A WSNs-based Approach and System for Mobile Robot Navigation

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1. Introduction

Mobile Robots are expected to do some routine or danger tasks automatically for human in many situations. Among the techniques related to the Mobile Robot, localization and navigation are the core techniques for Mobile Robots to realize true intelligence and complete autonomous moving.
J. J. Leonard and H. F. Durrant-Whyte summarized the problem of navigation into answering the following three questions (Leonard & Durrant-Whyte, 1991) : "where am I? ". "where am I going?" and "how should I get there". The first question lies to identifying the current location of the robot. The second and third questions are related to the capability of environment perceiving and path planning.
The navigation methods that are frequently used in Mobile Robots mainly include inertial navigation, visual navigation, sensor-based navigation and satellite navigation. Among the satellite navigation systems that are in use, the Global Positioning System (GPS) (Bock & Leppard, 1990) gives the most accurate information. But in some cases, the satellite system cannot or should not be used. To solve this problem, Wireless Sensor Networks (WSNs) was introduced into this area. In this chapter, a new navigation approach is proposed based on the localization function of Wireless Sensor Networks as a supplement to current navigation methods. The WSN can obtain various types of information about the environment such as the temperature, the humidity and the slope of the ground, and the proposed approach then use them to help the decision-making in navigation and path planning.
The chapter mainly includes 3 sections. The first section is about map building. A WSN-based method for environment modelling and map building was proposed. This method utilized the distributed environment information obtained by the WSN to establish the environment model and the grid map with multiple attributes. Simulative analysis showed that the environment model established by this method achieved good match result on the map. In section 2, the dynamic monitoring function of WSN was utilized to adapt the Mobile Robot to the requirement of navigation on the changing environment. An on-line path planning method based on WSNs was proposed. Using this planning method, the Mobile Robot could make trade-off between safety and efficiency through adjusting the parameters used in the algorithm. At last, an experimental WSN-based Mobile Robot

navigation system was designed and implemented to verifying the proposed navigation approach. The experimental result showed that the proposed approach could fit the application requirement of Mobile Robot navigation.

2. A WSNs-based Map Building Method for Mobile Robots

2.1 Introduction

Navigation is the key technology for mobile robot performing various tasks in a complex environment while mapping the surrounding environment and then planning the path on the basis of this map are core problems for autonomous move of the mobile robot. Map building has long been focused by researchers in corresponding fields. The process of mapping is actually a course for the mobile robot to perceive information in the surrounding environment. With the characters of quick deployments, convenience in being hidden and high quality in fault tolerance, WSN is especially fit for real-time information acquisition in unknown dynamic environment and therefore the prospects of WSN applied in mapping for mobile robot is extensive.

In a known environment, an artificial map of it is generally used for navigation as prior knowledge; in an environment without prior knowledge, the method of simultaneous localization and mapping (SLAM) are widely employed by researchers, through which on one hand they can mapping the working field of the mobile robot and on the other hand, they can localize the mobile robot (Davison & Kita, 2001) (Wang & Thorpe, 2002) (Sim & Roy, 2005); Sometimes it is relatively easier for a swarm of robots to perform a particular task than for a single robot to perform it. On the basis of this principle, multi-robot distribute map building is presented, in which the information about the local environment acquired by the robot itself are integrated with the information acquired by other robots to generate a global map. The typical feature of this method is its higher efficiency (Fenwick et al., 2002) (Burgard et al., 2000) (Yamauchi, 1999). The constructed map requires a proper representation to meet the need of path planning. There are three generally used methods for map representation: topological map, geometric feature map and gird-based map. Topological map builds a map from a global view of the studied environment; geometric feature map builds a map from the set of objects in the environment; grid-based map builds a map referring the details in the environment and it thereby is a comparably accurate method. Carnegie Mellon University (CMU) takes this kind of map representation method for its mars rover (Yahja, 1998).

In this section, the map building method based on WSNs are studied. To begin with, massive WSN nodes are deployed in the unknown environment, and then those WSN nodes transfer the distributable information acquired by them to the mobile robot. With this information, the studied environment is constructed and then the gird-based maps of this environment are also been constructed. By this way, after WSN nodes are deployed the global map can be quickly obtained, with which a global path planning can be performed to avoid possible blindness in local path planning.

2.2 Method description

The presented method can be described in the following five steps:

1. To deploy WSN nodes into the home range of the mobile robot.

2. The coordinates and sensor data of WSN nodes are transferred from WSN nodes to mobile robot. In the studied environment of our project, excessive high of the temperature, the humidity and the gradient will all obstruct the movement of the mobile robot and the factors of temperature, humidity and slope gradient are taken into account. However, the presented method is not limited to these three factors and other factors can be considered in the similar way according to the real situation.

3. With the sensor information of every WSN node, we can rebuild the estimated environment. The estimated environment is expressed in the form of temperature potential, humidity potential and gradient potential.

4. The estimated information in the environment can be binarized based on the constructed environment and predefined threshold and subsequently a grid-based map corresponding to some specific information.

Whether or not there is an obstacle in the map depends on the pre-defined threshold. In practice, the threshold is determined by the real property of the mobile robot. If the temperature at certain position is higher than the threshold of temperature, the position is thought to serve as an obsolete. Thus, a temperature map is obtained. Other maps such as humidity map and gradient map also can be gained in the similar way. As expressed in the equation (1).

$$f_{(x,y)} = \begin{cases} 1 & if\ g_{(x,y)} \geq g_0 \\ 0 & else \end{cases} \tag{1}$$

Where g(x,y) is the estimated sensor information in the point of (x, y) ; g0 is the threshold; f(x,y) is the obstacle value in the point of (x, y) . f(x,y) is a Boolean variable which is 1 when obstructed and is 0 when not obstructed.

5. To fuse the data of the map provided in step 4 and subsequently gets a synthetic grid-based map integrating multiple information.

A grid is obstructed when at least one of these information exceeds the corresponding predefined threshold. Consequently, a final map created by multi-information is acquired. The fusion equation from single information to multi-information is described in equation (2).

$$f_{overall(x,y)} = f_{temperature(x,y)} \mid f_{gradient(x,y)} \mid f_{humidity(x,y)} \tag{2}$$

Where $f_{temperature(x,y)}$, $f_{gradient(x,y)}$, $f_{humidity(x,y)}$ are the obstacle value of temperature, gradient and humidity respectively. $f_{overall(x,y)}$ is the obstacle value of multi-information." | " is the logical operation of or.

2.3 Simulation

Extensive simulations are performed to weigh the effectivity of this presented method. We studied a square area of 100m×100m, in which there are 250 (the number is determined according to the need our project) WSN nodes, in each of which a temperature sensor, a humidity sensor and a gradient sensor are equipped to acquire corresponding signals.

A. Construction of Simulation Environment

Firstly, we model the situations of temperature, humidity and gradient in the active environment of the mobile robot. The temperature differences in this environment result from some source of heat distributing in this area (fig.2); the humidity differences in this environment due to lakes and marshes in this area. Where there is a lake, there is a highest humidity; where there is a marsh, there is a higher humidity; where neither a lake nor a marsh is located, the humidity there is the lowest (fig.3);The gradient differences in this environment result from geological factors (fig.4). For other specific environment, similar method is also accessible through taking other factors obstructing the mobile robot into consideration.

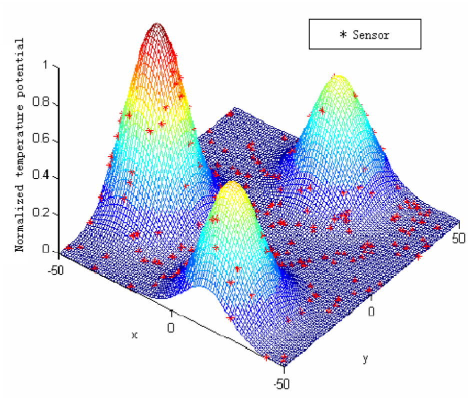

Fig. 1. Normalized temperature potential

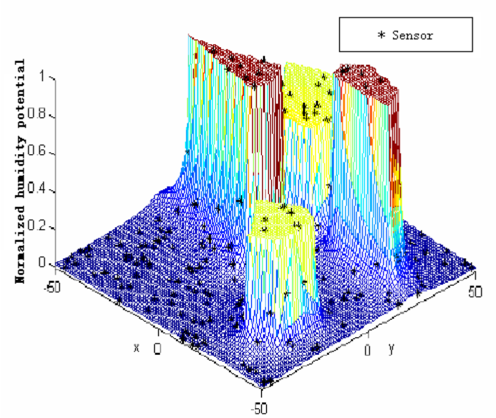

Fig. 2. Normalized humidity potential

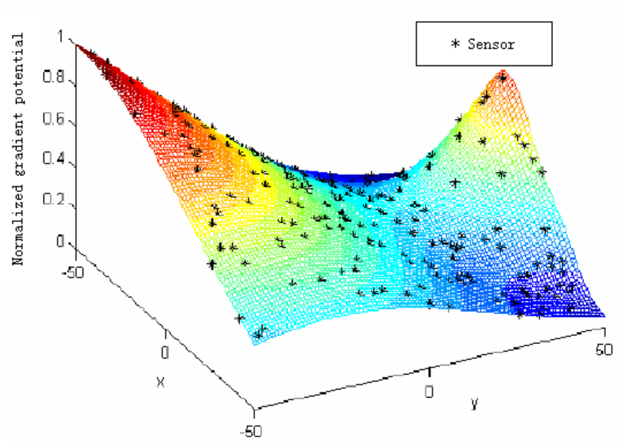

Fig. 3. Normalized gradient potential

B. Construction of the Environment Based on WSNs

In the monitoring area, after deploying 250 WSN nodes, the studied area is divided into many triangular sub regions with WSN nodes as their vertexes applying the method of Delaunay triangulation (fig.4) .

Implement interpolation for temperature, humidity and gradient information according to equation (3), the performance after interpolation is shown in fig.5, fig6, and fig7.

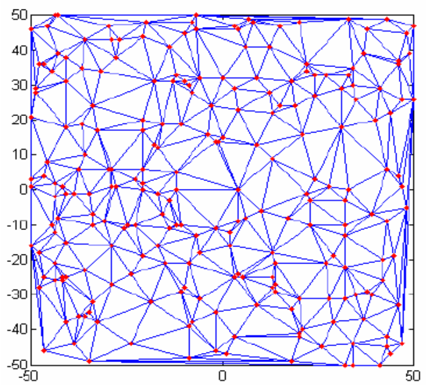

Fig. 4. Delaunay triangulation

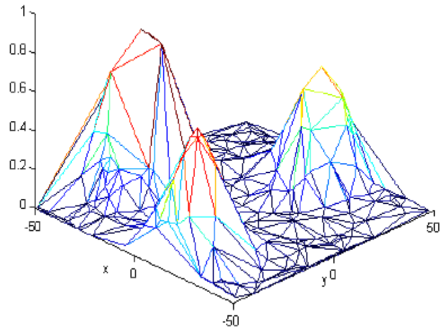

Fig. 5. Temperature potential after construction

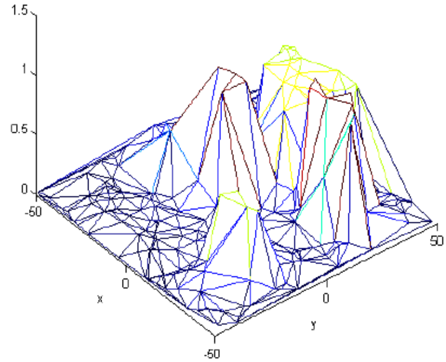

Fig. 6. Humidity potential after construction

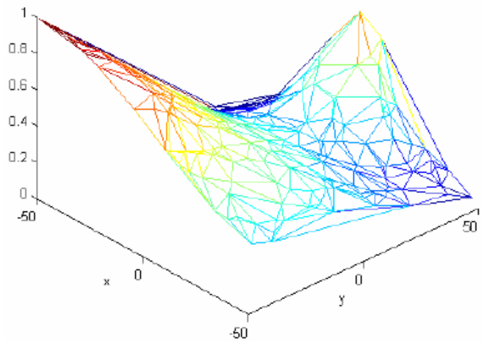

Fig. 7. Gradient potential after construction

C. Create Grid-based Map with the Constructed Environment

In simulation, the normalized temperature threshold, humidity threshold and gradient threshold are respectively designate as 0.35, 0.65 and 0.75 according to the practical situation. Thus, when the temperature in certain point is higher than 0.35, the point is thought to be obstructed by an obstacle and otherwise not be obstructed. Humidity and gradient are processed in the similar way. The grid-based maps of slope gradient, temperature and humidity obtained from the original ideal environment are respectively shown in fig.8 (1), (2), (3) while the grid-based maps of gradient, temperature and humidity obtained from the previous constructed environment are respectively shown in fig.9 (1), (2), (3), in which we can see the map error is relatively large near the edges of this area because some regions near edges are not located in any angular patch formed by WSN nodes, about which we only known little and the mobile robot thereby should avoid to pass through these regions. Consequently, on the basis of the consideration above, these regions are designated as obstacles artificially. Multi-information maps are built basing on single information maps as shown in fig.8 (4) and in fig.9 (4).

D. Error Analysis of Map Building

For a real system, the localization module of the WSN nodes has errors and there is measuring error for the equipped sensor in the node and the presented method based on limited WSN nodes also serve to introduce errors. All these errors contribute to bring about a synthetic error for the constructed multi-information map. Here we take the final error into account through extensive simulation.

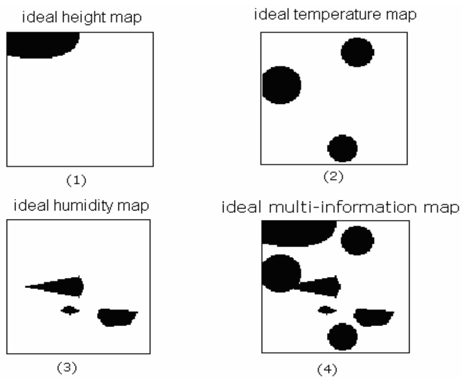

Fig. 8. Ideal map

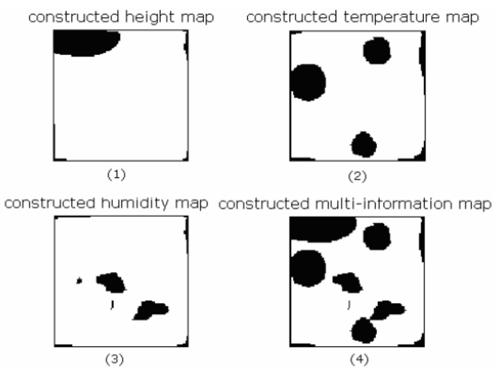

Fig. 9. Constructed map

We evaluate the effectivity of this presented method by comparing differences in the Boolean value between the constructed multi-information map and the ideal multi-information map. The error is calculated by the number of grids of which the logical value of the constructed multi-information map is different from that of the ideal multi-information map. The ratio of this error and the number of all grids in the map is defined as relative error. In simulation, the final results are computed by averaging each result of ten times.

WSN nodes number	Mapping error (%)					mean (%)	Standard deviation (%)
	1	2	3	4	5		
250	11.59	13.33	12.21	12.10	11.39	12.12	0.76
500	8.90	9.25	8.94	9.97	9.65	9.34	0.46
1000	3.77	4.29	4.00	4.44	3.82	4.064	0.29

Table 1. Mapping error analysis

The ranging error of the localization module is set to be 5% and the sensor errors of gradient, temperature and humidity are also set to be 5%. On this basis, three set of results are acquired through three simulations in which 250,500 and 1000 WSN nodes are respectively deployed. The simulation result is shown in table 1, from which we can see that the final error is not very large only by deploying a relatively small quantity of WSN nodes and the more WSN nodes are deployed, the smaller the error and the standard deviation of the final result and when a large amount of WSN nodes are deployed, the final error is very small. With the booming development in radio frequency (RF), integrate circuit (IC) and micro electromechanically system (MEMS), WSN nodes are becoming much smaller in size and much cheaper in price and the intensive deployment thereby are becoming more accessible which will bring about the essential reduction in final error of the presented method.

2.4 Conclusion

In this section, a map building method for mobile robot based on WSNs is presented. Combining the features of WSNs, a concrete operational scheme is also presented, in which several factors affecting the traffic ability characteristic of the mobile robot are taking into consideration enhancing the practicality of the map for subsequent navigation. What is more, the final map is expressed in the form of general used grid-based map. Extensive simulation indicates that the error of this method satisfy general needs for navigation and for situation requiring a relatively high accuracy, increasing the amount of WSN nodes is feasible to reduce the final error to some degree.

3. A WSNs-based Path Planning Method for Mobile Robot

3.1 Introduction

The main task of path planning for the mobile robot is searching an optimal path according the environmental model where the mobile robot safely arrives at the destinations without any collision.Currently, there are many methods about path planning for the mobile robot. According to whether environmental information is known or not, the mobile robot path planning algorithms can be divided into global path planning and local path planning.

Global path planning is based on priori information of the global environment. It uses the static global map for path planning. Because the global environment information is known, it can be used to optimize some performance indicators. However, the static information in the global path planning can not work well in dynamic environment. The local path planning, can obtain the environmental information in real time, such as location, shape and size information of the obstacles, through the sensors. The local path planning more suitable for the applications in dynamic environment.

The local path planning methods mainly include: Artificial Potential Field Algorithm, Genetic Algorithm and so on. Artificial Potential Field (Khatib, 1986) has the advantage of simpleness so that it is easy to be implemented. However, it has the local optimal solution problem, and also may cause dead lock (Yoram, et al. 1991). Genetic Algorithm (Holland, 1973) is more likely to obtain the global optimal solution, while it needs more memory space and operation time.

A wireless sensor network is consisted of a large amount of sensor nodes deployed densely in the monitoring environment. Through the positioning, temperature, vibration, light, electromagnetic and radiation sensors, we can obtain a wide range of global environmental information and use them to build a omnibearing map of global environment for mobile robots. Furthermore, wireless sensor networks can achieve real-time information of the environment, base on which the robot can make on-line path planning in the dynamic environment.

In this section, we propose an on-line path planning method for mobile robot which uses a wireless sensor network to obtain the dynamic environment information.

3.2 Method description

Here, we introduce an on-line path planning method based on WSNs. Artificial potential field algorithm is used in this method, while the WSN provides a real time information of the dynamic environment. The sensor nodes are used as landmarks during robot navigation. After arriving at a landmark, the robot choose next landmark to move toward according to the destination and navigation cost. The robot repeats this process until it reaches the destination.

Navigation costs are related to the potential of the sensor nodes and the distance between sensor nodes and destination. Higher potential means larger cost, while shorter distance induce lower cost. The mobile robot always chooses the landmark with the lower cost and makes itself safely arrive at the destination. The potential of a sensor node is related to the environment information of it, such as temperature , gradient and so on.

A. Set up the cost

Sensor nodes can obtain their own locations using self-localization mechanism, while several kinds of sensors can be ultilized to acquire different kinds of environment information and then translated into the potential.

$$U^m = \begin{cases} 0 & if(D_s \le D_{tl}) \\ \dfrac{D_s - D_{tl}}{D_{th} - D_{tl}} & if(D_{tl} < D_s < D_{th}) \\ 1 & if(D_{th} < D_s) \end{cases} \tag{3}$$

$$U_n = \max(U_n^1, U_n^2, \dots) \tag{4}$$

In equation (3), Ds is the sampled environmental information, Dth and Dtl denotes the upper and lower threshold, while Um denotes the potential of some environment factor. Equation (4) is used to integrate multi-environmental information, it takes the maximum potential among all of them.

We suppose the potential values will decrease with reciprocal of the square of the distance. So neighbor sensor node s which has a distance d to node n , sensor n will have the potential value:

$$U_{ns} = kU_s \tag{5}$$

Us is the potential of node s ; k is the coefficient of attenuation , so we can obtain this equation.

$$k = \begin{cases} 1 & \text{if } d \le 1 \\ \dfrac{1}{d^2} & \text{else} \end{cases} \tag{6}$$

We take the maximum remaining potential value among them from one hop to sensor node n as the effect of the neighbor sensor nodes , so the environmental potential value $U_n^{'}$ of sensor node n:

$$U_n^{'} = \frac{U_n + U_{ns}}{1 + k} \tag{7}$$

Suppose coordinate of node P in the environment is (xp, yp)， the potential value of point P is Up，the destination is T(xt, yt)，so the cost Cp from sensor P to the destination is：

$$C_p = \begin{cases} \infty & \text{if}(U_p = 1) \\ \sqrt{(x_p - x_t)^2 + (y_p - y_t)^2} + aU_p & \text{else} \end{cases} \tag{8}$$

After the sensor nodes in the working environment for mobile robot obtain the destination address, they can calculate their cost of the navigation from themselves to the destination. The mobile robot always choose the node with lowest cost as the next landmark.

B. Path selection strategy

Since the potential data and position data are obtained by the sensors, in general, the measured data surround the sensors is the most accurate and becoming worse with increasing the distance from the sensors to other places. In other words, the information surround the sensors are relatively reliable. Therefore, in the moving process, the mobile robot should walk along with the connection between sensor nodes and try the best to avoid deviating from the sensor nodes.

Under the above principles, we suppose at the moment the mobile robot places in location of the sensor node P and the corresponding path selection process is as follows:
(1) The robot set node P as arrived sign;
(2) The robot communications with P-node to obtain all the navigation cost of the 1-hop neighbor nodes of the P-node
(3) select the least cost node N as the next goal which has not arrived;
(4) If the node P does not exist non-infinite navigation price of the next node, the robot from the node P get back to the previous node and re- select the least navigation price of sensor node as the next goal node;
(5) The robot moves along with the connection path from the current node to the next node;
(6) Repeat these steps until the robot arrives at the destination.
In the moving process, when the robot has reached some node that will be set with arrived sigh which denotes that the sensor node has been reached and never reached again. Thus, we can effectively avoid falling into the loop. If there is no existing finite cost of navigation in the next step nodes, the robot will get back to the previous node and reselect the navigation path. So, we can avoid the oscillation and the loop through these methods.

3.3 Simulation

To verify the performance of the proposed method, we conducted simulation to study the method.
As shown in Fig. 10and Fig. 11, there are slope and temperature distribution models in the working space of mobile robot. The working area is 100m × 100m. navigation task is to make the mobile robot move from (10,10) to (90, 90) without any collision.
Sensor nodes are randomly deployed in the working space of mobile robot. Every node is equipped with temperature sensor and inclinometer. The communication radius among the nodes is 10m. As shown in Fig. 12 and Fig. 13, there are sampling results of slope and temperature information. The sampling error is set to 5%.

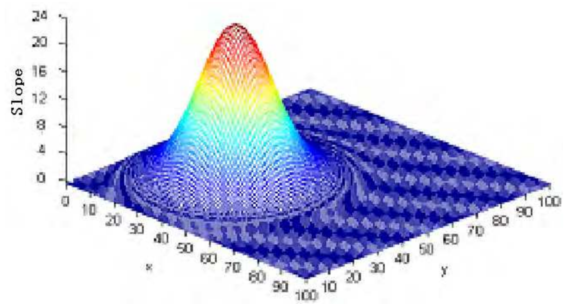

Fig. 10. Slop environment

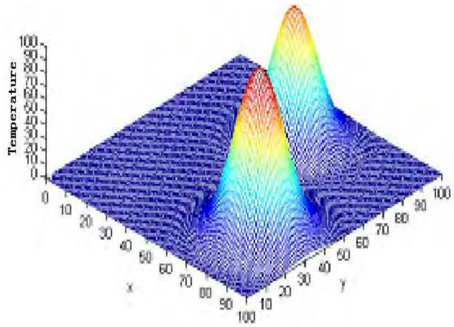

Fig. 11. Temperature environment

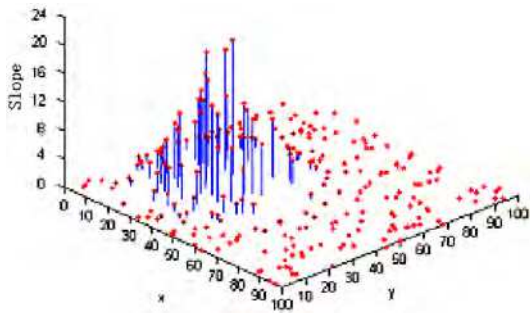

Fig. 12 Sampling Result of Slope Information

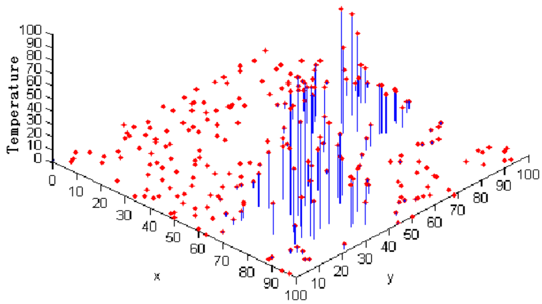

Fig. 13. Sampling Result of Temperature Information

We suppose that the upper threshold of temperature Dth is 50℃ and lower threshold Dtl is 20℃; The upper threshold of slope Dth is 10 and the lower threshold Dtl is 1. We will process Fig. 12 and Fig. 13 according to equation (3) to (4) to obtain their standard and integration results.

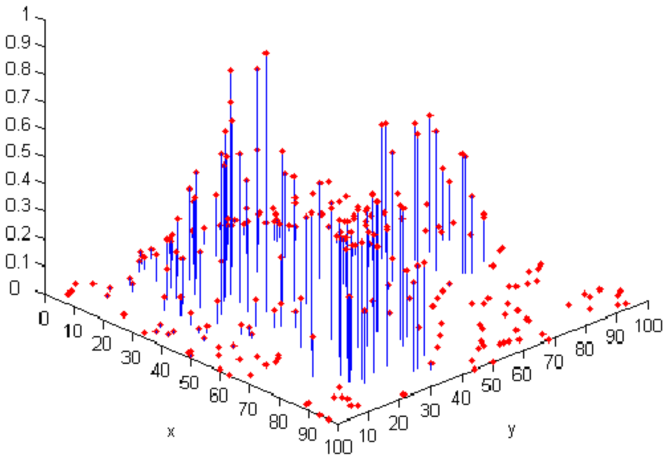

Fig. 14. Distribution of environment potential

Before the navigation, the mobile robot will firstly broadcast the destination address and "a" value (the parameter in equation (8)) to sensor nodes in the working space and every node will calculate the cost of navigation according to their potential value, destination address and "a".

The cost of navigation is the basis of path planning for mobile robot. The robot will choose the low cost of navigation sensor node to walk gradually toward the destination. In the process of navigation, robot can choose a relatively short path or a relatively safe path through adjusting the "a" parameter value in the equation (8). Fig. 15 and Fig. 16 gives the path planning result in the cases of a parameter equates to 40 and 20.

In the process of the navigation, the robot does not need to obtain the distribution of Environmental Potential and distribution of cost of navigation. In fact, the robot choose next step objective only on the basis of the cost of navigation of the 1-hop neighbor nodes.

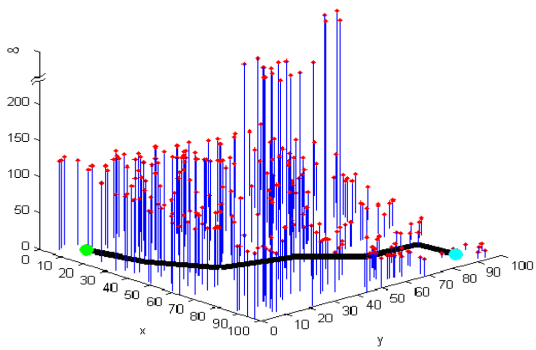

Fig. 15. Path planning result when a=40

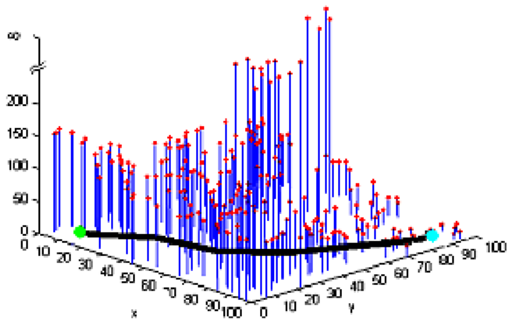

Fig. 16. Path planning result when a=20

According to the Fig. 10 and Fig. 11, we obtain gray environment model(Fig. 17) through normalizing and integrating the information. Then, using the threshold shown before, we continue to binarize the information to get the robot model(Fig. 18).

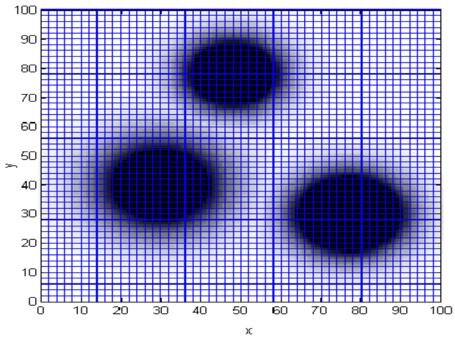

Fig. 17. Gray Environmental Model

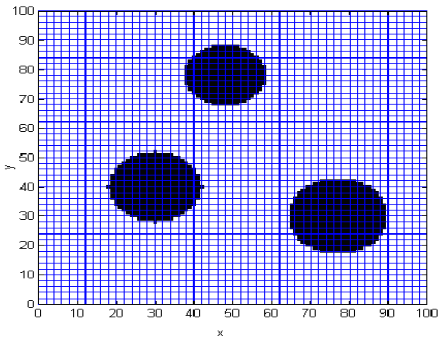

Fig. 18. Robot Mode

In order to know the effect of the path, we put the path into the constructed environment map to analyze.

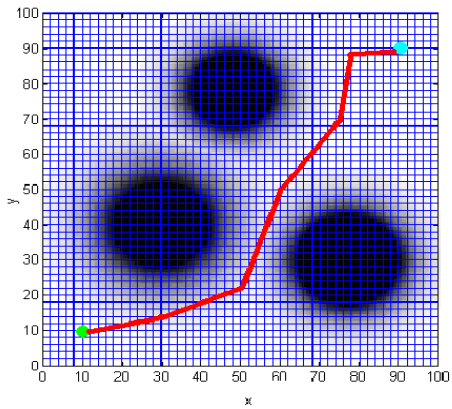

Fig. 19. Path planning result when a = 40

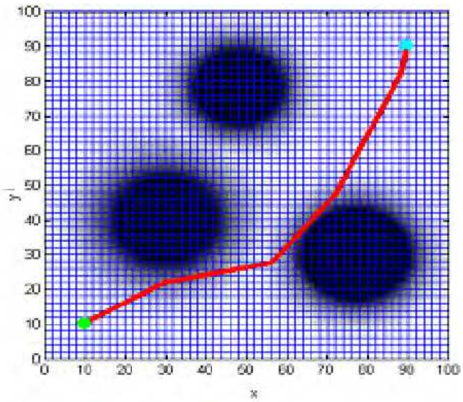

Fig. 20. Path planning result when a=20

It can be seen that when a=40, the robot chooses the safe path that can completely avoid the obstructions; when a=20, the robot chooses the shorter path although there are some obstacles in the path. However, the obstacles of the region are not beyond the limited ability of the robot so that the robot can also pass through them on the cost of paying a larger price.

In sum, we can achieve the on-line navigation for mobile robot based on the proposed method. Through adjusting the "a" parameter in the cost of navigation, the robot can get trade-off between safety and effectiveness.

This on-line path planning method based on wireless sensor networks has many advantages such as easily implemented, environmental adaptability, and low configuration requirements so that it is suitable for the battlefield environment, disaster relief and many other applications.

4. Implement of WSN-based Mobile Robot Navigation System

4.1 Introduction

The sections above mainly introduces the map building method and path planning method for mobile robot navigation based on wireless sensor networks. In this section, we develop a WSN-based navigation system using the technologies described above. Several experiments are carried out to study the validity of the system.

The mobile robot navigation system based on wireless sensor networks is mainly consist of a mobile robot, a base controller and the wireless sensor network. Wireless sensor network is composed of a large number of sensor nodes, which are scattered in the working area of robot. Sensor node is equipped with slope sensor and temperature sensor. The measurement accuracy of the slope sensor is 1◦. The sensor nodes also have a locating function based on the RSSI algorithm.

An AS-R robot is used as the mobile robot, which has the fastest mobile speed of 2.5m/s. On the other hand, a laptop is used as the base controller, which sends the commands and teleoperates the robot. The commands are relayed by the wireless sensor network. Fig. 10 shows the structure of the whole system.

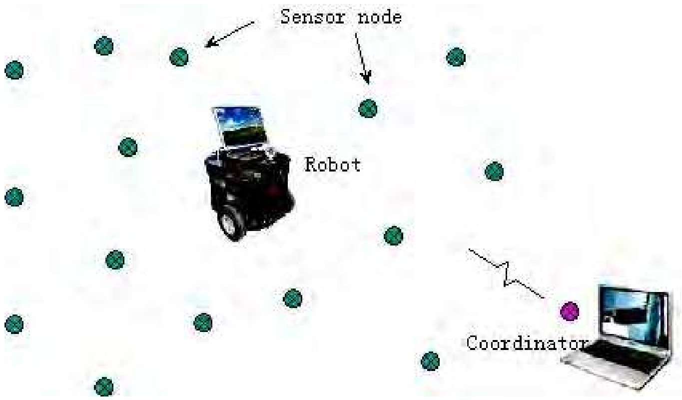

Fig. 21. The system structure

As shown in Fig. 21, the AS-R robot carries a sensor node, which we call mobile node, to locate itself. On the other hand, the base is also equipped with a sensor node, which we call coordinator node, to manage the WSN. The mobile node sends its location information to the coordinator in real time through the WSN, while the base obtains the robot location information from the coordinator, and displays it on GUI. Also, using the GUI of the base, control commands can be sent to the robot to assign tasks. The environment information obtained by WSN is transmitted to AS-R so that it can carriy out the mission of map building and path planning.

4.2 The experiments

Several experiments are carried out to study the performance of our system. A 20m x 20m square field is used as the working area of robot. Take the southwest corner of the field as the origin, divide the field into 2m x 2m cells. 2m is used as the unit in the experiments.

Fig. 22. Experiment field

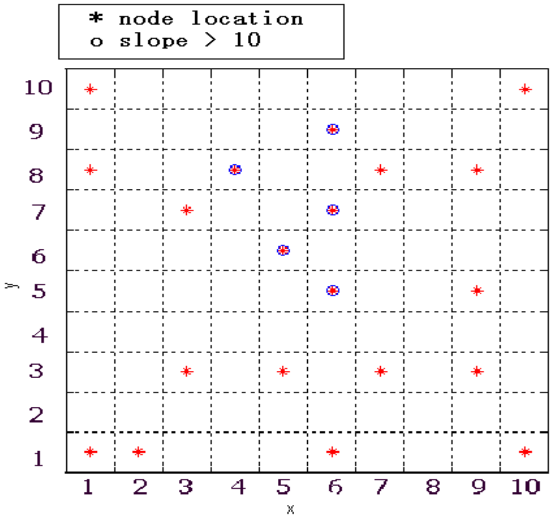

Fig. 23. Node distribution map.

20 sensor nodes are deployed in the field, four anchor nodes are deployed in four corners of the area. The coordinates of the anchors are (1,1), (1, 10), (10, 1) and (10, 10). Other nodes are placed randomly in a cell. All nodes are placed in the centre of the cells. The distribution of sensor nodes is shown in Fig. 23 .

In Fig. 23, + shows the location of a sensor node, while o means the slope of the sensor is bigger than 10◦. The experiment mission is to move the robot from the (1,1) cell to the (10, 10) cell, avoiding abstacles in the environment.

Real location(x,y)	Locating result(x,y)	Locating error (x,y)	slop(◦)
(1,1) *	(1,1)	(0,0)	2
(1,10) *	(1,10)	(0,0)	3
(10,1) *	(10,1)	(0,0)	3
(10,10) *	(10,10)	(0,0)	1
(6,9)	(5,9)	(-1,0)	75
(3,3)	(3,4)	(0,1)	2
(9,8)	(9,8)	(0,0)	0
(2,1)	(3,2)	(1,1)	4
(9,3)	(9,3)	(0,0)	0
(3,7)	(3,7)	(0,0)	1
(9,5)	(10,5)	(1,0)	2
(1,8)	(1,7)	(0,-1)	2
(6,5)	(6,5)	(0,0)	77
(4,8)	(4,8)	(0,0)	78
(5,3)	(5,3)	(0,0)	2
(7,8)	(8,8)	(1,0)	3
(6,7)	(6,7)	(0,0)	79
(7,3)	(7,3)	(0,0)	2
(6,1)	(6,1)	(0,0)	2
(5,6)	(5,6)	(0,0)	76

: * means anchor node.
Table 2. Node information

A. Using global path planning
Firstly, a series of experiments are carried out using global path planning to study the performance of the map building method mentioned before. The mobile robot communicates with the wireless sensor network and gets the environmental information. Using the map building method described above, we gets the environmental model as shown in Fig. 24. Set the slope threshold as 10◦, then gets the grid map in Fig. 25.

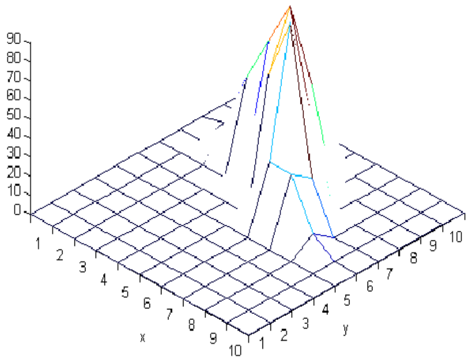

Fig. 24. Environmental model.

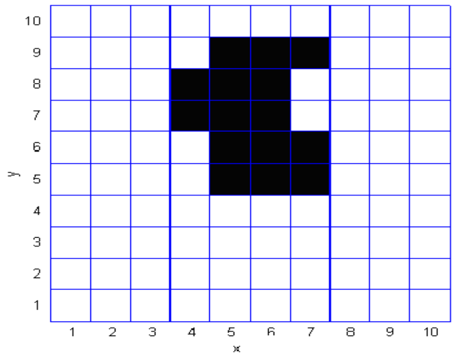

Fig. 25. Grid map.

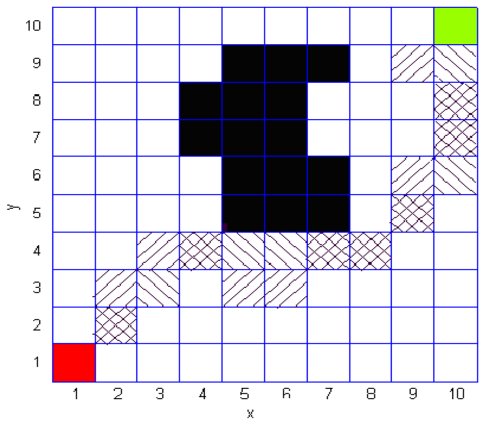

Fig. 26. Planned path and robot track in grid map.

The A* algorithm is used for path planning in the grid map. In order to move along the path, the robot gets its location with the help of WSN. Then the robot controls its move direction according to the planned path and its location in real time. In Fig. 26, the cells with "\" mean the planned path. while the cells with "/" means the track of the robot. There are some cells with "x", which means that the robot track overlaps with the planned path.

The experimental results show that the map building method based on WSN performs well, and is applicable in mobile robot navigation system. From Fig. 26, we also see that there exists deviation between the planned path and the robot track, this is caused by the locating error.

B. On-line path planning

Now we adopt the on-line path planning method described above to study the performance of the system. Using the on-line path planning method, the robot doesn't need to acquire the global environmental information. Before navigation, the robot floods the information, including the destination and the "a" parameter in equation 8, to the whole WSN. Then, then sensor nodes calculate their cost to the destination according to their environmental information and distance to destination. During the navigation, the robot finds next landmark and move toward it. After reaching the landmark, the robot finds next landmark again, until it reach the destination. Fig. 27 shows the costs of different nodes in the 10x10 grid map where: a=40, upper threshold = 10°, lower threshold=1° , destination=(10,10).

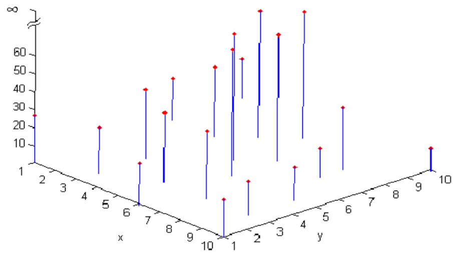

Fig. 27. Cost distribution (a=40)

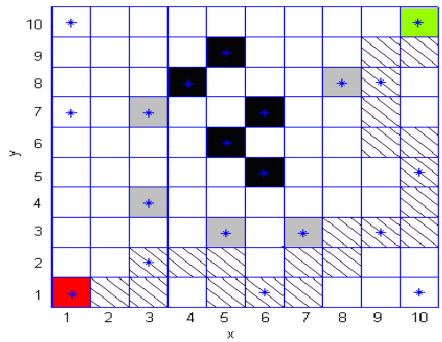

Fig. 28. Robot track in grid ma

In Fig. 28, "*" means sensor nodes, black cells are obstacles, cells with grey color have higher cost while white cells means free cell(with no sensor node). The cells with "\" shows the track of robot.

The experimental results show that the on-line path planning method proposed in section 3 succesfully achieve the navigation task, it's well suited for robot navigation applications. In the experiments, when using a smaller parameter "a", the robot trend to select a shorter path and move closer to obstacles. Sometimes it move into obstacle region which is caused by positioning error. By adjusting the parameter "a", the Mobile Robot can make trade-off between safety and efficiency.

5. Conclusion

A mobile robot navigation approach based on wireless sensor networks is presented. WSNs can obtain various types of information such as the temperature, the humidity and the slope of the ground, and the proposed approach then used them to help the decision-making in navigation and path planning.

A WSN-based method for environment modelling and map building was proposed. This method utilized the distributed environment information obtained by the WSN to establish the environment model and the grid map with multiple attributes. Simulative analysis showed that the environment model established by this method achieved good match result on the map.

Subsequently, a dynamic monitoring function of WSN was utilized to adapt the Mobile Robot to the requirement of navigation on the changing environment. An on-line path planning method based on WSNs was proposed. Using this planning method, the Mobile Robot could make trade-off between safety and efficiency through adjusting the parameters used in the algorithm.

At last, an experimental WSN-based Mobile Robot navigation system was designed and implemented to verifying the proposed navigation approach. The experimental result showed that the proposed approach could fit the application requirement of Mobile Robot navigation.

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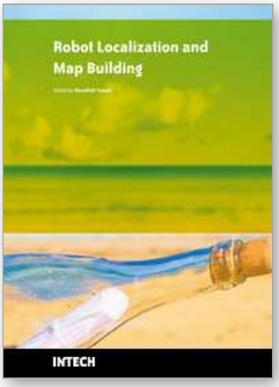

Robot Localization and Map Building

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Localization and mapping are the essence of successful navigation in mobile platform technology. Localization is a fundamental task in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning. Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that reality can be modelled in ways that communicate spatial information effectively. This book describes comprehensive introduction, theories and applications related to localization, positioning and map building in mobile robot and autonomous vehicle platforms. It is organized in twenty seven chapters. Each chapter is rich with different degrees of details and approaches, supported by unique and actual resources that make it possible for readers to explore and learn the up to date knowledge in robot navigation technology. Understanding the theory and principles described in this book requires a multidisciplinary background of robotics, nonlinear system, sensor network, network engineering, computer science, physics, etc.