Reactive Trajectory Deformation to Navigate Dynamic Environment

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Autonomous Motion in Dynamic Environment

- Where to move next?
- Dynamic environment
- Car-like model

Plan

- Motion Autonomy : Previous Approaches
- Our Approach : Trajectory Deformation
- Experimental Results

Motion determination - Deliberative vs Reactive Approaches

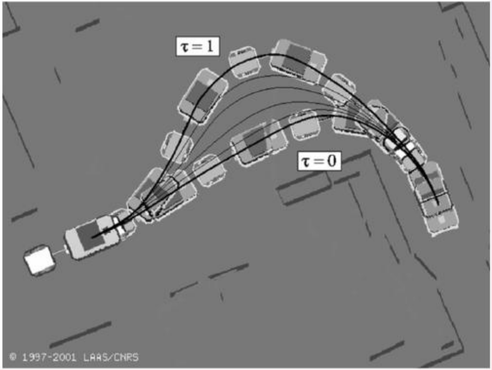
Two main approaches :

- Deliberative approaches
  - Solving of a motion planning problem
  - Require a complete model of the environment
  - High intrinsic complexity
- Reactive approaches
  - Computation of the action to apply during the next time step
  - Can operate on-line using local sensor information
  - Convergence towards the goal not guaranteed

Motion determination - Motion deformation

Principle :

- Modification of an initial motion in response to unexpected obstacles

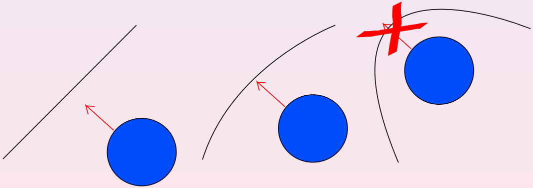


Previous solutions : Path deformation

Deformation of a path, ie. a **geometric** curve

- Brock & Khatib [BK97]
- Lamiraux and al. [LBL02]

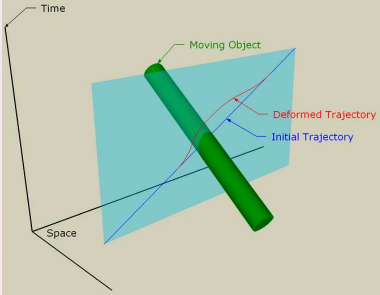
Drawbacks :



Our Solution : Trajectory Deformation (Teddy)

Trajectory ≡ Geometric path parametrized by **time**

- Features both spatial and temporal deformation
- Need to take in account a model of the future



Principle of the approach

Robotic system :

$$\dot{s} = f(s, u), s \in S, u \in U \tag{1}$$

$Trajectory \equiv [0; T_f] \rightarrow S$
Discrete trajectory : $\{n_0, \ldots, n_N\}$, $n \in S \times T$
Trajectory deformation due to two forces :

- External forces due to obstacles
- Internal forces to maintain the connectivity

External forces

- Purpose :
  $F_{ext}(n) = F_{ext}(s,t)$ exerted by the obstacles for collision avoidance
- In practice :
  Control points [BK97] $c^j = (p_j, t) \in \mathbf{W} \times \mathbf{T}$
  Potential field :

$$V_{ext}(c) = \begin{cases} k_{ext}(d_0 - d_{wt}(c^j))^2 & \text{if } d_{wt}(c^j) < d_0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

  k_{ext} is the repulsion gain
  Distance d_{wt} to the closest obstacle :

$$d_{wt}{}^2 = w_s{}^2(x_1 - x_0)^2 + w_s{}^2(y_1 - y_0)^2 + w_t{}^2(t_1 - t_0)^2 \quad (3)$$

External forces

- Resulting force in $\mathbf{W} \times \mathbf{T}$:

$$\mathbf{F}_{ext}^{wt}(c^j, t) = -\nabla V_{ext}(c) = k_{ext}(d_0 - d_{wt}(c))\frac{\mathbf{d}}{||\mathbf{d}||} \quad (4)$$

- Forces applied in the configuration space :

$$\mathbf{F}_{ext}^{ct}(q, t) = \sum_{j=1}^{r} J_{c^j}^{T}(q, t)\mathbf{F}_{ext}^{wt}(c^j) \quad (5)$$

- At last, $\mathbf{F}_{ext}(s, t)$ derived from $\mathbf{F}_{ext}^{ct}(q, t)$

Internal forces

- Purpose : Maintain the connectivity of the trajectory
  $\mathcal{R}(n_-)$ forward reachability set
  $\mathcal{R}^{-1}(n_+)$ backward reachability set
  3 successive nodes n_-, n, n_+
  Connectivity criterion :
  n must belong to $\mathcal{R}(n_-) \cap \mathcal{R}^{-1}(n_+)$
- In practice :
  Computation of $\mathcal{R}(n_-) \cap \mathcal{R}^{-1}(n_+)$ if possible

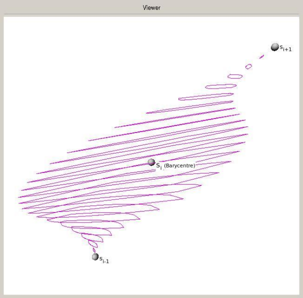
Internal forces

- Case $\mathcal{R}(n_-) \cap \mathcal{R}^{-1}(n_+) \neq \emptyset$:
  Potential field defined between a node n and the centroid H

$$V_{int}(n) = k_{int} d_{st(} n)^2$$

  k_{int} attraction gain
  Resulting force :

$$\mathbf{F}_{int}(n) = -\nabla V_{int}(n) = k_{int} d_{st(} n) \frac{\mathbf{d}}{||\mathbf{d}||}$$



- Case $\mathcal{R}(n_-) \cap \mathcal{R}^{-1}(n_+) = \emptyset$:
  Keep the connectivity with the past
  Moved to the closest node of $\mathcal{R}(n_-)$

Total force applied

Total force applied on a node n :

$$\mathbf{F}(n) = \mathbf{F}_{ext}(n) + \mathbf{F}_{int}(n) \tag{6}$$

- More weight to k_{ext} move the trajectory away from obstacles faster
- More weight to k_{int} increase the stiffness of the trajectory
- More weight to w_s ensure to keep a great secure distance from obstacles
- More weight to w_t increase the modifications applied on the speed on the system

Case Study (1) : Double Integrator System

State of the system $\mathcal{A}$: (p, v)

Dynamic of the system :

$$\begin{pmatrix} \dot{p} \\ \dot{v} \end{pmatrix} = \begin{pmatrix} v \\ a \end{pmatrix} \tag{7}$$

Input control : $u = a$

Constraints :

$$\begin{cases} v \leq v_{max} \\ a \leq a_{max} \end{cases}$$

Case Study (2) : Car-like system

State of the system $\mathcal{A}$: (x, y, θ, ϕ, v)
Dynamic of the system :

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\phi} \\ \dot{v} \end{pmatrix} = \begin{pmatrix} v\cos(\theta) \\ v\sin(\theta) \\ v\tan(\phi)/L \\ \omega \\ a \end{pmatrix} \tag{8}$$

Input control : $u = (a, \omega)$
Constraints :

$$v \in [0, v_{\max}], |\phi| \leq \phi_{\max}, |a| \leq a_{\max} \text{ and } |\omega| \leq \omega_{\max}$$

Experimental Results

Experimental Results

Teddy in action

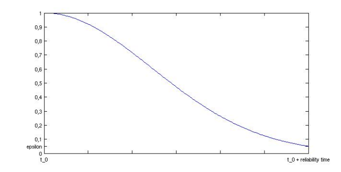
Conclusion and Future Works

Works done :

- Trajectory Deformation scheme
- Reactivity to information about obstacles behaviour
- Simulation over double integrator and car-like systems

Future Works :

- Prediction validity



- Integration within a global navigation architecture
- Tests on an actual robotic system

Thank you for your attention!

Questions ?