An Indoor positioning system based on smart phone - From Location Service to Travel Behavior Analysis

Abstract
Location-based services are rapidly being developed and popularized. However, in cities, especially in indoor buildings, traditional positioning methods cannot meet existing demands for positioning accuracy and positioning time. To address this problem, this research proposes an indoor positioning technology based on Wi-Fi, geomagnetic field, and pedestrian dead reckoning that can seamlessly switch to traditional indoor technology. Through the design of a positioning system based on C/S architecture and the provision of location services on smart phones, location services will accumulate a large amount of data, including location and user data. These data can be used to conduct travel behavior analysis, including the exploration of influencing factors and simulation of travel behaviors, as well as identify travel patterns and conduct statistical analysis, thus contribute to urban planning and urban management decisions.

1. Background

This research includes two aspects: the first aspect comprises the design of an indoor positioning method and the actualization of an indoor positioning system, and the second aspect comprises the use of mobile phone data in travel behavior research. With the popularity of smart devices, location-based services (LBS) are rapidly developing and showing broad prospects (Liu et al., 2017). In outdoor areas where there is good reception, LBS provided by satellites and base stations are accurate and efficient. However, due to building blocks, the multipath effect, and non-line-of-sight transmission, satellites and base stations have limited accuracy indoors and are therefore unable to meet demands for precision and accuracy in positioning methods. Given that people stay indoors for a long time in their daily lives, high-precision positioning services are required in many places, such as office buildings, apartments, shopping malls, and underground parking lots. To address this problem, I will use geomagnetic signal and Wi-Fi signal as position fingerprints, as well as propose corresponding filtering algorithm and matching algorithm. I will then design and realize a position system that provides real-time positioning services indoors.

Simultaneously, this position service will generate considerable data, including the user's location information and other data in application. These data are applicable to travel behavior research, as well as a data source for travel big data (Li et al., 2018). Compared with traditional survey data, data generated by the proposed position service can be collected effectively at a low cost. It will also offer real-time performance and more comprehensive coverage of population and geographic area. After processing, such as data cleaning and anonymization, data can be applied to travel behavior research such as identification of travel patterns, exploration of influencing factors, and prediction of travel behavior (Wang et al., 2017). Specifically, data can be applied to detect activities and trip types, derive travel routes, infer travel modes, analyze statistics of human travel behavior, and simulate travel behavior at the individual level.

The research and implementation of this indoor positioning system can collect a large amount of useful data for travel behavior research and solve the problem of data acquisition. Through the promotion of this application, such as publishing it in the application store for users to download, packaging the service, providing interface for the mall or map application, enough users can be accumulated and large amounts of data can be recorded.

2. Literature Review

Common indoor positioning method sources can be classified into three types according to the signal source, namely, radio frequency signals, built-in sensors, and a global navigation satellite system (Chen et al., 2017). When the radio frequency signal propagates indoors, some signal information, such as signal strength, will attenuate as it propagates, presenting a difference at varied locations. Position matching in a small range is achieved by capturing the unique characteristics exhibited by the signals at particular locations. The radio frequency signal used for indoor positioning mainly includes Wi-Fi (Yu et al., 2014; Liu and Yang, 2011; He et al., 2016), Bluetooth (Hua and Seo, 2017), cellular wireless signal, and near-field communication (Aguilargarcia et al., 2015). But this positioning method requires a sufficient amount of signal transmitting devices to be pre-arranged indoors so that the signal source covers the positioning area. By contrast, Sensor-based technologies use sensors to acquire some original attributes in indoor area, can positioning without additional transmitting devices, include pedestrian dead reckoning (PDR), geomagnetic positioning, visual positioning, infrared positioning, LED visible light positioning, and ultrasonic positioning. Among them, geomagnetic positioning is based on the unique distribution of geomagnetic field indoors that is disturbed by factors such as reinforced concrete wall and building structure. This unique distribution is used as a location fingerprint to achieve indoor positioning with proper geomagnetic matching technology (Deng et al., 2012), such as the use of genetic algorithms to optimize the model (GalvánTejada et al., 2014).

Compared to the use of a single signal source, considerable research focuses on multi-source indoor positioning methods to fully utilize the characteristics of multiple methods. A common solution is to combine PDR with geomagnetic or Wi-Fi signals, such as using classification characteristics of geomagnetic signals to solve changes in user walking speed (Subbu et al., 2013). Extensive research also focuses on the integration of Wi-Fi signals and geomagnetic signals for positioning. This integration can be achieved by improving the positioning accuracy of magnetic field positioning through fusing the Wi-Fi signal (Shu et al., 2015), using Wi-Fi signal to reduce initial positioning range, using geomagnetic field and improved particle filter algorithm to achieve indoor location tracking (Zhang et al., 2017), or designing a position fingerprint with channel state information and geomagnetic field (Huang et al., 2017). Besides, deep learning can also be used in scene recognition with images captured by camera for positioning (Liu et al., 2017b). In addition to a variety of positioning methods, matching algorithm is also an important factor to improve positioning accuracy, such as improved particle filtering (Kim et al., 2017; Zhang et al., 2017; Liu et al., 2017; Shang et al., 2015). Companies, including IndoorAtlas, have developed indoor positioning systems based on geomagnetism and have gradually applied such systems.

Positioning systems can collect data containing time and location. Insightful knowledge on these data can provide a new perspective for travel behavior research, by addressing time, place, and methods that individuals interact with places in urban areas (Jiang et al., 2011, 2012), these data form a way to better understand the urban environment and its dynamics (Steenbruggen et al., 2015) and can be used for identifying dynamics in travel patterns, including intra-personal and

inter-personal dynamics (Dharmowijoyo et al., 2014). Mobile phone data can also be used as a spatial distribution tool to monitor the concentration of visitors in certain tourist attractions (Ahas, et al., 2008). In data processing, pre-processing the raw mobile phone data collected with different positioning techniques have intrinsic problems, such as noise and positioning uncertainty, and thus need to be pre-processed first (Calabrese et al., 2014). Using some thresholds filtered out unrectifiable errors, such as distance and speed thresholds between two consecutive positioning points (Oksanen et al., 2015). Some scholars apply a time order method and use propagation methods to deal with the unrealistic positioning (Alexander et al., 2015; Traag et al., 2011).

3. Research Methodology

In the present research, my research is divided into three parts, including research on positioning methods, matching algorithm and positioning system.

- Positioning method

Analyze and compare principles and characteristics of different positioning methods, such as positioning technology based on Wi-Fi, geomagnetic field and PDR. Geomagnetic field has the characteristics of full-time and full coverage, and no additional equipment is required, but will be affected by indoor environment change (Chen et al., 2017), WiFi signal is relatively stable, but it is easily blocked by objects such as the human body, and the PDR needs to determine the starting position in advance (Kim et al., 2017; Liu et al., 2017b), and has problem of error accumulation. So, design a new hybrid positioning method to reduce the impact of each original method's shortcomings, improve the accuracy and stability of indoor position.

- Matching algorithm

The calculation of position is realized by scene analysis method, namely, the location fingerprint method, achieved by measuring the degree of correlation between the measurement sequence and any sub graph in the location fingerprint, common methods include nearest neighbor using Euclidean distance or Hausdorff distance.

To achieve heterogeneous positioning fusion, a complete solution for integrated hardware calibration, single source positioning, and multi-source fusion location is required. I will create loose couplings between positioning results of geomagnetic positioning and Wi-Fi positioning, with PDR using particle filtering, and estimate position and heading via sequential estimation method. I will also use appropriate filtering to analyze and identify the gross error data in the positioning source, and appropriate method (rough reject or adjust the variance matrix) to minimize the influence of the gross error and obtain accurate and reliable positioning results. At the same time, for the measurement deviation problem of different terminals, the spatial-temporal variation of the signal field such as magnetic field, a solution based on statistical data and modeling is proposed.

- Positioning system

In order to improve the positioning speed, the positioning system adopts the C/S architecture, where sensors in mobile phone collect required data, and the server performs the calculation and returns the result. The production and update of the location fingerprint are also done on the server, such that the service can be more conveniently deployed on the smart phone and can additionally be integrated with the map application and other applications on the mobile phone. Positioning

process is divided into two steps, offline training and online positioning, and the positioning system can be divided into measurement module, data processing module, matching module, communication module and display module. Of course, the positioning system should be real-time, safe and reliable.

- Travel behavior analysis

Research on travel behavior analysis comprises data extraction and processing, data analysis, and privacy issues. Abnormal or useless data must first be filtered to ensure that data used for statistical analysis do not contain the user's private information. Next, the required information from the data, such as location, time, and attributes, can be extracted. Data from mobile phone operators have played a pivotal role in understanding and simulating human activities (Steenbruggen et al., 2015). Thus for the purpose of intra-personal research, I plan to focus on the identification of travel patterns by detecting activities and trip types, deriving travel routes, inferring interest points and preferences, realizing crowd classification, and simulating personal travel behavior. As for the purpose of inter-personal research, the researcher will focus on the statistical analysis of human travel behavior with mobile phone data and improve existing models. Traditional statistical models have high requirements in terms of data accuracy and completeness, and they are extremely sensitive to data bias (Obitko et al., 2011). Additionally, because mobile phone data have unique attributes and unprecedented volume, developing appropriate models for travel behavior simulation using such data is necessary.

3. Expected Findings and Discussion

An indoor localization system based on C/S architecture can be designed and realized by including a positioning module, data processing module, communication module, acquisition module, and display module. The client program is deployed on an Android or iOS system. The system can provide high-precision positioning service indoors and, therefore, meet people's positioning needs indoors. In addition to this application, this research will also publish a service package and application programming interface. Users can create or improve the location fingerprints in certain areas, thus facilitating the promotion and deployment of the indoor localization system. This result will bring increased business value to research and provide a means of travel behavior analysis at a low cost. Through the study, data on where and at what times people cluster for social activities will be gathered, with analysis of the behaviors and patterns of people and individuals, business and cultural institutions will target and price more accurately and effectively (de Jonge et al., 2012), as well as provide the government decision support for traffic management and urban planning. These data also have the potential to contribute to the construction of smart cities.

At the same time, there are some problems that cannot be ignored. First, how can we get the user’s permission when we need their mobile phone data for research? Second, only when the positioning service is successfully promoted and there are a large number of users, sufficient data can be obtained. Third, mobile application and location services cater for a specific group of people, so the date collected have usually serious bias.

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