# On Distributed Cooperative Control for the Manipulation of a Hose by a Multirotobot System

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# 1. Introduction

- Unstructured environments.
- Resources and workers are required to move over the product being built.
- Hoses: allow the transportation of power and other resources.
- Problem: hose control formulated as a multirobot system task.

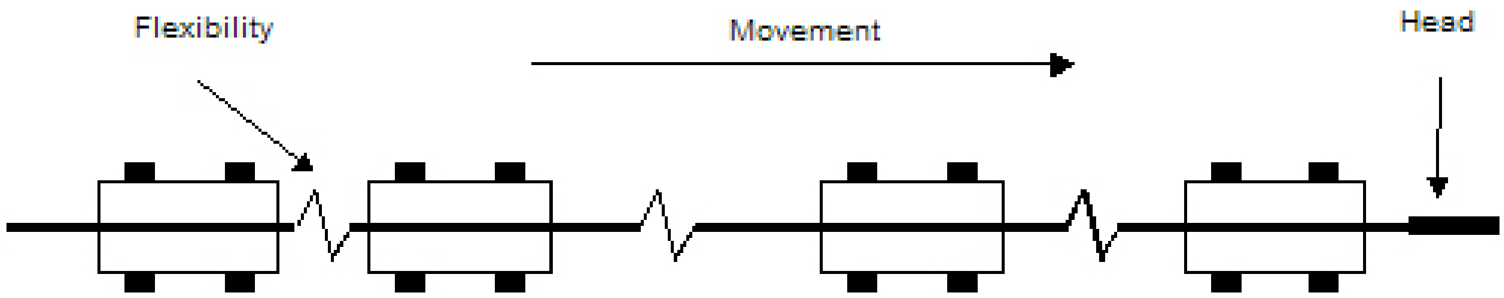
# 1. Introduction

# 2. Description of General System

- Individual robots attached to a hose.
- The hose is not a rigid link between the robots.
- The distance between robots may vary: the system is not a snake system.
- These are a source of uncertainty.
- Task: bring the hose head to a certain point in space.

# 2. Description of General System

- Abstract illustration of multirobot system:



# 3. System Elements

- A methodology developed by Beard is used for the formulation of decentralized control systems.
- This frameworks has been applied to the design of Unmanned Air Systems (UAVs).

# 3. System Elements

- Notation:
  - $z_i(t)$ : location of the i-th robot at time t.
  - $x_i(t)$ : state of the i-th robot at time t.
  - $X(t) = \{x_1, \cdots, x_N\}$: global state of the system al time t.
  - $z^*$ : goal position.
  - $\theta^*$ : coordination variable, the minimum information that must be shared to obtain a cooperative behaviour:
    - Time to the goal position, where must be placed the first robot at the hose head.

# 3. System Elements

- Notation (cont.):
  - $u_i(\theta^*, X, t)$ : control command of the i-th robot at time t.
  - $U(\theta^*, X, t) = \{u_1(\theta^*, X, t), \cdots, u_N(\theta^*, X, t)\}$: global set of commands at time t.

# 3. System Elements

- Cooperation Constraint:
  - Formal statement of the task to be accomplished by the robot team.

$$J_{constraint}\left(\theta^{*}\right)=\sum_{i=1}^{N}\left\|z_{i}\left(\theta^{*}+(i-1)\Delta\right)-z^{*}\right\|^{2}.$$

$\Delta$ : desired interval between arrivals to the goal.

# 3. System Elements

- Cooperation Objective:
  - Regularization property that enforces the cooperation between individual agents.

$$J_{objective}\left(\theta^*, X, U, t\right) = \sum_{i=2}^{N}\left(v_i\left(X, U, t\right) - v_{i-1}\left(X, U, t\right)\right)^2$$

$v_i\left(X, U, t\right)$: local velocity vector, depends on the conditions of the remaining robots.

# 3. System Elements

- Coordination Function:
  - Formal way of decoupling the Cooperation Objective function into each agent's local representation:

$$J_{objective}\left(\theta^{*}, X, U, t\right) = \sum_{i=1}^{N} J_{cf,i}\left(\theta^{*}, x_i, u_i, X, U, t\right)$$

$$J_{cf,i}\left(\theta^{*}, x_i, u_i, X, U, t\right) = \left(v_i\left(X, U, t\right) - v_{i-1}\left(X, U, t\right)\right)^2$$

# 3. System Elements

- Solving the Centralized System:
  - Distributed control problem can be stated as the minimization of the decoupled Objective Function subject to the Cooperation Constraint:

$$u_i = \text{argmin}\left\{ \sum_{i=1}^{N} J_{cf,i}\left(\theta^*, x_i, u_i, X, U, t\right) \right\}$$

$$subjetcto : J_{constraint}\left(\theta^*\right) = 0.$$

# 3. System Elements

- Solving the Centralized System (cont):
  - In special (trivial) circumstances the control will have the expression:

$$u_i = \frac{z^* - z_i(\theta^*)}{t_o + \Delta}.$$

# 3. System Elements

- Solving the Centralized System (cont):
  - Some factors introduce uncertainty and nonlinearities:
    - Hose elasticity.
    - Hose weight and the robot members distribution along the hose.
    - Physical distance between the robots ≠ Distance over the hose.
    - Traction effects between the robots due to the hose.
    - Misalignment of the motion vectors may cause chaotic behaviour.
    - Change in hose content may produce changes in dynamic parameters.

# 3. System Elements

- Solving Decentralized System:
  - A estimation of $\theta^*$ is needed to obtain $u_i$ .
  - Each robot has its own estimation $\theta_i$ , using a consensus schema (averaging rule):

$$\theta_i[n+1] = \theta_i[n] + \sum_{j=1}^{N} g_{ij}[n] K_{ij} \left( \left( \theta_j + v_{ij}[n] \right) - \theta_i[n] \right)$$

  - $K_{ij}$ : weighting matrix,
  - $v_{ij}$ : communications noise,
  - $g_{ij}$ : existence of links between robots.

# 3. System Elements

- Solving Decentralized System (cont):
  - The parameters $g_{ij}$ and $K_{ij}$ are set so that always hold the condition:

$$\sum_{j=1}^{N} g_{ij}[n]K_{ij} = 1$$

  - It has been shown that this consensus schema converges to the true value of $\theta^*$ if the graph that models the communications schema is a spanning-tree.

# 4. Conclusions

- The problem of decentralized control of a multirobot system for the manipulation of a hose is posed.
- The problem is posed in the framework developed by Beard.

Thanks!

Questions?