Robotica Probabilistica

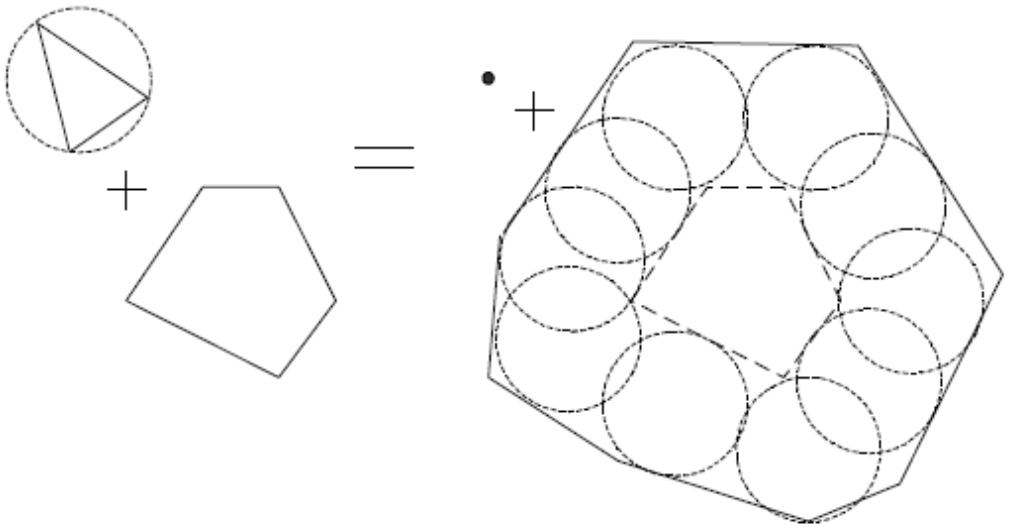
Navigazione

Navigazione

- Evitare ostacoli (fissi, mobili)
- Pianificare traiettoria
- Esplorare

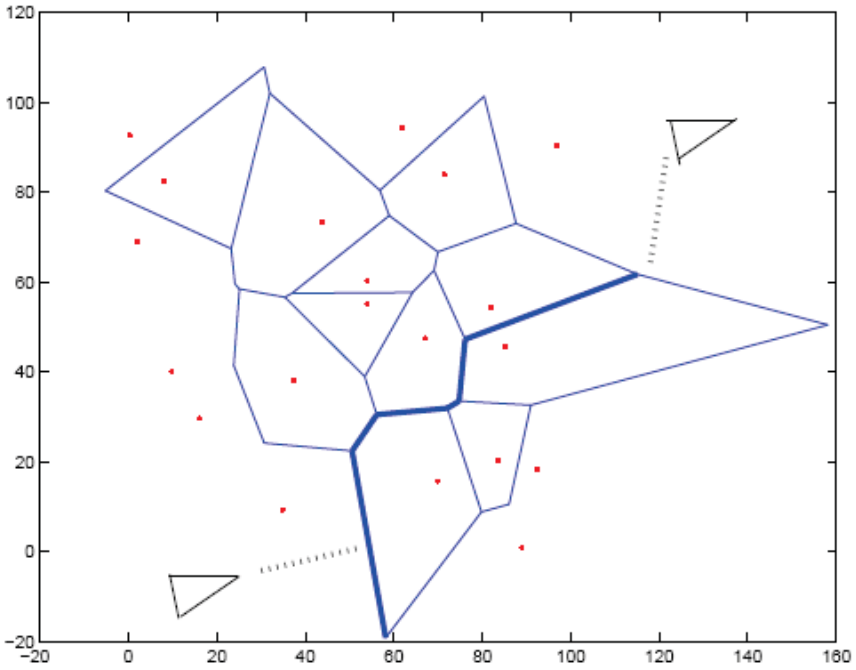
Ostacoli: Minkowski Sum

- Come rappresentare robot e ostacoli
- Forma ostacolo + forma del robot
- Robot approssimato da punto materiale
- Ostacolo aumentato



Percorsi tra Ostacoli: Metodi di Voroni

- Percorsi equidistanti tra i due punti-oggetto più vicini;
- Roadmap a partire dalla mappa:
  - Raggiungere il path vicino,
  - Path verso il goal,
  - Raggiungere il goal.



Percorsi tra ostacoli: Metodi Bug

- Metodi voroni richiedono mappa intera, percorsi equidistanti e lunghi.
- Metodo Bug:
  - Vai da A a B in linea retta;
  - Se c'e' ostacolo circumnavigalo finchè non incontri/vedi la linea AB.
  - Continua a seguire AB
- Non sempre un buon piano, ma garantito B se raggiungibile.

Percorsi tra Ostacoli: Metodi Potenziali

- Goal basso potenziale, ostacoli alto potenziale;
- Ad ogni punto potenziale:

$$\mathbf{U}_{\Sigma}(\mathbf{x}) = \sum_{i=1:k} \mathbf{U}_{o,i}(\mathbf{x}) + \mathbf{U}_{g}(\mathbf{x})$$

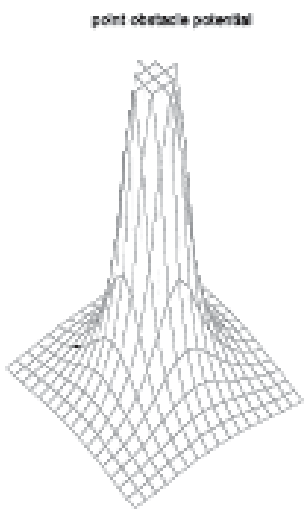
- Ad ogni punto forza:

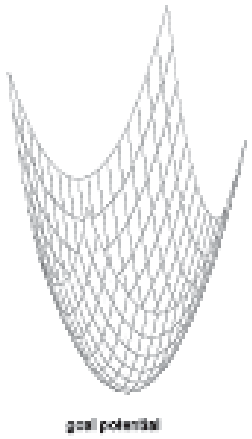
$$\begin{aligned}\mathbf{F}(\mathbf{x}) &= -\nabla \mathbf{U}_{\Sigma}(\mathbf{x}) \\ &= -\sum_{i=1:k} \nabla \mathbf{U}_{o,i}(\mathbf{x}) - \nabla \mathbf{U}_{g}(\mathbf{x})\end{aligned}$$

- Quale potenziale?

Percorsi tra Ostacoli: Metodi Potenziali

- Funzioni tipiche:





$$\mathbf{U}_{o,i}(\mathbf{x}) = \eta \begin{cases} \frac{1}{2}\left(\frac{1}{\rho(\mathbf{x})} - \frac{1}{\rho_0}\right)^2 & \forall \quad \rho(\mathbf{x}) \leq \rho_0 \\ 0 & \text{otherwise} \end{cases}$$

$$\mathbf{U}_g(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_g)^2$$

- Tra voroni e bug per vicinanza ad ostacoli
- Metodo locale, quindi problema minimi locali

Path Planning

Latombe (1991):

"…eminently necessary since, by definition, a robot accomplishes tasks by moving in the real world."

- Traiettorie prive di collisioni
- Il robot dovrebbe raggiungere la locazione prima possibile

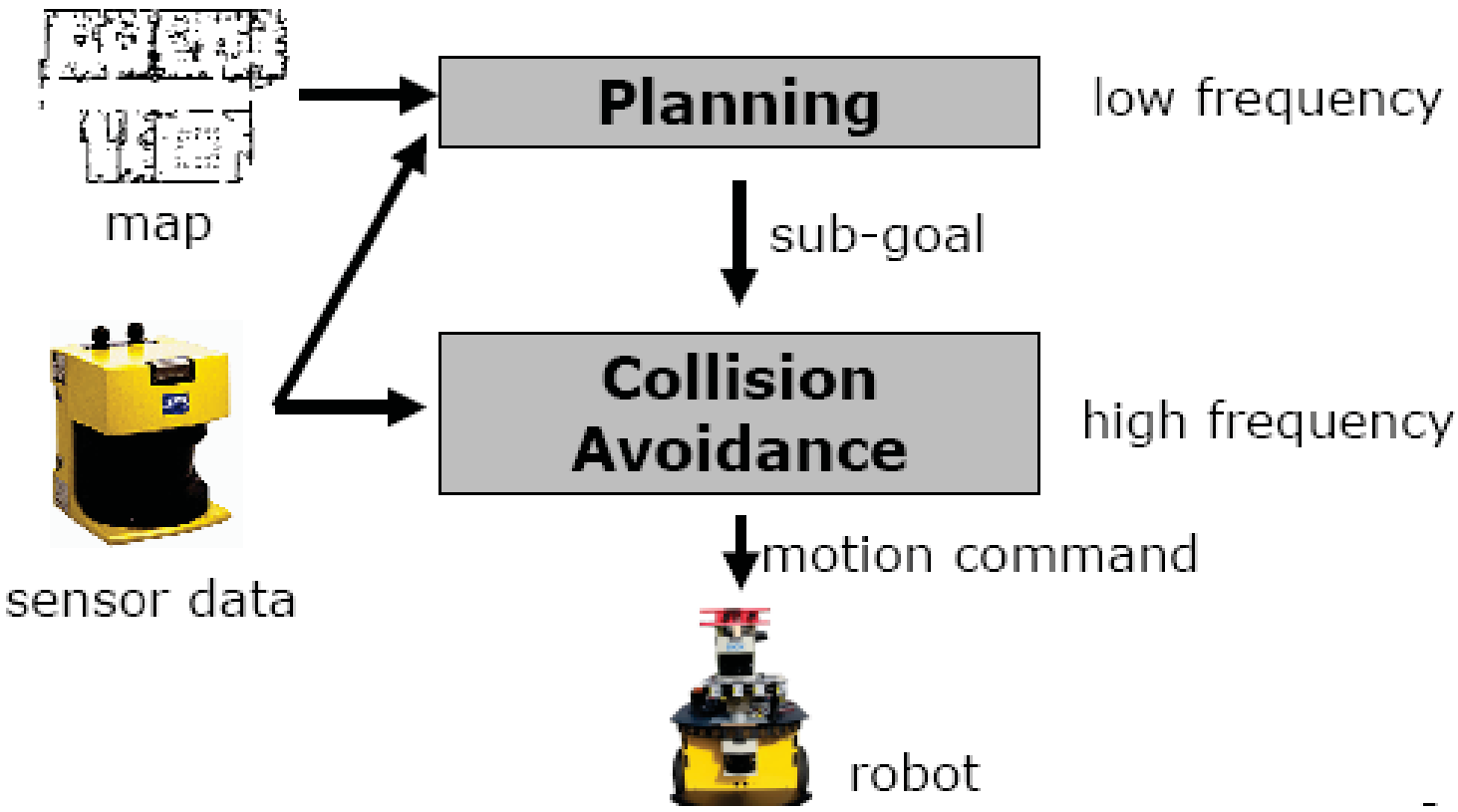
Path planning e Ambiente Dinamico

- Come reagire ad ostacoli imprevisti?
  - Efficacia
  - Affidabilità
- Approcci:
  - Dynamic Window Approaches
    [Simmons, 96], [Fox et al., 97], [Brock & Khatib, 99]
  - Grid map based Planning
    [Konolige, 00]
  - Nearness Diagram Navigation
    [Minguez at al., 2001, 2002]
  - Vector-Field-Histogram+
    [Ulrich & Borenstein, 98]
  - A*, D*, D* Lite, ARA*, ...

Obiettivi in ambiente dinamico

- Calcolo del path ottimo considerando incertezze potenziali nelle azioni
- Generare azioni rapidamente in caso di ostacoli imprevisti

Approccio Classico



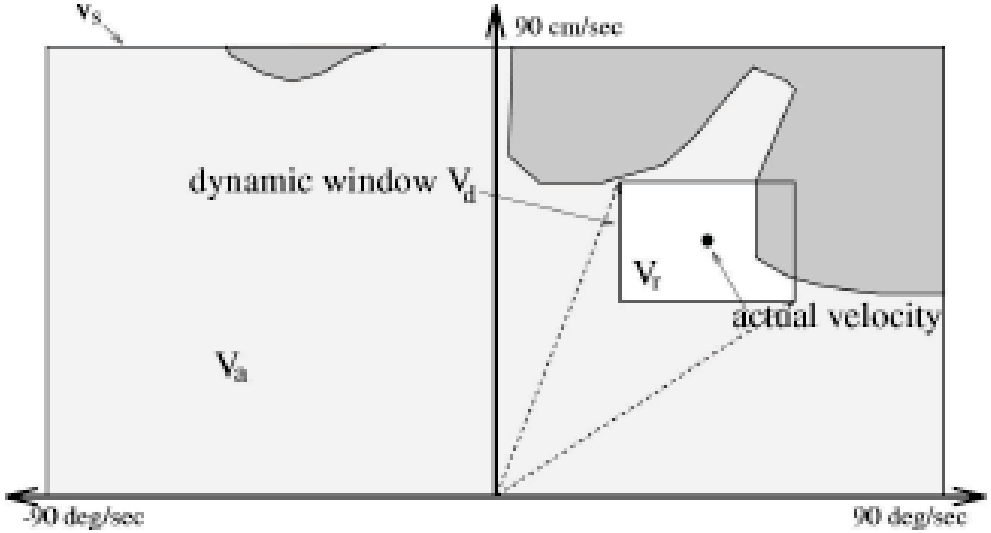
Dynamic Windows

- **Collision avoidance:** determine collision-free trajectories using geometric operations
- Here: robot moves on circular arcs
- Motion commands (v,ω)
- Which (v,ω) are admissible?

Dynamic Windows

Regolazione della velocità in funzione degli ostacoli

- Example search-space:



- V_s = all possible speeds of the robot.
- V_a = obstacle free area.
- V_d = speeds reachable within a certain time frame based on possible accelerations.

$$Space = V_s \cap V_a \cap V_d$$

Dynamic Windows

- How to choose <v,ω>?
- Steering commands are chosen by a heuristic navigation function.
- This function tries to minimize the travel-time by:
  "**driving fast** in the **right direction**."

Dynamic Windows

- Heuristic navigation function.
- Planning restricted to <x,y>-space.
- No planning in the velocity space.

Navigation Function:

$$NF = \alpha \cdot vel + \beta \cdot nf + \gamma \cdot \Delta nf + \delta \cdot goal$$

Goal nearness.

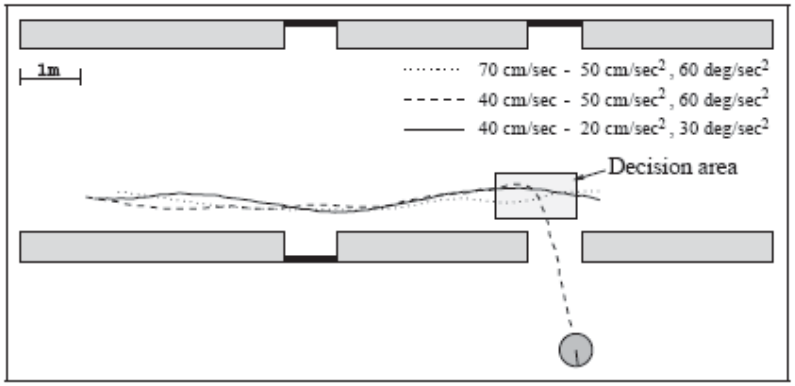
Maximizes velocity.

Considers cost to reach the goal.

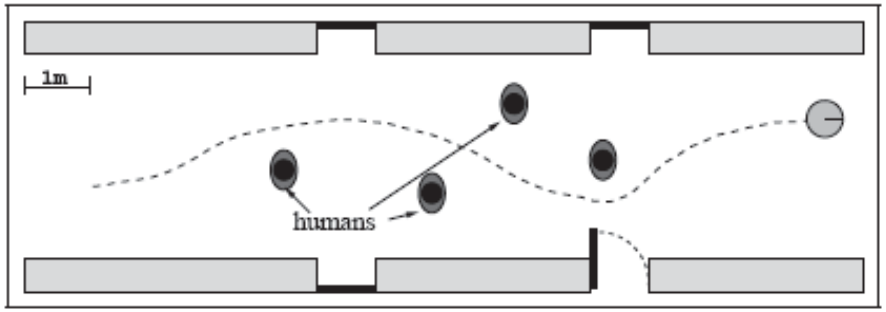
Follows grid based path computed by A*.

Dynamic Windows Approach

- Brevi tempi di reazione (dipendenti da parametri)



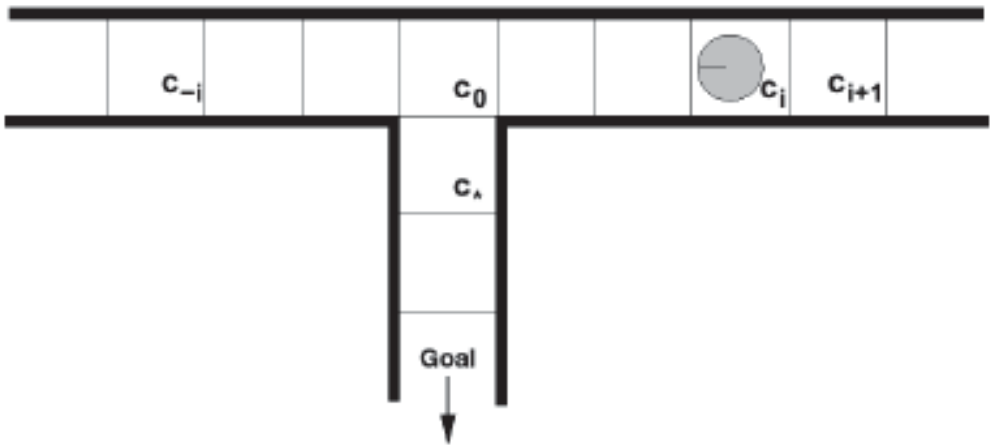
- Veloce in ambienti popolati



Dynamic Windows

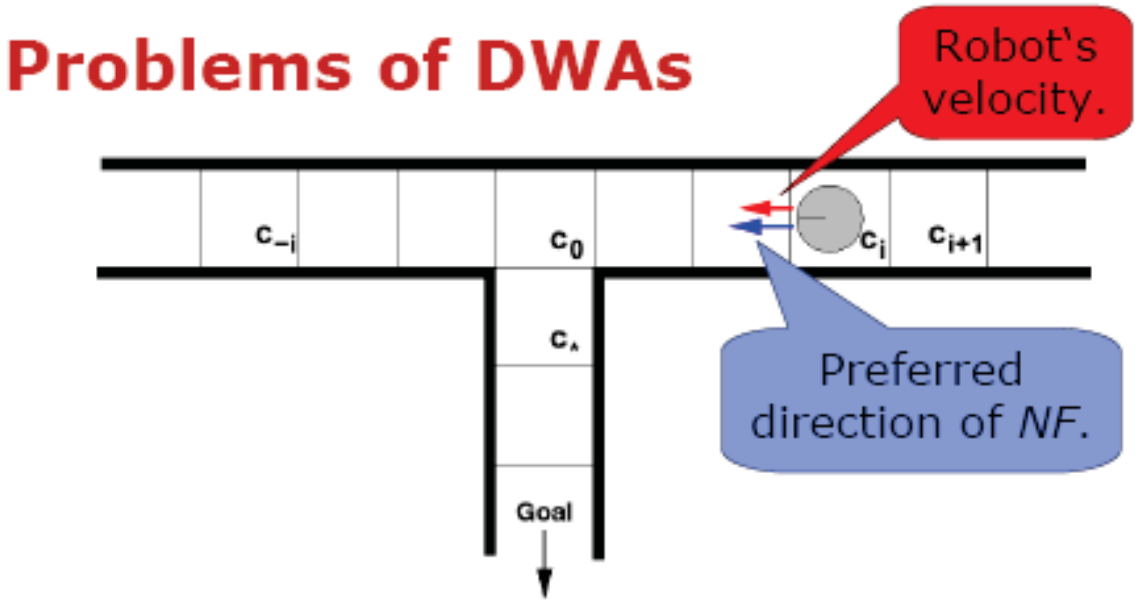
- Reacts quickly.
- Low CPU power requirements.
- Guides a robot on a collision free path.
- Successfully used in a lot of real-world scenarios.
- Resulting trajectories sometimes sub-optimal.
- Local minima might prevent the robot from reaching the goal location.

Problema con DWA



$$NF = \alpha \cdot vel + \beta \cdot nf + \gamma \cdot \Delta nf + \delta \cdot goal$$

Problema con DWA



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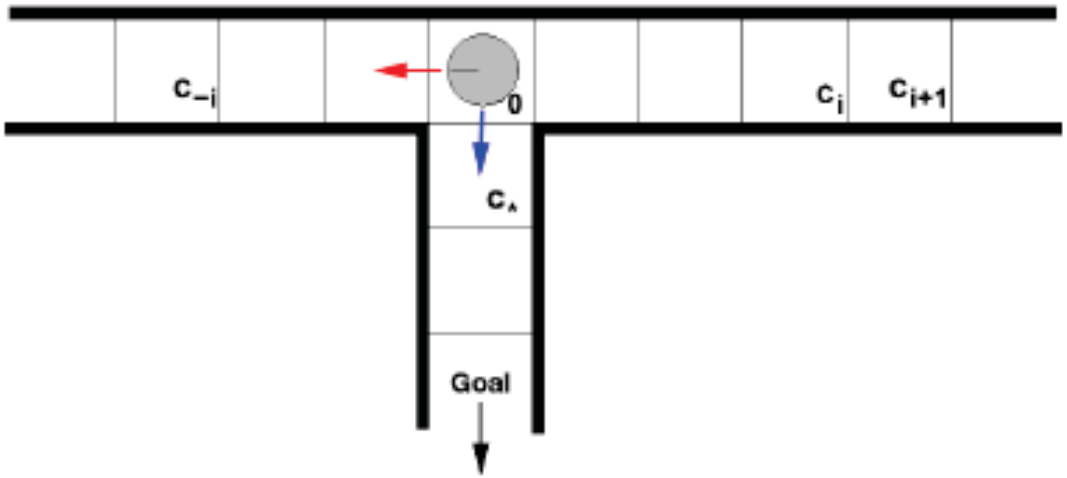
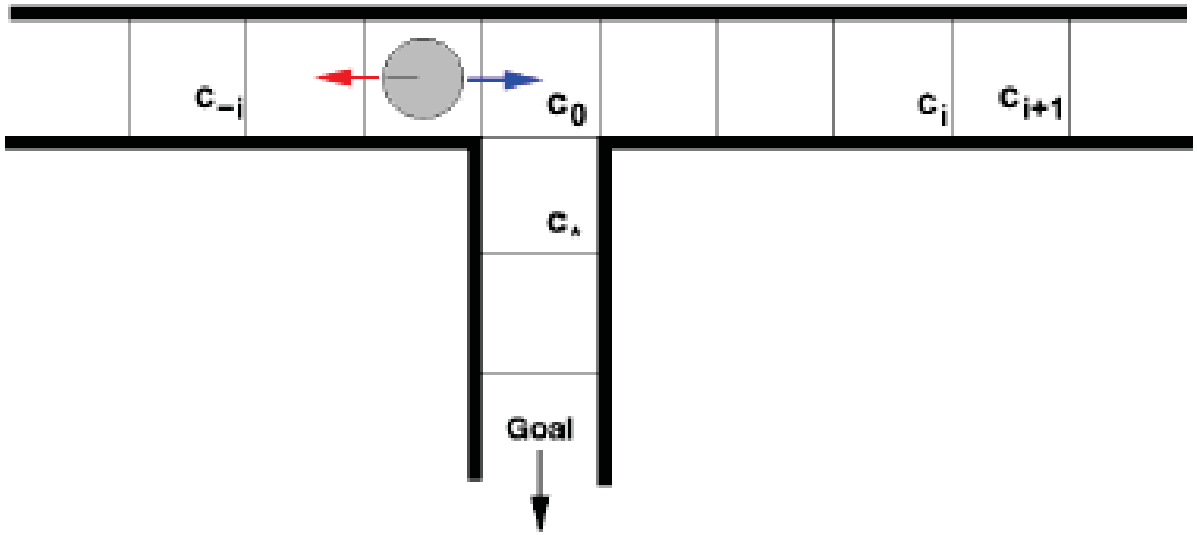
Problema con DWA



$$NF = \alpha \cdot vel + \beta \cdot nf + \gamma \cdot \Delta nf + \delta \cdot goal$$

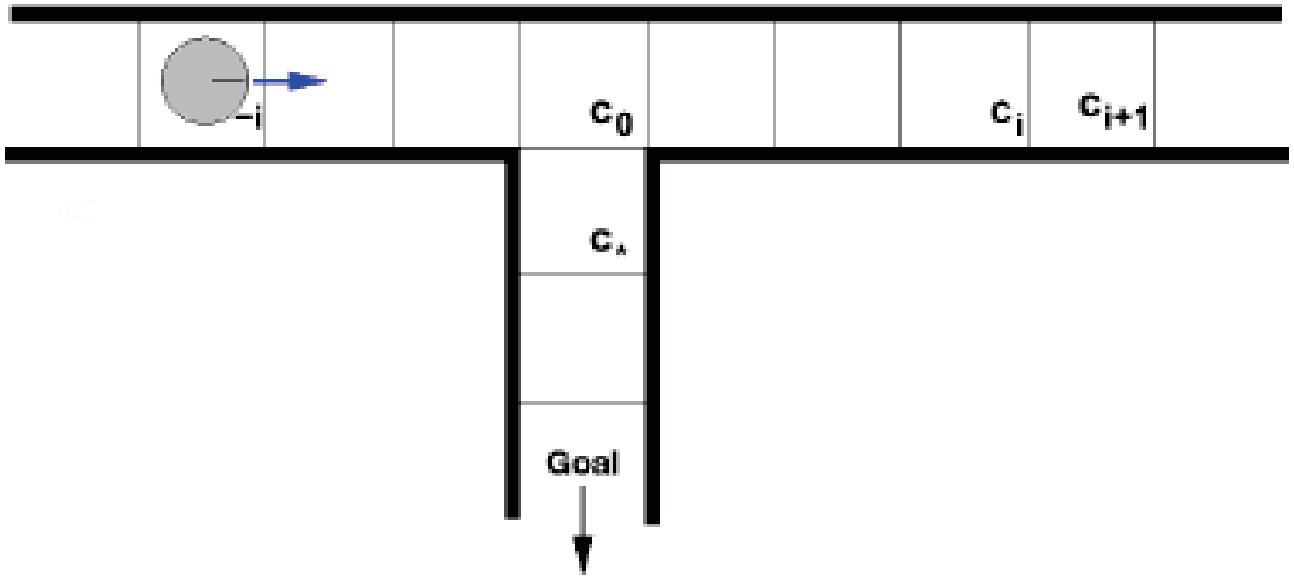
- The robot drives too fast at c_0 to enter corridor facing south.

Problema con DWA



$$NF = \alpha \cdot vel + \beta \cdot nf + \gamma \cdot \Delta nf + \delta \cdot goal$$

Problema con DWA



- Same situation as in the beginning.

  ➔ DWAs have problems to reach the goal.

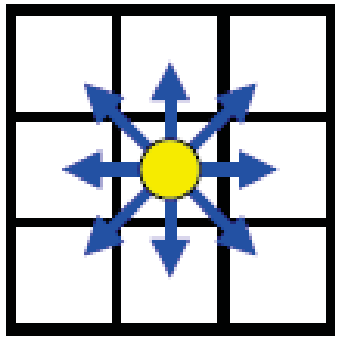
Problema con DWA

- Typical problem in a real world situation:

- Robot does not slow down early enough to enter the doorway.

Path Planning

- What about using A* to plan the path of a robot?
- Finds the shortest path
- Requires a graph structure
- Limited number of edges
- In robotics: planning on a 2d occupancy grid map



Minimizza costo stimato

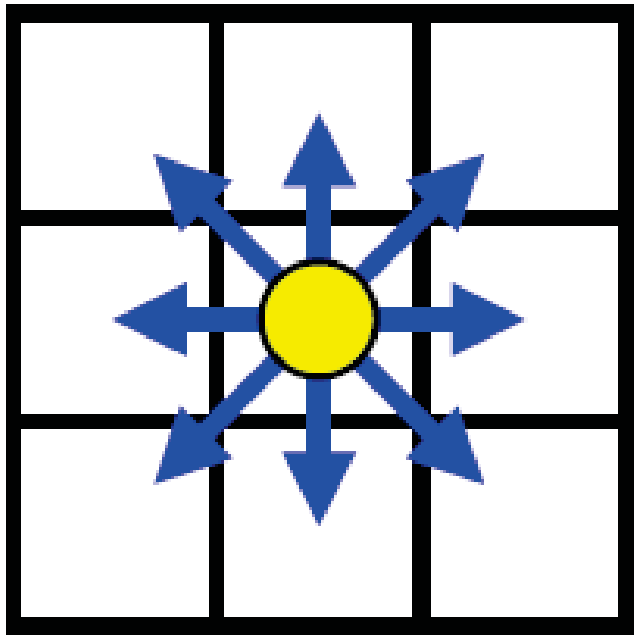
- $g(n)$ = actual cost from the initial state to n.
- $h(n)$ = estimated cost from n to the next goal.
- $f(n) = g(n) + h(n)$, the estimated cost of the cheapest solution through n.
- Let h*(n) be the actual cost of the optimal path from n to the next goal.
- h is admissible if the following holds for all n :

$$h(n) \leq h^*(n)$$

- We require that for A*, h is admissible (the straight-line distance is admissible in the Euclidean Space).

Path Planning nella grid map

L’algoritmo di A* può essere utilizzato nella grid map (occupancy grid)



Value Iteration

- To compute the shortest path from every state to one goal state, use (deterministic) value iteration.
- Very similar to Dijkstra's Algorithm.
- Such a cost distribution is the optimal heuristic for A*.

Assunzioni tipiche in A* path planning

- A robot is assumed to be localized.
- Often a robot has to compute a path based on an occupancy grid.
- Often the correct motion commands are executed (but no perfect map).

Is this always true?

Problemi

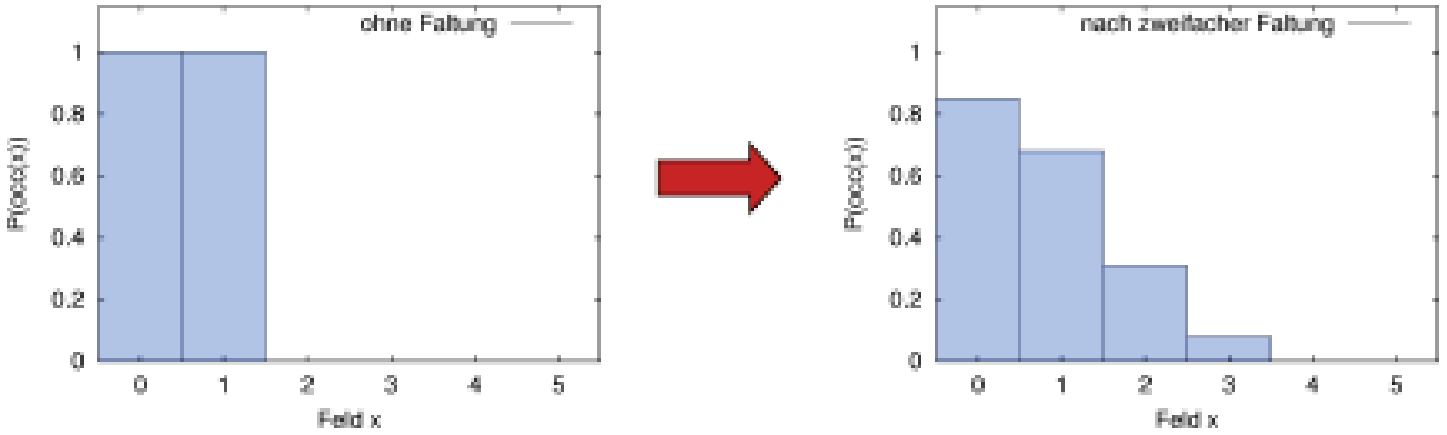
- What if the robot is slightly delocalized?
- Moving on the shortest path guides often the robot on a trajectory close to obstacles.
- Trajectory aligned to the grid structure.

Possibile Soluzione: convoluzione della grid map

- Convolution blurs the map.
- Obstacles are assumed to be bigger than in reality.
- Perform an A* search in such a convolved map.
- Robots increases distance to obstacles and moves on a short path!

Esempio

- 1-d environment, cells c_0, …, c_5



- Cells before and after 2 convolution runs.

Convoluzione

- Consider an occupancy map. Than the convolution is defined as:

$$P(occ_{x_i,y}) = \frac{1}{4} \cdot P(occ_{x_{i-1},y}) + \frac{1}{2} \cdot P(occ_{x_i,y}) + \frac{1}{4} \cdot P(occ_{x_{i+1},y})$$

$$P(occ_{x_0,y}) = \frac{2}{3} \cdot P(occ_{x_0,y}) + \frac{1}{3} \cdot P(occ_{x_1,y})$$

$$P(occ_{x_{n-1},y}) = \frac{1}{3} \cdot P(occ_{x_{n-2},y}) + \frac{2}{3} \cdot P(occ_{x_{n-1},y})$$

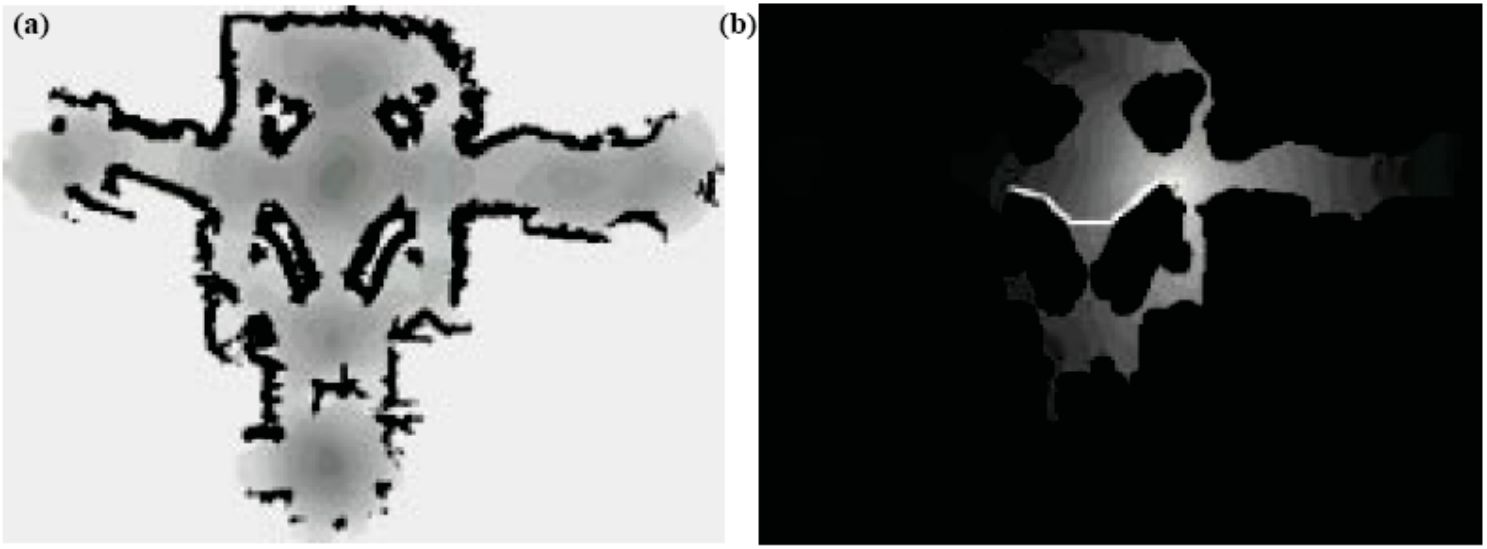
- This is done for each row and each column of the map.
- "Gaussian blur"

Applicazione di A*

- The costs are a product of path length and occupancy probability of the cells.
- Cells with higher probability (e.g., caused by convolution) are avoided by the robot.
- Thus, it keeps distance to obstacles.
- This technique is fast and quite reliable.

Costal Navigation

- Non il path più breve, ma quello che minimizza la probabilità di perdersi
- Considerare: lunghezza path e infromazione persa (es. Minerva Robot)
- Entropy Map:



5D Path-planning

- Alternativa all'approccio a due livelli
- Plans in the full <x,y,θ,v,ω>-configuration space using A^*.
  ➔ considers the robot's kinematic contraints.
- Generates a sequence of steering commands to reach the goal location.
- Maximizes trade-off between driving time and distance to obstacles.

Spazio di Ricerca

- What is a state in this space?
  $\langle x,y,\theta,v,\omega \rangle$ = current position and speed of the robot

- How does a state transition look like?
  $\langle x_1,y_1,\theta_1,v_1,\omega_1 \rangle \rightarrow \langle x_2,y_2,\theta_2,v_2,\omega_2 \rangle$
  with motion command (v_2,ω_2) and
  $|v_1-v_2| < a_v$, $|\omega_1-\omega_2| < a_\omega$. Pose of the Robot is a result of the motion equations.

Spazio di Ricerca

Idea: search in the discretized $<x,y,\theta,v,\omega>$-space.

Problem: the search space is too huge to be explored within the time constraints (.25 secs for online control).

Solution: restrict the full search space.

Passi dell'algoritmo

1. Update (static) grid map based on sensory input.

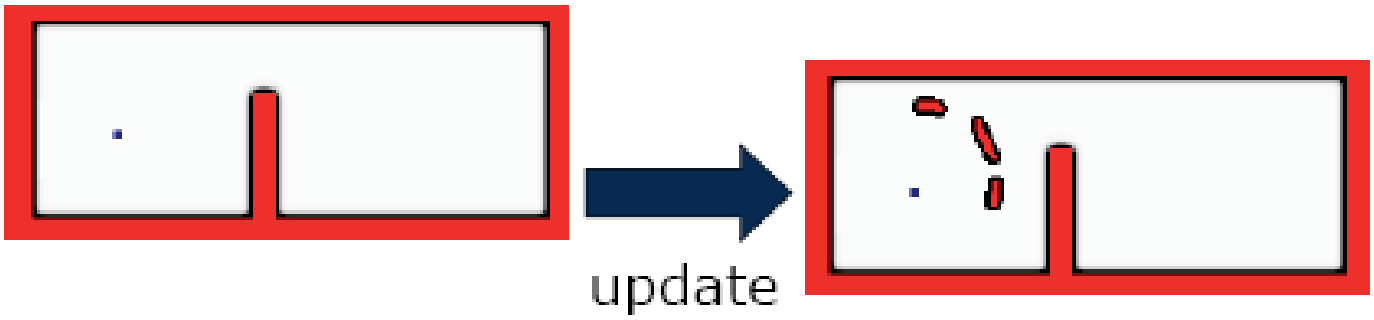
2. Use A^* to find a trajectory in the <x,y>-space using the updated grid map.

3. Determine a restricted 5d-configuration space based on step 2.

4. Find a trajectory by planning in the restricted <x,y,θ,v,ω>-space.

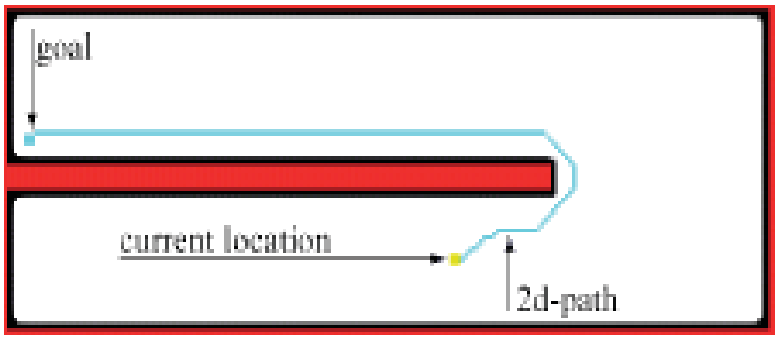
Aggiornamento della grid-map

- The environment is represented as a 2d-occupency grid map.
- Convolution of the map increases security distance.
- Detected obstacles are added.
- Cells discovered free are cleared.



Percorso nella mappa 2D

- Use A* to search for the optimal path in the 2d-grid map.
- Use heuristic based on a deterministic value iteration within the static map.



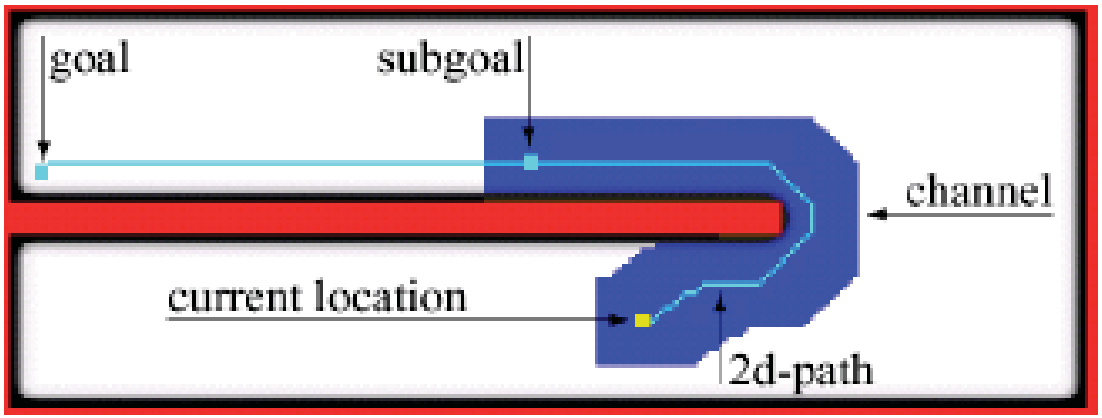
Restringi lo spazio di ricerca

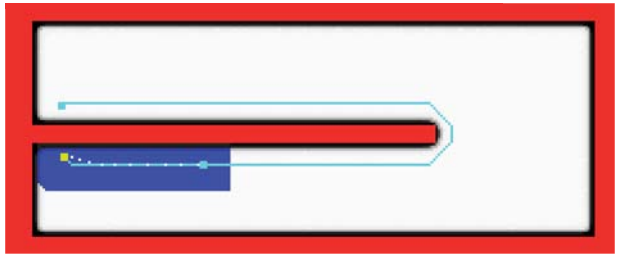
Assumption: the projection of the 5d-path onto the <x,y>-space lies close to the optimal 2d-path.

Therefore: construct a restricted search space (channel) based on the 2d-path.

Spazio di Ricerca

- Resulting search space =
  $\langle x, y, \theta, v, \omega \rangle$ with $(x,y) \in$ channel.
- Choose a sub-goal lying on the 2d-path within the channel.



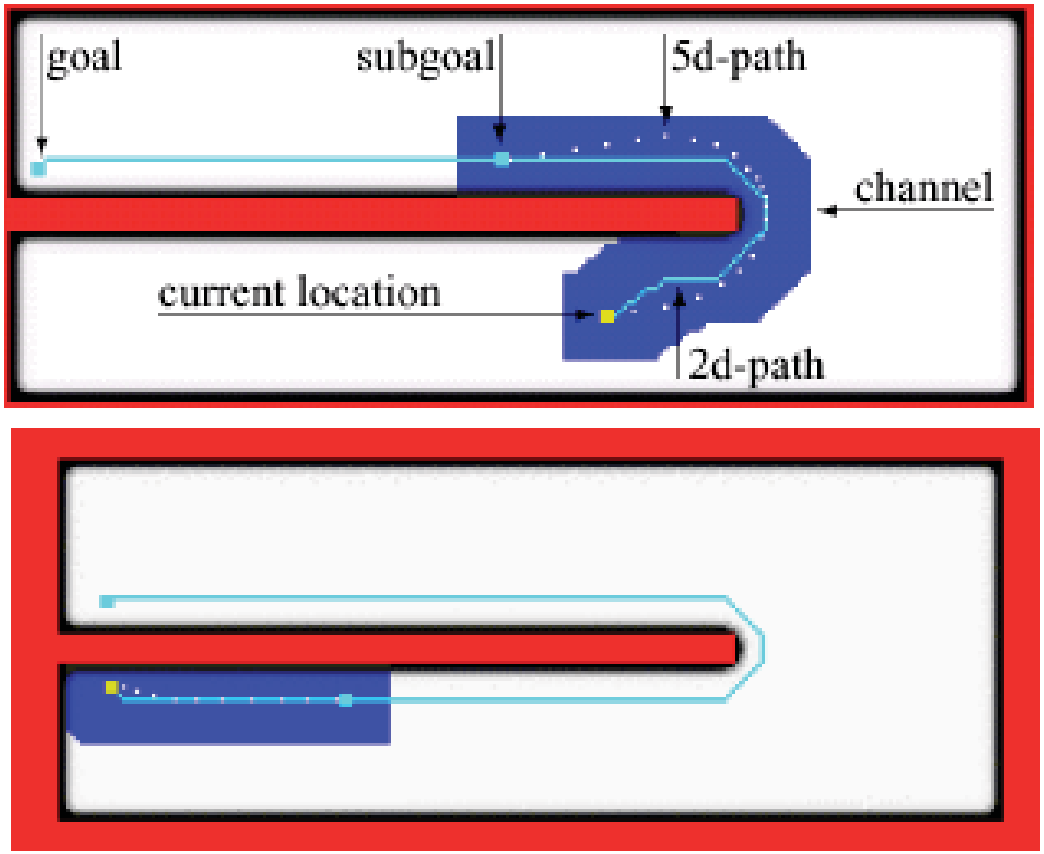


Trova il percorso in 5D

- Use A* in the restricted 5d-space to find a sequence of steering commands to reach the sub-goal.

- To estimate cell costs: perform a deterministic 2d-value iteration within the channel.

Esempio



Timeout

- Online robot control:
  new steering command every .25 secs.

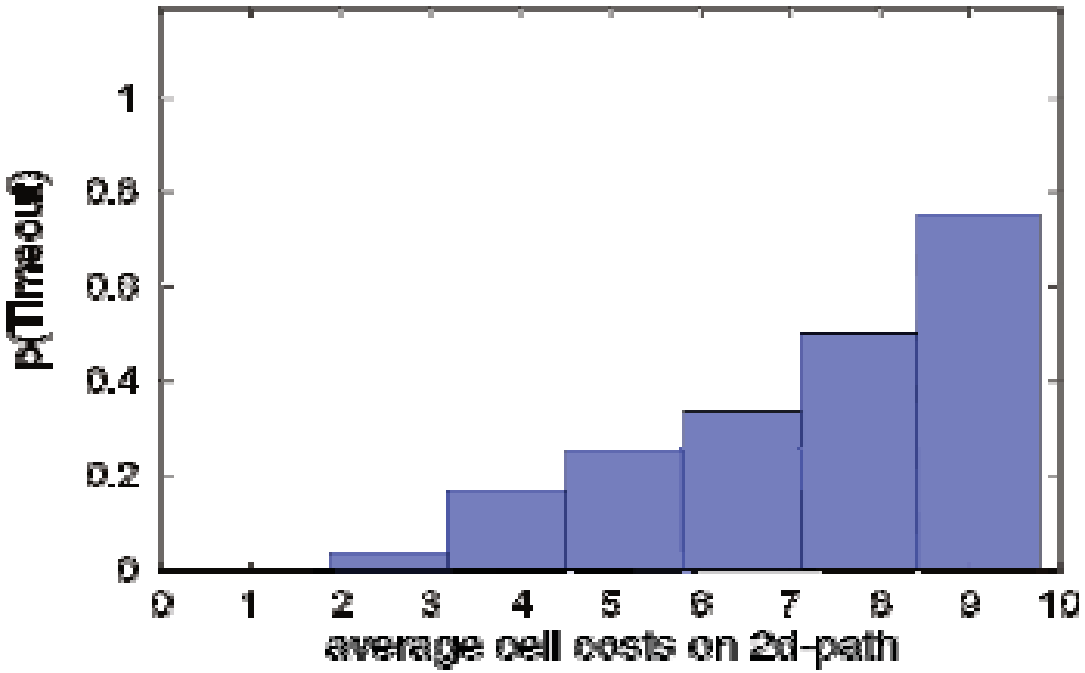
➔ Abort search after .25 secs.

How to find an admissible steering command?

Generazione di Comandi

- Previous trajectory still admissible? → OK
- If not, drive on the 2d-path or use DWA to find new command.

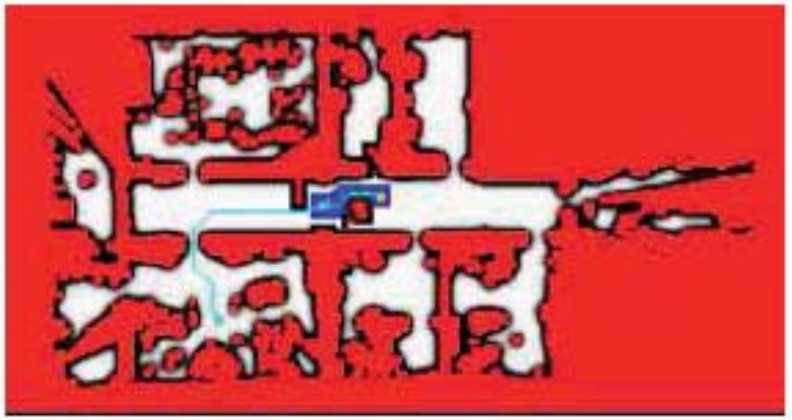
Timeout avoidance



- Reduce the size of the channel if the 2d-path has high cost.

Esempio

Robot Albert



Planning state

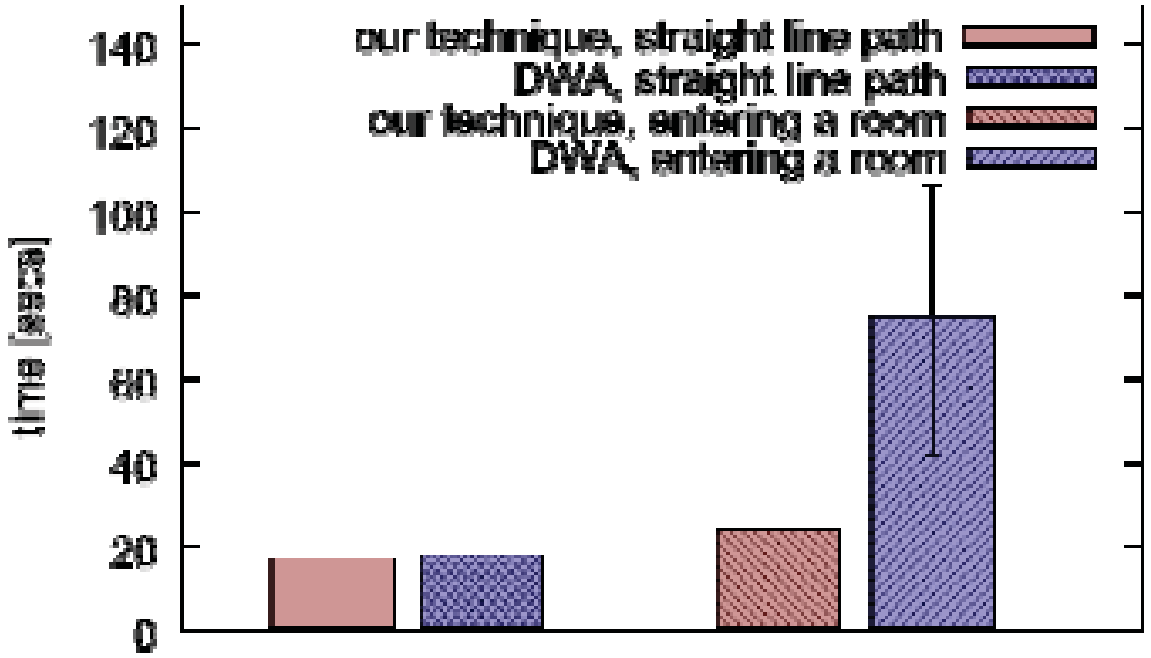
Confronto con DWA

- DWAs often have problems entering narrow passages.

DWA planned path.

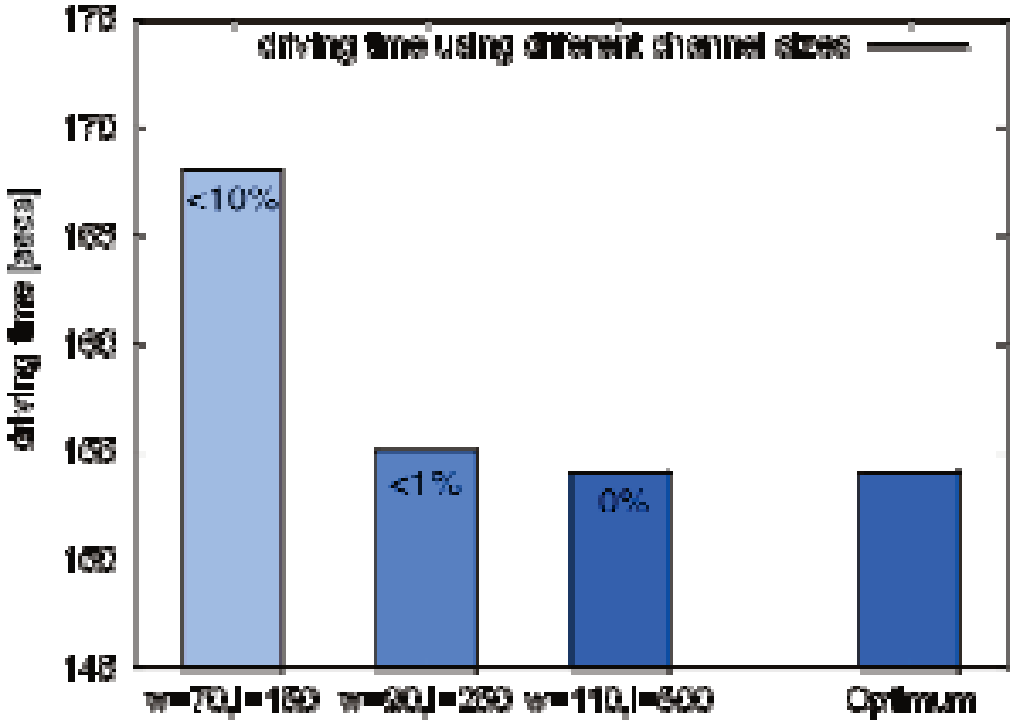
5D approach.

Confronto con DWA



➔ The presented approach results in significantly faster motion when driving through narrow passages!

Confronto con l'ottimo



Channel: with length=5m, width=1.1m

Resulting actions are close to the optimal solution.

Riassunto

- Robust navigation requires combined path planning & collision avoidance
- Approaches need to consider robot's kinematic constraints and plans in the velocity space.
- Combination of search and reactive techniques show better results than the pure DWA in a variety of situations.
- Using the 5D-approach the quality of the trajectory scales with the performance of the underlying hardware.
- The resulting paths are often close to the optimal ones.