Application of Trilateration Principle in Determining Optimal Call Locations

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Abstract

The trilateration principle, from a surveying or geomatics perspective, has significant applications in numerous industries, including the telecommunications sector. Because the navigation and wireless positioning techniques rely on electromagnetic energy propagated through the antenna and other communication devices mounted on telecoms tower (mast), the intersection of the signal circles of influence emanating from the masts installed in relation to each other on the Earth's surface plays a crucial role in determining the precise location of a mobile phone in order to make calls optimally. In this paper, we solved the trilateration algorithm problem using a function that accommodates twenty-seven (27) parameters in Python programming environment. The eight masts involved were paired into set of threes to form the interactions which produces the intersection point coordinates outputs. Mast 1 has the longest radius of length (476m) while mast 5 has the shortest radius of length (148m) from their respective circle centre. The intersection points of the cell tower's signals were discovered to be at the following coordinates: (789138.305E, 708318.903N; 789452.452E, 708368.940N; and 790157.613E, 707791.055N), which allowed the identification of three locations as the best positions for exhibiting optimised cell phone calls.

Keywords: Cell Phone, Cell Tower, GNSS, Telecommunication, Trilateration

INTRODUCTION

An antiquated technique of surveying used in ground control surveys for control extension, breakdown, densification, and other purposes is the principle of trilateration, in which the measured parameter of interest is only the distance. Different transformations have occurred in how this principle is applied over the years. Trilateration determines the lengths of the sides of a triangle rather than the angles as in the case of triangulation by using known distances measured with tape or electromagnetic distance measuring instruments (Sturges and Carey, 1987). Applying trilateration requires the participation of at least three known points (X, Y, and Z) to locate an unknown point (D). A circle whose radius equals the known point's distance from D is located at its center. The point of intersection of the three circles falls more or less precisely at the position of D. However, the accuracy is a function of how precise the measured distances are to the unknown point D.

According to STEM (2018), the principle of trilateration gains more relevance when it finds application in satellite ranging as an innovation capable of finding the position of a GNSS receiver from three distances. The travel time of an electromagnetic signal that is synchronized between the satellites and an observer on Earth's surface can be calculated when the positions of the satellites in the constellation are known, along with their distances, which cannot be directly measured but can be modeled (Wells *et al*., 1986). Because the satellite signal only intersects at one specific point, it is possible to fix the receiver's position precisely. In terms of positional accuracy, the more satellites that were tracked, the better (Zahradnik, 2021; Correa-Muoz and Cerón-Calderón, 2018).

The trilateration principle has also been applied in indoor wireless positioning in the electrical and electronic engineering fields, for example (Javaid *et al*., 2015; Dilibe *et al*., 2017; Tamas and Toth, 2019), but that is not the main focus of this paper. Instead, the surveying/geomatics aspect of the application of trilateration is explored.

Martinka (2019), emphasised the importance of telecommunication networks as part of the critical infrastructure of every country, necessary for successful coordination of operations and provision of emergency services. Because of the possibility of potential strategic attacks and competition between service providers, the general public does not have access to official information about the base stations in the network (Martinka, 2019). The topology of the network can be used commercially for location-based services based on available cellular networks, and new positioning algorithms can be further researched (Martinka, 2019).

The positioning techniques for wireless communication comprise the following (Martinka, 2019): (i) Global Navigation Satellite System-GNSS; (ii) WiFi access point; (iii) Bluetooth beacon; (iv) Mobile network connection comprising (Timing advance-TA, Angle of arrival-AoA, Time of arrival-ToA, Time difference of arrival-TDoA, Weighted centroid, Received signal strength-RSS; Fingerprinting).

In Nigeria, the mandate to regulate telecommunication activities was enshrined in the Nigerian Communications Commission (NCC) Act of 2003 and the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act of 2007. The two agencies are in charge of enforcing environmental standards, rules, regulations, policies, and guidelines for the telecoms industries (service providers), as well as making sure that environmentally friendly practices are followed and that public health and safety are protected.

The goal of this study is therefore to determine the most advantageous call-making locations within the study area using the trilateration method implemented in Python from a geomatics/surveying perspective, and to evaluate its efficacy.

The Role of the Telecommunication Towers

Cell towers or cell sites, as defined by Millman National Land Services (MNLS, 2016), are locations with mounted electric communications equipment and antennae that enable wireless communication for devices like radios and cell phones within their range. According to (MNLS, 2016), there are four different types of cell towers: lattice towers (also known as self-supporting towers), monopole towers, guyed towers, and stealth towers. Each having their merits and de-merits.

A communication tower can be categorised as single, double, triple, or multiple depending on how cell phone negotiations is concerned. In comparison to rural areas where they are spread out, cell towers are typically located close to each other in densely populated urban areas. Therefore, the former allows for a more accurate estimation of cell phone location than the latter. A typical telecom base station serves the following purposes: (i) cellular communication; (ii) wireless access point; (iii) charting and navigation; (iv) mediation between communication devices; (v) enabling shared infrastructure; and (vi) allowing for cell phone handover. Figure 1 portrays the prototype of how cell tower density in rural, urban, and densely populated urban centre.

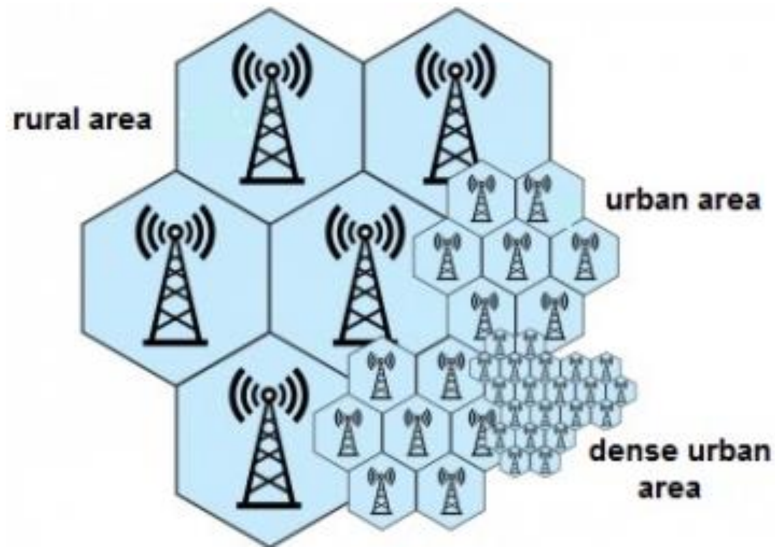

Figure 1: Cell density and sizes in different area. (Source: Martinka, 2019)

The Role of the Cell Phones

Here, the emphasis is on the function that a cell phone performs in the context of trilateration or multilateration. Numerous technologies are already built into a cell phone, including a gyroscope, Bluetooth, GNSS, WiFi, an accelerometer, a compass, and more.

Whenever a cell phone is put to use, it emits an electromagnetic radio wave (radio frequency) that is received by the nearest cell tower's antenna. Within a few microseconds of receiving the transmitted signal, the cell tower will transmit the signals to a switching center. This allows the call to be connected either to another mobile phone or a telephone network for an effective call-making experience (The HFT Guy, 2017). The cell phone will choose the strongest signal and release the weaker cell tower in the middle of a call experience as a user travels from one location to another (MNLS, 2020; The HFT Guy, 2017). This makes the weaker cell tower available to another caller.

The process of switching from one serving cell to another by a cell phone is called handover (Munir, 2005; Martinka, 2019). For a handover to take place effectively, the cell phone must be in simultaneous negotiation with at least two or three towers, though mutilateration involving multiple cell towers is also a possible option (The HFT Guy, 2017). Figure 2 shows the case of negotiation between a cell phone and two cell tower (masts).

METHODOLOGY

Study Area

The study area for this research is the University of Benin, Ugbowo Campus. Its location falls within the boundary between Egor LGA and Ovia North-East LGA of Edo State. The University of Benin is one of the premier universities in Nigeria. It was established in 1970 and upgraded to a full-fledged tertiary institution on July 1, 1971, when it received approval from the National Universities Commission (Oladosu and Muhammad, 2022). The geographic location of the campus in the Universal Transverse Mercator Zone 31-North has the listed coordinates: (788913.00mE, 707969.15mN; 790343.31mE, 708142.27mN). In sites A and B, this campus has a total land mass of about 200,000 hectares. Figure 3 shows the Google Earth extract map of the study location and the immediate surroundings.

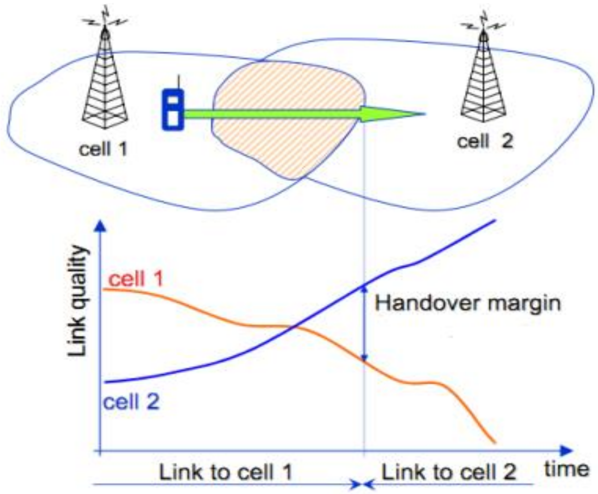

Figure 2: Handover process between cell phone and telecom masts (Martinka, 2019)

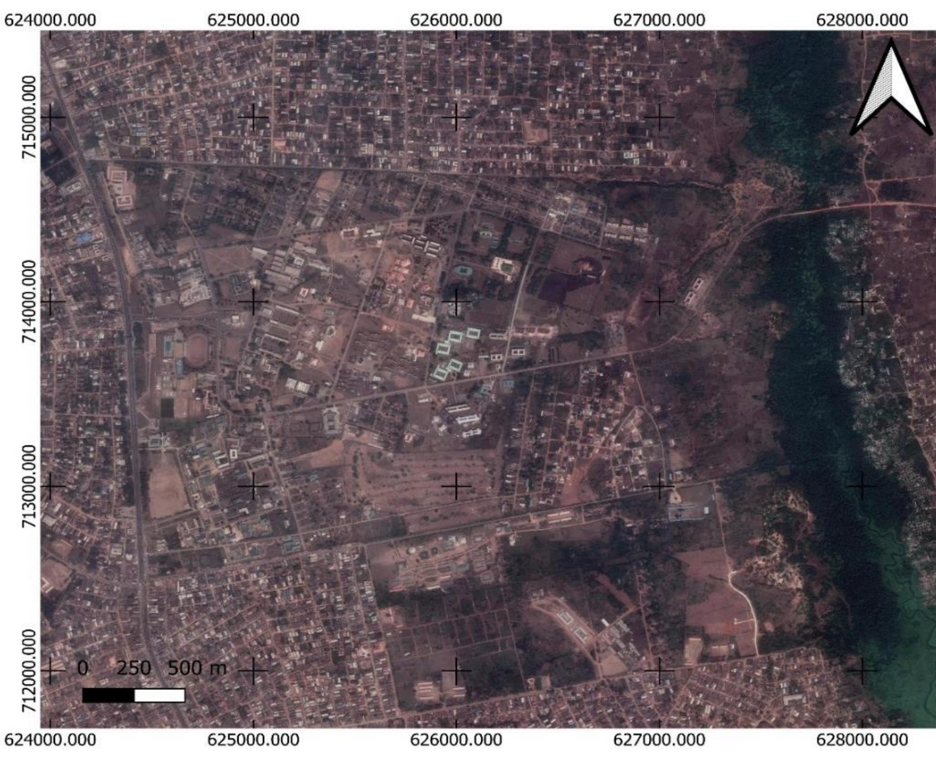

Figure 3: Google Earth map showing the study location

Data Acquisition

There are two phases to the data acquisition process. We employed Trimble R8 GNSS in the first phase and Trimble M3 DR Total Station in the second phase. The accuracy of RTK GNSS observation can be affected by radio signals (Dawidowicz and Barya, 2017; Rougerie *et al*., 2012), so the GNSS cannot be used solely to carry out the entire data acquisition, therefore, the Total station was incorporated. For the first phase, the GNSS base receiver was set on an existing control with the inscription "GPS 100" on campus and the rover receiver was used to transfer two points each close to all the telecom base stations in RTK mode. At the second phase, the established points were subsequently used for Total Station orientations and observations in connection with a reflector to acquire the coordinates of the masts centre. This procedure was followed to determine the centre coordinates of the eight telecom masts involved in the entire process to prevent radio signals from degrading the quality of the acquired data.

Data processing

A flash drive was inserted into the Total station to download the coordinates, which was later imported to a personal computer to retrieve the coordinates. These coordinates were saved as a.csv file and further used for design, processing and other editing work in AutoCAD 2016. Figure 4 shows the AutoCAD output of the radius of impacts, including the baselines and the links. Figure 5 depicts the flowchart to aid in executing the trilateration process.

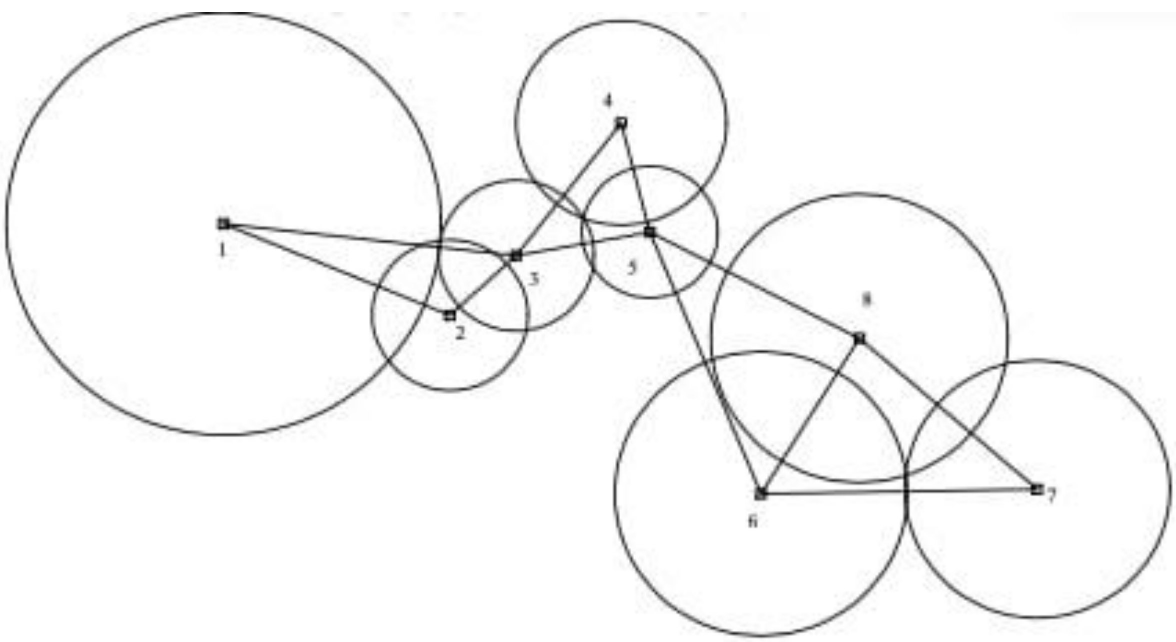

Figure 4: Cell towers interaction plot extract

Implementation of Trilateration Algorithm in Python

As soon as the needed data (Eastings and Northings) of necessary points were derived, a Python programme was written to execute the algorithm for trilateration to determine the unknown points. The Python algorithm uses a function that accommodates twenty-seven (27) parameters and return the (E and N) coordinates of the intersection point of the three sets of circles involved. Because a cell phone constantly emits roaming radio signals that may be picked up by three or more cell towers, trilateration calculation could estimate the coordinates of a mobile device using the (E and N) coordinates of the nearby cell towers and the estimated distance of the device from the cell towers. This process can make use of either signal strength or measured time delay in signal propagation between the towers and the cell phone (101computing.net, 2019). The mast were paired in three each to achieve the trilateration equations used in determining the coordinate of the unknown points. Equations (1-10) simplify the breakdown of the procedure and steps taken to derive the circle equation using easting and northing coordinates and the subsequent feeding of the appropriate inputs to the algorithms for the implementation. Table 1 contains some relevant input parameters used to form and run the complete Python codes.

$$(E - E_1)^2 + (N - N_1)^2 = r_1^2 \quad 1$$

$$(E - E_2)^2 + (N - N_2)^2 = r_2^2 \quad 2$$

$$(E - E_3)^2 + (N - N_3)^2 = r_3^2 \quad 3$$

Open brackets and expand the squares in equations (1-3) to get equations (4-6)

$$E^2 - 2E_1E + E_1^2 + N^2 - 2N_1N + N_1^2 = r_1^2 \quad 4$$

$$E^2 - 2E_2E + E_2^2 + N^2 - 2N_2N + N_2^2 = r_2^2 \quad 5$$

$$E^2 - 2E_3E + E_3^2 + N^2 - 2N_3N + N_3^2 = r_3^2 \quad 6$$

Subtract equation 5 from equation 4 similarly, subtract equation 6 from equation 5 to get equations 7 and 8

$$(-2E_1 + 2E_2)E + (-2N_1 + 2N_2)N = r_1^2 - r_2^2 - E_1^2 + E_2^2 - N_1^2 + N_2^2 \quad 7$$

$$(-2E_2 + 2E_3)E + (-2N_2 + 2N_3)N = r_2^2 - r_3^2 - E_2^2 + E_3^2 - N_2^2 + N_3^2 \quad 8$$

We can rewrite equations 7 and 8 concisely to form equations 9 and 10 using the alphabets G, H, I, J, K, L as follows.

$$\left.\begin{array}{l} G_E + H_N = I \\ J_E + K_N = L \end{array}\right\} \quad 9$$

$$\left.\begin{array}{l} E = \frac{IK - LH}{KG - HJ} \\ N = \frac{HJ - GL}{HJ - GK} \end{array}\right\} \quad 10$$

Where: E and N are the final easting and northing of the required intersection points of the participating circles in meters.

This procedure was repeated for the second set of three telecom masts and the third set of telecom masts to determine the eastings and northings coordinates of the optimum call locations at the respective circles overlap points.

Table 1: Input parameters

Telecommunication Masts Attributes					
Mast_ID	Easting (m)	Northing (m)	Radius (m)	Mast Link	Link Dist. (m)
1	788664.013	708356.770	476	1-2	536.69
2	789159.610	708150.806	170	1-3	644.36
3	789304.416	708285.473	170	2-3	197.80
4	789534.566	708583.739	230	3-4	376.69
5	789597.207	708338.420	148	3-5	297.54
6	789840.957	707749.038	320	4-5	253.19
7	790445.226	707759.202	290	5-6	637.80
8	790055.942	708099.153	325	5-8	517.42
9	N/A	N/A	N/A	6-7	604.35
10	N/A	N/A	N/A	6-8	410.85
11	N/A	N/A	N/A	7-8	516.83

Implementation of Python for Trilateration

Python is an open-source and one of the most significant programming languages being used globally, with its invention and development credited to Guido van Rossum in 1991 (Srinath, 2017; Dhruv *et al*., 2020). It is a high-level, interpretive, all-purpose, dynamic programming language that places a strong emphasis on code readability. It also includes built-in features for easy handling and problem-solving for any mathematically inclined problem (Chakraborty, 2021). Figure 6, represents a sample of the trilateration algorithm implementation interface in Python.

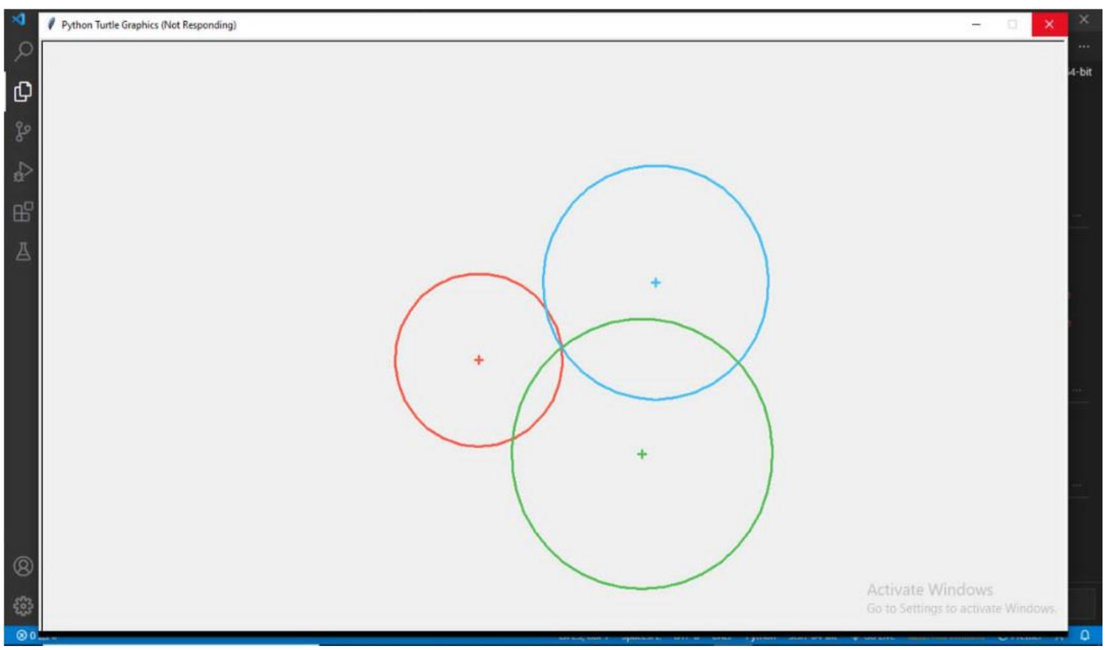

Figure 6: Trilateration implementation interface in Python (GUI)

RESULTS AND DISCUSSIONS

The following coordinates shown in Tables 2-4 were derived from the output of the trilateration algorithm implemented in Python. These outputted coordinates were automatically executed when running the codes to determine the optimised positions at the overlap of the three circles formed by the radius (distance) from the centre of the mast to the unknown (required call location). The configuration of first sets of participated masts involved masts (1, 2, and 3), their respective easting and northing coordinates. The output coordinates are shown in Table 2. Similarly, the configuration of second sets of participated masts consists of masts (4, 5, and 6), their respective easting and northing coordinates, and the output coordinates are shown in Table 3. Finally, the configuration of third sets of participated masts involved masts (6, 7, and 8), their respective easting and northing coordinates, and the output coordinates are shown in Table 2. In Table 5, the summary of the output of the combined optimised call location are shown.

Table 2: Configuration of first sets of participated masts

Mast_ID	Easting (m)	Northing (m)	Participated Masts	Output “E (m)”	Output “N (m)”
1	788664.013	708356.770			
2	789159.610	708150.806	1, 2, 3		
3	789304.416	708285.473		789138.305	708318.903

Table 3: Configuration of second sets of participated masts

Mast_ID	Easting (m)	Northing (m)	Participated Masts	Output “E (m)”	Output “N (m)”
4	789304.416	708285.473			
5	789534.566	708583.739	4, 5, 6		
6	789597.207	708338.420		789452.452	708368.940

Table 4: Configuration of third sets of participated masts

Mast_ID	Easting (m)	Northing (m)	Participated Masts	Output “E (m)”	Output “N (m)”
6	789840.957	707749.038			
7	790445.226	707759.202	6, 7, 8		
8	790055.942	708099.153		790157.613	707791.055

Table 5: Summary of optimised call locations

S/No:	Easting (m)	Northing (m)	Remark
1	789138.305	708318.903	Located
2	789452.452	708368.940	“
3	790157.613	707791.055	“

To verify, the effectiveness of the process done by inputting the respective output coordinates in Table 5 into the GNSS data logger (Controller). The optimised locations were navigated to and three phones (Nokia G20, Tecno F1, and Gionee S12) from different manufacturers were tested to make calls around the optimised positions and at other locations farther apart from the center of interaction of the circle of influence of the participating cell towers already identified. It was discovered that while calls were always successful with optimal call quality in the optimised locations, at other farther locations, occasional call drops and degradation in call quality were sometimes experienced.

CONCLUSION AND RECOMMENDATIONS

The procedures for locating optimal call locations using trilateration approach was carefully followed and successfully executed. The coordinates of the optimised locations were extracted and presented. Trilateration and by extension multilateration are critical to location-based services and other navigation information both to the telecommunications operators and the mobile phone users. This technique can be applied in a number of areas such as crime scene detection, rescue mission, subscribers cluster identification, security watch etc. Other common criteria for measuring call quality not investigated in this work but can be researched further within the study area are latency, jitter, and packet loss. For optimal citing and installation of cell towers for good coverage, we recommend the service of a professional Surveyors/Geomaticians especially in Nigeria because they are trained and as well have overwhelming understanding of the background knowledge of applying this practical field measurements to solving real life problem.

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