Journal of Theoretical and Applied Information Technology
15th March 2025. Vol.103. No.5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A DEGREE CONSTRAINED RESTRICTED MINIMUM SPANNING TREE METHOD FOR ROBOT NAVIGATION WITH ENHANCEMENT IN COLLISION AVOIDANCE

D SATYANARAYANA[1], ABDULLAH SAID Al KALBANI[2], GOPAL RATHINAM[3], NADIR KAMAL SALIH IDRIES[4], ALAYA HAMYAR AL AZZANI[5]

[1,2]Associate Professor, College of Engineering, University of Buraimi, Oman

[3,4]Assistant Professor, College of Engineering, University of Buraimi, Oman

[5]Lecturer, College of Engineering, University of Buraimi, Oman

E-mail: [1]degala.s@uob.edu.om, [2]abdullah.s@uob.edu.om, [3]gopal.r@uob.edu.om, [4]nadir@uob.edu.om, [5]alaya.h@uob.edu.om

ABSTRACT

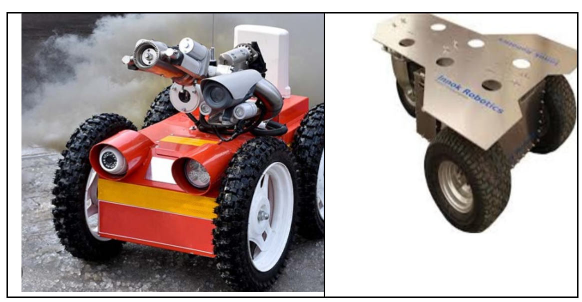
Robotics is the process of designing and building robots. The robot has to be intelligent enough to manage its tasks on its own. The mobile robot needs to be smart for travelling from a source to a destination location. The path identification of a mobile robot is a challenging task for the robots. In this paper, we propose a new localized algorithm, which uses Radio Frequency Identification technology to create a path of the mobile robot from a source to a specific destination. The proposed method constructs a route map, which is based on limiting the node degree of a minimum spanning tree. This method is also useful to reduce robot collision avoidance during the mobile robot travelling process. The simulation results show the performance of the proposed method.

Keywords: *Robotics, Mobile Robot, Minimum Spanning Tree, RFID Tags, Path Identification, Collision Avoidance.*

1. INTRODUCTION

Robots play a magnificent role in the current society. There are numerous sectors where robots are used. These sectors include industries, health sector, civil defense, military, mining sectors, entertainment, and home automation. The design of these robots depends on the requirements of tasks in the specific area. A mobile robot is a wheeled robot containing wheels with rotation motors attached to them. The power of the rotation motors depends on the size of the wheels, weight of the robot, and the speed requirements of the robot. In general, mobile robots may contain four wheels or three wheels, see Figure 1.

For a wheeled robot, it is important to identify a path from a source to its destination for traveling with lower cost and safer travelling strategies. Here, the lower cost means that robot travel necessarily consumes fewer resources. Safer travelling describes that robot travel should opt for collision avoidance and obstacle avoidance. The obstacle avoidance generally handled by the information provided by the specific sensors, such as ultra sonic sensor, IR Sensor, PIR Sensor, LIDAR, and Cameras [2]. On the other hand, identifying a path with low resource consumption for a mobile robot is an interesting problem.



(a) (b)

Figure 1: Wheeled Robot

There are a few methods presented in the literature for robot path identification [11],[12],[13],[20],[24]. Some technologies like Global Navigation Satellite Systems (GNSS), Global Positioning Systems (GPS), and Radio

Frequency Identification (RFID) support robot path identification. GNSS and GPS do not show higher accuracy in case of small distance travel, which is common in many indoor or in-house environments [1],[3]. The Received Signal Strength Indicator (RSSI) measurement is used for robot path identification [24]. The RSSI measurement is used to locate objects, and it is based on the Time of Arrival (TOA), Angle of Arrival (AOA), and Time Difference of Arrival (TDOA) algorithms [5,14]. However, the identification of the path based on the physical level parameters may limit the understanding of overall path of robot navigation. Hence, it is necessary to understand network level parameters to identify efficient robot paths.

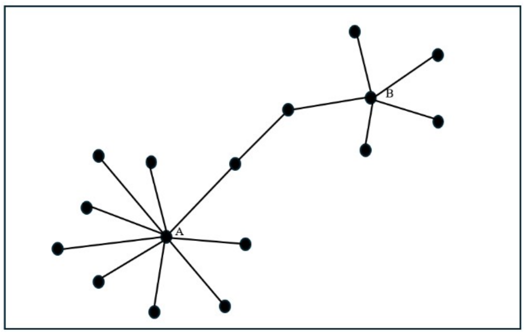


Figure 2: High Degree MST

Some researchers proposed RFID based communication infrastructure for robot path navigation [24]. However, the method suffers from the high computation processes at every stage of robot movement. Another paper presents a robot path identification method that reduces the travelling cost of by using a Restricted Minimum Stanning Tree (*RMST*) [20]. With the basic characteristics of Minimum Spanning Tree (*MST*), the robot uses the benefits of *MST* and reduces the travel cost. Nevertheless, the minimum spanning tree is not good for robot navigation if the number of edges connecting to a node is higher. For example, Figure 2 shows the high degree in MST at nodes *A* and *B*. The high node degree of MST in robot travelling path describes high traffic congestion in multi-robot travelling and it may cause robot-to-robot collisions. Even if robot-to-robot collisions are controlled by obstacle avoidance process through sensor information, it may be delayed in reaching destination location due to robot traffic congestion at the high degree nodes. The previous work merely focuses on reducing travel costs from sources to destination in terms of distance [20]. This proposal is quite good if it is a single robot environment. In the case of multirobot environment, there is a high possibility of either robot-to-robot collision or high delays of robot travel if many robots join at one point. In this paper, we propose a method to resolve the above-mentioned issue. The proposed method *Degree Constrained Restricted Minimum Spanning Tree (DCRMST)* algorithm controls the node degree of the communication network and enhances the efficiency in robot traveling.

The organization of the remaining paper is as follows. Section II describes the literature review related to the paper. Section III presents the proposed method *DCRMST* for mobile robots. Section IV describes the simulation work to see the performance of the proposed method. Section V concludes the paper.

2. RELATED WORK

The advancements in electronics and computer technology make civilians' life easier in their daily activities. Many countries adopted robots as a part of their daily activities, precisely the business and industrial activities [15],[16]. There are some sectors where robots are used in its activities. These sectors include the mining sector, industry, education, health care, home automation, and agriculture [4],[9],[18],[19],[27],[28]. The robotics can be defined as the process of designing and building the robots with the required components and adopting intelligence to the robot. For mobile robots, the intelligence of the robot can be the identification of its path from a source to a specific destination assured that the robot travel avoids the crashes with both objects and another robot in the path [7],[8].

A robot tracking method is presented in [10], which uses RFID technology in the methodology. The method is aimed at identifying the robot's location in indoor environments. The passive RFID tags are used to collect the phase measurement. The method is focused on theoretical analysis, and it may require more analysis on practical environment and its constraints. Another method presented for robot path identification in multi-robot transportation system for logistics and warehouse environment [11]. This method uses the shortest path algorithm for the robot to travel from a source to a specific destination. The objective of the research is to transport the goods by robots in the warehouse. The method uses a predefined communication infrastructure, and each robot has

Journal of Theoretical and Applied Information Technology
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an RFID tag for tracking the robot. A centralized controller is used to control all the robots to avoid robot-to-robot crashes. For the large-scale systems, the centralized systems are very expensive and must use localized algorithms [11].

A method for path identification of Autonomous Mobile Robot (AMR) has been presented in [12],[13]. The method uses coordinate geometry concepts to identify the new location of mobile robots. In this method, it has a condition that the three previously visited locations by the robot must be known before calculating the new location. The method also assumes that the previously visited three points are not co-linear. If the distances to the three points are d_1, d_2, and d_3, respectively, then the new location of robot is calculated as follows:

$$x = \frac{(d_1^2 - d_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2)(x_3 - x_2) - (d_2^2 - d_3^2 + x_3^2 + y_3^2 - x_2^2 - y_2^2)(x_2 - }{2((y_2 - y_1)(x_3 - x_2) - (y_3 - y_2)(x_2 - x_1))} \quad (1)$$

$$y = \frac{(d_1^2 - d_2^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2)(y_3 - y_2) - (d_2^2 - d_3^2 + x_3^2 + y_3^2 - x_2^2 - y_2^2)(y_2 - }{2((x_2 - x_1)(y_3 - y_2) - (x_3 - x_2)(y_2 - y_1))} \quad (2)$$

Here, (x_1,y_1), (x_2,y_2), *and* (x_3,y_3) represent the three previously visited points. The method computes the distances from a robot location to RFID tag by the concept of Received Signal Strength Indicator (RSSI) [5],[14]. The method presented to identify the robot path is either computationally complex or restricted with different conditions. Some methods were presented in the wireless communication area, where the concept is used to track the objects or saving the resources of the network [6], [21],[29].
A researcher presented a method to identify a path for mobile robots [26]. This method primarily focuses on obstacle avoidances in the path. The method uses a term *thin-path*, which describes that the mobile robot travels through the rough terrains, where the mobile robot uses rigid processes for avoidance of obstacles to safely direct the robot to the destination. In other words, the mobile robot named Zumo Robot passes through the high density of obstacles in the robot path. The mobile robot computes optimum angle for the *thin-path* to pass through the obstacles efficiently.

A fingerprint-based methodology has been proposed for robot path identification [17]. This method proposed a localized algorithm using RFID tags. In phase-based fingerprinting, the reference locations are sufficient instead of absolute locations. The method was compared to the RSSI approach, and it was shown that the presented method is better than RSSI. The method can also be applicable to Drones in the indoor environments [17].

An author presented a method based on the algorithm Colony Intelligent Tangent Bug Algorithm (CITBA) [25]. The method presented a procedure to identify the minimum distance path from an initial position to destination location. The method also considers obstacle avoidance during the robot travelling process. Nevertheless, the method reduces the complexity of processes by removing the useless paths.

A researcher presented a robot path identification method, which is based on graph theoretical structure [20]. The method uses a minimum spanning tree structure to establish a route map for the robot to travel from a source to any place in the network graph. RFID technology is used to establish a communication infrastructure that is used for robot navigation in the system. Once the RFID tags are installed in the area, the communication network graph can be formed using active RFID tags. The minimum spanning tree is computed from the network graph, which provides a low-cost path if mobile robots travel on the edges of the minimum spanning tree. The paper also presented a localized algorithm for constricting the minimum spanning tree called Restricted Minimum Spanning Tree [20].

A paper described a method for path identification of mobile robots using RFID tags [24]. This method considers obstacle avoidance while the robot travels. The mobile robot computes the new location whenever it wants to move forward. However, this method does not consider the overall communication topology for robot traveling, which is complex for the robot to take important decisions to move forward for a long-span distance between a source and the destination points.

Many of the methods presented need to focus on saving resources while mobile robot's travel. In the next section, a method *DCRMST* is presented, which oversees both minimizing resource

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

consumption during the mobile robot travel and robot-to-robot collision avoidance.

3. CONTRIBUTIONS

The mobile robot navigation or path identification is an important task in the design of mobile robots to safely pass robot to the destination. There are a few methods proposed in the literature for robot path identification [11],[12],[13],[20],[24]. A research paper presented a method which uses radio signals through the RFID technology [24]. In this method, it navigates the robot using coordinate geometry equations, eq. (1) and (2). The new point calculation is based on the fact that the three previously visited points are known before the new point is computed. However, the computational cost of the method is high as it computes new coordinate in path of robot travel every time the robot moves forward. In another method, the researchers propose a low-cost travelling method from a given point to the specific destination that depends on the minimum spanning tree [20]. The minimum spanning tree is a classical graph theoretic structure that constructs the tree with low weighted edges and the number of edges in the MST is *n-1*, where '*n*' represents the total number of nodes in the graph [22], see Figure 3.

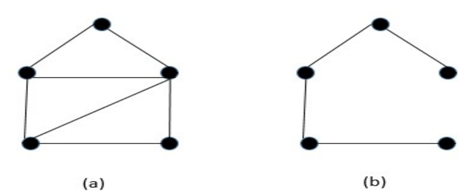

Figure 3: Minimum Spanning Tree

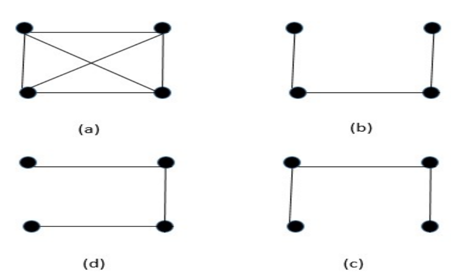

Figure 4: Multiple Minimum Spanning Trees

There can be multiple spanning trees for a given graph, where the total weight of the MST in all the derived spanning trees must be same [23]. For instance, if you consider the weight of each edge as one unit in the graph shown in Figure 4(a) then it derives multiple MSTs, Figure 4(b), Figure 4(c), and Figure 4(d) with the same total weight. Note that the MST is a connected graph. Since *MST* has the lowest cost, robot travelling based on paths of *MST* gives the low cost travelling for the robot. Sometimes, the MST construction from the given graph may be skewed, for instance, Figure 2 shows that node *A* and node *B* have high degree. Nevertheless, there are some cases where the degree of a node in the MST could be higher. The high node degree in MST leads to crashes of mobile robots in case of multiple robots' navigation system and the multiple robots join at high degree points in the *MST*. Even though mobile robots have sensors to avoid obstacles, the mobile robots could also be caught with high traffic congestion, which is followed by high delays in mobile robot travelling. In this section, we propose a new method *DCRMST* algorithm that can control the route map and reduce high node degrees to avoid robot-to-robot collisions.

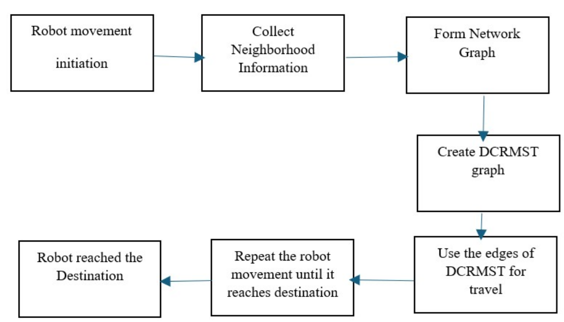

Figure 5: Methodology

The block diagram of proposed methodology is shown in Figure 5. In this methodology, it uses RFID technology to form the communication infrastructure. The RFID tags are attached at a specific place in the geographical area. We need to make sure that the tags are in the communication range to avoid the disconnectedness of geographic areas. Note that the RFID tags mentioned are active RFID tags, which have the capability of sending and receiving radio signals with specific range of frequencies. The RFID reader is attached to the mobile robot, and it can be able to detect the signals coming from active *RFID* tags. The *RFID* tags used in the methodology are homogeneous in communication characteristics and the transmitted radio signal patterns are in Omni directional. The communication network formed from the Active *RFID* tags is modelled into a network graph *G(V,E)*, where the vertices set V corresponds to

RFID tags and the edge set E corresponds to communication links formed by the *RFID* tags.

Algorithm1: Robot Navigation
1. Each *RFID* tag collects *ID* and its location information and broadcasts them. 2. The *RFID* tag collects its 1-hop neighbourhood information. 3. The communication network graph is formed with the information collected in step 2. The communication network graph is stored in the mobile robot. 4. The *DCRMST* is created with a network graph obtained in *step 3* using Algorithm 2. 5. The robot uses the *DCRMST* edges for travelling from a source to a specific destination point. 6. Obstacle avoidance during robot travelling is performed using *Bypass ()* function. 7. The robot moves forward with steps *5* and *step 6* until it reaches the destination.

Algorithm 1 shows the robot navigation method for the mobile robot. In this algorithm, it collects the 1-hop neighborhood information for each RFID tag. This information includes the ID and location information of RFID tags. The mobile robot collects communication network information and models it as a network graph. From this network graph, it computes the Degree Constrained Restricted Minimum Spanning Tree using Algorithm 2. In *DCRMST* algorithm, first it defines the parameter *Max_Degree* value. It removes all the edges from the network graph, which has longer edges than the communication range of RFID tags. Before computing *DCRMST*, make sure that the network graph is connected. If it is not connected, then place fewer RFID tags between the disconnected subgraphs so that the entire network is connected, see Figure 6. After updating the network graph with the required parameters, it sorts all the edges of the network graph in the ascending order with the Euclidean distances as weights. Select the edges in the order and verify whether the edge e_D does not form a cycle and the vertices of the edge v_1 and v_2 do not get the node degree more than the *Max_Degree*. Here, v_1 and v_2 are the vertices of the edge *eD*. If these conditions are satisfied, then add the edge e_D to E_D and vertices v_1 and v_2 to V_D. Repeat the this process of adding the edges and vertices to the *DCRMST* $G_D(V_D, E_D)$ until the n(V_D) is same as $n(V)$. Here, the n(V_D) represents the number of nodes in set V_D. Once the number of nodes in the *DCRMST* is the same as the number of nodes in the original network graph then it stops the process and returns the *DCRMST* to the mobile robot for planning of robot movement.

The *DCRMST* graph provides the sparseness of network graph that represents the low possibility of crashes for mobile robots. However, in the case of single mobile robot environment, the sparseness of the MST does not affect travelling time and robot-to-robot collisions. In other words, the proposed method is not very useful if the deployment environment has only one robot or fewer. On the other hand, if the communication network is small then the method DCRMST is not much appreciated than RMST [20]. The DCRMST performs well if the communication network is bigger in size. However, the practical applications depend on the deployment area and the nature of sector.

Algorithm2: DCRMST
1. Initialize parameter *Max_Degree* value. 2. The robot collects information about the network graph, which is formed from RFID tags. 3. Remove all the edges from the network graph which are longer than the communication range of RFID tags. 4. Verify whether the graph with all nodes is connected. If it is not connected, then insert some RFID tags so that the graph is connected and update the network graph information. 5. Sort all the edges in the ascending order with the Euclidean distance as weights. 6. Identify the least cost edge e_D with the vertices v_1 and v_2 from E and add it to E_D if the e_D does not form a cycle and a node degree of any node v_1 and v_2 in G_D is not more than *Max_Degree*. Add the v_1 and v_2 to V_D and e_D to E_D if the above conditions are satisfied. 7. Verify whether the V_D is same as V. If it is not the same, and $n(V_D) < n(V)$ then it repeats the *step 6*. 8. If $n(V_D) = n(V)$ then return the $G_D(V_D, E_D)$ as *DCRMST*.

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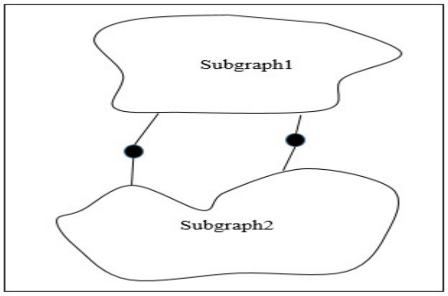

Figure 6: Connecting Subgraphs

The following are some of the characteristics of the proposed method.

Theorem 1: The maximum degree of a node in MST with 'n' number of nodes is n-1.

Proof: Consider a node scenario, where the distance between any two leaf nodes is more than the distance between the node and root node, see Figure 7. This structure shows the star connection with nodes leading to degree n-1. Hence, theorem proved.

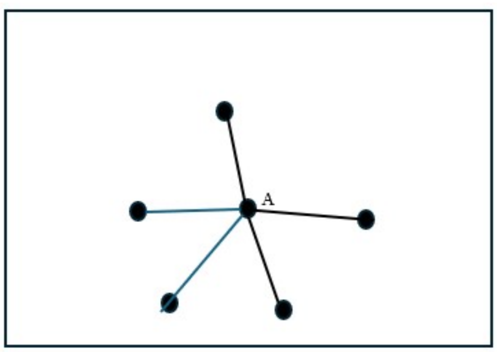

Figure 7: Star Connected Mst

4. SIMULATIONS

The simulations have been carried out using *ns2 and* Python programming. The ns2 is used to generate network scenarios for the active *RFID* tag network. The simulation grid area is of dimension 50x50 m^2. Five different node scenarios are taken for simulations. These sets are of sizes 20, 25, 30, 35, and 40 nodes. Here each node is considered as an Active UHF RFID tag. For these RFID tags, five different communication ranges were chosen, 11, 15, 20, 25, and 30 meters. Here, all the RFID tags are assumed to be homogeneous in the communication characteristics. The RFID reader too has the same communication range as RFID tag. We have conducted different experiments to analyze the behavior of the proposed method.

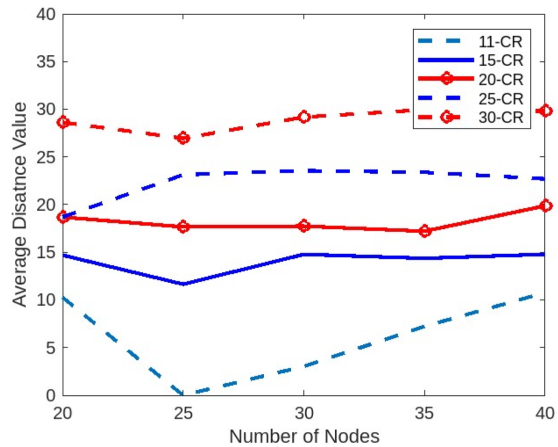

Figure 8: Average Distance Value

The first experiment is conducted to compute the average distance between the Mobile robot and RFID tags. Figure 8 shows the plot of average distance values. The experiment calculates from five different node scenarios and for each node scenario, five different communication ranges are considered. From graph plot, it shows that the average distance value is increased with the increase in communication ranges. The number of RFID tags connected to the robot are calculated with different node scenarios and communication ranges, see Figure 9. From the plot, it shows that the number of RFID tags connected to robot is directly proportional to the communication ranges of Active RFID tags.

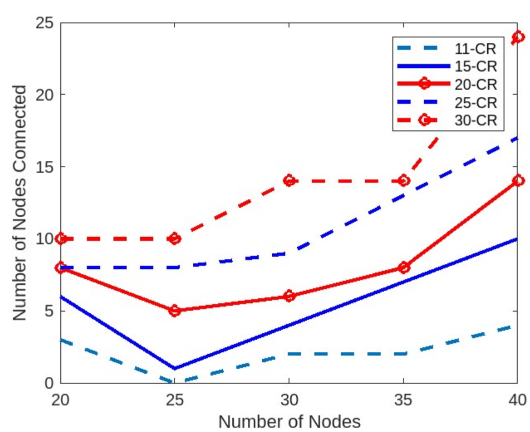

Figure 9: Number Of Nodes Connected

Figure 10 shows the number of RFID tags that are out of communication range of robot. Figure 11 and

Figure 12 plotted graphs for minimum and maximum distance values between RFID tag and the robot with different communication ranges and various node scenarios. Figure 11 shows that the maximum distance is increased with the increase in communication ranges. However, the minimum distance values are not changed strongly with the communication ranges.

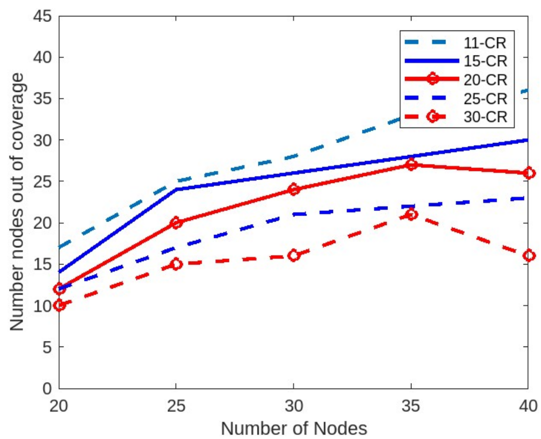

Figure 10: Number Of Nodes Disconnected

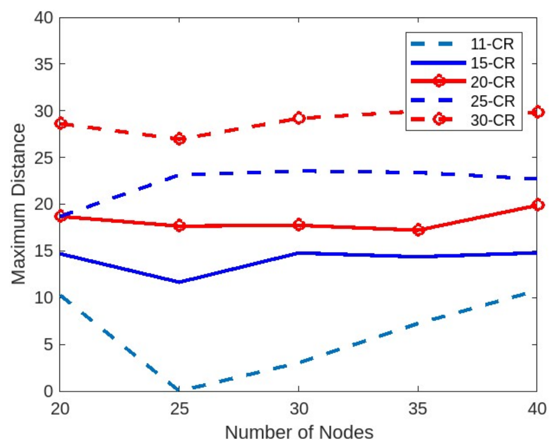

Figure 11: Minimum Distance Value

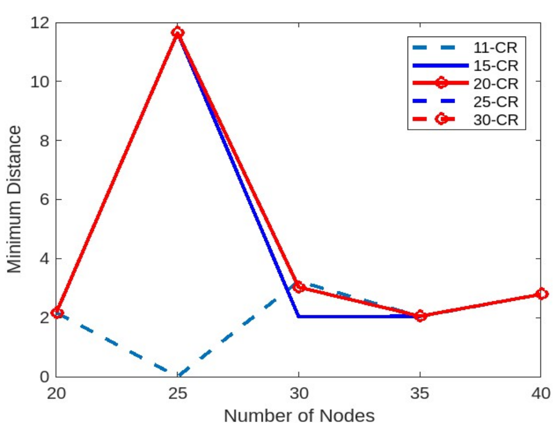

Figure 12: Maximum Distance Value

5. CONCLUSIONS

Path identification for mobile robots is a challenging task because the design of mobile robot needs to consider fewer resource consumptions and provide the safety of the robots from crashes of object obstacles or other mobile robots. A literature survey was carried out on various mobile robot path identification methods. A new method, *DCRMST,* for path identification of a mobile robot has been proposed. This method supports not only the fewer resources consumptions with the communication infrastructure formed by Minimum Spanning Tree but also reduces the possibility of robot-to-robot crashes with the adaptation of constrained node degree in the localized MST. The simulation work has been carried out to show the performance of the proposed method *DCRMST*. As future work, proposed method would be investigated and analyzed on the characteristics of spareness of *MST* that can contribute in reducing robot travelling delay and robot-to-robot crashes.

ACKNOWLEDGEMENTS

The research work is supported by the Internal Research Grant, project number: *IRG/UoB/CoE-004/2022*, University of Buraimi, Sultanate of Oman.

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