Research Proposal: Multi-Robot Coverage of Modular Environments

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CSE Track
Outline

• What is Coverage?
• Why?
• Multi-Robot Coverage
• Preliminaries
• Our setting: Modular Environments
• State of the Art
• Research Plan
What is Coverage?

• An environment of which we know the map
• A set of points of interest in the map
• A mobile agent, equipped with a ‘covering tool’ of finite size

The goal is to find a path:
• optimal
• such that each point of interest fall under the covering tool at least once
Why?

• To physically pass over a specified set of points
Why?

- To physically pass over a specified set of points
- To gather data about the environment
Why?

• To physically pass over a specified set of points
• To gather data about the environment
• For search and rescue applications
Multi-Robot Coverage

An approach that comes from the Multi-Robot Systems area

Advantages:
• it provides robustness (i.e., supporting the loss of a robot)
• it increases efficiency

Drawbacks:
• it needs to address coordination
• Increased algorithmic complexity
Multi-Robot Coverage

Formally:

The problem of Multi-Robot Coverage is defined as the planning of a number of paths, one for each robot, over a known environment...

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The problem of Multi-Robot Coverage is defined as the planning of a number of paths, one for each robot, over a known environment such that, when followed by the agents, all the points of interest fall under the covering tool (of finite size) of at least one agent,

...
Multi-Robot Coverage

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The problem of Multi-Robot Coverage is defined as the planning of a number of paths, one for each robot, over a known environment such that, when followed by the agents, all the points of interest fall under the covering tool (of finite size) of at least one agent, the constraints of the environment are considered and the solution is optimal w.r.t. a certain metric.

[Kong, C.S. et al., 2006]
Multi-Robot Coverage

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The problem of Multi-Robot Coverage is defined as the planning of a number of paths, one for each robot, over a known environment such that, when followed by the agents, all the points of interest fall under the covering tool (of finite size) of at least one agent, the constraints of the environment are considered and the solution is optimal w.r.t. a certain metric

[Common metrics: MINSUM, MINMAX]

[Kong, C.S. et al., 2006]
Preliminaries

From environment to graph

• Points of interest of the environment → nodes
• Connections between points → edges

Example: Voronoi tessellation

[Moratz, R., Wallgrün, J.O., (2003). Fig 8a]
Preliminaries

Traveling Salesman Problem (TSP):

“Given a set of cities and the distances between each pair of them, what is the shortest possible route that visits each city and returns to the origin city?”

Cities $\rightarrow$ nodes
Distances between cities $\rightarrow$ edges with associated cost
Origin city $\rightarrow$ depot
Multiple Traveling Salesmen Problem (mTSP):

“Given a set of nodes and a cost metric defined in terms of distance or time, let there be \( m \) agents located at a single initial node, called depot. The remaining nodes are called ‘intermediate nodes’. The mTSP consists of finding tours for all the \( m \) agents, which all start and end at the depot, such that each intermediate node is visited exactly once and the total cost of visiting all the nodes is minimized”

[Bektas, T., 2006]

NP-Hard
Preliminaries – mTSP approximations

• Frederickson et al. (1976): tour-splitting heuristic
  ➢ Approximation factor: $\frac{5}{2} - \frac{1}{m}$

• Malik et al. (2007): for GMTSP (Generalized Multiple depot mTSP) with symmetric costs and triangle inequality satisfied
  ➢ Approximation factor: 2

Our idea: exploit constraints on the environment to get tighter bounds
Our setting: Modular Environments

• Repeated identical subparts: the ‘modules’
• Environment is made up only by these modules, all identical to each other, and their interconnections
Our setting: Modular Environments

Exemplified by residential buildings
Our setting: Modular Environments
Our setting: Modular Environments

- All robots are considered equivalent
- Robots can move at constant speed through the whole environment
- Same starting location for all robots
- We are interested in minimizing the completion time (MINMAX)
State of the Art

Common approaches:

• Split the TSP solution
• Use clustering
State of the Art

Split the TSP solution

[Frederickson, G.N. et al., 1976]
State of the Art

Split the TSP solution

6 robots

[Frederickson, G.N. et al., 1976]
State of the Art

Split the TSP solution

6 robots

[Frederickson, G.N. et al., 1976]
State of the Art

Clustering

[Chandran, N. et al., 2006]
State of the Art

Clustering

3 robots

[Chandran, N. et al., 2006]
Research Plan

Purpose: investigate the potential improvements over the bounds of approximations given by path planning algorithms for multi-robot coverage problems enabled by considering environments characterized by repeated identical sub-structures

Three phases:
• Phase 1: integer algorithm
• Phase 2: algorithm with no integrity constraints
• Phase 3: splitting the TSP global solution
Research Plan: Phase 1

Integer algorithm:
• Modules considered as indivisible parts
• Each module assigned to one and only one robot
• Look for an algorithm that provides an assignment that minimizes the completion time
Research Plan: Phase 2

Algorithm without integrity constraints:
- Relaxation of the integrity constraints
- Each module can be shared among multiple robots
- Expected to provide tighter approximation bounds
Research Plan: Phase 3

Splitting the global TSP solution:

• Compute the TSP solution over all the nodes
• Split it using a heuristic on the modules that considers:
  • Relative positions
  • Size of each module
  • Number of modules
  • Internal structure of modules
# Research Plan

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Thank you for the attention

Questions?