July 2015

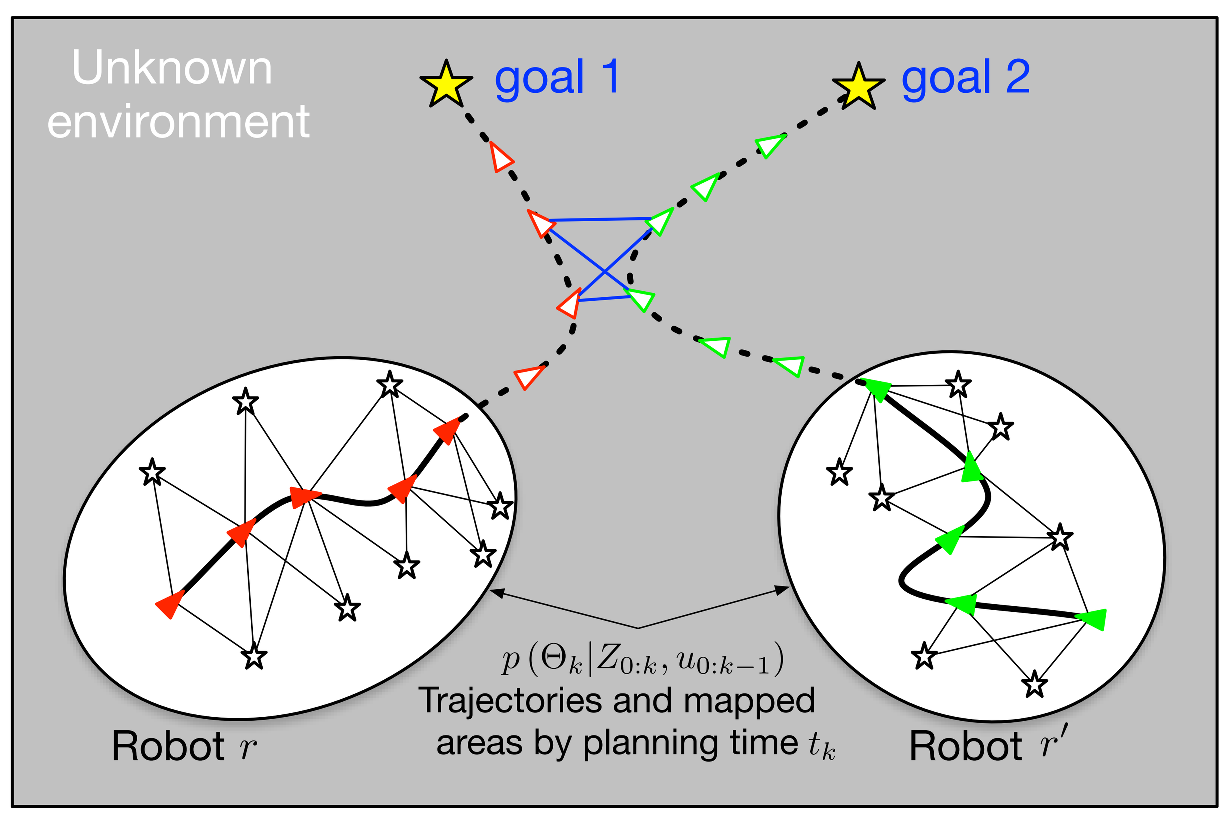
Multi-Robot Active Collaborative Inference in Unknown Environments via Belief Space Planning

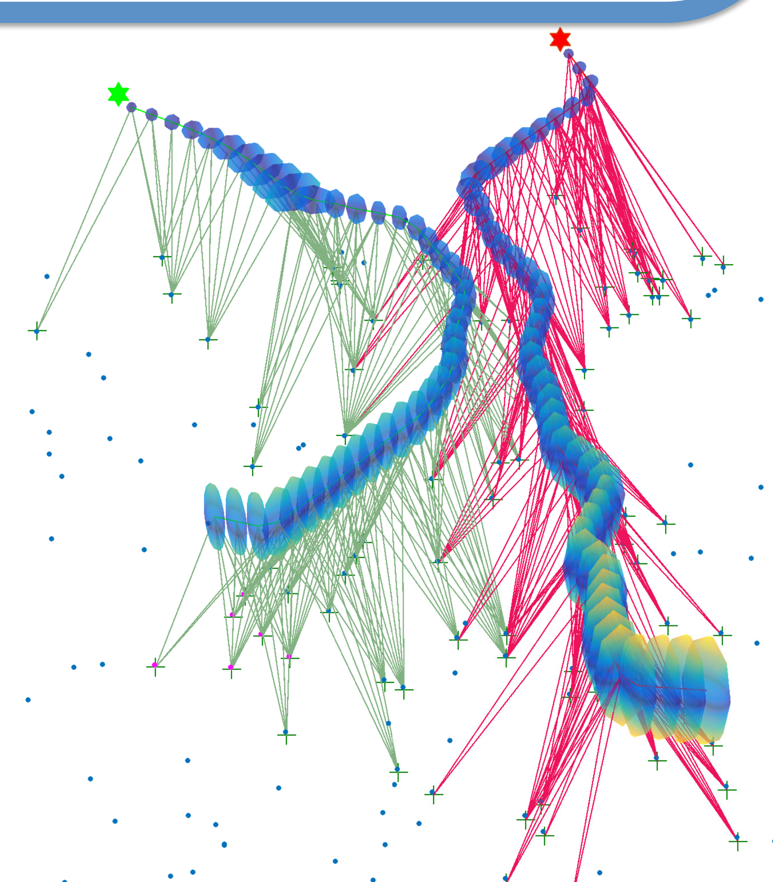
Vadim Indelman

Technion – Israel Institute of Technology

Introduction

- Collaboration between robots can significantly improve estimation accuracy
- Passive aspects of the problem (i.e. robot actions are given) have been extensively investigated
- **This work** – active collaborative inference: how to determine robot actions such that estimation accuracy is improved?





Concept

- Formulate the problem within belief space planning paradigm
- Existing approaches assume the environment to be known, or consider environment observed *by* planning time
- **Key idea**:
  - Reason about future observations of environments that are unknown at planning time
  - Incorporate within the belief indirect multi-robot constraints that correspond to these future observations

Approach

- Denote the joint state for R robots as:

$$\Theta_k \doteq X_k \cup L_k \ , \ X_k \doteq \{X_k^r\}_{r=1}^R$$

- Joint multi-robot PDF at planning time:

$$b(\Theta_k) \ \doteq p(\Theta_k|Z_{0:k}, u_{0:k-1}) \propto \prod_{r=1}^{R} p\left(\Theta_k^r|Z_{0:k}^r, u_{0:k-1}^r\right)$$

- General multi-robot objective function:

$$J(u_{k:k+L-1}) \doteq \mathbb{E}\left[\sum_{l=0}^{L} c_l\left(b\left(\Theta_{k+l}\right), u_{k+l}\right) + c_L\left(b\left(\Theta_{k+L}\right)\right)\right]$$

- Objective: find optimal controls
- Incorporating future multi-robot constraints:

$$b(\Theta_{k+l}) = \eta b(\Theta_{k+l-1}) \prod_{r=1}^{R} p\left(x_{k+l}^r|x_{k+l-1}^r, u_{k+l-1}^r\right) p\left(Z_{k+l}^r|\Theta_{k+l}^{ro}\right),$$

with

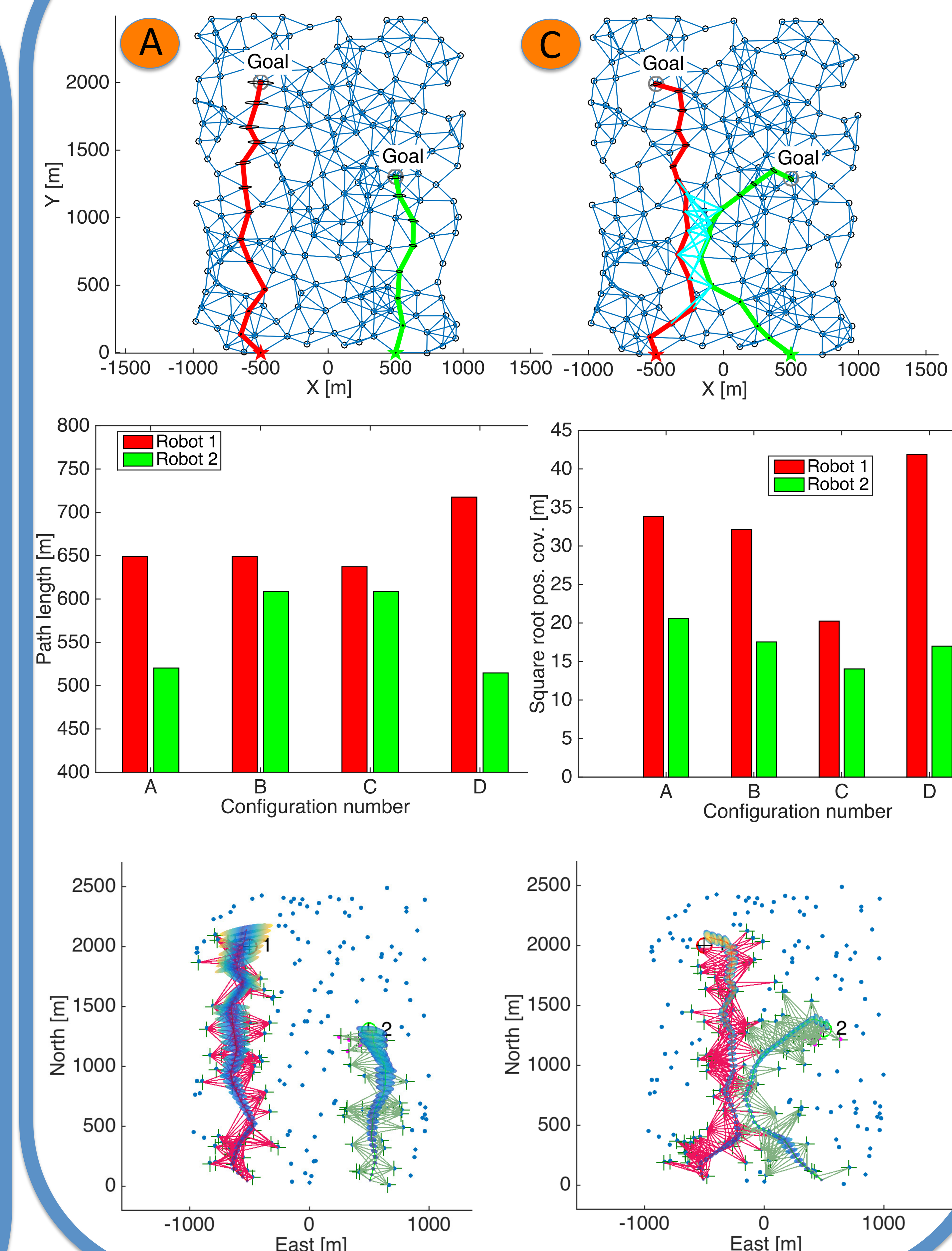
$$p\left(Z_{k+l}^r|\Theta_{k+l}^{ro}\right) = \prod_{l_j \in \Theta_{k+l}^{ro}} p\left(z_{k+l,j}^r|x_{k+l}^r, l_j\right) p\left(z_{k+l,k+l-1}^r|x_{k+l}^r, x_{k+l-1}^r\right)$$

$$\cdot \prod_j p\left(z_{k+l,k+j}^{r,r'}|x_{k+l}^r, x_{k+j}^{r'}\right).$$

References

[1] "Planning in the continuous domain: a generalized belief space approach for autonomous naviga- tion in unknown environments.", V. Indelman, L. Carlone, and F. Dellaert, *Intl. J. of Robotics Research*, 2015

Results



Conclusions

Reasoning about mutual future multi-robot observations of unknown environments within belief space planning can improve estimation accuracy.