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 framework 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.
  - $X(t) = \{x_1, \ldots, x_N\}$: global state of the system at 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.
  - \( U(\theta^*, X, t) = \{u_1(\theta^*, X, t), \ldots, u_N(\theta^*, X, t)\} \): global set of commands at time t.
3. System Elements

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

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

\( \Delta \): desired interval between arrivals to the goal.
3. System Elements

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

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

\( v_i(X, U, t) \): 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:

\[
J_{\text{objective}}(\theta^*, X, U, t) = \sum_{i=1}^{N} J_{cf,i}(\theta^*, x_i, u_i, X, U, t)
\]

\[
J_{cf,i}(\theta^*, x_i, u_i, X, U, t) = (v_i(X, U, t) - v_{i-1}(X, U, t))^2
\]
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:

\[
 u_i = \arg\min \left\{ \sum_{i=1}^{N} J_{cf, i} (\theta^*, x_i, u_i, X, U, t) \right\}
\]

subject to \( J_{\text{constraint}} (\theta^*) = 0 \).
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):
    \[
    \theta_i[n+1] = \theta_i[n] + \sum_{j=1}^{N} g_{ij}[n] K_{ij} \left( \theta_j[n] + v_{ij}[n] \right) - \theta_i[n]
    \]
    
    - $K_{ij}$: 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?