The Seamless Localization System
for Interworking in Indoor and Outdoor Environments

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Abstract

In order to provide the fully covering localization services in the indoor and outdoor environments, the seamless localization for interworking is basically needed to persons working in these environments using GPS and Wi-Fi technologies. Thus, the objective of this paper is focus on the developing of the seamless localization system for interworking in indoor and outdoor environments. The main technologies developed in this paper are such as 1) Seamless localization function in indoor and outdoor environments; 2) Indoor localization function based on Wi-Fi; 3) Wi-Fi radio map building function; 4) Prototyped system of the seamless localization for interworking. The performance of the developed system was estimated by four measurement metrics such as: 1) Connection and interworking delay time; 2) Practical localization system for interworking on GPS and Wi-Fi environments; 3) Normal interworking operation and region recognition ratio among three regions; 4) Error distance of the proposed system for interworking in Wi-Fi environment. By the experiments, it can be confirmed that the measured results are satisfied to the early development requirements of the project.

Keywords: Wi-Fi, GPS, Interworking, Localization, Indoor Positioning.

1. Introduction

As smart phones have been used to a lot of peoples, the Location Based Service (LBS) based on Global Positioning System (GPS) has been emerged, and the domestic mobile communication operator companies and the related enterprises are now trying a number of aggressive business. The researches and developments for indoor LBS are greatly required to make the pedestrian navigation life more conveniently because the service area of past and current LBSs were limited to only outdoor area and the demands of indoor life patterns in great shopping malls and convention centers including the outdoor area are now increased.[1-3]

In this paper, we proposed the seamless localization for interworking in indoor environment such as museum, exhibition and convention center as well as outdoor environment. The enlargement of user convenience and the utilization in indoor environment can be especially obtained because of the seamless localization in basis on the common regions that mean the overlapped regions in indoor and outdoor environments. So, the proposed localization system might create the expansion toward to IT convergence product competition by technology basis and the opportunity of the new demand generation. The developed system consists of four parts such as: 1) Seamless localization function in indoor and outdoor regions; 2) Indoor localization function based on Wi-Fi; 3) Wi-Fi radio map building function; 4) Prototyped seamless localization system for interworking.

2. Related Studies

Electronics and Telecommunications Research Institute (ETRI) had developed the localization platform that enables continuous localization between indoor and outdoor regions that has less than 5m accuracy using the location database (DB) of Access Point (AP) the and signal strength pattern DB in Wi-Fi environment. The Hubilon had developed the real time map matching solution that matches the object’s movement data with the map, and the solution also provides the daily life information by recognizing user location, direction and neighbor situation using smart phone sensors such as GPS, accelerate sensor, gyroscope sensor and camera. The Wi-Fi Positioning System (WPS) developed by Skyhook had provided the positioning information solution using AP in outdoor region, it had been adapted to early version of iPhones. The Senion Lab in Sweden had been developed a localization technology which guides users to the destination route using smart phone sensors in indoors environment.[4]

3. System Design and Implementation

3.1 Design Philosophies

Most of localization technologies at present is focused on developing only the outdoor localization using GPS in the world. But, the demands for indoor localization function including outdoor localization function are now largely required according to the revolutionary provision of smart phone and increase of indoor workers. Thus, we would like to propose the seamless location system that can operates in both indoor and outdoor regions simultaneously when users are moving from(to) outdoor to(from) indoor direction without any breaks or additional operations by automatically. Thus, main design philosophies for designing our localization system are as follows.
Seamless localization in the common regions that the indoor and outdoor environments are overlapped (coexisted).
Indoor and outdoor localizations using Wi-Fi and GPS signals in each distinct region.
Indoor localization based on Wi-Fi radio map (Fingerprint map).
Prototyped seamless localization system for interworking.
Estimation of performance metrics in the common regions - GPS/Wi-Fi signal measurement and interworking delay time; Practical interworking operation on GPS and Wi-Fi environments; Normal interworking operation and region recognition ratio.

3.2 Seamless Localization Function

The seamless localization function enables the continuous positioning when the user moves from the outdoor region to indoor region or from the reverse way as shown in Fig. 1 (left). The positioning estimation steps in the function are divided into three modules: 1) The positioning estimation module for only outdoor region based on GPS; 2) The positioning estimation module for only indoor region based on Wi-Fi; 3) The positioning estimation module for the common regions based on both GPS and Wi-Fi.[5-8]

The flowchart of the seamless localization function is shown in Fig. 1 (right). If the user is moving to the indoor or the outdoor region, the user smart phone gets continuously the location data that is the indoor region data or the outdoor region data during the user are moving. But, GPS and Wi-Fi information data are commonly received to the user smart phone on a proper threshold level, the user smart phone checks whether the user exists in the common regions or not by the correlation of GPS and Wi-Fi signal levels. Thus, if the user location is estimated the common region and the previous location before the common regions is the indoor region, the outdoor map viewer loads the outdoor map about the neighbor map of the location. On the contrary, if the user location is estimated the common regions and the previous location before the common regions is the outdoor region, the indoor map viewer loads the indoor map about the neighbor map of the location.

Fig. 1 Concept (left) and flowchart (right) of the seamless localization function for interworking in indoor and outdoor environments.

3.2.1 Positioning estimation module for only outdoor region based on GPS

The positioning estimation module for only outdoor region based on GPS estimates the user location using the longitude and the latitude coordinates from GPS. The GPS data format for the localization in outdoor region is recommended by the National Marine Electronics Association (NMEA), and it is stored to Global Positioning System Fix Data (GPGGA) information. So, after the GPGGA information is parsed, the longitude and latitude coordinates can be extracted and these are used for localization.

3.2.2 Positioning estimation module for only indoor region based on Wi-Fi

The positioning estimation module for only indoor region based on Wi-Fi estimates the user location using the Received Signal Strength (RSS) value from AP, Wi-Fi receiver, in indoor region. This value includes RSS Indicator (RSSI) and Service Set Identification (SSID) of AP. The RSSI and SSID values in the specified spot of indoor region are stored to the Wi-Fi radio map (Fingerprint map). Therefore, the user location can be estimated by searching the most approximate value after comparing with the RSSI in the Wi-Fi radio map.

3.2.3 Positioning estimation module for common regions based on both GPS and Wi-Fi

This module defines the common regions in which both GPS and Wi-Fi signals can be normally received simultaneously to user smart phones in the common regions between indoor and outdoor regions. Thus, as the user enters into the outdoor region to indoor region, if the module detects the Wi-Fi signals from the indoor region, it checks that whether the signal change for seamless localization is necessary or not in this time. Thus, if the module decides the signal change is necessary at the time, it firstly releases the assigned GPS channel and establishes the new Wi-Fi channel instantly, and starts the localization algorithm on the Wi-Fi. In the case of reverse direction, the logical flows of the positioning algorithm on the module is the same as the user above case.
3.3 Indoor Localization Function based on Wi-Fi environment

The Indoor localization function based on Wi-Fi environment estimates the user location based on the RSSI of AP to provide variable LBS services. It has been developed on the Wi-Fi radio map that is the most popular method used in Wi-Fi based localization as shown in Fig. 2 (left). If user smart phone receives RSSI value from multiple APs, it sorts the values by signal strength, and selects four RSSIs among received RSSIs by ascending order, and estimates the user location using the Wi-Fi radio map. The software of the proposed localization system is developed by Eclipse on Java platform in Windows7, and is verified on the Dalvik virtual machine (VM), and it was really executed as a form of apk file in the embedded device.

3.4 Wi-Fi Radio Map Building Function

The Wi-Fi radio map building is the technology that receives and analyzes the strength of the signal from neighbor AP, remakes it to the localization typed format and finally regenerates Wi-Fi radio map database as shown in Fig. 2 (right). The device, mobile device simulator, has a role of the Wi-Fi radio map builder, and stores the obtained radio map data to the Android OS typed device. The Wi-Fi radio map building process is divided into four steps: 1) Indoor map extraction; 2) AP layout design; 3) Wi-Fi signal collection; 4) Radio map building as shown in Fig. 3 (left).

![Fig. 2 Configuration of indoor localization function based on Wi-Fi (left) and Wi-Fi radio map building concept (right).](image)

The Wi-Fi radio map building function is developed on Java SE Development Kit (JDK), Android Software Development Kit (SDK), Eclipse, and Android Development Tool (AD) Plug-in for Eclipse in Windows 7 OS.

3.5 Seamless Localization System for Interworking in Indoor and Outdoor Environments

The seamless localization system for interworking in indoor and outdoor environments has a role of user positioning seamlessly in the common regions as well as the indoor or outdoor environment without any connection break while user is moving to any directions as shown in Fig. 3 (right). After the signal analysis algorithm for the common regions in the system for interworking analyze the validation of the signal strength, it select one of three regions such as the indoor, outdoor, and common regions.

![Fig. 3 Wi-Fi radio map building processes (left) and architecture of the proposed system (right).](image)

3.6 Prototyped Seamless Localization System for Interworking

The prototyped seamless localization system for interworking consists of two subsystems such as the Wi-Fi signal strength analysis and monitoring subsystem and the radio map building subsystem. The Wi-Fi signal strength analysis and monitoring subsystem analyzes and monitors the Wi-Fi signal strength and related information in the proposed system for interworking in indoor and outdoor environments. Fig. 4 (left) shows the running scene of the Wi-Fi signal strength analysis and the monitoring subsystem in the proposed prototype. Fig. 4 (center) shows the front/side and back/inside views of the proposed prototype in indoor and outdoor environments.

4. Experimentation and Performance Analysis

4.1 Experimentation Environment for Common Regions of GPS and Wi-Fi

The experimentation in the common regions is executed using the developed prototype in the assigned indoor and outdoor environments by repeatedly walking in the outdoor region (Outward entrance of First information & Telecommunications Building at Tongmyong University - latitude: 35.12013, longitude: 129.10306) and in the indoor
region (Region B of indoor map, First information & Telecommunications Building at Tongmyong University) as shown in Fig. 4 (right). The performance of the developed system was estimated by four measurement metrics such as: 1) GPS/Wi-Fi signal measurement and interworking delay time; 2) Practical interworking operation on GPS and Wi-Fi environments; 3) Normal interworking operation and region recognition ratio among three regions; 4) Error distance of proposed system in Wi-Fi environment.

4.2 GPS/Wi-Fi Signal Measurement and Interworking Delay Time

The GPS signal measurement time (outdoor), Wi-Fi signal measurement time (indoor) and the interworking delay time of the common regions in the developed interworking system are shown in Fig. 5 (left), respectively, and these are obtained by trying 100 times. In order to compare these delay time each other, these are also indicated to bar graph as shown in Fig. 9 (right). As shown in Fig 5 (right), it can be seen that average GPS and Wi-Fi connection time are measured to each 0.96ms, 0.97ms, and interworking delay time is measured to 2.25ms.

4.3 Practical Interworking Operation on GPS and Wi-Fi Environments

The developed system was practically experimented at the above indoor and outdoor regions of Tongmyong University, and the executing scenes on the mobile device simulator with map are shown in Fig. 6 (left/right). Fig. 6 (left) shows an execution scenes on GPS environment in the outdoor and common regions, and Fig. 6 (right) shows an execution scene on Wi-Fi environment in indoor and common regions, respectively.

4.4 Normal Interworking Operation and Regions Recognition Ratio among Three Regions

Fig. 4 Running scene of the Wi-Fi signal strength analysis and monitoring subsystem in the proposed prototype (left), front/side and back/inside views of proposed prototype (center), and experimentation scenes in indoor and outdoor environments (right).

Fig. 5 GPS/Wi-Fi signal measurement and interworking delay time (left), and comparison of GPS/Wi-Fi signal measurement and interworking delay time (right).

Fig. 6 Execution scenes on GPS environment (left) and execution scene on Wi-Fi environment (right) in outdoor and common regions.
In order to confirm the performance of the developed system, the normal interworking operation (NIO) and the region recognition ratio (SRR) among three regions such as indoor, outdoor and common regions are measured and shown in Fig. 18. In Fig. 18, ‘1’ and ‘0’ mean normal and abnormal operations, respectively. In addition to this, the region recognition ratio among three regions also measured and shown in Fig. 7 (left). The meaning of ‘1’ and ‘0’ is same as the normal interworking operation case. In addition to this, the average normal interworking operation ratio and the average region recognition ratio among three regions such as indoor, outdoor and common regions in the developed system are 97% and 91% in Fig. 7 (right).

![Fig. 7 Normal interworking operation and region recognition ratio (left), and average normal interworking operation ratio and the average region recognition ratio (right).]

4.5 Error Distance of Proposed Localization System in Wi-Fi Environment

The experimentation of error distance of the proposed localization system in Wi-Fi environment was executed in the indoor region (1st floor Robby) at First information & Telecommunications Building of Tongmyong University as shown in Fig. 8 (left). In this region, after the experimental location is assigned to each A5 in A section and F4 in F section as shown in Fig. 8 (center), the error distance of the proposed localization system is measured by running 30 trials. As a result, the average and maximum error distances of F4 and A5 in the proposed system in Wi-Fi environment is 6.2m and 9m (F4 case), 4.6m and 8m (A4 case) as shown Fig. 8 (right).

![Fig. 8 Region views for experimentation of error distance (left), execution scene of experimentation of error distance (center), and error distance of proposed system in Wi-Fi environment (right).]

5. Conclusions

In this paper, we proposed the seamless localization system for interworking by positioning in indoor space such as museum, exhibition and convention center as outdoor space. The enlargement of user convenience and the utilization of convention center can be obtained because of the seamless localization system in basis on the common regions that means the common regions of the indoor and outdoor environments. The proposed system consists of four parts such as: 1) Seamless localization function in indoor and outdoor environments; 2) Indoor localization function based on Wi-Fi; 3) Wi-Fi radio map building function; 4) Prototyped seamless localization system for interworking.

The performance of the developed system was estimated by four measurement metrics such as: 1) GPS/Wi-Fi signal measurement and interworking delay time; 2) Practical interworking operation on GPS and Wi-Fi environments; 3) Normal interworking operation and region recognition ratio among three regions; 4) Error distance of proposed localization system in Wi-Fi environment. By the experiments, it can be confirmed that the measured results are satisfied to the early development requirements of the project.

It is expected that the developed system would be applied and expanded to the development of Internet of Things (IoT) based various applications. Moreover, we have business plan of commercial services after improving the developed function.

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References

Biography (Professor Dong Myung Lee)
Prof. Lee had worked as a principal member of research staff at Electronics and Telecommunications Institute (ETRI) that located in Taegon during 18 years. In ETRI, he had participated to some national projects for developing some systems that running various network protocols based on the OSI model during 1982-1988. After then, he had participated to the CDMA cellular system project, and had designed and implemented the call processing and handoff functions that are a key role at the Base Station in the CDMA cellular system during 1991-1998. He had also worked the fundamental researches for the 3rd generation wireless system and joined a project to develop the IMT-2000 system during 1996-2000. In the year 2000, he had transferred to the department of computer engineering in Tongmyong University. He has been teaching network related courses (computer network, network programming) in undergraduate school and some advanced courses in graduate school (mobile computing and high speed communication network) in Tongmyong University since 2000. He has been now working about the researches on sensor based localization algorithms with my graduate school students by the project funded from the National Research Foundation of Korea (NRF) since Nov. 2015.