Routing of autonomous wheeled mobile robot in external environment using Wireless Sensor Network

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***Abstract*— This paper proposes the application of wireless sensor network for routing of wheeled mobile robots in dynamic external environment. Wireless sensor network (WSN) in navigation of mobile robots avoids the need of knowledge of map in advance. Sensor nodes will enable mobile robot to build the map of the external location while moving around. The problem of localization can be solved by determining robot's physical distance from sensor nodes. In proposed navigation system, the robot can navigate autonomously without the need for a map, by acquiring the information from RF emission sensors deployed in an external environment. This approach is easy to implement and proposed model shows that accurate navigation can be achieved by this method.**

***Index Terms*— Wireless Sensor Network (WSN); QoS; Sensor Nodes; Automated Guided Vehicle (AGV)**

I. Introduction

Advancements in microelectronics field have led to significant reduction in size and cost of components required for sensor nodes. This has led to rapid development in the field of wireless communication. Large number of sensor nodes connected with neighboring nodes and subsequently to control room forms a Wireless Sensor Network. Sensor nodes are capable of computation as well as communication with neighbor nodes. Wireless sensor network has to be power efficient. Efficiency can be increased by using many application specific routing algorithms.

Wireless Sensor network has found its application in many areas such as in military area for surveillance and battlefield assessments, structure monitoring, pollution and toxic level monitoring, rainfall and flood monitoring, wind speed along with its direction and temperature monitoring to forecast weather conditions, habitat monitoring, medical applications like tracking patients, drug administration monitoring in the hospitals, traffic monitoring and vehicle identification. Despite the innumerable applications of WSNs, these networks have several restrictions, e.g. limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques [1]. The design of routing protocols in WSNs is influenced by many challenging factors like energy consumption, node deployment, fault tolerance, coverage, data aggregation, Quality of Service (QoS) [2].

Indoor routing of mobile robot is comparatively easier task than outdoor routing. Navigation of robots in external environment is a far complex process because robots are not aware about their current position. The problem of localization and path planning can be solved by continuous communication with neighboring sensor nodes. Sensor network in external environment has many constraints like battery life, coverage and quality of service. Hence, efficient routing algorithms have to be implemented to increase the life time of sensor nodes.

The problem of mobile robot navigation in external environment deals with navigation on the scale of a few meters around the desired outdoor location, such as desert, wide open area, where the main task for successful implementation lies in the robot's current location, which means to determine an assignment of coordinates to nodes in either a wireless sensor network [3]. There are other method of position measurement of the robots e.g. odometry, Inertial Navigation, Magnetic Compasses, Global Positioning System (GPS) [4]. The position measurement method using sensor network is consistent with accurately measured pair wise node distance. The localization problem in mobile robots has received attention of many researchers in recent years. This problem can be solved by building occupancy grid map of the present environment around the robot [4, 11]. This solution can be used to determine the navigation direction such that the robot is safely guided towards a desired location**.** The user in the control room should also acquire position of each sensor node if sensor nodes are not stationary. If correct position of sensor nodes is not known, information obtained from nodes is useless. The sensor node must know its own position first, and then it can know the position where the events happen, in an effort to fulfill the tasks such as location and tracking for the object. Combination of more than one orthogonal technique for path planning helps to reduce possible errors in position estimation. The mobile robots will be able to communicate with each other and with the wireless sensor network. Whenever multiple mobile robots are operating in nearby region, their motions have to be coordinated to avoid deadlocks or collisions. The coordination between multiple robots will be handled by central controller [5]. The location information has been proven to be useful in the remote surveillance, router communication, object tracking and network administration [10].

In my propose method for routing of mobile robots in outdoor environment, robot can find the routes autonomously without the need of the map. Of course, prior knowledge of map helps robot to navigate but map cannot be reliable for navigation in dynamic external environment. Hence, robot can navigate autonomously by extracting information from radio wave sensor installed in outdoor environment and the relative inter node distance between them. Once enough information about inter node distances to draw a graph of the sensor node is obtained, we can run any of several well suited localization schemes to compute node coordinates, then by measuring the distance from one sensor node after another using triangular localization method, the robot locates itself and knows its current orientation. Compared with the traditional methods, my proposed algorithm is conceptually simple and easy to implement.

The other topics of the paper are as follows: Part 2 deals with brief review of related work of the localization methods for mobile robots. Part 3 describes the system design of our proposed model in external environment with provided Sensor Network. Part 4 describes operation of proposed model and real time applications of our model in outdoor environment. Part 5 consists of conclusions and future work.

II. Related Work In Localization Method

The first step of localization is knowledge of the exact position of the vehicle. Automated guided vehicles (AGVs) should not be confused with mobile robots because AGVs use magnetic tape, buried guide wires or painted strips on the ground for routing. AGVs cannot freely alter their path. On the other hand mobile robots can easily alter their path according to sensor outputs. Hence, positioning of mobile robots has no elegant solution. The best solution is to use GPS based mobile robot positioning for outdoor environment [9]. The reduction in size, cost and power dissipation level of various sensors and microcomputers due to advancements in microelectronics field has made sensor network feasible to be used in external environment. All localization problems can be seen as a problem attempting to find the position of unknown nodes using as much of the available information as possible.

Recently, various relative methods have been proposed for solving this larger problem The RADAR system [7] based on RF signal strength measurements can track the location of users within an indoor environment. The Cricket location support system [8] is proposed for indoor localization by using ultrasound information. In indoor routing of mobile robots [5], a rectangular grid of beacons and RF connectivity constraints are considered for indoor localization. The detailed analysis on performance of the system can be seen in [10]. An iterative multi lateration is investigated in [11]. The presented algorithm performs well when a large percentage of beacons are available, the graph connectivity is high and precise range measurements can be determined.

As mentioned above, most approaches generally rely on the assumption that each node being able to know its distance to the others close to it. According to type of measurement for the angle or distance of the sensor node information, the Localization algorithms can be roughly divided into two categories: range-based and range-free [5].

In range-based algorithms, sensor nodes estimate their distance to seeds using some specialized hardware. These measurements are used in methods like triangulation [4] or trilateration [4], which are based on the concept that a node location can be uniquely specified when at least the coordinates of three reference points are available for a node. Although the use of range measurements results in a fine grained localization scheme, range-based algorithms require the sensors contained hardware to make range measurements. From the sensor node point of view, range-based algorithms are computationally expensive, which limits their use as a tool for practical use. Later attempts have been made to overcome this problem, the recently proposed range-free localization method provides a solution to the drawbacks of range-based method, which has been proven to be suitable for the sensor network.

Range-free algorithms do not use radio signal strengths, angle of arrival of signals or distance measurements and do not need any special hardware. Range-free algorithms require that each node knows the following items:

i. Which nodes are within radio range
ii. Their location estimates
iii. The (ideal) radio range of sensors.

No other information is required for robot localization.

Thus, range-free techniques are more computational efficient for the reason that they do not require sensors to be equipped with any special hardware, but use less information than range-based algorithms.

Considering the pros and cons of the traditional approaches, and our outdoor environment analysis, our proposed localization method can be described as follows:

i. The measurement for the sensor nodes orientation acquisition and detection
ii. The estimation of the position based on the acquired orientation information.
iii. The final localization based on the revolutions.

The system design, operation of environment analysis and detailed description of the algorithm will be given in the following section.

III. System Diagram

The proposed system is the design of a wireless sensor network with both static and mobile nodes to monitor environmental parameters. A set of self navigating robots acts as mobile nodes in the system. Each robot is embedded with obstacle finding sensors and environmental parameter monitoring sensors. There is a centralized server to coordinate the activities of robots. Total area considered for surveillance is divided into a number of regions. Central controller will assign operating region of each robot and hence it has to balance the sensing load and provide surveillance of the whole area.

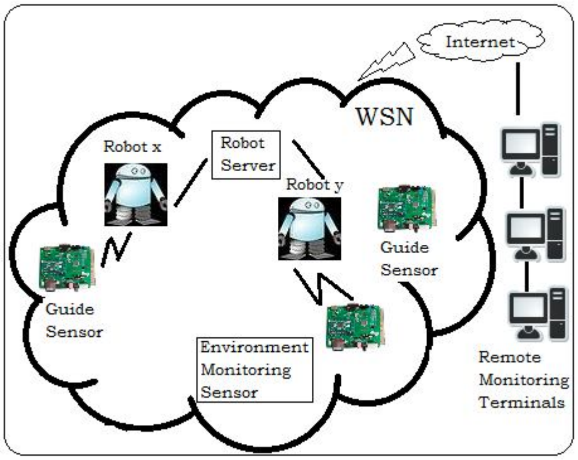

Fig. 1: System Design

The data captured by mobile robots is monitored at remote monitoring terminals by connecting them with robot servers in the Wireless sensor network via internet.

IV. Proposed Model

A. Environment Navigation Analysis

In proposed navigation system for mobile robot, sensor nodes will act as signpost and accordingly they inform the robot of the next node to pass through, while the robot follows each sensor node along the routing path and interchange distance information with each sensor node.

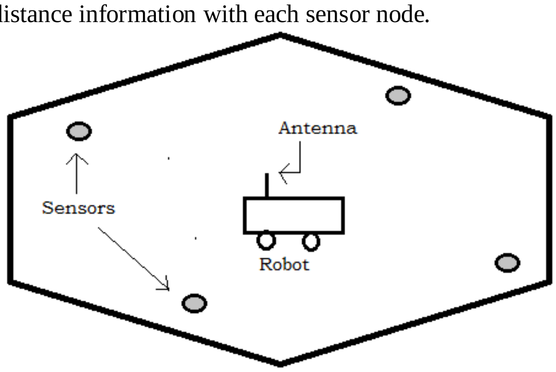

Fig. 2: Positioning with triangulation in outdoor environment

Fig. 2 indicates the valid coverage of the sensors. As we can see from the figure, the sensor nodes are scattered around the robot's operation environment and form the whole ad-hoc sensor network, their positions are known. The radio emission devices are set on each sensor node, which can emit the electro-magnetic wave with specific frequency. The robot is equipped with a rotatable antenna, which is used for receiving the radio signals from the sensor nodes, and labeling each sensor by extracting the frequency information. We denote the wireless sensor nodes set by $S = \{S_i\}$, and sensor notes groups $N_i = \{(S_{il}, S_{i2}, S_{i3})\}$, and we denote the corresponding frequency groups by $F_i = \{(F_{i1}, F_{i2}, F_{i3})\}$, as well as frequency space $F = \{F_i\}$. We divide the mobile robot's operation space E into a series of subspaces E_i where E_i belongs to $E = \{E_i\}$. We set one sensor nodes group in every subspace E_j, where each sensor node will be fixed at the different position. Note that the position $P_i = (P_1, P_2, P_3)$ is known in advance, which is easy to implement.

When mobile robot attempts to navigate in the operation space E, it will receive the radio signals from the various wireless sensor nodes scattered cross the environment. The antenna will rotate by a specific speed, during the location procedure, and the antenna will search for the specific frequency in the frequency space F, after a certain number of rotation cycles, when the magnitude M_i of frequency for the specific orientation exceeds the predefined threshold T_i, which means one sensor node has been detected with the known orientation. The robot traverses the environment by the limited number of search, and all the sensors in the subspace sensor nodes group N_i and the relative orientations can be detected.

We build the map between the sensor nodes and its positions as follows,

$$\text{Map} = m(N_i, E_i, P_i, F_i) \qquad (1)$$

In above equation, m stands for the corresponding relations among the sensor nodes, subspaces, frequency bands and robot's absolute position.

B. Positioning with triangulation

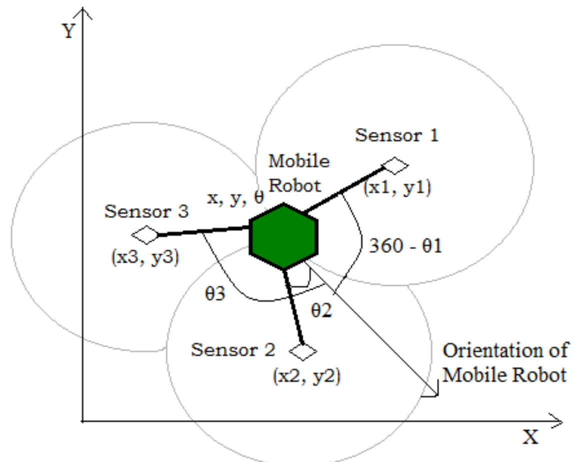

Fig. 3: Triangulation

In this paper, triangulation method is employed to estimate position of mobile robot using information of radio sensors in the sensor group N_i in subspace E_j, including their a priori coordinates in the reference frame and directions with respect to robot. As shown in Fig. 3, mobile robot detects three sensors S_i (i=1, 2, 3) around it.

C. Real Time Applications

Mobile robots following proposed model for path planning and navigation can be used to replace the battery / sensor node in the wireless sensor network. This model can be used in any external environment where position determination is impossible with conventional process [12].

V. Conclusion and Future Work

This paper proposes a new model of mobile robot positioning based on wireless sensor network. With the help of radio sensors deployed with known coordinates in the outdoor environment, mobile robot can detect the directions of sensors and estimate its position by triangulation method. The future work will focus on the improvement on robustness and extend my work to more general environment. My focus will also be on to use lightweight algorithms for sensor nodes to communicate with each other efficiently. Due to which, life time of the sensor node will be increased.

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