7630 – Autonomous Robotics
Obstacle Avoidance

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Today

Obstacle Avoidance

Objectives

- Follow a trajectory/path/behaviour while avoiding collision with obstacles.
- Obstacle avoidance: move around the obstacles.
- Collision avoidance: avoid collision by stopping.

Requirements

- Local perception of the environment.
- Eventually a local map.
- Eventually a kinematic/dynamic model of the robot.

Outline

Reference Obstacle Avoidance

- Bug 1 and Bug 2
- Vector-Field Histogram
- Dynamic Window and Ego-Kinematic Space

Specialized Obstacle Avoidance

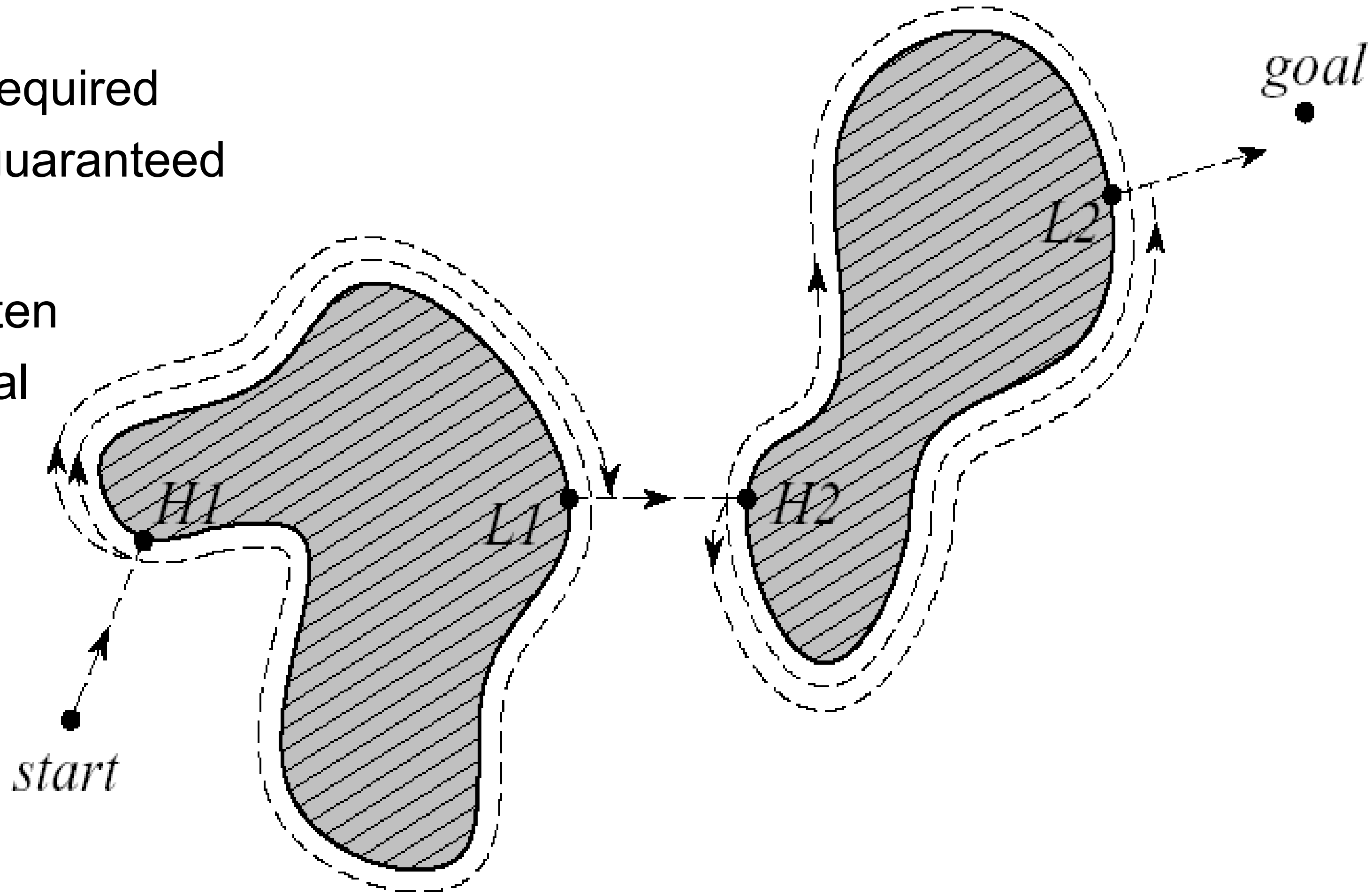
- Trajectory deformation
- Lane Following
- (Reciprocal) Velocity Obstacles

Outline

Obstacle Avoidance: Bug1

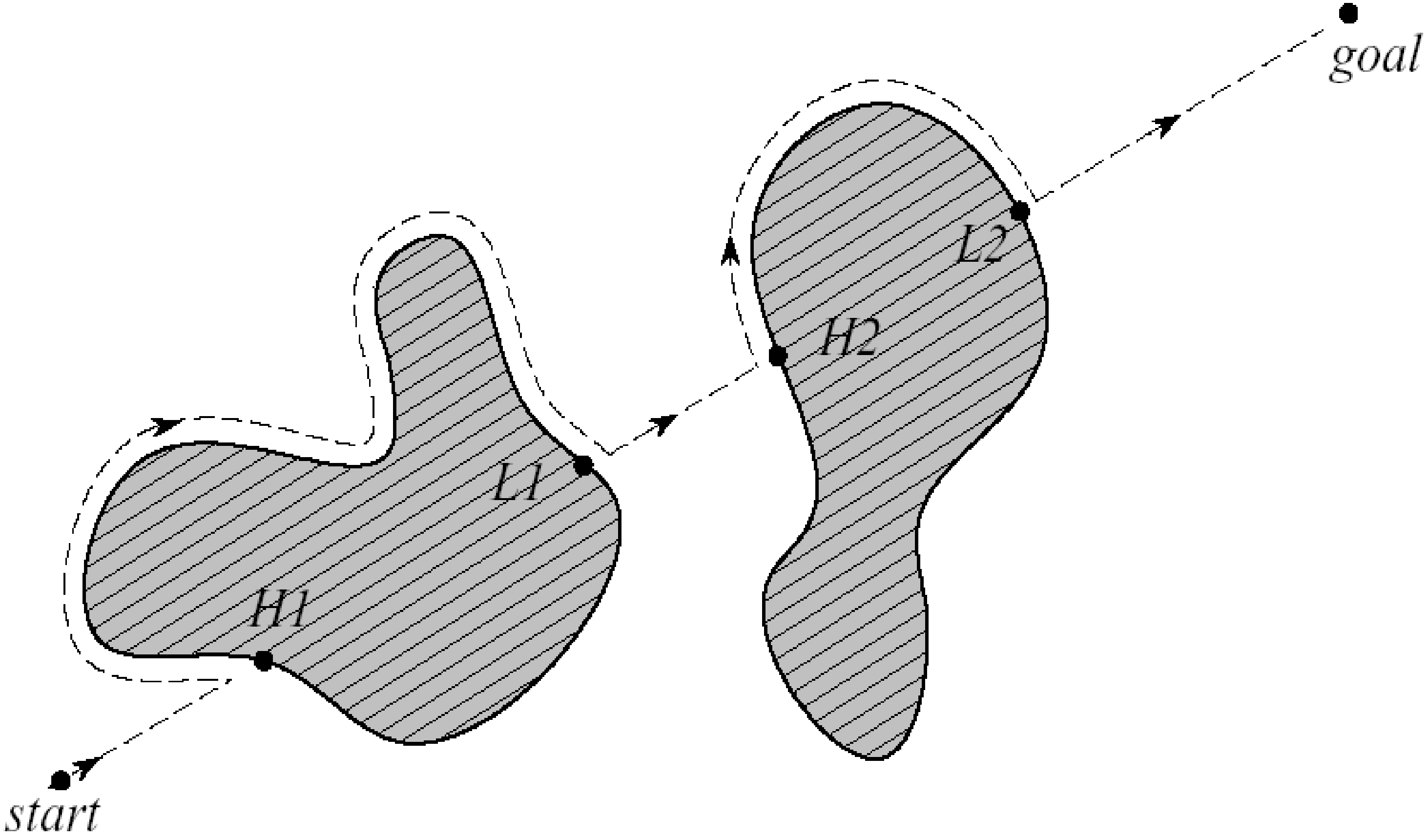
- Following along the obstacle to avoid it
- Each encountered obstacle is once fully circled before it is left at the point closest to the goal

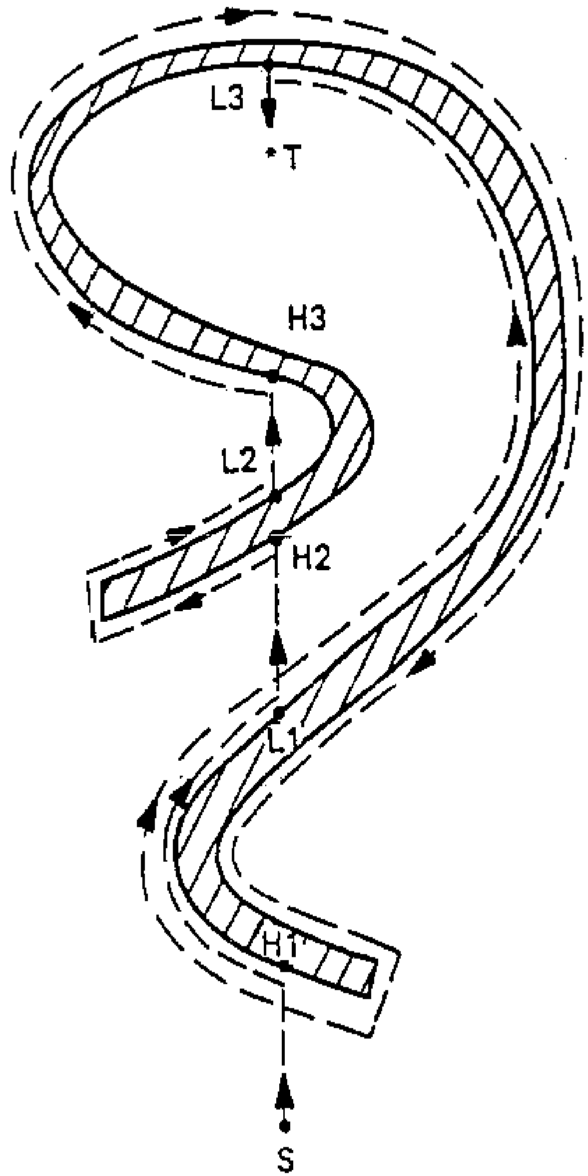
- Advantages
  - No global map required
  - Completeness guaranteed
- Disadvantages
  - Solutions are often highly suboptimal



Obstacle Avoidance: Bug2

- Following the obstacle always on the left or right side
- Leaving the obstacle if the direct connection between start and goal is crossed





Outline

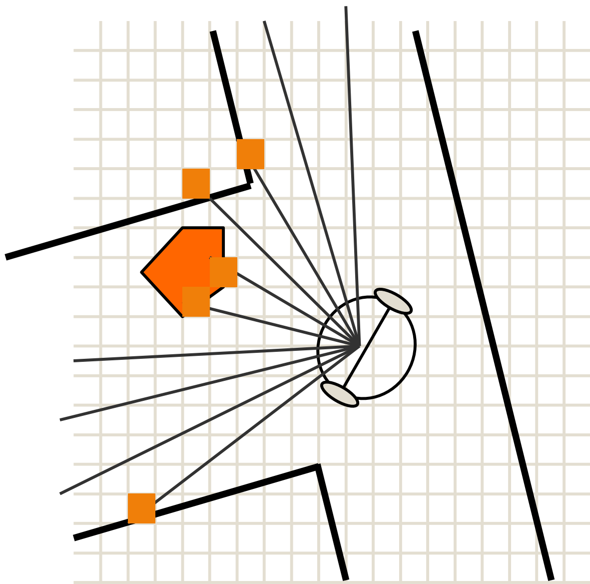
Obstacle Avoidance: Vector Field Histogram (VFH)

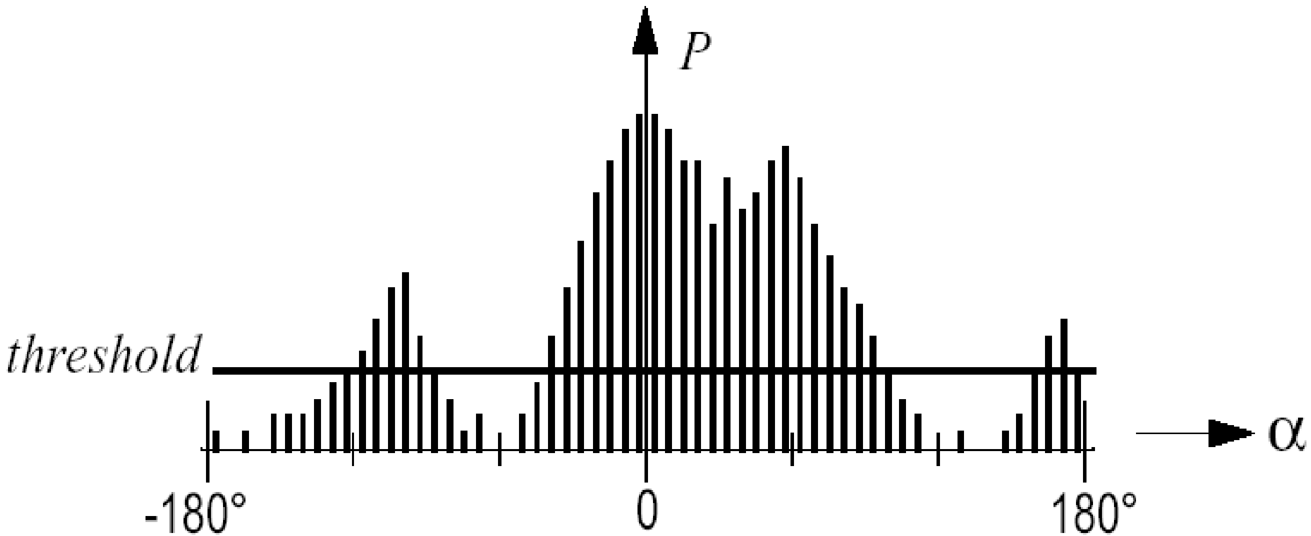
- Environment represented in a grid (2 DOF)
  - cell values equivalent to the probability that there is an obstacle
- Reduction in different steps to a 1 DOF histogram
  - The steering direction is computed in two steps:
    - all openings for the robot to pass are found
    - the one with lowest *cost function G* is selected

$$G = a \cdot \text{target\_direction} + b \cdot \text{wheel\_orientation} + c \cdot \text{previous\_direction}$$

target_direction = alignment of the robot path with the goal
wheel_orientation = difference between the new direction and the currrent wheel orientation
previous_direction = difference between the previously selected direction and the new direction

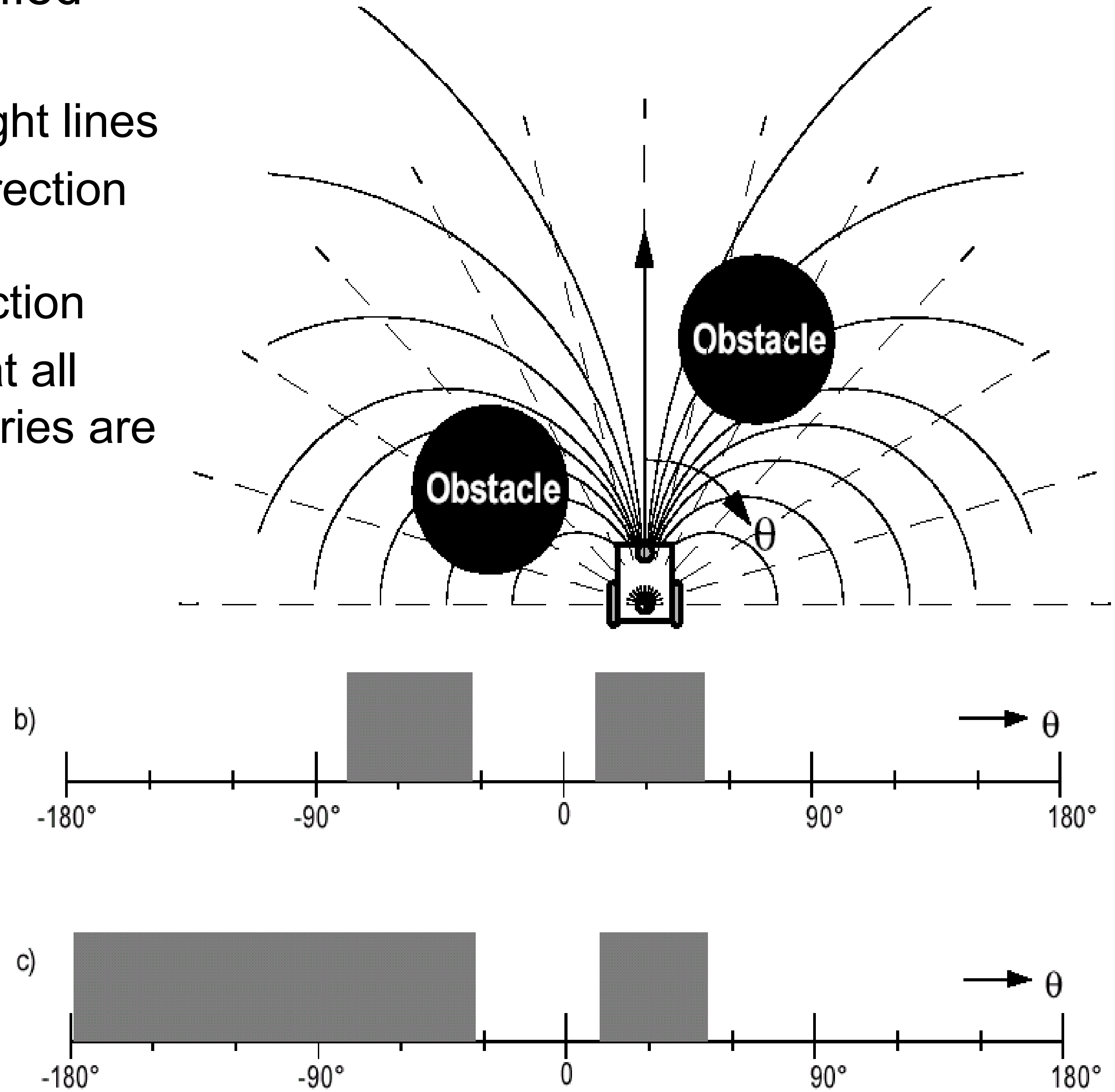
Borenstein et al.





Obstacle Avoidance: Vector Field Histogram+ (VFH+)

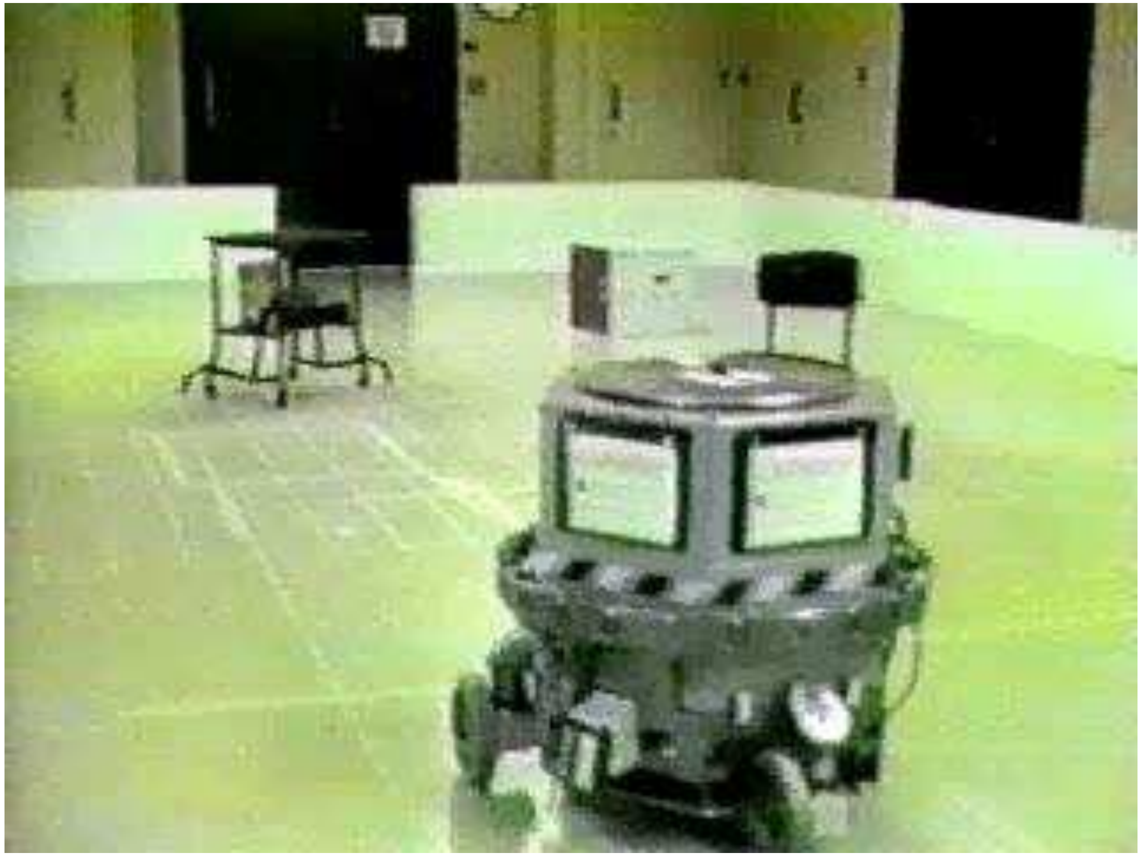
- Accounts also in a very simplified way for vehicle kinematics
  - robot moving on arcs or straight lines
  - obstacles blocking a given direction also blocks all the trajectories (arcs) going through this direction
  - obstacles are enlarged so that all kinematically blocked trajectories are properly taken into account



Borenstein et al.

Obstacle Avoidance: Limitations of VFH

- Limitations:
  - Limitation if narrow areas (e.g. doors) have to be passed
  - Local minima might not be avoided
  - Reaching of the goal can not be guaranteed
  - Dynamics of the robot not really considered



Borenstein et al.

Outline

Obstacle Avoidance: Dynamic Window Approach

- The **kinematics** of the robot are considered via search in velocity space:
  - Circular trajectories : The dynamic window approach considers only circular trajectories uniquely determined by pairs (v,ω) of translational and rotational velocities.
  - Admissible velocities : A pair (v, ω) is considered admissible, if the robot is able to stop before it reaches the closest obstacle on the corresponding curvature. (b:breakage)
  - Dynamic window : The dynamic window restricts the admissible velocities to those that can be reached within a short time interval given the limited accelerations of the robot

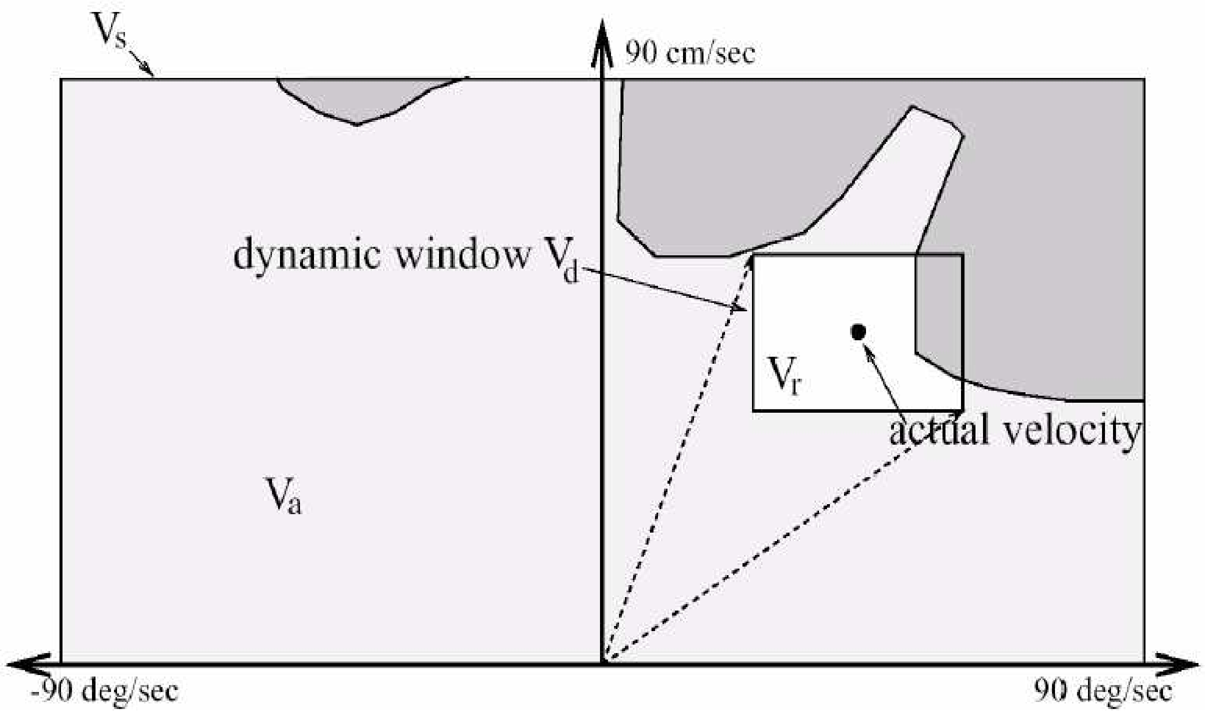
$$V_d = \left\{ (v, \omega) \middle| v \in \left[v_a - \dot{v} \cdot t, v_a + \dot{v} \cdot t \right] \wedge \omega \in \left[\omega_a - \dot{\omega} \cdot t, \omega_a + \dot{\omega} \cdot t \right] \right\}$$

Obstacle Avoidance: Dynamic Window Approach

- Resulting search space
  - The area *Vr* is defined as the intersection of the restricted areas, namely,

$$V_r = V_s \cap V_a \cap V_d$$

V_s: static limits in velocity
V_d: dynamic limits in change in velocity
V_a: limits due to nearby obstacles



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Dynamic Window Approach

- Maximizing the objective function
  - In order to incorporate the criteria target heading, and velocity, the maximum of the objective function, $G(v,\omega)$, is computed over V_r.

$$G(v,\omega) = \sigma\left(\alpha \cdot heading(v,\omega) + \beta \cdot dist(v,\omega) + \gamma \cdot velocity(v,\omega)\right)$$

heading = measure of progress toward the goal
dist = Distance to the closest obstacle in trajectory
velocity = Forward velocity of the robot, encouraging fast movements

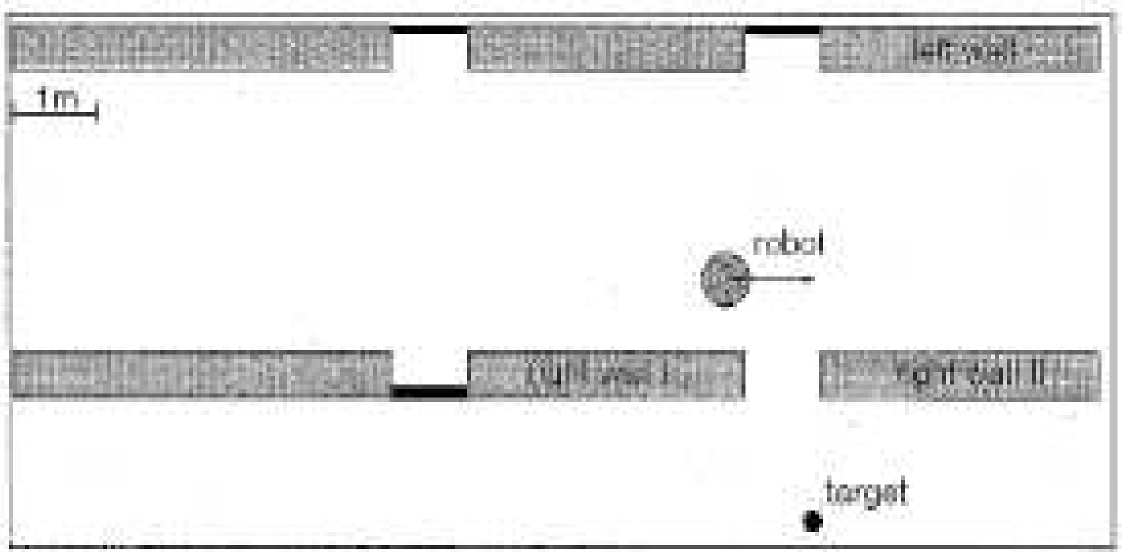

Figure 2. Example Situation.

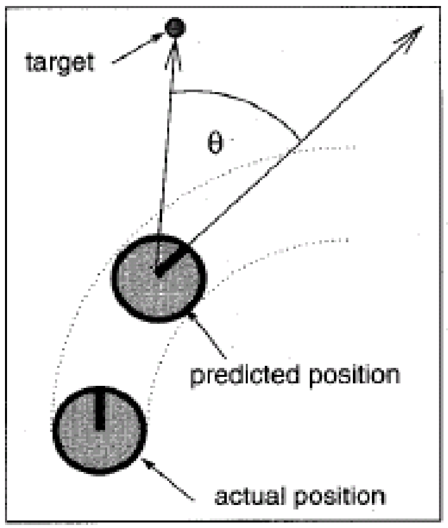

Figure 6. Angle θ to the Target.

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Ego-Kinematic Space

Reference

Minguez, J.; Montano, L.; Santos-Victor J., "Reactive Navigation for Non-holonomic Robots using the Ego-Kinematic Space" International Conference on Robotics and Automation (ICRA), 2002

Questions: Comparison DW / VFH / EKS

- Pros and Cons for each method.
- Identify favorable context for each method.

Outline

Trajectory Deformation

Reference

- Quinlan, S.; Khatib, O., "Elastic bands: connecting path planning and control," Robotics and Automation, 1993. Proceedings., 1993 IEEE International Conference on , vol., no., pp.802,807 vol.2, 2-6 May 1993
- Boyer, F.; Lamiraux, F., "Trajectory deformation applied to kinodynamic motion planning for a realistic car model," Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on , vol., no., pp.487,492, 15-19 May 2006

Questions:

- Differences w.r.t VFH / DW / EKS?
- Differences between both approaches?
- Link with Potential Fields?
- Requirements?

Outline

(Reciprocal) Velocity Obstacles

Reference:

- P. Fiorini and Z. Shillert, "Motion Planning in Dynamic Environments using Velocity Obstacles," Int. Journal of Robotics Research, vol. 17, no. 7, pp. 760–772, 1998.
- Jur van den Berg, Ming C. Lin, Dinesh Manocha "Reciprocal Velocity Obstacles for Real-Time Multi-Agent Navigation" Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), 2008.

Questions:

- Principle of Velocity Obstacles
- Link with Dynamic Window
- Assumption for Reciprocal Velocity Obstacles
- Application context and requirements

Outline

Real-life obstacle avoidance: Boss

Reference

- Urmson, Chris, Joshua Anhalt, Drew Bagnell, Christopher Baker, Robert Bittner, M. N. Clark, John Dolan et al. "Autonomous driving in urban environments: Boss and the urban challenge." Journal of Field Robotics 25, no. 8 (2008): 425-466.

Questions:

- Principle?
- Closest approach?

Summary

Many approaches for obstacle avoidance:

- Static vs dynamic environments
- Predictive or reactive
- Computationally more and more expensive

How to choose?

- Above criteria.
- Processing power
- Sensors
- Not impossible to layer them as well.