Location Estimation of a Remotely Controlled Robot using an RDV-HOP Algorithm in Wireless Sensor Networks

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Abstract
In this study, an RDV-HOP algorithm that improves the DV-HOP algorithm is proposed to estimate the self-location of a remotely controlled robot and a simulation of this algorithm is performed by applying various indoor environments as its model. Regarding its performance, the number of sensor nodes that represents performance improvements is less than 20% as the effective distance is less than 40%. Also, as the effective distance is a range of 40~80%, it shows the largest decrease in location errors. Also, in the comparison of the results with the conventional DV-HOP algorithm, the proposed algorithm decreases the average absorption of 52.2% maximum and the distance error of 121.89% maximum.

Key words:
Wireless Sensor Network, Remotely Controlled Robot, DV-HOP, Estimative Distance, Sensor Node, Reference Node

1. Introduction

A remotely controlled robot is usually used in an environment that allows monitoring of external situations and carrying required works in a remote place using wire and wireless networks. In particular, a location based technology should be required to estimate the self-location of a robot for a user who controls a robot in a remote place. The location based technology recognizes physical and geographic information in robots. In location recognition devices, GPS is used in interior environments and infrared rays, ultrasonic waves, RF, and electronic compasses are usually used in exterior environments.

In the existing studies on the self-location recognition of a remotely controlled robot, a method that recognizes the location of a robot by accumulating some data including traveling distance, speed, and direction of a robot through inertial sensors and odometry information and a SLAM (Simultaneous Localization And Map building) algorithm that recognizes the location of a robot through recognizing specific objects around the robot using image information are used. In the method that uses inertial sensors, it has some errors in practical robot traveling even though the errors are corrected using the Kalman filter. It is due to the fact that such errors are accumulated according to the increase in traveling time because angular velocity and acceleration are obtained by summing sensor data. Whereas, the method that uses the SLAM algorithm has some drawbacks that lots of characteristic points are to be stored in a memory section for writing a map for recognizing the entire robot traveling paths and a high performance controller is required due to the comparative calculation for determining such characteristic points in practical traveling even though this method represents a high accuracy level [1]. Thus, it is necessary to conduct lots of studies on location recognition as such inertial sensors or SLAM algorithm are used to operate robots in wide areas for a long time.

According to the recent development of ubiquitous environments active studies on wireless sensor networks have been conducted. Thus, studies on the recognition of locations of sensor nodes, which can be used in wide areas for a long time, has been lively conducted [2-5]. The recognition is represented as a method that recognizes locations based on local area network communication by installing wireless communication modules to specific mobile devices, such as remotely controlled robots, cleaning robots, and guard robots, as sensor nodes and configuring reference nodes for recognizing their locations. This method can be classified into a range-based method that uses range information and a range-free method that does not use range information. As the range-based method determines the accuracy of locations according to the accuracy of distance measurement, it requires a high cost device for measuring such accurate distance. Thus, the use of this method to low price remotely controlled robots is a burden to its cost. Whereas, the range-free method operates a robot using an algorithm oriented method based on the information given to remotely controlled robots without any specific information including absolute distances or angles and makes possible to present a high accuracy level through a cooperative network with neighbor sensor nodes.

The algorithms that measure the locations of sensor nodes installed to robots are AOA (Angle Of Arrival), TOA (Time Of Arrival), TDOA (Time Difference Of Arrival), RSSI (Received Signal Strength Indication), and etc. AOA a direction detection location recognition system that calculates the directions of received signals using an

Manuscript received June 5, 2011
Manuscript revised June 20, 2011

array antenna [6]. TOA is a range-based location measurement system that calculates distances by measuring the absolute time between a beacon that transmits signals for measuring distances and a robot that receives the signals from the beacon [7,8]. TDOA is a method that measures beacon locations based on the time difference in the arrival of signals, which are received from several receivers [29,32]. In this method, it is difficult to recognize the absolute time of the signals transmitted from the beacon. Also, this method measures the individual arrival time of the signals received by the receivers, which are timely synchronized, from the beacon. RSSI is a method that measures the distance between a beacon and a remotely controlled robot using a characteristic that shows the difference in the strength of received radio waves according to distances [6]. A method that measures the strength of the signals received from a robot applies a comparative method that compares the signals with its probability distribution based on a statistical way.

Lots of studies on location measurement systems have been carried out based on these algorithms. APIT and APS are the representative algorithms used in such systems. APIT is a region-based location measurement algorithm in wireless sensor networks. This algorithm has location information even a very small part of them by GPS or other mechanisms among several sensor nodes and requires anchors that are fixed reference nodes with a high output transmitter. Based on the beacon signals transmitted by these anchors, a node will select three anchors in several anchors, which are recognized by this node. Then, this node determines a triangular region using these three anchors and investigates whether it is located inside the triangular region. As described above, APIT is an algorithm that measures locations by narrowing the region that is to be expected to include subject nodes [9]. APS is a location measurement system that combines a triangulation method used in GPS with a hop-by-hop information transmission method used in distance vector routing. That is, more than three land marks for measuring locations are searched through neighbor nodes using such a hop-by-hop method like GPS. Here, the land marks periodically transmit self-location information as reference nodes, which recognize its own locations. According to the hop-by-hop search reference in land marks, the algorithm can be classified into DV-HOP and DV-Distance algorithms [10,11].

In this study, an assumption that sensor nodes are randomly distributed in wide areas and a remotely controlled robot has a wireless communication module for recognizing its location in which the robot is operated through a single sensor node in the entire wireless network is used. In addition, the number of hops between the robot and the sensor node is determined based on one-hop distance calculated by using the reference nodes and that is used to describe the DV-HOP algorithm, which is used to measure the distance between the robot and the reference nodes. Then, an algorithm that recognizes the location of the robot using the strength of radio waves in the communication between the robot and other sensor nodes is proposed. In this study, as several wireless communication modules including remotely controlled robots or user terminals are required, the verification of this proposed algorithm will be performed through simulations instead of applying such devices to a practical robot.

2. DV-HOP algorithm in a remotely controlled robot

The DV-HOP algorithm was proposed by Dragos Niculescu and that consists of a reference node, which has already recognized its own location, a remotely controlled robot, which includes a wireless communication module, and a sensor node with a user terminal. This algorithm measures locations by combining a routing transmission method in a multi-hop method with a triangulation method under the situation in which the transmission range of the reference nodes cannot reach to all distributed sensor nodes. Here, a path configuration message is transmitted with a specific time phase for configuring its path and updates a path table by receiving the path configuration message from a sensor node or a remotely controlled robot. Then, the query message received from a user is transmitted to the remotely controlled robot in the path table and the data message received from the robot is transmitted to the user. The remotely controlled robot or sensor node transmits a path configuration message with a specific time phase and updates a path table by receiving path configuration messages from other sensor nodes. General data messages are transmitted to upper nodes according to the path table and the reference nodes finally receive these messages. That is, the reference nodes broadcast beacon signals, which include its location information, and the remotely controlled robot that receives the beacon signal transmits the information that has the minimum number of hops. Thus, each node can recognize the information of the smallest number of hops distanced from the reference nodes. Then, the reference nodes calculate an average one-hop distance using the distance information exchanged with other reference nodes and the information of the number of hops. The calculation of the one-hop distance can be performed using Eq. (2.1).

$$1\ hop\ distance_{RN_i} = \frac{\sum_{RN_{i,j} \in RN}^{n} distance(RN_i, RN_j)}{\sum_{RN_{i,j} \in RN}^{n} hopcount(RN_i, RN_j)} \qquad (2.1)$$

where RN is the reference node, $distance(RN_i, RN_j)$ is the distance from the reference node, RN_i to RN_j, and $hopcount(RN_i, RN_j)$ shows the minimum number of hops from RN_i to RN_j. Thus, the DV-HOP algorithm determines its own location by receiving the beacon and one-hop information transmitted by the sensor and reference nodes through converting such information into distances. In the measurement of the one-hop distance by the reference nodes, it means that the sum of the distances to all reference nodes, which receive beacons, is determined by dividing the sum by the sum of its corresponding number of hops. The measurement can be carried out by following three steps.

1. Calculating the minimum number of hops between the remotely controlled robot and the reference nodes.
2. Calculating the shortest hop-distance between nodes. Then, the distance between nodes is calculated.
3. Locations of the sensor nodes are measured using a triangulation method.

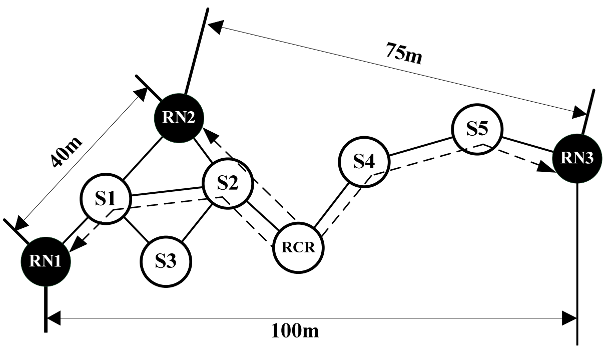


Fig. 2.1 DV-HOP algorithm for recognizing locations of the remotely controlled robot

For instance, Fig. 2.1 shows the DV-HOP algorithm for recognizing locations of the remotely controlled robot where *RN1, RN2,* and *RN3* represent the reference nodes, which have already recognized the distance between nodes, and *RCR* is a remotely controlled robot. The number of hops from the reference node *RN1* to the reference nodes *RN2* and *RN3* shows two hops, *RN1 → S1 → RN2*, and six hops, *RN1 → S1 → S2 → RCR → S4 → S5 → RN3*, respectively. Also, by applying Euclidian distance, the average distances between single hops in the nodes *RN1*, *RN2*, and *RN3* are determined as $\frac{(100+40)}{(6+2)} = 17.50m$, $\frac{(40+75)}{(2+5)} = 16.42m$, and $\frac{(75+100)}{(6+5)} = 15.90m$, respectively. The locations of the remotely controlled robot, *RCR*, to the reference nodes *RN1*, *RN2*, and *RN3* represent three hops, *RCR → S2 → S1 → RN1*, two hops, *RCR → S2 → RN2*, and three hops, *RCR → S4 → S5 → RN3*, respectively. As the DV-HOP algorithm performs calculations based on the distance of the closest node, the distance (1-Hop) between the nodes calculated in the reference node *RN2* is 16.42m. Thus, the distances of the remotely controlled robot *RCR* to the reference nodes *RN1*, *RN2*, and *RN3* are determined at 3 hops×16.42m, 2 hops×16.42m, and 3 hops×16.42m, respectively.

These hop distances are based on the presupposition that nodes in the network are uniformly distributed and there is an assumption that one-hop distances in which the distance between the anchor and the sensor node is divided by the number of hops are all the same. However, the routing path of the beacon may represent a detour path or a linear path according to the locations of sensor nodes. The sensor node that receives beacons through a detour path will represent more hops than the hops, which are to be practically determined for the distance to actual anchors. Also, the sensor node of the remotely controlled robot that receives beacons through a linear path will represent less hops than the hops, which are to be practically determined for the distance to actual anchors. Thus, in the use of the DV-HOP algorithm, the distribution of reference nodes is important. Also, the accurate measurement of the distance from the remotely controlled robot to the reference nodes in the triangulation method significantly affects the location recognition accuracy in the remotely controlled robot.

3. Proposed RDV-HOP algorithm

3.1 RDV-HOP algorithm

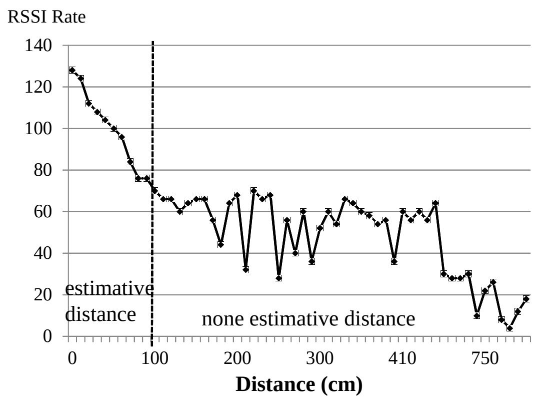


Fig. 3.1 RSSI measurement for wireless sensor modules

RSSI in wireless sensor networks is used to measure distances using the strength of radio waves in transmitting wireless data between the remotely controlled robot and user terminal nodes. In the measurement of RSSI, although the measured data can be varied according to the radiation pattern and performance of an antenna, it can measure the distance between nodes by obtaining the linear data in RSSI as nodes are close to each other, i.e., narrow distances between sensor nodes, as shown in Fig. 3.2.

Fig. 3.2 shows RSSI data according to the distance in wireless communication modules, which use a 2.4GHz chip antenna. The distance ranged from 0 to 1.0m maintains linear data, 78-130, and the distances after 1.0 and 4.5m represent 30-70 and below 30, respectively. In this study, RSSI data in the remotely controlled robot and user terminals is measured. Then, as shown in Fig. 3.2, an RDP-HOP algorithm that recognizes locations of the remotely controlled robot by dividing the measured data into an estimative distance (ED), which can measure the distance within 1.0m, and non-estimative distance (NED), which can measure the distance after 1.0m, is proposed. This algorithm recognizes locations by applying the distances measured by using RSSI as the remotely controlled robot and user terminals are located within estimative distances. Whereas, as the remotely controlled robot and user terminals are located in non-estimative distances this algorithm performs data communication only and applies the previously mentioned DV-HOP algorithm for recognizing locations.

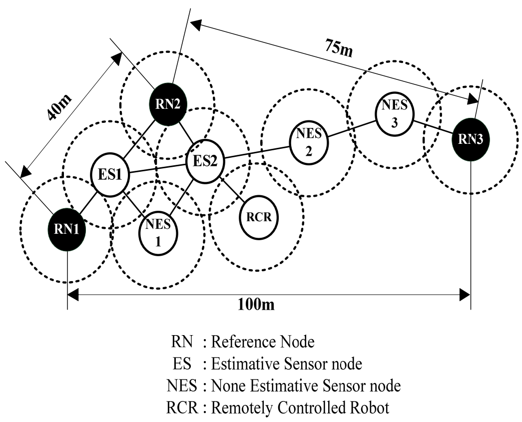
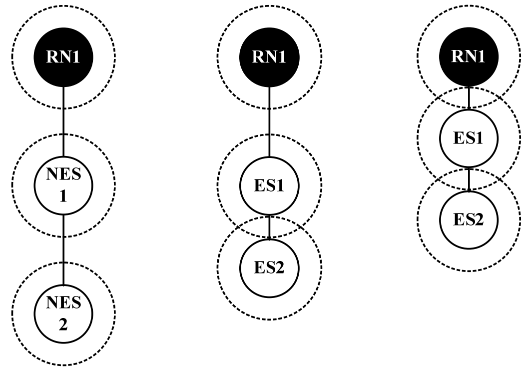


Fig. 3.3 RDV-HOP algorithm using RSSI information

Fig. 3.3 illustrates the RDV-HOP algorithm based on RSSI information in the DV-HOP algorithm. The dotted circles represent the RSSI estimative distances in sensor nodes (distance-measurable regions). *ES1* and *ES2* show the nodes that can recognize locations using RSSI as the dotted circles are contacted with other terminals, and *NES1*, *NES2*, and *NES3* represent the nodes that recognize locations by applying the hop-by-hop distance employed in the DV-HOP algorithm as the dotted circles are not contacted with other terminals. *RCR* is the remotely controlled robot. As the paths from *RN1* and *RN2* are determined as *RN1* → *ES1* → *ES2* → *RCR* and *RN2* → *ES2* → *RCR*, respectively, the robot recognizes locations based on RSSI data because these paths are located in estimative distances. The path from *RN3* is determined as *RN3* → *NES2* → *NES3* → *RCR*. Then, locations can be recognized by calculating one-hop distance in the DV-HOP algorithm because these are located in non-estimative distances.



(a) Applying DV-HOP (b) 1 hop+ED (c) 0 hop+ED

Fig. 3.4 Distance inference between sensor nodes

A method that recognizes locations of the reference and remotely controlled robot is presented in Fig. 3.4. Fig. 3.4 (a) represents a case in which the estimative distance between the remotely controlled robot and the sensor nodes is far more than the distances between sensor nodes. Here, the distances between sensor nodes can be calculated using the one-hop distance measured by using the DV-HOP algorithm in which the distances to *NES1* and *NES2* represent one and two hops respectively. In Fig. 3.4 (b), as *ES1* and *ES2* are located within estimative distances, *RN1* can be applied to the reference nodes and user terminal *RN1* through applying the one-hop distance measured by using the DV-HOP algorithm and the distance measured by using RSSI is applied to the distance between *ES1* and *ES2* where the distances to *ES1* and *ES2* represent one-hop and one-hop + RSSI distance respectively. In addition, Fig. 3.4 (c) applies estimative distances because *ES1* and *ES2* are located within estimative distances.

3.2 Description of the RDV-HOP algorithm

Size / Packet	8 bit	8 bit	8 bit
Header	Source ID	Destination ID	Command
	Type	Header Length	Header Checksum
User Data	User Data Length	Hop Count	Estimative Distance
	Node ID List[0]	Node ID List[0]	Node ID List[0]
	. . .	Node ID List[n-1]	Data Checksum

Fig. 3.5 Packet Structure for the path set-up and RSSI data transmission in the RDV-HOP algorithm

For transmitting and receiving data in wireless sensor networks the generation of the data transmission path can be performed by transmitting IDs in sensor nodes to the hop-by-hop routing reference nodes. Each node requires path configuration and data transmission packets for calculating the number of hops between nodes and transmitting distance data. For implementing it, the reference nodes transmit path configuration messages with a specific time phase and update a path table by receiving the path configuration messages from sensor nodes. In addition, the reference nodes receive query messages from users and transmit these messages to a proper sensor node in the path table. The sensor nodes transmit the path configuration messages with a specific time phase and update the path table by receiving the path configuration messages from the next node [15].

Table 3.1 Classified definitions of the functions of reference nodes and sensor nodes

Field	Size (bit)	Description
Source ID	8	It represents unique IDs in sensor nodes themselves.
Destination ID	8	It represents unique IDs in destination nodes and generally means the unique ID of a cluster master.
Command	8	It shows commands for transmitting data including path configuration and location recognition.
Type	8	It shows the function of nodes, type of sensors, and number of packet frames. That is, the numbers 1 and 2 in the upper nibble show the reference and sensor nodes, respectively, and the lower nibble represents the number of packet frames.
Length	8	It shows a length of the entire packets and has the sum of the sizes in each field item.
Hop Count	8	It represents the number of hops from sensor nodes to reference nodes. The hop shows an increase of one hop as it passes a node.
Estimative Distance	8	If the neighbor nodes are located in estimative distances, they show estimative distance data. Otherwise, they have a value of 0.
Node ID List	Max 10	It has an ID that represents the minimum number of hops from sensor nodes to reference nodes.

Fig. 3.5 shows a packet structure for configuring paths and transmitting estimative distance data in the RDV-HOP. Packets are divided into Header and User Data sections. The Header consists of commands for recognizing its own ID (Source ID), destination ID of target destinations (Destination ID), path configuration, and locations of a remotely controlled robot, types for determining whether the Header itself is a reference node or a sensor node, and check sums of the length and header for the entire packets. Also, user data consists of the number of hops (Hop Count), estimative distances (Estimative Distance), node ID lists (Node ID List), and etc. Although node IDs are determined up to a maximum of n, in this study the IDs are limited to maximum 10 IDs. In the case of more than 10 IDs, these IDs are recognized as unknown nodes. Table 3.1 describes the individual fields in the packets presented in Fig. 3.5.

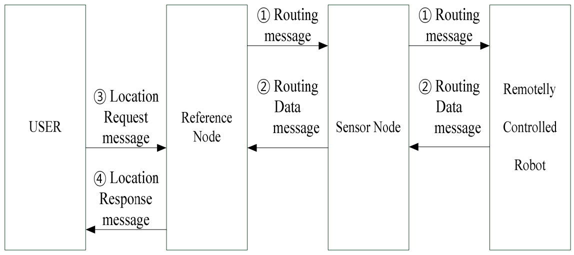


Fig. 3.6 Message Flow diagram of the location recognition in the RDV-HOP algorithm

Fig. 3.6 shows the sequence of message transmission for recognizing locations of the remotely controlled robot in the RDV-HOP algorithm. The reference nodes transmit path configuration messages to the remotely controlled robot and sensor nodes with a specific time phase in order to determine its path, and then the nodes that receive these messages update their own path table and transmit their path data to the reference nodes. The reference nodes receive the paths of all sensor nodes and update their path tables. As users transmit query messages, which require locations of the remotely controlled robot in a specific time, to the all reference nodes, the reference nodes transmit the information including the path lists to the robot, one-hop distance, number of hops, and estimative distances between paths. The users who receive such information from the reference nodes calculate the location of the robot using the one-hop distance of the reference node, which has the minimum number of hops, and the estimative distance between paths.

Through the process ① as shown in Fig. 3.6, the reference nodes transmit routing messages to the remotely controlled robot and sensor nodes. Then, the robot and sensor nodes that receive these messages generate a path as follows:

1) The reference nodes transmit *Routing messages* for configuring paths to sensor nodes.
2) As the remotely controlled robot that receives the *Routing messages* stores the IDs of the reference nodes or sensor nodes, which transit such messages.
3) The remotely controlled robot generates the paths of its neighbor nodes and adds the paths in the *Routing Data message* packet.
4) As all neighbor nodes are to be added to the *Routing Data messages*, Step 3) is to be repeated.
5) As the *Routing Data messages* are to be transmitted to neighbor nodes, the path table of the remotely controlled robot is updated.

Through the process ② as shown in Fig. 3.6, as the reference nodes receive the *Routing Data messages* from the remotely controlled robot or sensor nodes, the process for generating a path is as follows:

1) A single path data is selected from the *Routing Data messages.*

2) If the selected path is not included in the existing path table, this new table is to be stored in the path table.
3) Until the path data is presented to the *Routing Data messages*, Steps 1) and 2) are to be repeated.

Through the process ③ as shown in Fig. 3.6, as the reference nodes receive the *Location Request messages* from users who want to recognize locations of the remotely controlled robot, the process for transmitting the information of the locations of the robot is as follows. Fig. 3.10 shows the pseudo code for this process.
1) The IDs of the reference nodes and remotely controlled robot are to be stored.
2) The distances to the remotely controlled robot and the number of hops are to be initialized.
3) Step 4) is to be repeated while moving to the reference nodes after searching the parent node of the remotely controlled robot.
4) If the distance between the parent node of the remotely controlled robot and the present node is located within the estimative distance, the distance will be accumulated to the estimative distance and one hop will be reduced.
5) As the travel following the path reaches to the reference nodes, as noted in Eq. (3.2), the distance of the remotely controlled robot is stored to the response message, and then the response message is transmitted to users.

$$distance_{RN_i}[SN_j] = hopcnt_{RN_i}[SN_j] \times onehopdist[RN_i] + rssidist_{RN_i}[SN_j] \tag{3.2}$$

Through the process ④ as shown in Fig. 3.6, as users receive the *Location Response messages* from the reference nodes, the process for recognizing locations of the remotely controlled robot is as follows:
1) If the distance information of the received *Location Response messages* is smaller than the previously calculated distance information, the existing reference node information will be deleted, and then the new reference node information is stored.

4. Performance analysis of the RDV-HOP algorithm

Table 6.4 Simulation parameters used in this experiment

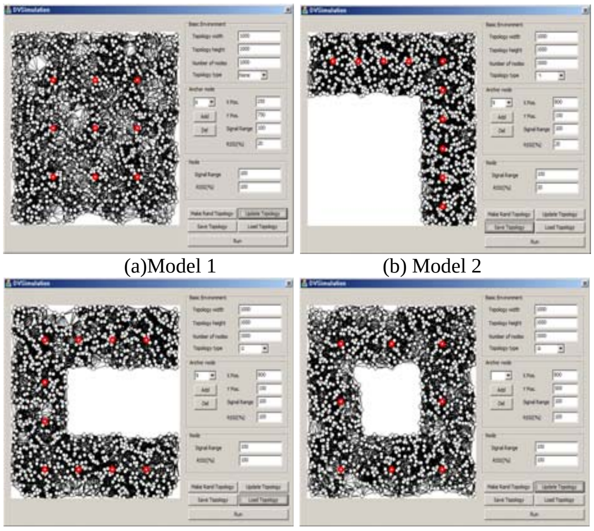
Condition	Configured Size
Network Size (Field Size)	1000 × 1000
Network Topology	Four models by configuring arbitrary obstacles
Number of reference nodes	10
Number of remotely controlled robots and general sensor nodes	1000
Data transmission range	100m
RSSI estimative distance range	Increased by 20% within data transmission ranges
Distribution of sensor nodes	Random distribution
Topology	Mesh topology

For evaluating the performance of the RDV-HOP algorithm, large traveling areas, such as large scale exhibition centers, airports, underground shopping centers, and etc., and wireless network systems in these areas are required. Also, remotely controlled robots that include lots of sensor nodes and wireless communication modules are randomly distributed in these areas. However, as it is difficult to implement these practical situations, the performance of the location recognition in a remotely controlled robot will be performed through simulations.

The simulation parameters in the wireless sensor network system used in this experiment are presented in Table 6.4. The network field size was determined as 1000 × 1000. Also, one field is assumed as 1m. The network structure was designed as four different models by considering external features employed in large scale exhibition centers, grounds, and underground shopping centers. Fig. 6.7 (a) shows the first model that has no obstacles in network fields. Figs. 6.7 (b), (c), and (d) represent the second, third, and fourth models. In addition, the reference nodes in the entire network were determined as 10 and sensor nodes were limited to 1000 in order to recognize locations of the robot through the communication of sensor nodes as its maximum. The transmission range of the reference and sensor nodes was determined as 100m, which is the maximum performance in commercial wireless communication modules. Also, the strength of radio waves in each node was determined to the same level and the battery consumption was not considered. In each network structure model, the reference nodes were distributed in the locations that have specific distances and the general sensor nodes and the sensor nodes installed at the remotely controlled robots were randomly distributed. The topology employed in this experiment was a mesh topology.

The simulation was carried out using the MFC of Microsoft Visual Studio. In the simulation, the RSSI estimative distance that can measure distances in sensor nodes was increased by 20% in order to obtain the average number of hops in sensor nodes, the number of hops that have reduced distances in the location recognition, and the location error distance data.

The network models applied to the simulation are presented in Figs. 6.7, 6.8, 6.9, and 6.10. Also, it was assumed that the remotely controlled robots and general sensor nodes are randomly distributed in a space with 1000 × 1000 fields.



(a)Model 1 (b) Model 2

(c)Model 3 (d) Model 4

Fig 6.7 Network application models

Table 6.5 One-hop distance for each applied network model

Model	Model 1	Model 2	Model 3	Model 4
1-hop distance	81.067	81.30	73.12	76.66

Table 6.5 shows one-hop distance for each network application model in the application of the DV-HOP algorithm. The first and second application models represent the one-hop distance of about 81m that is longer than that of the third and fourth models, about 73m and 77m, respectively. It shows that the remotely controlled robots and sensor nodes in the first and second models are largely distributed. Thus, the distances in the second model between the remotely controlled robots and general sensor nodes are most largely distributed and most close to the third model.

5. Results and analyses

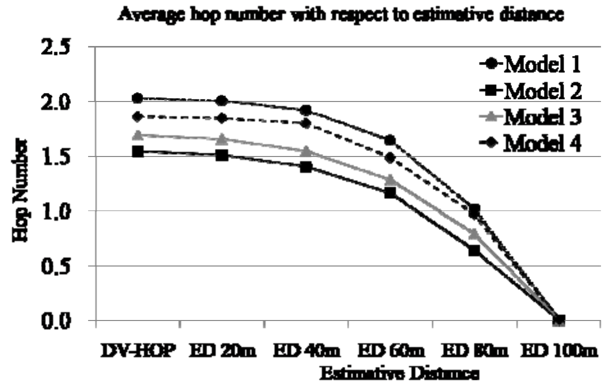


Fig. 6.8 Number of average hops for estimative distances

Fig. 6.8 shows the average number of hops from the sensor nodes ranged within 100m to the reference nodes as the estimative distances between the remotely controlled robots and sensor nodes are extended to a scale of 20m. As the application of the DV-HOP algorithm, the first model has the highest average number of hops because the model represents the longest distance between sensor nodes. As the second model has the shortest distance, the second model represents the lowest average number of hops. The reason that the average number of hops are decreased as the RDV-HOP algorithm is applied compared to the of the application of the DV-HOP algorithm means that there are many nodes, which apply RSSI estimative distances instead of applying hop distances for recognizing locations of the remotely controlled robots. As the estimative distance in the RDV-HOP algorithm is determined as 100m, all network application models represent 0 average hops. In addition, the estimative distances between 40m and 80m show the best performance. It is due to the fact that the largest number of nodes represents the distances between 40m and 80m in the distribution of the remotely controlled robots and general sensor nodes.

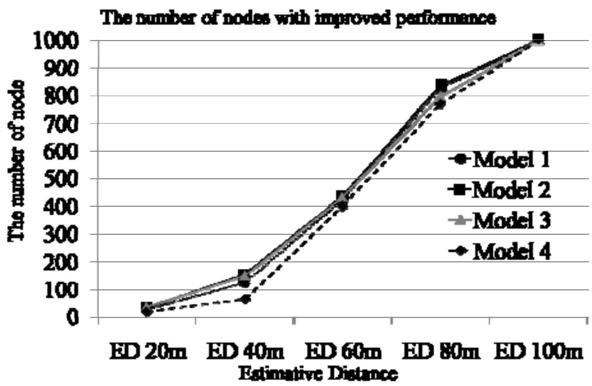


Fig. 6.9 Number of nodes in improved performance

Fig. 6.9 shows the number of performance improved nodes. It represents the number of sensor nodes that recognizes locations of the remotely controlled robots by applying estimative distances instead of using the one-hop distance in the DV-HOP algorithm. As the estimative distance is determined as 20m in all network application models, the number of sensor nodes is not many because the distances between the remotely controlled robots and most of sensor nodes represent larger distributions than the range of 20m. However, in the case of the distances ranged between 40m and 80m, it shows the best performance because most of distances between sensor nodes are located in this area.

Fig. 6.10 shows the errors between the real and measured locations in the applications of the DV-HOP and RDV-HOP algorithms in each network application model. In the case of the application of the DV-HOP algorithm only, the first model shows the largest errors and the third model represents the smallest errors. In addition, in the case of the application of the RDV-HOP algorithm, the estimative distances between 40m and 80m showed the best performance. Although the error was 0 in the case that has the estimative distance of 100m, it has no meaning because it is not possible in practical applications.

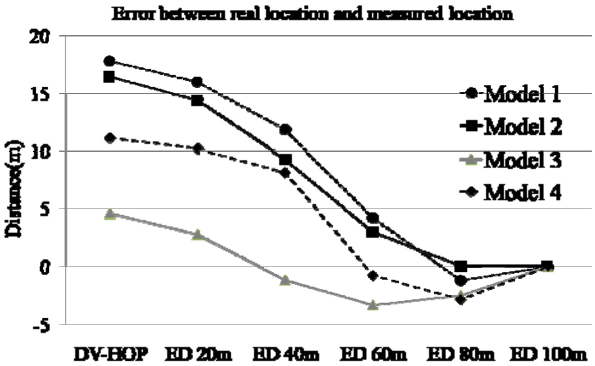


Fig. 6.10 Errors between the real and measured locations

Table 6.6 Performance of the RDV-HOP algorithm (average hop)
(unit: %)

Model	ED20m	ED40m	ED60m	ED80m	ED100m
Model 1	1.23	5.56	19.13	49.83	100.00
Model 2	2.14	8.64	24.29	58.25	100.00
Model 3	2.07	8.58	23.91	53.02	100.00
Model 4	0.70	3.28	20.16	47.69	100.00

Table 6.7Performance of the RDV-HOP algorithm (number of nodes)
(unit: %)

Model	ED20m	ED40m	ED60m	ED80m	ED100m
Model 1	2.7	12.6	42.5	82.6	100
Model 2	3.4	15.4	43.5	83.7	100
Model 3	3.5	15.1	43.2	79.7	100
Model 4	1.7	6.5	40.1	77	100

Table 6.8 Performance of the RDV-HOP algorithm (distance error)
(unit: %)

Model	ED20m	ED40m	ED60m	ED80m	ED100m
Model 1	10.04	33.50	76.41	106.87	100.00
Model 2	12.38	43.64	82.01	99.76	100.00
Model 3	39.81	125.42	173.19	155.18	100.00
Model 4	8.13	26.74	106.88	125.75	100.00

The performance improvement rates in the RDV-HOP algorithm by comparing it with the DV-HOP algorithm are presented in Tables 6.6, 6.7, and 6.8. Tables 6.6, 6.7, and 6.8 represent the performance improvements rates with respect to the average number of hops, number of nodes, and average distance errors, respectively. Regarding the performance improvement rates presented in Table 6.6 for the average number of hops and Table 6.7 for the number of nodes, the second network application model shows the best performance. Also, the third model shows the best performance improvement rate for the average distance errors as noted in Table 6.8 where the estimative distance of 60m shows the best performance, 173.19%.

Based on the results of this experiment for recognizing locations of the remotely controlled robots in large scale areas, the performances of the DV-HOP algorithm that recognizes the locations using wireless sensor networks and the RDV-HOP algorithm that recognizes the locations by measuring the strength of radio waves between sensor nodes were verified. Then, it was verified that the location recognition errors were decreased according to the increase in estimative distances. In addition, the errors were most largely decreased as the transmission distances in sensor nodes were determined between 40m to 80m.

6. Conclusion

In this study, the RDV-HOP algorithm that applies the RSSI information in sensor nodes in addition to the DV-HOP algorithm that measures one-hop distance for estimating self-location of a remotely controlled robot and calculates the number of hops in sensor nodes was proposed. The number of sensor nodes that represents performance improvements as the estimative distances are determined less than 40% was less than 20%. Also, the distance errors were most largely decreased as the estimative distances were determined as 40-80%. In the comparison of this algorithm with the conventional DV-HOP algorithm, the average number of hops and the distance errors were decreased by 52.2% and 121.89% maximum, respectively. Therefore, it is considered that the RDV-HOP algorithm proposed in this study can be applied to all fields that use wireless sensor networks in ubiquitous environments.

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