

Decentralized Kinematic Control of Payload Transport by Mobile Manipulator Collectives

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Motivation

Why Cooperation?

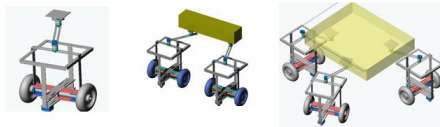
- Tasks are too complex
- Distinct benefits – “Two hands are better than one”
- Instead of building a single all-powerful system, build multiple simpler systems
- Motivated by the biological communities



How do we incorporate similar cooperation in artificial (multi-robot) systems?

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Architecture and Features



Goal: Flexible, scalable and modular framework for cooperative payload transport by autonomous wheeled mobile manipulators.

Features:

- Accommodate changes in the relative configuration using the compliant linkages.
- Detect relative configuration changes using sensed articulation.
- Compensate for external disturbances using redundant actuation of the bases.

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Research Issues

Design

- Type / Configuration Selection
- Dimensional / Formation Optimization

Analysis / Simulation

- Constrained Kinematics / Dynamics
- Kinematics / Actuation Redundancy

Control

- Redundancy Resolution
- Distributed Operation

Collaboration

- Accommodation
- Detection
- Correction

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Challenges

- Nonholonomic (wheel) / holonomic (closed-loop) constraints
- Mobility / workspace increased (but also increases redundancy)
- Mixture of active/passive components

Our Focus

Creation of a decentralized kinematic control scheme

To realize an arbitrary set of end-effector motions for an overall system subject to mixtures of holonomic/nonholonomic constraints & active/passive joints

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Our Approach

Develop a motion plan using only actuation of wheeled-bases

Two level hierarchical control

Upper level (Steerable Vector Fields):

- Verify that arbitrary end-effector motion is feasible.
- Partitioning of feasible motion distribution:
 - Actively-realizable (using wheeled bases)
 - Passively-accommodating (using articulations)
- Configuration dependent partitioning
- Steer the actively-realizable vector-fields

Lower level (Stable local controller):

- Posture stabilizing controller

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Kinematic Model of Individual Module

Twist matrices expressed in Frame (E) Body-fixed frame of the payload

$${}^E [{}^E T_a] = {}^E [{}^E T_a] \dot{\theta}_1 + {}^E [{}^E T_a] \dot{\theta}_2 + {}^E [{}^E T_a] \omega_{M'} + {}^E [{}^E T_a] v_{M'}$$

$${}^E \dot{\xi}_a = \begin{bmatrix} 1 \\ L_1 S_1 \\ L_1 C_1 + L_2 \end{bmatrix} \dot{\theta}_1, \quad {}^E \dot{\xi}_b = \begin{bmatrix} 1 \\ L_2 \\ L_2 \end{bmatrix} \dot{\theta}_2, \quad {}^E \dot{\xi}_c = \begin{bmatrix} 1 \\ L_1 S_1 \\ L_1 C_1 + L_2 \end{bmatrix} \omega_{M'}, \quad {}^E \dot{\xi}_d = \begin{bmatrix} 0 \\ C_{12} \\ -S_{12} \end{bmatrix} v_{M'}$$

Assembled

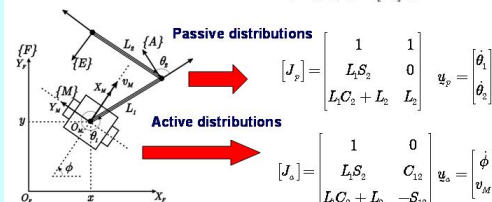
$${}^E [{}^E F_a] = \begin{bmatrix} {}^E \omega_{Bx} \\ {}^E v_B \end{bmatrix} = \begin{bmatrix} {}^E \dot{\xi}_a & {}^E \dot{\xi}_b & {}^E \dot{\xi}_c & {}^E \dot{\xi}_d \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \omega_{M'} \\ v_{M'} \end{bmatrix}$$

Twist Assembled Jacobian Matrix

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Twist Distribution Analysis

Partition the Jacobians: ${}^E \dot{\xi} = [J_a] \dot{u}_a + [J_f] \dot{u}_f$



Can any arbitrary twist be realized using only the active distribution?

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Twist Distribution Analysis

Reciprocity Check

$$[J_a] = \begin{bmatrix} 1 & 0 \\ L_1 S_1 & C_{12} \\ L_1 C_1 + L_2 & -S_{12} \end{bmatrix} \xrightarrow{\text{Reciprocal Wrench}} \begin{bmatrix} -L_1 C_1 - L_2 C_{12} \\ S_{12} \\ C_{12} \end{bmatrix}$$

Given arbitrary twist ${}^E \dot{\xi} = [\omega_{Bx} \ v_{Bx} \ v_{By}]^T$

Condition $[-L_1 C_1 - L_2 C_{12}] \omega_{Bx} + [S_{12}] v_{Bx} + [C_{12}] v_{By} = 0$

Transform an arbitrary twist from {E} to {M}:

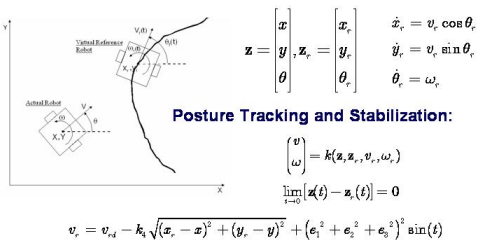
$${}^M [{}^M \dot{\xi}] = \begin{bmatrix} \omega_{Bx} \\ [L_1 S_1 + L_2 S_{12}] \omega_{Bx} + C_{12} v_{Bx} - S_{12} v_{By} \\ [-L_1 C_1 - L_2 C_{12}] \omega_{Bx} + S_{12} v_{Bx} + C_{12} v_{By} \end{bmatrix}$$

Achieved by aligning the forward travel direction with the direction of the velocity

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Lower-Level Controller

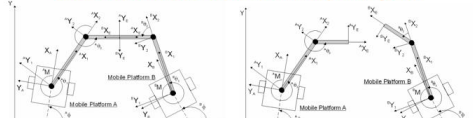
Control of Single WMR – Virtual Robot Algorithm [Canudas et al., 1996]



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Decentralized Collaboration

Frame attached to the common object is the end-effector frame of the two mobile manipulator systems



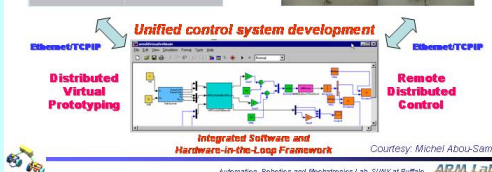
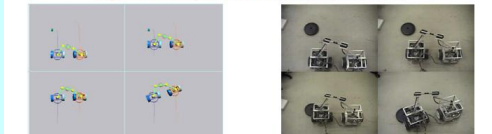
Experiment: Straight line with disruption



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Implementation Framework and Results

Left robot comes to a halt. Right robot compensates to maintain the formation.



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Discussion

- Successful implementation of decentralized control for our system
- Well-suited for online implementation
- Combined system is able to accommodate, detect and correct disturbances

Summary of Current Research Effort

- Manipulability-Based Configuration Optimization
- Geometric-Based Formation Optimization
- Artificial Potential-Field Framework for Distributed Motion Planning

Future Work

- Examine the control framework in much larger formation
- Develop dynamic motion planning / control schemes

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Related Conference Proceedings:

C. P. Tang, R. M. Bhatt, and V. Krovi, "Decentralized Kinematic Control of Payload Transport by a System of Mobile Manipulators", in the Proceedings of the 2004 IEEE/ICRA International Conference on Robotics and Automation, New Orleans, LA USA, April 26 – May 1, 2004.

Acknowledgement:

We gratefully acknowledge the support from The Research Foundation of State University of New York and National Science Foundation CAREER Award (IIS-0347653) for this research effort.