Advanced Concepts in Geomatics Engineering: A Deterministic Approach to Solving Problems of Geo-Based Systems

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Abstract

The use of maps as tools in assisting professionals and ordinary people in providing firsthand information on locations of objects and as a guide to their destinations until last two decades has been bedevilled by its several shortcomings. Being analog in nature, updating, scale variation and coordinate transformation are among the several identified difficulties.

With advancement in technology since the last two decades, the ease with which integrated systems have been assisting in providing alternative solutions to decision makers cannot be overemphasized. To a business oriented enterprise or an individual, time is crucial. Since a time lost cannot be regained, therefore, this paper discussed the need for providing real time spatial information in solving several man-environment (geo-based systems) problems. Firstly, sensors integration in advanced concepts in geomatics engineering was discussed, samples of some researches in advanced concepts in geomatics engineering were highlighted and finally empirical applications of GPS/GIS integrated systems, in adding value to map by providing real time information for navigators and monitoring of assets, were carried out. Results obtained from the two Assisted GPS (A-GPS) techniques, GPS Vehicle tracker and GPS Navigator, despite the harsh urban environments in Lagos, where multipath error is predominant, have been remarkable. Empirical analysis showed a maximum horizontal error not exceeding 5metres. This study has confirmed the reliability of Advanced Concepts in Geomatics Engineering in providing deterministic real-time solutions to many geo-based systems.

Keywords: Geo-based systems, Global Position System (GPS), Geographic Information Systems (GIS), Assisted GPS (A-GPS), Value-added map.

1.0 . INTRODUCTION

Surveyors have perfected the art of producing maps and charts of varying scale and accuracy over the years, however, what is of social and economic importance today is the value added to the map. Unfortunately, many surveyors in developing economy, including those in charge of training have not fully appreciated the meaning of value added maps. Today in all aspects of surveying, computerization is causing big revolution in both the methods and instrumentation, thereby making the operations easier, the methods more flexible, the cost cheaper, the results more accurate and the applications more marvelling- thus resulting in the production of value-added maps.

A value-added map is one that portrays the spatial distribution or trend of issues and events which are of value to an individual, a corporate organization or government. Put in a technical perspective, a value added-map is a base map enhanced to show items of value, which are located in space. Fortunately, the training of a surveyor puts him at a vantage position to carry out the mappings of many of the map based values commonly required for environmental monitoring and resource management activities, for social, economic, commercial, engineering and political decision making processes [1].

This paper discuses sensors integration in providing real-time value-added spatial information.

Some researches carried out, based on advanced concepts in Geomatics Engineering, in solving problems in geo-based systems such as; WebGIS, optimal route planning, modelling hydrological functions, digital elevation model (DEM), modelling forest fire prone areas, optimal location of landfills for municipal solid waste (MSW) disposal, Line-of-Sight (LOS) and telecommunication signal strength mapping, 3D modelling/facility mapping (underground or on the earth surface) and air pollution mapping were briefly discussed. Finally, locational and travel time accuracy attainable by the integration of GPS, GIS and Communication devices for real-time tracking of mobile assets and navigation of commuters on some roads in Lagos Metropolis were determined. The travel time accuracy determination was based on Floyd–Warshall algorithm for Dynamic Programming of Shortest Path. Some Points of Interests (POIs) and Location Based Services (LBSs) were mapped. The two (2) Assisted GPS (A-GPS) systems, GPS Vehicle tracker and GPS Navigator, were integrated with GIS on a moving platform (vehicle) to carry out the comparisons. Topology of the street network map was created to allow for network analysis in order to optimize routes from origins to destinations. Availability of valid GPS position fixes on the two (2) systems was consistent and was above 95%. The Navigator recorded a maximum horizontal error of < 2m while the GPS Vehicle tracker recorded < 5m.

2.0 . WHAT IS VALUE-ADDED SPATIAL INFORMATION?

According to [1], the space-time system is thus a continuum having the three dimensions of space and that of time in which any entity or event can be located. The practical realization of the space-time system for our global earth is achieved by choosing the first two locational axes as lines running along the great circles of the earth and labelled as latitude and longitude (φ and λ in angular units). This pair of values (φ, λ) locates uniquely any entity on the earth surface. With the first two axes defined, the third locational axis is often left free for the user to assign a definition (v) depending on the type of description to be made about the entities or events of interest. For example, it can be chosen to represent the heights of surface points above the Mean Sea Level (MSL). It can also denote the amounts of rainfall; population density; customer preference for a product; severity levels of the incidence of an epidemic; traffic; colour; temperature; noise levels; pollution levels; features; available facilities such as petrol stations, shopping malls, schools, communication masts; etc. This third axis is often used to define the **attributes of objects**, which may be described as **values for the map**.

The fourth dimension to these measures is the time *t*. The time dimension is selected based on some observable epochs such as the passage of celestial objects through specified points within the space. The time unit is denoted as *t* in seconds and can be conceived as the distance of the event from a selected epoch. This time scale (axis) is constantly a dynamic axis that changes often. For a value-added navigable spatial information, the time scale can be defined as which route is the shortest to a destination based on certain time constraints? What food is available in the nearest restaurant to my office at a particular time? Which mobile telecommunication mast is to serve region Y at what time? Which fuel station has gasoline with fewer queues at a specified time? and so on. These are all real-time based spatial queries that require immediate intelligent answers in order to take a decision. This **"what-is-where-at-a-time"** intelligent spatial results obtained has transformed the duty of traditional surveyors from just a geodata provider to a decision-assisted spatial information provider i.e. geomatics engineers.

Therefore, these time based values are mapped using suitable simple social survey methods and are attached to the other locational and attribute measures (φ, λ and v) to obtain a real-time valued added spatial information (φ, λ, v, t) to solve problems of geo-based systems such as navigation by mobile subscribers (Fig. 1).

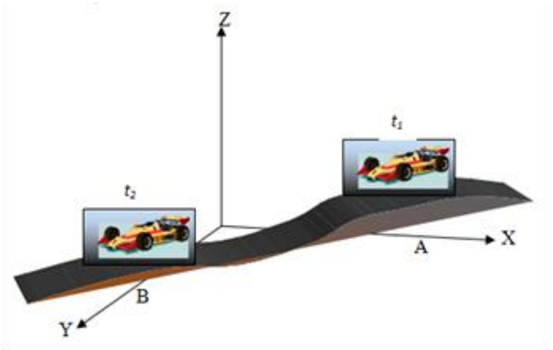


Fig. 1. Shows 4-D Navigation of a Vehicle on motion.

-At time t_1, the vehicle was at A having X_1, Y_1, Z_1 and t_1 coordinates, but
-At time t_2, the vehicle is now at B having X_2, Y_2, Z_2 and t_2 coordinates.
Navigation from A to B is a function of position and time differential (i.e. $t_2 - t_1 = \Delta t$). For a real-time

application, spatial-temporal analysis is usually required.

3.0 . FUNDAMENTAL CONTRIBUTIONS OF ADVANCED CONCEPTS IN GEOMATICS ENGINEERING TO SOLVING PROBLEMS OF GEO-BASED SYSTEMS

Modern World challenges in Position Navigation and Wireless Location, Earth Observation and Space Mapping, Geographic Information Systems (GIS) and Land Tenure and Digital Imaging Systems combined with communication gadgets, have given birth to the need for advanced concepts in geomatics engineering. Research activities in advanced concepts in geomatics engineering have produced novel systems based on geo-spatial data and knowledge, and fostering interdisciplinary relationship in solving problems of geo-based systems.

Advanced concepts in geomatics engineering deal with the realization/creation of *Geospatial Information Products* (GIPs) and *Systems* (GIS) needed to **simplify**, **improve reliability**, and **reduce costs** of a multitude of land & land–related processes, operations or procedures including planning, management and administration of projects in Civil Engineering, Space Exploration, Civil Aviation, Mining, Navigation, Architecture, Physical Planning, National Defence, Mapping, Archaeology, Oceanography, Tourism, Land Use & Allocation, Land Administration, and Political Administration at all levels of Government, and so on.

As advanced concepts in geomatics engineering provides answers to an infinite range of *where* and *when* questions at what *time*, which are intrinsic to human existence, our societies, our infrastructure and our environment, it has also produced professionals trained to manage knowledge that is fundamental to nearly all sectors of our world, be it securing economic systems by land tenure, geospatial modelling of engineering systems, climate change, environmental impact assessment, disaster management, resource management, intelligent transport solutions just to mention but a few. For all sectors of our world, 3-D/4-D Virtual Reality Modelling and Visualization and Enterprise GIS are now a reality.

4.0. SENSORS INTEGRATION FOR VALUE ADDED MAPPING

Based on the scientific framework of geodesy, advanced concepts in geomatics engineering uses terrestrial, marine, airborne, and satellite-based sensors (GPS, digital cameras/scanners, communication devices, etc.) to acquire spatial and other data. It includes the process of transforming spatially referenced data from different sources, in three- and four-dimensional measurement science (3-D [φ, λ, v], and 4-D [φ, λ, v, t]), into common information systems with well-defined accuracy characteristics. Researches in advanced concepts in geomatics engineering includes spatiotemporal measurement science, spatial data infrastructures, and geographic information science.

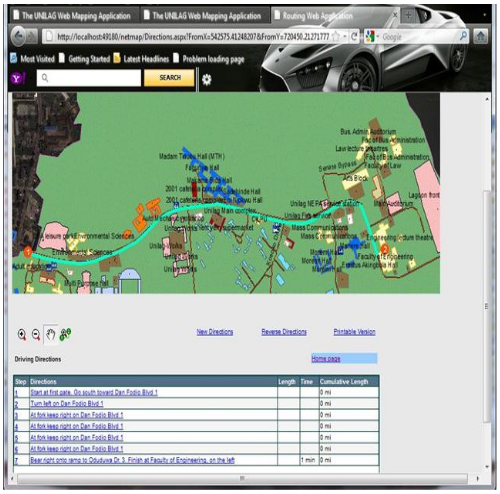
For navigation and asset tracking/fleet management applications carried out in this research, Global Positioning System (GPS), Digital Cameras, Communication devices and Geographic Information Systems (GIS) [2] are technologies on their own recognition used for different applications, but their integration opens a new world of applications. This means fundamentally that one can locate the position of any feature on the earth surface (GPS), navigate to a street or a point-of-interest (POI), captures the scene and plot these positions for real-time 2-D, 3-D or 4-D visualization in a digital environment (GIS).

These sensors integrated with GPS permit straight-forward interfacing with GIS, as they are capable of recording and storing attribute information about particular position or an entity. For instance, a digital camera integrated with GPS and tracker can easily acquire (through the GPS), the co-ordinates (φ and λ) of a vehicle, and also record attributes (v) of that vehicle, such as image of the occupants, audio recording of their conversation, street name, speed of the vehicle, distance travelled, etc, at a particular time (t) and stored them in the GPS receiver before moving on to the next location. Acquiring and storing spatial data directly on the field, saves time and greatly facilitates subsequent data processing. For mobile subscribers, since their locational data change with time, there is need to put in place a dynamic structure that gives room for updating their spatial information.

Mapping Point of Interests (POIs) and Location Based Services (LBSs) are part of advanced applications of Geomatics Engineering. Creating real time location awareness have become part of life in advanced economy while it is still a mirage to many location based service providers and point of interest navigators in the developing economy [3]. The ease with which POIs or LBSs can be located while in motion by mobile service subscribers is incredible due to the fact that mobile devices of different types and capacities (cell-phones including web-based GIS ones), GPS navigators, vehicle trackers, etc. have GPS based maps on them. Unlike the desktop publishing, mobile service subscribers are now enjoying an enhanced efficiency in time management that is based on advanced concepts in geomatics engineering applications.

5.0. SOME RESEARCHES ON ADVANCED CONCEPTS IN GEOMATICS ENGINEERING IN SOLVING PROBLEMS OF GEO-BASED SYSTEMS

Researches based on the integration of different sensors such as GPS, digital camera and communication devices in a GIS environment were carried out to solve some geo-based problems. They include, webGIS, optimal route planning, modelling hydrological functions, digital elevation model (DEM), modelling forest fire prone areas, optimal location of landfill for municipal solid waste (MSW), telecommunication Line-of-Sight (LOS) and signal strength mapping, 3D modelling/facility mapping (underground or on the earth surface), road-setback compliant/parking spaces availability analysis and mapping air pollution. Some of these are graphically shown:



Driving Directions

Step	Directions	Length	Time	Cumulative Length
1	Start at first gate. Go south toward Dan Fodio Blvd 1			0 mi
2	Turn left on Dan Fodio Blvd 1			0 mi
3	At fork keep right on Dan Fodio Blvd 1			0 mi
4	At fork keep right on Dan Fodio Blvd 1			0 mi
5	At fork keep right on Dan Fodio Blvd 1			0 mi
6	At fork keep right on Dan Fodio Blvd 1			0 mi
7	Bear right onto ramp to Oduduwa Dr 3. Finish at Faculty of Engineering, on the left		1 min	0 mi

Fig. 2a. WebGIS based Origin to Destination (O-D) Routing to a POI in Unilag (showing directions).

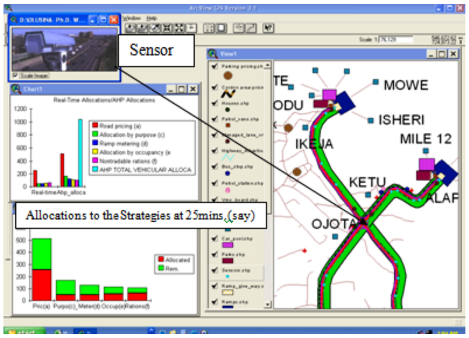
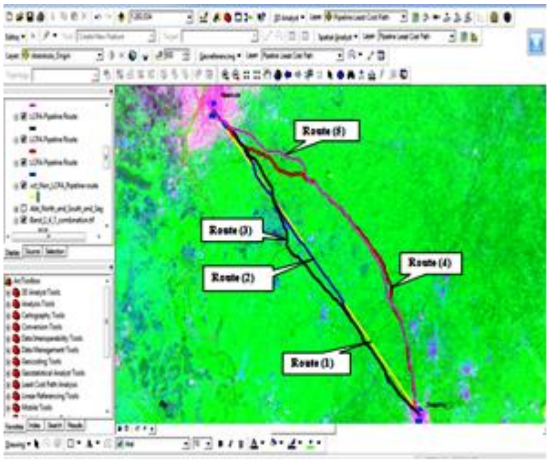


Fig. 2b. Modelling Traffic Congestion in a Geomatics Environment.



Costs	Route (1)	Route (2)	Route (3)	Route (4)	Route (4)
No of river crossings	8	7	7	3	5
Length (meters)	46,775.30 m	52,439.53 m	48,230.786 m	52, 630.872 m	49, 129.418 m
Length of settlement passage	7,065.904 m	5,840.682 m	9,733.941 m	9, 836.181m	10, 525.207 m

Fig. 2c. Optimal Path Planning for New Roads & Pipelines.

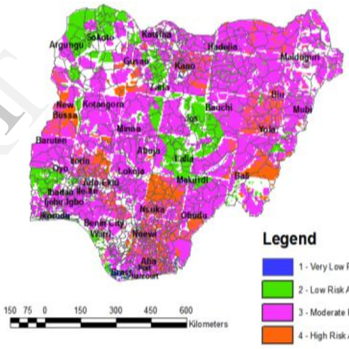


Fig. 2d. Mapping Forest Fire Susceptibility Areas using Analytic Hierarchy Process (AHP).

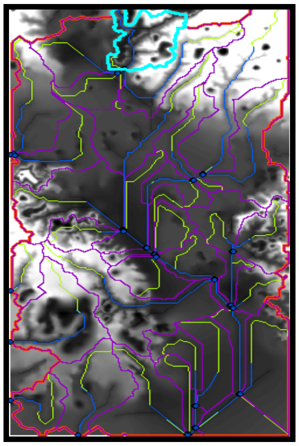


Fig. 2e. Sub-Watershed Mapping.

Fig. 2f. 3D extrusion of Structures, Unilag.

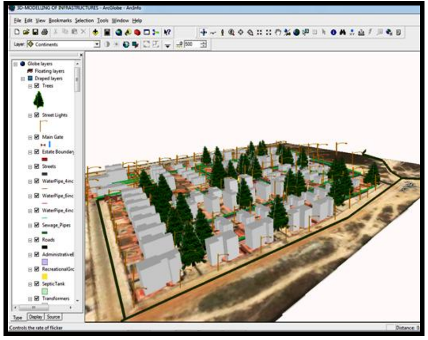


Fig. 2g. 3D Modelling of Goshen Estate, Lagos.

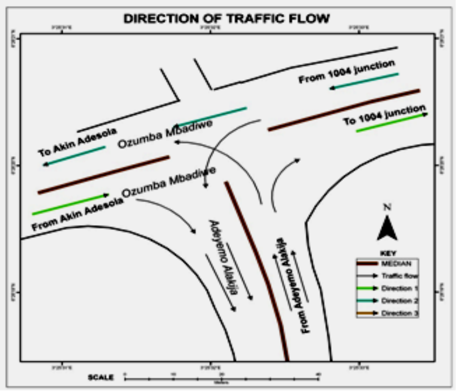
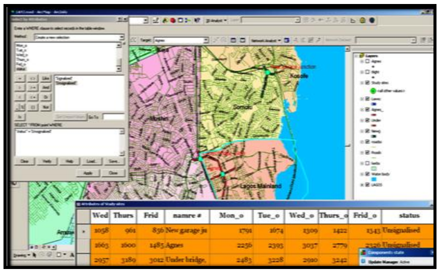


Fig. 2h. Traffic Flow Pattern at Law School Junction, Lagos.



Wed	Thurs	Frid	namre #	Mon_o	Tue_o	Wed_o	Thurs_o	Frid_o	status
1058	961	836	New garage ju	1791	1674	1309	1422	1343	Unsignalised
1663	1600	1485	Agnes	2256	2393	3037	2779	2326	Unsignalised
2957	3180	3012	Under bridge.	2483	3228	2910	3242		

Fig. 2i. Traffic Analysis (A.M. & P.M. peak periods at a Non-Signalised New Garage Junctions.

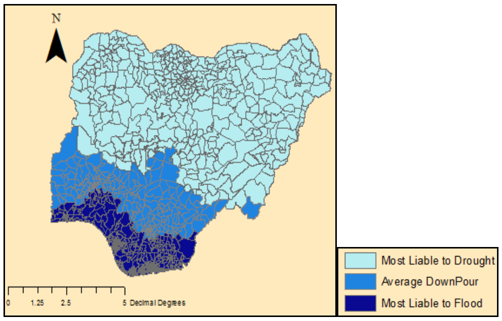


Fig. 2j. Map showing the Projected Distribution of Rainfall (2000-2050).

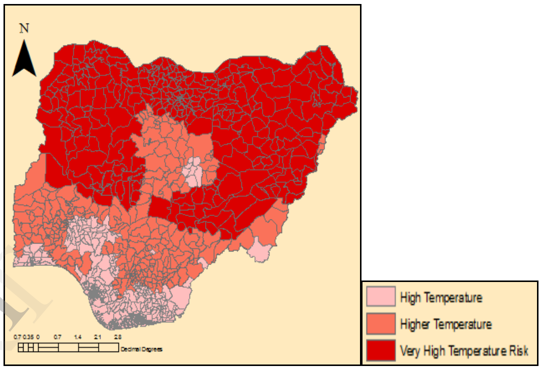


Fig. 2k. Map Showing the Projected Max. Temp. (2000-2050).

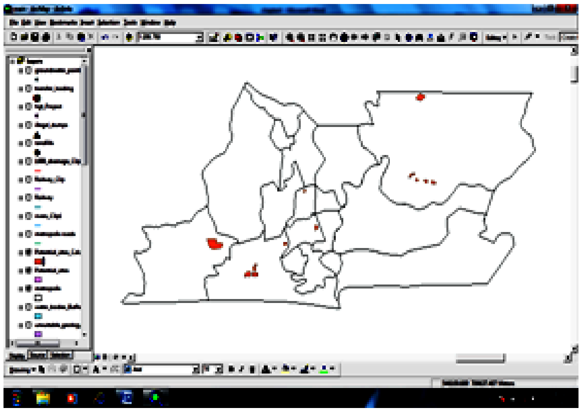


Fig. 2l. Potential (Optimal) Landfill Site (10-25hects. criteria), Lagos Metropolis.

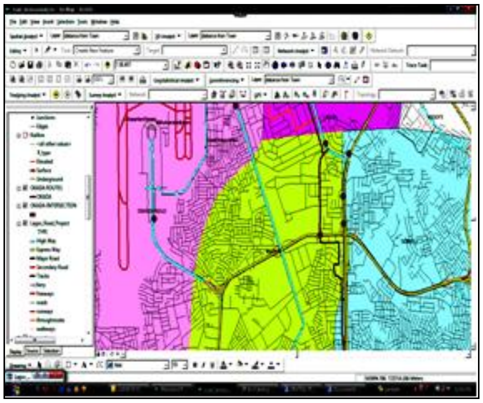


Fig.2m. Modelling a Seamless Multimodal Transportation Network in Mainland Local Govt Area, Lagos.

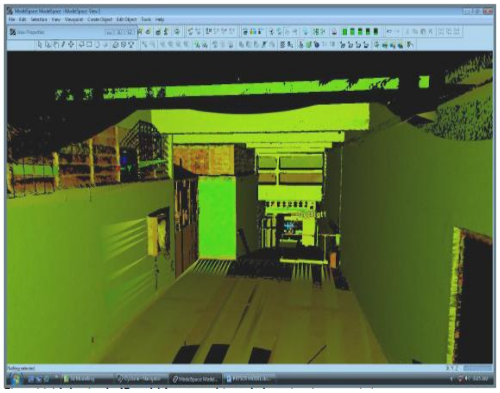


Fig. 2n. HD 3D Model of Part of Engineering Faculty (Towards Engineering Mezzanine), Unilag.

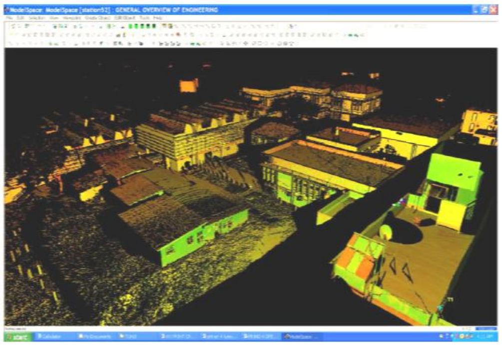


Fig.2o. Aerial View of Engineering Faculty, Unilag.

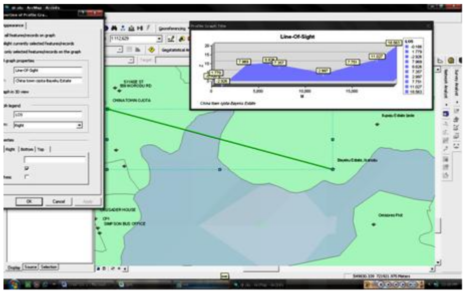


Fig. 2p. LOS 30m Elevation From China Town Ojota - Bayeku Estate, Ikorodu.

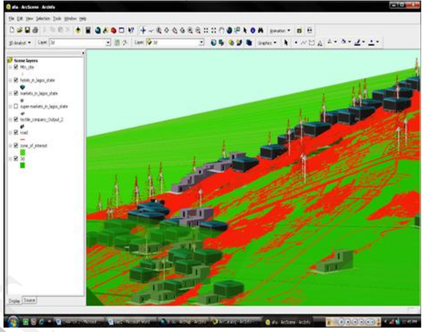


Fig 2q. LOS (Transmission & Network Optimization) 3D Terrain Modelling of China Town Ojota - Bayeku Estate Ikorodu.

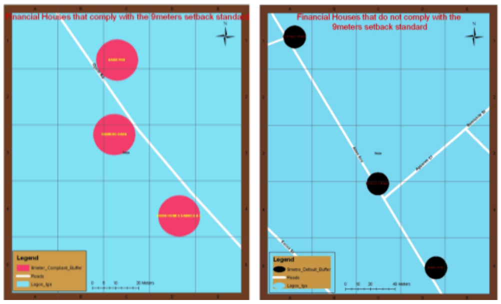


Fig.2r. Road-Setback Compliant (Pink) and Non-Compliant (Black) of Financial Institutions along Opebi Road.

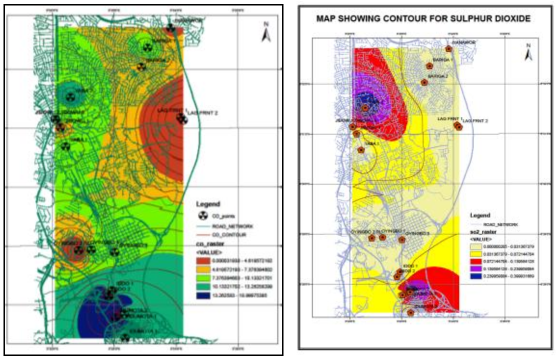


Fig.2s. Air Pollution Maps showing Contours of Carbon Monoxide and Sulhur Dioxide respectively, along Ikorodu Road, Lagos.

Section 6.0 discussed the architecture and applications of two of these geo-based system, asset trackers (for mobile assets tracking on desktops, laptops or cell-phones) and navigator (for route guidance of commuters from an origin to a destination). Mapping of Point of Interests (POIs) [4] for LBS range of applications and services [5] (such as: finding locations of hotels, bus stops, hospitals, recreations centres; navigation with traffic constraints [no U-turn, avoid toll-roads], location based advertising and social networking) was carried out.

6.0. MOBILE ASSETS TRACKING AND GPS NAVIGATION

For the two advanced concepts in geomatics engineering applications mentioned at the end of Section 5.0, they are based on two basic similar architecture:

i) Tracking System Architecture: The integrations of GPS, digital camera, communication devices and GIS, as shown in Figure 3.

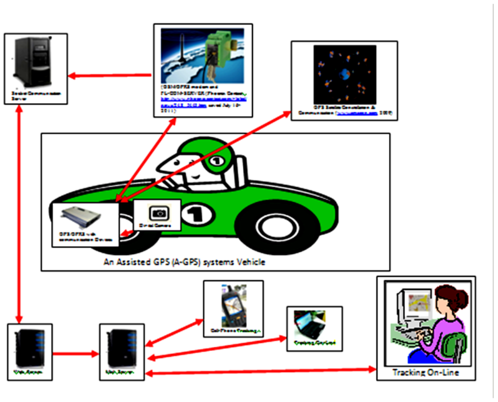


Fig. 3. Tracking System Architecture.

Asset Tracking **[6]** Application Areas include:

- Logistics, Fleet Management, Commercial Vehicle Monitoring, Delivery & Courier Services, Public Transport Systems, Taxi Services and Emergency Vehicles and Security Vehicles.

ii) POI-LBS Navigational System Architecture: It consists of integrations of GPS, communication devices, camera and GIS (Fig. 4).

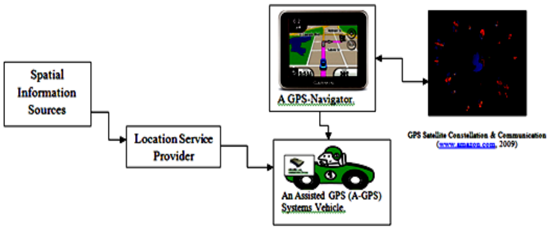


Fig. 4. POI-LBS Navigational System Architecture.

In the research, a GPS vehicle tracker was installed in a vehicle and a Garmin NUVI 265W was initialized and setup for local navigation with an onboard local street map. A specific route, Oworonsoki to Former Tollgate along Lagos-Ibadan Expressway, was tracked while the NUVI was used to navigate from the origin to destination. More than twenty (20) observations were carried out. The route preference on the NUVI was based on the principle of *Shorter Distance* (Section 7.0). The two A-GPS systems were operated under the same condition of clear visibility, weather and over the same route and terrain.

An integration of these positioning systems with Geographic Information Systems (GIS) actually created powerful real time navigation and mapping systems. In this research, Street Network of Lagos was created in ArcGIS to serve as the Basemap, topology was built, network analysis (in form of *Shortest Path Analysis*) was carried out (Section 7.0 and Fig. 6) and exported to ExpertGPS. POI Loader from *garmin.com* was used to transfer the created POIs and LBSs spatial data into the Garmin NUVI navigational unit. MapSource and Goole Earth/Map were also used for geospatial data transfer and visual display of the street network and the POIs (e.g. Bus Stops, Road Intersections and Schools) and the LBSs (e.g. Banks, Eateries and Hotels) information. Image files of LBSs and POIs were attached to give a firsthand visual representation. Google Earth post wizard was used to send the results of any LBS or POI request to interested users via e-mail (Figs. 7 – 8b).

The route tracked and navigated by the two systems were plotted [7] and [8] and compared against the Basemap showing all the routes. Similarly, the "Travel Time" obtained by these systems were compared with the Travel Time obtained from the **Bureau of Public Roads** (BPR) Model for all the routes (Section 8.0).

7.0. SHORTEST-PATH DETERMINATION USING FLOYD–WARSHALL ALGORITHM

In graph theory, finding a path between two nodes (vertices) in a graph such that the sum of the weights of its constituent edges is minimized is crucial. In the two applications, tracking and navigation, the problem of shortest-path is paramount since each commuter is interested passing through the shortest-path to his destination. The nodes represent the locations (such as origin and destination) while the road segments represent the edges and the weights represent the travel time on that segment. The travel time in this research is constrained based on the travel time from an origin to a destination. There are three major variations in shortest-path problems: undirected, directed and mixed graphs; and each of them can be weighted or non-weighted. The theories on these shortest-path problems, which this work is based on, are briefly discussed below.

According to [9], for **Single-Source Shortest Paths**, let *G* be a weighted graph. The length (or weight) of a path *P* is the sum of the weights of the edges of *P*. That is, if *P* consists of edges e_0, e_1, ..., e_{k-1} then the length of P, denoted by *w(P)*, is defined as:

$$w(P) = \sum_{i=0}^{k-1} w(e_i) \tag{1}$$

The distance from a vertex *v* to a vertex *u* in *G*, denoted *d(v,u)*, is the length of a minimum length path (also called *shortest path*) from *v* to *u*, if such a path exists. Dijkstra's algorithm in Figures 5a – 5c illustrates the solution to the shortest path problem from the origin O to the destination T. Distances (weights) between nodes are labelled on the edges [10].

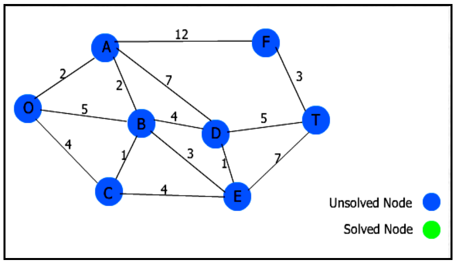


Fig. 5a.Shortest Path from O to T to be determined.

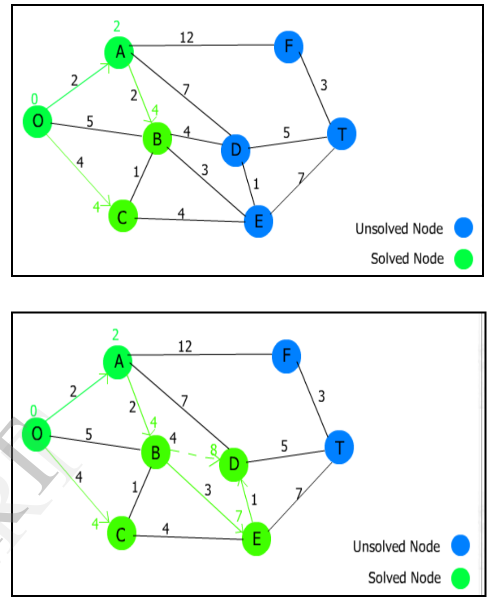
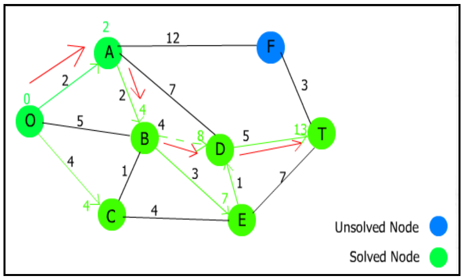
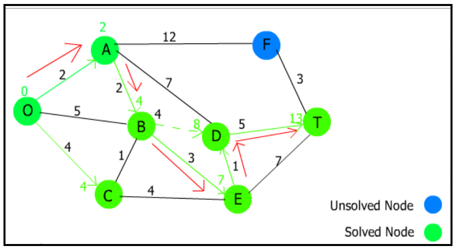


Fig. 5b. Determining Shortest Path from O to T.



The First Shortest Routes: O–A–B–D–T.



The Second Shortest Routes: O–A–B–E-D–T

Fig. 5c. Determining Shortest Path from O to T.

However, for **All-Pairs Shortest Paths**, to compute the shortest path distance between every pair of vertices in a directed graph $\vec{G}$ with *n* vertices and *m* edges with $\vec{G}$ having no negative-weight edges, the Dijkstra's algorithm can also be used. For this research, since a commuter is interested in all-pairs shortest path distances and then take decision, a dynamic programming algorithm to compute all-pairs shortest path distances in a digraph without negative cycles, in which the Navigator is based upon, is described below.

A Dynamic Programming Shortest Path Algorithm

Let $\vec{G}$ be a given weighted directed graph. The vertices of $\vec{G}$ is numbered as (v_1, v_2, ..., v_n). As in dynamic programming algorithm, the key construct in the algorithm is to define a parameterized cost function that is easy to compute and also allows us to ultimately compute a final solution. In this case, we use the Cost function, $D^k_{i,j}$, which is defined as the distance from v_i to v_j using only intermediate vertices in the set {v_1, v_2, ..., v_k}. Initially,

$$D^0_{i,j} = \begin{cases} 0 & if\ i = j \\ W\left(\left(v_i, v_j\right)\right) & if\ \left(v_i, v_j\right) is\ an\ edge\ in\ \vec{G} \\ +\infty & otherwise \end{cases} \quad \ldots.\ (2)$$

Given this parameterized cost function $D^k_{i,j}$, and its initial value $D^0_{i,j}$, we can then easily define the value for an arbitrary *k > 0* using **Floyd–Warshall algorithm** as:

$$D^k_{i,j} = min\{\, D^{k-1}_{i,j},\ \ D^{k-1}_{i,k} + D^{k-1}_{k,j} \} \quad \ldots\ldots.\ (3)$$

In other words, the cost for going from v_i to v_j using the vertices numbered 1 through *k* is equal to the shortest of two possible paths. The first path is simply the shortest path from v_i to v_j using the vertices numbered 1 through *k-1*. The second path is the sum of the costs of the shortest path from v_i to v_k using vertices numbered 1 through *k-1* and the shortest path from v_k to v_j using vertices numbered 1 through *k-1*. Moreover, there is no other shorter path from v_i to v_j using vertices of {v_1, v_2, ..., v_k} than these two. If there was such a shorter path and it excluded v_k, then it would violate the definition of $D^{k-1}_{i,j}$, and if there was such a shorter path and it included v_k, then it would violate the definition of $D^{k-1}_{i,k}$ or $D^{k-1}_{k,j}$. In fact, note that this argument still holds even if there are negative cost edges in $\vec{G}$, just so long as there are no negative cost cycles. The cost functions (travel time) in this work include: congestions, pot-holes effects, signalized and non-signalized intersections and wrong driving. Though these cost functions were not modelled differently, they all constitute to the total travel time from origin to destination. The total travel time model used is based on the simple Bureau of Public Roads (BPF) Model.

8.0. TOTAL TRAVEL TIME COMPUTATION

Using the simple **Bureau of Public Roads (**BPR) equation for travel time [11]:

$$T_f = T_o * \left(1 + \alpha * \left[\frac{V}{C}\right]^{\beta}\right) \quad \ldots\ldots\ldots.\ (4)$$

where:

T_f = predicted mean travel time,
T_o = free-flow travel time,
V = volume,
C = capacity (possibly adjusted by green time/cycle length ratio),
a, ß= parameters (a= 0.15, ß= 4) but for various road/congestion condition.

The average travel times, by the Vehicle Tracker and the Nuvi Navigator, for the different observations for the given route are in Tables 1a and 1b.

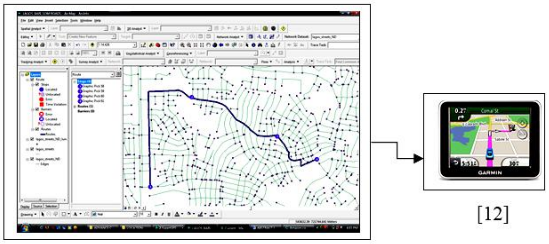
9.0. RESULTS AND ANALYSIS OF RESULTS

Results obtained and analysed are discussed below.

9.1. RESULTS

Derived Maps

The following maps were obtained for the two (2) A-GPS Mobile Systems:



[12]

Fig. 6. Topological Street Network of Lagos showing Part of the Navigable Route.

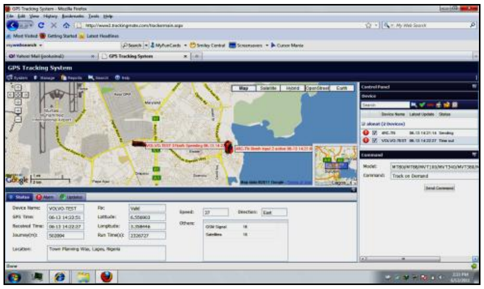


Fig. 7. A Web-Based Real-Time Tracking of Vehicles on Part of the Tracked Route.

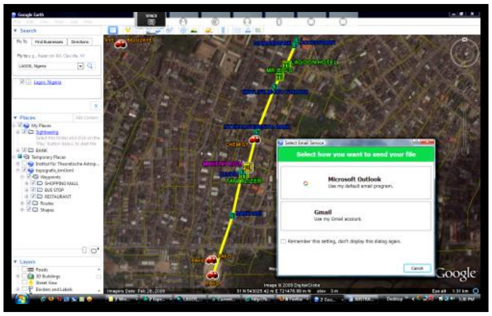


Fig. 8a. Sending the Navigated Route Result to POI/LBS Users via e-mail.

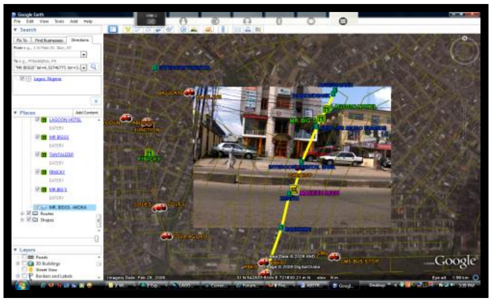


Fig.8b. Adding Image Overlay (an Eatery) to Value Added Mapping.

Comparing the Results of the Two (2) A-GPS Systems

Comparing maps from the Nuvi navigator, the GPS-based Vehicle Tracker versus the Basemap. The following results were obtained:

Fig. 9a. Part of *Tracked* Route From Oworonsoki To Alapere Junction.

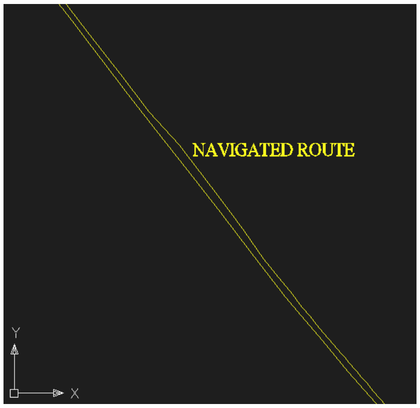


Fig. 9b. Part of *Navigated* Route From Oworonsoki To Alapere Junction.

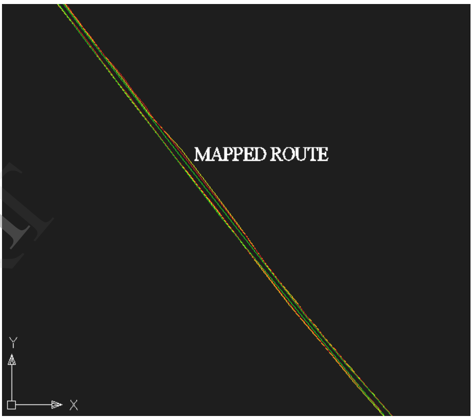


Fig. 9c. Combined Map of Part of the Route from Oworonsoki To Alapere.

Fig. 9d. Comparing the Tracker (Light Green) and Nuvi (Yellow) Mapped Routes vs. Basemap (Red on the Study Area image).

Travel Time Determination

Travel Time recorded by these two A-GPS systems were downloaded and the BPR Travel Time (Equation 4) for the different average speed recorded by the two systems were also tabulated (Table 1a).

Table 1a. Travel Time by the A-GPS versus the BPR Travel Time Model.

Route	Basemap Distance (Km)	Tracker Average Speed (Km/H)	Nuvi Average Speed (Km/H)	Tracker Travel Time (Min.)	Nuvi Travel Time (Min.)	BPR (Tracker) Travel Time (Min.)	BPR (Nuvi) Travel Time (Min.)
To =	6.61	25.60	23.70	15.55	16.43	16.03	17.
Fro =	12.89	28.55	28.00	27.05	27.36	28.02	28.57

The differences between the BPR model and the Travel Times by Tracker and Navigator are shown in Table 1b.

Table 1b. Differences between the Travel Times by the A-GPS and the BPR Travel Time Model.

Route	ΔT (min.)	ΔN (min.)
To =	0.48	0.89
Fro =	0.97	1.21
Average =	0.73	1.05

ΔT = Differences between BPR (Tracker) Travel Time (min.) and Tracker Travel Time (min.)
ΔN = Differences between BPR (Nuvi) Travel Time (min.) and Nuvi Travel Time (min.)

9.2. ANALYSIS OF RESULTS

1. Travel Time Analysis

The differences between BPR Travel Time and the A-GPS Travel Time are graphically displayed in Fig. 10.

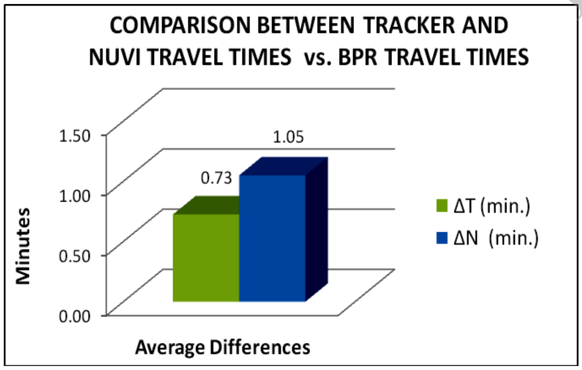


Fig. 10. Comparisons between Tracker & Nuvi Travel Time vs. BPR Travel Time.

From Figure 10, Nuvi Navigator has greater Average Travel Time difference than the Tracker. This may be as a result of the "Re-Calculating" of the Navigator when you are navigating to a destination.

2. Positional Errors Determination

The different derived maps (Figures 9a – 9c) were compared at a Scale of 1: 5,750 and the graphical dispersions, Nuvi and Tracker, from the basemap are discussed below.

Since the graphical plottings from the two A-GPS (tracker and navigator) are very close, the Average Coordinates Dispersion (i.e. the average graphic dispersion of the two A-GPS from the Basemap) is obtained from Equation 5a:

$$A = \left(\sum_{i=1}^{n} B_i - G_i /_{n} \right) \quad \ldots\ldots\ldots\ldots\ldots (5a)$$

where:

A = Average Coordinates Dispersion in Eastings/Northings
B = Basemap Coordinates
G = A-GPS (Tracker and Navigator) Coordinates
i = The Individual Points mapped
n = The Number of Points mapped considered

Using coordinate differences, the Average Coordinates Dispersions (*A*) are shown in Table 2.

Table: 2. Average Coordinates Dispersions (*A*) of the Garmin Nuvi Navigator and the GPS Vehicle Tracker from the Basemap (*B*).

A-GPS Systems	Average Coordinates Dispersion-E (Decimal Degrees)	Average Coordinates Dispersion-N (Decimal Degrees)	Dispersion-E (m)	Dispersion-N (m)
Garmin Nuvi Navigator	0.00000	-0.00001	0.0000	-1.1100
GPS Vehicle Tracker	0.00003	0.00002	3.3300	2.2200

This is shown graphically in Fig. 11.

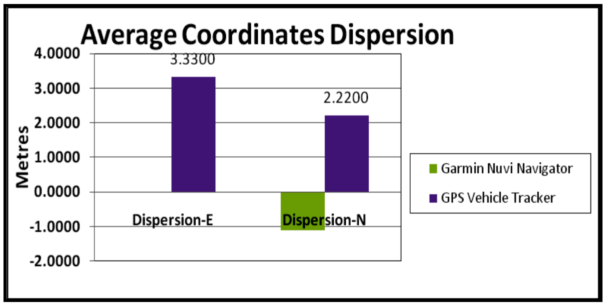


Fig. 11. Graphical Plot of the Average Coordinates Dispersions (*A*).

From the figure, GPS Vehicle Tracker has greater Average Coordinates Dispersions (A) in both Easting (E) and Northings (N). Using these average coordinates dispersion values, the Horizontal Dispersion (H_d) of the A-GPS systems were determined from Equation 5b:

$$H_d = \sqrt{A_E^2 + A_N^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5b)$$

Using Equation 5b, the Average Horizontal Dispersions (H_d) are tabulated in Table 2.

Table: 2. Average Horizontal Dispersions (H_d) of the Garmin Nuvi Navigator and the GPS Vehicle Tracker from the Basemap (B).

A-GPS Systems	**Average Horizontal Dispersion- H_d (m)**
Garmin Nuvi Navigator	1.1100
GPS Vehicle Tracker	4.0022

This is shown graphically in Fig. 12.

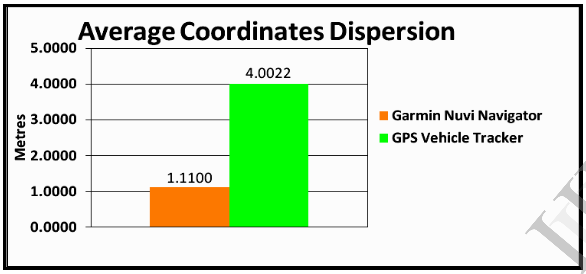


Fig. 12. Average Horizontal Errors/Dispersions from the Basemap.

From the Average Horizontal Dispersion (H_d) data, Garmin Nuvi Navigator has 4.0022m while GPS Vehicle Tracker has 1.1100m. The reasons for the differences/dispersion may be due to: (i) GPS signal strength variation and the mobile platform (the vehicle used) did not keep to a specific lane. It can be inferred that Garmin Nuvi Navigator has better horizontal positional accuracy than the vehicle tracker. Despite the fact that these systems are not static, i.e. on motion, and data collection rate was based on kilometres/hour, each system can still be used for a 3rd Order mapping applications.

10.0. CONCLUSION

With the gamut of various information technology (IT) and geospatial mapping capabilities now available in the market, easy mobile mapping and navigation among other advanced concepts in geomatics engineering have made adding of values to maps a possibility which was not available to traditional surveyors.

In this research, several POIs and LBSs were mapped and navigated to. Voice and image enhanced navigation system was created to assist users. Results of navigation to POIs and LBSs queries and tracked routes were sent to different users/subscribers online. Travel time accuracy between Vehicle Tracker and Nuvi Navigator were determined against BPR Travel Time Model. Nuvi Navigator has greater Average Travel Time difference than the Tracker, while the Tracker has greater horizontal positional accuracy. The horizontal positional accuracy obtained for both A-GPS systems was of 3rd Order which is acceptable for mobile system applications.

Today, 3-D and 4-D real-time mapping for various applications are now available to solve and provide various solutions to several problems in "geo-based systems'. Value can easily be added to maps. Similarly, Enterprise GIS, an aspect of advanced concept in Geomatics Engineering, enables government activities to be run with business orientation.

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