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Mobile Pedestrian Navigation Framework for Multi-factors Resources Allocation

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Abstract

Although it is possible for pedestrian to walk to unfamiliar places, familiarizing and finding a way out of new environments is quite challenging unless a pedestrian navigation system (PNS) is used. Most existing PNS solutions are employing vehicle navigation framework, however, such systems are designed to work efficiently for vehicular systems and not suitable for finding shortest path in environment with poor geospatial mapping. This study designed pedestrian navigation framework for PNS that supports resource allocations in environment with poor geospatial mapping. Mixtures of qualitative and quantitative methods have been used to interview prospective users for requirement specifications and experimental research for designing the framework, respectively. Prototyped route network framework with routing data were implemented using Open source QGIS software, and a route analysis achieved using QGIS shortest path network analysis. The resulted framework shows more than 3.5% improvement between optimal routes established by PNS on proposed framework as compared to optimal route established by existing systems.

Keywords: Mobile, Pedestrian, Navigation, System, Framework.

Introduction

Advancement in technology has made navigation easier for pedestrians to acquire knowledge about position and direction towards destination even in unfamiliar environment (Gaisbauer and Frank 2008, Ondieki and Murimi 1997). Due to advancement of mobile and geographical information systems (GIS) technologies, several studies in pedestrian navigation systems (PNS) have integrated mobile and GIS to establish mobile GIS frameworks that facilitate mobility and portability of PNS in providing rich geospatial features and services to pedestrian (Millonig and Schechtner 2007). Studies have proposed mobile GIS frameworks that varied from standalone to multi-tier client-server frameworks, however, existing frameworks have developed to efficiently work on infrastructure whose features are well mapped in GIS systems (Fang et al. 2015).The authors in Löfberg and Molin (2005), and Poorazizi and Alesheikh (2008) studied a simplest mobile GIS framework called standalone client architecture where both GIS data and application reside on a mobile device. The framework is useful for simple data and low processing applications, which are good aspects in minimizing drawbacks of mobile computing including processing power and storage capability. However, their main short falls include the fact that associated PNS applications become platform dependency and therefore difficulty to handle big volumes of data as well as hard to process GIS data, which require high processing power. To address these shortfalls, Elwakil et al. (2015) proposed a client-server GIS architectural framework whose data are hosted in cloud servers capable to process and handle a big volume of data and increase efficiency of processing GIS data. However, the shortfall of this study is the fact that it did not consider management of processing transactions between the client-side mobile unit and data computation at cloud server-side plus the fact that it cannot support navigation on poor geospatial mapped environment.

Rodriguez et al. (2017) built the distributed architecture of a mobile GIS framework whose flexibility is offered by NoSQL relational database for scalability. However, in GIS discipline, a combination of PostGIS/PostgreSQL is known to function well as spatial database extender than NoSQL plus the fact that it cannot support navigation on poor mapped environment. Another study by Elwakil et al. (2015) proposed a framework that exploits advantages of cloud computing to increase efficiency in processing of geospatial data. However, despite the usefulness of cloud computing, it makes difficulty for PNS to dynamically choose optimal route due to transmission time as well as it cannot support navigation on poorly GIS mapped environment.

Due to challenges associated to the existing similar solutions, this study designed a multi-factors mobile pedestrian navigation framework for PNS systems that supports digital allocation of resources in environment with poor GIS mapping. The solution uses multiple environmental factors to addressed challenges due to lack of sufficient GIS points in environments where pedestrians prefer to use unmapped shortcuts instead of mapped roads.

Materials and Methods

Research design

This study used qualitative research method to establish requirements specifications and quantitatively designed the framework using experimental approaches. As depicted in Figure 1, the study qualitatively collected important data and information by interviewing randomly sampled users drawn in targeted population, which the framework will be deployed. The study further performed expert interview and questionnaires with a number of geologists who were purposively sampled for in-depth collection of geological data of selected area of study. While in the same part, the study analyzed collected data and established system specifications for architectural framework. As depicted in Figure 1, the second part mainly used experimental quantitative research methods to design the PNS framework and its shortest route algorithm based on gathered requirements and established specifications. During the designing phase, the functional and non-functional specifications of the framework were evaluated through discussion with local Information Technologies (IT) and GIS stakeholders. Based on the design, the study developed an architectural framework and associated PNS prototype, which was used in testing the performance of the framework and validation of its usefulness in targeted community.

Study area

The study considered an area surrounding the University of Dar es Salaam (UDSM), Julius K. Nyerere Mlimani Campus, located in Kinondoni District, Dar es Salaam city of Tanzania, as focal area of the study because of composition of all kinds of resources in close proximity. This area was purposively selected because it constitutes resources with infrastructure whose geographical information have not been well digitally established. Moreover, most users of the resources are pedestrians who walk daily from other campuses to locate resources thereto and users have to walk from one end to another to locate the service, which are structurally decentralized. The focal area occupies approximately 1,625 acres, which comprises of various academic and non-academic resources and services, lies between longitudes 39°11'36" and 39°13'19" East of Greenwich and between latitudes 6°46'16" and 6°47'17" South of Equator.

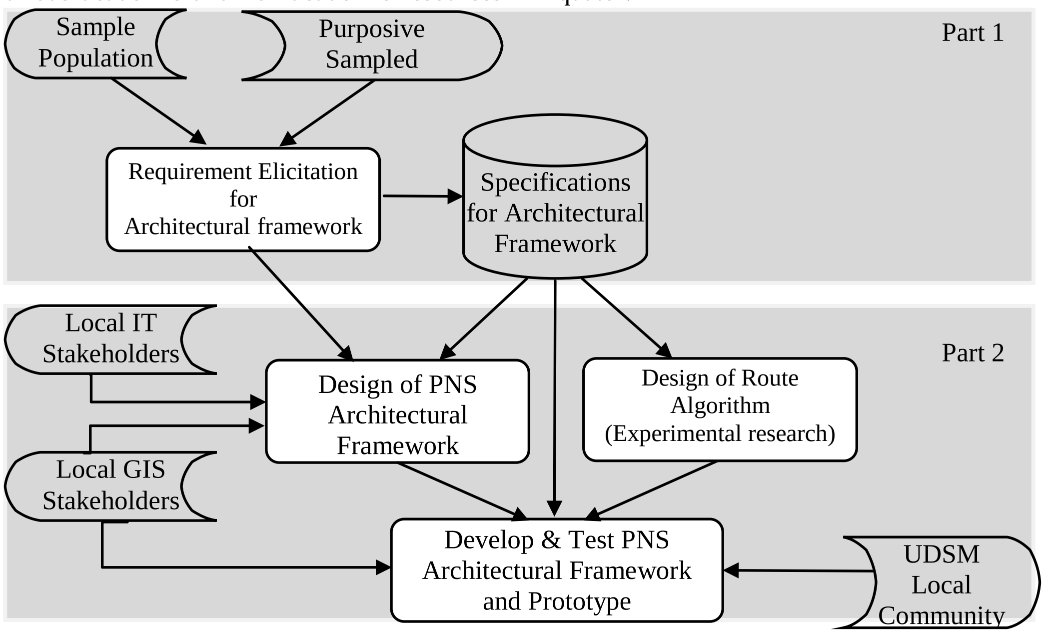


Figure 1: Research design.

Sample size for qualitative research

The target population of this study consisted of visitors of the resources in the focal study area including students who prefer to use shortcuts to reach several halls of residence in the campus and outside colleges, nearby and distant homes. Also, academic and administration staff residing inside and outside the campus, and other visitors from different works of life. Assuming a population of infinite visitors due to the nature elaborated earlier, the study used Cochran's formula to calculate sample size with intention to achieve a level of precision (margin of error) of ± 7% with a confidence level of 90% and a standard deviation of 0.5. Thus, using the Cochran's formula, a sample size of 138 users was drawn as shown in Equations 1 and 2.

$$n_0 = \frac{z^2pq}{e^2} \quad (1)$$

Where n_0 represents sample size, z as confidence level of 90% whose z-score equals to 1.645, $p$as estimated proportion of an attribute presented in the population assumed to be 0.5, $q = 1 - p$, and e as the margin of error of ±7% equals to 0.07. Replacing the value into equation 1 we get Equation 2.

$$n_0 = \frac{0.5*(1-0.5)*(1.645)^2}{(0.07)^2} = 138 \quad (2)$$

Sampling frames of 138 users of the resources in study area were purposively selected to be involved in qualitative research that establishes requirements for the design of PNS framework.

Data collection and requirements elicitation

The primary data was collected using a questionnaire as it allows the collection of large amounts of information from a large number of people in a short period. Various hypothetical questions were asked with intention of establishing requirements and system specifications. The study was curious to determine the relevance of mobile-based solutions by crosschecking the proportion of participants who own smart devices. Table 1stipulates the results on the question, whereby 94% of the respondents declared to own smart devices.

Table 1: Ownership of smart devices

Ownership status	Male	Female	Percentage
Own	73	57	94%
Not own	6	2	6%

The study asked whether participants have ever used GIS-based applications such as Google Maps, Google Earth, or Uber in daily activities. Table 2 stipulates the summary of responses to this question, whereby 89% of the respondents indicated to use GIS applications.

Table 2: Participants usage of GIS applications

GIS Apps usage status	Male	Female	Percentage
Used GIS Apps	70	53	89%
Never used GIS Apps	9	6	11%

The study listed five common factors that mostly influence pedestrians' choices of routes and asked to rank them in the order of importance in making route decisions, from 1 (the most influential factor) to 5 (least influential factor). Table 3 stipulates the summary of responses on factors that influence route choices of pedestrians.

Table 3: Ranking of factors that influence pedestrian choices of routes

Factors	Ranks					%	Order of Influence
	1	**2**	**3**	**4**	**5**		
Distance	72	39	13	5	5	28.4	**1**
Cost	5	26	46	34	23	17.8	**3**
Safety	53	46	17	11	7	26.3	**2**
Simplicity	2	13	34	43	42	14.5	**4**
Pleasant	2	10	24	41	57	13	**5**
Total	**134**	**134**	**134**	**134**	**134**	**100**	

To determine useful PNS features that guide pedestrians towards destinations, seven features of the PNS were rated on a Likert scale of least-important (1) to very high important(5). Table 4 summarizes the average scores on usefulness of each feature.

Based on results shown in Table 4, the second feature of *"Display route to destination on the map dynamically"* was rated with highest mean score of 4.33, implying that most participants agreed that displaying route towards destination dynamically is very important in guiding the pedestrian.

The study also wanted to establish favourite functionalities or services that if offered by the PNS will increase usability by setting them on a Likert scale from least-important (1) to very high important (5). Table 5 summarizes the average scores of favourite functions that attract usability of the PNS.

Table 4: Features of a pedestrian navigation system (PNS)

S/no.	Features	Mean score
1.	Display landmarks (recognizable features) labelled on the map	**3.48**
2.	Display route to destination on the map dynamically	**4.33**
3.	Generate text-based instructions on turn-to-turn basis	**3.43**
4.	Display pedestrian location dynamically as he/she navigates towards destination	**4.03**
5.	Displaying geo-tagged images to crosscheck for the right route	**3.25**
6.	Notify users upon reaching the destination or deviating from the right path	**4.27**
7.	Display distance to destination for a route choice	**3.20**

Table 5: Functionalities offered by a pedestrian navigation system

S/no.	Statements	Mean score
1.	Calculate the best path to destination	**4.30**
2.	Help pedestrians find each other and meet	**3.52**
3.	Help users identify resources and services	**4.13**
4.	Help users know better about places (geographic orientations)	**3.50**
5.	Find nearby places of interests (services and resources)	**4.39**

The results showed that the fifth feature of "*Find nearby places of interests (services and resources)*" was rated with highest mean score of 4.39, implying that PNS will attract more users if it includes a function that enables users to find nearby places of interests like services and resources.

Requirement specification

Reflection from requirements elicitation clearly showed the status of ownership and usability of smart devices which promised the usefulness of mobile-phone based PNS. The objectives to achieve useful features in proposed solutions were deduced from data collected and summarized in Table 5. Based on these features, the study established three design objectives and coded each objective with supplement descriptions stipulated in Table 6.

Table 6: Objectives for required useful features

Objective code	Objective description
OBJ-01	*To help users identify resources and services* The framework must help users to identify resources and services such as: ▪ Lecture and residential halls, ▪ Bus stops and parking spots, ▪ Food and drinks services, ▪ Bank branches and ATMs, etc.
OBJ-02	*To calculate the best path to destination* The framework should be able to calculate best (optimal) path to destination based on assigned costs and user needs
OBJ-03	*To find nearby places of interests* The framework must be able to identify nearby places from users of the system based on assigned distance.

Summary in Table 4 indicated users' preferences on dynamic displays of routes to destination on a map, which would obviously need storage of both spatial and non-spatial information. Table 7 therefore stipulates breakdown of types of information that the proposed solution would need to store mapped with associated objectives.

Table 7: Requirements for information storage

Software requirement code	Description and objective mapping	
SR-01	Information of resources and services.	
Associated objectives	*OBJ-01*: To help users identify resources and services.	
	OBJ-03: Find nearby places of interests.	
Description	The framework must store information about resources and services in the form of point vector files.	
Specific data	*Information*	*Data type*
	Name of resources and services	String
	Location	Geometry
	Service type	Integer
SR-02	Information about route network	
Associated objectives	*OBJ-02:* To calculate the best path to destination.	
	OBJ-03: To find nearby places of interests.	
Description	The framework must store information about navigation routes in the form of line vector file.	
Specific data	*Information*	*Data type*
	Segment ID	Integer
	Segment location	Geometry
	Segment length	Double precision
	Attribute scores	Float

The summaries of data collected in Table 1 and Table 2 shade light on characteristics of users of the proposed solution. However, there would be many actors that externally interact with the solution who could not necessarily be users. Thus, the study identified possible actors that interact with the proposed solution and the roles played by each as stipulated in Table 8.

Therefore, from the collected data and reflections of user requirements, the study established a system requirements specification that helps to translate user requirements for system designers such that

- The framework must provide means to search and view important resources and services around the area of interest;
- The framework must provide means to search nearby places of interests upon request;
- The framework must provide base-map layers that the user can choose as background information to assist with identification of resources and services;
- The framework must be able to provide optimal path to destination upon request by the user;
- The framework must provide means to guide and track the pedestrian to destination;
- Tracking mechanism must be able to identify and notify the pedestrian on deviation;
- The framework must be able to identify the pedestrian location and associate it with his/her position the map dynamically;
- The framework must be able to identify whether a given

destination is within reach or not; and

- Pedestrian must be notified upon reaching the destination.

Table 8: Identification of possible actors

AC-01	Pedestrian
Associated objective	*OBJ-01***:** To help users identify resources and services. *OBJ-02:* To calculate the best path to destination. *OBJ-03:* To find nearby places of interests.
Criterion	This is an actor when we classify actors according to interactions with the framework.
Description	The framework must provide interface for pedestrians to interact with it in search of resources and services. A pedestrian is anyone who is travelling a short distance on foot.
AC-02	*GIS Framework Manager*
Associated objective	*OBJ-01:* To help users identify resources and services. *OBJ-02:* To calculate the best path to destination. *OBJ-03:* To find nearby place of interests.
Criterion	This is an actor when we classify actors according to interactions with the framework.
Description	The framework must provide interface for framework manager to manage both pedestrian and GIS contents. GIS framework manager is essentially a framework administrator with geospatial knowledge.

Design of pedestrian navigation system (PNS) architectural framework

The study designed PNS architectural framework that governs distribution of functions and data storage as main components identified in requirements specifications. Due to robustness of the Web technology in support of dynamic display/presentation across devises as well as portable data transmission over hypertext transmission protocol (HTTP), the study designed the PNS framework on three-tier client-server architecture for mobile GIS. As depicted in Figure 2, the first-tier known as client-tier consists of Web GIS client that supports querying and display of spatial data from remote storage over the Internet. The second tier of Web map server that responds to client's HTTP query and map presentation using three standards of Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS). The third tier dealt with data storage consists of geospatial database to allow storage and querying of information on location and mapping.

The heart of the PNS framework is map-layers that serve as means of visual display of directions to pedestrians. One source of map-layers is real-world road networks and location whose base-maps are presented as vector files and stored in spatial database. But these base-maps alone are not sufficient to provide full information and aesthetic appeal to end users. Thus, as depicted in Figure 2, this study supplemented base-maps with geo-referenced map images that queried over the Internet using Web Map Service (WMS) in Map Server. The study enabled WMS to listen via HTTP interface and interrupt any query for map images from spatial database, route-finder or web server so as to reduce round-trip time of serving a request.

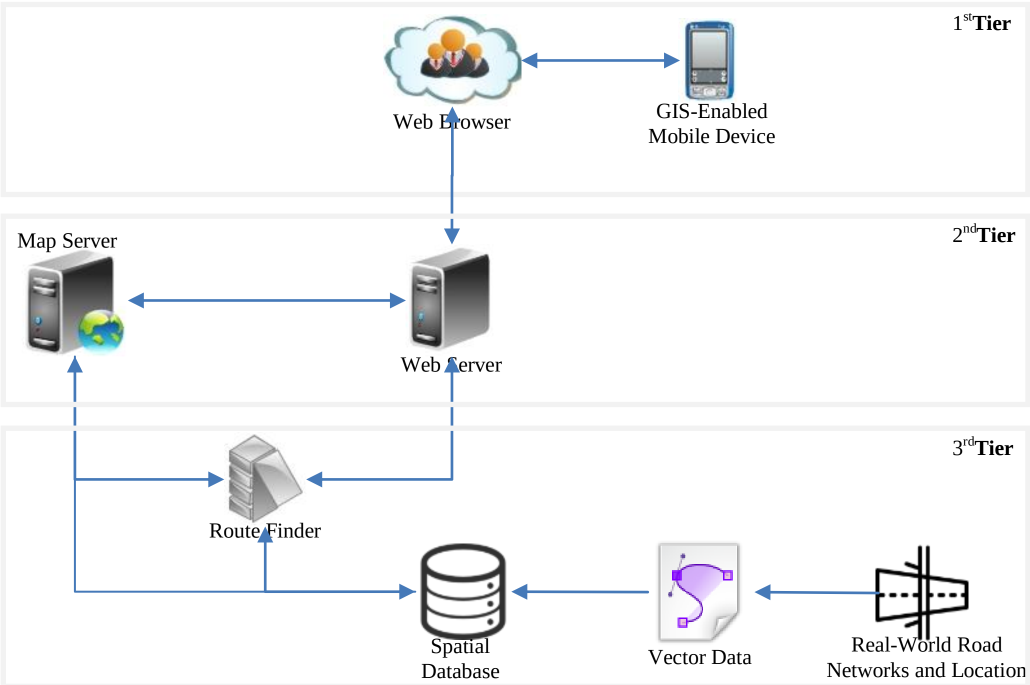


Figure 2: Designed pedestrian navigation system (PNS) architectural framework.

To achieve the objective of calculating the best path to destination, the study designed an integrated route network component that facilitate sufficient and automatic route computation to desired destinations. This component uses abstract graphical model to represent topological connectivity along pedestrian routes such that edges represent roads and junctions represent marked features along the routes. As depicted in Figure 3, the study establishes overall data structure with associated classes of the route network component using Unified Modelling Language (UML). The Geometry class is a root and heart of the route network component that binds links and nodes with spatial reference system, which defines associated coordinate system. The class is composed of two subclasses, namely point and curve, which represent points and lines, respectively. The subclass associated with geometric curve class is a line string which represents a series of points that link line segments, whose string is formed by two subclasses; a line and a linear ring. A line is a linear edge connecting two points while a linear ring is a closed path with starting point equal to the end point.

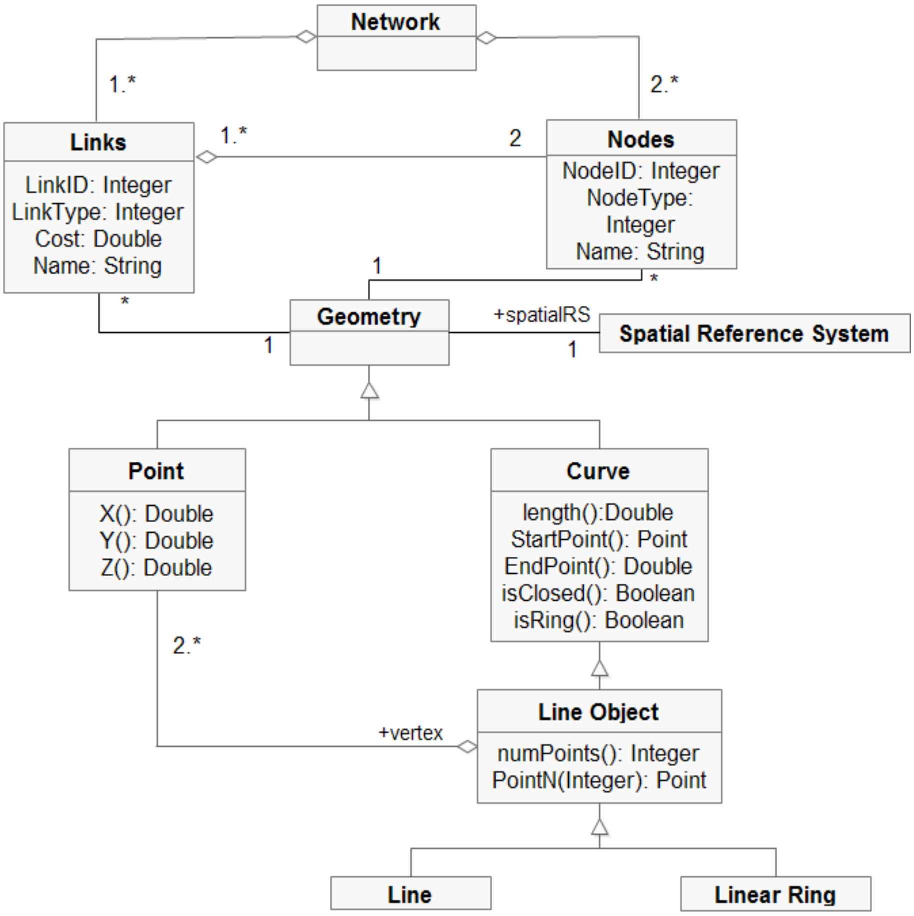


Figure 3: UML representation of data structure of route network component.

Basically, pedestrians are normally navigating on either side of the road, thus a better representation is to model pedestrian routes on either side of the shared road and not on the central line. Also, when moving between the cross points, pedestrians often cross from one corner to the next nearest corner. Therefore, as depicted in Figure 4, a rationale to represent this scenario is to model the pathways on each side of the road and a line segment at each crossing.

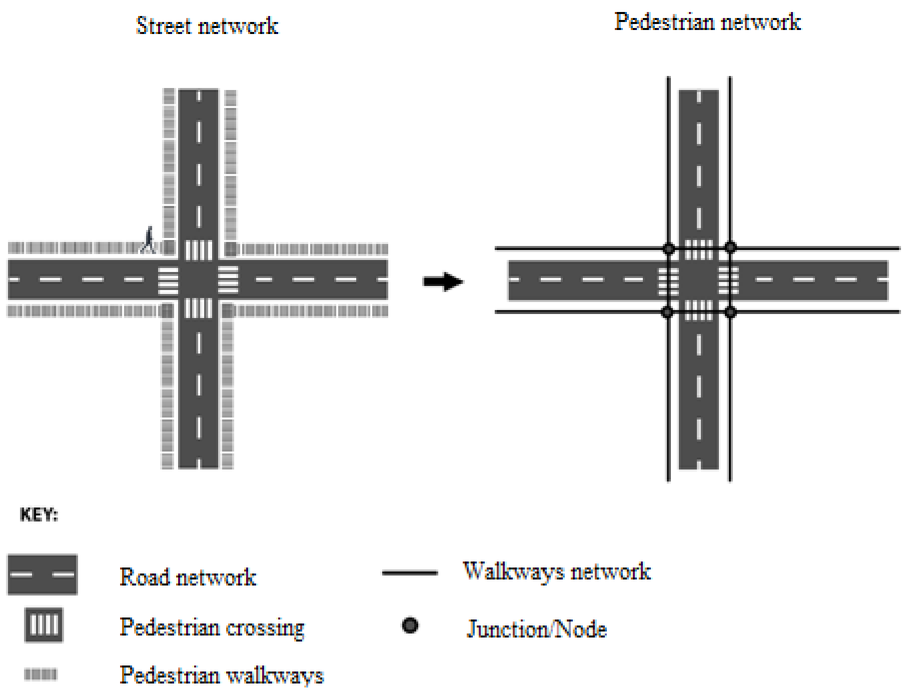


Figure 4: Shared road intersection modelling.

According to Gaisbauer and Frank (2008), pedestrians often walk directly towards the desired line of sight as they cross open spaces, which implies that there is no single decision point whenever pedestrian cross such spaces. To model this scenario, the study makes connection of line segments at each possible pathway such that whenever line segments intersect between diagonals, it implies no node can be created since there is no such possible route. Also, when there is no routing decision to be made at the point of meeting of links, they usually do not get connected by a node as shown in Figure 5. This scenario is predominant to open spaces and route crossing separated by a bridge.

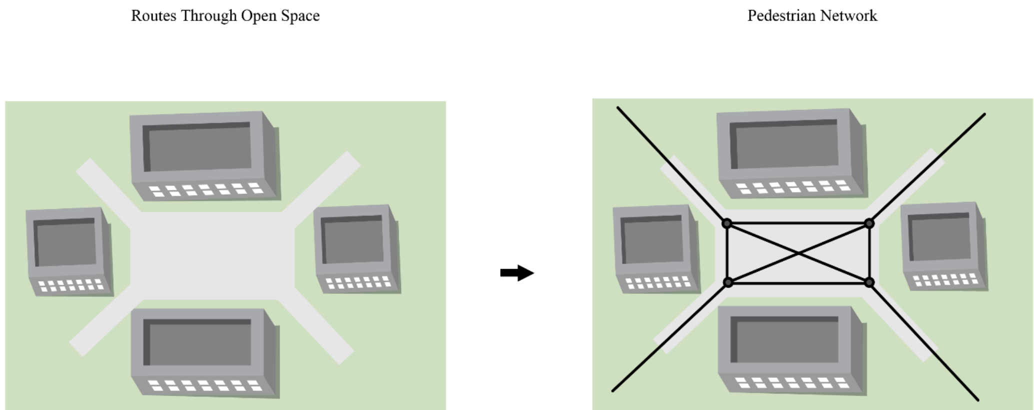


Figure 5: Open space pedestrian network modelling.

To prepare for prototype of the PNS architectural framework, the study creates a model for the University of Dar es Salaam (UDSM). Initially, a polyline vector layer was prepared in QGIS software by digitizing all pathways used by pedestrians to reach different locations. To provide routable capability for the network, the routes were created as segments meeting at each intersection. As shown in Figure 6, these segments were then connected to form a single route network.

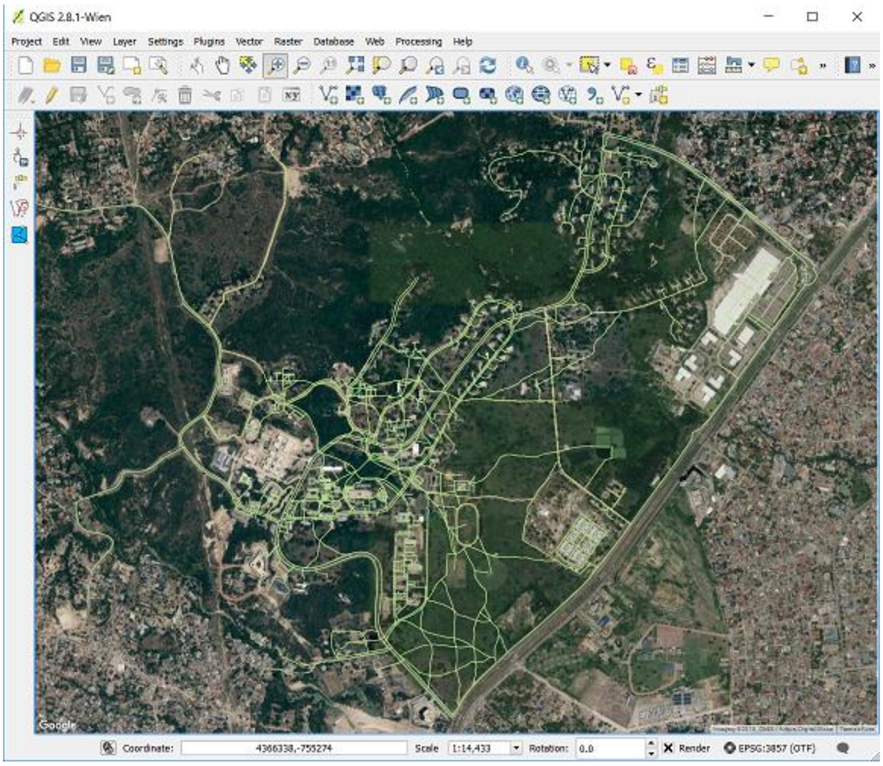


Figure 6: UDSM campus route network model.

Design of route choicesalgorithm

According to the findings presented in Table 5, pedestrians do not make route decision based on one factor alone, for instance, although the shortest-route factor influenced decision by 28.4% but other pedestrians asserted that shortest-route is not necessarily the best if it is not safe, cheap, simple and pleasing to pedestrians. This finding was supported by results in Naharudin et al. 2017), which recommended use of multiple factors to optimize route decisions. This study used weighted sum scalarization method to transform multiple factors recommended by participants into one composite factor for easy computation.

Assuming the network of roads in the study area is represented as undirected graph $\mathrm{G} = (N, S)$, where N represents a finite set of nodes of the graph (i.e. features along the roads) and S represents the road segments that connect intersections. In order to obtain composite factor, the study associated each road segment along path, $s \in S$ with five factors recommended in Table 5 that include the length of the segment $l(s)$, safety risk $r(s)$, cost $c(s)$, simplicity $s(s)$ and pleasantness $p(s)$. Let path P on G defined as connected sequence of edges from a particular source to a particular destination connected through sequence of edges, the length, safety, cost, simplicity and pleasantness of the path *P* from source to destination is represented in Equation (3) such that

$$l(P) = \sum_{s \in S} l(s);\ r(P) = \sum_{s \in S} r(s);$$
$$c(P) = \sum_{s \in S} c(s);\ s(P) = \sum_{s \in S} s(s);$$
$$p(P) = \sum_{s \in S} p(s) \qquad (3)$$

Let the function of i^{th} factor of path j represented by $f_i(s^j)$, using weighted sum scalarization method, the optimum combination of all attributes of the path to give a scalar objective $\emptyset_j(w,s)$ is derived as shown in Equation (4) such that

$$\emptyset_j(w,s) = \sum_i^5 w_i f_i(s^j) \qquad (4)$$

Where; $f_i(s^j)$ and $w_i (w_i \geq 0\ and\ \sum_i^5 w_i = 1)$ are the function and weight of i^{th} attribute along segments of path *j*. However, since equation (4) requires all factors to be in the same unit measure, then in theory, the functions of different attributes must be normalized as shown in Equation (5) such that

$$\emptyset_{j,nom}(w,s) = \sum_{i=1}^5 w_i f_{i(nom)}(s^j) \qquad (5)$$

whereby $f_{i(nom)}(s^j)$ is the normalized function attribute. According to the theory of normalization, normalized function is achieved by multiplying $f_i(s^j)$ with a normalization factor Q_i such that if normalization is based on magnitude of objective function at initial point of path j, s_0^j, then $Q_i = \frac{1}{f_i(s_0^j)}$. Otherwise, if normalization is based on the range of functions from initial to final interval of path *j*, then $Q_i = \frac{1}{f_i(s_n^j) - f_i(s_0^j)}$. According to the study by Grodzevich and Romanko (2006), the latter normalization method is more practical and useful because it provides good representation of optimal attribute. Thus, replacing normalization factor into equation (5) results into Equation (6) such that

$$\emptyset_{j,nom}(w,s) = \sum_{i=1}^5 w_i f_i(s^j)\, Q_i$$
$$= \sum_{i=1}^5 \frac{w_i f_i(s^j)}{f_i(s_n^j) - f_i(s_0^j)} \qquad (6)$$

Equation (6) serves as normalized function for getting composite factor of network path *j*. Thus, in order to make best route choices, the PNS should determine normalized composite factor of all the possible paths from source to destination and then run a comparison analysis to obtain an optimal path in a sequence flow shown in Figure 7.

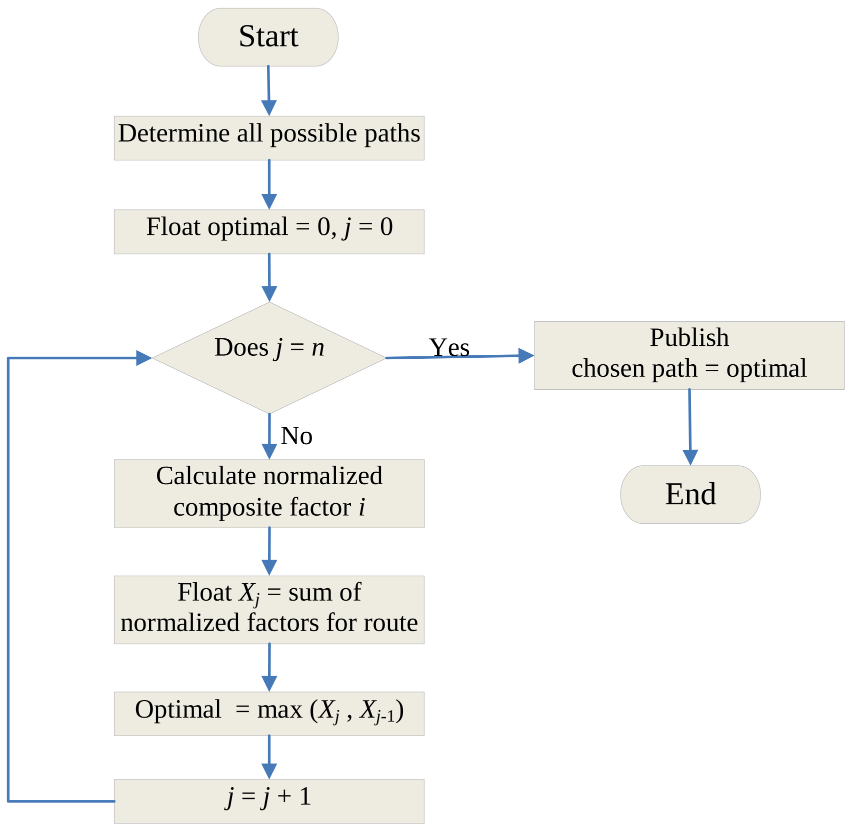


Figure 7: Flowchart for optimal path determination.

Route guidance on deviation

With optimal route to destination, the pedestrian must be guided to follow the right path to desired destination. According to the results stipulated in Table 6, most pedestrians with a mean score of 4.33 prefer PNS guidance that displays route to destination on the map dynamically. The designed PNS architectural framework uses GIS-enabled mobile device that can learn geospatial traces using GPS points collected in real time. Most GPS receivers update positions every second, however, GPS data points are usually unreliable and inefficient due to noise interference. Since it is possible that by the time route-finder determines optimal path, the user could be deviated in another non-optimal path, then GPS raw data need to be prepared before being used in route tracking or else data may cause false deviation.

In order to improve accuracy of the GPS raw data, the study made assumptions that attributes of two locations with very slight differences are treated with same weight, similar locations in a row (e.g., the pedestrian is idle) are reduced to one, if the distance between two consecutive locations is greater than a threshold then it leads to GPS disconnection, and if a location is substantially different from the surrounding locations then it leads to GPS noise. As depicted in Figure 8, assume that a pedestrian is at point P_s, which is away from known trail connecting source to destination.

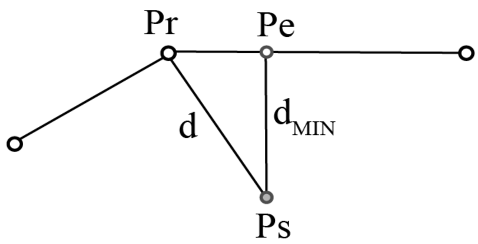


Figure 8: Estimation of deviation point.

In order to associate P_s to the trail along P_r and P_e, the algorithm calculates shortest possible perpendicular distance (d_{MIN}) such that if $d_{MIN} > Minimum\ Allowable\ Distance$, the association to the known route is pronounced impossible and new optimal route from P_s should be calculated. Otherwise, if distance $d_{min} > d_{th}$, the deviation is considered tolerable and within known track, else if $d_{min} \geq d_{th}$, then the deviation is considered significant and user must be alerted.

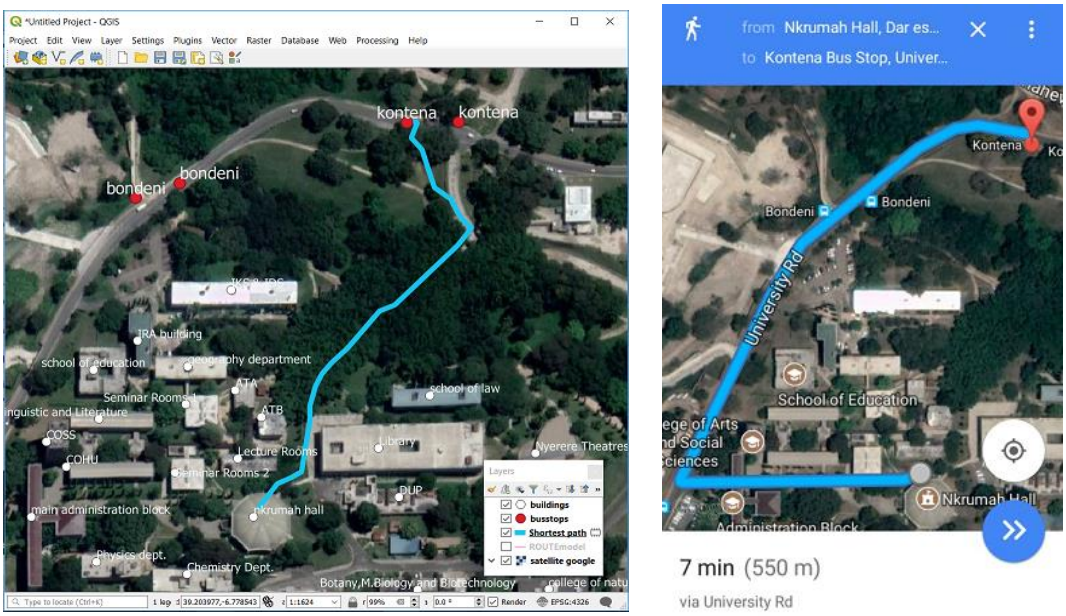
Establish testing prototype

To verify efficiency of proposed framework, the study configured environment whereby all-important services and resources of the chosen study area were digitized as point vectors using open source QGIS software. First, open layers QGIS plugin was used to load multiple geo-referenced open data layers for digitization, then these data were stored into an open source PostgreSQL database. Since, PostgreSQL by itself has no capability to store spatial data, then a spatial database extender, PostGIS, was used to add support for geographical objects. PgAdmin, an open source administration and development platform for PostgreSQL, was used to access the database and its features. To add more routing information to the loaded shape-file (route), PgRouting extension was used to provide geospatial routing functionality to PostGIS/PostgreSQL.

Results and Discussion

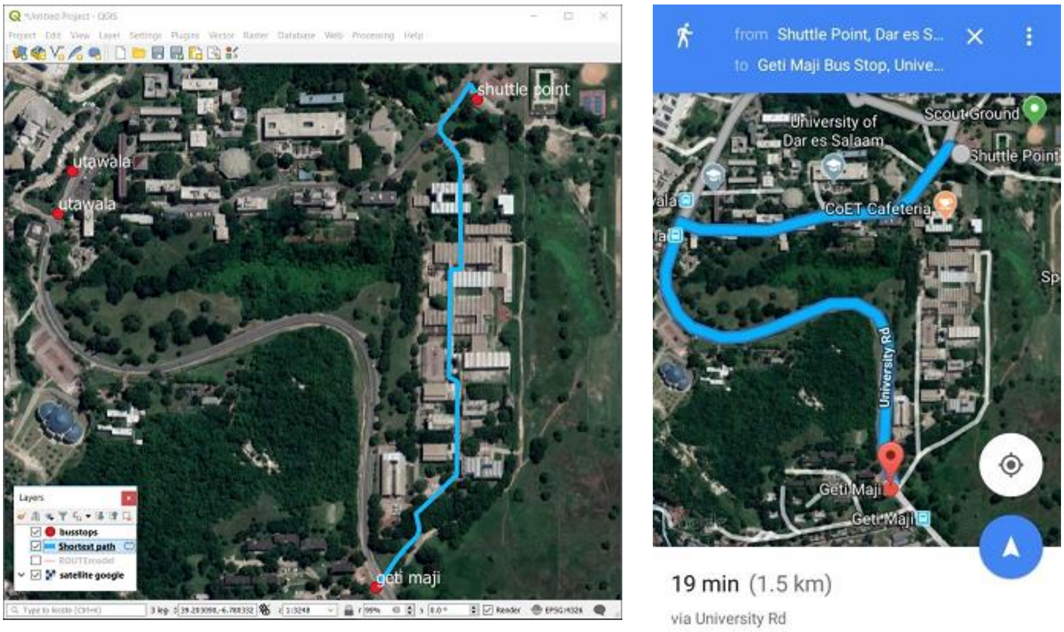
A prototyped framework was installed into a Geoserver system as a service in port number 8080. The tested environment was created as web-service on network topological route along features on geospatial map of the University of Dar es Salaam (UDSM), Julius Nyerere Mlimani campus. Using prototyped web-service, the search results of the shortest route between Nkrumah Hall and Kontena bus-stop that were computed using proposed PNS framework and Google Maps are shown in Figure 9(A) and 9(B), respectively.

Based on metrics observed in Figure 9(A) and 9(B), the PNS on proposed framework gave relative shorter path of 320 m, which accounts for 72% shorter than Google Maps. Another route from Shuttle Point to Geti Maji Bus Stop points were compared as shown in Figure 10, whereby the proposed PNS framework gave a shortest path of 732 m against Google Maps of 1.5 km that accounts for 105% relatively shorter.



(A) (B)

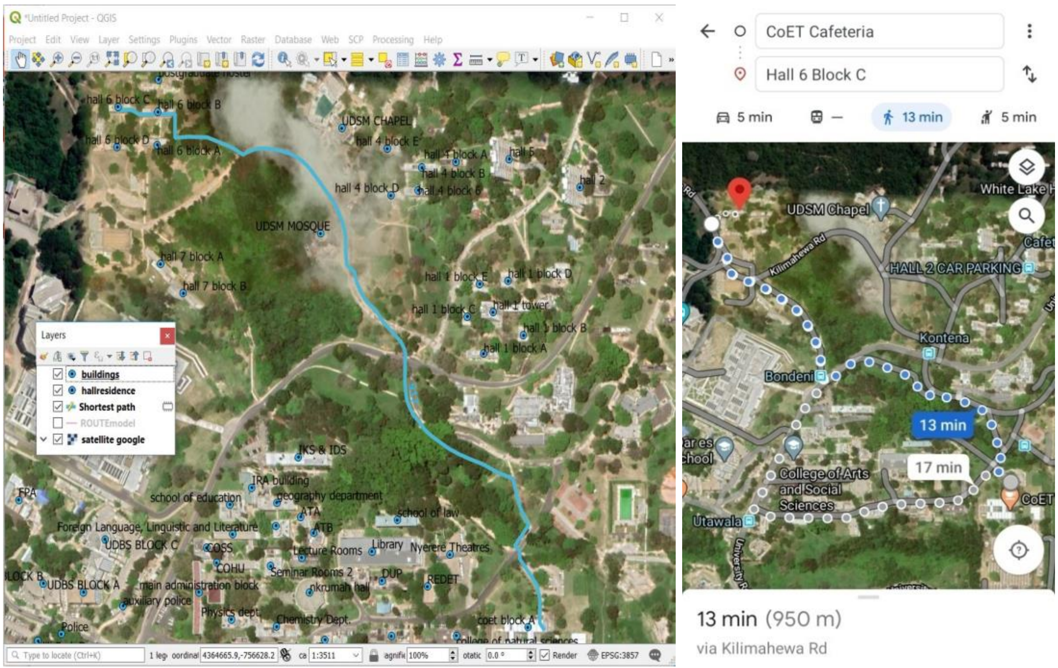
Figure 9: Created route using (A) proposed PNS model and (B) Google maps for walking.



(A) (B)

Figure 10: Created route using: (A) proposed PNS model and (B) Google maps for walking.

Similar observations were noted when searched shortest path from College of Engineering and Technology (CoET) Cafeteria to Hall 6 Block C whereby the PNS on proposed framework gave 917 against 950 m by the Google maps, which accounts for 3.5% longer as shown in Figure 11.



(A) (B)

Figure 11: Created route using: (A) proposed PNS model and (B) Google maps for walking.

Conclusions

The study focused on design of a PNS framework that would support resource allocation on mobile devices in environments where GIS maps have not been well established. Based on the design of the proposed PNS framework and the test of prototyped environment, the optimal walking route searched by the proposed PNS framework outperformed the searched results by Google maps by at least 3.5%. This was attributed by the fact that the proposed PNS framework used multiple features to establish optimal path in environments where GIS has not well developed while Google maps used only features identified along vehicular road networks. Thus, it is clear the resulted PNS framework provides important references to implement and guide a functioning pedestrian navigation system that considers local environmental features. The proposed framework devised route choices algorithm that incorporates multiple criteria to mimic the reality on how human beings make decisions when navigating from two points on walking.

Recommendations

The aim of this study was to design a pedestrian navigation system (PNS) framework that can support pedestrian get rid of unfamiliar environment whose GIS map has not well established. The study designed PNS framework, which comprised of foundation principles like shortest path algorithm. It lays down novel framework that incorporate route choices algorithm using features that mimic human behaviours in choosing favourite walking routes. Despite the promising results, further study is recommended to improve the accuracy of pedestrian positioning in environments where or whose GIS maps have not been well established as currently it assumes last detected position. GPS alone offers limited positioning accuracy to the point that the detailed nature of pedestrian navigation loses its flavour and even its feasibility.

Conflicting of interest

Authors declare that no conflict of interest exists.

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References

Elwakil MM, Ibrahim RF and Hefny HA 2015 New architecture for mobile GIS cloud computing. *New Architecture* 4(10): 1-7.

Fang Z, Li Q and Shaw SL 2015 What about people in pedestrian navigation?*Geo-spat Inf. Sci.* 18(4): 135-150.

Gaisbauer C and Frank AU 2008 Wayfinding model for pedestrian navigation. 11th AGILE International Conference on Geographic Information Science, University of Girona, Spain. Girona, Spain: Springer-Verlag.

Grodzevich O and Romanko O 2006 Normalization and other topics in multi-objective optimization. Proceedings of the Fields-MITACS Industrial Problems Workshop. Toronto: 89-101.

Löfberg M and Molin P 2005 *Web vs standalone application-a maintenance application for business intelligence*. Master Thesis in Software Engineering, Blekinge Institute of Technology.

Millonig A and Schechtner K 2007 Developing landmark-based pedestrian-navigation systems. *IEEE Trans. Intel. Transport. Syst.*8(1): 43-49.

Naharudin N, Ahamad MS, Sanusi S and Sadullah AF 2017 Optimizing pedestrian-friendly walking path for the first and last mile transit journey by using Analytical Network Process (ANP) decision model and GIS network analysis. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* 42: 137-144.

Ondieki CM and Murimi SK 1997 Applications of geographic information systems. *Environ. Monit.* 11: 314-340.

Poorazizi E and Alesheikh AA 2008 Developing a mobile GIS for field geospatial data acquisition. *Asian Network Sci. Inf: J. Appl. Sci.* 8(18): 3279-3283.

Rodriguez J, Malgapo A, Quick J and Huang CY 2017 Distributed architecture of mobile GIS application using NoSQL database. *Int. J. Inf. Electron. Eng*. 7*(*6*)*: 156-160.