PRECISE POSITIONING AND POWER SUPPLY CONTROL FOR LOGISTIC TRACKING SYSTEMS USING PHS

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Abstract: In this research, focusing on the PHS positioning service used in logistics, an error offset method for improving positioning accuracy, and a power saving method using vibration for decreasing power consumption and communication cost are invented. The error offset method learns patterns of positioning results and the highest signal strength at each points, and matches them with the new data according to Mahalanobis distance. Additionally, by measuring the acceleration amplitude continuously, and measuring the terminal position with PHS intermittently, threshold of acceleration to distinguish the stop and moving state is learned. Then the power of PHS terminal is set ON only when the acceleration is higher than the threshold. Then the power consumption and the communication cost are reduced.

Key words: PHS, Positioning, Logistics, Power supply control, Vibration

1. INTRODUCTION

Recently, the PHS modules have been drastically miniaturized producing such as W-SIM device with the development of microsystem technologies. In the sensor networks, the positioning technology is one of the most important applications. Nowadays, more than 5,000 PHS terminals are in use with the PHS positioning system, since the system is easily used by small-scale companies, can track transport equipment both inside and outside buildings, and the terminals need little electricity to work [1]. However, the PHS system has a defect that the measurement error is large ranging from several ten meters to several hundred meters. In addition, it is important to reduce the number of position measurement times since the main part of power consumption and cost in this system are those by radio communication. Some transport equipments such as pallets and containers do not move for a long time, e.g., several months, and do not need to be searched continuously.

In order to overcome these problems, an error offset method for improving positioning accuracy, and a power saving method using vibration for decreasing power consumption and communication cost are invented.

2. PHS POSITIONING METHOD

2.1 RSSI Positioning Method

Position calculating method in this research using PHS is called RSSI (Received Signal Strength Indicator) position calculation method. This method is a technique to estimate the terminal location based on the CS (Cell Station) position information which distinguished by CS-ID and received RSSI data from each CS with a PHS terminal. Electric field intensity E from each CS is measured as RSSI by a PHS terminal. Here, the relational expression between electric field intensity E and RSSI is defined as below:

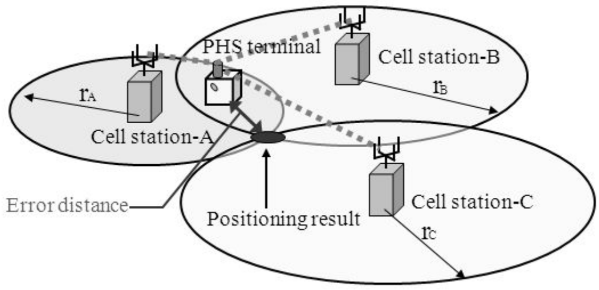

Fig.1: Principle of position measurement method using RSSI from PHS cell stations.

$$E = 10^{RSSI/20} \quad (1)$$

In addition, the distance r between CS and PHS terminal is estimated by following equation,

$$r = c / E = c \cdot 10^{-RSSI/20} \quad (2)$$

where c is a constant which depends on the installation environment of the terminal. Therefore, a position of a terminal is estimated on the circumference with radius r around a CS location, as shown in Fig. 1. The intersection point of each circle is provided by applying Eq. 2 to several CS data and specifies that a PHS terminal is located in a neighborhood of the point of intersection.

2.2 Barycentric Position Calculation

In the actual environment, Eq. 2 doesn't consist because the measured E contains error caused by the attenuation of radio waves by buildings around the terminal. However, the CS's that the terminal catches often concentrate around the terminal [2]. Consequently, in this research, the estimated location of terminal (x, y) was calculated by barycentric positioning method.

$$(x, y) = \sum_{i=1}^{N} m_i (x_i, y_i) \Big/ \sum_{i=1}^{N} m_i \tag{3}$$

The above expression shows the formula of the barycentric positioning method to calculate the terminal location. Here, m_i shows the RSSI of radio wave from CS_i, (x_i, y_i) shows the position coordinates of CS_i location, and N shows the number of received CS's in descending order of RSSI.

2.3 Position-Matching Method

PHS positioning system is primarily used in location information management of the transport equipments and the valuables. Practically, the system is often used in combination with *position-matching method* since the positioning error using PHS is too large. This matching method registers the locations of the warehouses and offices in advance where the equipment might move, and then ascribes the terminal location to a registered position when the calculated position is within 1 km from the position. As for this method, when the distance among registered positions becomes 2 km or less, it is not possible to use. Therefore, the development of the position-matching method with higher resolution than conventionally method is demanded. In this research, an error offset method is developed which learns patterns of positioning errors (latitude and longitude) and the highest signal strength at major logistic points, and matches them with the new data measured at actual distribution processes according to Mahalanobis distance.

3. ERROR OFFSET METHOD OF PHS POSITIONING RESULT

3.1 Measurement Condition

In this research, the RSSI data of each CS were measured with a PHS terminal AH-N401C (NEC). By one measurement, RSSI and CS-ID of each CS less than 20 are acquired. The location of the CS can be specified by acquired CS-ID. Figure 2 shows the RSSI measuring points donated by the cross marks of A-F

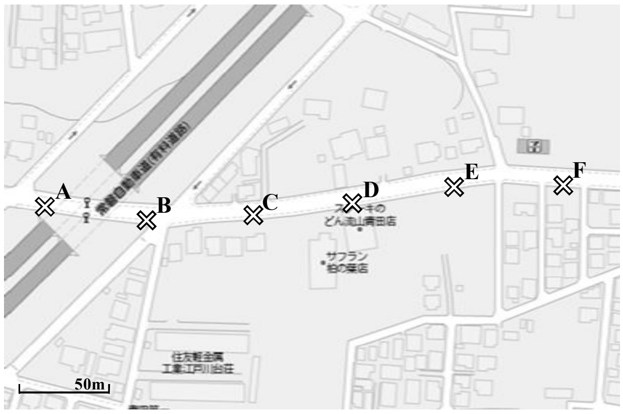

Fig. 2: RSSI measurement points using PHS terminal.

that exist at intervals of about 50 m on a route in Chiba Prefecture, Japan. Among the measured RSSI data, 200 data were used for the training data, and 100 data were used for the test data which are treated as its measuring point are unknown with respect to each measuring point.

3.2 Error Offset Method Using Mahalanobis Distance

The barycentric positioning results measured at the close locations are likely to overlap each other. Overcoming this problem, a method using the highest RSSI data is proposed. Even if the calculation results of several measuring points are the same, the highest RSSI is different by measuring location. Figure 3 shows the positioning results of the training data measured at A to F points in Fig. 2 on 3D space that add the highest RSSI to the calculation result of 2D space (longitude and latitude). A vertical axis shows the highest RSSI. This result indicates that the positioning results are likely to separate with respect to each measuring point also between the positions where the calculation results overlap each other on 2D space.

Next, Mahalanobis distance was used as a similarity evaluation between the training data and test data. Mahalanobis distance is expressed as Euclidean

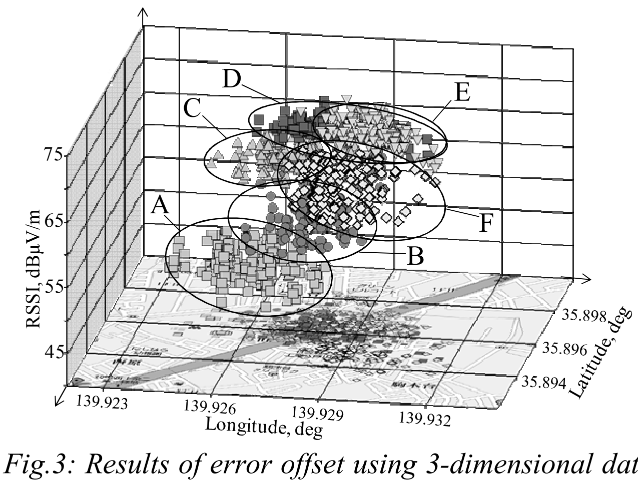

Fig.3: Results of error offset using 3-dimensional data learning.

Table 1: Position discriminant result using Mahalanobis distance.

		Discriminant result, %					
		A	B	C	D	E	F
Test data	A	100	0	0	0	0	0
	B	0	100	0	0	0	0
	C	0	1	97	0	1	0
	D	0	0	0	96	0	4
	E	0	0	0	0	99	1
	F	0	0	0	0	0	100

distance divided by the standard deviation of data. When the test data is obtained, the point where the data might be measured is distinguished as a point where the training data that the Mahalanobis distance is minimized was measured. Table 1 shows the position discriminant results of the test data measured in each measurement point using training data and Mahalanobis distance. Using this location evaluation method, it is possible to identify the terminal location with accuracy of around 99 % at intervals of 50 m. This result indicates that the space resolution was improved to 1/40 compared with conventional position-matching method.

4. POWER SUPPLY CONTROL

4.1 Algorithm for Judging Moving Status of Transport Equipment

In this section, to reduce the number of position searches, a method for detecting the movement of transport equipment using an accelerometer is developed. In practical measurement, it is difficult to set a threshold of the acceleration level for judging whether the equipment is moving or not. The acceleration level on the moving equipment depends on equipment types and moving directions. Therefore, a threshold needs to be set after observing the moving status of equipment. In this research, a method which extracts the approximate minimum acceleration value of moving equipment and maximum value of standing equipment was devised. The method is as follows when the PHS positioning interval is one day as is usual in palette tracking.

(1) Measurement and pre-processing of acceleration

Acceleration is constantly measured. Let A1 donates the maximum absolute value of accelerations measured for a period from one PHS positioning to the next PHS positioning.

(2) Method for setting threshold

First, let an A1 at a day when equipment moves donates Amove and let an A1 at a day when equipment doesn't move donates Astop. The initial value of Amove is set to 0 and the initial value of Astop is set to infinity. Next, the position of equipment is located by PHS once a day, and then the transport equipment status is judged insofar as to whether it has moved within the day or not. Next, Amove and Astop are refreshed. Amove is set to the minimum value of A1 in days when the transport equipment moves. Specifically, the value of Amove is refreshed to that of new A1 when the value of new A1 is higher than the recorded value of Amove, and it is not refreshed when the value of new A1 is not higher. Astop is set to the maximum value of A1 in days when the transport equipment is standing. Specifically, the value of Astop is refreshed to that of new A1 when the value of new A1 is lower than the recorded value of Astop, and it is not refreshed when the value of new A1 is not lower. Finally, the threshold of acceleration level, Ath, for judging the equipment's moving status is set. The threshold is set to the average of the value of Amove and that of Astop.

(3) Judgment of transfer equipment using threshold of acceleration level

After determination of the threshold, judgment of the equipment's moving status can be done using only the acceleration level. The transport equipment is judged as moving if the value of A1 is higher than the value of Ath. If judged as moving, a PHS terminal is powered on; then the position of the transport equipment is located by PHS and the located position is displayed.

4.2 Sampling of acceleration

Equipment was moved and stopped on the assumption of its practical movement in the field of logistics; its acceleration was measured by the attached accelerometer. The output voltage of dual-axis accelerometer, ADXL202E from Analog Devices, Inc., was recorded using a data logger, ZE-DMR10 from Omron Corporation. Sampling interval was 1 kHz. The accelerometer is attached directly to a dolly (Fig. 4).

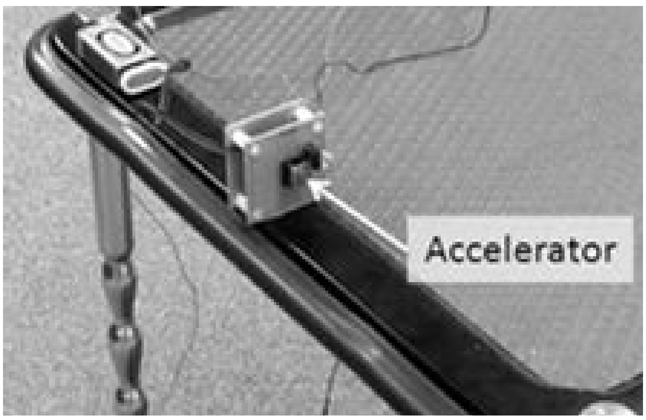

Fig.4: Methods of accelerator attachment.

4.3 Application of The Algorithm

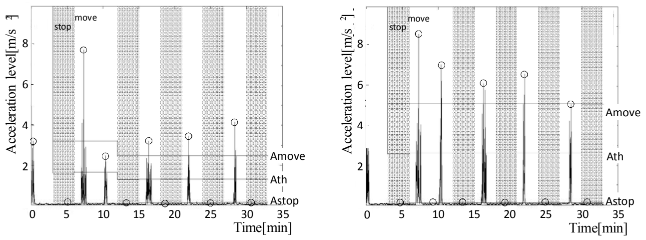

Fig. 5: The result of the algorithm application.

Transport equipments with an accelerometer attached was moved intermittently for 30 minutes and the accelerations along their traveling direction and vertical direction were recorded. After that, the absolute values of acceleration were calculated. This experiment was carried out on the assumption that PHS positioning interval is 3 minutes (one day in actual use) and the values of Astop and Amove are refreshed every 3 minutes. The days when equipments moved were distinguished manually from the days when they did not move. Fig. 5 shows the process of setting the threshold for this case.

Fig. 5a shows the acceleration level along the travelling direction in the combination. Ath was not refreshed after the time when 15 minutes had elapsed; thus, the repeat count was 3. Fig. 5b shows the acceleration level along the vertical direction in the combination. Ath changed little after the time when 9 minutes had elapsed; thus, the repeat count was 1. As described above, the threshold gets stable virtually within 3 of the day when an equipment move. In case the equipment moves every other day, the learning process with this algorithm is finished in 6 days. After the time when a threshold is set, the time when the equipment starts to move can be detected and PHS positioning is carried out at that time, since the equipment's moving status is judged constantly.

5. A TERMINAL FOR JUDGING MOVING STATUS

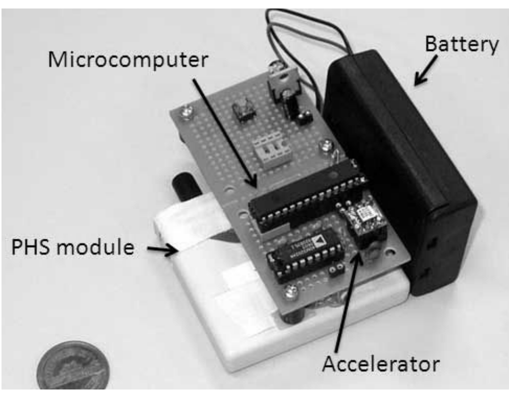

Fig. 6: Prototype of the movement judging terminal.

A PHS terminal including accelerometer was developed which sets a threshold in order to judge whether the equipment is moving or not using the algorithm explained in the previous section and locates its position in conjunction with the PHS positioning server when the judgment result is "moving". A configuration diagram of the terminal is shown in Fig. 6. The terminal consists of a dual-axis accelerometer, ADXL202 from Analog Devices, Inc, a microcomputer, PIC-16F873 from Microchip Technology Inc., a PHS module, LC102 from Toshiba Corporation and four AA size alkaline batteries.

The PHS module receives a positioning request from the remote positioning server, sends measured strength of wave from PHS cell stations surrounding it to the positioning server and receives its status of movement determined by the PHS positioning. Its LED lights with a specific pattern when it receives the status information "moving". The microcomputer detects the LED lighting; thus, the microcomputer knows its moving status during the learning process in the threshold setting algorithm.

6. CONCLUSION

In this research, focusing on the PHS positioning service used in logistics, an error offset method for improving positioning accuracy was invented and evaluated. With this positioning error offset method using training data and Mahalanobis distance, it was possible to identify the terminal location with accuracy of 99 % and the resolution of 50 m. In addition, the algorithm for judging whether transport equipments move or not by detecting their vibrations was devised for the purpose of reducing communication costs and power consumption of the terminal. Experimental results using a cart show that the learning of acceleration level on moving equipment within 3 days allows for the judgment of movement status without depending on vibration characteristics of the equipments.

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