Development of Ultimate Seamless Positioning System for Global Cellular Phone Platform based on QZSS IMES

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BIOGRAPHY

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Kazuki Okano is a chief engineer at GNSS Technologies Inc. He is involved in hardware design and development for Pseudolites and IMES.

Makoto Ishii is a Director of Strategic Marketing and Sales of GNSS Technologies Inc. He is coordinating GNSS based technologies in the business department including IMES.

Masahiro Asako is a director of engineering department and supervises software and hardware development. He has more than 25 years of experience in the GNSS related technologies and applications.

Hideyuki Torimoto is a president of GNSS Technologies Inc. He is one of the pioneers of satellite navigation related application businesses such as car navigation, earthquake monitoring, marine and air navigation, cell-phone based timing 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 for the global promotion of the technology. He served as Satellite Division Member of ION for 2003-04.

Satoshi Kogure is an associate senior engineer of JAXA. He received MS in aerospace engineering from University of Colorado in 2001. He has been working for satellite positioning system as a satellite systems engineer since 2001. He is one of the members to design and develop IMES.

Hiroaki Maeda is the founder and managing director of Lighthouse Technology and Consulting Co., Ltd (LHTC). He received Ph. D from the Tokyo University of Marine Science and Technology in 2008. Since 2003 he has been a technical lead of the Japanese satellite navigation system, QZSS. He is one of the members to design and develop IMES.

ABSTRACT

In Japan, USA and many other countries it is now necessary for cellular phones to provide E911 or similar service that is capable of providing its position within certain accuracy level. The cellular phone shall be able to provide position anywhere where the phone is working including the emergency cases. At the moment cellular phones are equipped with GPS receiver for such service. However, due to weak signal in indoor environment, the accuracy provided by the system varies from few tens of meters to few hundreds of meters. The system may also fail to provide position in deep indoors though cell phone is still working. Since the accuracy is not stable they may not meet the requirements of the E911 service all the time. Although there are Assisted GPS and eGPS technologies, their position accuracies are also variable depending upon location environment and they still have difficulties to provide position in deep indoor locations.

In order to solve such problems, we have developed IMES (Indoor Messaging System). IMES is capable of providing position even in deep indoor environment with fixed accuracy level of 10-20m. IMES can be one of the most suitable and reliable solutions for E911 services especially for indoor and deep indoor environments.

The basic concept of IMES is to transmit position data and/or unique ID from the transmitter while keeping similar signal structure as of QZSS/GPS signal. IMES has the same RF properties as GPS/QZSS and PRN IDs from
173 to 182 are exclusively assigned for IMES. The only difference is in the contents of navigation message which can be set as per user’s necessity and application types. It is not necessary to compute pseudorange, hence a single unit is enough to provide position data. The next generation of cellular phone navigation technology is going toward 3-D map for pedestrian navigation even in big buildings or underground area. IMES message structures are capable of handling such 3-D data including floor information.

Experiments have been conducted in various locations to verify the IMES capabilities and concepts. The seamless navigation capability has been successfully demonstrated by using IMES capable cellular phone when the user moves indoors or outdoors.

INTRODUCTION

The fundamental problem in navigation applications is to get the correct position information regardless of location environment and time. This is even more difficult in case of deep indoor locations. There will be more than one hundred million cell-phones equipped with GPS receivers in Japan within a couple of years. The number of world cell-phone figure has crossed 3.3 billion in November 2007, which is almost half the worldwide population. We can forecast huge demand of cell-phones in future as well. The introduction of E911 or similar services in USA, Japan and many other countries require GPS/GNSS devices to be equipped in cell-phone to provide position within certain accuracy level in case of emergency.

Satellite-based navigation systems like GPS and GLONASS work well outdoors but their use is limited indoors due to poor visibility of satellites. In near future, there will be GALILEO, QZSS and COMPASS for satellite-based navigation systems. However, for good 3D position estimation at least four visible satellites are necessary. It’s almost impossible to compute a position indoors using such satellite signals without any external aiding of information. Though, there are weak signal processing capable receivers, they do need information about the satellite orbits and/or time which are normally provided by some external means. There are also positioning systems that are based on the combination of GPS and cellular phone networks. However, they still do lag in providing correct 3D information and need infrastructure setup in the existing cellular networks which are not always possible. In the case of emergency, how do we know that whether the victim is in the 50th Floor, room number 510 or room number 512? Or how do we know that whether the victim is in the 5th Floor below the basement in room number 110? The key point here is to identify precisely the location of the victim without any mistakes. We do not want to search and rescue the victim, but we would like to locate and rescue the victim. This is the fundamental difference between other GNSS based systems and IMES.

In order to overcome these problems a new signal has been defined in QZSS IS document which is known as IMES (Indoor Messaging System). IMES has been jointly developed by Japan Aerospace Exploration Agency (JAXA) and GNSS Technologies Inc. The development includes hardware, software, signal structure and message formats. Patents related to IMES signal design, transmitter, receiver, data management and other related filed jointly in Japan as well as abroad countries.

IMES CONCEPT

The main concept of IMES is to transmit position and/or ID of the transmitter with the same RF signal as GPS and Quasi-Zenith Satellite System (QZSS). IMES will broadcast position and other information using similar message format to GPS and QZSS periodically instead of ephemeris and correction messages that are necessary for receiver’s position estimation. A single unit of IMES is enough to get the position data since the position itself is directly transmitted. If only ID is transmitted, then the receiver will connect to the server to get further information including position. Figure 1 shows the basic concept of IMES.

![Figure 1: Basic concept of IMES. IMES transmits position and/or ID and/or other data](image)

The most significant characteristic of IMES is to provide seamless positioning and navigation. Figure 2 shows the concept of seamless navigation using the IMES where the same receiver is used both indoors and outdoors without any interruption. GNSS satellites are used for positioning and navigations outdoors whereas IMES is used for indoor navigations. Since the signal structures of GPS satellites and IMES are similar except for the navigation message contents, the same receiver can be used for both
cases. Current GPS receivers will be capable of receiving IMES signals with modification of firmware only to decode the navigation message.

Figure 2: Seamlessness of IMES. The same IMES receiver can be used indoors and outdoors.

SIGNAL DESIGN CRITERIA OF IMES

The following points were considered during the signal design of IMES:

- Same hardware will be used for both indoor and outdoor positioning with minimum modifications on the firmware in the GPS chipset.
- High precision like sub-meter order is not required. Precision of position around 10m seems to be enough for users to know where they are per moderate room size, each shop or portion in shopping complex. Accuracy of such order at any time is more important than higher precision.
- Low power consumption is required for cell phone use. Smooth switching of indoor/outdoor continuous positioning is one of the key issues to decrease additional power consumption.
- Low cost transmitter is essential as well as low cost installation and maintenance of it.
- Compatibility with GPS, QZSS and other GNSS is an essential requirement. IMES signal must not cause harmful interference with other GNSS signals.

Taking account of above requirements, the main characteristics of the current IMES design concepts were defined as follows:

SAME RF PROPERTIES AS GPS AND QZSS

In order to share the same RF front-end as GPS and QZSS, IMES uses the same L1 center frequency, 1575.42 MHz and BPSK modulation, 1.023MHz Gold code family as GPS/QZSS C/A signal which is defined on IS-GPS-200D [8] and the Interface Specification for QZSS Users (IS-QZSS) [2] respectively. Table 1 shows the signal properties of IMES. The transmitter power is set based on location environment and separation between the transmitters keeping the maximum power level below the threshold value set by Japanese radio regulation. The power level at the IMES receiver will be maintained approximately within -126dBm to -130dBm.

PRN codes from 173 to 182 of 210 C/A codes are assigned for the dedicated usage of QZSS-IMES [1]. Receiver can distinguish the tracking signal from IMES transmitter and from satellite easily and smoothly by acquiring and tracking these dedicated IMES codes in parallel with codes assigned for satellites of GPS/QZSS.

It should be noted that the use of IMES PRN codes is currently limited in Japan. However, there is a possibility to extend their use to worldwide in future, since IMES transmitter covers small area in indoor and PRN code is to be re-used without overlapping coverage zone of the transmitter with the same PRN code.

Table 1: Signal properties of IMES

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Centre Frequency</td>
<td>1575.42Mhz</td>
</tr>
<tr>
<td>PRN Code Rate</td>
<td>1.023Mhz</td>
</tr>
<tr>
<td>PRN Code Length</td>
<td>1ms</td>
</tr>
<tr>
<td>PRN ID</td>
<td>173 – 182</td>
</tr>
<tr>
<td>Navigation Message Rate</td>
<td>50bps</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Polarization</td>
<td>RHCP</td>
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</tbody>
</table>

NO TIME SYNCHRONIZATION AND PSEUDORANGE

The usage of IMES does not require measuring the pseudorange between transmitter and receiver. In the case of QZSS/GPS it includes almanac and ephemeris related messages in the navigation message. Pseudoranges are estimated from more than three satellites and position data are computed using pseudoranges. However, in the case of the IMES, position is directly transmitted embedded in the navigation message and hence it is not necessary to compute pseudorange.

Therefore, the time synchronization among all transmitters as well as synchronization with outside GPS time is not required. This leads to simple system architecture rather than pseudolite system which requires more than four time synchronized transmitters. This enables to build low cost transmitters.

NO OVERLAP WITH OTHER TRANSMITTERS’ COVERAGE

The coverage zone of one transmitter should not overlap with other transmitters. The IMES cell-coverage area is
designed with ten assigned PRN Code with one guard cell between IMES cells. The resolution of the position data is limited by the coverage of the transmitter signal. The size of each coverage zone is equivalent to maximum positioning error. Usually, one coordinate for a moderate sized room can be transmitted by one transmitter. Large areas such as underground malls, metro stations, and department stores, the transmitters may be distributed at 20-30m span.

**RF COMPATIBILITY WITH OUTSIDE GNSS SIGNALS**

IMES signals are transmitted at low power to avoid interference with live GNSS signals. In addition to this low power transmission, the separation between transmitters contributes to avoid increasing noise floor by multiple IMES signals. Moreover, an appropriate separation distance between an IMES transmitter and an outside GNSS receiver should be maintained. The separation distance is to be defined in the annex of IS-QZSS as an installation standard. Results of interference analysis are discussed in the later section of the paper.

**MESSAGE STRUCTURE**

The structure of the navigation message is defined in QZSS-IS [2]. The message structures are discussed in detail in paper [6]. There are four types of messages defined. Message type “0” and “1” are used for 2D and 3D position respectively. Message type “3” and “4” are used for short ID and medium ID respectively. Since, the navigation message is transmitted at 50bps, it takes 0.6 seconds to read one word (30bits). The use of message type is related with application type and time to read message (TTRM).

**IMES HARDWARE AND SOFTWARE**

Figure 3 shows picture of IMES signal generator and power spectrum of IMES L1C/A signal. The signal generator complies with the signal specifications defined in QZSS-IS document. The IMES signal properties and message types can be controlled by using GUI based software shown in Figure 4. The user can select PRN code, input device position data, message types, message sequence combination and control the RF power output.

A prototype IMES software receiver has also been developed. The receiver can process IMES signal and decodes navigation message. The receiver provides position data for message type “0” or “1”. If the message type is “3” or “4”, it is necessary to access to a database where the position of the device is available based on the device ID. Since there are different message formats, the receiver output may vary depending upon the message types and applications. However, in all cases, the position of the receiver will be available either directly from the message or through the access to the database. The position data can be linked or displayed on other applications like Google Earth as shown in Figure 5. This is one of the differences between the conventional GPS receivers and IMES receivers. The main approach of IMES is to use its position data and ID to link the user position to the outer world for more LBS and many other spatially related applications and database. Such integration of IMES data with other database will expand applications related with GNSS that ultimately will create huge LBS related business.

**Figure 3: IMES signal generator and power spectrum of IMES L1C/A signal**

**Figure 4: GUI to control IMES signal generator**
IMES EXPERIMENTS

IMES experiments have been conducted in different areas to demonstrate its capability of seamless navigation. Standard mobile phones with IMES capability and software receivers are used for analysis. The analysis includes signal availability, propagation properties, effect of different types of transmitting antennas, interference to GPS, location of receivers such as inside the pocket or bag etc. The experiments have been conducted at underground parking areas, underground train stations, office and building rooms, open spaces etc. The IMES receiver worked well when the receiver is moved from indoors to outdoors or vice-versa. Detail discussions about IMES experiments are presented in [7].

CONCLUSIONS

We have designed and developed IMES for seamless navigation. IMES will be used for indoor navigation purpose where GPS signals are not available. Signal design of IMES is done to minimize the impact on existing GPS receivers. It only needs modification in the existing GPS receiver firmware to decode the navigation messages as specified in the QZSS-IS document. The flexibility of using different types of navigation messages and their combinations are quite powerful tools for the IMES to suit the needs of different applications including E911 and related services. Experiments using mobile phone with IMES and GPS receiver have been conducted to show the seamlessness of IMES when the user moves from indoor to outdoor or outdoor to indoor.

REFERENCES