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AGENT-BASED ALGORITHMS FOR MULTI-ROBOT EXPLORATION OF UNKNOWN ENVIRONMENTS

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ABSTRACT

An agent-based simulation model is proposed to explore an unknown tree with arbitrary edge distances by a set of robots which are initially located at the root of the tree and expected to return to the root after all nodes are explored. The proposed algorithm depends only on local information stored at nodes using a bookkeeping token. We show that the proposed algorithm with the Earliest Selection Policy is superior to the Random Selection Policy. The agents-based simulation can be used to study general cases of network and tree exploration problems by multiple robots.

1 INTRODUCTION

This paper presents an agent-based simulation (ABS) approach (Konak et al. 2018) to the multi-robot tree exploration problem, which is defined as follows. A set of identical robots is going to explore an unknown terrain represented as an undirected tree with N nodes. The objective of the robots is to discover all nodes of the tree and return their base in the shortest amount of time. The robots have no prior knowledge of the topology of the tree and its explored segments during the exploration process. The robots can only communicate through local interactions with active tokens used to mark explored nodes and edges. This problem arises in the context of many application areas ranging from search-and-rescue to cleaning operations. In the context of a search-and-rescue operation, the nodes of the tree correspond to unknown locations, and edges represent roads or hallways connecting these locations. The ABS model proposed in this paper for a multi-robot exploration of unknown trees is based on the assumptions given in (Brass et al. 2011; Cabrera-Mora and Xiao 2012) as follows: (*i*) All robots start the search from the root of the tree; (*ii*) There is no limit on the range of the robots; (*iii*) The robots are capable of identifying nodes and edges using active tokens; (*iv*) Active tokens store exploration information such as the number of the robots that visited the node, the edge that each robot selected, and the last time when a robot started traversing an edge. However, the ABS model also relaxes some of the assumptions in the earlier algorithms as follows: (*i*) Robots can move from one node to another in multiple time steps and (*ii*) Multiple robots can traverse the same edge simultaneously. Thereby, trees with arbitrary edge lengths can be explored.

2 DESCRIPTION OF THE ABS

Table 1 summarizes the agents used in the ABS model and their states. Each edge starts the simulation in the Not Traversed state, meaning that a robot has not passed through the edge yet. When a robot starts traversing the arc in the backward direction, the state of the edge becomes Closed, which prevents other robots to use the edge. A Closed edge means that all child nodes that can be accessed through the edge have been already explored. Similarly, each node starts the simulation in the Not Visited state, meaning that a robot has not visited the node yet. As soon as a robot visits a node that is in Not Visited state, the robot deploys an active token, and the state of the node becomes Visited. When all outgoing edges of a node are in the Closed state, then the node enters the Discovered state.

Table 1: The agents used in the ABS model and their states.

Agent	Agent States	Initial State
Robot	Decide, Move Forward, Move Backward	Move Forward
Node	Not Visited, Visited, Discovered	Not Visited
Edge	Not Traversed, Traversed, Closed	Not Traversed

A robot has three major states, Decide, Move Forward, and Move Backward. When a robot arrives at a node, it deploys a token if the node is in the Not Visited state. In the Decide state, a robot is ready to select the next admissible edge to traverse. An edge is called admissible if it is in the Not Traversed or Traversed state. If the current node of a robot has no admissible outgoing edges, the robot starts moving towards the root through the incoming edge of the current node (Move Backward State).

The edge selection decision of a robot is important for minimizing the time to explore the nodes of the tree. In (Cabrera-Mora and Xiao 2012), a robot randomly selects one of the available open edges. This policy is referred to as Random Selection Policy (RSP). In our ABS model, the robot prioritizes edges that have not been traversed yet. The robot selects randomly and uniformly one of the edges that are in the Not Traversed state. If such an edge is not available, then the robot considers the time when the last robot selected each Traversed edge and selects one with the earliest time. This edge selection policy is called Earliest Selection Policy (ESP) and assumes that the unknown tree segment branching from the traversed edge with the earliest-last selection time is likely to be larger than other unexplored segments of the tree because robots went through the edge and not returned yet.

3 COMPUTATIONAL RESULTS

The ABS model was coded in NetLogo (Tisue and Wilensky 2004). We performed simulation runs to study the effectiveness of the ESP with respect to the RSP on randomly generated trees of 200 nodes with varying diameters. In addition to the topology of trees, the variability of edge distances and the number of robots were considered. The ESP and RSP were tested for each simulation scenario using 100 random replications. We investigated the relationship between the exploration time and the tree topology, Edge Distance Randomness, Number of Robots, and Edge Selection Policy. The main objective of the experimental study was to investigate the effect of the ESP on the total exploration time. We fitted a linear regression function to predict the exploration time as a function of the above input parameters and compare two policies. The results of the regression analysis showed that the ESP reduced the exploration time up to 2.4% (p=0.0, R^2=0.847). In particular, the ESP improved the exploration time for trees with unbalanced topologies and arbitrary edge distances. The regression results also indicated that robots tended to discover wider trees in a shorter amount of time compared to longer trees.

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