Robot Path Routing for Shortest Moving Distance in Wireless Robotic Sensor Networks*

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SUMMARY The wireless robotic sensor network (WRSN) is a combination of a mobile robot and wireless sensor networks. In WRSN, robots perform high-level missions such as human rescue, exploration in dangerous areas, and maintenance and repair of unmanned networks in cooperation with surrounding sensor nodes. In such a network, robots should move to the accident site as soon as possible. This paper proposes a distance-aware robot routing (DAR) algorithm, which focuses on how to pick the shortest path for the mobile robot by considering characteristics different from packet routing. Simulations are performed to demonstrate the benefits of using the proposed algorithm.

Key words: wireless robotic sensor networks, path planning, robot, routing algorithm, distance

1. Introduction

A wireless robotic sensor network (WRSN) is a combination of a wireless sensor network (WSN) and one or more unmanned mobile robots. Its network application model is, for example, that an unmanned mobile robot is sent to an area with a wireless sensor network to observe an accident within the area, make a report, and carry out emergency measures at the accident site. There have been studies on novel WRSN applications for human rescue and exploration [1] and on the navigation and localization of moving objects within a network through numerous sensors [2,3]. If WRSN is used for such purposes as human rescue and exploration in dangerous areas in case of a poisonous gas leak or fire, an important issue is to transport a robot capable of carrying out emergency measures to the accident area as quickly as possible.

One way to move a robot to an accident area is by installing GPS in the robot and sensor nodes [3]. However, installing such a high-power-consuming device in each node of a sensor network is inappropriate, given that the sensor network requires low power and capacity according to the IEEE 802.15.4 MAC/PHY standard [4]. In addition, such an approach is costly. The presence of GPS can be burdensome in practical robot applications for which low cost is a primary object, and calculating locations through GPS is impossible in indoor environments. However, a robot can reach a destination without GPS if guided by sensor nodes through wireless communication.

In this study, we attempt to solve the problem of selecting the shortest path by allowing a mobile robot to communicate with surrounding nodes through wireless communication. Robot’s movements are guided, in a manner similar to packet movements through a routing algorithm, by receiving information regarding the route to the destination. Such an approach enables us to build robotic sensor networks easily and optimize the installation costs.

One way to calculate a robot’s route is to adopt existing routing algorithms, such as DSR and AODV, used in the ad hoc network [5]. However, the shortest path determined from the perspective of packet delivery is different from those of the shortest path determined from the perspective of a mobile robot. While the shortest path in the former case has the fewest routers or hops rather than the shortest physical distance, the latter case literally requires the shortest physical path. Thus, it is not suitable to apply the packet routing method without changes to mobile robot path planning approaches. Taking into account the fact that the mobile robot movement is different from the packet movement, this paper proposes a distance-aware routing (DAR) algorithm to obtain the shortest path in terms of actual distance.

Section 2 describes the proposed DAR algorithm in detail. Section 3 evaluates the performance of DAR, and Section 4 concludes this paper.

2. Distance-Aware Robot Routing Algorithm

The DAR algorithm adds a new parameter called cumulative distance information (CDI) to the fields of the route request header and goes through a route discovery process that is different from the processes used in reactive routing methods. In the DAR algorithm, each node of a network should have its own neighbor distance tables (NDTs) to maintain the distance information between neighbor nodes and itself. Distance information is defined as the distance to a neighbor node within the communication range of each sensor node. Without GPS
recognizing absolute geographic locations, the distance between nodes can be obtained by measuring received signal strength indication (RSSI) and/or round trip time. The sensor node that usually has a microprocessor, sensors, clock and wireless communication can estimate the distance between itself and the neighbor by measuring round-trip time of the packet.

DAR obtains its path through route discovery. When an event occurs in an area where a wireless sensor network is installed, the first node to recognize the event sends out its location to other nodes in the network. Other nodes broadcast this information upon receiving it. Then, a mobile robot wandering around the network receives the broadcast information, checks the location where the event happens, and initiates the DAR route discovery to find a path to the destination.

DAR uses the source routing method. A mobile robot sends RREQs through simple local broadcast packets for route discovery. The packets are then delivered to all the adjacent nodes through the wireless transmission range. When a node receiving an RREQ is not the destination, it forwards the RREQ to its neighbor nodes. This process is repeated until the RREQ is received by the destination node. When the destination node finally receives the RREQ, RREP is sent to the mobile robot in unicast in the reverse order of node addresses on the path from the robot to the destination, which are listed in the RREQ header.

In the route discovery process, the node receiving the RREQ scans its NDT and updates CDI with the distance between itself and the neighbor node sending the RREQ. By going through intermediate nodes to the destination, the CDI is updated with the cumulative distance values among the nodes. The nodes maintain the CDI cache to store the RREQ of the minimum CDI in order to send it to the destination.

As seen in the example shown in Figure 1, node B receives RREQs from two paths and forwards the received CDI smaller than ones in its CDI cache. Let node B have an RREQ with a CDI value of 18 in its CDI cache. If it receives an RREQ with a CDI of 20 and thus greater than 18, it will ignore the received RREQ. If it receives an RREQ with a CDI of 15 and thus less than 18, it forwards the received RREQ and replaces the old RREQ with the new RREQ of CDI 15 in its CDI cache. As this RREQ transmission process is repeated, only the RREQ with the minimum CDI is sent to the destination. In the RREQ transmission process of the DAR algorithm, only the RREQ with the minimum CDI value is sent to the destination by each node; RREQ selection is based on the CDI cache information of each node within a certain period with certain timeouts. As a result, one can choose nodes on the geometrically shortest path between the source and the destination. Once RREQs from diverse paths reach the destination node through such a process, the destination node sends RREP to a mobile robot in a direction opposite to that of the RREQ with the minimum CDI value.

The destination node is capable of receiving one or more RREQs. Thus, it resorts to the CDI cache to send RREQ with the minimum CDI value before a timeout through RREP.

![Fig. 1. DAR route discovery: RREQ transmission process.](image)

Figure 2 shows the process of sending an RREP from the destination node. If the destination node D receives an RREQ with a CDI value of 100, it stores the RREQ in the CDI cache. If it receives another RREQ whose CDI value is greater than the one stored in the CDI cache, the received RREQ is ignored; if it receives another RREQ whose CDI value is smaller, the CDI cache is updated.

![Fig. 2. DAR route discovery: RREP transmission process.](image)

In the proposed algorithm, it is assumed that in the sensor area there exists no obstacle and no wall. In the case that there is the obstacle or wall between two nodes, the distance between these nodes is set to very long. When CDI of the path becomes too large, the path will not be selected. If the robots can detect the obstacles with cameras or sensors, they avoid these obstacles and then calculate the path from the current position to the destination using DAR with updated distances between sensor nodes.

In WRSN, the mobile robot can be modeled in a way similar to a packet in a sensor network. A conventional...
reactive packet routing process updates paths when network topology changes are detected during route maintenance. The network topology can be changed when intermediate nodes on the route move away or fail to function. The packet routing method should not change the path while packets are being delivered. However, a mobile robot’s movement speed is considerably slower than that of a packet, which means path change during movement may be necessary even after a mobile robot has begun to move toward a destination. This is more likely when a disaster such as a fire causes the network to become unstable.

With the DAR algorithm, a mobile robot may have an invalid initial path due to changes in the network environment; it then resets the path to the destination accordingly using adjacent nodes as sources in a certain cycle according to the state of the network environment.

3. Performance Evaluation

Using the QualNet simulator, simulations were conducted to evaluate the performance of the DAR algorithm. For comparison purposes, an existing reactive routing algorithm, namely, Dynamic Source Routing (DSR) [6], was adopted to decide the robot path; DSR finds the route with the minimum number of hops called the shortest path in the term of the communication network. Thus it does not minimize the physical distance but the hop count. DSR has been abbreviated as ERR (existing reactive routing) to avoid confusing with DAR.

After ZigBee wireless nodes (based on IEEE 802.15.4) were placed randomly on a 400 m × 400 m virtual plane. ERR and DAR were evaluated in turn according to simulation scenarios based on the environments and parameters shown in Table 1.

Table 1. Parameters for network simulation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC/PHY</td>
<td>IEEE 802.15.4</td>
</tr>
<tr>
<td>Antenna model</td>
<td>Omnidirectional</td>
</tr>
<tr>
<td>Antenna Tx power</td>
<td>-5.0 dBm</td>
</tr>
<tr>
<td>Energy model</td>
<td>MICAz energy model</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>40, 50, 60, and 70</td>
</tr>
<tr>
<td>Distance (robot to destination)</td>
<td>200m, 300 m</td>
</tr>
</tbody>
</table>

Figure 3 shows the results obtained for the mobile robot paths from the source node, which is the first sensing location, to the destination node after 50 sensor nodes are randomly placed in the QualNet simulator based on the simulation parameters in Table 1. The upper figure shows the mobile robot’s path when using ERR; the lower one, when using DAR. The figures indicate that the mobile robot’s path is closer to the geometrically shortest path from the source node to the destination node when using DAR than when using ERR. The simulation was conducted setting the mobile robot’s moving speed at 2 m/s. In comparison with ERR, DAR reduces the moving time, and thus, reduces energy consumption.

Figure 4 shows the robot’s moving route and route distance according to each path selection algorithm. The field is assumed to have no obstacle so that the robot can move in a straight line between adjacent nodes. The number of nodes was increased in increments of 10 from 40 to 70. The moving paths when using DAR and ERR are shown when the straight-line distance between the source and destination nodes is 300 m. The straight-line distance between the source and destination nodes is represented by a solid line. The discontinuities on each path line represent that mobile robots are at the locations of ZigBee wireless nodes. The figures clearly show that DAR involved shorter paths than ERR. Regardless of the number of nodes, DAR provided a shorter distance than ERR despite having more hops. In particular, when the number of nodes was 70, the moving distance obtained using DAR was shorter than that obtained using ERR by 58 m. The simulation results show that DAR performs better than ERR in terms of path length despite having more hops than ERR.
Figures 5-6 show graphs that compare the path distances when the distances between the source and destination nodes are 200 and 300 m, respectively. The graphs show the mobile robot’s moving distance versus the number of nodes when using ERR and DAR. The bar graphs represent the moving distance obtained by DAR and ERR, and the line represents the straight-line distance. The graphs clearly show that DAR produces a shorter path than ERR in all cases, regardless of the distance between the source and destination nodes or the number of nodes. While DAR reduces the path distance as the number of nodes increases, ERR shows no connection between the path distance and the number of nodes. This is because ERR attempts to produce a route for reducing hop counts, which is the general approach for routing protocols in communication networks.

4. Conclusion

This paper proposed a distance-aware routing (DAR) algorithm to quickly guide a robot to an accident area through the shortest geometrical path between the source and destination. DAR enables mobile robots or vehicles to carry out rapid emergency measures at the accident site when an accident or event occurs in an area where WRSN is installed. The proposed routing algorithm provides the shortest path to the robot, based on a packet routing algorithm; it alters the routing approach used for packet delivery to a routing algorithm suitable for mobile robots. As seen in the graphs of the simulation results, the proposed robot routing algorithm produces a shorter moving path distance than conventional reactive packet routing methods. Using the DAR algorithm, mobile robots can move to an accident area quickly through the path with the shortest distance without GPS installed in WRSN; thus, the proposed algorithm has several advantages such as easier network installation and lower costs. As future work, the distance-aware routing considering the obstacles and walls will be studied.

References