Safe Prediction-Based Local Path Planning using Obstacle Probability Sections

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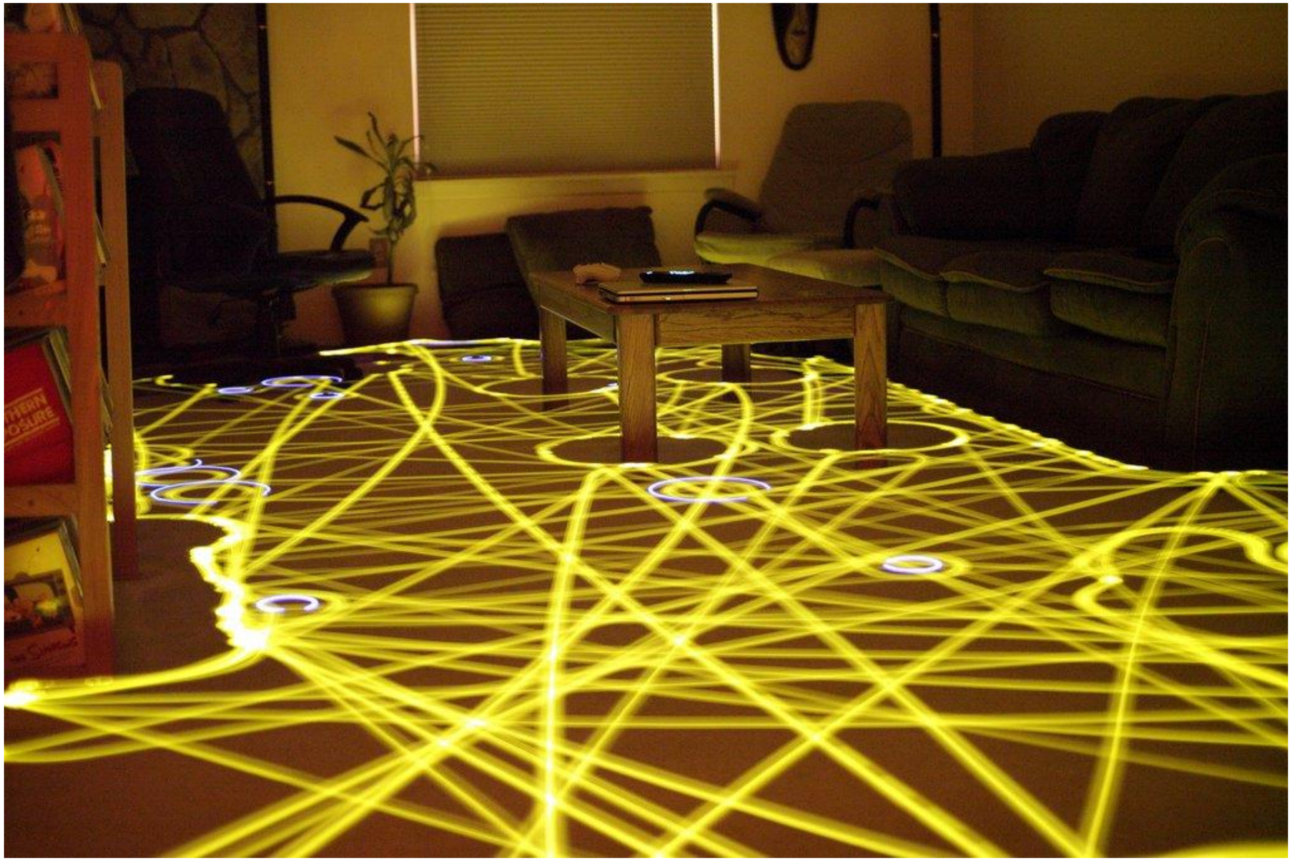
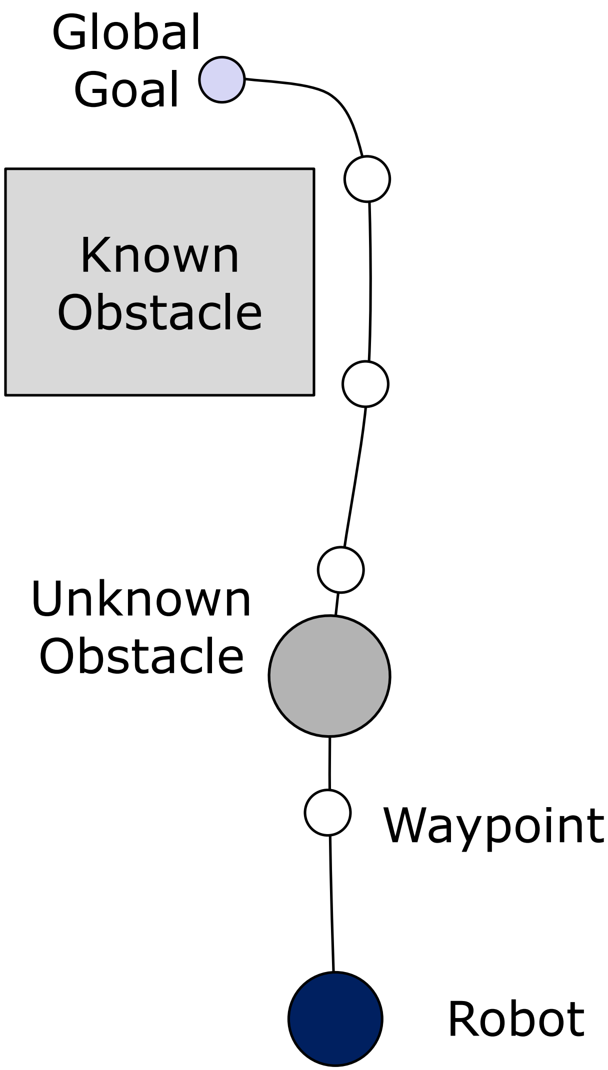
Motivation

Local path planning for mobile ground robots with moving obstacles



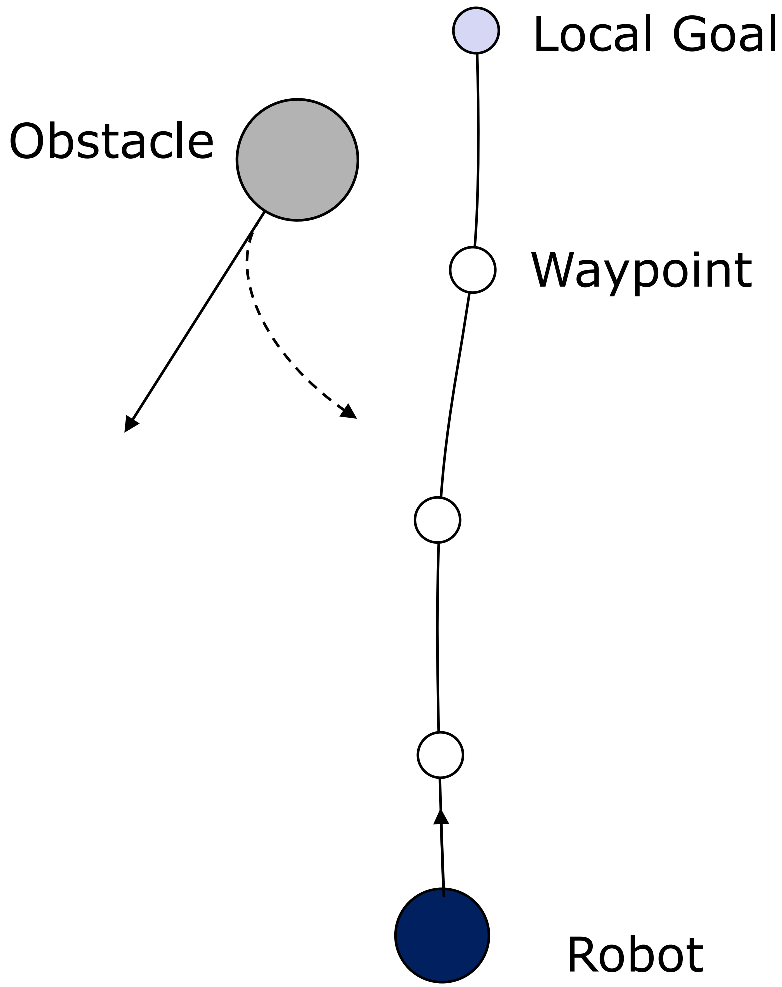
Motivation



In partially or completely unknown environment:

- Safe local path planning is required
- Minimizing collision risk has the highest priority
- The robot‘s motion law, future collision risks and obstacle motion have to be considered

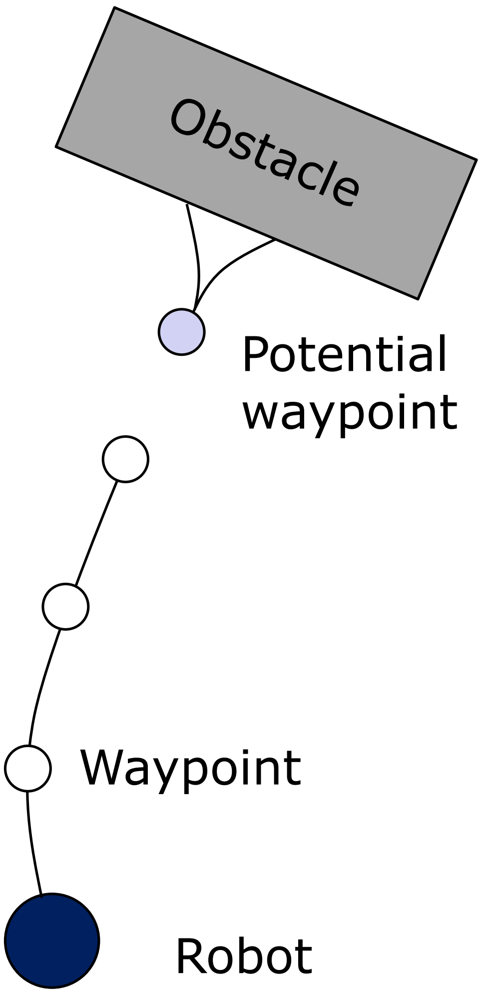
Problem Description: Dynamic Obstacles



- Compromise between total safety and unrestricted motion
- Sudden deviation from assumed obstacle motion
  - Possible collision
- Considering all possible motions of obstacles leads to huge obstacle regions

How to consider atypical motion without making path planning impossible?

Problem Description: Future Collision Risks



- A waypoint is collision-free but further motions would lead to collisions
- A path cannot reach the goal, planning got stuck
- Checking future collision risks is required
  - Consideration of robot`s motion law and initial configuration

State of the art

Examples of other local path planning approaches:

	Moving obstacles	Atypical motion	Future collision risks	Robot dynamics
Schmidt & Berns	NO	NO	NO	YES
Petti & Fraichard (PMP)	YES	NO	YES	YES
Goerzen & Whalley	NO	NO	NO	YES
Our approach	YES	YES	YES	YES

Method

Method description:

1. Generate a 2D grid map
2. Calculate motion probability sections for moving obstacles
3. Determine a local goal according to criteria
4. Apply the Modified Wavefront algorithm
5. Generate a path considering criteria

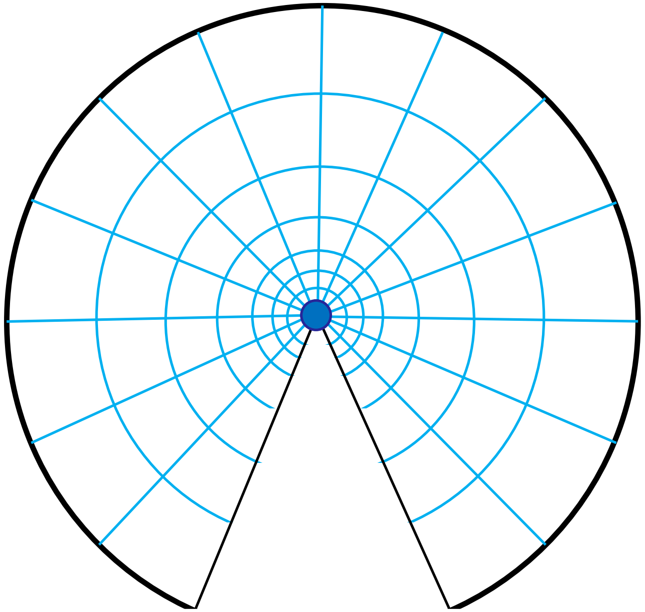
Criteria for waypoints:

- Outside of obstacle probability regions
- Low future collision risks
- Safe distance to obstacles and sensor range
- Reachable

Method

1. Generate a 2D grid map

- Construct a grid map within the robot‘s sensor range
- Consider the field of view‘s spherical geometry of the applied sensor
- Adjust the cells to the field of view‘s shape



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Method

2. Calculate motion probability sections for moving obstacles

- Represent possible obstacle positions for a given time frame

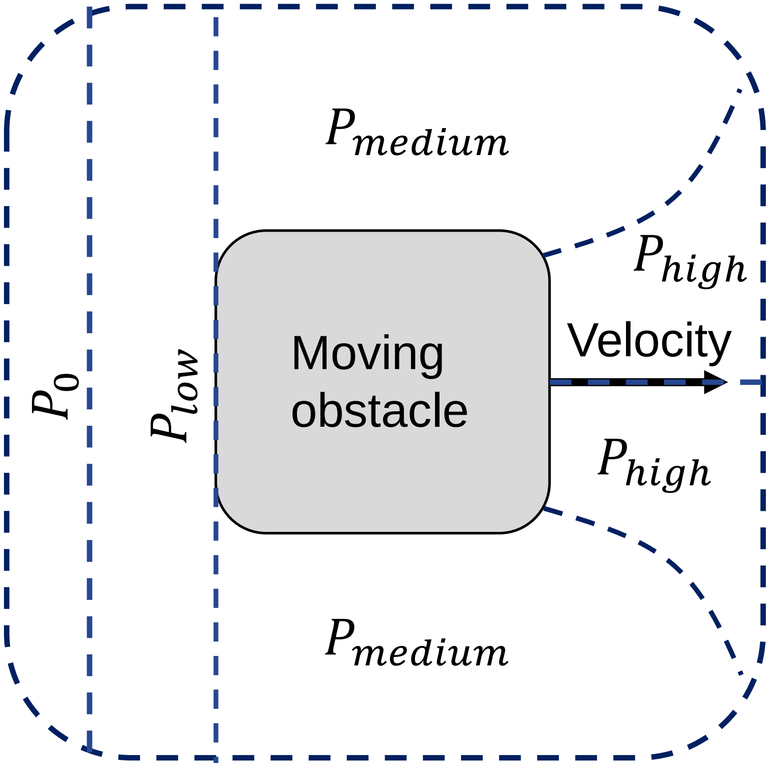
Approach:

- Determine an approximated reachable set for obstacles
- Calculate the maximum distance with the formula for uniform acceleration
- Separate the set into sections
- Assign probabilities to the sections determined by using standard normal distribution

Method

2. Calculate motion probability sections for moving obstacles

Division into sections:
- With regards to
  - Kinematics
  - Motion direction
  - Current velocity



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Method

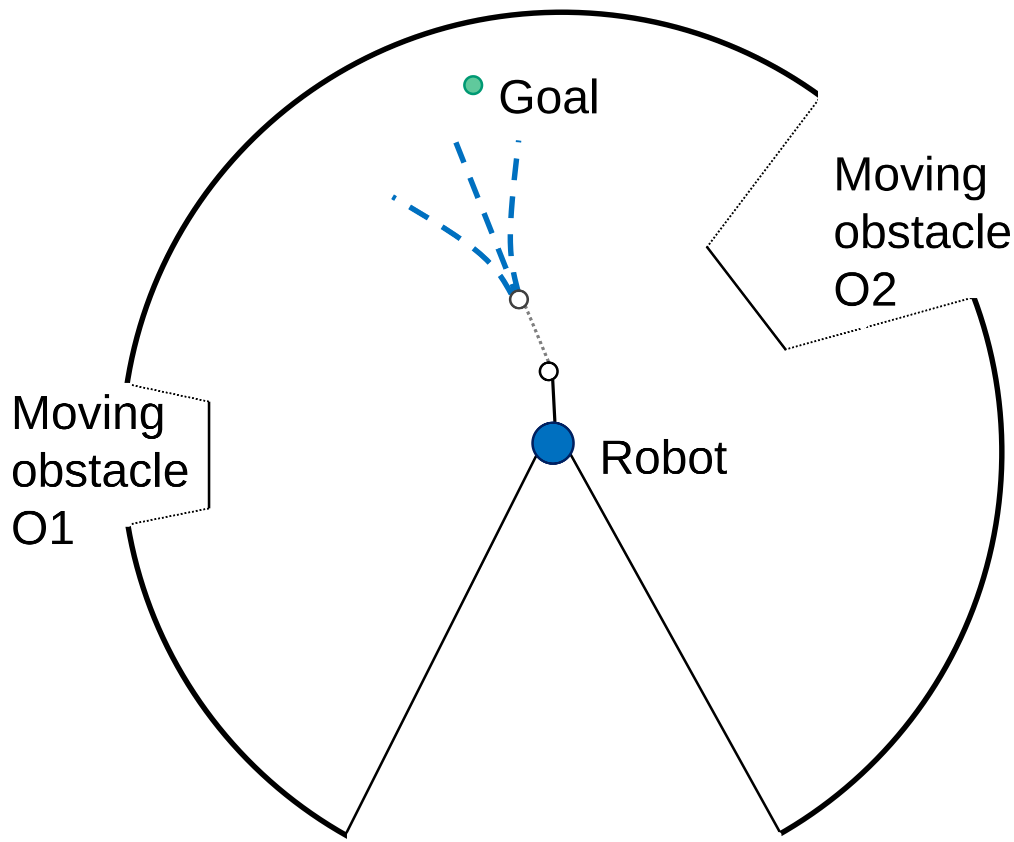
3. Determine a local goal according to criteria

- As close as possible to global goal and not within an obstacle region

- Check future collision risks:
  - Applying the Inevitable Collision State (ICS) method [Fraichard]
  - ICS is a state in which a collision with an obstacle is unavoidable
  - A state is an ICS if no trajectory exists that does not lead to a collision
  - Checking all possible trajectories is not possible – simplified ICS approach [Petti]

Method

3. Determine a local goal according to criteria



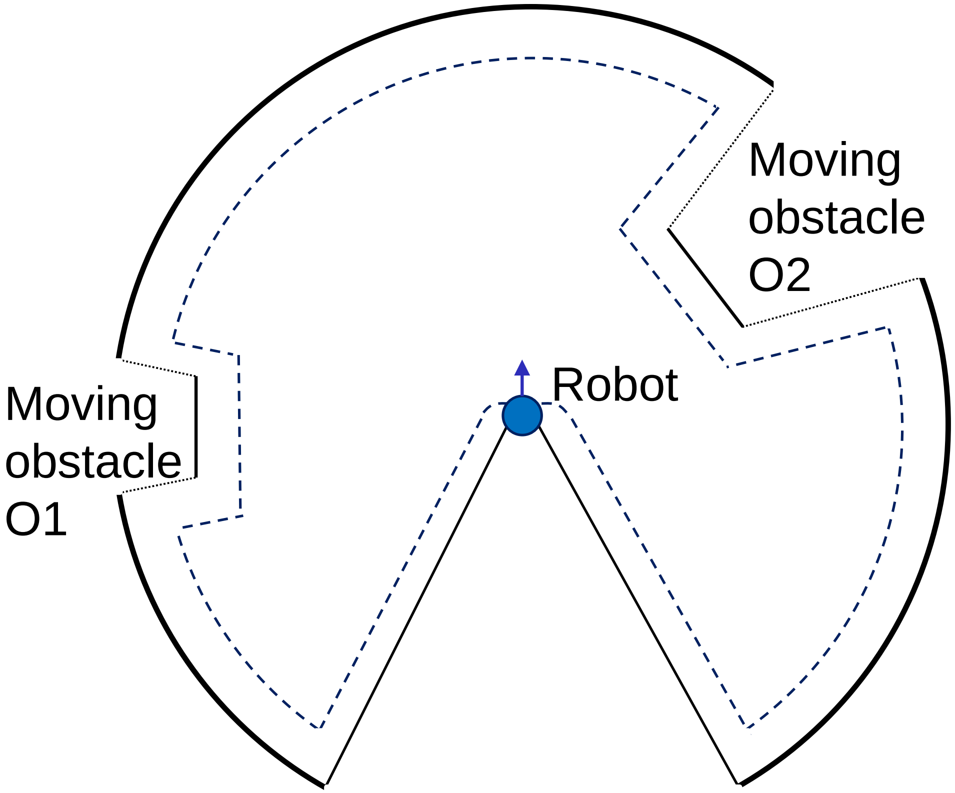
ICS-check:

- 3 trajectories tested for collisions:
  - Maximum turning maneuvers
  - Straight forward motion
- With maximum deceleration

Method

3. Determine a local goal according to criteria

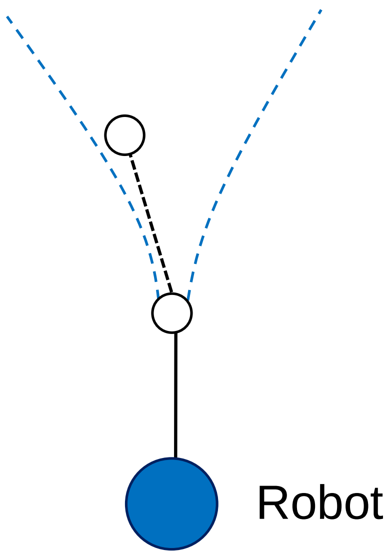
- ❑ Safety distance: To avoid collisions caused by simplification in the approach



- For obstacles in the planned motion direction:
  - Minimum braking distance + half of the robot length
- Else:
  - Half of the robot length

3. <u>Determine a local goal according to criteria</u>

- Reachability:
  - Checks if trajectories are feasible



- Approximated reachable set with assumed slow velocity reduction (to not interrupt motion flow)
- Maximum turning maneuvers as boundaries

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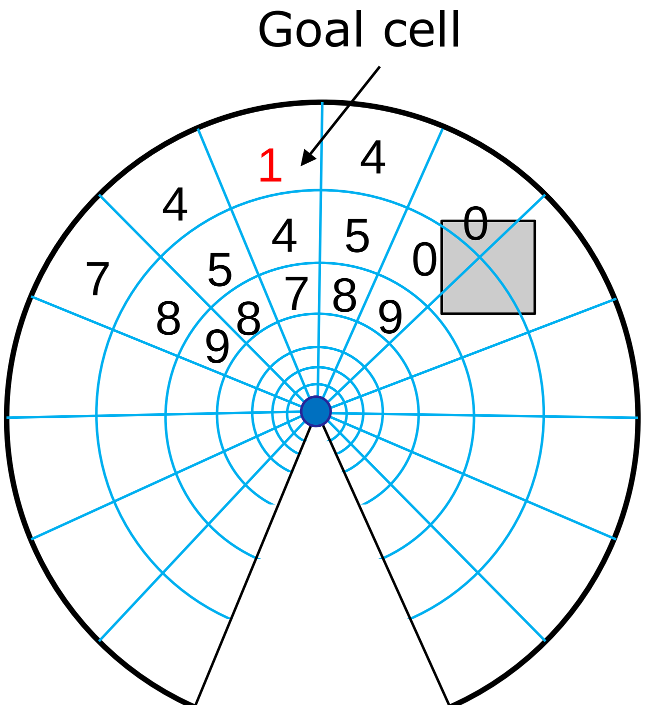
Method

4. Apply the Modified Wavefront algorithm [Oh]

- Requires a grid map
- Sets the goal cell to the local goal and its cost value to the minimum
- Assigns cost values to the neighboring cells



Advantages:

- Applicable in 2D and 3D environments
- Finds shortest paths
- Real-time capable
- No local minima

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Method

5. Generate a path considering criteria

A waypoint is added to the path if:

- it has a lower cost value than the last waypoint in the path
- it fulfills the criteria checked during the local goal selection

Evaluation

Tests in OpenRAVE:

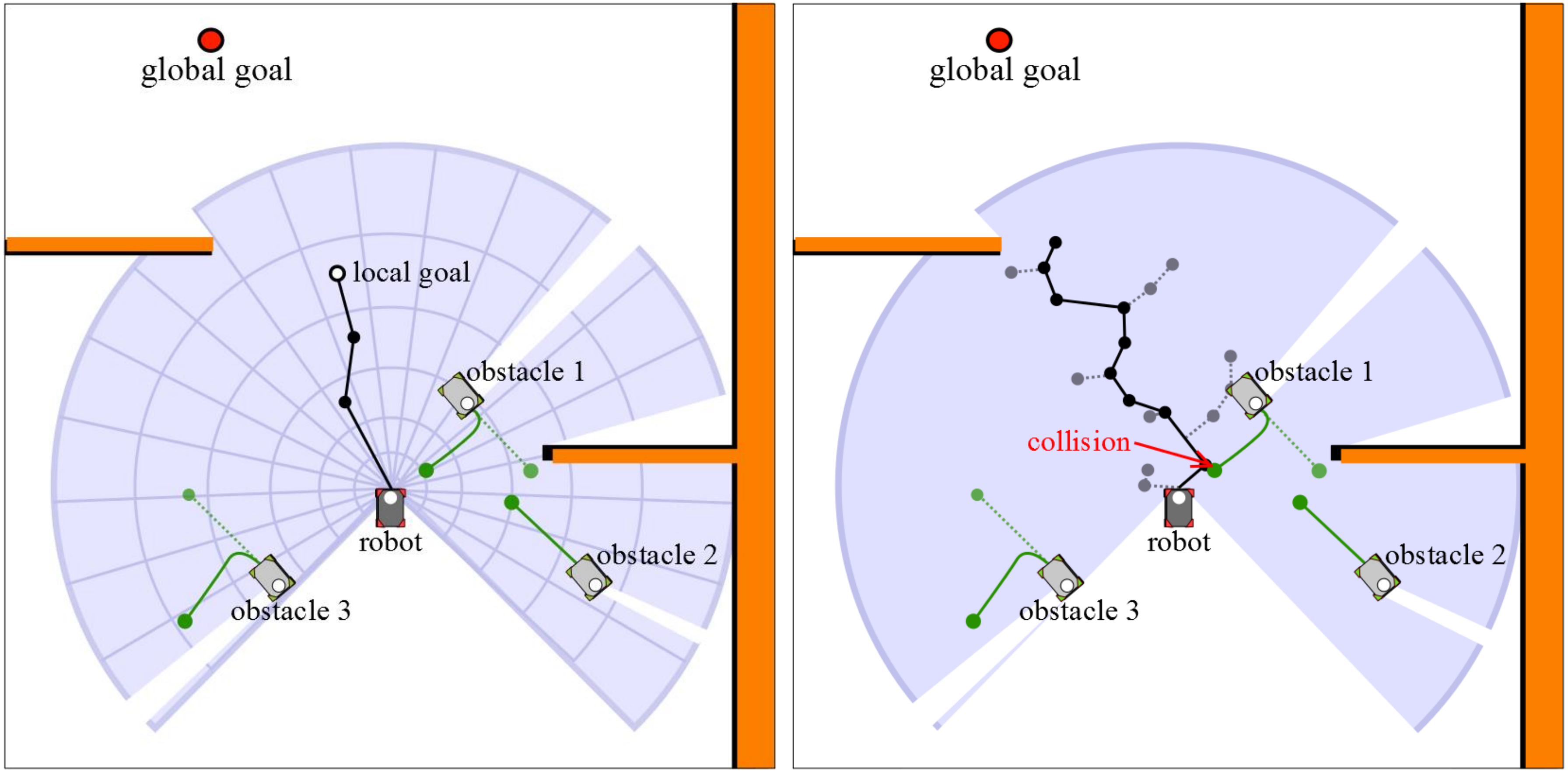
- KUKA youBots as the robot and moving obstacles
- 2D laser scanner applied to the robot (Ø 10m)
- Simple motion model
- Up to four dynamic obstacles within the robot‘s sensor range
- The robot has to be in a safe situation in the initial state

Compared with the Partial Motion Planning (PMP) method [Petti]:

- It is based on Rapidly-Exploring Random Tree (RRT),
- checks Inevitable Collision States (ICS) and
- predicts future motion of obstacles with motion patterns

Evaluation

In contrast to PMP our approach avoided all collisions in the simulations



Presented algorithm

PMP algorithm

Evaluation

Results

- The main contribution is the proposed method avoids collisions even for atypically moving obstacles
- If possible, the planner always found a safe path to the global goal in our simulations
- In regions with high collision risks, the local goal is closer to the start cell than to the global goal

Conclusion

- A combination of probability sections, ICS and reachability checks led to safe paths within the robot‘s field of view

Future work:

- Path smoothing
- Optimization of calculation time
- Minimum harm in case of a collision
- Extension to 3D environments

Thank you for your attention

In case of questions:
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Bibliography

[Schmidt]	D. Schmidt, K. Berns, "Construction Site Navigation for the Autonomous Excavator Thor", in 6th International Conference on Automation, Robotics and Applications (ICARA), IEEE, 2015, pp. 90-97.
[Petti]	S. Petti, T. Fraichard, "Safe Motion Planning in Dynamic Environments", in IEEE/RSJ International Conference on Intelligent Robots and Systems, 2005, pp. 2210-2215.
[Goerzen]	C. Goerzen, M. Whalley, "Minimal Risk Motion Planning: a new Planner for Autonomous UAVs", in AHS International Specialists Meeting on Unmanned Rotorcraft, 2011.
[Oh]	J. S. Oh, Y. H. Choi, J. B. Park, Y. F. Zheng, "Complete Coverage Navigation of Cleaning Robots using Triangular Cell Based Map", in IEEE Transactions on Industrial Electronics, vol. 51, IEEE, 2004, pp. 718-726.
[Fraichard]	T. Fraichard, H. Asama, "Inevitable Collision States. A Step towards Safer Robots?", in IEEE/RSJ International Conference on Intelligent Robots and Systems, 2003, pp. 388-393.