On the control of a multirobot system for an elastic hose

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ICONIP 2008, Auckland New Zealand, november 26, 2008

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- Motivation
- Hose model
- Basic multirobot centralized control problem
- Introducing the internal dynamics
- Further and on-going work

Motivation

- Hoses are quite common in construction sites:
  - Shipyards
  - Building sites
- They transport
  - Water
  - Power
  - Air
  - Fluids of other kind

Motivation

- Problem statement
  - Design of a control strategy for a multirobot system composed of a collection of cooperative robots manipulating the hose
- Desired features
  - Distributed: the local decisions are based on local knowledge
  - Self-sensing: able to determine its actual configuration
  - Adaptive: able to perform under uncertain and new environmental conditions
    - Able to sense the environment

Motivation

- Long term research plan
  - Assuming global perfect knowledge
    - Model hose dynamics
    - Derive adaptive control rules
  - Assuming perfect local knowledge
    - Model local hose dynamics
    - Local control rules
  - Incorporate communication noise
  - Incorporate local sensing
    - Integrate local models from uncertain local and remote sensing information

Motivation

- Scope of the paper
  - Introducing the geometrical model of the hose
  - Giving an adaptive rule for configuration modification
    - Based on global knowledge
    - Without taking into account internal dynamics
  - Giving some hints about the introduction of the internal dynamics in the system model

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Hose geometrical modeling

- Splines
  - Give a continuous description along the unidimensional object
  - Geometrically Exact Dynamic Splines (GEDS)
    - Accounts for the rotation of the hose at each point
    - Exhaustive and rigorous mechanical analysis exist for this kind of systems.
  - Def: piecewise polynomial functions

Hose geometrical modeling

- Splines: a set of control points are parameters of the curve

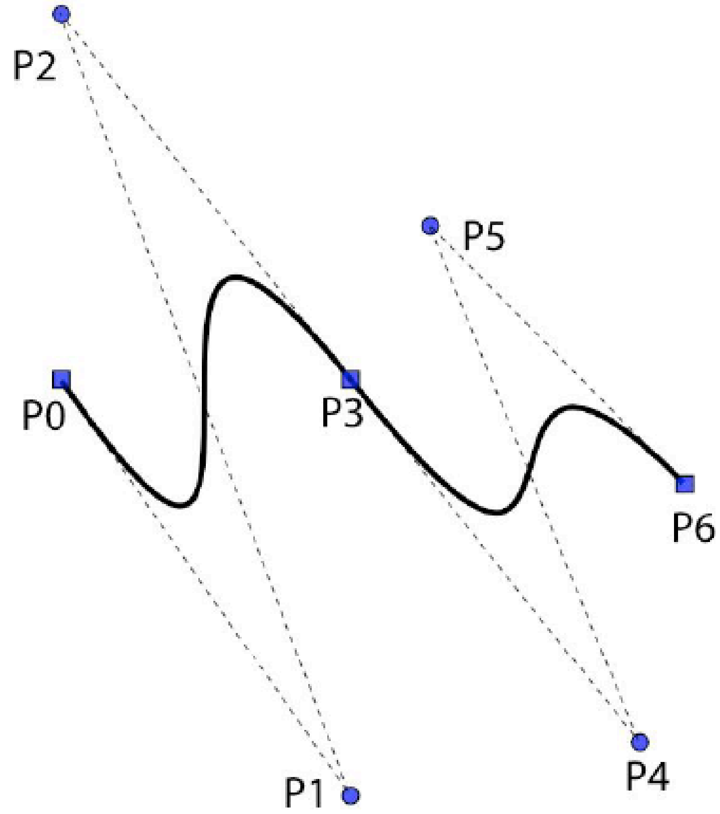

Fig. 1. Cubic spline with six control points

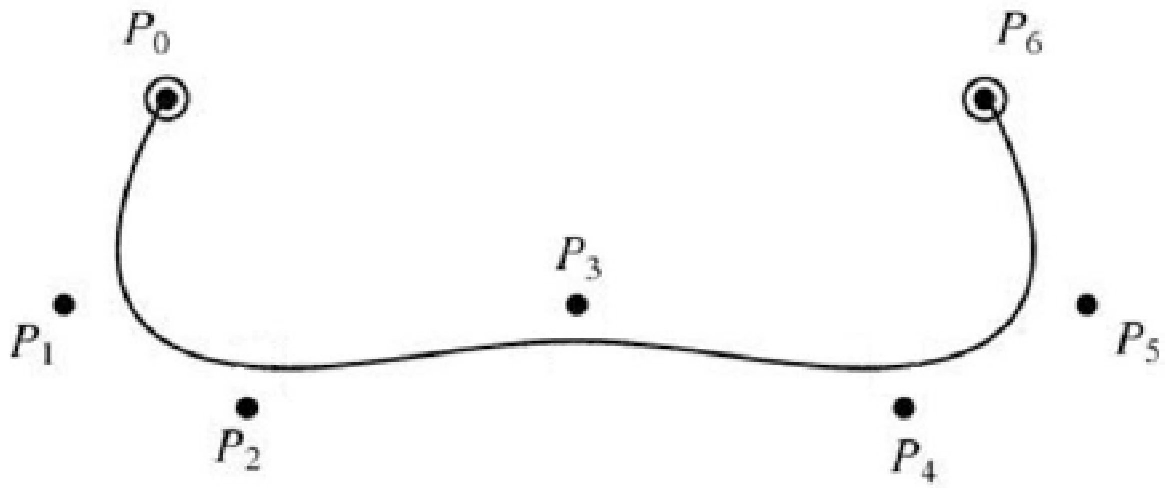

Fig. 2. Hose modelled with cubic splines

Hose geometrical modeling

- We assume
  - Constant section diameter
  - Transversal sections not deformed
  - No internal dynamics in the initial model

- GEDS model $q = (c, \theta) = (x, y, z, \theta)$
  - The hose is described by a collection of traversal sections
    - centers $c(t) = (x(t), y(t), z(t)),$
    - orientations $\theta(t).$

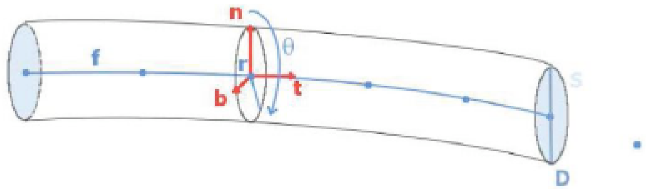

Fig. 3. Beam

Hose geometrical modeling

- The spline model

$$q(u) = \sum_{i=1}^{n} b_i(u) \cdot qi, \quad \begin{cases} b_i \text{ is the basis function of the control point } q_i. \\ u \in [o, L]. \\ s \text{ arclength} \end{cases} \qquad (1)$$

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Basic control

- Goal: to give an adaptive rule for the transition between hose configurations
- No internal dynamics
- Spline model
- Robots placed at regular intervals along the hose

Basic control

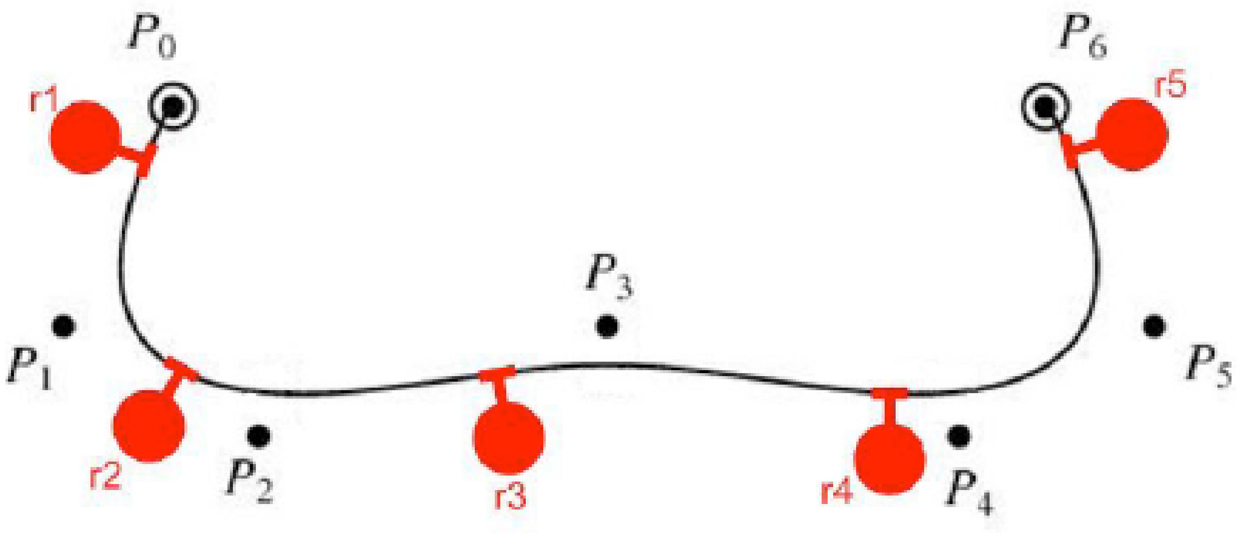

Fig. 4. Multirobot configuration for the hose control

Basic control

- Derivative of hose points relative to control points

$$\frac{dq}{dq_i} = \frac{d\left[\sum_{j=1}^{n} b_j \cdot q_j\right]}{dq_i}$$

$$\Downarrow$$

$$\frac{dq}{dq_i} = b_i \frac{dq_i}{dq_i} = bi$$

Basic control

- Dynamic dependence of individual robot speed on the variation of the spline control points

$$\dot{q}_r = J_{ri}.\dot{q}_i$$

$$J_{ri} = \begin{pmatrix} \frac{\partial q_{r_1}}{\partial q_1} & \dots & \frac{\partial q_{r_m}}{\partial q_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial q_{r_1}}{\partial q_n} & \dots & \frac{\partial q_{r_m}}{\partial q_n} \end{pmatrix} = \begin{pmatrix} b_1(r_1) & \dots & b_1(r_m) \\ \vdots & \ddots & \vdots \\ b_n(r_1) & \dots & b_n(r_m) \end{pmatrix}$$

Basic control

- Objective function: distance between actual and desired control point positions

$$D(q) = \sum_{i=1}^{n} \|q_i - q_i^*\|^2$$

- Minimized by gradient descent

$${q_i}^{n+1} = q_i^n - \lambda \nabla (D(q_i^n))$$

Basic control

- Let it be u(t) the position of the spline control point

$$\frac{du}{dt} = -\nabla D(u(t))$$

$t = \frac{t_0}{1-s}$,

$$u(s) = \begin{cases} u(s) = u * + e^{\frac{-2s}{1-s}}[u(0) - u_*], s \in [0, 1) \\ u(1) = u*, \dot{u}(1) = 0 \end{cases}$$

Basic control

- The multi robot dynamics that move the hose to the desired configuration is given by

$$\dot{q}_r(s) = J_{ri}.\dot{u}(s)$$

↓

$$\dot{q}_r(s) = \begin{cases} J_{ri}.\{-2e^{\frac{-2s}{1-s}}(u(0) - u_*)\}, s \in [0,1) \\ u(1) = u*, \dot{u}(1) = 0 \end{cases}$$

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Internal dynamics

- The relationship between the external and the internal forces is given by eq.

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) = F_i - \frac{\partial U}{\partial q_i}, \forall i \in \{1, \ldots, n\}.$$

  - F : external forces
  - U: hose potential energy
  - T: kinetic energy

Internal dynamics

- External forces
  - F_s streching force
  - F_T tension torque
  - F_B curve torque

$$F = \begin{pmatrix} F_S \\ F_T \\ F_B \end{pmatrix}.$$

Internal dynamics

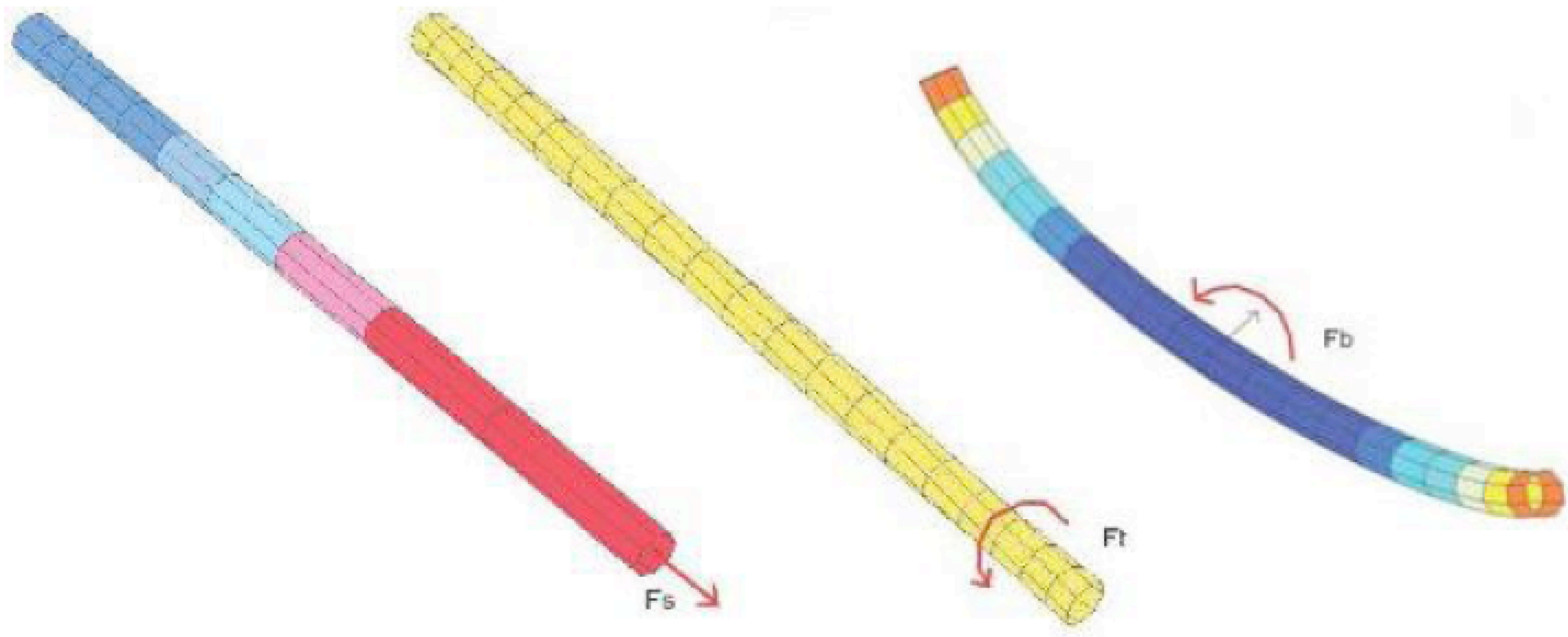

Fig. 5. Potential energy induced forces on the hose

Internal dynamics

- Potential energy

$$U = \frac{1}{2}\int_0^L \varepsilon^t H \varepsilon ds$$

Hokke matrix ,H

tension vector ε

stretching tension ε_s

torsion ten sion ε_t

curve tension ε_b.

Internal dynamics

- Kinetic energy

$$J = \begin{pmatrix} \mu & 0 & 0 & 0 \\ 0 & \mu & 0 & 0 \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & I_0 \end{pmatrix}$$

Inertial matrix

$$T = \frac{1}{2}\int_0^L \frac{dq^t}{dt} J \frac{dq}{dt} ds$$

Internal dynamics

- We arrive to a matrix expression of the external forces needed to reach the desired configuration

$$F = MA - P$$

where

$$P^i = -\frac{\partial U}{\partial q_i}$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_i} = \sum_{j=1}^{n} M_{i,j} A_j$$

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On going work

- Integrate the internal dynamics into the basic multirobot control
- Development of simulation models
- Design of physical realizations
  - Gripping
  - Sensing: the hose and the environment
  - Communication

Further work

- Design of the decentralized control system
- Design cooperative sensing strategies
- Design of experimental settings and tasks

- Thanks for your attention