Virtual Node Based Coverage and Exploration by Multi Agents System and Communication Network

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Abstract

Coverage and exploring problems are an important research and applications problems in autonomous systems area that has been studied before by many researchers. Many algorithms had been suggested to deal with these problems, each one with some advantages and shortcoming. This paper considers the problem of area coverage and exploring by multi-agent system (MAS). The MAS consists with two autonomous robots. This problem is addressed in two distinct backgrounds; maximization of coverage and exploration and keep the constant communication between the robots. The developed system has a capability of obstacle avoidance and avoids collision between robots. The system is tested for efficiency in an experimental scenario. The test results show that MAS is more efficient than single robot in coverage and exploring the environment.

Keywords

Multi-agent system, mobile robots, coverage, exploring, communication networks.

1. Introduction

The problems of coverage and exploring of an unknown environment using Multi Agent System (MAS) has been considered. Our work considers the problem as a two problems in term of distinct backgrounds. The first problem is coverage and exploring by MAS. It is defined that the area that is explored by robot's sensor can be classified as a covered area [7]. It is required to cover the all the possible areas by the robots with minimum overlap areas.

Second problem is keeping the communication between the robots as they move alone, since the robots use communication mechanism to coordinate their behavior. It is defined that MAS should be consisted with a mechanism that guides its agents to organizing and coordinating their behaviors [1]. Moreover the agents should work independently but together to achieve their goals [1].

2. Related Work

The coverage paradigm was invented by Gage and classified into three different behaviors; Blanket coverage, Barrier coverage and Sweep coverage [7]. The algorithm proposed here is addressing the Sweep coverage behavior. Sweep Coverage is defined as achievement of group of agents over a coverage area that maximizes the number of detection per time while minimizing the undetected area [7].

Coverage and exploring problem has been studied before [2, 3, 4, 5, 8, 9].]. One of the works had been done based deployment of radio beacons in the environment [2]. This approach have used network of radio beacons to guide the robot and the beacons are spread in the environment by the robot as it goes. Furthermore the information is saved locally on the beacon. Beacons create an ad-hoc communication infrastructure. Therefore the network is also used for navigation of the robots.

The requirements of communication with other robots is also used for avoiding collisions since it is not only sufficient to decide the collision free path based on static objects, but also other dynamic robot's path needs to be considered before choosing the collision free path [10].

Communication between agents benefits increase of the performance of the system, because through the communication agents can get more information. On the other hand more transmission of data does not provide more performance unless data is used efficiently [6]. Therefore in our system, the requested information is transmitted between the agents upon agent request.

Our propose algorithm based on the above approach concept but different from it in many ways. Mainly there approach is based on only single robot, while our algorithm based on MAS that consists with two robots. Our algorithm mainly based on keeping track virtual nodes of the environment, while they use the deployment of beacons.

The final goal is an algorithm for coverage and exploring the environment that relies on the communication between the two robots. In proposed algorithm both robots keep their "home" (starting point) as the reference point. The robots move only straight forward and they do not move in an angular direction. Also robots turn in angle of 90 degrees and they do not move while they are turning. When robots are moving, they move only three blocks at a time. The point that comes after every three blocks they marked it as a node by saving that point's x-y coordination in their memory. Also they keep track of their turning directions (north, east, south and west) at each node, since they turn only at the nodes.

3. Exploring and Coverage Algorithm

This section explains our algorithm that is mainly responsible for explore the world and maximize the area coverage. The algorithm mainly based on the keeping the track of virtual nodes of the world. In order to keep the track of virtual nodes, both robots need to have one reference node. The reference node has chosen the starting point of one of the robot. It is important that both robots should start the tracking virtual node once they come to the reference point. For example, if Robot-1's starting point is chosen as a reference point, therefore Robot-1 starts keeping track of virtual nodes straight away, while Robot-2 cannot start the keeping track of virtual node straight away, it needs from Robot-2 to go to the reference point and start the keeping track of virtual node.

Once robot is in a node, first it checks for obstacles in its path (in the direction of where it is turned) with the laser beam. If there is no any obstacle within the range of 3.5m distances, robot moves forward for distance of 3m. If there is obstacle in that direction, the robot will turn to an obstacle free direction based on Keep In Touch (KIT) algorithm. Once it is turned to obstacle free direction, it will move forward for distance of 3m.

Whenever robot moves distance of 3 m, it stops at that point and marked that point as a virtual node. First robot search that point in its database. If it is not found in the database, new entry will be created and marked the entered direction of the robot as covered that node as shown in Figure 1and 2.

Figure 1- Node 1

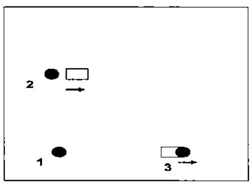

Figure 2 - Node 2 & 3

Robot's database consists with each node's x position, y position and status of the four directions (north, east, south and west) whether it is covered or not. Basically, according to this algorithm, the robots either turn at the nodes only or move straight line. The details of the performing steps of exploring and coverage algorithm are shown as a block diagram of the algorithm in Figure 3.

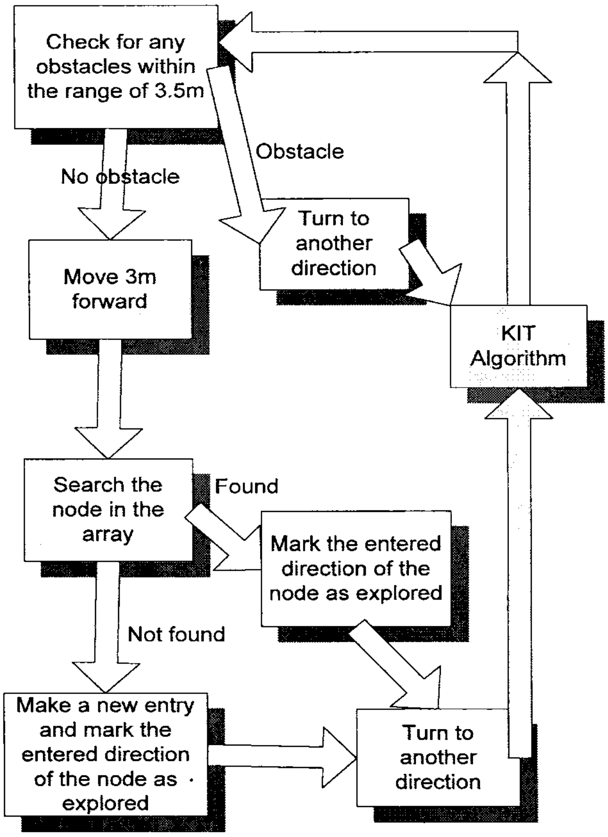

Figure 3 - Block diagram of exploration and coverage algorithm

4. Keep In Touch (KIT) Algorithm

This algorithm is responsible for choosing the robot turning direction. There are two things need to be considered, while choosing the turning direction.

1. Maximization of Robot's area coverage.
2. Keep the both robots within the distance of communication coverage area

It is assumed that robots can stay maximum of 10m apart, while keeping the communication. Also in the situation of deadlock, where a robot has to decide either keep the communication with the other robot or maximize the coverage area, the robot will choose to keep the communication. It is important to keep the communication within the two robots, since the system based on concept of "work together as a team to reach the goal".

Before turning to any direction, the robot communicates with the other robot and share the information. Once communication take place the robot knows whether other robot has visit this node or not, if so what was it's the directions of its turned at the node was. Also the robot receives the next node information of the other robot.

The algorithm work as first the robot searches the open directions and calculates the next node for each open direction. Then it will calculate the distance between the next nodes and other robot's next node and filter the directions according to the communication distance. If there are any directions, once they are filtered, robot turns to a filtered direction randomly. If there is no any direction available after the filtering, the robot does the processing again for all the directions regardless of whether direction is open or not.

Then it will get the direction that has smallest communication distance and turned to that direction. If that direction does not work, it will try direction that has next smallest communication distance and so on.

Once robot is turn to a direction it will check for obstacles in the path of turned direction. If there is no obstacle within the distance of 3.5, the robot exit from the KIT algorithm and move to the exploring and coverage algorithm. If there is any obstacle, the robot turns to the next filtered direction without doing all the processing again. Therefore robot will eventually finds a direction that has free path.

To explain the how the algorithm works by example, as Figure 4 shown, let's assume that the two robots are Robot-A and Robot-B. When Robot-A goes to a node, it will request information from Robot-B about that node and expected node of Robot-B, expected node of Robot-B is Robot-B's next node. Once Robot A receives the information it will calculate all possible expected nodes and distances form Robot-A's expected nodes to Robot-B's expected node. The all possible expected nodes are nodes in the directions that Robot-B has not turned.

If the Robot-A receives that all the directions are covered, it will take all the directions are possible directions and there will be four expected nodes.

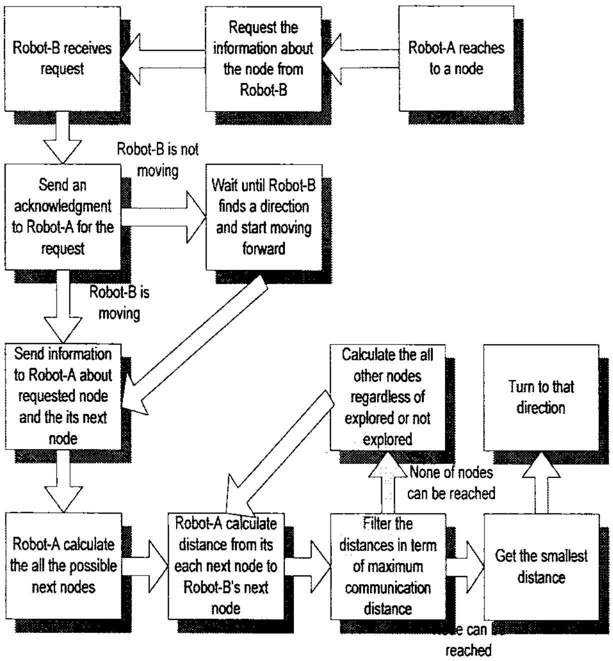

Figure 4 - Block diagram of KIT algorithm

5. Communication Between the Robots

To send the messages within the robots the following protocol is used, as Figure 5 illustrated.

Flag	X Pos	Y Pos	North	East	South	West
0	integer	integer	0	0	0	0
1			1	1	1	1
2						

Figure 5 - Communication Protocol

Flag : 0 – Requested respond.
1 – Acknowledgement of request message
2 – Acknowledgement of requested respond

X Pos : Integer
Y Pos : Integer

North : 0 – Not covered
1 – Covered

East : 0 – Not covered
1 – Covered

South : 0 – Not covered
1 – Covered

West : 0 – Not covered
1 – Covered

When a robot receives a request message, immediately acknowledgement of request message is sent to the sender. When a robot receives an acknowledgement of request message, it will wait for the requested respond. When a robot receives a requested respond, immediately acknowledgement of respond is sent to the sender.

When a robot identifies a node, it will communicate with other robot and share the information. Let's assume Robot-A track a new node. First Robot-A sends a message to Robot-B requesting information about the node. The request message contains the request flag which is "0" and Robot-A's current node (the node that required information) as shown in Figure 6.

Flag	X Pos	Y Pos	North	East	South	West
0	3	3	0	0	0	0

Figure 6 - Request information of [3,3]

As soon as Robot-B receives the message it will send an acknowledgment of message received to the Robot-A. So now Robot-A knows that Robot-B is in the within the communication range and wait for a respond from the Robot-B as appear in Figure 7. Until Robot-A receives the respond from Robot-B, it will stay static in the node.

Flag	X Pos	Y Pos	North	East	South	West
1	0	0	0	0	0	0

Figure 7 - Receive acknowledgment

Robot-B send the respond to the Robot-A, when it is moving one node to another. It does not send when it is turning, since there is an uncertainty about next node. As a respond Robot-B sends respond flag which is "2", its next node x-y coordinates and information about requested node if it has. Basically information about the requested node is whether each direction is explored or not. If any direction is explored that field is "1" otherwise "0", as Figure 8 shown.

Flag	X Pos	Y Pos	North	East	South	West
2	6	0	1	0	1	0

Figure 8 - Receive information

6. Experiment and Analysis

We have conducted a series of simulation experiments to investigate the empirical properties of the exploration and coverage algorithm and KIT algorithm. Experiments are based on two main properties; coverage and time for the coverage.

Experiments were conducted in the Player robot server with the combination of Stage multi-agent agent simulator. The robots are consists with 180 degree laser range and differential mobile robot base. The differential mobile robot base helps to turn the robot at the same point without moving. The algorithms that are developed using Stage can be transferred to real hardware with little modification.

In order to find out the efficiency of the MAS, we have conducted an experiment on the same algorithm with only one robot. This will lead us to compare the efficiency of the MAS. Time takes to find new virtual node is taken as a measuring tool. Even though this measuring tool does not accurately represent the exploration and coverage, it is able to provide an idea about exploration and coverage.

As the graphs in Figure. 9 shown, it is obvious that MAS is taking less time to explore and cover the area. The difference of area coverage by single robot and MAS is 7 minutes and 24 seconds. Moreover it is identified that MAS has explored more direction at nodes than the single robot.

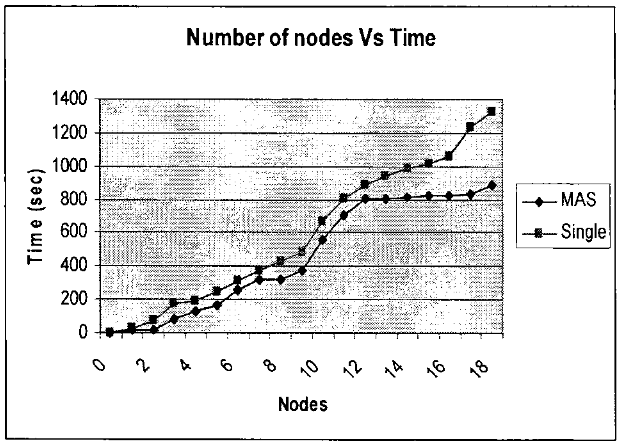

Figure 10 - MAS Vs Single Robot

In order to justify the efficiency of the system in more cases and situations since the above experiment is prove just one side, the path of both robots in MAS is analyze

Figure 10 shows the path of Robot-1, while Figure 11 represents the order of movement within nodes. Robot-1's beginning point is taken as reference point of the system. In other words this Robot-1's beginning point is "node 0" and its coordinates are [0, 0]. Based on this coordinates all other nodes coordinates are taken.

Figure 12 shown the path of the Robot-2 and Figure 13 represents the path order within the nodes. At first Robot-2 goes to the reference node which is node 0 and then start tracking the nodes.

It is adequate to investigate the area overlapped by the robots in MAS. Higher overlapping of area means less efficiency as well as inadequate resource management.

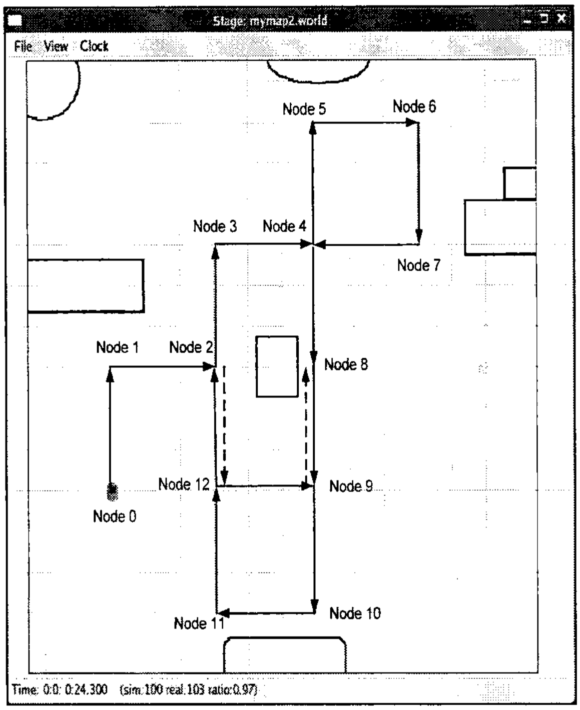

Figure 11 - Path of Robot – 1

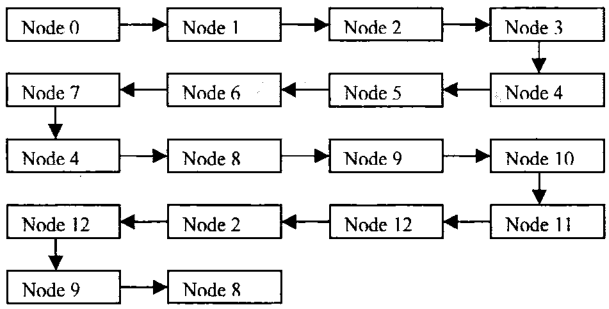

Figure 9 - Path order of Robot 1

Figure 14 illustrate all the paths that were explored by the Robot-1 and Robot-2. Also it is being identified that there are three unexplored paths and one unidentified node. Apart from that there are five overlapped paths in the MAS. These information indicates that MAS is capable of explore and cover the 88% of the environment. In term of efficiency system has 78% of efficiency. Exploration percentage calculated based on number of total possible paths and number of unexplored paths, while efficiency is calculated based on number of explored paths and number of overlapped paths.

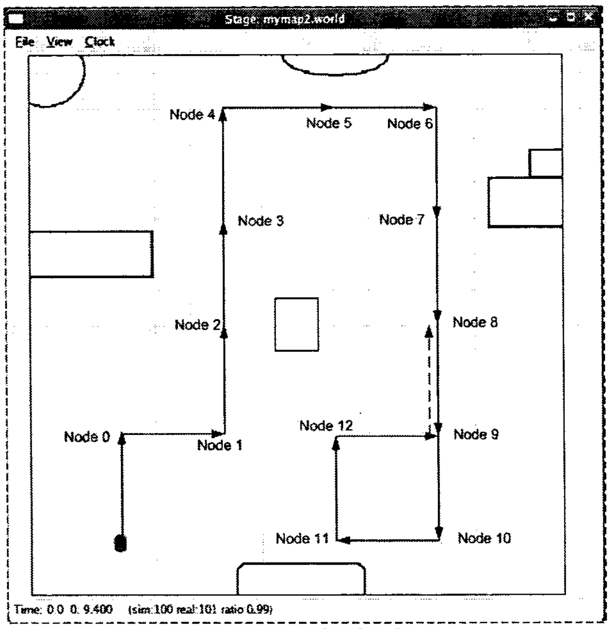

Figure 12 - Path of Robot – 2

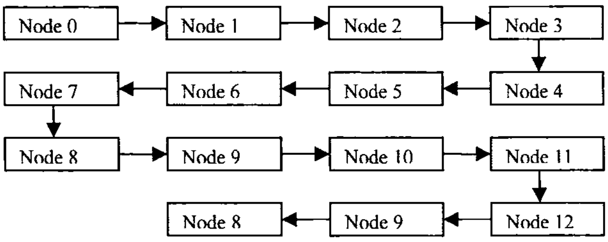

Figure 13 - Path order of Robot 2

Moreover to find out the capabilities of the system more experiments were conducted such as change the environment, change the reference point of the system.

7. Conclusion

This paper gives an overview of two algorithms which aim to solve the problem of area coverage and exploration of multi agents system. The algorithms have capability of obstacle avoidance, robot-robot collision avoidance and path planning. The system is tested for efficiency against single robot through out an experiment scenario. The test results show that MAS is more efficient than single robot in coverage and exploration of the environment.

In MAS each robot's path has been identified. Also more information has been investigated such as number of identified nodes, unidentified nodes, explored paths, unexplored paths and overlapped paths.

Based on those information capability of exploration coverage percentage and efficiency of MAS is being identified where found very encouragements results.

A future work has been suggested that extend the MAS up to three robots, where can have higher communication rage, and test the system need in real world with real robots.

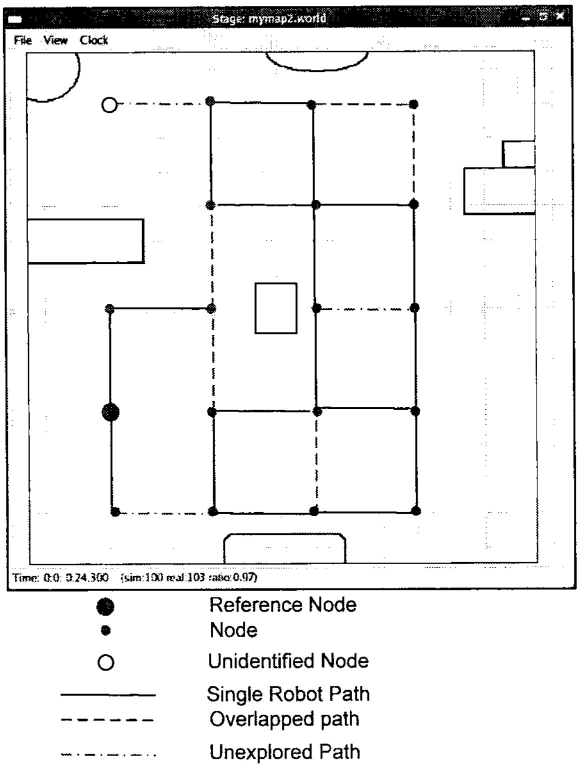

Figure 14 - Path and Node coverage of Robot-1 and Robot-2

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