Comparison of Classical and Interactive Multi-Robot Exploration Strategies in Populated Environments

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Outline

What is multi-robot exploration?

Definition

The Multi-robot exploration aims to design efficient robots control for accurately reconstructing an unknown environment.

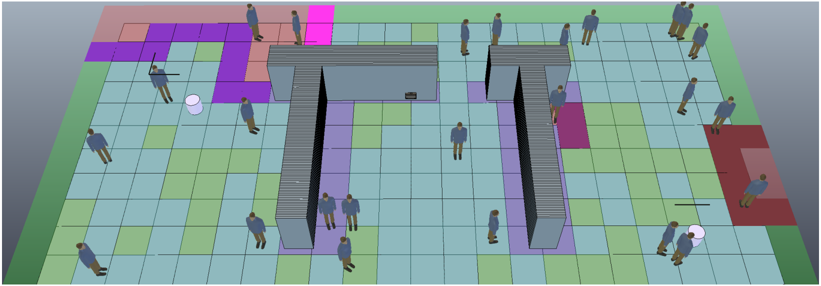
Efficient control and accurate reconstruction

- Control efficiency is addressed at several levels (coverage, time, distance, energy, overlapping, ...)
- Reconstruction accuracy is the degree of closeness to the ground truth

Populated environments

We investigate

- human-aware exploration,
- how can human presence help to explore dynamic environments?



Multi-Agent System simulated in V-REP [Rohmer et al., 2013]

Multi-agent system formalization

Formally let...

- $\mathcal{E}$ be an environment
- $\mathcal{R} = \{R_1, .., R_n\}$ be a set of robots
- $\mathcal{H} = \{H_1, .., H_m\}$ be a set of humans

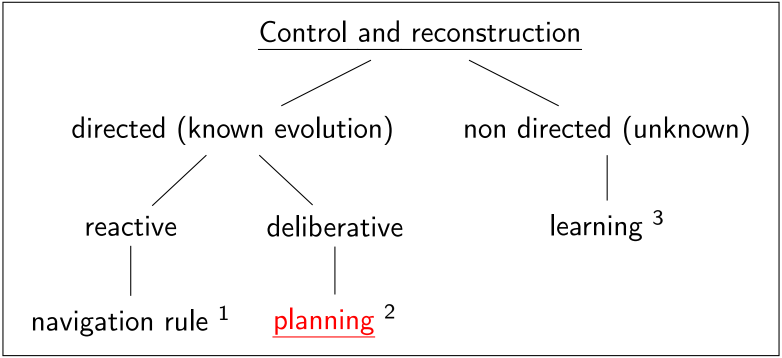
And for exploration...

- $\mathcal{O}_i^t \subset \mathcal{E}$ be $\mathcal{R}_i$'s observation at time t
- $\theta_i^{0:t} = \theta_i^{0:t-1} \cup \mathcal{O}_i^t$ be $\mathcal{R}_i$'s local history

Exploration terminates when...

- $\Theta^{0:t} = \bigcup_{i=1}^{n} \theta_i^{0:t}$ be the global history
- $\nexists \mathcal{O}_i^{t+1} \not\subset \Theta^{0:t}$

Multi-Robot Exploration



MRE classification example

[1] [Baronov and Baillieul, 2007, Morlok and Gini, 2007]

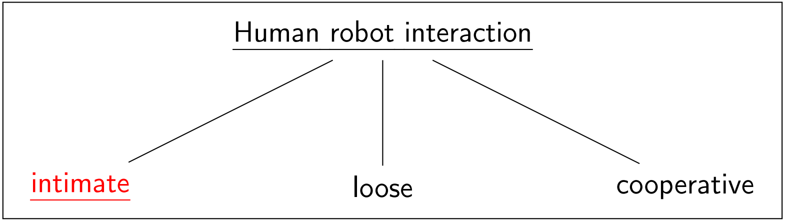
[2] [Yamauchi, 1997, Faigl et al., 2012, Bautin et al., 2012, Burgard et al., 2005, Macedo and Cardoso, 2004, Moorehead et al., 2001]

[3] ?

Human-robot Interaction

Definition [4]

The HRI problem is to understand and shape the interactions between one or more humans and one or more robots.



HRI classification [5]

[4] [Goodrich and Schultz, 2007]
[5] [Takeda et al., 1997]

Summary

Our work bridges together Multi-Robot Exploration Planning and Human-Robot Intimate Interaction into a task allocation framework.

Definition

Robots, tasks, costs, assignments

- $\mathcal{R}$ be a set of robots
- $\mathcal{T}$ be a set of tasks
- $c_{\mathcal{R}_i\mathcal{T}_j}$ be the cost for $\mathcal{R}_i$ to accomplish $\mathcal{T}_j$
- $a_{\mathcal{R}_i\mathcal{T}_j} = \begin{cases} 1 \text{ if } \mathcal{R}_i \text{ must accomplish } \mathcal{T}_j \\ 0 \text{ otherwise} \end{cases}$

$c_{\mathcal{R}_i\mathcal{T}_j}$	$\mathcal{T}$
$\mathcal{R}$	$\mathcal{C}_{\mathcal{R}\mathcal{T}}$

$\xrightarrow{\text{opt.}}$

$a_{\mathcal{R}_i\mathcal{T}_j}$	$\mathcal{T}$
$\mathcal{R}$	$\mathcal{A}_{\mathcal{R}\mathcal{T}}$

Our approach: Mixed Exploration

We consider the following tasks/targets

- frontiers to reach
- humans to interact with (opening doors, etc.)

Frontier based[6] $\mathcal{F} \subset \mathcal{T}$

A frontier is the observed boundary between explored and unexplored space.

Interaction based[7] $\mathcal{H} \subset \mathcal{T}$

Human-robot interaction is defined as the reciprocal influence between a human and a robot, followed by one or more effects.

[6] [Yamauchi, 1997]
[7] [Kaldé et al., 2014]

Positive interaction

What kind of interaction takes advantage of human knowledge in populated environment?

Assumption : Humans have a natural adaptive navigation heuristic.
Interaction : Robots can interact implicitly by following humans

How to define a human-robot interaction cost to speed up exploration?

Cost formula

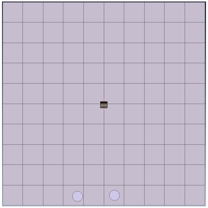
Cost formula $f : \mathcal{R} \times \mathcal{T} \rightarrow \mathbb{R}$

f combines target inactivity time t, distance to target d and reorientation to target o.

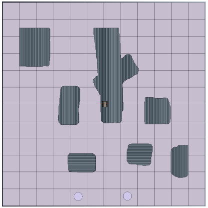
$$f(x, y) = \alpha \cdot g(x, y) + (1 - \alpha) \cdot h(x, y)$$
$$g(x, y) = d$$
$$h(x, y) = \begin{cases} \sigma \cdot (t + o) & \text{if } y \in \mathcal{F} \\ (1 - \sigma) \cdot (t + o) & \text{if } y \in \mathcal{H} \end{cases}$$

$\alpha \in [0, 1]$, weight for immediate costs g and penalty heuristic h
$\sigma \in [0, 1]$, weight for frontier or interaction penalties

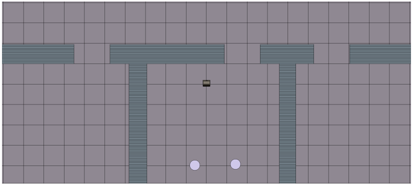
Test environments



(a) Empty ($100m^2$)



(b) Unstructured ($144m^2$)



(c) Structured ($242m^2$)

Parameters

Parameters are as follows:

- Human density (% of env.): $[0, 30]$
- Robot range of view: 2m
- Costs optimization strategy:
  - *individual greedy*
  - *group greedy*
- Modulators: $(\alpha, \sigma) \in [0, 0.25, 0.5, 0.75, 1]^2$

Metrics

Multi Robot Exploration metrics

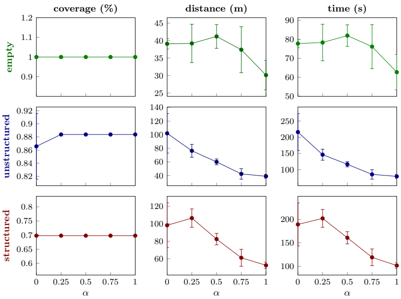
Each scenario is evaluated with classical MRE metrics:

- coverage,
- distance,
- time,
- and number of allocations.

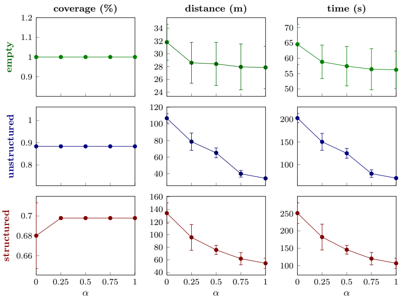
HRI metric [Olsen and Goodrich, 2003, Steinfeld et al., 2006].

We use a common metric in HRI, called the 'Robotic Attention Demand' (RAD). Here we consider the number of interactions initiated during exploration.

Results in non-populated environment

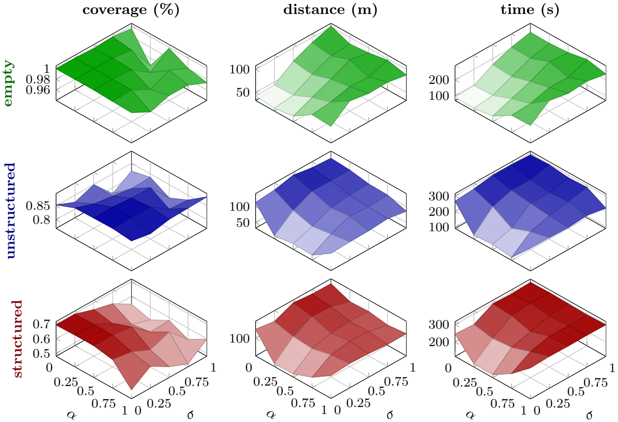


(a) individual greedy

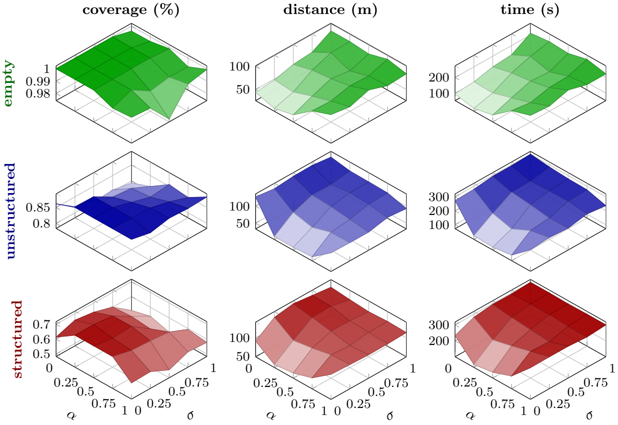


(b) group greedy

Results in populated environment 1/2 (individual greedy)



Results in populated environment 2/2 (group greedy)



Conclusion and perspectives

Conclusion

- our heuristic can improve exploration performances,
- our cost function cannot promote human-robot interactions.

Perspectives

- improve cost function to promote interactions,
- robot-(robot/object) interactions,
- perform real life experiments,
- learn to adapt exploration,
- dynamic parameter tuning.

Thank you for your attention.

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