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Research Article

Application of LIDAR Technology in Oil and Gas Pipeline Route Selection and Optimization

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ABSTRACT

The far reaching advantage of Airborne LiDAR technology in the acquisition of highly dense 3D spatial data for hydraulic modelling and geomorphic studies as well as route analysis, selection and/or optimization etc. cannot be overemphasised. Our aim in this work is to show the significant of extracting coordinates of linear feature from Airborne LiDAR cloud data obtained at low altitude and how these can be used to procure gas pipeline corridor mapping for effective design and implementation. Although the data so obtained can be used invariably to derive various environmental components and derivatives like: DTM, DSM, DEM, TIN, LULC map, contour map, profile map, etc. in accordance with what is demanded or the requirement of the end users. The terrain of study spanning about 27km is (swampy and waterlogged) rendering ground survey methods ineffective. Hence, aerial survey expedition with the aid of Piper Navajo PA-34 airplane coupled with other accompanied equipment were flown. From the point cloud obtained, 1,340 coordinate points were used to generate gas pipeline route alignment, profile and right of way (ROW). Subsequently TIN for the project area was consequently derived. Five route options with total coordinates nodes listing of up to 44 in grand total were extracted and used in best route analysis. Option_5 was selected as the best route after satisfying the conditions imposed for selection.

Keywords: DHM; DSM; Airborne LiDAR; Pipeline survey; Piper navajo PA-34 airplane; Route selection; TIN

INTRODUCTION

Various derivatives can be obtained from airborne LiDAR 3D data as occasion demand by the end users for different applications and/or solutions. For most ground survey work carried out particularly for oil and gas pipeline purposes, the terrain (platform) to stand on, for quality data acquisition has consistently been of great challenge especially in swampy mangrove forest. In recent years the efficacy of LiDAR technology in the acquisition of highly dense 3D terrain data for classification into various components of the environment has been demonstrated. Airborne LiDAR capture everything about the terrain above or below the datum at low altitude (i.e. bare-ground and non-ground features) for a specified project area, hence, it is a nonselective mapping method. LiDAR point cloud constitutesirregular, distinct but interconnected points. Because of the densely populated points algorithms for effective separation of outliers and earth's component filtering is mandatory. The methods of separating bareearth and non- ground points, as required by different area of research interest have been the focus of many researchers in recent years [1-3]. Most of the time, it is not every features captured by airborne LiDAR that are of interest in solving specific environmental problem, therefore the need for filtering is of great importance. For more than two decades as reported by [3], many algorithms have been put forward to tackle filtering of LiDAR data since a lot of time is needed to obtain the DTM from DSM. Further derivation of other derivatives can be accomplished when digital height model (DHM) has been obtained. Therefore DTM realization must be properly achieved in order to prevent other dependent derivatives from prospective errors and/or false interpretation.

There exist various techniques/methods used by researchers for more than two decades with other new ones being proposed to classify LiDAR data. They include: filtering by mathematical morphology as contained in the work of Vosselman, (2000) with its inherent challenges in window sizing and the suggested solutions by [1-19]. Another brand of filtering is what called, the progressive densification of a Triangulated Irregular Network (TIN) used by the following [10-11]. Another approach used is termed segmentation including all its various forms of other combination for example the works of Lin and Zhang, (2014) [14-

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16]. Some studies have investigated the integration of the utility of airborne (LiDAR) data and airborne multispectral imagery for detailed structural mapping of lineament feature for instance [5,13]. Alshawabkeh Y., (2020) utilized the combination of LiDAR and Photographs for extracting linear features from LiDAR point cloud and concluded that interpretation and quantification of weathering activities as well as dangerous cracking were made a lot better.

Legal aspect of pipeline survey in Nigeria

Guidelines and procedure for the construction, operation and maintenance of oil and gas pipelines and their ancillary facilities are issued pursuant to the provision of section 31 of the Oil and Gas pipeline Act CAP 338 of the Law of the Federation of Nigeria (1990). It prescribes the procedure to be followed to obtain all necessary licences and approvals for the construction of oil and gas pipelines, the guidelines to follow during the construction, commissioning, operation and maintenance of pipelines and their ancillary installations. Permit to survey a pipeline route shall be mandatory for the route of the proposed flowline or pipeline to be surveyed or that of an existing pipeline to be re-surveyed before the grant of an Oil Pipeline Licence or the renewal for an expired licence. For the purpose of this work, a Permit to Survey was obtained in accordance with the provisions of Sections (4) and (5) of the Oil Pipeline Act CAP 338.

Legal aspect of flying aircraft for surveying in Nigeria

According to Nigerian Civil Aviation Authority, (2019) report on Nigeria's Airspace Guidance second edition, The Nigeria Civil Aviation Regulations (Nigeria CARs) was first promulgated in (2006) to provide national requirements in line with the provisions of the Civil Aviation Act. About five steps are recommended by NCAA before permission can be granted to carry out aerial (LiDAR) survey in Nigeria. These steps were fufiled, therefore permission was granted to carry out the survey. The steps are readily available in NACA website.

MATERIAL AND METHODS

Study Area

The study area covered about 27km, playing hosts to the Gas pipeline station and the connecting pipeline link. The area fall within 4°45'31.6"N, 6°58'54.2"E and 5°03'40.9"N 7°02'30.8"E.

Figure 1, is a representative map of the study area.

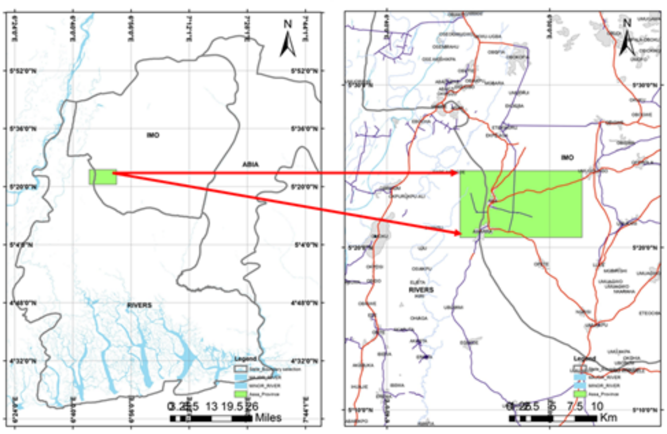

Figure 1: Map of the Study Area.

Description of piper navajo PA-34 aircraft and accompanied equipment

The summary of information regarding the equipment deployed for the work are mentioned here, likewise, Figure 2, shows the pictures of the Piper Navajo PA-34 airplane and the ALTM equipment with brief description (Table 1).

Figure 2: Picture of the ALTM equipment and the Piper Navajo PA-34 air craft

Table 1: Piper Serena airplane Information (Source: Piper Seneca Information Manual, 1972)

S/No	Item	Description	Unit
1	Weights	Gross weight(Ibs) Max Takeoff	4200
2		Gross weight(Ibs) Max Landing	4000
3		Empty weight (Standard) (Ibs)	2625 (Approx.)
4		Useful Load (standard) (Ibs)	1575 (Aprox.)
5	Dimensions	Wing Span (ft)	38.88
6		Wing Area (sq.ft)	208.7
7		Length (ft)	28.5
8		Height (ft)	9.9
9		Wing Loading (Ibs per sq. ft)	20.1
10		Power Loading (Ibs per hp)	10.5
11		Propeller Diameter (in.)	76

- Piper Navajo PA-34 Air craft model with tail number 4X-CBD
- Applanix IMU system
- Aerial Photography systemTrimble Rollei AIC Pro with phase one digital back 39mp size
- LiDAR System Optech Airborne Laser Terrain Mapper (ALTM) 3100 including semiconductor
- laser for making range finder (distance) with pulse repetition

rate up to 100kHz.

- Laser for making range finder (distance) measurements with pulse repetition rate up to 100 kHz.

The seneca airplane and system is made up of a twinengine, all meta retractable landing gear. It consists of seating arrangement capable of accomodating seven crew and two separated luggage compartment respectively. The 400 total horsepower of Seneca engines makes possible a high cruise speed and excellent climb performance. The aircraft is powerd by two fourcylinder, lycoming, fuelinjected engines, each rated at 200 horsepower at 2700 RPM. A symmetric thrust is eliminated during takeoff and climb by counterotation of the engines, the left engines rotating in a clocwise direction when viewed from the cokpit and the right engine rotating counterclocwise (Piper Seneca Information Manual, 1972).

Data acquisition procedure

This LiDAR mapping system along with an Optech Gemini 12bit (Airborne Laser Terrain Mapper) 3100 full waveform digitizer were mounted consecutively in a twin engine Piper PA-34 Navajo Chieftain (Tail Number 4X-CBD),which is an infrared laser mapping sensor (Table 2).

Table 2: The main parameters used in the flight planning.

S/No	Parameter	Specification
1	Laser wavelength	1064nm
2	Range Capture	Up to 4 range measurements, including 1, 2, 3, and last returens
3	Flight height (Altitude)	3100m
4	Pulse frequency	100kHz
5	Scan frequency	35 Hz
6	Scan width (FOV)	±25°

Aerial flight planning

Flight planning for airborne Lidar expedition calls for carefulness in every aspect in order to accommodate both natural and artificial barrier capable of militating against a successful flight operation. A comprehensive and clear procedure to be taken was highlighted by Massimiliano et al., (2018), in any aerial flight plan operation for that matter. Planning is very crucial for a fruitful mission of both manned and unmanned airborne. We considered the following steps before lunching out for proper flight operation:

- Suitable sensor and platform were selected
- The design of flight plan was made and
- We carefully analysis those factors needed to be controlled during flight operations.

Data processing and filtering

LiDAR data can be separated either to Ground or Non-ground features based on the pulse returned as recorded and tagged in the LAS data set (Figure 3).

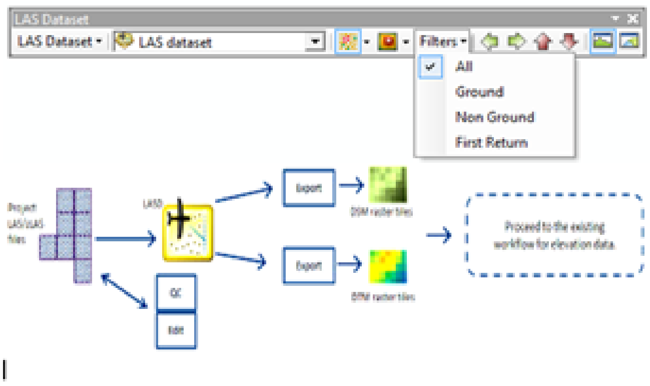

Figure 3: Procedure to obtain filtered surfaces from LAS dataset. Source Esri, (2020)

Steps to create DTM, DHM and DSM raster from LAS dataset in ArcGIS

We implemented the workflow recommended by Esri, (2020) for a scalable, fullresolution raster files in TIFF format in ArcGIS version 10.2, first, by performing Quality Control on the LiDAR files using the LAS dataset. Since the steps in the workflow help create multiple raster tiles having ability to accept large amount of data collections, it is therefore recommended to use the “LAS Dataset to Tiled Rasters” geoprocessing tool to create a single output raster file in the software which we adopted since our obtained LAS data comprise less than 20 GB memory Esri, (2020). The steps we followed are stated as follows:

- Load/Add LAS dataset into ArcGIS 10.2 environment.
- Configure the LAS dataset for bare earth by using the ground filter on the “LAS” file Dataset toolbar. Another way to achieve this is by opening the layer properties in the table of contents pane and then select last returns only with class codes set to “GROUND”
- Run the LAS Dataset to Tiled Rasters tool and enter the following data.
- For the Input LAS Dataset, drag the LAS dataset layer from the table of contents into the geoprocessing tool. Care must be taken not to reference the LAS dataset from the ArcCatalog pane or else the filter for ground points will not be applied.
- Under LAS Values to Export, choose Elevation.
- Under Output Destination, enter the folder to store the DTM/DSM tiles.
- Under Output Base Name, you can enter a common base name for all tiles, such as “Asa North_DTM” or “Asa North DSM”. Unique tile numbers will be appended to the base name for each DTM tile, stored in TIFF format.
- For Cell Size, input the resolution for the DTM tiles as determined in the preliminary step undertaken for Quality Control.
- Under Z factor, enter 1. Any other value will rescale the z-values of the output DTM. If the lidar data is recorded

in feet, multiply by 0.3048 will rescale the values to meters, but it is generally recommended to build all raster surfaces in the coordinates of the source data to facilitate Quality Control, and then their height values can be rescaled in the later elevation workflow.

- Under tool option, set Interpolation Type, Under Interpolation Options/Void Fill Method, use the setting determined above. The recommended selection is Natural Neighbor, assuming you have a polygon to define the usable data extents, Under Tiling Options/Tile Overlap in Pixels, it is recommended to use the default value of 64. This is particularly useful in case one need to reproject. For Tiling Options/Tile Definition, choose Columns and Rows if you want the tool to generate tiles automatically, or choose Features if you have an existing feature class to define the boundaries and names of the output DTM tiles. For the tool options, under Interpolation Options/Interpolation Type, the typical selection is Bin with Maximum Value for the DSM.
- Use the Raster Storage environments recommended setting to build pyramids for these DTM tiles. Choose bilinear resampling and LZ77 compression. After the tool successfully runs, it will create a set of DTM tiles that may be processed as a new elevation data collection, as described in elevation best practices.

RESULTS

The results obtained are categorized into three basic map derivatives: First the generation of the DTM and DHM from the DSM; the production of the TIN for the selected pipeline best route and the procedure for best route extraction and selection.

Generation of DTM and DHM Integrated map

Depicts the DTM and DHM map which shows the bareearth and the gas pipeline main station in connection with the adjoining linking pipeline (from source to destination) at glace based on the selected best route which are made possible from the generated DHM by filtering. This map is very useful because information not needed such as tree canopies, buildings, electric poles and towers etc. have been removed. Hence, only the information needed is duly captured and represented (Figure 4).

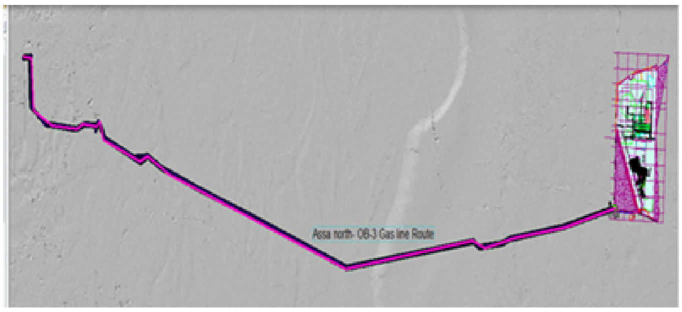

Figure 4: DTM and DHM map

Generation of TIN for extracted gas pipeline route

Figure 5 shows the triangulated irregular network (TIN) generated from a total number of 1,340, filtered points which were concatenated and prepared in excel and added to ArcGIS 10.2 for delineating the extent of the pipeline route right of way (ROW). The elevation was re-sampled to five classes with the lowest and highest being recorded elevation being 8.5 and 46.6 respectively.

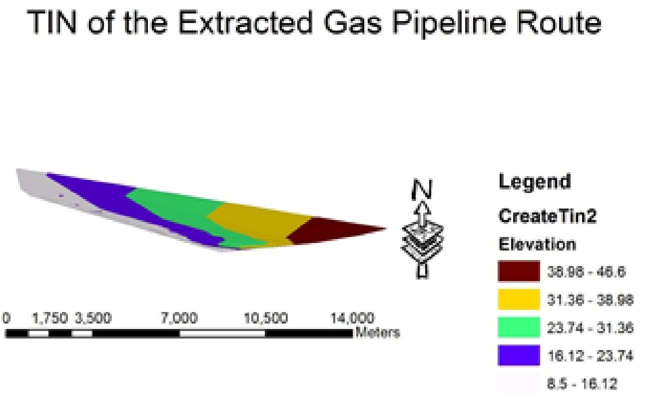

Figure 5: TIN of the Extracted Gas Pipeline Route

Best pipeline route analysis and selection

The analysis and selection of best route for effective hydraulic flow and avoidance of interference with urban developmental plan was a demanding exercise. Figure 6 demonstrated the steps taken in order to arrive at our selected best route for the pipe laying work. Five attempts were made with imposed conditions which must be satisfied.

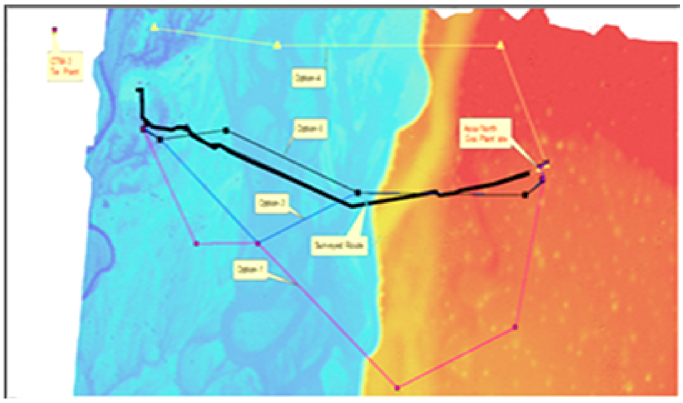

Figure 6: Route analysis and selection

DISCUSSION

First the coordinates for each option were extracted along a definite path and the shortest distance computed within a Euclidean space. Codes were assigned with the possibility of some common intersections. The coordinates of points forming intersecting nodes and those of points with peculiar identification per route options were carefully separated for clear understanding. Route option_1 has nine extracted coordinates, option_2 has eight extracted coordinates, option_3 has ten extracted coordinates, and option_4 consists of seven while option_5 consists of ten coordinates points respectively. A total sum of forty four coordinates' points was altogether extracted. The coordinates with at least two intersecting nodes are up to eleven in numbers, while the coordinates of points peculiar to specific route option are up to six in numbers. For each option, these coordinate points were connected with polyline lines to bring out the shape of the route overplayed on the DTM map. Computation of route geometry was done in ArcGIS to determine the length of coverage in each route option. The summary of this analysis is as presented in Table 3.

Table 3: Extracted coordinates used in Gas Pipeline route selection and optimization.

Option_1	E (m)	N (m)	Option_2	E (m)	N (m)	Option_3	E (m)	N (m)
A	482379	152008	A	482379	152008	A	482379	152008
B	482170	151883	B	482170	151883	B	482170	151883
P	471315	149694	R	463512	155821	D	481582	151089
R	463512	155821	I	467341	155947	P	471315	149694
C	482232	151535	J	469352	159029	R	463512	155821
Q	468937	149687	M	480637	155431	E	475158	151149
S	466925	152984	T	468574	157727	G	467566	152679
O	476662	145543	K	479208	158936	C	482232	151535
N	481194	147279				S	466925	152984
						H	467027	153149
Total Coordinates Extract=9			Total Coordinates Extract=8			Total Coordinates Extract=10		
Option_4	E (m)	N (m)	Option_5	E (m)	N (m)	Nodes Common To Route Options:		
A	482379	152008	A	482379	152008	Option (1, 2,3, 4 and 5)		A, B and R
B	482170	151883	B	482170	151883	Option (1, 3 and 5)		C
R	463512	155821	D	481582	151089	Option (3 and 5)		D
L	472064	155418	H	467027	153149	Option (3 and 5)		E
M	480637	155431	R	463512	155821	Option (3 and 5)		G
T	468574	157727	E	475158	151149	Option (3 and 5)		H
I	467341	155947	F	470106	152944	Option (2 and 4)		I
			G	467566	152679	Option (2 and 4)		M
			C	482232	151535	Option (1 and 3)		P
			S	466925	152984	Option (1, 3 and 5)		S
Total Coordinates Extract=7			Total Coordinates Extract=10			Option (5)		F
						Node Peculiar To Route Options:		
						Option (2)		J
						Option (2)		K
						Option (4)		L
						Option (1)		N
						Option (1)		O
						Option (1)		Q
Grand Total of Extracted Coordinates=44								

Table 4, represents the summary of the Option_1 route could not be selected as the optimal route because, it only satisfied conditions 1 and 4 but failed to fulfil others set conditions. Route Option_2 could not be selected also because it satisfied conditions 1, 3, and 5 but failed to meet conditions 2 and 4. Besides, Route Option_3 failed to satisfy conditions 1, 2 and 5 even though it satisfied condition 3 and 4, therefore it was not selected. Furthermore, Route Option_4 quite satisfied conditions 1 and 2 but did not satisfy condition 3, 4 and 5 so it was not rejected. Finally Route Option_5 satisfied the required conditions 1, 2, 3, 4 and 5 adequately therefore it was selected as the best route for the pipe laying and construction work with minimal cost implication safety, environment and security.

Table 4: Summary of Imposed conditions for on Optimal Route Selection

Route Option_ ID	Route Option Length (km)	Proposed length (km)	Difference (km)	Cost Implication (₦)	Optimal Route Alternative	Assign Code
Option_1	40.2	27	13.2	20,00,00,000	1,4	1
Option_2	35.1	27	8.1	17,00,00,000	1,3,5	2
Option_3	30	27	3	16,50,00,000	3,4	3
Option_4	35.06	27	8.06	16,90,00,000	1,2	4
Option_5	27.12	27	0.12	13,00,00,000	1,2,3,4,5	5
Note: Condition (1)=Safety; Condition (2)=Security; Condition (3)=Construction; Condition (4)=Environment; Condition (5)=Cost						

CONCLUSION

This work which utilizes airborne LiDAR technology for indiscriminate 3D spatial data acquisition has been carried out successfully over the study area and the results obtained from the analysis carried out produced the DHM and the DTM respectively. Because LiDAR data are non-discriminating, several derivatives can be obtained even if it is after thought incorporation. Data can be scrutinized and extracted for different purposes. Finally, pipeline route analysis implemented showed the capability of LiDAR data as a tool in route selection and optimization.

RECOMMENDATIONS

- LiDAR technology is a good option to look out for when the terrain is poor and rugged.
- With availability of LiDAR data, unnecessary repetition and extension of ground survey work may not be required as data can be extracted from previous airborne survey expedition.
- If data requiring DSM at low altitude is highly needed, then LiDAR technology is a very good option to consider.
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- With availability of LiDAR data, unnecessary repetition and extension of ground survey work may not be required as data can be extracted from previous airborne survey expedition.
- If data requiring DSM at low altitude is highly needed, then LiDAR technology is a very good option to consider.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare in this work.

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