© 2018 IJSRSET | Volume 4 | Issue 9 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

Digital Mapping of Roads and Network Navigation in Spatial Database Applications

Sk.Shalini[1], K.Bhushanam[2]

[1]M.Tech Scholar Department of CSE, NRI Institute of Technology Visadala (V&M),Guntur(Dt), Andhra Pradesh, India

[2]Assistant Professor Department of CSE, NRI Institute of Technology Visadala (V&M),Guntur(Dt), Andhra Pradesh, India

ABSTRACT

GPS technology has been embedded into portable, low-cost electronic devices nowadays to track the movements of mobile objects. This implication has greatly impacted the transportation field by creating a novel and rich source of traffic data on the road network. Although the promise offered by GPS devices to overcome problems like underreporting, respondent fatigue, inaccuracies and other human errors in data collection is significant; the technology is still relatively new that it raises many issues for potential users. These issues tend to revolve around the following areas: data reliability, data processing and the related application. This thesis aims to study the GPS tracking from the methodological, technical and practical aspects. It first evaluates the reliability of GPS-based traffic data based on data from an experiment containing three different traffic modes (car, bike and bus) traveling along the road network. It then outline the general procedure for processing GPS tracking data and discuss related issues that are uncovered by using real-world GPS tracking data of 316 cars. Thirdly, it investigates the influence of road network density in finding optimal location for enhancing travel efficiency and decreasing travel cost.

Keywords: GPS tracking, Reliability, Road network, Visualized map, Map-matching, P-median Model, Network density.

I. INTRODUCTION

Global Positioning System (GPS) is a fast-growing, technologically sophisticated field combined with a satellite navigation system that broadcasts location information (latitude and longitude, speed, heading, altitude, etc.) across the planet. GPS was originally designed for military use; the technology was declassified and released to the public in the year 2000. Much like personal computers, the technology quickly became faster, smaller and cheaper. In less than a decade, GPS technology has spread like wildfire and is used in a wide array of applications. The most common applications have been land, air and marine navigation, and surveying. It has become an integral part of daily life for many individuals and geographic information systems, as well as businesses, construction, resource, environment and agriculture. GPS technology can be embedded into many portable, low-cost electronic devices nowadays to track the movements of mobile objects. This implication has greatly impacted the transportation field by creating a novel and rich source of traffic data. Wolf (2000) concluded that GPS devices could be used to substitute, rather than supplement, the traditional travel diary. GPS devices have since then become an essential contributor to location-based services and intelligent transportation systems for traffic management and control, transportation routing and planning, as well as transportation policy and travel behavior analysis. The results show that the geographical positioning is reliable. Velocity is slightly underestimated, whereas altitude measurements are unreliable. Post-processing techniques with auxiliary information is found necessary and important when solving the inaccuracy of GPS data. The densities of the road network influence the finding of optimal locations. The influence will stabilize at a certain level and do not deteriorate when the node density is higher.

II. EXPERIMENTAL DESIGN AND DATA COLLECTION

We want to examine how well GPS tracking data matches an actual route travelled. Vehicles are in focus for this study and we therefore assume them being restricted by an underlying road network. We consider the vehicles bike, car, and bus being the dominating means of private transportations. In the experiment, the vehicles travel on pre-set routes of known geographical position and altitude with speeds decided in advance. While they are travelling their mobility is being tracked by a GPS device. For the experiments, a standard and integrated GPS device that could be broadly used in different vehicles under various circumstances is preferable. Smart phone with GPS application restricted to cellular network or wireless network is therefore not considered. Other important features in selecting the device are that the device is user friendly, easy to operate and has a durable battery. BT-338 (X) was finally chosen after a survey in the product market, this device is a combination of a GPS receiver and a data logger4 . According to the manufacturer, the device should provide a geographical positioning within an error of 5 meters and a measurement error of velocity less than 0.4 km/h. The manufacturer makes no claims about the precision in the measurement of altitude.

III. PROCESSING GPS DATA ON THE SPATIAL DATABASE

Data from the GPS logger file The original GPS tracking data from volunteers were recorded into Data Logger files. Each Data Logger file consists of three main variables, Date, TP and positional recording. The variable Date notes the latest date and time when the file was loaded from the device to the computer by using the software Global Sat Data Logger PC Utility. It is in the format of YYYY-MM-DD-tt:mm:ss. The variable TP represents the tracks, in which a track is defined as the sequentially linked line based on a number of positional recordings in a specific time period. Each positional recording contains the information in the sequence of latitude, longitude, time, date, velocity and altitude. The longitude and latitude are referenced by the World Geodetic System 84 (WGS 84) in the degrees decimal minutes format and are measured with a precision of 5 meters. The time is in the format of ttmmss. The date is in the format of DDMMYY. The velocity was measured in the unit of km/h. The altitude was not recorded and was assigned value -1. shows an example of a Data Logger file from volunteer Domnarvet11. The Date shows that the file was loaded at 2011-04-29-13:15:56. The TP 1= 001, 2011-04-05:20:20:27 signifies that the first track was assigned to 001 and it started at date 2011-04-05 and time 20:20:27. The volunteer Domnarvet11 made 17 tracks in total.Although the promise offered by GPS devices to overcome problems like underreporting, time inaccuracies, respondent fatigue, and other human errors in data collection is significant, the fact that the technology is relatively new raises many issues for potential users as well. These issues tend to revolve around the following areas: reliability, data processing and the related application of the results. GPS hardware is evolving rapidly with smaller size, higher compact units and lighter weight to improve the accuracy of data. A key issue in the accuracy of GPS devices is the number of available satellites. Research to-date suggests that, for travel mobility analysis, a GPS device should be capable of simultaneously tracking four or more satellites in order to maintain an acceptable accuracy. As GPS devices become more accurate, efficient, and cost-effective, can it be entirely reliable in real applications?

There are shortcomings found in the GPS data, for instance:

Inaccuracy: Most modern low-cost GPS receivers have a stated accuracy of 5 meters in• geographical positioning. This implies a precision in instantaneous speeds calculated from this data to be ±18km/h, if a 1 second sampling interval is used.

Complexity: The inaccuracies outlined above mean that for any real useful purpose,• complex rules must be imposed when analyzing the data in order to try to reflect the individual's mobility. Furthermore, the reliability evaluation is more crucial in transportation applications due to the inherent restriction from the road network. While the reliability of GPS traffic data is influential for its applications in intelligent transportation systems, there is also considerable effort and expense involved in processing the data with detailed information. Specifically, the data processing is required to: 1) format and store raw data tracked by the GPS device; 2) process the data and generate user output, or reformat the raw data for input into other analysis software; 3) provide visualization of the data or link the data to a geographic information system (GIS); 4) map-match the data to a digital road network for correction and analysis; 5) compress the data for storage and retrieval. Along with the reliability evaluation and data processing, applying processed and reliable GPS data for mobility analysis suggests that individuals have strong preferences for optimal travel routes along the road network. The location of a travel destination is one crucial factor in determining people's travel behavior and mobility pattern. The induced effect, such as pollutant emission, traffic congestion and construction change can vary enormously due to the different choices of facility locations, especially in a complex road network. However, it could be troublesome to efficiently find the optimal location of facilities using a specific method (for example p-median model) for geographically distributed demands in a dense road network. This prompts us to consider the influence of different densities of the road network in choosing the optimal location of a facility.

The main goals of this thesis are therefore the following:

Methodological goal: evaluate the reliability of GPS-based traffic data. This evaluation• has been conducted based on data from an experiment containing three different traffic modes (car, bike and bus) traveling along the road network.

Technical goal: outline the general procedure for processing GPS tracking data and discuss related issues that are uncovered. This procedure is carried out by using real world GPS tracking data of 316 cars.

Practical goal: investigate what the influence of road network density is when finding• optimal location. In particular, how does the method p-median model perform in a complex and dense road network? conclusions based on these three studies and proposes possible studies for future research.

IV. DATA PROCESSING

With the knowledge of how reliable the GPS-based traffic data are, the recorded positions and instantaneous velocities from a portable, low-cost GPS device can be applied with fairly good reliability. However, direct use is limited with the risk of negating valuable information and introducing error. The vulnerability of GPS data needs to be supported by additional information to obtain the desired accuracy, integrity and availability for applications. Several studies have addressed certain issues that arise in processing GPS tracking data. For instance, Kharrat et al. (2008) proposed an algorithm (NETSCAN) for mobile object clustering and applied it in an environment constrained by a network. Gannett et al. (2011) presented a query and data mining system named M-Atlas, but noted that it is difficult to transform GPS tracking data into mobility knowledge. Etienne et al. (2012) provided a method for detecting outliers of spatiotemporal trajectories with primary applicability for travel behavior analysis No study has attempted to discuss all issues related to processing GPS tracking data simultaneously, let alone provided a procedure for doing so. This paper aims to address several of the issues arising in processing GPS tracking data and thereby outline a general procedure for the data processing. The study is carried out by using real-world GPS tracking data of 316 cars that were originally collected for the purpose of studying CO_2-emissions induced by retailing. Descriptive statistics and visualized maps are used to summarize and illustrate the mobility patterns. This paper confirms that a general procedure in GPS data processing is necessary to have a detailed understanding of the capability of the GPS device and the output of the GPS logger, to generate a clear definition of movement, to visualize the data pattern as well as match the GPS data on the digital network.

V. OPTIMAL LOCATION

Road network exhibits its key function in the previous two studies. This informs us that in transportation analysis, optimal travel routes are influenced by roads but are determined by destinations. Whether the headed facility is optimally located or not is crucial in route optimization. However, when the road network becomes more complex, finding the optimal location could be troublesome. This paper aims to investigate the density of the road network in influencing the performance of p-median model in finding optimal location of facilities. The p-median model is a corner-stone in location science. Hakim (1964) outlined the p-median model in the network space and showed that the optimal solution is found at the nodes of the {dqp}, where N is the number□N we minp□network (Hakim, 1965).

The objective function is Σq of nodes, q and p indexes the demand and the facility nodes respectively, wq is the demand at node q, and dqp is the shortest network distance between the nodes q and p. Since the p-median problem has been proven NP-hard by Kariv and Hakims (1969), solutions are generally found by use of some of the many heuristic algorithms proposed in the literature. Algorithms, spatial aggregation of demand points, and choice of distance measure have been studied extensively.

However, few studies have scrutinized the density of the road network with the p-median solution. In particular, Han et al., (2013) studied the p-median solutions when the density of a road network was varied from 500 to 70,000 nodes. For a density beyond some 10,000 nodes, they found a gradual worsening in solutions. This study checks their finding by using a competing heuristic (vertex substitution) and replicating their study. We reject their finding. The solutions stabilize at about 10,000 nodes; they do not deteriorate in higher node density. This study complements the research of Han et al. (2013) by replicating their study and including an alternative heuristic algorithm to check their surprising finding of poor solutions for very dense networks. This provides a better understanding in optimally locating facilities on the road network where the complexity is continuously increasing nowadays.

VI. CONCLUSION AND FUTURE RESEARCH

This thesis summarizes the assessment of GPS-based traffic data and its related use for human mobility on the road network. The main goals of this thesis are first to evaluate the reliability of the GPS-based traffic data, and then to outline a general procedure for processing this type of data. Based on these works, the third aim of the thesis is to assess the density of a complex road network in influencing the performance of p-median model on finding optimal locations. The specific contributions are driven by the goals above, and they include: Firstly, a well-designed field experiment is conducted to assess the reliability of traffic data based on GPS devices as traffic sensors. No evaluation has been done on traffic modes of car, bus and bike simultaneously. The results show that the geographical positioning is reliable, but it has an error greater than postulated by the manufacturer and a non-negligible risk for aberrant positioning. Velocity is slightly underestimated, whereas altitude measurements are unreliable. This evaluation method can be applied to assess other types of GPS-based traffic sensors as well. Secondly, the analysis and documentation of general procedures is presented for processing GPS- based traffic data. No study has attempted to discuss all issues related to processing GPS tracking data simultaneously, let alone outline a procedure for doing so. Based on the understanding of the reliability of GPS data, a processing procedure is provided by using real world GPS tracking data of 316 cars. In particular, post-processing techniques with auxiliary information is found necessary and important when solving the inaccuracy of GPS data. Thirdly, a connected investigation of optimal locations is studied based on the understanding of the importance of a road network. The use of GPS in the sports field to examine the speed and route choices would be an interesting to check the relationship between competition strategy and outcome in the absence of road network restriction.

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