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Challenges and opportunities for geospatial integration into 'trotro' road travel in Ghana

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Abstract

Travel routing is vital for an efficient delivery of public and private services and the movement of people and goods. In Ghana, the major nature of travel routing is through the 'trotro' system. The trotro system uses an automobile to move people and goods along a prescribed travel route, with locally known stops where people get on and off the vehicle. The trotro system is significant because Ghana's road network and street addressing are imperfectly mapped. Thus, this paper critically evaluates the research challenges and opportunities for the development of an integrated trotro geographic addressing system. The widespread trotro address assignment and the availability of geolocation technology on mobile phones, make the integrated trotro geographic addressing framework an inexpensive and a comprehensive approach. The key research questions that need investigation for the development of such an integrated geographic addressing system are identified, together with a critical review of the problem, and its research challenges and prospects.

Keywords: GIS, Road travel, Trotro, Global Positioning System, GPS mapping, Travel routing

1. Introduction

Ghana's road network and street addressing are imperfectly mapped, with limited, inaccurate and inadequate spatially referenced landmarks for efficient road travel. The lack of adequate street names, and spatially referenced house numbering represent the foundational infrastructure needed for efficient movement of people, services and goods. Adequate street names and spatially referenced house numbering provide crucial societal benefits (Astutik *et al.,* 2017; Farvacque-Vitkovic et al. 2005; Hancock *et al.,* 2001; Doug and Bunge 2016; Kammoun *et al.,* 2012; Anurogo *et al.,* 2017), including crime mitigation, revenue collection, business growth and productivity, service delivery such as health, policing, firefighting, ambulance travel routing, and emergency and disaster services. That is, locational travel route infrastructure underlie efficient functioning of the country's economy in its growth and productivity. The social and economic impact that results from this lack of locational infrastructure is apparent in the delivery of services by private businesses and the public sector. This lack of proper geographic addressing system in Ghana is typical of most developing countries, and there are growing economic and social rationale to address this challenge.

Technological advancements in geospatial referencing (Lubis *et al.,* 2017) such as Global Positioning System (GPS) and Earth observation through remote sensing provide inexpensive means of acquiring locational information. However, these innovations can only facilitate the existing nature of movement of people, services and goods. The major nature of movement of people, services and goods in Ghana is through the 'trotro' system. The trotro system uses an automobile to move people and supplies along a prescribed travel route, with locally known stops where people can get on and off the vehicle. The trotro system represent a rich source of local information due to its wide and frequent usage, yet it has not been incorporated into the existing travel route infrastructure. Trotro routes are widely used travel routes and represent a significant spatial coverage of the road network. The integral role of the trotro route is further underscored by the lack of adequate street names and reliable house numbers. The trotro stops and key landmarks are popular referenced locations for: people to meet, travel plans (Taki and Lubis, 2017), and delivery points for merchandize and services. The trotro system is an informal address assignment that is spatially unstructured, and it is typical of most developing countries where geographic addressing is not well defined.

The wide availability of GPS capability on mobile phones and the widespread local trotro address assignment, provide both a challenge and an opportunity to develop an integrated trotro geographic addressing system. Such a geographic addressing system will incorporate local travel route data and a formal geospatial framework. The research needed for the development of such an integrated geographic addressing system is commendable, yet it is important to critically review the problem and outline its challenges and opportunities.

2. Problem description and state of the art

2.1 An overview of geographical location and addressing system in the developing world

It is important to briefly describe key terms for the purpose of their use in this paper. The term, geographic location or simply location, refers to a specific place or position on the Earth surface; whereas an address refers to details or information about a location. Accordingly, geographic addressing system refers to a framework that allows accurate determination of a geographic location and associated descriptive information about that location. An addressing system is a procedure of assigning information or details to a geographic location.

There is an increasing need to improve the address system of geographic locations in developing countries like Ghana, given the rapid economic development and widespread availability of mobile phone (or smartphone) technology equipped with Global Positioning Systems (GPS). GPS is a global network of satellites that interact with a corresponding receiver to determine its exact location in latitude and longitude values using the WGS84 coordinate referencing system. The GPS latitude and longitude output is unfamiliar for most unskilled users as it requires knowledge of geographic coordinate referencing. While GPS technology is revolutionary in determining position for any location on the Earth surface, it requires a corresponding physical addressing system to make this information practically useful. Currently, GPS technology allows smartphones to determine geographic positions for locations, however the local geographic addressing system in Ghana, like most developing countries, is not well-defined.

This problem of improving geographic addressing through GPS coupling has been the focus of intense investigation of several authors including, Geohash invented by Gustavo Niemeyer in Niemeyer (2017), Natural Area Code (NAC) in NAC Geographic Products Inc. (2017), Open Location in Doug and Bunge (2016), Geographic Location Referencing System and Method (GLRSM) in Hancock et al. (2001), what3words geographic addressing system in Sheldrick et al. (2017). Geohash is a geocoding system that uses a hierarchical spatial data structure by subdividing space into buckets of grid shape, thus enabling geocoding specific points as a short string to be used in web URLs (Fox et al., 2013). Geohash is represented by a binary string of base-32 encoding with each character designating alternating divisions of the global longitude-latitude rectangle. Geohash is mainly used as a unique identifier to represent point data, and for geotagging.

The NAC system is similar to geohash in terms of its grid structure of dividing the Earth into 30 discrete divisions, each for longitude and latitude. NAC uses a base-30 character string to derive three character strings separated by blank spaces, where the first character string represents longitude, the second string represents latitude, and the third string represents altitude. Each 30 discrete division is assigned one character, and can be subdivided into another 30 discrete divisions. The subdivision can be undertaken at third, fourth and other levels. The NAC system, based on WGS84 coordinate referencing system, can represent a point anywhere on Earth, a line section of constant longitude or constant latitude, an area bounded by constant longitude and constant latitude and a three-dimensional region bounded by constant longitude, constant latitude and constant altitude.

Open location defines an address for a location that is shorter than latitude and longitude values by using a number base of 20. The open location address has a 20 maximum character set derived using characters 0-9, and A-Z. In the open location coding, most building addresses are assigned a 10 character coding covering 14 meter by 14 meter square area. Accordingly, each open location address is assigned to an area (not a point) defined by latitude and longitude values in the WGS84 coordinate referencing system.

The what3words system uses a 3-word-combination to assign to the center of a 3 meter by 3 meter square grid that is defined in latitude and longitude values. Accordingly, the entire Earth surface is divided into a 3-by-3 meter grid such that locations overlapping any 3 meter grid have a 3-word-combination address and a position defined by latitude and longitude values.

The GLRSM approach uses a hierarchical grid address defined at several levels including top, second, third, and a predefined alpha code. The top level code represents a country, the second level code represents a state/province/region, the third level code represents a city/town, and the predefined alpha code represents a specific object in the city/town.

However, the majority of these formal geographic addressing systems have minimal community uptake in developing countries like Ghana. The key underlying factor for low adoption of these geocoding technologies being that they are far removed from the local knowledge of geographic address assignment. While these formal geographic addressing systems are well-structured, most local geographic addressing are often unstructured and not well-defined.

2.2 Local geographic addressing system in Ghana

The local geographic addressing system in Ghana is best exemplified by the trotro system. As noted, the trotro is an automobile that is used to move people and goods along a prescribed travel route, with locally known stops where people can get on and off the vehicle. The trotro stops have a specific geographic location, with the addresses informally assigned by the local people. Typically, the geographic location of the trotro stops are situated close to key landmarks including cultural features such as schools, hospitals, road intersections and police stations, and natural features such as trees, valleys and rivers. The trotro geographic addressing system, though simple, is powerful and it is important to review its key properties.

Physically meaningful: the trotro address assignment is physically meaningful in the way it uses cultural and natural features to provide an address to a place. The immediate implication of this property is that the address is dependent on the continual existence of those cultural and natural features. Additionally, there is a risk of non-uniqueness for locations with similar cultural or natural features. For example, if two schools are located near each other along a certain road, then a physically meaningful address such as 'school junction' will not be unique as a spatially referenced address and will lead to either locations of the two schools.

Cultural: the trotro address assignment is deeply cultural as this method of navigation is not only limited to road travel but permeates all forms of movement of people. The Ghanaian society is socially vibrant, so people navigate in a sequential pattern in a way that a person will arrive at a prescribed location or address and then ask someone for further direction to a more specific location. This cultural address assignment means that trotro geographic addressing is very broad in terms of specificity of a place. The trotro address assignment is best described for a geographic locality or a place instead of a specific geographic position. That is, trotro geographic addressing is primarily aimed to support navigation in an intermediary way to a more specific location. It is noted that there are examples of trotro address assignment for specific locations. The unstructured nature of trotro system means that address assignment can refer to either a geographic location or a locality.

Based on need: trotro geographic addressing is assigned on need basis. That is, trotro address assignment is not regular along a road network but based on locations of societal relevance and of persistent use. The implication of this property is that trotro geographic addressing is aimed to support operational activities of local people. Thus, there is no consistent pattern or national procedure for assignment of geographic addresses.

Widespread: given the cultural and operational nature of the trotro system, it is the most widely used form of geographic addressing by local people. The immediate implication of this property is that any geographic addressing system that integrates the trotro system is likely to have high societal impact, whereas an addressing system which ignores this important societal information is likely to encounter less community impact.

2.3 Geospatial framework for geographic addressing system

Most formal geographic addressing systems (Doug and Bunge, 2016; Hancock *et al.,* 2001) require key fundamental components including a geographic referencing system, a geospatial database framework, and an address definition system. Given the widespread availability of GPS on smartphone devices, WGS84 is the most commonly used geographic referencing system. An address definition system is a procedure for deriving address characters. For example, characters derived from 0-9 and A-Z were used in open location addressing, a 3-word-combination in what3words system, and hierarchical encoding was used in GLRSM approach.

The key properties of a geospatial database framework include efficient storage, querying, and transformation capabilities for large geospatial data. To achieve these properties, geopspatial databases are equipped to store data with a geometric component where topology and distance-based queries are important (Fox *et al.,* 2013). As a relational database management system (RDBMS), geospatial database framework require spatial indexing. Spatial indexing facilitates efficient data retrieval and spatial queries. Widely used spatial indexing include R-tree, and QuadTree. It is important to note B^+-trees, as they provide a tree structure on linearly ordered data such as a time field in a database table. Though B^+-trees do not store higher dimensional data, they are widely used to organize data structures which can serve to index multi-dimensional databases (Fox *et al.,* 2013).

R-tree store n-dimensional geometries by replacing each geometry with its minimum bounding (n-dimensional) rectangle, which are in turn stored in a B^+-trees structure (Guttman, 1984; Manolopoulos et al., 2005). QuadTree is a tree structure where each non-leaf node has exactly four children, allowing the splitting of a rectangular region into quarters in a natural way (Kanth and Abugov, 2002; Finkel and Bentley, 1974). A comparison of R-tree and QuadTree for geospatial data by (Kanth and Abugov, 2002) showed that R-tree performs better than QuadTree and that extensive experimentation is required to find the optimal tiling level for optimal Quadtree performance.

3. Challenges and opportunities

3.1 Challenges for the integration of GPS into the local trotro system

The key elements of a geospatial framework for geographic addressing system has been outlined in the previous section. The trotro system represents a typical example of geographic addressing in most developing countries. The overarching challenge is how to smoothly integrate the trotro system into a formal geographic addressing system, facilitated by smartphones with GPS geolocation capability. The development of the integration platform for local trotro and formal geographic addressing is not without challenges. To effectively address these challenges, the following key research questions need investigation.

3.1.1 Geospatial framework for spatially unstructured trotro route information

Practical geospatial database require key capabilities including efficient data entry, storage and retrieval. Existing knowledge and technology including ESRI geodatabase, and PostGIS have well established mechanisms for geospatial data storage and retrieval. However, entry of spatially unstructured data into geospatial databases is a challenge. Particularly, the validity of geometric properties and subsequent building of topology which is required for query and retrieval of geographic data. To address this challenge, a preprocessing procedure is needed to validate the quality of trotro data and ensure their readiness for entry into the geospatial database.

Moreover, the local nature of trotro route and landmark information means that data would usually be spatially unstructured, a potential drawback of trotro data which can lead to inaccurate locational information. A common feature of this inaccuracy may result from poor sequential matching of key landmarks on trotro routes. Critical research is needed to design a real-time geographical database system that can determine usable and accurate information from the unstructured trotro system. As a result, two key components of the preprocessing procedure should include a trotro data definition dictionary, and a local referencing system to mitigate potential locational errors. The trotro data definition dictionary should be in relation to cultural and natural features, as trotro address assignment are typically in reference to either cultural or natural features. The data dictionary is required to provide locational information and a broad description of these cultural and natural features, in order to spatially validate assigned trotro addresses. The local referencing system is to ensure that geographical locations of trotro addresses are within the locality under consideration. For example, a road network can be used as a local referencing system to verify geographic locations.

3.1.2 Formal address definition system

Address assignment in the trotro system is informal and unstructured, yet the corresponding geographic locations and localities are unique. This property of unique geographic locations can be used as a basis to develop a formal address assignment. An adapted version of the hierarchical address assignment is the most suitable for unstructured trotro system. Hierarchical address assignment uses several levels including top, second, third, and a predefined object level. The levels in the hierarchical structure are flexible and can be changed to accommodate different stratifications. The flexible property and the predefined object level mean that different partitions are acceptable and that the original trotro addresses do not have to change. That is, the predefined object level in the hierarchical system will correspond to the original trotro address. Maintaining the original trotro addresses is key, as they have local significance and have been used for a long period of time. As in the GLRSM approach, the top level code in the hierarchical addressing system will represent a country, the second level code for a region, the third level code for a city/town, the forth level code for a locality, and the predefined object code for the local trotro address.

3.1.3 Mapping of trotro routes and key landmarks

The trotro address system is widely used yet the geographic locations are not well mapped or geocoded with known coordinates. To develop a formal trotro geographic addressing system, the trotro stops and key landmarks need to be properly mapped. A practical and an inexpensive approach to geocode/map trotro stops and landmarks is through the use of a hand-held GPS or smartphone equipped with GPS geolocation capability. This will require GPS geocoding of trotro routes, collection of local descriptive information on these routes, and validation with existing road network.

3.1.4 Development of a trotro geospatial addressing system

To enhance the practical use of the trotro system, a formal geographic addressing system is needed in order to facilitate data entry, query, and retrieval of locational information in practical cases including travel route planning, emergency routing, businesses, and general travel needs. Currently, the local trotro system lack these practical geospatial features. A formal trotro geographic addressing system will require comprehensive research into integrating the knowledge gained from: (a) geospatial framework for spatially unstructured trotro data, (b) a formal trotro addressing definition system, and (c) a map of trotro routes and key landmarks. The formal trotro geographic addressing system should be developed into a geospatial decision support in order to facilitate real-time travel routing.

3.1.5 Delivery and communication platforms

The choice of the delivery and communication platform for the formal trotro geographic addressing system will impact the level of direct community uptake. Given the widespread use of mobile phone and the availability of GPS capability, the suitable medium of choice is the mobile platform. Online platform is complementary in cases where the cost of internet usage is inexpensive. Delivery of a formal trotro geographic addressing system onto mobile phone and online communication platforms will require further refinement in terms of real-time GPS communication for practical travel routing. A key requirement of any travel plan is its locational accuracy and practical currency (or timeliness) of travel information. This important task should be achieved by establishing a real-time communication channel between the developed geographical database and the GPS information. That is, the GPS will provide a timely locational information, which in turn can be validated by the geographical database system to provide a matching and a practical travel route information. The travel route communication medium should be in, at least, one global language such as English or French, and one local language. The platform should be equipped with written and audio language formats, cultural and standard cues for travel routing, together with a flexible program interface to facilitate wide usage.

3.2 Opportunities for integration of GPS into local trotro system

The development of a formal trotro geographic addressing system is fraught with challenges, yet there are potential opportunities for a practical and wide adoption. A successful development of the trotro geographic addressing system will represent a truly mixed approach to geographic addressing, incorporating an informal and local trotro system together with a formal geographic addressing system. Such a mixed approach will signify a culturally relevant geographic addressing system and a formal incorporation of local knowledge, rooted in a strong public ownership since most trotro address assignment is done by the local people. Though geographic addressing is not well defined in most developing countries, the formal incorporation of existing locally assigned addresses will strengthen the social character of the trotro geographic addressing system.

Moreover, a strong local participation in address assignment means opportunities to crowdsource trotro data. Crowdsourcing of local trotro data will significantly reduce field geocoding, provide inexpensive data collection and a wide spatial coverage of the trotro geographic addressing system. To crowdsource trotro data, local people will geocode trotro stops and key landmarks and provide descriptive information of geocode locations. A validation procedure together with the developed trotro data definition dictionary and a local referencing system should be used process the crowdsource data, for direct incorporation into the overall trotro geographic addressing system. The development of a validation framework for crowdsourced trotro data, will further strengthen the geospatial framework for handling unstructured trotro data.

Furthermore, there is the prospect to extend the knowledge gained in the development of an integrated trotro geographic addressing system, to district, region/state and national levels in order to develop their local geographic addressing system. The research challenges identified are all independent of the nature of travel routing, making the integrated trotro geographic addressing framework easily transferable to other localities with different modes of travel routing. The smooth transferability of the integrated trotro geographic addressing framework also indicates its flexibility to allow modification of the key components identified in this paper.

4. Conclusions

This study has critically reviewed the challenges and opportunities for the integration of geospatial technology into the trotro system in Ghana, but also applicable to most developing countries and areas where geographic addressing system is not well defined. A detailed description of the problem of lack of formal geographic addressing system has been outlined, together with a survey of existing formal geographic addressing methods. The majority of formal geographic addressing methods lack local address assignment, instead they make use of formulated characters with limited cultural relevance. Consequently, the formal geographic addressing systems are not widely used mainly because they require extensive resources for implementation and intense public education for adoption. However, the widespread trotro system for local address assignment and the availability of geolocation technology through GPS on smartphones, make the integrated trotro geographic addressing framework a more socially acceptable approach.

As outlined, the development of an integrated trotro geographic addressing system is not without challenges. Critical research areas have been identified together with research questions that need investigation in order to develop the integrated trotro geographic addressing system. The key research areas include: geospatial framework for spatially unstructured trotro data, formal address definition system to incorporate informal trotro address assignment, mapping of trotro stops and key landmarks, a framework for an integrated trotro geographic addressing, and a delivery and communication platform for the integrated trotro geographic addressing system.

Moreover, this paper has outlined opportunities for the development of such an integrated trotro geographic addressing system. The integrated trotro geographic addressing system represents a truly mixed approach that incorporates local trotro address assignment with formal geographic addressing, indicating a culturally relevant framework. The cultural signature of the integrated trotro geographic addressing system will create the opportunity to crowdsource trotro data and local knowledge on address assignment. This will extend the spatial coverage of the trotro geographic addressing system and make it acceptable for wide community adoption. There are additional research prospects in the development of validation frameworks needed to process spatially unstructured crowdsource data, and the extension of the integrated trotro geographic addressing system to region/state and national levels and areas with different modes of travel routing.

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