Development of IMES Installation, Setup and Management System

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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.

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 a technology to provide 3-D indoor position data. The IMES transmitter broadcasts position (latitude, longitude, height and floor ID) and other data embedding them into the navigation message. Existing and future GPS receivers can process IMES signal by updating only the firmware. The receiver decodes the navigation message and provides 3-D position data broadcasted by the transmitter and hence it is neither necessary to have multiple units of transmitter nor estimation of pseudorange between the transmitter and the receiver.

In order to provide indoor positioning and navigation data for users, it is necessary to deploy IMES devices effectively in terms of cost, space and management. The installation of IMES needs to set up PRN ID, transmitter power level, position data (Latitdue, Longitude, Height), Floor ID and other device specific data.

We have developed IMES Installation, Setup and Management System to facilitate IMES deployment so that cost and time can be minimized. The system will also help ordinary service providers to deploy IMES efficiently. The system is divided into four parts (a) IMES Setup Tool (b) IMES Database Management Tool (c) IMES 3-D Mapping Tool and (d) IMES Signal Propagation Tool. In this paper we present the details of each tool.

INTRODUCTION

The IMES Setup Tool (ISET) is used to setup the IMES transmitter. The tool provides two basic functions; (a) to setup signal related data and (b) to setup message related data. The signal related data includes setting of PRN code, transmitter power, navigation message rate and so on. The message related data includes position data, floor data, message types and their contents, message sequence and so on. The R&D version of IMES also allows transmitting some special data for research and development purpose. It is possible to change preamble value different from GPS, load different PRN code table than IMES, change navigation message data rate, make BOC(1,1) signal to test L1C like signals and change the RF frequency etc. The setup tool also has user access management so that only authorized users can change certain sensitive data like PRN code, position data and transmitter power.

3-D Mapping Tool (IMAP) provides necessary 3-D map database for IMES and computation of 3-D coordinates of IMES transmitter. The deployment of IMES needs 3-D position data of IMES transmitter. In case if this information is not available, it is necessary either to measure the 3-D coordinates using a nearby reference point or using existing drawings and information. 3-D Mapping Tool assists in calculating the 3-D coordinates of the transmitter by using many different types of available data. The mapping tool can use 3-D vector data (for example existing DXF files), raster image data or direct user input. The mapping tool has it’s own 3-D mapping system based on laser scanner. It consists of laser scanner and digital CCD camera for data capturing. Point cloud data from laser scanner are used to generate the 3-D model of the surrounding area. 3-D data of walls, windows, doors, ceilings and other smaller objects are generated from laser data. If data are available in paper drawings, they are scanned and raster images area created
before digitizing them into vector formant. The system will ultimately create 3D database of a building at floor level that can be linked with external databases. The spatial data from IMAP and non-spatial data from IDBM are linked using key fields.

IMES signal propagation loss tool (IPMODEL) is developed to simulate the signal level where IMES will be setup. It is necessary to have optimum deployment of the transmitter to cover the area as large as possible within the allowed power level. The tool is developed based on Frii’s Free Space Path Loss Model. The signal level at any receiving grid is computed considering the direct signal, reflect signal and pass-through signals by objects like partitions, walls, windows and doors. The signal output computed by the IMODEL tool and actual measurement data has been compared to check the accuracy of the model.

The IMES Database Management Tool (IDBM) simplifies IMES installation and management by providing necessary database. The database includes building related database, service provider database, device related database, other integrated sensors database (if any) and signal related database. Since, IMES is controlled, managed and guaranteed, authorized services can be provided for dedicated applications. This enhances the reliability of the IMES based positioning system which is needed for infrastructure, security and safety related applications.

**IMES SETUP TOOL (ISET)**

In order to deploy IMES, it is necessary to design optimum IMES transmitter locations based on the installation environment and setup various signal and message related parameters. Figure 1 shows the interface for IMES transmitter setting. The parameters that have to be set up can be divided into three main categories which are signal related, message related and operation related.

The signal related parameters are PRN code, central frequency offset and signal EIRP power. PRN codes 173-182 are supported. These PRN codes are assigned by the US government for Japan. It is also possible to set-up other PRN codes for test and research purpose. The center frequency offset is +8.2kHz or -8.2kHz from 1575.42MHz. These offset values are chosen to minimize the harmful interference to weak GPS signals within the vicinity of the IMES signals if any. The EIRP power can be controlled from -64dBm to -104dBm at 1dB step. There will be -36dB loss at 1m distance from the transmitter antenna for GPS signal. The guideline given by the QZSS IS document (Reference ???) is used to setup the EIRP by adjusting the RF attenuation. The EIRP is controlled in such a way that the maximum power at the receiver antenna located at 3m distance is less than -110dBm for indoor area where GPS signal is also available (near glass windows). The IMES EIRP shall be less than -120dBm where weak GPS signals are available. The navigation message rate is selectable from one of the following values: 50, 100, 250, 500 or 1000bps. The default value is 50bps. IMES Chip has two channels to transmit two different types of IMES signals that can be used for diversity and other applications. Each channel can be controlled independently with different parameters and values using this setup tool.

The message related parameters are 2D/3D position data, Floor ID, Short ID, Medium ID, Boundary Bit, Message Type and Sequence of Messages if multiple messages have to be transmitted. Currently, four types of messages are defined that are type 0, 1, 3, and 4. Message type “0” contains 2D position data and Floor ID. Message type “1” contains 3D position data and Floor ID. Message type “3” contains 12bits long Short ID and it’s range is from 000 to FFF or 0 to 4095 in decimal values. Message type “4” contains 33bits long Medium ID and its range is from 000000000 to 1FFFFFFFF or 0 to 8589934591 in decimal values. The transmitter can be setup to transmit any of these messages or combination of any of these messages. Figure 3 shows the setup of message sequence. This setup transmits Short ID (Message Type “3”) three times followed by 2D position data (Message Type “0”). Thus, it will take 3.6 seconds to transmit all the messages. The way the message sequences are designed depends on the type of applications and targeted users. It may be enough just to transmit 2D position and Floor ID (Message Type “0”) for some applications however for some other applications, it may be necessary to have Short ID as well. Some applications may need only Medium ID and get position and other related information by accessing a database server linked by the Medium ID.

The IMES Setup Tool User Interface

Figure 1: IMES Setup Tool User Interface
The operation related parameters limit the control of the device by limiting the access to ISET. For example, a standard user can set the device on or off or run test and maintenance of the device but can not change signal related parameters or message related parameters. A maintenance user can change signal related parameters but not the message related parameters. A super user can change any parameters as required. Such control of user access to the device is necessary to limit the access to sensitive parameters like power level, PRN code and position data. The maintenance tab allows changing the signal type to SS (CW modulated with PRN Code and NAV Data), CW (carrier only) or other combinations of CW, PRN Code, NAV Data and Overlay Code (Figure 2). These controls are provided for test and research purpose for interference, jamming and propagation loss. A standard user can not have access to these settings. By default SS signal is transmitted.

3-D MAPPING TOOL (IMAP)

The 3-D Mapping Tool allows generation of 3-D indoor map database either from existing data or complete new data using laser scanning system as shown in Figure 4. In the case of existing data, the tool allows to use raster data or paper drawings or vector data. The raster data formats can be JPG, BMP, TIFF and so on. The vector data format is DXF. In the case of paper data, the drawings are scanned to convert into raster data. Once the data are converted into raster format, coordinate conversion is applied. The raster data is first converted from image coordinate to local coordinate and then to global coordinate by using the known control points in the data. At least two control points are necessary. The selection of control points is done manually. A manual shift and rotation is done if necessary for fine adjustment of the coordinates after conversion.

Raster to vector conversion tool is used to extract the detectable lines as far as possible. The conversion of raster to vector depends upon the data quality and available useful features. As an alternative, the extraction of floor data, ceiling data and other objects can also be done manually. Since, raster data is only 2-D data, it is necessary to provide height data to each object manually by the user. For example, to create a wall object the width and length (or only length) is available but height data shall be given by the user using known sources. The objects that can be created are floor, ceiling, wall, partition, window and door. They are created into different layers.

If there are no existing data, a complete new 3-D model could be generated using either laser scanning system or using manual entry method. The laser scanning system consists of a laser scanner, a CCD camera and a pan-and-tilt device. The laser scanner provides point-cloud data of the surrounding area. The range of the scanner is 30m and it can scan at 0.25° resolutions. One scan provides 1080 data points. The accuracy of range measurement is within 3cm. The laser scanner is mounted in such a way that it scans vertically. The pan and tilt device is used to pan (horizontal movement) the laser scanner so that it can scan in many directions from the same point. All these scans are later combined using the pan and tile angle information and laser coordinates. The sensors are rigidly mounted on the same platform and hence they have the same relative movement. The system is calibrated for conversion of coordinates between the sensors and is valid unless the devices are removed or shifted from its original locations.
Table 1: Technical specification of Laser Mapping System equipments

<table>
<thead>
<tr>
<th>Sensor Device</th>
<th>Model</th>
<th>Scanning Details</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Scanner</td>
<td>HOKUYO UTM-30LX</td>
<td>Scanning Rate</td>
<td>Resolution</td>
<td>Coverage</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40Hz</td>
<td>0.25</td>
<td>270°</td>
<td>30m</td>
</tr>
<tr>
<td>CCD Camera</td>
<td>SONY XCD-SX90CR</td>
<td>Resolution</td>
<td>Frame Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1280x960</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pan-and-Tilt Device</td>
<td>PTU 46 175</td>
<td>Tilt Range</td>
<td>Pan Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-47° to +31°</td>
<td>+159°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Laser Scanning System

Figure 6: Data processing flow to generate 3D Object Models from Existing Data.

Figure 7: Data processing flow to generate 3D Object Models from Mapping the System.

Figure 8: 3-D indoor data generation from floor layout paper drawing
IMES SIGNAL PROPAGATION TOOL (IPMODEL)

IMES signal propagation tool is developed to simulate and visualize the signal availability in the area where IMES will be setup. It is necessary to have optimum deployment of the transmitter to cover the area as large as possible within the allowed power level. Although, the allowed maximum EIRP power level is -64dBm for Japan, the approach is always to use the least power possible to cover the area to avoid any harmful interference to other systems as well as to limit the availability of the signal only in the desired area.

The simulation tool uses 3-D spatial data that may include walls, floors, ceilings, partitions, windows and doors. Other objects like tables, chairs and racks can also be used. All these objects can be generated using IMAP. Each object has a database associated that includes the material type and electrical properties like reflection coefficient, absorption coefficient etc which needed to calculate the signal loss after reflection and penetration. Figure 10 shows the general process of IPMODEL.

IPMODEL Algorithm

The model computes the received power within a grid area set by the user. The grid plane can be set in 3-D as well. For example, we can define a grid plane 1.2m above the floor to represent the height from the floor when a person is using a mobile phone shown by green dotted line and yellow dots in Figure 11. As shown in Figure 11 we compute the receiving power at a point by considering all the rays both direct, reflect and penetrated rays. In order to calculate the power at Point 3, we consider the power loss due to penetration of the signal by partition 1 and 2 as well as the incoming signal by reflection (ray 3) from the wall. In this model, only the first reflected ray is considered to minimize the computation time. Since the computation is done in 3-D space, consideration of 2nd reflected ray will massively increase the computation time. We do not foresee the necessity of computation considering the 2nd reflected ray for IMES signal.

The IPMODEL algorithm is developed based on Free Space Path Loss model. Friis’s Free Space Propagation Loss (FSPL) is given by (1)

\[ L = G_T G_R \left( \frac{\lambda}{4\pi d} \right)^2 \]

Figure 11: Propagation loss computation at each grid point using direct, reflect and pass-through rays

where,
- \( d \) is the distance from the transmitter to the receiver in meter
- \( \lambda \) is the wavelength of the signal in meter, for GPS L1 band \( \lambda = 0.19m \)
- \( G_T \) is gain of the transmitter antenna
- \( G_R \) is gain of the receiver antenna
- \( L \) is propagation loss. Actually it is gain with negative sign when the value is computed in dB

The above equation can be written as shown in equation (2) to compute the power loss in dB unit.

Figure 10: IPMODEL Model Flowchart
The term $20 \times \log_{10}(4\pi)$ is constant and $20 \times \log_{10}(\lambda)$ depends only in the signal wavelength. Also, we assume that the transmitter and receiver antenna have unit gain (or loss, 0dB). Hence we can re-write equation (2) for GPS L1 Band (1575.42 MHz) as equation (3)

$$L(dB) = -36 - 10 \times \log_{10}(d)^2$$

(3)

$$L(dB) = L_0 - 10 \times \log_{10}(d)^2$$

(4)

where, $L_0 = -36dB$.

If the surrounding environment is not a “Free Space” but has objects that reflect, absorb or block the signal, then equation (4) is modified as shown in equation (5)

$$L(dB) = L_0 - 10 \times \log_{10}(d)^2$$

(5)

Where,

$N$ is a Propagation Loss Factor, the value of $N$ varies depending upon the surrounding environment.

For example:

- $N = 2.0$ for Free Space
- $N = 2.5$ for Office Room with mild multipath
- $N = 3.0$ for Office Room with heavy multipath
- $N = 3.5$ for factories with heavy multipath

In the simulation model, $N = 2.5$ is used by default.

$L_0$ is the Constant Power Loss for GPS L1 Band, 36dB

The above equation is further modified as shown in equation (6) to include the path loss due to material reflection and penetration.

$$L(dB) = L_0 - 10 \times N \times \log_{10}(d) + \sum_{i=0}^{m} R_i + \sum_{j=0}^{n} P_j$$

(6)

Where,

- $G_T$ is gain (Actually Attenuation value with negative sign) of the transmitter antenna
- $R$ is the Loss due to Material Reflection in dB with negative sign
- $P$ is the Loss due to Material Penetration in dB with negative sign

The values for $R$ and $P$ shall be provided by the user in the database file. These values differ depending upon the material types like concrete, wood, glass, metal and their thickness. Refer Table ?? for some examples of these values used in the Simulation Model.

The ITU Propagation Model is given by equation (7).

$$L(dB) = 20 \log_{10}(f) + N \times \log_{10}(d) + L_f(n) - 28$$

(7)

Where,

- $f$ is the signal frequency in MHz
- $d$ is distance in meter and $d > 1m$
- $N$ is the Propagation Loss Factor
- $L_f$ is the loss due to Floor Penetration
- $n$ is the number of floors between the transmitter and the receiver

The ITU model is basically similar to the Friis’s Model except that it accounts for the number of floors between the transmitter and the receiver.

Figure 12 shows the model output values for a simulation of large department store. The floor size of the area is about 90m by 40m. IPMODEL can be used to see the signal availability based on the location of IMES devices, room partitions, and material types of walls, partitions, windows and doors. Figure 13 shows the simulation output for the same area but with different layout of IMES (at the right side of the building) and transmission power (at the left side of the building). Two additional IMES are also installed outside the main room. The correctness of the model has been evaluated by validating the actual measurement values of the signal and model output values. A difference of 3-9 dB in exists between the measured values and the model output. Such difference will exist due to the difficult nature of generating the exact 3-D data of the environment. There are many small objects like air-conditioner units inside the room that are not considered in the 3-D data. The purpose of the model is to provide general signal availability visualization for initial planning rather than to measure the exact signal level at a location.
**IMES DATABASE MANAGEMENT TOOL (IDBM)**

IMES DataBase Management Tool (IDBM) manages the entire database needed for IMES setup, maintenance, 3-D building data, building attribute data and other related data. These data are grouped into IMES DB Server and CAD DB Server as shown in Figure 14 and Figure 15.

These two database systems are linked by a relational database system. Any update in the map database can be reflected into the IMES setting. The combined system of these two database servers is called Master DB System. The master database system may have a local server for maintenance and set-up of the system locally. Figure 16 shows a general concept of the overall database management system.

**SUMMARY**

All the necessary tools to deploy IMES have been developed. These tools are iSET, iMAP, iMODEL and iDBM. The use of these tools simplifies the IMES deployment process. iMAP simplifies the fixing of 3-D coordinates in indoor areas, which otherwise might have been a quite complex task. Texture data will be applied in the future version of iMAP.

**REFERENCES**


