Results of IMES (Indoor Messaging System) Implementation for Seamless Indoor Navigation and Social Infrastructure Platform

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BIOGRAPHY

Dinesh Manandhar is a Senior Researcher at GNSS Technologies Inc. He is also a visiting researcher at the University of Tokyo. He received Ph. D. from the University of Tokyo, Japan in 2001. Currently, he is involved in developing indoor navigation system based on IMES for seamless navigation environment.

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Hideyuki Torimoto is president of GNSS Technologies Inc. He is one of the pioneers of satellite navigation related application businesses in Japan. He established Trimble Japan in 1986. In 2002, he founded GNSS Technologies Inc. to promote R&D as well as marketing in the field of GNSS in Japan. He is managing GNSS R&D including IMES to promote the technology internationally. He served as Satellite Division Member of ION for 2003-04.

ABSTRACT

IMES is an innovative technology for seamless positioning that uses GPS chipset receiver. Any device that has a GPS chipset in the receiver can use IMES for seamless positioning. The use of mobile phones in the past four years has been doubled and currently about five billion mobile phones are in use globally. This trend will continue and growth rate will even increase due to the requirement of “E911” and “SAR” services. In order to provide such services GPS/GNSS are used in mobile phones. Various applications have been developed due to the availability of GPS/GNSS devices. However, in indoor and deep indoor locations, the position outputs from mobile phone devices are not satisfactory for many applications and services. In order to solve the problems of indoor navigation various technologies like Pseudolite, A-GPS and WiFi exist with their own limitations. IMES has been developed to solve the problems of indoor positioning for seamless position with a single unit of transmitter device to provide 3D position.

IMES provides 3D position in indoor and deep indoor locations with a single unit of transmitter device. Due to this feature, IMES can be deployed for social infrastructure platforms like search and rescue in the case of emergency and disasters, social networking services and location based applications. Any application that uses location information needs position data. IMES provides position data with an accuracy of about 10m with floor information of a building and it does not need any communication link to compute position data. IMES is designed in such a way that the same GNSS receiver can process both GNSS and IMES signals leading to the seamless navigation between outdoor and indoor environment. The message type and contents are variable and can be changed as per the application requirements.

We have conducted pilot projects at indoor shopping mall at Shin Toyota Station and underground shopping mall at Kobe Station. This paper discusses IMES concept, signal properties, installation management system and findings of the pilot projects. The paper also includes findings from the pilot project conducted at a shopping mall at Shin Maru Building in Tokyo.

INTRODUCTION

There are about five billion cell phones currently used in the world. This covers about 70% of the total population on the earth. There were only 2.5 billions of mobile phones in 2006 and this number has been doubled in the past four years. The future growth of cell phone is also expected in the same fashion or even at higher growth rate. Due to the emergence of smart phones and LBS, mobile
phones are used not only for communications but also for many applications related with LBS, entertainment and games. GPS/GNSS devices are included in mobile phones due to compulsory requirement of “E911” and “SAR” services by law in many countries. GPS/GNSS devices work satisfactorily in outdoor environments for positioning and navigation. However, they have serious limitations in indoor and deep indoor environments due to lack of visibility to three or more satellites. Hence, for indoor navigation, there exist various technologies like Pseudolites, A-GPS, WiFi, Bluetooth, RF Tag, and so on. However, these technologies have their own limitations and are not the best suitable tools for seamless positioning and navigation.

Pseudolite system is used for indoor positioning. It is technically sound and used by many users. However, it needs at least four or more units of signal transmitting devices. In order to cover a large area, it needs a lot of transmitting devices suitably located and they should be synchronized in time to each other or their clock errors shall be known. Pseudolite system provides position data based on range calculation from the receiver to a number of the transmitting devices. The range calculation is heavily affected by signal multipath. Table 1 shows comparative difference between IMES and Pseudolite.

### Table 1: A comparison between IMES and Pseudolite

<table>
<thead>
<tr>
<th>Item</th>
<th>IMES</th>
<th>Pseudolite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudorange measurement</td>
<td>No Ranging</td>
<td>Ranging</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Not required</td>
<td>Required</td>
</tr>
<tr>
<td>Multipath effect</td>
<td>Nothing</td>
<td>Strong</td>
</tr>
<tr>
<td>Flexibility of installation</td>
<td>Perfect</td>
<td>Complex</td>
</tr>
<tr>
<td>2D positioning</td>
<td>by 1 unit</td>
<td>by 3 units</td>
</tr>
<tr>
<td>3D positioning</td>
<td>by 1 unit</td>
<td>by 4 units</td>
</tr>
<tr>
<td>Implementation to GNSS receiver</td>
<td>PRN code only</td>
<td>PRN code only</td>
</tr>
</tbody>
</table>

A-GPS is widely used in the mobile phones to compute position data using GPS/GNSS. A-GPS technology includes high-sensitivity signal processing to acquire weak signals and external assistance of data like time, approximate position and satellite orbit related parameters. In order to provide these assist data, it is necessary to have a communication link between the receiver unit and the source of the data. In the case of mobile phone these data are provided by the mobile phone network itself. Thus, A-GPS will not be possible if there is no communication link. Normally, A-GPS provides 2D position data. The height data (if 3D output is available) will be highly erroneous. The accuracy of such position data varies from few tens of meters to few hundreds of meters. Also, the position data is heavily affected by signal multipath. Figure 1 shows the comparison of IMES position and mobile phone position when measured inside the office building. The A-GPS position error is about 300m in this case.

![Figure 1: Indoor position from high sensitivity GPS and IMES.](image)

WiFi is used for indoor positioning in many mobile phone devices. A mobile phone device provides position data either from built-in GPS Receiver, WiFi Device or Cell ID or the combination of any of these or all the devices. Recently, position data from WiFi is getting popular for indoor as well as outdoor position. The basic reason is that WiFi signals are available freely. However, in order to use these WiFi signals they must be registered with their location data. In order to do so, a huge number of WiFi devices are registered driving around the city. Since these devices are basically installed for communication purpose, they can be relocated, removed or new devices may be installed without any information to the users or service providers. Thus continuous maintenance and update of all these devices are necessary which may not be possible or may not be economically practical. The coverage of WiFi devices is not uniform and may vary a lot from area to area which affects the position accuracy. Telecom service providers are considering the possibilities of seamless positioning technologies. They would like to have one single device that can provide 3D position data both indoors and outdoors without any additional power and cost budget with satisfactory 3D position information. If such a perfect seamless positioning technology is available, there is no doubt that it will generate a huge global commercial market. The availability of such technology will even aid in development of new applications in the fields of Locations Based Services, Location Based Advertisement, Location Based Marketing, Location Based Entertainment and Gaming.
Unfortunately, no such technologies exist until the development of IMES. We have been conducting research in the field of indoor positioning for the past few years beginning from Pseudolite system [4]. Finally, IMES has been developed to meet the shortcomings of the technologies described above for indoor and deep indoor positioning. IMES is an ultimate solution for seamless positioning environment that can be implemented in any device that has a GPS/GNSS receiver without hardware modification. IMES can provide satisfactory 3D position data with a single transmitter device without performing range calculation.

**IMES CONCEPT**

The main concept of IMES is to transmit position and floor ID of the transmitter with the same RF signal as GPS. IMES transmits latitude, longitude, height and floor ID by replacing the ephemeris and clock data in the navigation message of GPS. A single unit of IMES is enough to get the position data since the position itself is directly transmitted.

The most significant characteristics of IMES are to provide seamless position data and seamless 3D route guidance. Figure 2 shows the concept of seamless position data using the IMES where the same receiver can be used both indoors and outdoors without any interruption. GNSS satellites are used for positioning and navigations outdoors where as IMES is used for indoor navigations. Since the signal structures of GPS satellites and IMES is the same except for the navigation message contents, the same receiver can be used for both the cases. Current GPS receivers will be capable of receiving IMES signals with modification of firmware only to decode the navigation message. Figure 3 shows the concept of seamless 3D route guidance. Refer [3] for details about IMES design concepts.

**IMES SIGNAL PROPERTIES**

IMES signal is designed similar to GPS signal. It uses the same centre frequency as GPS with an offset of +/- 8.2 kHz to minimize the possible interference from IMES to GPS signal. Ten PRN codes from 173 to 182 are assigned for IMES. These codes are provided by the US government, [1]. Other signal related parameters are the same as GPS L1 C/A code signal. This makes any GPS receiver also capable of receiving IMES signal with firmware update for PRN code and navigation message decoding. Table 2 shows IMES signal properties with respect to GPS signal.

IMES has four different types of navigation messages. The most significant message is Type 1 as shown in Figure 4. It transmits latitude, longitude, height and floor ID. The transmission of floor ID is a key factor for perfect 3D position data. Other message types are Type 0, Type 3, and Type 4. Refer [2] for QZSS IS document or [3] for details about message types.

<table>
<thead>
<tr>
<th>Item</th>
<th>GPS</th>
<th>IMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Frequency</td>
<td>1575.42MHz</td>
<td>1575.42MHz +/- 8.2kHz</td>
</tr>
<tr>
<td>PRN ID</td>
<td>1-32</td>
<td>173-182</td>
</tr>
<tr>
<td>PRN Code Chip Rate</td>
<td>1.023MHz</td>
<td>1.023MHz</td>
</tr>
<tr>
<td>PRN Code Length</td>
<td>1ms</td>
<td>1ms</td>
</tr>
<tr>
<td>Data Rate</td>
<td>50bps</td>
<td>50bps</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
<td>BPSK</td>
</tr>
<tr>
<td>Polarization</td>
<td>RHCP</td>
<td>RHCP</td>
</tr>
</tbody>
</table>

Figure 2: Seamless IMES Navigation Concept

Figure 3: Seamless 3D Route Guidance using IMES

Table 2: IMES signal properties with respect to GPS
IMES INSTALLTION, SETTING AND MANAGEMENT SYSTEM

In order to deploy IMES, it is necessary to design optimum IMES transmitter locations based on the installation environment. The parameters that have to be set up are PRN Code, power level, 3D position data, floor ID, message type, message sequence etc. A map database of the location is also necessary for setup and management purpose. Figure 5 shows a GUI for IMES transmitter setting. It can set the transmitter’s signal related parameters like PRN code, power level, message type, message sequence, latitude, longitude, height, floor ID and so on. Figure 6 shows a system to develop a map database either from existing sources or from a laser scanning system. The system will ultimately create 3D database of a building at floor level that can be linked with external databases. Figure 7 shows the overall concept of the IMES database system that includes both IMES setting and 3D map database systems. The two database systems are linked by a relational database system. Any update in the map database can be reflected into the IMES setting. This system is being under development.

IMES DEVELOPMENT PLAN

Figure 8 shows IMES development plan. The current version of IMES is used for experiments, tests, demos, and pilot projects. IMES will be available in LSI chip by 2010 and commercial productions will be done from 2011. Figure 9 shows the block diagram of IMES LSI chip. This will tremendously reduce the cost, size and power consumption. Since, IMES is also designed to be used for emergency purpose; the power consumption must be as low as possible.
IMES MULTIPLE TRANSMITTER TEST

We have conducted IMES multiple transmitter tests to analyze the performance when multiple transmitters are deployed in an area. Figure 10 shows a case when two IMES transmitter are used with the same transmit powers at 30m distance apart. When the user is at location A, the receiver gets the position data from the transmitter at A. As the user moves towards location B, the signal strength from A decreases. At the middle position between A and B, the receiver may get signals from either A or B. Currently, we use the stronger signal to provide the position output. As the user moves toward location B, we get position data from transmitter B. We will have an overlap zone at the middle location between the two transmitters. This zone can be narrowed or eliminated by setting up the transmission power and antenna direction of the transmitters. In order to set up these parameters, we can use the IMES Installation, Setup and Management Tool since it also includes signal propagation model. The maximum transmission signal level in each country is defined by the radio regulation. In Japan, for license free radio signals at 1.5GHz, the EIRP power level is -64dBm. The IMES device can be easily configured for maximum power level using the IMES Installation, Setting and Management System. In this case, the IMES transmit power level was set to cover a radial distance of about 15m.

IMES IMPLEMENTATION FOR SOCIAL INFRASTRUCTURE

We have conducted pilot projects under the sponsorship of the Japanese Government to test the IMES capabilities for seamless positioning and navigation as well as implementation of IMES for social infrastructure platform. Table 3 shows the list of the projects conducted.

Table 3: List of pilot projects conducted under the sponsorship of the Japanese Government

<table>
<thead>
<tr>
<th>Item</th>
<th>Project Name</th>
<th>Area</th>
<th>Government Organizer</th>
<th>No of IMES Device</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Social experiment for seamless positioning</td>
<td>Toyota City, Shopping Mall</td>
<td>Ministry of Land, Infrastructure, Transport and Tourism</td>
<td>6</td>
<td>Mar-08</td>
</tr>
<tr>
<td>2</td>
<td>Free Mobility Project in Kobe</td>
<td>Kobe City Underground Shopping Mall</td>
<td>Ministry of Land, Infrastructure, Transport and Tourism</td>
<td>70</td>
<td>Mar-09</td>
</tr>
<tr>
<td>3</td>
<td>Seamless Positioning System at underground shopping mall</td>
<td>Tokyo City Underground Shopping Mall</td>
<td>Ministry of Economy, Trade and Industry</td>
<td>11</td>
<td>Mar-10</td>
</tr>
</tbody>
</table>
The Free Mobility Project in Kobe is the biggest social experiment using IMES for seamless navigation under the sponsorship by the Ministry of Land, Infrastructure, Transport and Tourism. The project was conducted in an underground shopping mall of Kobe railway station. Shopping mall visitors were requested to participate in the navigation using IMES capable mobile phones. The visitors navigate themselves inside the shopping mall with the help of the mobile phone and the signals transmitted from the IMES devices. Most of the visitors could follow the route they had chosen or find the destination point.

A total of 70 IMES transmitter units were installed at various locations that include ticket counters, elevator entrance, emergency exits, fire extinguisher locations, staircase, station entrances and alley of the shopping mall. Figure 11 shows a part of the IMES transmitter location map. It covers one of the sections of the shopping mall. Figure 12 shows various locations where IMES transmitter devices were installed. The installation of IMES near the emergency exits, fire extinguisher locations, staircases etc are for emergency uses as well as for intelligent route navigation. As shown in Figure 13 intelligent 3D route guidance can be performed based on the user preference. For example, a user on wheelchair must be guided a route that has no staircases shown by green route in Figure 13 to reach the goal point. A pedestrian can be guided by red route which is the nearest route to reach the goal.

The distribution of IMES transmitter is done in such a way that it covers a radial distance of 10m to 20m. The deployment density of IMES depends upon the location environment where the device has to be installed. If an IMES device is located near the entrance, the coverage distance will be around 10m to minimize the transmitted power. IMES device in deep indoor location can cover a radial distance of about 15m to 20m.

Commercially available mobile phone devices with firmware update for IMES are used to receive the IMES position data. The mobile phone devices also include the shopping mall and station map together with related databases for various applications. Figure 14 shows the display of mobile phone monitors showing outdoor and indoor positions.
Figure 16 shows IMES installation map inside the Marunouchi building in Tokyo. It shows successful implementation of seamless 3D route guidance using IMES. As the user moves from outside to inside, the mobile phone shows GPS and IMES modes respectively and provides the user position information. Similarly, Figure 17 shows IMES implementation in a shopping mall in Shin Toyota Station. In this case also, mobile phone device shows user position perfectly using IMES signal.

Figure 16: IMES navigation at Shin Maru Biru in Marunouchi, Tokyo.

Figure 17: IMES navigation at Shin Toyota

Figure 14: Display of mobile phone screens showing the position data outdoors (GPS signal) and indoors (IMES signal).

Figure 15: Seamless navigation by mobile phone using GPS and IMES.

Figure 14: Seamless navigation by mobile phone using GPS and IMES.
CONCLUSIONS

The pilot projects conducted under the sponsorship of the government of Japan have shown quite successful results of using IMES for indoor and deep indoor positioning and 3D seamless route navigation. Commercially available mobile phones with IMES firmware were used during the project. Due to the successful implementation of IMES, it has encouraged many government agencies and private industries for further studies and research in the field. The results have provided us many issues that had to be solved. They are related with IMES installation, setup, control, and management including the indoor base maps. In this regard, we are developing a complete IMES system that includes installation, setup, control and management tools. We are also developing a 3D indoor mapping system using laser scanner. The system also includes IMES signal propagation modeling to setup transmit power level, antenna type and locations etc. We have not encountered any serious problems related with the IMES technology itself.

Finally, we would like to recommend using GPS for outdoor environment, A-GPS or “medium” high-Sensitivity GPS for “shallow indoor” environment and IMES for indoor and deep indoor environment. Combination of GPS with “medium” high-sensitivity GPS and IMES will be the best choice for accurate and reliable indoor positioning and seamless 3D route guidance. The position data from super high-sensitivity GPS (to track signals weaker than -146dBm or so) is unstable and can not be used for seamless 3D route guidance.

ACKNOWLEDGMENTS

The authors would like to thank all the participants who helped us conducting self navigation using IMES capable mobile phone devices during the project period.

REFERENCES