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1 Introduction

Routing a fleet of robots in a known surface is a complex problem. It consists in the determination of the exact trajectory each robot has to follow to collect information. The objective is to maximize the exploration of the given surface. To ensure that the robots can execute the mission in a collaborative manner, connectivity constraints are considered. These constraints guarantee that robots can communicate among each other and share the collected information. Moreover, the trajectories of the robots need to respect autonomy constraints.

Applications of this problem can be found in space scattered sensor visit problems for data collection and/or power up purposes. Again, robots can be used to restock particular resources to precise locations as, for instance, water in emergency areas or informations to soldiers in war zones [1, 2].

2 Problem definition

The multi-robot routing problem under connectivity constraints (MRRP, for short) consists in routing a fleet of robots to explore a given surface. The problem aims at determining the exact trajectory followed by each robot in order to maximize the exploration of the surface, namely, the number of points explored by the fleet. To ensure that the robots act in a collaborative way, we consider connectivity constraints which are necessary to ensure the information sharing and communication of these different informations among the members of the fleet. Finally, due to the limited energy reserve of every robot, we add autonomy constraints.

Our problem consists in routing a set $\mathcal{R} = \{1, ..., R\}$ of identical robots that need to visit over a discrete time horizon $\mathcal{T} = \{0, ..., T\}$ a given number of points on the pre-built grid $\mathcal{S}$, characterized by the length of the equilateral triangle edges that form it. Each robot $r \in \mathcal{R}$ can then be characterized using its initial position x_0^r, its autonomy A^r and the sensing range R_s. The autonomy limits the maximum distance a robot can travel and the sensing range gives us the information we need about the area sensed by each robot.

To keep the model close to reality, we suppose that during each time period $t \in \mathcal{T}$, a robot $r \in \mathcal{R}$ can move from its current position x to a point in its neighbourhood. The neighbourhood of a point x, denoted $\mathcal{N}_x$, contains all points defining edges with point x on the triangular grid $\mathcal{S}$. We add that each point is its own neighbour so that the robot can remain on the same position for subsequent time-steps and consequently it has not to move during each time period.

When a robot stands on a point of the grid, we say that the point is *visited*. When two robots stand on two vertices of the grid connected by the same edge, the robots are said *connected* or *neighbours* and are hence able to communicate and exchange information between each other. An edge is said to be *covered* when two robots occupy the vertices defining this edge.

A set of robots positions is said to respect the connectivity constraints if and only if for each pair of robots, there exists a path on the grid that goes from the current position of a robot to the position of the second robot using only covered edges.

The objective of the problem is to determine one trajectory for each robot of the fleet over the time horizon $\mathcal{T}$. However, these trajectories need to maximize the number of visited points, to always respect autonomy constraint and to *regularly* respect connectivity constraints. This last issue means that the fleet does not need to verify the connectivity constraints at each time period, but rather periodically or pseudo-periodically.

3 Methodology

We propose an overlay $\mathcal{H}$ of the surface $\mathcal{S}$ made of identical hexagonal tiles. Each hexagonal tile has edge of length $R-1$, namely R points of the exploration surface are on the edge of the hexagonal tile. Based on this decomposition of the surface $\mathcal{S}$ to explore we propose a two-phase heuristic algorithm. In the first phase we calculate trajectories of robots to explore a hexagonal tile. These trajectories are such that :

— the robots are initially aligned on one edge of the hexagon tile ;
— the robots conclude their trajectories aligned on one other edge of the hexagon tile ;
— all the trajectories are similar with respect to energy consumption.

In particular, this third characteristic of the trajectories allows us to get rid of the exact energy management for each robot with a consequent decrease in the combinatorics of the problem.

In order to step into the second phase of the algorithm, we create a graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ where each vertex of $\mathcal{V}$ corresponds to the center of a hexagonal tile in $\mathcal{H}$. We write v_i to indicate the vertex associated to tile h_i. The edge set $\mathcal{E}$ is defined as

$$\mathcal{E} = \{(v_i, v_j) | \text{tiles } h_i, h_j \in \mathcal{H} \text{ are neighbours}\}$$

Intuitively, we say that two tiles are neighbours if the robots can directly enter one tile when exiting the other. With each edge $e \in \mathcal{E}$ we associate a gain g_e and an energy consumption c_e. The former is the number of new points that we would explore if the edge is taken. The latter is the energy consumption that robots in the fleet would suffer if e is taken. These values are dynamic and are updated each time the fleet moves : the gain is taken into account only once, the first time the tile is explored. The second depends on the previous visited hexagon. A path that maximizes the gain while respecting the autonomy constraint is sought.

4 Results

Computations are run on an Intel Core i7-5600U 2.6GHz with 8Gb of RAM. A grid with 500000 points to visit is considered. Test on different values of the fleet size ranging from 11 to 91 and with different values of autonomy are executed. Analysis of the results will be presented during the conference.

Références

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