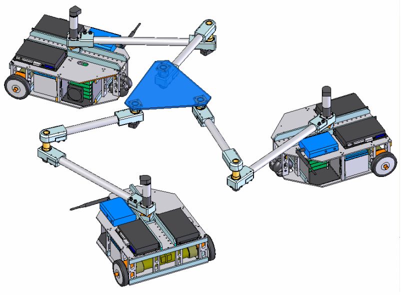
University at Buffalo *The State University of New York*

Motion and Force Control of a Mobile Robot

Abstract

- Goal: The overall goal of this research is to develop a decentralized control method to control the position and environment interaction force of a mobile robot.
- Look at the differences between centralized/decentralized control methods. We adopt a decentralized approach and focus on completely controlling the behavior of a single robot.
- Develop a position/force control method that allows us to independently specify the behavior of the manipulator and mobile base.
- Validate this control routine on a virtual prototype robot.
- Develop a physical prototype robot for real-world testing and implementation.



Cooperation in Nature

- Cooperation of autonomous robot collectives is not a new concept.
- Many examples of cooperation are inspired by collectives that already occur in nature.


Ants Gathering Food


Fish Schooling


Birds Flocking


Human Cooperation

Advantages of Cooperation

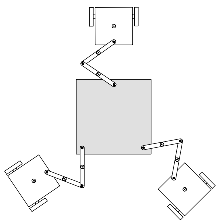
- Modularity
  - Endows the robot configuration with flexibility.
  - Robots can be added or subtracted from the collective.
- Redundancy
  - Increased manipulation capability
  - Accommodate for robot failures
  - Handle uneven terrain
- Error Correction
  - Alter force distribution
  - Change robot configuration

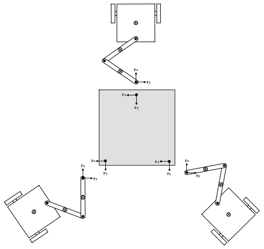
Centralized vs. Decentralized Control

- Centralized
  - Single control routine that is responsible for controlling all robots in the collective.
  - Exact collective information is needed, more complex.
  - Typically more efficient.
  - Little redundancy.
- Decentralized
  - Control routines are distributed partially or completely to the individual robots in the collective.
  - Exact collective information not needed.
  - Typically less efficient.
  - Greater redundancy.

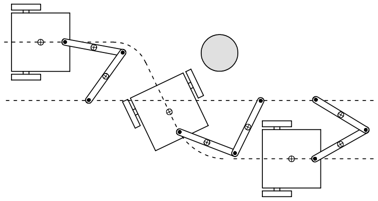
Mobile Robot Control Problem

- We adopt the decentralized control problem as:
  - Disconnect mobile robots from collective.
  - Develop a control routine to completely control the behavior of a single mobile robot.
  - Group robots back into collective.


Robots operating on a payload


Robots disconnected from payload

- The individual mobile robot can then be made to follow independent end-effector and base trajectories.
- Example:
  - End-effector follows straight line.
  - Base moves on different trajectory to avoid obstacle.


End-effector and base moving on different trajectories

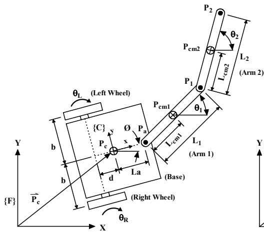
Kinematic and Dynamic Nomenclature

- Non-holonomic constraint and null-space matrices:

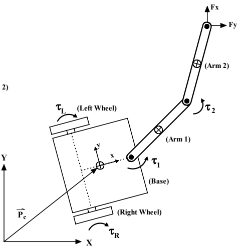
$$A=\begin{bmatrix}-\sin\phi & \cos\phi & -d & 0 & 0 & 0 & 0\\ -\cos\phi & -\sin\phi & -b & r & 0 & 0 & 0\\ -\cos\phi & -\sin\phi & b & 0 & r & 0 & 0\end{bmatrix}\qquad S=\begin{bmatrix}c[b\cos\phi - d\sin\phi] & c[b\cos\phi + d\sin\phi] & 0 & 0\\ c[b\sin\phi + d\cos\phi] & c[b\sin\phi - d\cos\phi] & 0 & 0\\ c & -c & 0 & 0\\ 1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

- Lagrange Dynamics

$$M(\underline{q})\underline{\ddot{q}} + V(\underline{q},\underline{\dot{q}}) = E\underline{\tau}_m + E_2\underline{F} - A^T\underline{\lambda}$$



Kinematic Nomenclature



Dynamic Nomenclature

Control

- Develop a control routine to control the motion of the end-effector (task-space) and the base (configuration-space).

$$\underline{\tau} = J^T W(\underline{u} - \dot{J}\underline{\dot{q}}) + \overline{N}^T H(\underline{v} + \dot{\overline{J}}\underline{\dot{x}}) + C\underline{\dot{q}} + g + J^T\underline{F}_E$$

  - *u* is the input to the task-space, which results in *x*-*y* Cartesian motions of the end-effector.
  - *v* is the input to the configuration-space, which results in all other motion of the arms and base.
- Task-space control law
  - The input, *u*, can be specified as a function of the velocity, position, and force error:

$$\underline{u} = \underline{\ddot{x}}_d + k_v\underline{\dot{e}} + k_p\underline{e} + k_f(\underline{F}_d - \underline{F}_E)$$

  - The controlled closed-loop dynamics then become:

$$\underline{\ddot{e}} + k_v\underline{\dot{e}} + k_p\underline{e} = k_f(\underline{F}_d - \underline{F}_E)$$

  - This forms a linear system and the behavior of the end-effector motion can now be designed according to k_v, k_p, and k_f.

- Configuration-space control law
  - The input, *v*, is specified as:

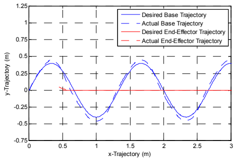
$$\underline{v} = \begin{bmatrix}v_R\\ v_L\\ v_1\\ v_2\end{bmatrix} = gR\begin{bmatrix}-u_1 + k_v(V_{des} - V_{act})\\ -u_2 + k_\omega(\omega_{des} - \omega_{act})\\ 0\\ 0\end{bmatrix}$$

$$where:\ u_1 = -k_1(v_r,\omega_r)e_1$$

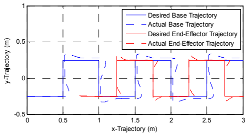
$$u_2 = -k_4(v_r,\omega_r)v_r\frac{\sin(e_3)}{e_3}e_2 - k_3(v_r,\omega_r)e_3$$

Results

- Tracking ability of end-effector and mobile base with no environment interaction force.

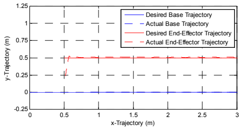


End-effector tracks straight line, Base tracks sinusoid.

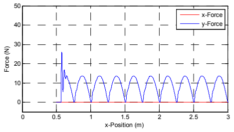


End-effector and base track square wave.

- Tracking ability of end-effector and mobile base with environment interaction force.
- Base tracks y = 0, end-effector tracks y = 0.5, a wall is also placed at y = 0.5.
- Sinusoidal interaction force between wall and end-effector



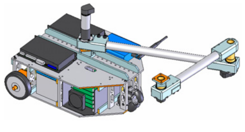
End-effector and base track trajectories.

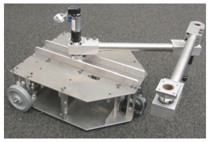


Interaction force is tracked.

Future Work

- Real-world application
  - Construct a physical prototype.
  - Run control in real-time on physical prototype.
- Research Issues
  - Effectiveness in multi-robot collectives.
  - Practicality of running in real-time.
  - Data latency, quantization, communication.


Virtual model


Physical prototype

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