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Decreasing Overload of Mobile Robots Path Planning in Wireless Sensor Networks Localization

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Abstract: In wireless sensor networks (WSN), localization is an essential and fundamental problem. In many application, sensor nodes should be localized for correct function. one obvious method for localization of network nodes is equipping them with GPS (Global Positioning System). Using of GPS increases the consumed cost of sensor nodes particularly for wide environments. To counteract against the problems caused by nodes using of GPS, different algorithms are proposed for sensor nodes localization which don't need placing GPS on all the nodes. In this case, just a number of nodes exploit GPS for localization and by distribution of their coordinates, they can help other nodes of network in localization. In such conditions, a useful method is using of a mobile robot. Mobile robot is equipped with GPS and moves in network space in order to obtain the place of other nodes. During using of mobile robot, one of the important issues is planning a suitable movement path for network traverse by the robot. In this paper, first, path planning of mobile robot is studied using of Graph theory and considering wireless sensor network as non-directional graph, this problem is illustreated by help of covering tree. For this purpose, two algorithms of path traverse called as MMNF (Most Margin Neighborhood First) and LDF (Least Distance First) are suggested for covering tree which the proposed algorithm provides more powerful localization for path planning compared to the present algorithms such as BRF (BReadth First) and BTG (Back Tracking Greedy) and also in real conditions and simulation, it exhibits higher efficiency and has an important role in decreasing the consumed energy by the mobile robot.

Key words: Wireless sensor network · Localization · Path planning · Graph theory · LDF algorithm · MMNF algorithm

INTRODUCTION

The issue of localization in wireless sensor networks is among of topics which plays an important role in many applications. There are two main method for nodes localization which these two methods include anchor-based methods and anchor-free method. A significant number of localization methods use a number of nodes which these nodes know already their positions and play an important role in localization of other nodes. The positions of these nodes are determined by hand or by GPS. These nodes are said anchor nodes. As their name refers to it, anchor-free methods don't need any anchor and in these methods, final place of sensor node will depend on the coordinates of map and the presence or absence of connectivity between different nodes is used for localization. The advantages which Anchor-based localization methods have compare to the anchor-free one include that these methods consume less energy and there is no need already to determine the domain of network deployment and the procedure of nodes distribution but instead of it, they have also some defects that include: these nodes are more expensive and to some extent, they cause to decrease system security.

Because of decrease in cost and also decrease in the consumed energy in anchor-based methods, it is very important that just a few number of nodes shall be equipped with GPS and these nodes should send their coordinates to other sensors to help them in localization. such methods have relatively low costs but will have higher precision in localization to the anchor-free methods. Now, if we can perform localization helping a mobile robot which is aware of its place (for example, using of Gps), we can again decrease the consumed energy and cost. In this direction, path planning of mobile robot is regarded as a basic and fundamental problem

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because the accuracy of localization is always influenced by robot movement path. In this paper, path planning of mobile robot is studied to minimize the consumed energy and to maximize the accuracy of sensor networks localization. At first, the paper uses the proposed algorithms by sichitiu [1] and the others in which Received Signal Strength Index (RSSI) is used for distance determination. Then, path planning of mobile robot is studied using of graph theory and considering wireless sensor network as non-directional graph, this problem is illustreated by help of covering tree. For this purpose, two algorithms of path planning called as MMNF and LDF are suggested for covering tree which the proposed algorithm provides more powerful localization for path planning compared with the present algorithms such as BRF and BTG and also they exhibit higher efficiency in real conditions and simulation and have an important role in decreasing the concumed energy by the robot.

Related Works: In past, several mobile robot based localization method are presented. These methods fall into two general classes. First class are methods in which mobile robot has not its local information whereas second methode are methodes in which mobile robot has its local position information. this local position information can be available for mobile robot by GPS.

First Class: In methods in which mobile robot has not its local information, mobile robot considers its beginning point as the coordinates origin and moving along the sensor network domain, it sends its relative coordinates for the other sensors of the network. This method is usually used when we want to use localization information for routing in sensor network.The reason is that sensors' relative information is enough to determine the least distance.

Second Class: pathiran and others in [2] have used radio waves and mobile robot to perform localization and received signal strength measurement to estimate mobile robot distance, Their simulation has been for four sensors and they didn't present a clear path for their mobile robot movement. Corke and others [3,4] have used a bird robot which is equipped with GPS for localization and Radio waves strength measurement to estimate the distance up to mobile robot. There are fixed robot in their method which localize a percentage of network nodes. Sichitiu and Remadurai [5,6] have also used GPS and Received signal strength measurement to determine the distance of node up to mobile robot. Ssu and the others [7,8] have presented a distance independent method. In this method, a mobile robot which is equipped with GPS, moves in operation environment and distributes its place everywhere.

To design movement path of mobile robot in which network nodes can localize themselves using of the received signals from it, three standing path of Scan, Double-Scan and Hilbert are proposed in [9]. Then, some methods are proposed to improve robot movement path to increase localization accuracy. In [10], two path of Circles and S-curves are suggested. Also in [11], two dynamic algorithms for path planning named as BRF and BTG are proposed which have better performance in respect of the consumed energy of the robot in comparison with the static methods for path planning.

Distance Measurement: In the study and review of mobile robot path planning, the orientation suggested by sichitiu and the others [1] is used in which RSSI is used for distance determination. The regulation step for creating PDF table is before calculation step of the given place. This table is saved on all the nodes and writes each RSSI by Probability Distribution Function(PDF). The received RSSI by each node based on Probability Distribution Function is converted into the distance between two nodes.

Localization Process: In most localization algorithms, several models for distribution localization are suggested which don't need Gps installation on all the sensors.

Localization algorithms proposed in [12,13] use just a limited number of nodes equipped with GPS and these nodes send their coordinates to other nodes to help them in localization. In this paper, a mobile robot is used for sensor networks localization. Based on these algorithms, during passing through the network area periodically and in definite intervals, mobile robot sectionally distributes beacon packages in width of network. when the node received beacon package, it refers to PDF table to obtain its distance from the anchors which distribute beacon packages. This process will be repeated for each beacon package which is received. When the node receives more than three beacon packages from the robot, it can calculate its coordinates.

Path Planning for Mobile Robot: Main goal to design a path for mobile robot is to create suitable efficiency in terms of cost and precision in order to localization for network nodes. In fact, these method are seeking to design a suitable path for mobile robot movement along the sensor network area such that most nodes of the network shall be localized and the robot shall consume less energy for this path traversing. Among the existing methods to design mobile robot path for localization of unknown nodes, BTG algorithm has a better performance to the other existing algorithms. This algorithm along with BRF algorithm have been proposed and evaluated in paper [11]. In this algorithm, for planning movement path of mobile robot, it was conducted in this way that during path traversing, for selecting the next node among the neighbors, the robot would pay attention to the marginal node which had a less weight.

In this paper, for robot consumed cost decrement in path planning for mobile robot and also for localization of a more number of nodes by it, we suggest some methods which are highly more efficient and more inexpensive according to the performed evaluations.The proposed methods are within two algorithms named as LDF and MMNF which have been formed like previous algorithms that is BTG and BRF based on graph theory.

The following hypotheses have been considered to design mobile robot path by implementing Graph Theory:

- WSN nodes use multi-directionl antennas.
- communication area is circular-shaped and by radius of R_c. communication radius of robot is also R_m.
- All nodes of wireless sensor network have similar technical characteristics.
- All wireless communications between the nodes are bi-directional.

Definition 1-Neighbor-Nodes: If during visiting time of robot with node v_i, the distance between the node v_n and robot is less than r_m, the node V_n is called as neighbor-Node of V_i.

Definition 2-Interior-Node: If during visiting time of robot with the node V_i, the distance between V_n an the robot is less than 2 R_m / 3, the node V_n is called as Interior-Node of V_i.

Definition 3-Margin-Node: If during visiting time of robot with the node V_i, the distance between the node V_n and robot is less than r_m and more than $2R_m$ / 3, the node V_n is called as Margin-Node of V_i.

Definition 4-Non-directional node: In graph G=(V(G),E(G)),V(G) and E(G) are the nodes of wireless sensor networks and communication directions between the nodes, respectively, which are called the vertices and edges of non-directional graph.

Definition 5-vertices Weight in Non-directional Graph: If the number of unknown neighloor nodes v_i is n, the weight of node v_i is regarded as 1/n.

Definition 6-spanning Tree: spanning tree is a sub-tree which includes all vertices of graph G and enough number of edges for the construction of the connective subgraph but has not any cycle.

LDF Algorithm: The first proposed dynamic algorithm is Least Distance First algorithm. As it is evident by algorithms name, the basis of mobile robot movement in this algorithm is the least distance of robot from the Neighbor-Nodes. In fact, this algorithm for selecting the next node of mobile robot in path planning algorithm, addresses the current distance of robot from the Neighbor-Nodes and we select a node which has the least distance. A justification which exist to select the least distance is that firstly, by selecting shorter distances, we can increase localization precision for network nodes because at less distribution distance of beacon, mobile robot can often distribute its place, therefore at less distances, we expect better localization, secondly, by increasing nodes visited by the robot, more beacons will be distributed in the network, this causes to increase the probably of receiving more beacons by each node in the network and consequently, the number of nodes which can be localized, will be increased. However, regarding to increase in precision due to short distribution distances by mobile robot, its consumed energy will be increased which a trade off between localization precision of nodes and the consumed energy of mobile robot is observed. pseudocode of the first proposed method is expressed called as LDF algorithm in algorithm 1.

Algorithm1: Least Distance First (LDF)
Step 1
A margin vertex v_0 regard as the root of the Spanning Tree.
The ROBOT starts to visit vertex v_0

Step 2
For all the Neighbour-Nodes of vertex v_i visited currently
If Neighbour-Node v_n is Interior-Node of vertex v_i
Delete the vertex v_n
Else
compute *Distance* of margin-node v_n
End
End
If (*Distance* of vertex v_n is *minimal*)
Take vertex v_n for the current visited vertex;

Go to Step 2;
End

Step 3
If (there are WSN nodes that are not localized)
Take the nearest vertex v for the current visited vertex;
Go to Step 2;
End
End of algorithm

MMNF Algorithm: The fundamental problem of LDF algorithm is that traversing steps of the robot is relatively high and increases its consumed energy. This means that time and energy is not desirably used in some way. To remove LDF weak point, we suggest an algorithm named as Most Margin Neighborhood First. In this algorithm, for selecting the next node during path traversing in network graph, we select a node that has more margin-neighbors. Regarding to the above-mentioned explanations, pseudocode of the proposed MMNF algorithm is expressed in algorithm 2.

Algorithm2: Most Margin Nodes First (MMNF)

Step 1
A margin vertex v_0 regard as the root of the Spanning Tree.
The ROBOT starts to visit vertex v_0

Step 2
For all the Neighbour-Nodes of vertex v_i visited currently
If Neighbour-Node v_n is Interior-Node of vertex v_i
Delete the vertex v_n
Else
compute number of Margin-Neighborhoods of margin-node v_n
End
End

If (*number of Margin-Neighborhoods* of vertex v_n is *maximal*)
Take vertex v_n for the current visited vertex;
Go to Step 2;
End

Step 3
If (there are WSN nodes that are not localized)
Take the nearest vertex v for the current visited vertex;
Go to Step 2;
End
End of algorithm

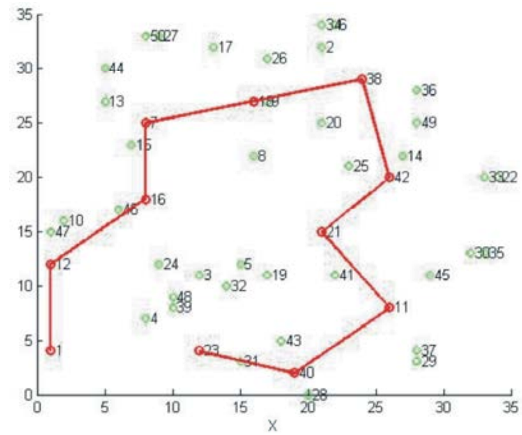

Fig. 1: The order of nodes visiting in LDF algorithm

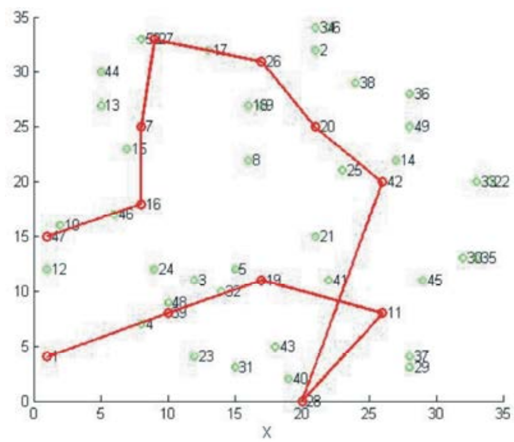

Fig. 2: The order of nodes visiting in MMNF algorithm

Simulations: The performance of the proposed algorithms (i.e the order of visiting nodes) in constant conditions includes, number of nodes, network dimensions and radius of communications is shown in figures 1 and 2. Simulation environment is 35m*35m in size, nodes number is 50 and communication radius is 10m.

In the above figures, green nodes represent network nodes and red nodes represent nodes visited by mobile robot and robot movement path in any of the above-mentioned algorithms is shown by red.

For comparison between the proposed algorithms and the previous dynamic algorithms, several simulation scenarios are conducted which we point out to two cases of these scenarios and then we will analyze the obtained results. In simulation scenarios, we have studied three criteria of the number of visited nodes, the traverse distance and the number of localizaed nodes by robot against three factors of change in nodes number, change in simulation dimensions and change in communication radius, respectively.

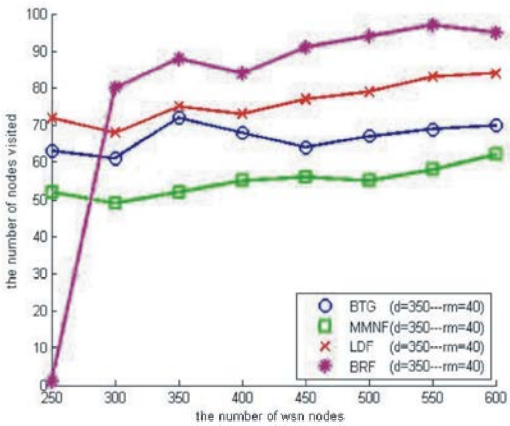

Fig. 3: The number of visited nodes against increase in nodes number

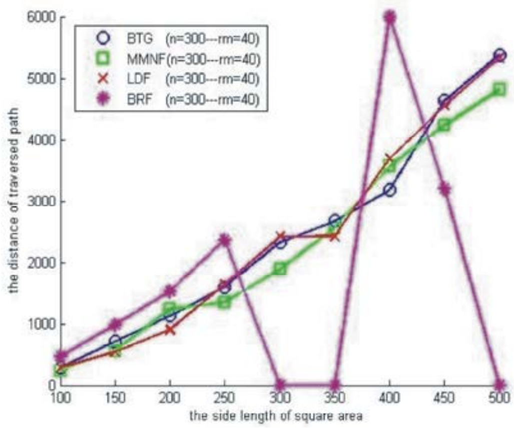

Fig. 4: The traverse distance by robot against increase in environment dimensions

Scenario1: The effect of the visited nodes number against the increase in nodes number.

In this scenario, we want to assess the visited nodes number against the change in nodes number in a simulation environment with fixed dimensions with an ordinary communication radius. For this purpose, we change nodes number from 250 up to 600 while simulation environment dimensions are supposed 350m* 350m, Also, R_m is equal to 40m.

As it is seen in Figure 3, the proposed MMNF algorithm in an ordinary simulation environment has less number of the visited nodes in comparison with BTG, BRF algorithm and the proposed LDF algorithm. something, in the above figure, for example, when the number of simulation nodes is equal to 250, BRF algorithm does not cover most nodes and for this same reason, the number of visited nodes of this algorithm reaches approximately zero. To compare the algorithm in respect of the visited nodes against increase network nodes number, we study two states: First state is when network nodes number is 350, In this case, the visited nodes number of BRF and BTG and LDF and MMNF algorithms are 88, 67, 74, 53 respectively. on the other hand, it can be said that above-mentioned algorithms to cover network nodes in this state, should visit 25.14% ¡19.14% ¡21.14%, 15.14% of network nodes, respectively. The ratio of MMNF algorithm improvement to BTG and LDF algorithms in this state is 4%, 6%, respectively. Second state is when network nodes number is 600.In this state, the visited nodes number of BRF and BTG and LDF and MMNF algorithms are 101, 71, 81 and 56,respectively. on the other hand, it can be said that the above-mentioned algorithms to cover network nodes in this state, should visit 16.83% ¡11.83%¡ 13.5%, 9.33% of network nodes, respectively. In this state, the ratio of MMNF algorithm improvement to BTG and LDF algorithms are 2.5%, 4.2%, respectively.

Scenario2: The effect of traverse distance by the robot against increase in environment dimensions.

In this scenario, we want to assess the traverse distance against the change in simulation environment dimensions with a fixed number of nodes and with an ordinary communication radius. For this purpose, we change simulation environment dimensions from 150m*150m to 500m*500m. while the number of network nodes is fixed and it is equal to 300. Also, R_m is equal to 40m.

According to the diagram, the algorithms act very closely to each other in this state. of course, in exception of BRF which has a weak performance. Here, we study three states: when simulation environment dimensions is 250*250, when distance dimensions is 350*350 and finally, when distance dimensions is 500*500m. In the first case, distance lengthes in MMNF, LDF, BTG and BRF algorithms are 1384, 1631, 1594, 2356m, respectively and their percentage equivalents to the whole area of the environment are 2.15%, 2.61%, 2.55%, 3.77%, respectively. In 350*350 dimensions, these values are equal to 2559, 2425, 2677, 0m equivalent to 2.08%, 1.98%, 2.17%, 0%, respectively. Finally, in 500*500 dimensions, these values are 1.92%, 2.13%, 2.14%, 0%, respectively. Figure 4 represents this that the proposed MMNF algorithm acts better than the other algorithms in most times and by a small difference.

Scenario 3: The effect of localized nodes number against increase in communication radius.

In this scenario, we want to assess the number of localized nodes against increase in communication radius in a simulation environment by fixed dimensions with a suitable number of nodes. For this purpose,

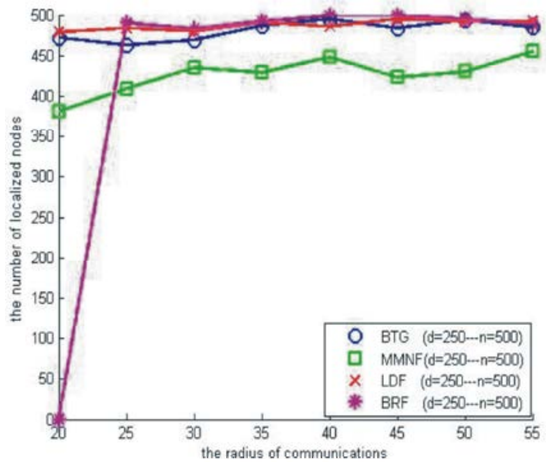

Fig. 5: The number of localized nodes against increase in communication range

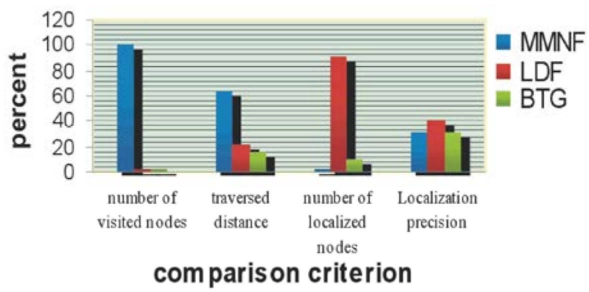

Diagram 1: Comparison of path planning algorithms in an environment by dimensions of 400*400m, communication range of 40m, nodes number of 300

we change communication range from 20 to 55m while we have supposed simulation environment dimensions equal to 205*250. Also, nodes number is equal to 500.

With increasement of communications radius the number of localized nodes by BRF reaches a significant value because in this state, the neighboring nodes of robot become more and the robot has access to more nodes to continue its activity. In this state, according to Figure 5, all algorithms have a performance close to each other except of MMNF algorithms.

The Comparison of Algorithms Priority Frequencies Percentage in 100 Times of Simulations: According to diagram 1, in part of the visited nodes number, the column related to MMNF algorithm shows the statistics 100 percent which represents that all the times, MMNF algorithm has better efficiency to the other two algorithms in times of the criterion of visited nodes number.

CONCLUSION

In this paper, path planning for mobile robot in wireless sensor networks has been studied. wireless sensor networks are introduced as non-directional connective graph and the issue of path planning has been converted in to covering tree and traversing graph. Two algorithms of path traversing called as MMNF and LDF are proposed in distance statistics which are obtained from simulation show that these two algorithms have been adapt very well for wireless sensor networks applications in bigger scales. These two algorithms obtain relatively high efficiency for localization and perform localization by more effective use of energy. Also, due to shorter distribution distance, LDF algorithm increases the probability of the required information reception to determine the situation of unknown nodes of the network and as a result, it improves the factor of localized nodes number in the network. This is while the proposed MMNF algorithm because of addressing margin neighbors which have more distance to interior neighbors of robot, exhibit better performance in terms of energy consumption and path traversing time. This is because which in MMNF algorithm, robot visit less nodes number and consequently traverse less distance to cover all nodes of the network. therefore, Finally, it spends less energy and cost for doing this. According to the statistics which was obtained by simulation, in 63% of cases, MMNF algorithm has a better efficiency in respect of the traverse distance to the other algorithms, In 21% of cases, LDF algorithm and just in 16% of cases, BTG algorithm have been efficient in these respects. In respect of the localized nodes number according to diagram1, in 91% of cases, LDF algorithm has better efficiency in respect of the localized nodes number to the other algorithm. In 9% of cases, BTG algorithm has been efficient and in none of cases, MMNF algorithm has a better performance to the other two algorithms in this case. In the case of the number of visited nodes, MMNF algorithm acts always better than BTG algorithm and BTG algorithm acts always better than LDF algorithm.

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