Calibration of Dead Reckoning with IMES for Indoor Pedestrian Navigation

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Abstract—**Our research goal is to realize indoor pedestrian navigation. Dead reckoning (DR), which uses integrated sensors as smart phones do, is a key technology because DR technology allows indoor navigation without installing any further devices to determine one's position in a building or outdoors. The main concern with DR-based pedestrian navigation is that DR presents problems due to cumulative errors. To improve the cumulative error for DR, we propose a calibration technique using an indoor messaging system (IMES). An IMES can transmit an absolute position to a Global Positioning System receiver using latitude, longitude and floor level data, thus providing an interface between outdoor and indoor navigations systems. The IMES assumes that positioning accuracy better than 10 m will be required in order to satisfy users who would like to know where they are in indoor places such as buildings, shopping areas, and airports. This technique is able to calibrate the DR error, and prevents the accumulation of large error. However, the IMES requires the installation and maintenance of IMES transmitters even if the combination of DR and IMES technologies requires a minimum number of installed transmitters. This calibration technique of DR with an IMES can obtain the location data from both positioning technologies and either set of data is used as position data by itself. This paper presents a prototype of a calibration technique for DR with an IMES and several experiments on indoor pedestrian navigation. We confirm that the accuracy, including maximum error, of this method is better than that of a DR-only system.**

Keywords—Calibration, Dead Reckoning, Indoor Messaging System, Indoor Pedestrian Navigation

I. INTRODUCTION

It is important to know one's position using an indoor pedestrian navigation system in places such as large-scale stations and underground shopping centers where people move around routinely, because it is difficult to find clear landmarks in these places.[1][2] Today, there are widespread outdoor location-based services using global navigation satellite systems such as the Global Positioning System (GPS), Galileo, and Quasi-Zenith Satellite System. However, an indoor positioning system has not yet been adopted anywhere because the signal of global navigation satellite systems cannot be received indoors.[3] Although there are positioning methods that employ, for example, Wi-Fi, radio-frequency identification (RFID), and visual tags, these methods require the installation of equipment such as transmitters and tags within indoor spaces.[3] Dead reckoning (DR) is a technique for deriving cumulatively how much a person has moved from the position he or she was at just before [4]. It is derived by detecting pace, direction, and steps using data provided by a sensor group such as an acceleration sensor and gyro sensor included in a smart phone. In addition, DR has an advantage in that it is able to determine position anywhere and anytime, as it does not rely on a system that determines the position around the user. However, DR tends to accumulate errors as it is used, as pointed out in a previous study. [5] [10] This leads to separation from the actual position.[5] Our research is based on the concept of revising the position obtained from DR with an indoor messaging system (IMES).[6] An IMES is a positioning system that can transmit to an area absolute position data using latitude, longitude and floor level data and enables positioning by the GPS receiver even in indoor locations where the GPS signal does not reach.[7] In this paper, we propose a calibration technique of DR with an IMES for indoor pedestrian navigation and describe a prototype system and its evaluation.

II. POSITIONING TECHNOLOGY FOR INDOOR PEDESTRIAN NAVIGATION

It would be difficult to apply only inertial positioning to indoor pedestrian navigation because human behavior is complicated and the output of inertial positioning often includes large error.[5] In addition, it has a drawback in that the error grows cumulatively. To solve these problems, various research on DR has been carried out. For example, Beauregard[8] suggested a DR technique using both a GPS unit and inertial measurement unit for specific use by police officers and firefighters that requires the user to put on head gear. Kourogi[9] presented a positioning technique that detects characteristic data such as the direction and velocity of walking from sensors such as an acceleration sensor and geomagnetism sensor. This technique requires that sensors are secured to the tester's waist. Although most conventional research solutions require specific devices to be attached to users, users do not have to attach sensors to specific parts of the body. Kamisaka[10] proposed a positioning system that does not require a sensor to be secured to the body. He considered a way to distinguish the hold and swing modes of a mobile phone, and established a proper positioning method using the characteristic values of properties in each case. A problem with the system is that it uses a geomagnetism sensor and the data obtained by geomagnetism sensors tend to be uncertain indoors. He pointed out that a calibration technique would be necessary for his system. The system Jiménez Ruiz[11] proposed is precise to within a few meters using active tags for calibration. The issue with this system is that users require an RFID reader and many RFIDs need to be set for the system to be precise.

III. Indoor Positioning System Using IMES Calibration (IPSUIC)

TABLE I. SPECIFICATIONS OF THE MULTI-FUNCTION RADIO SENSOR

Specification of TSND121	
CPU	RX621(Renesas Electronics Corporation)
Operating Time	About 6 hours
Size	37mm(W)×46mm(H)×12mm(D)
Accelerometer and Gyro	Inven Sense MPU-6050
Accel Full Scale Range(g)	±2
Accel Sensitivity(LSB/g)	16384

The realization of indoor pedestrian navigation requires three technologies: indoor positioning, indoor mapping and indoor routing. This paper focuses on improving the average positioning accuracy relative to conventional indoor positioning. The prototype of the calibration system proposed in this paper is named the Indoor Positioning System Using IMES Calibration (IPSUIC). Figure 1 shows the configuration of the IPSUIC prototype system. This prototype system consists of a multi-function radio sensor as an accelerometer, an IMES receiver, and a personal computer (PC) for processing positioning data. Both the sensor and receiver are connected to the PC via a Bluetooth or USB serial port. IMES transmitters are installed on the ceiling of a building. The software for IPSUIC is installed on the PC. The specifications of a TSND121 multi-function radio sensor (ATR-Promotions) are given in Table 1. A SuperStarII GPS receiving board (Novatel) is used as an IMES receiver because its firmware can be modified to receive IMES signals as open source software. Two types of algorithms for calculating position are developed using the PC software as shown in Figure 2. Type 1 is a simple algorithm that treats the positioning data of the IMES as the position if the IMES receiver detects an IMES signal. If the receiver cannot detect the IMES signal, the DR positioning data are treated as the position. Type 2 focuses on the received signal strength (RSS) of the IMES receiver. Type 2 uses an appropriate threshold to filter unstable data, and calibration is carried out when the maximum strength of the signal received is more than the threshold. To implement this system in real time in the future, it is feasible to take not only the maximum strength but also the maximum strength with filtering of the unstable data. The appropriate threshold of the IMES signal strength is set according to data obtained in an experiment.

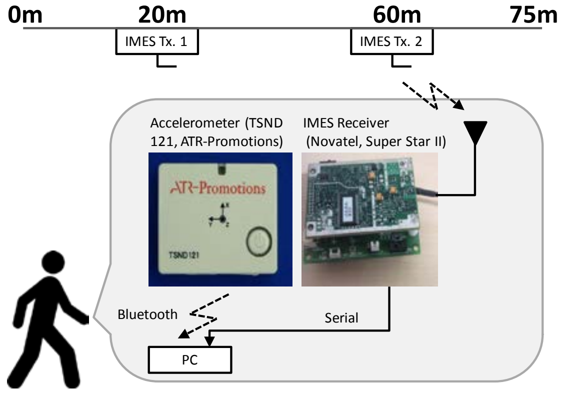

Figure 1 System Configuration and Experimental Course

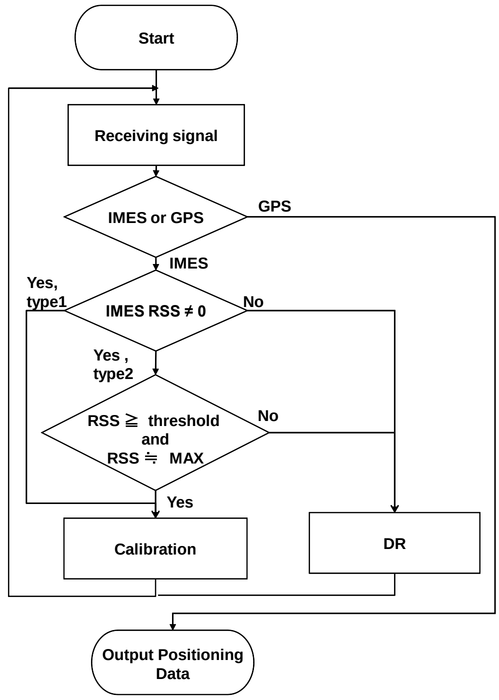

Figure 2 Flowchart of the IPSUIC Positioning Algorithm

IV. Experimental Test with Prototype System

The experiment was performed in a 75-m corridor with two IMES transmitters installed as shown in Figure 1. The experimental space was a narrow hallway 3 m wide with no-one present except for two testers. The transmitter of the IMES had height of 2 m and was set 1 m from the walking course. The direction of transmission was downward. Points were marked at every 0.5 m and we treated the difference between the real location and location given by DR as error. The strength of the IMES transmitters was changed by adjusting the attenuator. We experimented with three signal strengths for the IMES by changing the value of the attenuator as –64 dBm (ATT = 0), –79 dBm (ATT = 15), and –94 dBM (ATT = 30). The operable ranges changed according to the signal strength. The tester walked the corridor with the accelerator and IMES receiver in their right hand as shown in Figure 3. The assistant walked with the tester and held a PC connected to the accelerator and IMES receiver. The tester stepped on a marker set at every 0.5 m on the experimental course and the walking speed was approximately 1 m/s.

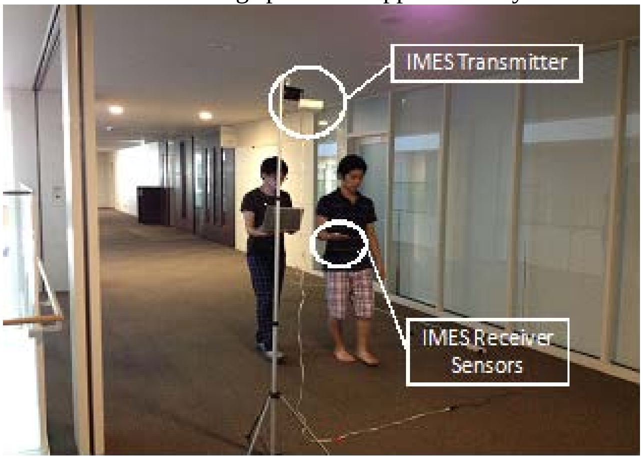

Figure 3 Experimental Setting

V. Results

First, we confirmed that there was no significant difference in the signal strength for each IMES by employing the same receiving conditions and configurations. However, the case of the lowest transmission intensity had the smallest error. We then set the appropriate threshold of the IMES signal strength from the data obtained in this experiment to eliminate noise from the IMES. The DR was calculated from the data obtained in the experiments and calibrated using two types of IPSUIC. The positioning errors in the cases that the strength of IMES transmitters was –64, –79, and –94 dBm are shown in Figures. 4, 5, and 6.

The positioning error for the Type-2 algorithm was less than 7 m in the case that the strength of IMES transmitters was –64 dBm. In addition, the positioning was accurate to within 10 m when the tester walked 75 m. In contrast, the positioning error of the Type-1 algorithm was greater, and was as much as 20 m.

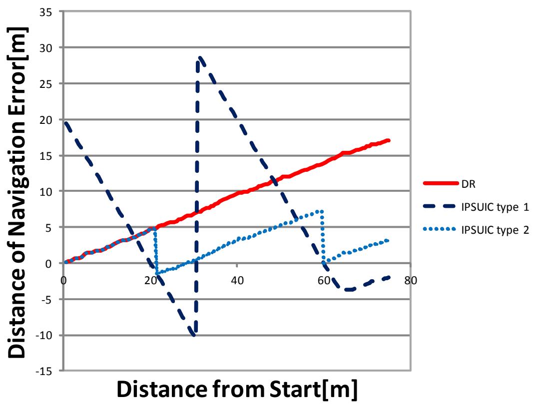

Figure 4 Distance of positioning error (–64 dBm)

The positioning error of the Type-2 algorithm in the case that the strength of IMES transmitters was –79 dBm was less than 8 m. In addition, the positioning was accurate to within 10 m when the tester walked 75 m. In contrast, the error for the Type-1 algorithm was greater, and was as much as 20 m. DR error exceeded 17 m when the tester walked 75 m.

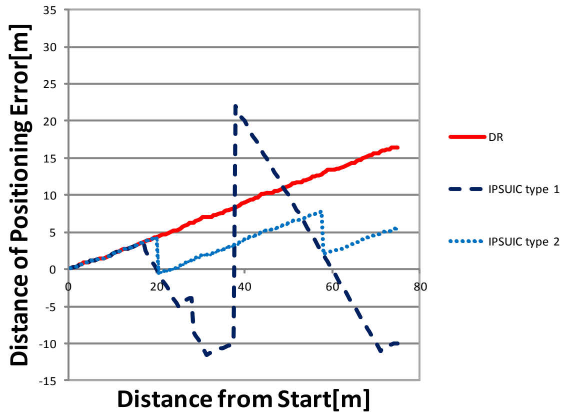

Figure 5 Distance of Positioning Error (–79 dBm)

The positioning error for the Type-2 algorithm in case that the strength of the IMES transmitters was –98 dBm was less than 7 m. In addition, the positioning was accurate to within 10 m when the tester walked 75 meters. In contrast, the positioning error of the Type-1 algorithm was greater, and was as much as 25 m.

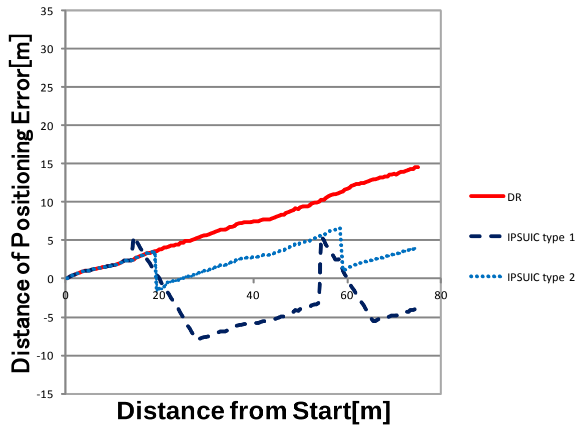

Figure 6 Distance of Positioning Error (–94 dBm)

VI. Discussion

The results show that the calibration of DR using the Type-2 algorithm with positioning data from the IMES receivers and RSS is useful. Using the Type-2 algorithm, we can achieve proper indoor positioning. The positioning error is less than 5 m in most cases and the maximum error is less than 8 m in all experiments. In nine trials, the Type-2 algorithm achieved this result and we thus confirmed the repeatability of the experiment. Therefore, we found that calibrations using the

Type-2 algorithm can support DR used continuously for a long time.

On the other hand, the positioning error using the Type-1 algorithm was often more than the positioning error using DR. The maximum error exceeded 25 m. When the area receiving signals from the IMES transmitter was short, errors in the case of the Type-1 algorithm were not significant. In the case that the strength of the IMES transmitters was –79 or –94 dBm, the receiver could detect the signal of the IMES placed at a distance of more than 20 m. The obtained results show that it is ineffective to use the Type-1 algorithm for calibration in the case that the DR error is not large and we should set the signal strength of the IMES such that distant values are not received. In all conditions that we tested, the INSUIC can calibrate the distance of positioning error when DR is less accurate than the accuracy needed as long as the error of the DR is not too low and there are IMES data. It seems that the error becomes less than 5 m by narrowing the installation of the IMES to 30–35 m. In addition, the setting of the threshold should be adjusted to the maximum value of the RSS. This is because the calibration is of low accuracy if the threshold is too small relative to the maximum strength.

VII. Future Works

Future work will consider the calibration of the direction component. In this paper, we only considered the distance component and calibrated using two calibration methods. We should evolve the calibration methods to include the direction component. In this experiment, we used a corridor that lies across the diameter of the transmitting area of the IMES. However, people in the real world walk in various ways, and cross the transmitting area of an IMES in diverse ways. We hope to deal with this problem by improving our system. We need to consider various indoor environments and the unforeseeable movement of examinees.

In addition, we need to adapt for the problem of ambient signal reflection from surrounding walls or other obstacles, including people. We need to take into account, for example, the height of the ceiling, whether a colonnade exists, and the busyness of the street, regarding the use of the RSS of the IMES. In addition, we should evaluate the IMES as an integrated system after it has been implemented on a smart phone with a GPS receiver that can receive the IMES signal and use an accelerometer, because some concerns exist with regard to battery use.

VIII. Conclusion

This paper reported that the calibration technique of DR with an IMES can support indoor positioning, especially in the case of walking a long distance. It is necessary to evolve calibration methods to include the direction component and various paths of people in the transmitting area of the IMES in the future. Additionally, we need to develop a device that contains GPS sensors that can receive the IMES signal and accelerometer data for commercialization after clearing these challenges.

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