Indoor and Outdoor Seamless Positioning using Indoor Messaging System and GPS

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***Abstract*— Our research goal is developing and deploying indoor and outdoor seamless Location-Based Service (LBS) that covers indoor and outdoor locations. The prime concern for GPS-based positioning systems such as car navigation are that they are not allowed to use inside building nor underground, where GPS signals are out of range. To increase flexibility for providing such services, both indoor and outdoor seamlessly, we have developed a novel seamless positioning system with the following three steps. First, IMES (Indoor Messaging System), an innovative technology for seamless positioning that uses GPS chipset receiver was applied to realize indoor positioning. Any device that has a GPS chipset in the receiver can detect IMES signal for positioning. Second, the firmware on GPS chipset was modified in order to smoothly provide seamless location information both indoor and outdoor in accordance with the movement of the user. Third, Network-Assist GPS/IMES was developed to improve time to first fix and vertical positioning accuracy. The system will meet the needs of emergency where quick and accurate personal location information dramatically makes difference. The application may be extended to commercial activity as well for personal store navigation. A prototype of system has been implemented and a shopping application has been investigated.**

***Keywords*—Location-Based Service; Indoor and Outdoor Seamless Positioning; Indoor Messaging System**

I. INTRODUCTION

Even though LBS was predicted to become the killer application of mobile commerce, their dominance has not yet materialized, but is predicted to do so soon. The LBS market size has been predicted to grow exponentially from 2006 to 2010. Within this four-year time span, Asia's LBS market size is expected to increase from $291.7 million to $447 million, Europe's market from $191 million to $622 million, and the U.S. market from $150 million to $3.1 billion [1]. LBS has been available for several years. Initially, location determination for cellular phones was solely cell-based, and location accuracy was determined by the cell size. Whereas cell-based approaches do not require modifications to the handset or network, other location techniques, such as WiFi-based, picture-based, or GPS-based require modification to give increased location accuracy.

The GPS-based positioning system is the most widely spread for the LBS in the world. The prime concern for GPS-based positioning systems is that they are not allowed to use inside building nor underground, where GPS signals are out of range. To increase flexibility for providing such services, we are developing a novel indoor and outdoor seamless positioning system which enables GPS chipset receiver to communicate without extra hardware both indoor and outdoor seamlessly with technical and business designs.

II. IMES: INDOOR MESSAGING SYSTEM

The key technology of our seamless positioning system is IMES [2]. IMES uses satellite signals outside in the usual way, while using signals from IMES transmitter indoors, where satellite signal quality is reduced. IMES signal structure is similar to that of GPS satellites signals, except for the data of the navigation message. Therefore, the same GPS chipset receiver can be used both indoor and outdoor as shown in Figure 1. IMES transmitter sends an RF signal similar to that of GPS and the Japanese Quasi-Zenith Satellite System (QZSS), giving its three-dimensional position, the position of the center of its cell coverage zone [3]. The position and additional information in the IMES navigation message is periodically broadcasted instead of the ephemeris data, clock corrections, and so on contained in the GPS message. IMES assumes that positioning accuracies of ten meters will satisfy users who would like to know where they are in indoor places such as rooms, underground shopping areas.

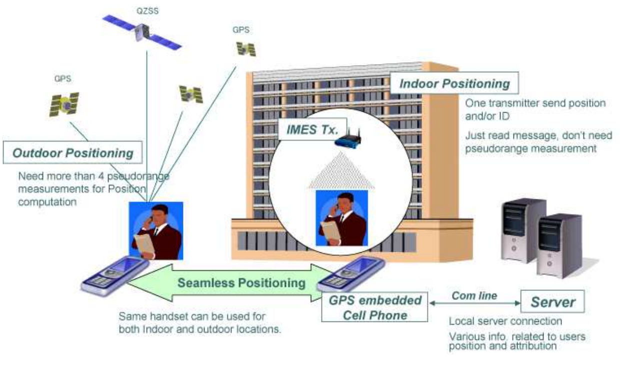


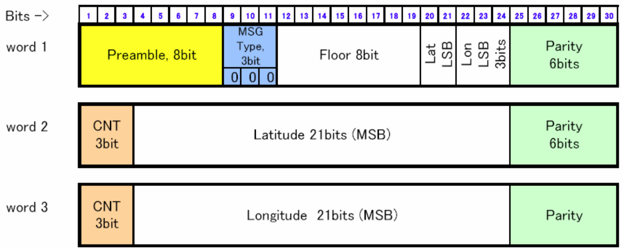
Figure 1. Indoor and Outdoor Positioning using IMES and GPS

Table 1 shows signal properties of IMES. The RF characteristics of IMES are the same as the L1 C/A code for GPS and QZSS. Transmitted at the same center frequency (1575.42 MHz) as GPS with an offset of +/- 8.2 KHz to minimize the possible interface from IMES to GPS signal, IMES has a bandwidth of 2.046 MHz or more including the main lobe. In the current interface specification for GPS, the U.S. government has approved allocation of the Pseudorandom Noise (PRN) code 173 to 182 for use by other GNSS allocations such as IMES. The IMES receiver uses the codes only for de-spreading the spread-spectrum modulation and as a step to decoding the navigation message. Pseudo range or time determination is not necessary because the desired position is read directly out of the navigation message. This gives simpler equipment architecture than when using pseudolites.

TABLE I.
IMES SIGNAL PROPERTIES WITH RESPECT TO GPS

Item	GPS	IMES
Center Frequency	1575.42 MHz	1575.42+/-0.0082 MHz
PRN ID	1-32	173-182
PRN Code Rate	1.023MHz	1.023MHz
PRN Code Length	1ms	1ms
Data Rate	50bps	50bps
Modulation	BPSK	BPSK
Polarization	RHCP	RHCP

The message structure of IMES is similar to GPS L1C/A or QZSS and is defined in the annex IS-QZSS [4] by Japan Aerospace Exploration Agency. The message consists of words of 30bits. Depending upon message type, the number of words in a frame can vary. There are four types of IMES messages defined that are named as type 0, 1, 3, and 4. Message Type 0 contains 2-D position data using three words of 30 bits each as shown in Figure 2. This is the shortest message length to transmit absolute position data using latitude, longitude and floor data. Message Type 3 contains only IDs and is one word long as shown in Figure 3. The first of each frame has an eight bit preamble followed by message type. The corresponding words of a frame have three bit counter at the beginning of each word. Since, Message Type 3 has one word only, it does not have counter bits. It takes 0.6 second to read one word at 50bps. This message type does not contain any position data or coordinates. The position data are retrieved from database server based on the unique ID to get the latitude, longitude, height, floor number as well as other information such as guidance map, advertising and so on. Short IDs are defined and maintained by each operator. It is possible to define up to eight different types of message structure.



#	Content	Bit Length	LSB	Range minimum	~	maximum
1	Floor	8	1 th	-50 th	~	204 th
2	Latitude	23	2.1E-05 deg (2.39 m)	-90 deg	~	90 deg
3	Longitude	24	2.1E-05 deg (2.39 m)	-180 deg	~	180 deg

Figure 2. IMES Message Type 0

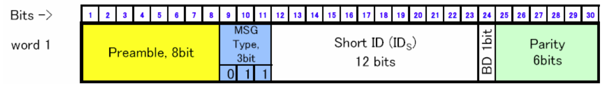


Figure 3. IMES Message Type 3

III. REALIZING SEAMLESS POSITIONING

To increase flexibility for providing the LBS, both indoor and outdoor seamlessly, we have developed a novel seamless positioning system with the following three steps.

A. Indoor Positioning with IMES

IMES transmitters were installed at various locations in a shopping mall. Figure 4 shows a location where IMES transmitters were installed inside a ceiling. The distribution of IMES transmitter is done in such a way that it covers a radial distance of 10m to 20m. Mobile devices with open source firmware on GPS chipset receiver are used to receive the IMES position data. IMES experiments have been conducted at each position with GPS/IMES experiment cart shown in Figure 5. Mobile devices with IMES capability are used for the experiments. Figure 6 shows the IMES signal acquisition by mobile device at various distances from the transmitter. The graph shows signal power level for two different IMES transmitters located at Point 1 and Point 33. In this case, the mobile device tracks the IMES signal nearer to the receiver. When the receiver is at the middle, it is possible that the receiver may track signals from both transmitters. Currently, the receiver is designed to choose the IMES device that has higher C/N0 value at the receiver. Therefore, it is possible to have an overlap zone between the IMES transmitters. It is necessary to control the IMES power level, their location, antenna type, and orientation. An installation and management system is considered to set up and operate IMES power level and transmitter location.

B. Modification of Firmware on GPS Chipset

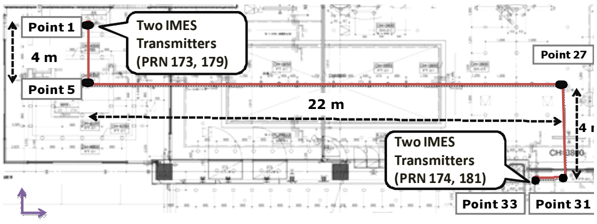


Figure 4. Location of IMES Transmitters

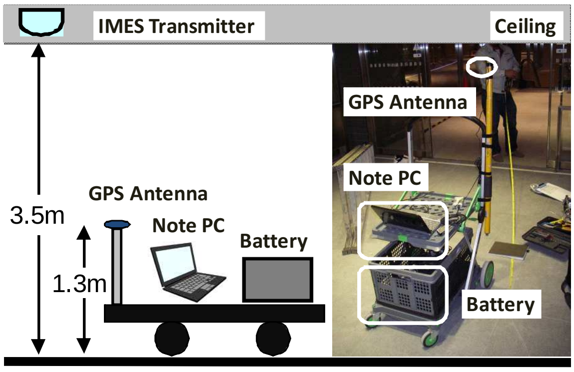


Figure 5. GPS/IMES Experiment Cart

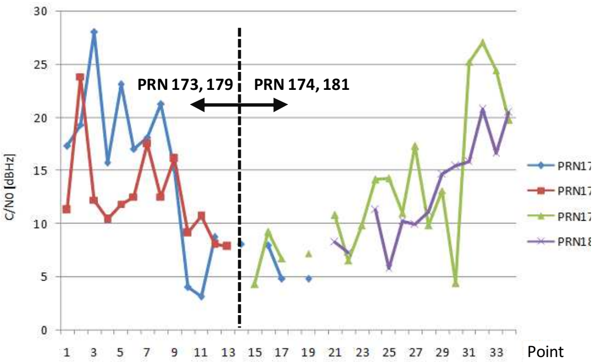


Figure 6. IMES Signal Tracking Status

Figure 7 shows a prototype of a mobile device with a GPS chipset receiver (NovAtel Super Star II), a GPS antenna, and a cell phone (NTT docomo/Toshiba T-01A). The GPS chipset receiver is connected to the mobile device through a USB interface. Major feature of this prototype was the use of GPS chipset receiver that can freely change proprietary algorithms using open source firmware. The GPS chipset receiver inside the cell phone is not used at this time because the software on the GPS receiver in this cell phone is not an open source firmware.

The following scheme is adopted in order to smoothly provide seamless location information both indoor and outdoor in accordance with the movement of the user. First, four from the twelve reception channels used are allocated to the acquisition and tracking of the signal from the IMES transmitter with the remaining eight channels allocated to acquiring and tracking of the signal from the GPS satellite. When an IMES signal is received, the location information output from the short ID is read from the IMES signal. As the IMES transmitter has been designed so that the L1 band center frequency is suppressed to an offset of less than 0.2ppm, it is important to grasp the frequency offset of the receiver to restrict the frequency search range during the capturing process. The

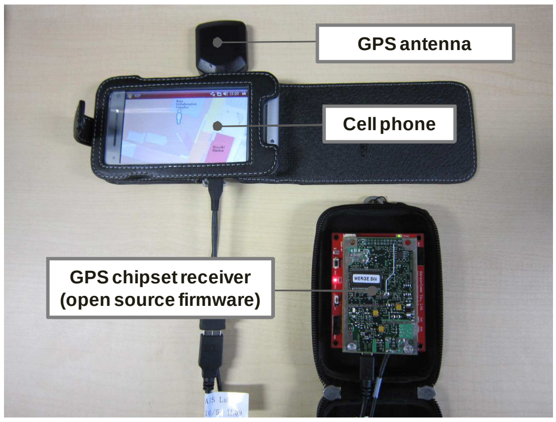


Figure 7. Prototype of Mobile Device

clock offset information of the receiver is retrieved from the outside positioning results and used in the frequency bin specification at the commencement of IMES signal search inside. These kinds of construction successfully shorten the time required for location acquisition from a maximum of over 30 seconds at the beginning of the experiment to around 3 seconds under the conditions of the demonstration experiment.

C. Network-Assist GPS/IMES

As the third step, we are developing and deploying Network-Assist GPS/IMES in a commercial facility to improve time to first fix vertical positioning accuracy as shown in Figure 8. Data to find GPS signal such as GPS orbital data, ephemeris, and almanac are received from GPS satellites at a GPS reference station and stored Assist Data Server (ADS). IMES location Data to acquire IMES signal are also registered in the ADS. These data are provided from Radio Network Controller to a GPS chipset receiver via network to look to GPS signal or IMES signal more rapidly. Height data at just previous to the present time is used to calculate to improve vertical positioning accuracy.

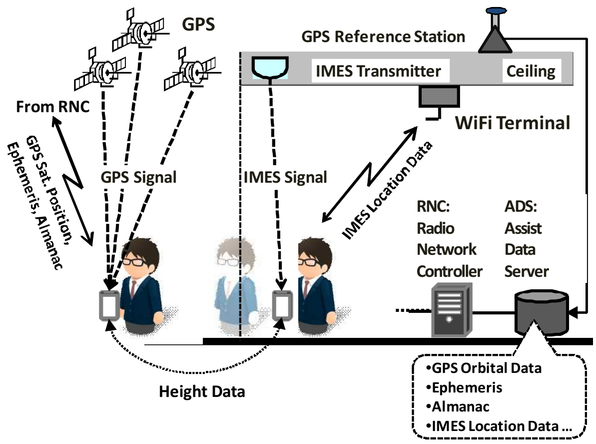


Figure 8. Network-Assist GPS/IMES

Figure 9 shows one example of error distribution in a horizontal direction to compare the vertical position accuracy between Stand Alone and Network-Assist GPS/IMES. The vertical position accuracy was improved by Network-Assist GPS/IMES.

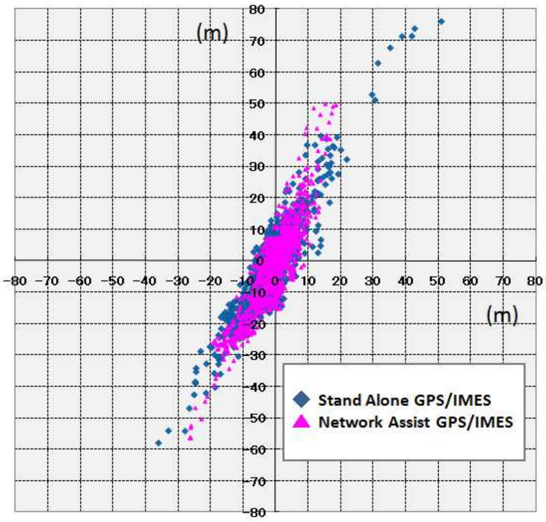


Figure 9. Error Distribution in a Horizontal Direction

IV. POTENTIAL APPLICATIONS

To show advantages of indoor and outdoor seamless positioning, we have installed IMES transmitters in a super market and designed a shopping support application. Figure 10 shows shopping cart with an attachment for a mobile device (left) and the mobile device (right). Figure 11 shows three snapshots of the application on a mobile device. This application provides an item list and a navigation map which corresponds to the location data of the user, whether located inside or outside buildings. The followings are three features of the application.

Locating Items Indoor: The item selection is done by selecting recipes or searching from categories (Figure 10, left). When the user select a recipe, ingredients of the recipe are registered on the shopping list and would then be shown on the store map.

Zooming In and Zooming Out of Indoor and Outdoor Map: The advantage of this application is that users can use this application not only outdoor but also indoor (Figure 10, center and right). For example, if an item is sold out at the store, a customer may zoom out the map from indoor to outdoor searching for other stores nearby. Using this function, a customer can compare prices with other stores.

Receiving of Advertisements Depending on Location and Profile: A customer may receive through the portable device an advertisement based on the location and user profile (Figure 10, center). This benefits not only the users but also the store owners. Recording data on user profile, location, time and advertisement delivery in the database, the store owners later on gain the opportunity to analyze the market trend.

V. CONCLUSION

The development and deployment of indoor and outdoor seamless positioning is a research theme not just

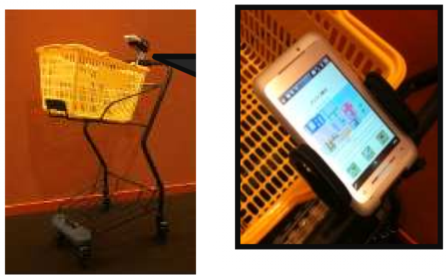


Figure 10. Shopping Cart with an Attachment and Mobile Device

Figure 11. Snapshot of Shopping Support Application

in Japan, but also common to the world. We will endeavor to further refine this technology such that it can spread around the world in an era when not just cell phones, but also various information devices such as PCs and game consoles are becoming equipped with GPS functions. Concerning the improvement of the positioning usage range and time, technology of seamless positioning with IMES will expand to areas such as inside or underground shopping malls, which are out of range of transmissions from satellites, and the diffusion of appropriate technology is expected to bring about great benefits for our everyday life. We wish to continue research, development, and demonstration experiments in a real environment so that this technology becomes widespread and many people can experience its convenience.

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