Linked Multicomponent Robotic Systems

Basic Assessment of Linking Element Dynamical Effect

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Outline

1. Introduction
   - Problem statement
   - System definition
2. Approach
   - Control scheme
   - Simulation Results

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Linked Multicomponent Robotic Systems

- Definition: group of robotic units physically-linked by a non-rigid element.
- Working hypothesis: physical link introduces new non-linear dynamics and physical constraints in the system, altering its behaviour.

Main Questions Addressed

- Does the physical link introduce new dynamics in the system?
- Should these linked systems be treated as non-linked ones?

Study of a Paradigmatic Problem

- Carry a hose along a predefined path
- Hose is attached at the robots, keeping L meters long segments between them
- Well-known problem in MCRSs. Not yet studied for L-MCRSs.

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Basic definitions

- Path: $\vec{H}(s) = (h^x(s), h^y(s))$
- Each robot's position: $\vec{P_i} \equiv [P_i^x \, P_i^y]$
- Desired position along the path for the i^{th}robot: $\psi_H(s, L, i)$
- Desired bi-dimensional position for the i^{th}robot: $\vec{H}(\psi_H(s, L, i))$

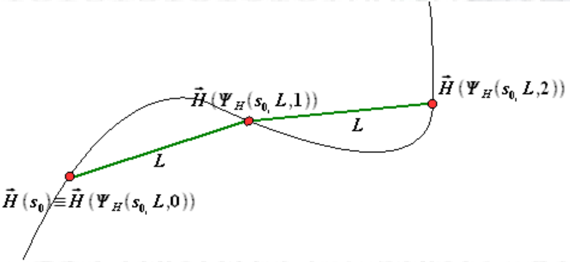

Figure: Deriving desired positions from a base s_0

Dynamic Models I

- Vehicles: Basic holonomic dynamic

$$\frac{d\vec{V}_i}{dt} = \frac{F_i}{m}$$

- Physical links: Simple clamped springs

$$\vec{T}_i = K \cdot \max(0, |\vec{P}_i - \vec{P}_{i+1}| - L) \cdot \{\cos(\beta_i), \sin(\beta_i)\}$$

Dynamic Models II

- Both models together:

$$\frac{d\vec{V}_i}{dt} = \frac{\vec{F}_i - \vec{T}_{i-1} + \vec{T}_i}{m}$$

Individual Performance Measure

- Mean square euclidean distance error between robots:

$$e_i^{dis} = \frac{1}{t}\int_0^t \left(\left\|\vec{P}_i - \vec{P}_{i+1}\right\| - L\right)^2.$$

- Mean euclidean distance error between robots and their desired position:

$$e_i^{pos} = \frac{1}{t}\int_0^t \left(\left\|\vec{P}_i - H(\vec{s_i})\right\|\right)^2.$$

System Performance Measure

- Distance between robots: $e^{dis} = \sum_{i=0}^{n-2} e_i^{dis}$
- Distance between robots and their references: $e^{pos} = \sum_{i=0}^{n-1} e_i^{ref}$

Outline

Reference-Following Technique

- Each controller instance drives its vehicle towards its reference ($\vec{H}(s_i)$):

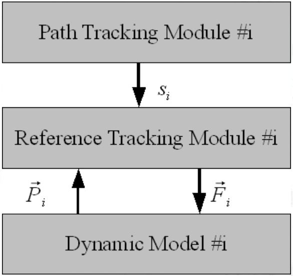

Figure: Usual reference-following control scheme

Consensus-Based Cooperation Methodologies

- Based on R. Beard and W. Ren's work
- Definition of a centralized scheme
- Distributited control algorithm subject to defined constraints is derived

Applying Consensus-Based Methodology

- Coordination variable as a group-level reference state: ξ
- Local i^{th} instance of the coordination variable: ξ_i

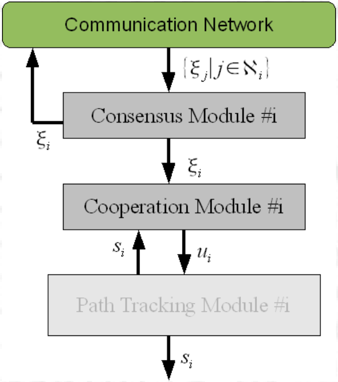

Figure: Consensus-based cooperation scheme

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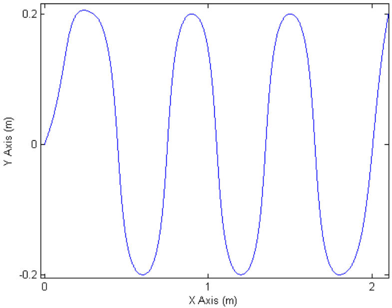
Simulation

- Two experiments where conducted: with and without the linking element
- Last robot's maximum output force was limited, so its individual performance's effect on system performance could be measured
- Robots were driven along a predefined path:



Individual Performance: Without Physical Link

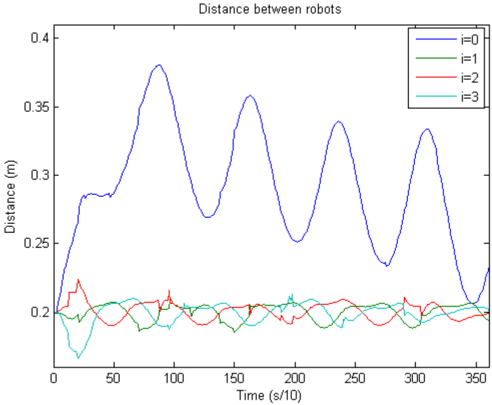


Figure: Distance between robots with no linking element elastic force $K = 0$

Individual Performance: With Physical Link

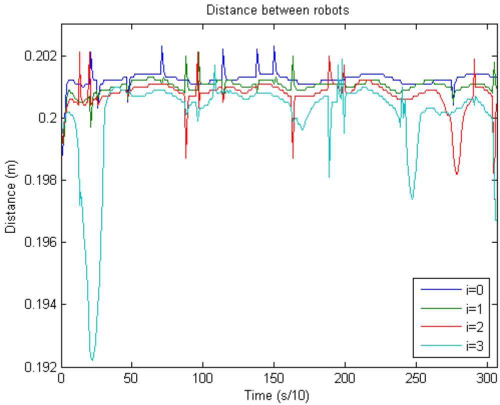


Figure: Distance between robots when there is a linking element elastic force $K = 40N$

Individual Performance: Without Physical Link

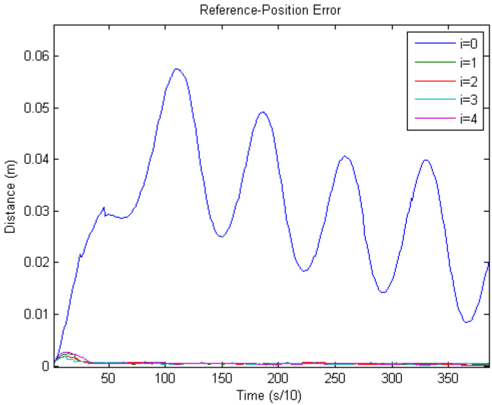


Figure: Reference position error without linking element elastic force $K = 0$

Individual Performance: With Physical Link

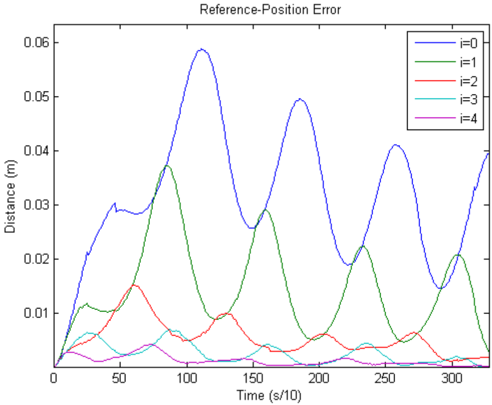


Figure: Position error when there is linking element elastic force involved

System Performance

Table: Simulation experiment results

$K=0$	e^{dis}	0.0104
	e^{pos}	0.0111
$K=40$	e^{dis}	0.0000
	e^{pos}	0.0216

Thanks

Thank you very much for your attention.

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