ZigBee Network System for Observing Operating Activities of Work Vehicles

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***Abstract*— Observing activities of working vehicles on a work site, such as a factory, is important in regard to managing the lifetime of vehicles and achieving high operational availability. However, it is a problem that an administrator cannot completely grasp the activities of a working vehicle. Existing systems cannot cover a large area, particularly in an indoor environment. A system is proposed for monitoring operating activities of working vehicles, regardless of whether they are operating indoors or outdoors. The system calculates the activity rate of a vehicle by analyzing the topology of a network configured by the wireless technology ZigBee. In addition, it was experimentally verified that network topology and RSSI can be used to estimate activities of working vehicles.**

***Keywords*-ZigBee, Sensor Network, Activity, Status**

I. Introduction

Activities of working vehicles (forklifts, aerial work platforms, automatic guided vehicles, etc.) are essential in a work site, such as a factory. However, it is a problem that an administrator cannot easily monitor the operational activities of all working vehicles effectively. For example, 1,000 or more work vehicles often operate on a large-scale work site, such as construction of a new airport. An administrator is not able to answer questions such as how many working vehicles are actually in operation and how long they have been operating. Therefore, the activity of the working vehicles becomes inefficient. In addition, working vehicles equipped with automatic navigation often operate outside the field of view of the administrator. Consequently, the administrator might not notice if a working vehicle has stopped working.

These problems can be solved by monitoring the activities of working vehicles on the basis of positional information. GPS is a typical way for achieving such positioning; however, it cannot be used in indoor environments because GPS signals are blocked by walls or ceilings.

On the other hand, in recent years, a wireless technology called ZigBee[1] has been applied in the field of sensor networks. ZigBee can build a link between devices that are near each other regardless of whether their location is indoors or outdoors. It is also possible to use ZigBee to construct complex network topologies.

In this study, aiming to improve work efficiency, a system for observing operating activities of working vehicles by utilizing ZigBee is proposed. The system estimates the relative positional relation of working vehicles on the basis of information concerning a ZigBee-configured network. The system then calculates the activity rate of each working vehicle from the time-series change of the positional relation. Finally, activities of all working vehicle are displayed on a tablet so the administrator can monitor them.

II. Related Works and Objectives of Study

A. Related works

KOMTRAX,[2] developed by the construction equipment company Komatsu Ltd., is an “activity-observation system” utilizing location information. However, it cannot be used indoors because it utilizes GPS to measure positions of machinery units. Many existing systems using GPS have a similar problem.

Other systems use RF-ID [3] [4] or magnetic tape [5] as a method of obtaining positional information without using GPS. These systems, however, cannot cover a wide area because numerous sensors need to be installed in the field. In addition, they cannot respond flexibly when the worksite changes.

Other methods estimate position by using radio technology such as WiFi [6] and Bluetooth [7]. However,

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WiFi and Bluetooth require installation of access points for mutual communication. It is thus difficult to cover a wide area in which more than 1,000 vehicles are operating.

On the other hand, applying ZigBee wireless technology for constructing sensor networks is attracting attention. ZigBee can connect up to 60,000 units or even more devices. By constructing a mesh network, it also enables units to "multi-hop communications."

B. *Objectives of This Study*

In consideration of the circumstances described above, a system for observing operating activities of working vehicles by utilizing ZigBee is proposed. The proposed system monitors both indoor and outdoor operations by estimating the activities of vehicles from their relative positional relationships. The estimated activity is recorded as a pattern, and the activity rate (estimated from the pattern) is displayed on a tablet.

III. Overall Structure of Proposed System

A. *Overview of proposed system*

An overview of the proposed system is shown in Figure 1. This system utilizes a ZigBee device attached to a working vehicle to observe the activities of the vehicle. The system collects topology and RSSI data from the network built by the ZigBee. The collected data are sent to the tablet. These data are used for estimating relative positions of the working vehicles. The activity rate of each working vehicle is calculated by analyzing the position information in a time-series manner. Finally, the calculated activity rate of each working vehicle is displayed on the tablet.

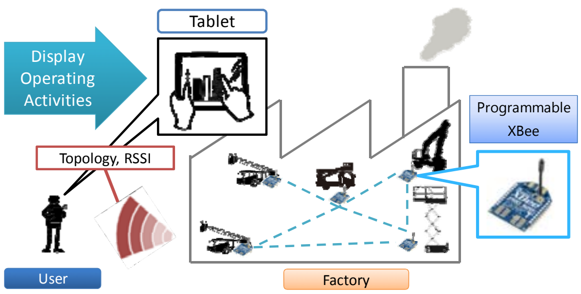


Figure 1. Overview of proposed system

In this manner, the proposed system is characterized by estimating the activity status from changes occurring in the network. Moreover, it utilizes a relative positional relationship between the devices instead of the absolute position. The reasons for using ZigBee are threefold: 60,000 or more terminals can be connected; multi-hop communication is enabled by constructing a mesh network; and energy consumption is reduced.

Digi's Programmable XBee[8] is adopted as the ZigBee device. XBee can be applied as a single unit, without having to utilize other microcomputers such as Arduino, because it has a mounted communication chip for ZigBee (equipped with a microcomputer).

B. *Methods for observing operating activities of vehicles*

The topology of the constructed network is estimated first. The relative relationship between the devices on the network is estimated from that topology. Second, a received-signal-strength indicator (RSSI) is obtained from adjacent devices. The RSSI is used to estimate the distance relationship in real space because its value changes according to distance.

The methods for obtaining each this information are explained below.

1) *Topology*

As shown in Figure 2, the topology of a network is estimated by using the "node discovery" standard function of ZigBee. The device can acquire the address of the peripheral devices by using node discovery. However, the results of node discovery include the address of devices two or more hops away. For this reason, node discovery alone cannot estimate the entire network's topology. Therefore, the response time from connected node is used to detect the number of hops. The response time is the round trip time when sending a message to peripheral node.

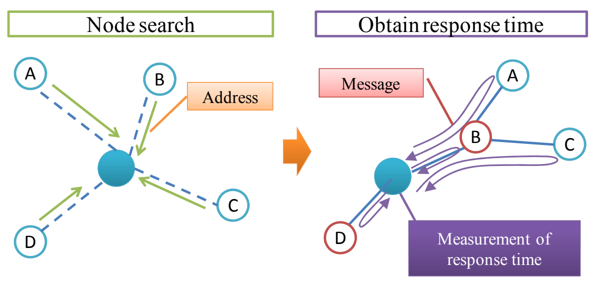


Figure 2. Methods for estimating network topology

2) *RSSI:*

RSSI cannot be obtained from the ZigBee device via two or more hops. An RSSI is thus acquired from devices connected directly on the basis of the estimated topology.

IV. EVALUATION OF ZIGBEE FUNCTIONS

A. Hop counts estimated from response time

1) Outline of experiment

To reveal the relationship between hop counts and response time, ZigBee devices were experimentally evaluated. In this experiment, four ZigBee devices were configured in a linear topology by placing them at 30-m intervals within the communication limit for an indoor environment. The device located at the end of liner topology sends packets to the other devices, and the response time was measured.

2) Experimental results

The measured average response time and number of hops are plotted in Figure 3. The figure shows that response time increases by about 7 ms with each increment of hop count. Since response time linearly increases according to number of hops, the hop counts of any device can be estimated from the response time. Furthermore, it is noted that the response time of the adjacent device is 30 ms or less.

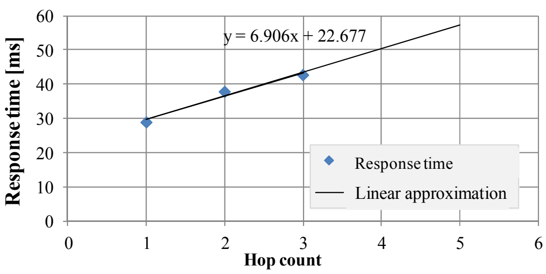


Figure 3. Relationship between response time and hop count

B. RSSI

1) Outline of experiment

To clarify the relationship between RSSI and distance in real space, ZigBee devices were experimentally evaluated. In this experiment, two were used. The distance between devices is set in the range of 1 to 100 m.

2) Experimental results

The relation between devices and RSSI is shown in Figure 4, which indicates that RSSI decreases exponentially as the distance increases. For this reason, the distance in the real space can be estimated from RSSI.

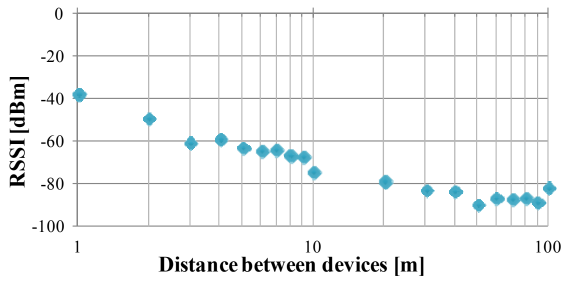


Figure 4. Relationship between distance between devices and RSSI

V. PROPOSED ALGORITHM FOR ESTIMATING ACTIVITIES

A. Estimation of topology

The algorithm for estimating topology used by the proposed system is shown in Figure 5. When information contained in node A is only available, node A does not know that node E is connected via node B (Figure 5: A). Furthermore, node A cannot know that there is a link between node C and node D (Figure 5: A). When the system acquires the number of hops from all nodes, it estimates the whole topology by combining the results from all the nodes (Figure 5: B). In this manner, the proposed algorithm determines the whole topology.

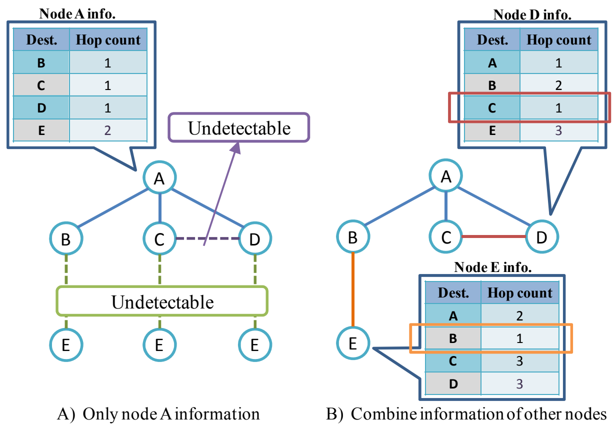


Figure 5. Estimation of topology

B. Estimating movement of working vehicles

The movement of a working vehicle can be estimated by analyzing the change of the estimated topology in a time series. The working vehicle is judged to have moved when the connection relationships between the nodes change. For example, if the connection relationship changes as shown in Figure 6, the moved node can be estimated to be node A and/or node D. In this case, the system records that node A and/or node D has moved and has thus been operating.

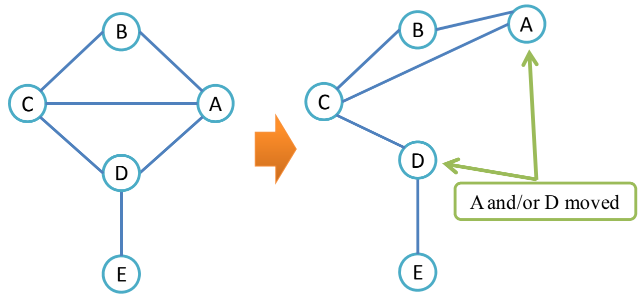
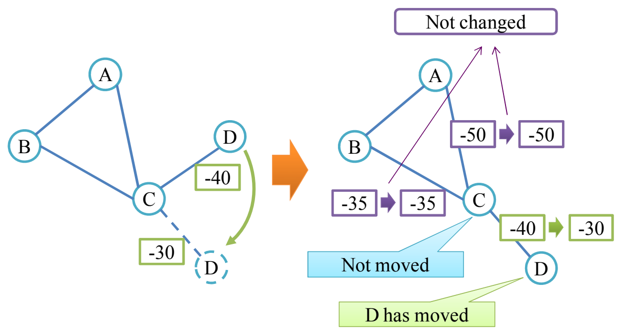


Figure 6. Example changes in ZigBee topology

On the other hand, the working vehicle might be operating even when the network topology has not changed. In this case, the movement can be further estimated on the basis of RSSI. As shown in Figure 7, if node D has moved, then RSSI between nodes C and D changes. This change in RSSI between C and D cannot identify whether node C or D has moved (Figure 7: A). Accordingly, the proposed algorithm further uses RSSI data obtained by nodes C and D to other nodes such as B and A. In the case that node D has moved, RSSI from node C to other nodes does not change (Figure 7: B).



A) Only RSSI between C and D B) Combine information of other nodes

Figure 7. Estimating movement of a working vehicle by RSSI

C. *Analysis of activities of working vehicle*

An example of recording the activity (i.e., operating pattern) of a working vehicle at predetermined times is shown in Figure 8. In this analysis, the cell value is set to "1" when operation was observed, and to "0" when operation was not observed. For example, operation is monitored every five minutes, and 96 cells are made from 9:00 to 17:00. Starting time of the working vehicle is estimated as the time that the first operation was observed. Finishing time is estimated as the time that the operation was no longer observed. Activity time, namely, the difference between the starting time and closing time, is calculated by dividing the number of recorded "1"s by the number of cells in the working hours in field. Furthermore, when the operation pattern greatly changes, it is judged that the working vehicle has a problem or its work has changed.

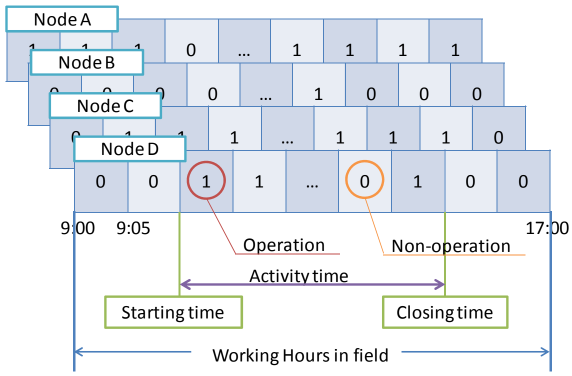


Figure 8. Operation pattern of working vehicles

VI. EXPERIMENT AND EVALUATION OF PROPOSED SYSTEM

A. *Outline of experiment*

The performance of the proposed ZigBee network system experimentally measured during tests performed from September 14 to 18, 2015. It was measured with respect to five "automatic guided vehicles" (AGVs) with the help of a construction company in Niigata prefecture Japan. ZigBee devices using XBee were installed in each AGV. The appearance of the system installed on an AGV (and driven by a mobile battery) is shown in Figure 9. Topology and RSSI data were acquired every 5 minutes from 7:30 to 18:30. Therefore, an activity pattern having 132 cells was created for each AGV.

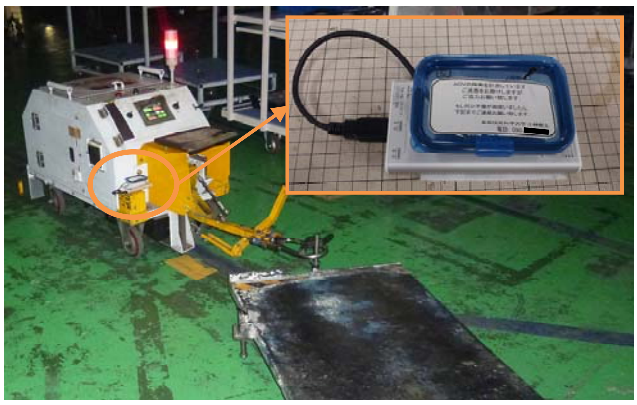


Figure 9. The proposed system attached to an experiment vehicle

B. *Verification of connectivity of ZigBee network*

Rates of undiscovered nodes by node discovery are listed in Table 1. These results confirm that the links are established with a probability of more than 95% on average. In other words, the proposed system is sufficiently available in an indoor environment. Further, each working vehicle was found to be working at the finishing time.

Table 1 Undiscovered rate of ZigBee nodes by discovery function

From \ To	AGV1	AGV2	AGV3	AGV4	AGV5
AGV1		0%	0%	0.30%	17.1%
AGV2	0.15%		0.30%	0.30%	13.8%
AGV3	0.15%	0.30%		0.30%	14.8%
AGV4	0.15%	0.15%	0.15%		10.8%
AGV5	11.8%	9.8%	10.0%	11.8%	

C. *Verification of experimental data*

Response times obtained from AGV4 to AGV1 on September 15th are shown in Figure 10. Hop counts were estimated by using the proposed method. As shown in this figure, in the time zone of 11:30 to 14:30, hop counts change more frequently than in the other time zones. In this manner, hop counts change during working hours. These results indicate that the proposed method can estimate the activity pattern of working vehicles.

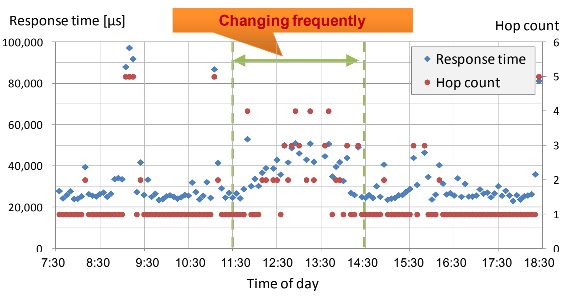


Figure 10. Response time obtained by AGV1 to AGV4

VII. Conclusions and Future Work

A system is proposed for monitoring the operating activities of working vehicles, regardless of whether they are operating indoor or outdoor. The proposed system determines the relative positional relationship between the working vehicle from a change in the ZigBee topology and RSSI. The topology is estimated by a combination of response-time estimation and node search (a standard function of ZigBee). It was found that the response time between adjacent devices is 30 ms or less. Based on these experimental results, an algorithm for estimating the patterns of activities of working vehicles was proposed. This algorithm was used for in an experiment on collecting topology data from AGVs. The results of the experiment indicate that the operating activities of each AGV differ according to working hours.

In the future, to grasp the activity of a working vehicle by creating an activity pattern, the proposed system will be evaluated experimentally. In addition, a function for visualizing the activity of working vehicles on a tablet will be implemented. This study was partly supported by SCAT.

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