Obstacles Avoidance for Car-Like Robots
Integration And Experimentation on Two Robots

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Inital Motivation

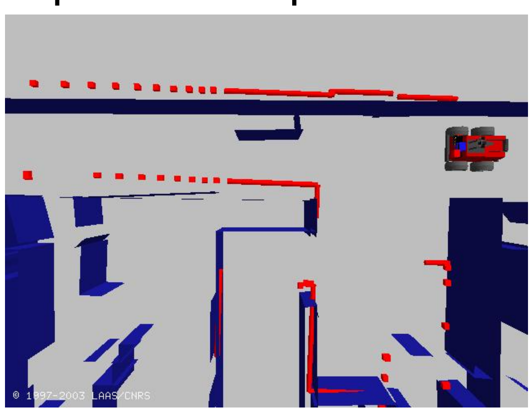
A collision-free path for a non-holonomic system being given.
It can be in collision at execution time.

How to reactively adapt the trajectory to :

– avoid collisions
– keep the non-holonomic constraints satified

Collisions can come from :

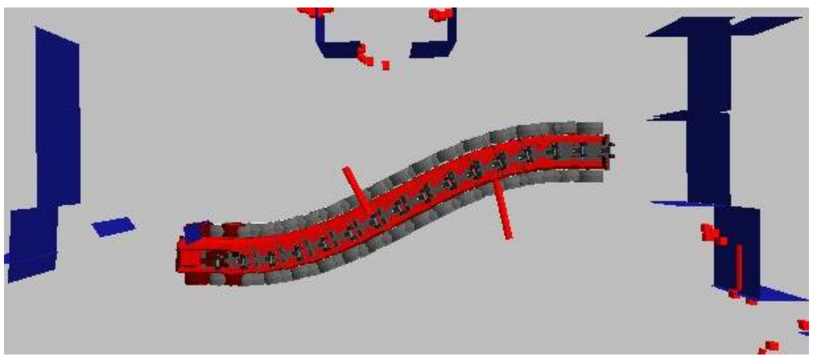
map imprecisions poor localization

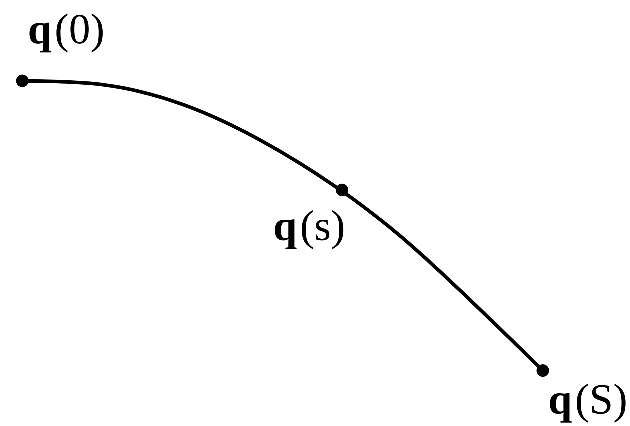


unexpected obstacles

Non-holonomic Path Deformation

To avoid collisions, we deform the initial trajectory in order to **get away from obstacles** while **keeping the non-holonomic constraints satisfied**.





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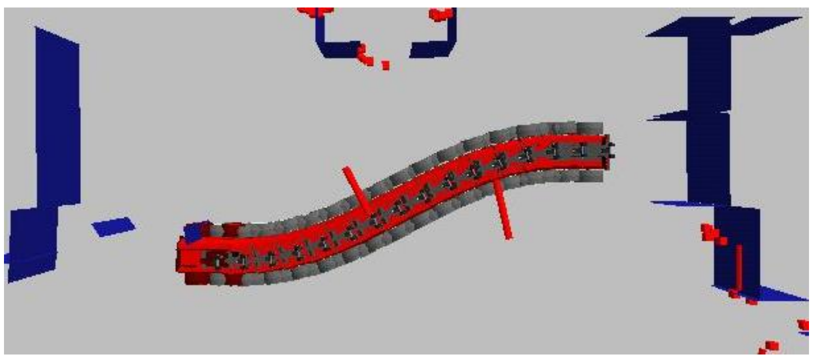

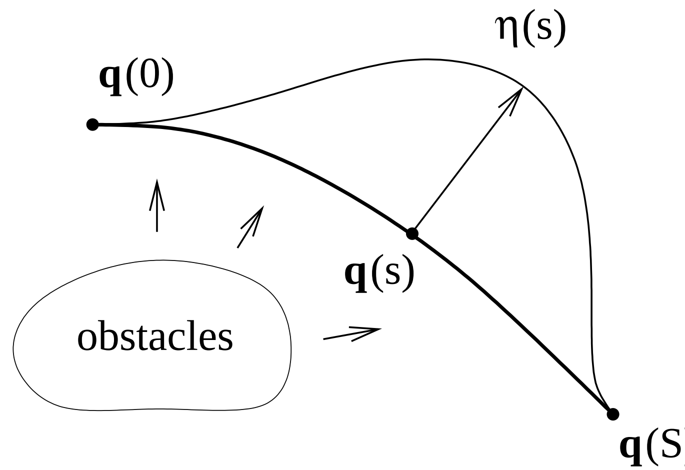

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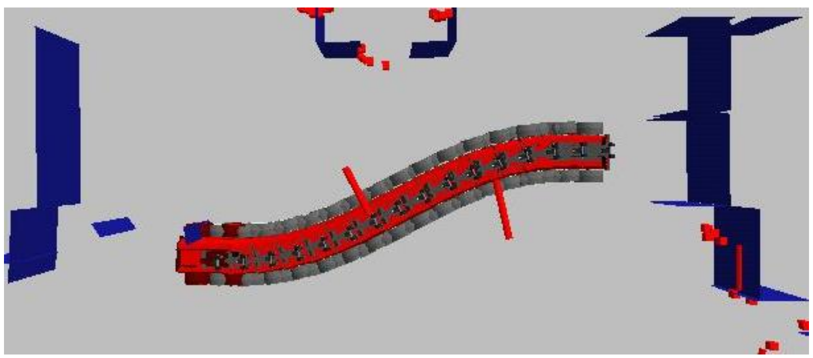

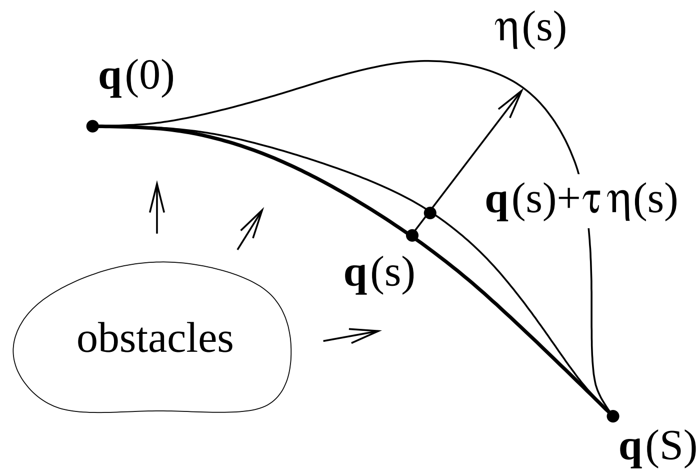

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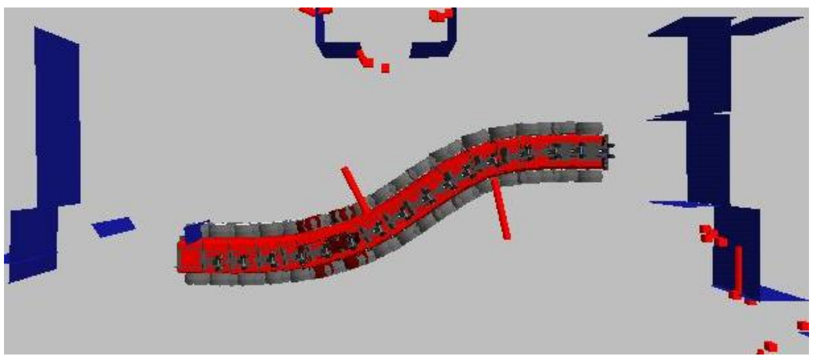

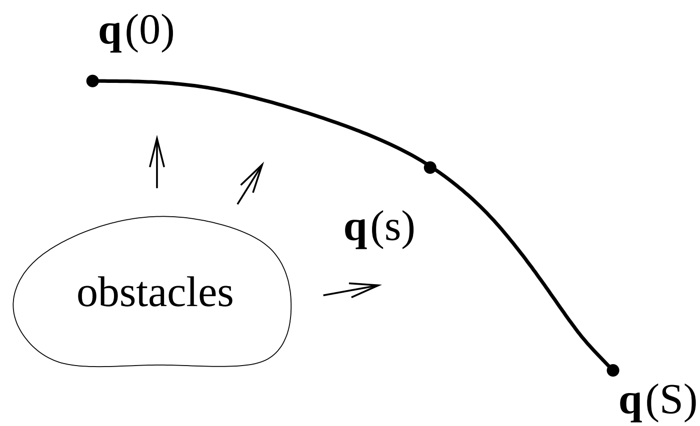

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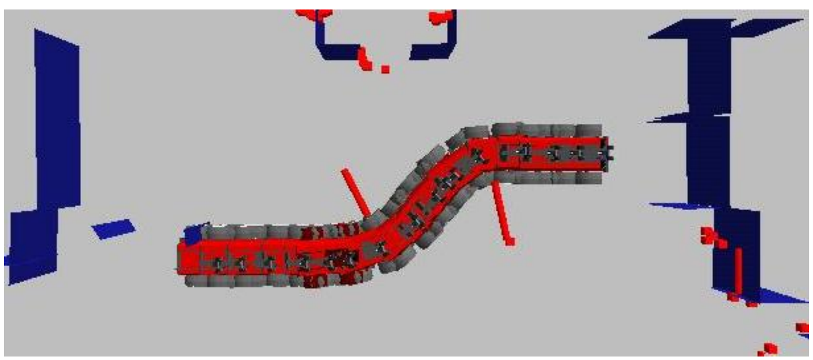

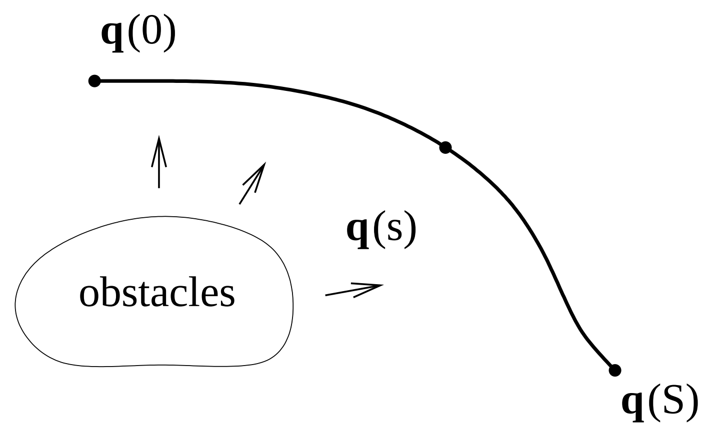

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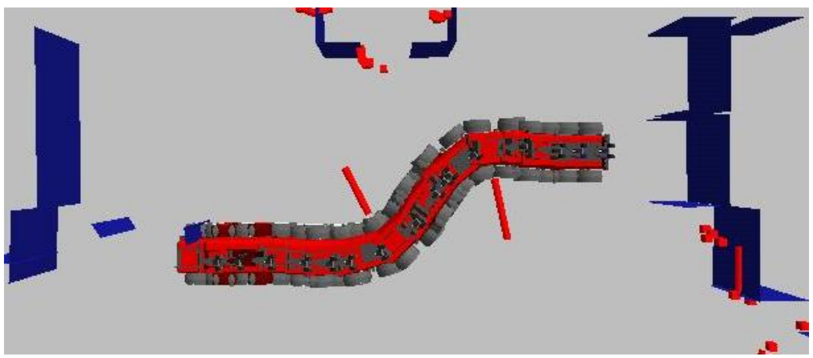
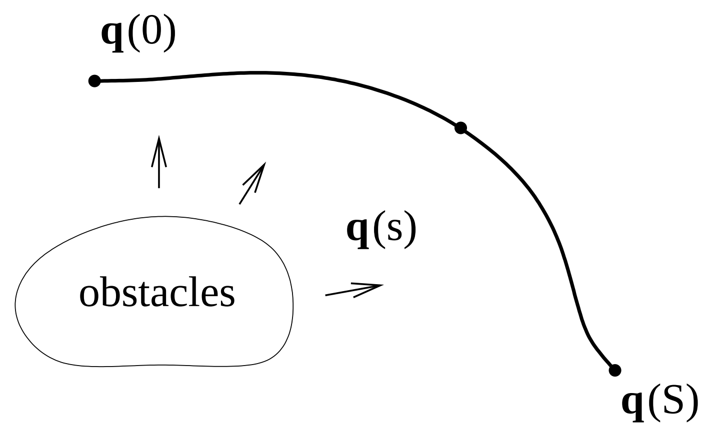




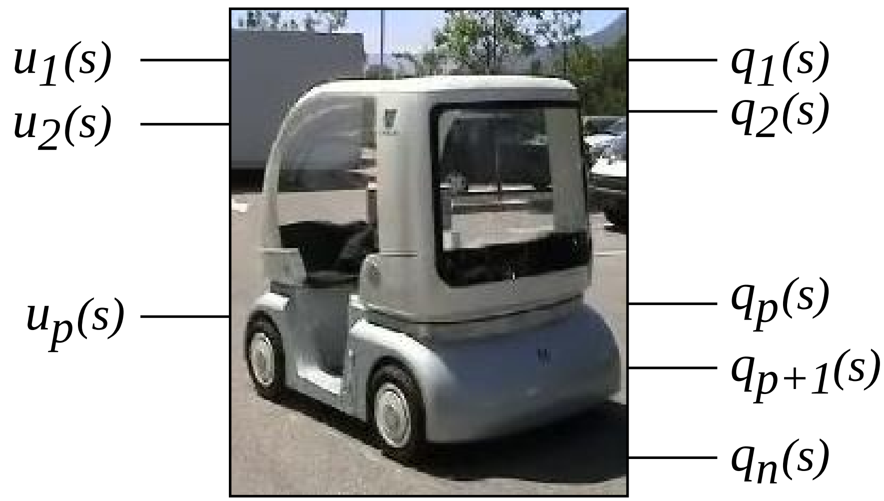
Properties of the Direction of Deformation

How to compute $\eta(s)$ in such a way that

1. the non-holonomic constraints remain satisfied along $\mathbf{q}(s) + \tau\eta(s)$,
2. the deformed path starts and ends at the same configurations $\mathbf{q}(0)$ and $\mathbf{q}(S)$,
3. the trajectory gets away from obstacles.

Non-holonomic System

A non-holonomic robot is a system with less input variables than configuration variables.



$p < n$

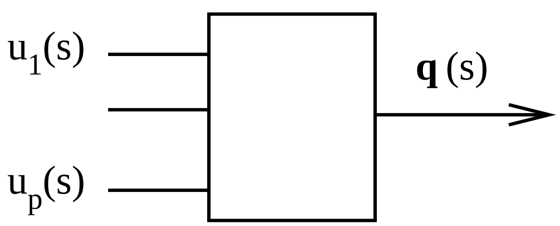
The velocity of a non-holonomic system is a linear combination of vector fields :

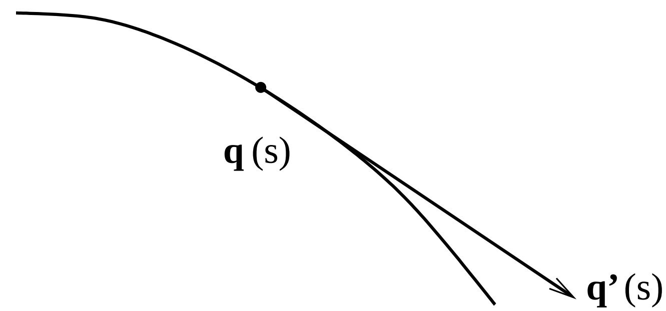
$$\mathbf{q}'(s) = \sum_{i=1}^{p} u_i(s) X_i(\mathbf{q}(s))$$

Trajectory Deformation

The direction of deformation $\eta(s)$ is obtained by perturbing the inputs of the system :

$$\mathbf{u}(s) = (u_1(s), ..., u_p(s))$$

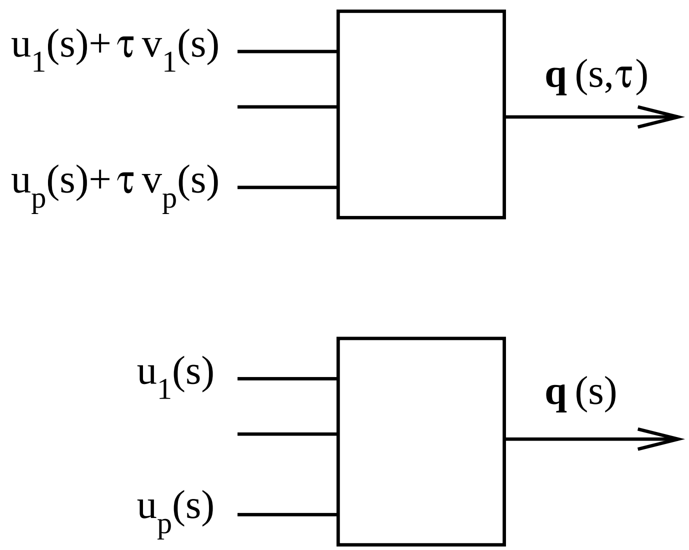


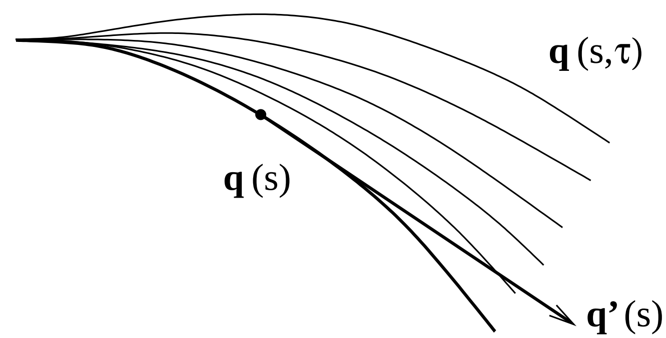


Trajectory Deformation

The direction of deformation $\eta(s)$ is defined by perturbing the input of the system :

$$\mathbf{u}(s,\tau) = \mathbf{u}(s) + \tau \mathbf{v}(s)$$





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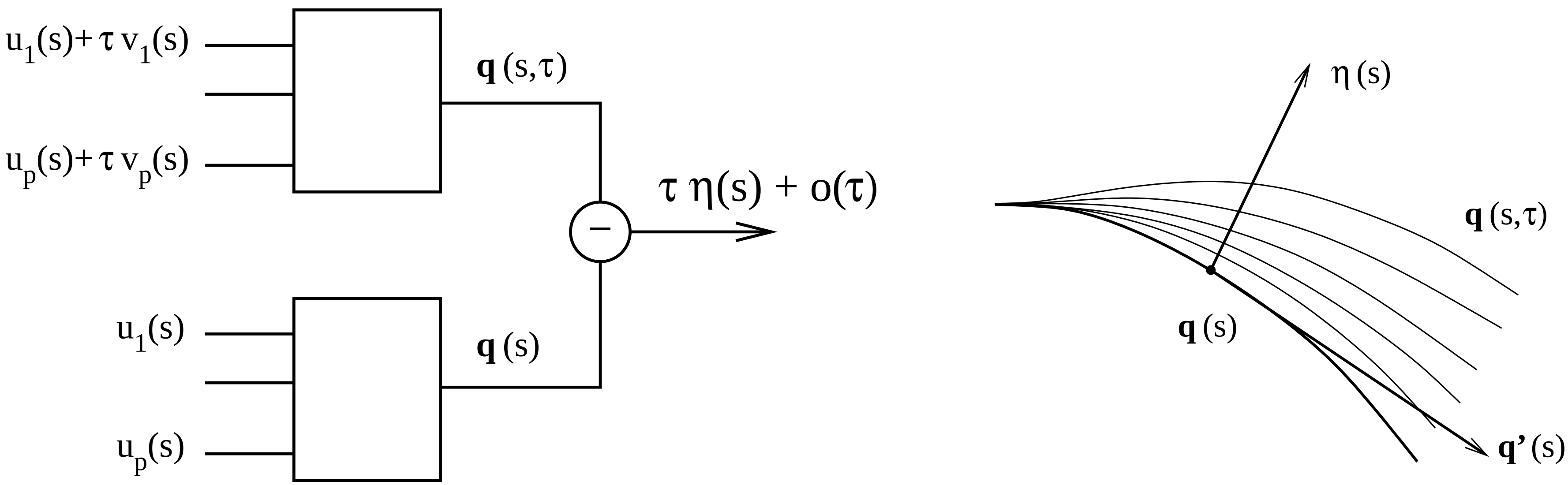

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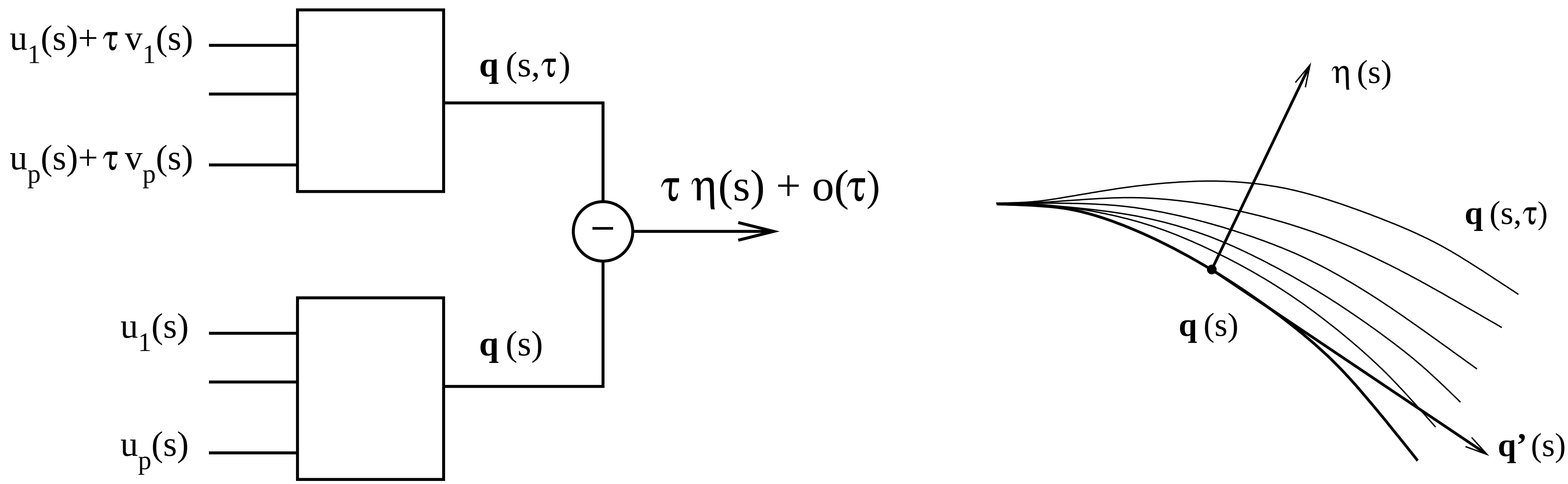
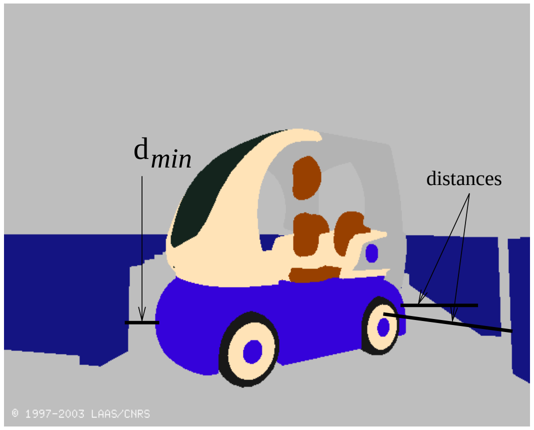


Obstacle Avoidance

To avoid obstacles, we define potential functions :

- over the configuration space :

$$U(\mathbf{q}) = \frac{1}{d_{min}(\mathbf{q})}$$



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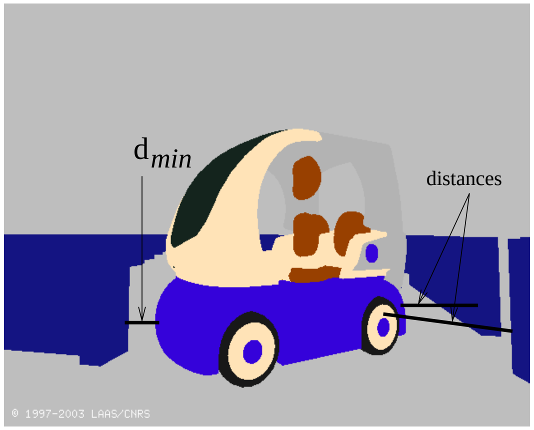

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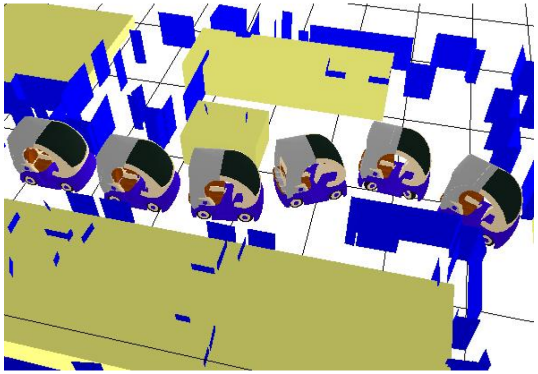


- over the set of feasible paths :

$$U(\text{Path}) = \int_0^S U(\mathbf{q}(s))ds$$

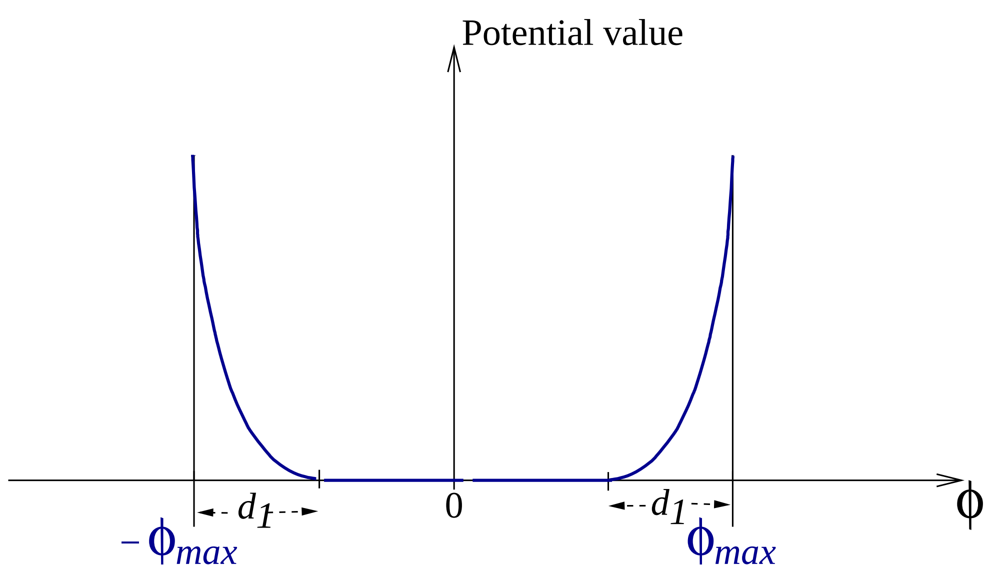
Non-holonomic Path Deformation for Car-like Robots

Bounded steering Angle

The deformed path must respect the steering angle bound.

Potential on the steering angle ϕ

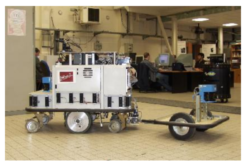
The angle bound is treated as an obstacle.



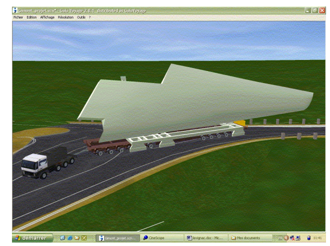
Experimental Results

Previous Experiments

Robot Hilare2 towing a trailer in a cluttered environment.



Trajectories for truck carrying huge plane components.



Integration on rover Dala and car CyCab

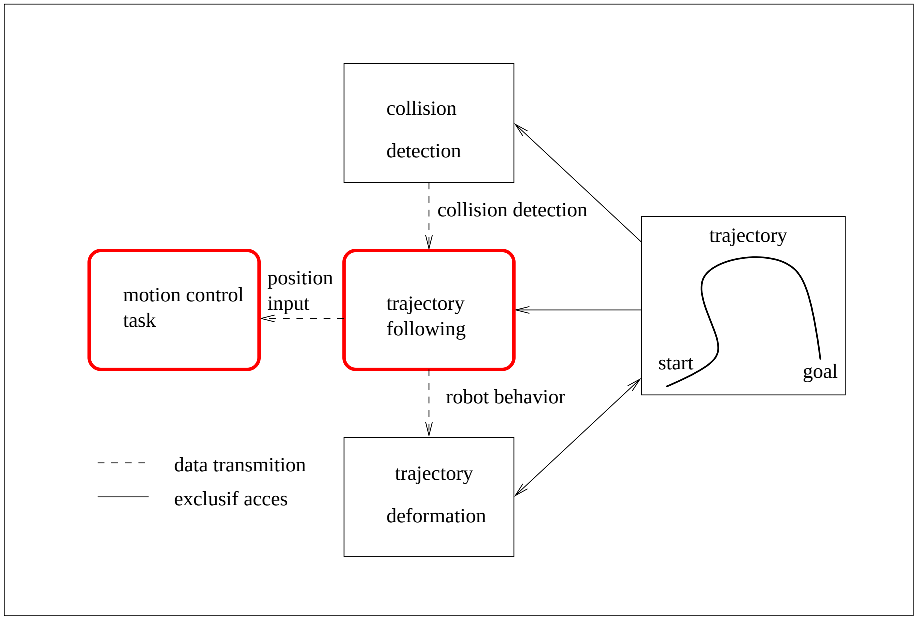
robot Dala

robot CyCab

Architecture

Ensure

Slow down before collisions to get time to deform.
Do not deform on the current configuration.
Avoid Collisions



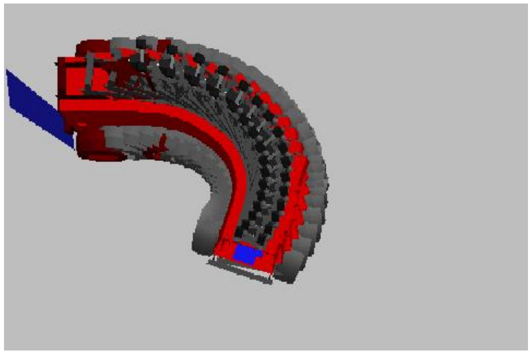
From infeasible trajectories to cusp points

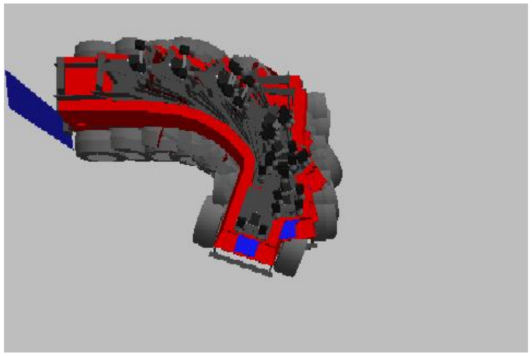
Initial motivation

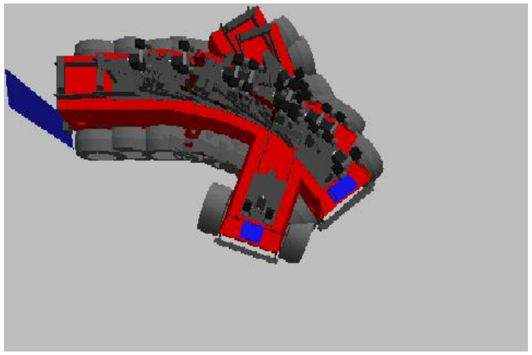
Avoid obstacles with a smooth trajectory in order to avoid slipping.

Corollary

A too curved trajectory becomes feasible with the natural introduction of cusp points during the deformation process.

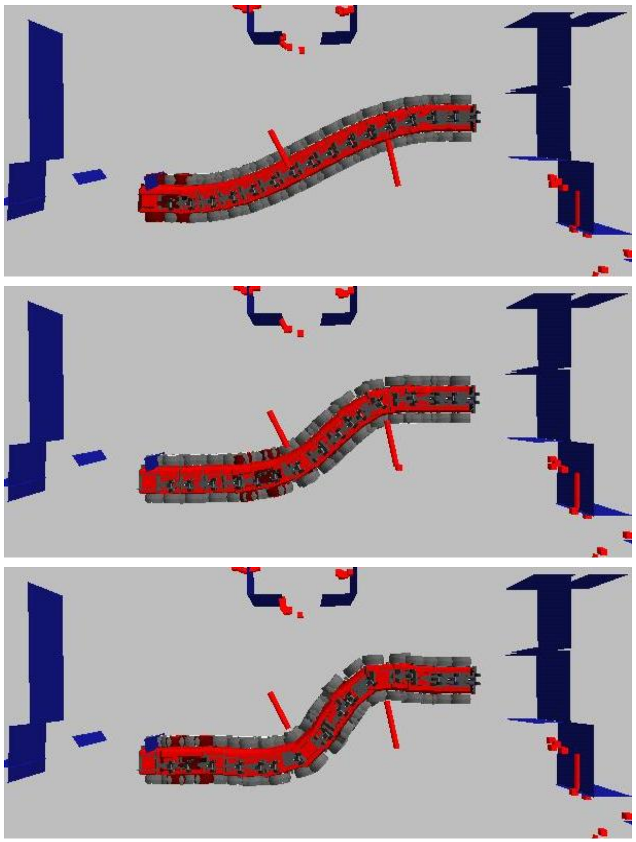


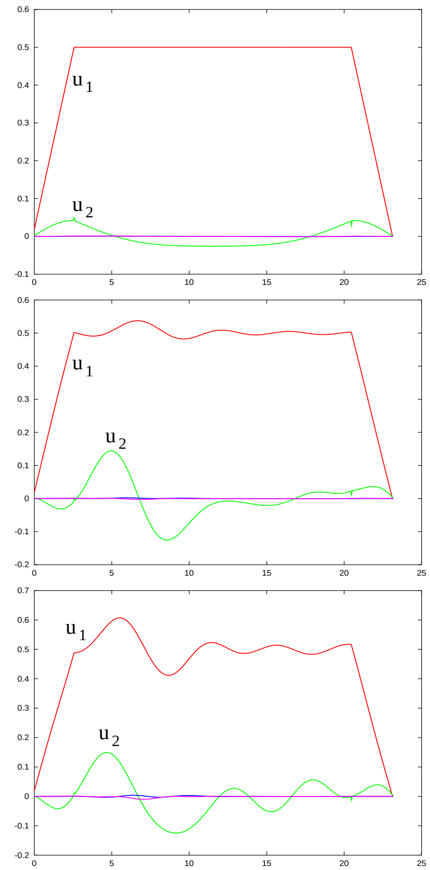




Effect on the System Inputs

Trajectory deformation results in input transformation.

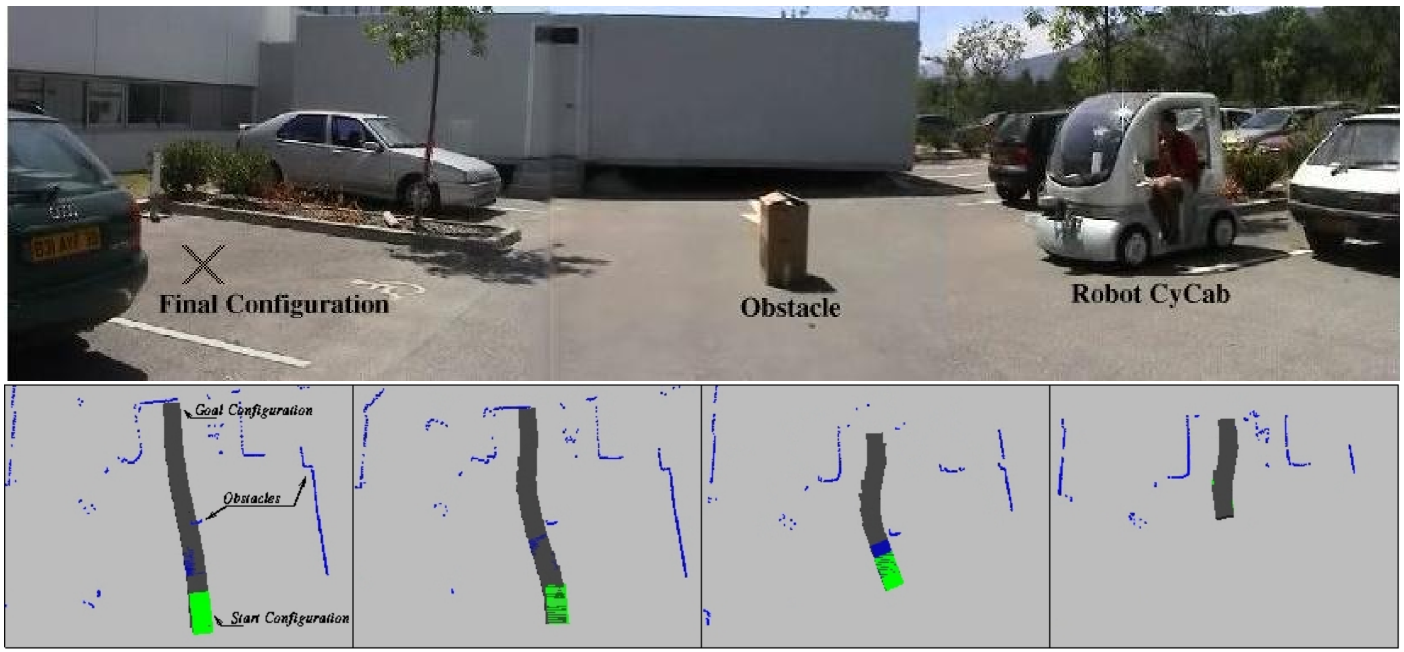




Experiment with robot CyCab

Movie

From a parking space to an other



Conclusion

Non-holonomic path optimization method.

Optmization upon the curvature criterion.

Integration and experiments on two robots.

Future work

Optimization upon speed and acceleration criteria.

Use visual perception.