

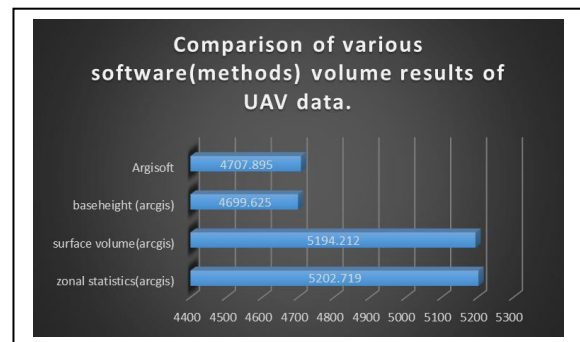


Fig. 17: Comparison of various software and their volume Results of UAV Data

e). Comparison of Time

Comparison of the time used for the two methods (TST and UAV) was carried out as shown in Fig. 18.

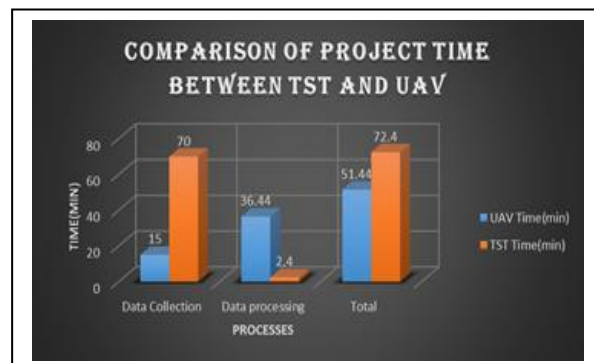


Fig. 18: Comparison between Project Time of TST and UAV

f). Comparison of Accuracy

Accuracy between the two instruments was a bit tedious, since there was no reference result for comparison. But technically, the accuracy could be deduced from the models. Volume accuracy was contingent on denser points and no single points, hence, accuracy would be awarded to that instrument which delivers denser points and a much denser model. In this project, the UAV gave 9,989,658 points, why the TST was 77 points, this points were used to produce models. A critical look at the TIN generated from the TST data depicted large triangles because the density of points was small. Hence, number of points (dense points) played a major role in volume accuracy.

B. Discussions

The traditional method with TST to estimate volumes of stockpile was carefully compared with UAVs data. The post processing was performed in ArcGIS, AutoCAD Civil 3D and Surfer respectively with the data obtained from the TST; while the image processing and volume computation was generated from the UAVs data in Agisoft, and further processed with ArcGIS.

The study period, helped to reveal the instruments that was more effective. During the fieldwork, UAV took lesser time than TST, but in post processing, the TST data were processed faster than the UAV. For the sake of accuracy and effectiveness between the instruments, the shape, size and nature of the environment must be considered. The more irregular the shape of the stockpile, the larger the size of the stockpile and finally the messier or murkier the environment, the worthier it was to employ the UAV.

Accuracy was deduced comparing the models generated by the two instruments and also considering the number of points used for the model generation. It became obvious that UAV produced denser models to TST, and thus UAV was more accurate for volume measurement to TST.

After comparing the results, it was obvious that the TST calculations using ArcGIS, and AutoCAD Civil 3D were better for volume computation than the Surfer since TIN yielded better and more accurate volumes than the grid modelling.

IV. CONCLUSION

Given the successful volume estimation of the materials and the 3% difference between the TST and UAV it was possible to conclude that both methods confirmed to be comparable in terms of accuracy, effectiveness and expenditure of time. The result of this study presents and demonstrates the capability of software in volume computation, and the accuracy, efficiency, and reliability of the Unmanned

Aerial Vehicle, when it comes to volumetric measurements.

“Reference [8] noted that any surveyor using this (UAV) technology will be convinced that aerial survey is a revolutionary improvement to the traditional topography and brings the surveying of difficult-to-reach or potentially dangerous areas within reach”. Hence, the UAV technology could be considered as ‘lateral thinking’ and a new ‘magic wand’ for volume determination in surveying.

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