Planning in Mobile Robotics

A Short Overview of Research Streams

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Personal overview

- Jan Faigl (*1979)
- 2013 dpt. of Computer Science and Engineering (ATG)
- 2003–2012 dpt. of Cybernetics (IMR)
- 2010 Ph.D. thesis "*Multi-Goal Path Planning in Cooperative Sensing*"
- Research Interest (related to *mobile robotics*)
  - multi-goal path and motion planning, computational geometry, optimal sampling design, *multi-robot system*
  - **robotic systems for autonomous long-term environment monitoring**
- *Personal Curiosities*
  - FreeBSD at the workstation

    since $\sim$ *2000 (starting with FreeBSD 3.4)*
  - Vegetarian

    since $\sim$ *1997*
  - Hiking, biking, swimming, running

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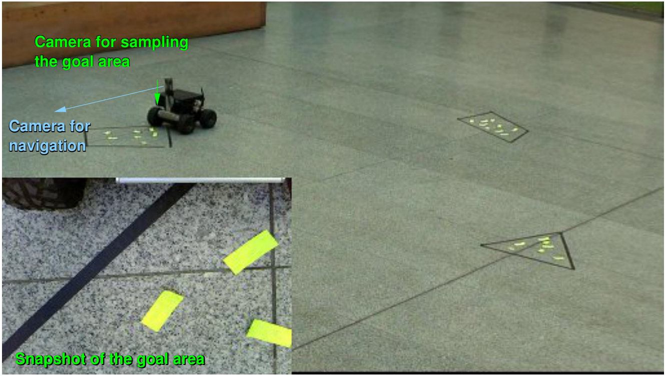
Multi-Goal Path Planning for Autonomous Mobile Robots

Inspection, surveillance or environment monitoring missions.

E.g., Visit goal regions to take a sample measurement at each goal



The proposed planning framework is based on Self-Organizing Map

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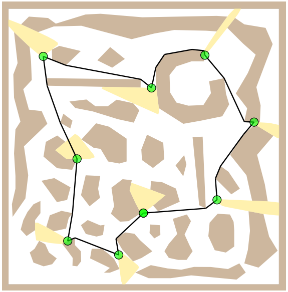
Problem Specification:

- A map of the environment
- A set of goals
- A shortest path visiting all requested goals
- Sensing and motion constraints
- Autonomous navigation capabilities



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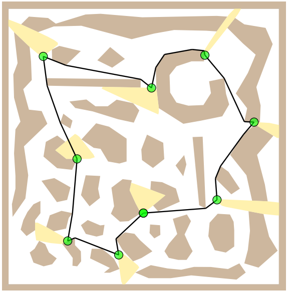

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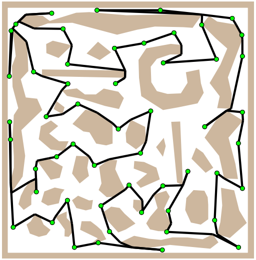
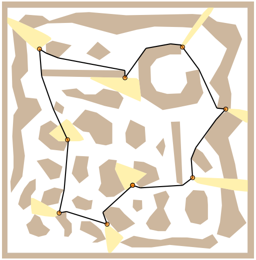
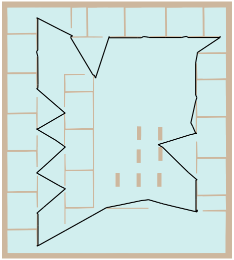
Unifying Planning Framework



Point Goals



Polygonal Goals



Continuous Sensing

- Faigl J.,*Approximate Solution of the Multiple Watchman Routes Problem with Restricted Visibility Range*, IEEE Transactions on Neural Networks, 21(10):1668–1679, (2010).
- Faigl J., Přeučil L., *Inspection planning in the polygonal domain by Self-Organizing Map*, Applied Soft Computing, 11(8):5028–5041, (2011).
- Faigl J., Vonásek V., Přeučil L., *Visiting Convex Regions in a Polygonal Map*, Robotics and Autonomous Systems, doi:10.1016/j.robot.2012.08.013.

Autonomous Inspection / Surveillance

The problem is to maximize the frequency of goals' visits.

Visit must be precise and reliable

SURFNav - Robust and reliable autonomous navigation with mathematical model of the location uncertainty evolution

$$\boldsymbol{A}_{i+1} = \boldsymbol{R}_i^T \boldsymbol{M}_i \boldsymbol{R}_i \boldsymbol{A}_i \boldsymbol{R}_i^T \boldsymbol{M}_i^T \boldsymbol{R}_i + \boldsymbol{R}_i^T \boldsymbol{S}_i \boldsymbol{R}_i,$$

$$\boldsymbol{M}_i = \begin{bmatrix} 1 & 0 \\ 0 & m(a_i, a_{i+1}, \mathcal{M}) \end{bmatrix}, \boldsymbol{S}_i = \begin{bmatrix} s_i \eta^2 & 0 \\ 0 & \tau^2 \end{bmatrix}$$

$m(a_i, a_{i+1}, \mathcal{M})$ - model of the visible landmarks

$\eta, \tau \sim$ *"odometry and heading error"* (variances)

Krajník T., Faigl J., Vonásek V., Košnar K., Kulich M., Přeučil L., *Simple yet stable bearing-only navigation*, Journal of Field Robotics, 27(5):511–533, 2010.

We proposed planning framework considering model of the localization uncertainty to improve reliability and robustness of autonomous navigation.

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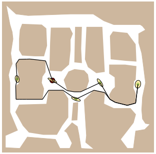
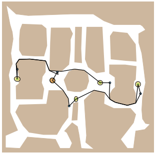
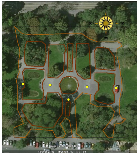
Autonomous Navigation - Experimental Results



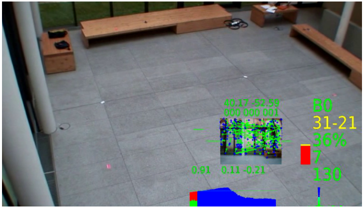




Real overall error at the goals decreased from 0.89 m $\rightarrow$ 0.58 m

(improvement about 35%)

Overall error at the goals decreased from 16.6 cm $\rightarrow$ 12.8 cm



Improvement of the success of the goals' visits 83%$\rightarrow$95%

Faigl J., Krajník T., Vonásek V., Přeučil L., *On Localization Uncertainty in an Autonomous Inspection*, ICRA, 1119–1124, 2012.

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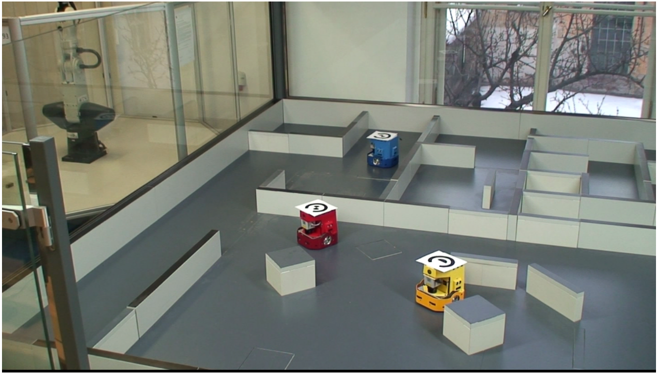
SyRoTek - A Robotic System for Education

- Design of the system architecture
- Implementation of the core system functions



Kulich, M., Chudoba, J., Košnar, K., Krajník, T., Faigl, J., Přeučil, L., *SyRoTek-Distance Teaching of Mobile Robotics*, IEEE Transactions on Education, doi: 10.1109/TE.2012.2224867.

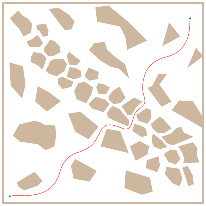
Autowaves based Path Planning

- *Autowaves* - a class of nonlinear waves that propagate through an active media.
- *Reaction-Diffusion* (RD) models – dynamical systems capable to reproduce the autowaves.

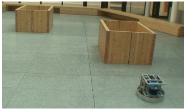
- RD model describes spatio-temporal evolution of two state variables

$$\begin{aligned} \dot{u} &= \varepsilon\left(u - u^3 - v + \phi\right) + D_u \triangle u \\ \dot{v} &= \left(u - \alpha v + \beta\right) + D_v \triangle u \end{aligned}$$

FitzHugh-Nagumo (FHN) model



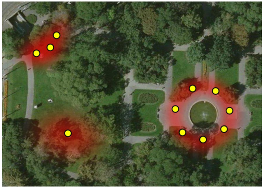
Vázquez-Otero A., Faigl J., Muñuzuri A. P., *Path Planning based on Reaction-Diffusion Process*, IROS, 896–901, 2012.



Surveillance with Swarm of MAVs

Optimal static coverage of areas using swarm of MAVs while dynamic feasibility of the coverage is guaranteed.

An unsupervised learning would provide on-line problem solving.

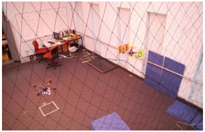


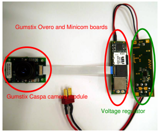
Cooperation with Prof. Vijay Kumar (GRASP, PENN)

Vision based relative localization (enabling technology)

- On-board image processing for Gumstix Overo/Caspa

processing up to 60 Hz





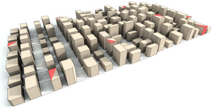
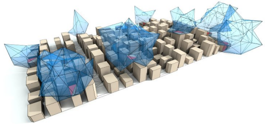
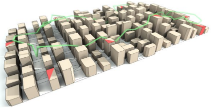
Faigl J., Chudoba J., Krajnik T., Saska T., Přeučil L., Low-Cost Embedded System for Relative Localization in Robotic Swarms, ICRA, 2013.

Surveillance of Objects of Interest in 3D

- Multi-goal path planning in 3D considering motion and sensing constraints.

The idea is based on SOM for the WRP (2D)

- Motion constraints considered as probabilistic roadmap
- Fast visibility queries are the key issue
- Objects can be covered from covering spaces

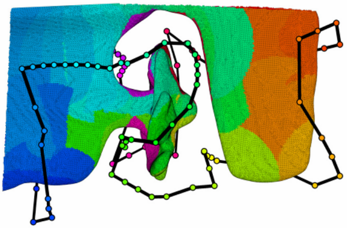
Janoušek P., Faigl J., Speeding Up Coverage Queries in 3D Multi-Goal Path Planning, ICRA, 2013.

Self-Organizing Maps for Multi-Goal Path Planning

- Problems:
  - Optimal sampling design and motion constraints
  - High-dimensional configuration spaces
  - Models of sources of uncertainties

planning in belief space

- Framework for Planning Robotic Missions:
  - Inspection, Coverage, Surveillance
  - Environment Monitoring and Data Collections



Post-Doc GAČR (2013-2015)

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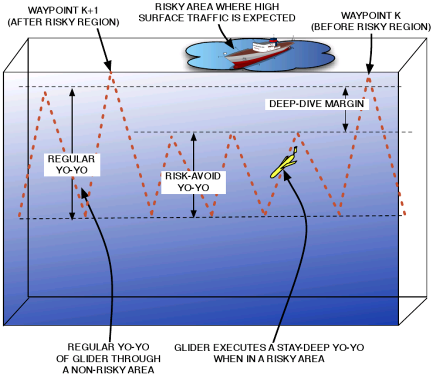
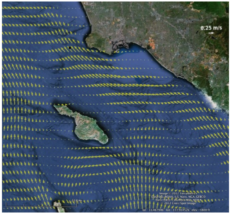
Multi-Goal Path Planning in Spatio-Temporal Spaces

- Find a short and low risk path for an autonomous underwater vehicle
- Consider ocean currents influencing the autonomous navigation





Thank you!