

센서 네트워크를 활용한 모바일 로봇의 Path Planning

Path Planning of a Mobile Robot Using RF Strength in Sensor Networks

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This paper proposes a novel path finding approach of a mobile robot using RF strength in sensor network. In the experiments based on the proposed method, a mobile robot attempts to find its location, heading direction and the shortest path in the indoor environment. The experimental system consisting of mesh network shares node data and send them to base station. The triangulation and the proposed Grid method calculate the location and heading angle of the robot. In addition, the robot finds the shortest path by using the base station attached on it to receive data of environment around each node. Kalman filter reduces the straight line error when the robot estimates the strength of received signal. The experimental results show the effectiveness of the proposed algorithm.

Key Words: RF Strength (RF 강도), Sensor Network (센서네트워크), Shortest Path Finding (최단경로탐색), Triangulation Method (삼각 측량법), Grid Method (그리드 측량법)

기호설명

θ = the first angle between the heading direction of the robot and the x axis of the coordinate

θ' = the second angle between the heading direction of the robot and the x axis of the coordinate

(a, b), (c, d) : coordinates of anchor nodes

x, y : real time coordinates of robot

r1, r2 : a radius of each circle

d1, d2 : a distance between two coordinates

1. Introduction

The development of mobile robot technologies combined with sensor networks has become one of the most prominent technological driving forces. The use of these robots working with sensor networks embedded in the environment has broadened conventional industries and has become the basis of new industries. Sensor nodes act as signposts for the robot to follow, thus obviating the need for a map of localization on the part of the robot. These devices are being incorporated with industries such as the semiconductor, communications, MEMS, etc. industries enabling better production. Besides, in order for a WSN (Wireless Sensor Network) to provide meaningful information regarding its

environment, the node positions must be well localized by being fully connected. Mobile robots provide a dynamic capability with a network of sensor nodes with greater computational resources, an augmented sensor suite, and additional degrees of freedom afforded by mobility. The objective of this study, described in this paper, is to improve the information acquisition ability of a mobile robot for use in its navigation by using a sensor network. This network consists of several elements such as an Active Badge, Active Bat, Mica series, RF tag, H-mote, and ZigbeX to collect fast and accurate information on the environment. There are some research efforts on sensor network systems for localization using different kinds of sensors.¹⁻³ Their localization errors have a range from 1 to 3 m. To reduce the localization error, the approximate position of the mobile robot and its surround information has been used by Batalin et al.⁴ The sensor network needs subsidiary techniques for collecting accurate information during particular circumstances such as fire and other dynamic situations. In the situation described in Mobile robot navigation using a sensor network,⁴ to find a fire source, the mobile robot scatters inexpensive sensor nodes and gets environmental information such as temperature and humidity, etc. The acquired data on the environment in modified form is transmitted to fire-fighters to enhance their fire fighting performance with less damage. By using static and (or) dynamic mote sensors, it is possible to prevent some accidents such as fire, gas leakage, etc. In order to complete the users' specified tasks, knowledge on the pose of mobile robots is one of the fundamental requirements while the robots are moving in any environment. There have been several papers concerning the localization of mobile robots equipped with sensors such as vision systems, mote systems, IR sensors, ultrasonic sensors, and laser and sensor networks.⁵⁻⁹ However, such systems are rarely applicable in the real world because of the complex process for reducing errors of in each of the coordinates and the high price.

In this study, we considered an inexpensive sensor network with cheap sensor nodes to find the path of a mobile robot. The transmitted information data on various environments is used for a robot in a network to detect its own position using a RSSI (Received Signal Strength Indicator) to go to destination using the shortest

path. To know the localization of a mobile robot using a sensor mote, the robot has to know an accurate RSSI value from anchor nodes. Based on the proposed method, the location of a robot is estimated by comparing the measured data with the reserved reference data, the RSSI values for each node.

2. Sensor Network

Mote modules consist of 3 kinds of sensor network routers such as the star, cluster, and mesh. The mesh router transmits all of the data of each node to the base node through RF communication. It constructs an ad-hoc route, in the case of a system malfunction, by duplex communication between the sensor nodes or based node and sensor node. Motes are designed to transmit information about the environment in real-time. In the case of an emergency, a robot should move to a destination in the shortest path to solve the problem.

Table 1 Measurement of distance using signal strength

Distance (cm)	Average strength of each node			
	no.1	no.2	no.3	no.4
10	218	229	233	229
20	226	229	235	231
30	228	226	235	227
40	231	230	234	229
50	230	231	234	231
60	235	229	237	231
70	235	233	239	234
80	234	233	243	239
90	249	236	239	239
100	246	246	249	246

Table 1 shows the measurement of distances between motes using signal strength. The data in Table 1 is a part of DB which is the collection of all RSSI values of 4 directions measured by the interval of 10cm from the coordinates of each node. After regulating the power parameter for the minimum value of the RF signal strength, we recorded the measurement of distance

through the signal strength. For controlling the RF signal strength, we modified the NesC program in TinyOS, an event-driven operating system for sensor networks. The TOS component transmits the measured strength of the signal to CPU and the CntToLedsAndRfm component transmits it to the TOS component.

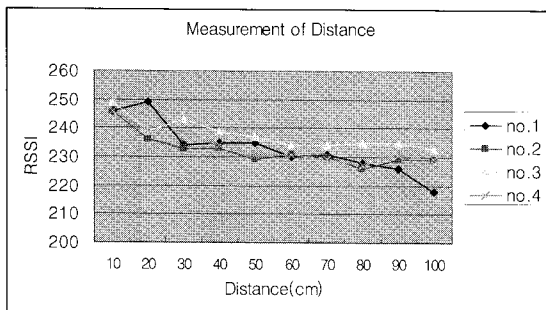


Fig. 1 Features of the RSSI

When a mobile robot is in a detectable range, it can estimate the distance according to the signal strength value indicated in Table 1. Fig. 1 shows features of the RSSI depending on the distances. We suggest finding the real coordinates using the average strength of the RF signal for each node as shown in Table 1. Actually, it is difficult because strength is not a gap yet, as shown in Fig. 1. We have considered that the robot is acquiring the real-time RSSI data from 4 anchor nodes and is located confronting the two directions of each node. The acquired RSSI data from each node is translated into a position coordinates of the robot by being compared with the reference RSSI DB. When the robot gets more than 3 position coordinates, the average position of them is updated as a new position of the mobile robot. This DB is constructed from over fifty times of experiments for 4 directions of each node. Fig. 1 shows the different strength per node. Since the experimental results are subject to the environment or noise by interference, there are different features for each node. We designed the arrangement of nodes as shown in Fig. 2 and controlled the signal strength of each node by minimizing the RSSI values. Based on the data, the robot calculates the distance between two coordinates for finding a heading. A robot knows its own coordinates while moving in a sensor network.

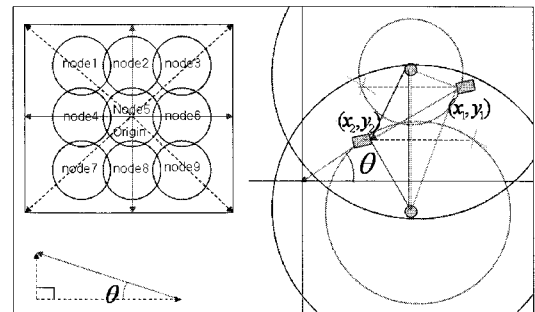


Fig. 2 Finding the heading by the vector angle's gap

3. Movement of the Mobile Robot

3.1 Heading of the robot

The robot communicates with nodes in the network locally, and makes navigation decisions based on which node it is near.

The mobile robot decides its movement according to the following procedure: The robot

- Measures the exact distance through the signal strength (RSSI).
- Calculates its own coordinates in the strength range among the nodes.
- Moves based on the measured distance.
- Calculates the moving distance by using two coordinates.
- Estimates the real coordinates of itself by using distance.
- Decides the vector direction from the angle (θ) for the origin.
- Decides the vector direction (heading) from the angle (θ') for the origin.
- Moves to the destination.

Fig. 3 represents the coordinates calculation process of a mobile robot using a comparison and triangulation method as shown in the flowchart. Figure 2 and 4 show how to decide the heading direction of the mobile robot. The right part of Fig. 2 represents the distance between two nodes according to the coordinates of the robot where θ is the angle between the heading direction of the robot and the x axis of the coordinate. After controlling the angle θ , the robot decides to move to the next position. Equations (6) and (7) describe the distances in the x and y axes and θ , respectively.

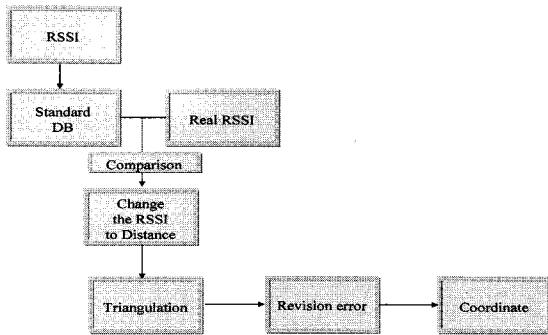


Fig. 3 Flowchart of the coordinate measurement using RSSI

$$(x-a)^2 + (y-b)^2 = r_1^2 \quad (1)$$

$$(x-c)^2 + (y-d)^2 = r_2^2 \quad (2)$$

$$(1+a^2)x^2 + (-2a+2a'(b'-b))x + (a^2 + (b'-b)^2 - r_1^2) = Ax^2 + Bx + C = 0 \quad (3)$$

where,

$$a' = \frac{-(a-c)}{(b-d)}$$

$$b' = -\frac{(r_1^2 - r_2^2) - (a^2 - c^2) - (b^2 - d^2)}{2(b-d)}$$

$$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (4)$$

$$y = \frac{-(a-c)x}{(b-d)} - \frac{(r_1^2 - r_2^2) - (a^2 - c^2) - (b^2 - d^2)}{2(b-d)} \quad (5)$$

$$d_1 = |a-c|, \quad d_2 = |b-d| \quad (6)$$

$$\theta = \arctan \frac{d_2}{d_1} \quad (7)$$

The heading of the robot is determined by using the angle θ of the first coordinate and the angle θ' of the second coordinate under the assumption that the goal node is known. We can calculate the coordinates by using Eq. (1) and Eq. (2). The first angle θ and the second angle

θ' are calculated by Eq. (6) and Eq. (7). θ' decides the heading direction of the robot for the goal position. To find the coordinate, we use a triangulation method and get the strength from at least three nodes. In addition, we can obtain the exact data when comparing the DB with the measured strength values.

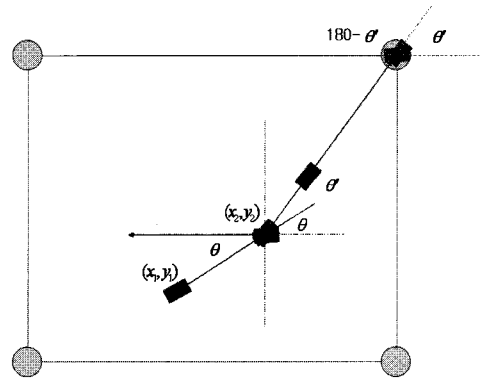


Fig. 4 Heading determination of a mobile robot

3.2 The algorithm for finding the shortest path

The shortest path is defined by sending a packet from the first-source to the destination with minimum cost. The shortest path presents a relatively lower link where the link values show a transmission capacity and traffic load.

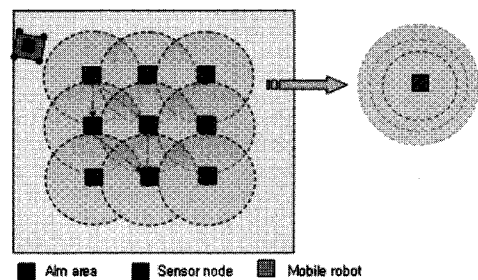


Fig. 5 Selection of an optimal route among multiple routes

Since the proposed method for the shortest path is very simple and easy to scale, a mobile robot can find a shortest path to its destination wherever it is. If more than two routes are created, as shown in Fig. 5, the patterns are constructed by the following steps:

a. Give the node number.

b1. If the number of the destination > the node number of the starting point, 1)compare the next nodes,

2)select the biggest node, 3)using this number, then, move to the destination

b2. If the number of the destination < the node number of the starting point, a robot moves to find the lowest node number.

4. Simulation and Experiments

We performed several experiments and simulations using the MATLAB software package under the following conditions. First, the robot did not have any errors during moving. Second, the environment was an open space without any obstacles. Third, we did not consider some other possible influences by other external environmental conditions such as air resistance, inertia, gravity, and so on in the simulation.

The simulation results are shown in Figs. 6-9. The robot starts to move toward a goal point in Fig. 6 where the number 1 is the start position and the first coordinate

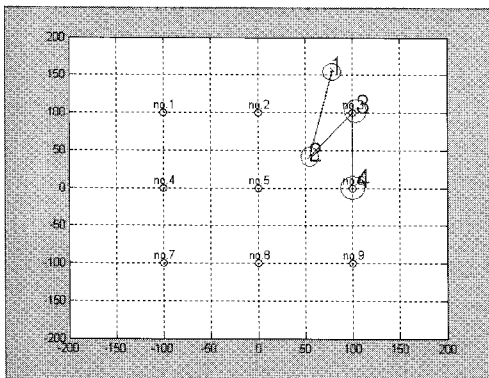


Fig. 6 The result of simulation 1

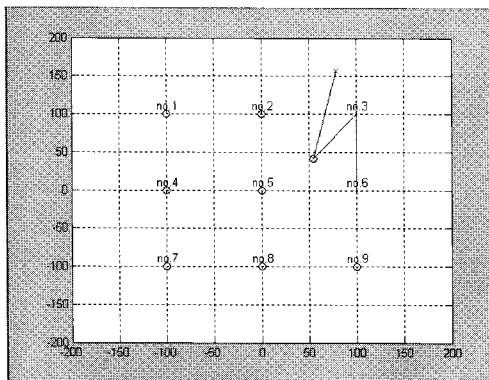


Fig. 7 The result of simulation 1-1

and number 2 is the second coordinate. Here, we can calculate θ and calculate θ' when the robot goes to 3 to determine the heading direction of the robot. For the current position of 3, the heading of the robot is toward the left of no.3. Finally, the robot calculates the angle to go to 4, the goal position that changes depending on the event node position. These figures show that the starting and goal position are random. As a result of the simulation, the robot follows an ideal path without error. The parameters of the experiment with 5 mote sensors are shown for the shortest path planning of the robot as below.

1. The radius of the mote: 1m ~ 1.5m
2. The dimension of the environment: 3 X 3m
3. The load: a base mote on the robot

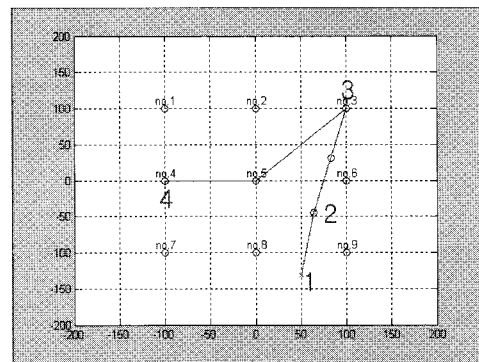


Fig. 8 The result of simulation 2

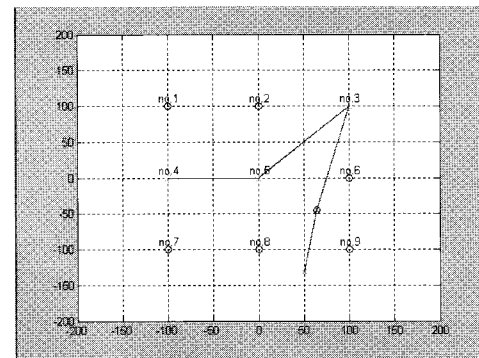


Fig. 9 The result of simulation 2-1

It is difficult to measure distance according to signal strength because of specific features of RF signal. So the signal strength is set to the lowest value (3dBm) to reduce the reflection ratio of the RF signal. In addition, the

distance according to the signal strength value makes the limited area (about 2m~3m). We can get the results shown in Table 1 which are applied to the experiment where any local sensor for finding a robot heading is used. The experimental apparatus consists of four mote sensors and one gateway mote. The distance information, through the signal strength of each node, is gathered through several experiments and the DB is used to reduce errors. The location of the robot is estimated by computing the distance from each node with the on-line data from the RSSI and the DB.

As shown in Table 2, the differences between the real coordinates and the measured coordinates are presented as errors. To measure its coordinates, a mobile robot needs to gather the RSSI values from each anchor node by a triangulation method. However, as shown in Table 2, the error between the gathered coordinates and the real coordinates is not negligible.

Table 2 Error from the real-coordinates

Real coordinate	Measured coordinate	Error
(0, 30)	(69, 69)	(69, 39)
(70, 80)	(71, 72.5)	(1, -7.5)
(130, 180)	(48, 90)	(-82, -90)

To compensate for the error, we propose a new way:

1. When the sum of the two data elements (data of one node is the two RSSI values) is below 200, a robot chooses the largest one. On the other hand, when the sum is over 200, it takes the average value of the two data elements.

2. If there is comparable data from one point (the coordinates of the point on the plane) at the same time, it takes the average value of the sum of the data.

3. If the error value is positive for each of x and y coordinates, the measured coordinates are subtracted from the average error. In the opposite case, its measured coordinates are added to the average error.

Table 3 presents the revised error results where the values of the coordinates of the revised errors are reduced in comparison with the previous results. Also table2 and table3 are the represented range of reduced error from sample data. Therefore it showed a better performance comparing with previous results. Fig. 10 shows the

experimental environment.

Table 4 represents the angular errors according to the real coordinates where θ and θ' are the angles for the first coordinates and the second coordinates with $x = 0$ and $y = 0$, respectively. The proposed method for revision shows the desirable results as shown in Table 4. However, in the case of θ' , the angle of the previous revision error is better than that after the revision error angle, because the proposed way of revising with the average error was applied to this system. Although the revised error angle is bigger than the previous one, the result is also a close value to the real coordinate angle.

Table 3 Revised errors

Real coordinate (cm)	Measured coordinate	Error	Revision coordinate	Revised error
(0, 30)	(69, 69)	(69, 39)	(6.5, 25)	(6.5, -5)
(70, 80)	(71, 72.5)	(1, -7.5)	(74.5, 72)	(4.5, -8)
(130, 180)	(48, 90)	(-82, -90)	(157.5, 154.5)	(27.5, -25.5)

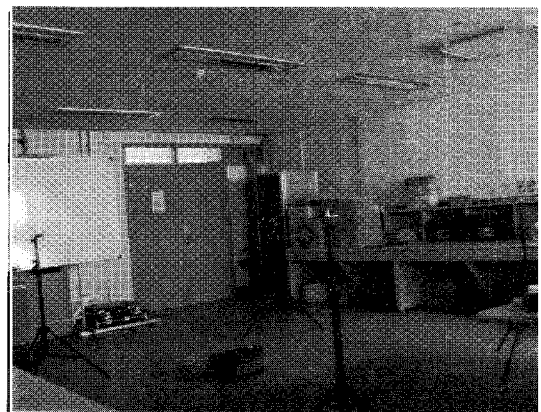


Fig. 10 Experimental environment

Table 4 Angular errors in the real coordinates

Angle	Real coordinate	Before coordinate revision	After coordinate revision	Before error revision	After error revision
θ	35.5°	60.3°	34.7°	-24.8°	0.8°
θ'	42.7°	44.7°	45.6°	-2°	-2.9°

For finding the heading direction of a robot, the system needs more accurate coordinates than the current

result. So, we propose another way. The grid method measures with the RSSI for each 10 cm on the coordinates of the experimental environment. This method gets only one coordinate using 4 nodes from the RSSI and α (constant) depending on the case. Fig. 11 represents the decision of the coordinate using the grid method.

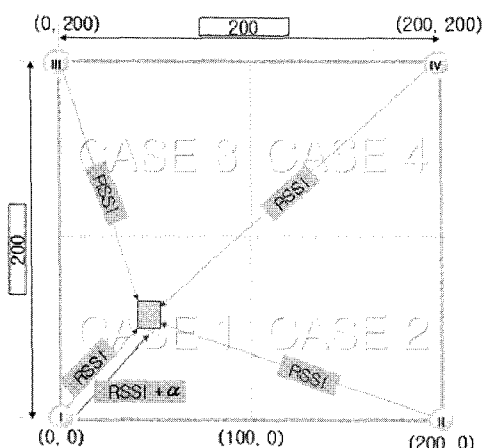


Fig. 11 Decision of the coordinate with the grid method

Based on the assumption that the coordinates of a mobile robot should be in accord with the DB coordinates, a mobile robot estimates the approximate coordinates to calculate the angle several times when moving. A robot updates the coordinates to enhance accuracy. In addition, a robot calculates the accurate heading angle to move to a destination by using shortest path rules. Table 5 shows the results of the grid method.

Fig. 12 shows the process of calculating the coordinates of the robot. In this figure, window 1 represents the measuring coordinates of the robot. This process compares the DB with the real RSSI values resulting in the revised coordinates. Window 2 prints the received data: the strength and node number. In addition, window 3 shows the strength at each node.

Finally, when a mobile robot moves in a straight direction, it uses a Kalman filter to go accurately to the destination as shown in Fig. 13. In this figure, the red, yellow, and green lines are the reference, the measured encoder, and the Kalman filter application, respectively. As a result of the experiment, when the process applies the Kalman filter, the error is close to zero. In the

experiment, the Kalman filter is applied to reduce the error for a straight line path. The state equations of Kalman filter for this application are the basic equations by D. Simon.¹⁴ The implementation of the real application is based on a Pioneer II as shown in Fig. 10. However, it cannot be used in the case of RF communication which is subject to noise.

Table 5 Results of the grid method

Sequential movement	Coordinates	Angle
By the revised triangulation	(6.5, 25) → (74.5, 72)	34.7°
By grid method	(74.5, 72) → (130, 110)	34.4°
Toward a destination	(130, 110) → (200, 200)	52.1°

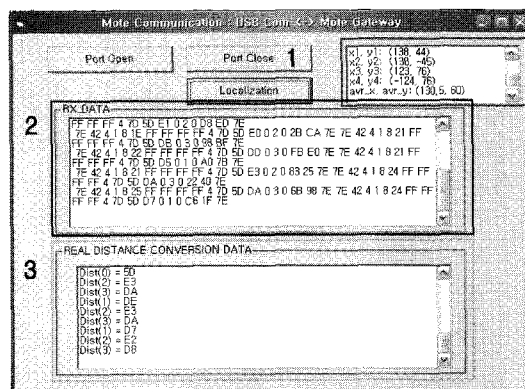


Fig. 12 Data processing and coordinates

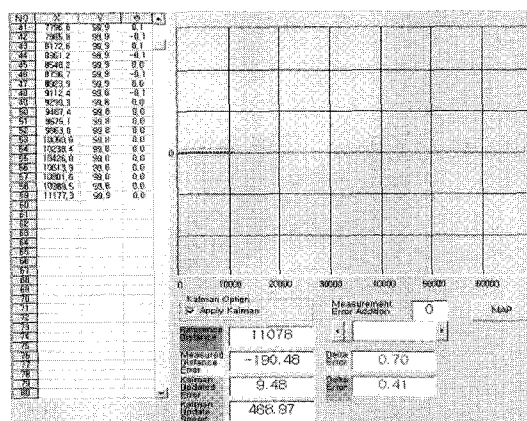


Fig. 13 The application of the Kalman filter

5. Conclusions

Localization is one of the most important parts of path finding of a mobile robot based on a sensor network. The proposed methods for location of the mobile robot are a triangulation and a grid method. When the mobile robot moves several times for reducing error and if the robot's coordinates accord with a grid DB, it has accurate coordinates by using an update. To avoid repetitive movement of a mobile robot for finding its coordinates in accord with the grid DB, we measure using a RSSI of the Grid DB for each value (below 10cm) of the coordinates of the experimental environment. The proposed method has some advantages over conventional approaches. First, when an event happens, it becomes available for any robot in the constructed environment. Second, controlling the algorithm is simple making it possible to be improved for a dynamic environment. Finally, we have presented the way of finding coordinates and the heading direction of a mobile robot using signal strength values without any local sensor.

In forthcoming research, we intend to improve results by combining our results and other algorithms. We are currently working on extending this approach to the problem of localizing nodes in R3. We envision that such a scheme would be useful for localizing and navigation of a robot among sensor motes.

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