Kaa: An Autonomous Serpentine Robot Utilizes Behavior Control

IS Robotics
Exploring the Future

Rajiv Desai, Charles Rosenberg, Joseph Jones

August 9, 1995

Funding by Mitsubishi Heavy Industries and the MITI Micromachine Center

Kaa gets its name from Rudyard Kipling's <u>The Jungle Book</u>.

▶ Presentation Overview

1. Serpentine Robots / Prior Work

2. Pipe Mobility

3. Kaa Robot Hardware
   a) Electronics
   b) Mechanics

4. Software Control System
   a) Overview
   b) Grasping
   c) Folding and Unfolding

5. Conclusions and Future Work

Serpentine Robots

Manipulator Arms

- A six degree of freedom arm gives little or no choice to the position of each joint in space
- Obstacles reduce usefulness
- Ideal manipulator has an infinite number of zero size links

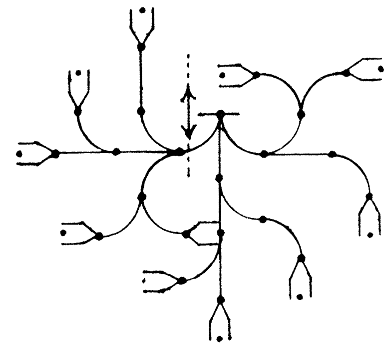
Hyper-Redundant / Serpentine Robots

- Ability to position an end effector in a small or cluttered workspace
- Whole arm manipulation
- Mobility without legs or wheels

Prior Work

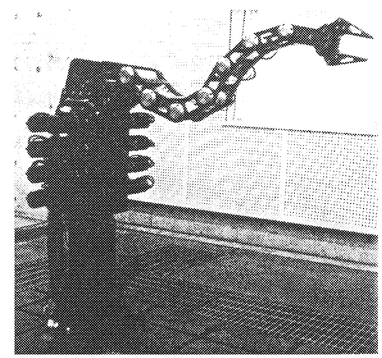
<u>Taylor, Lavie, and Estat 1983</u>

- cable driven arm
- 3 degree of freedom links
- manipulator and camera end effector



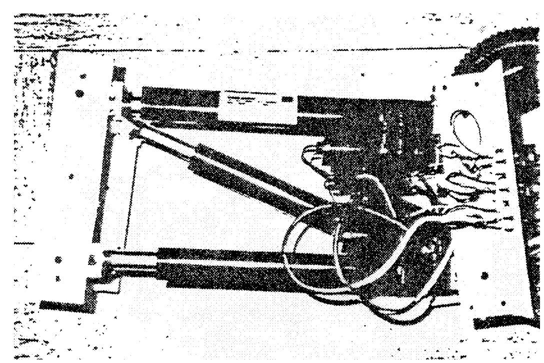
<u>Ma, Yoshinada, and Hirose 1990</u>

- cable driven arm
- 9 planar degrees of freedom
- manipulator end effector
- centrally located actuators



<u>Chirikjian and Burdick 1991, 1993</u>

- work on kinematics of grasping, manipulation and locomotion
- 30 planar degrees of freedom
- 10 indentical three DOF truss structures
- actuators distributed throughout robot



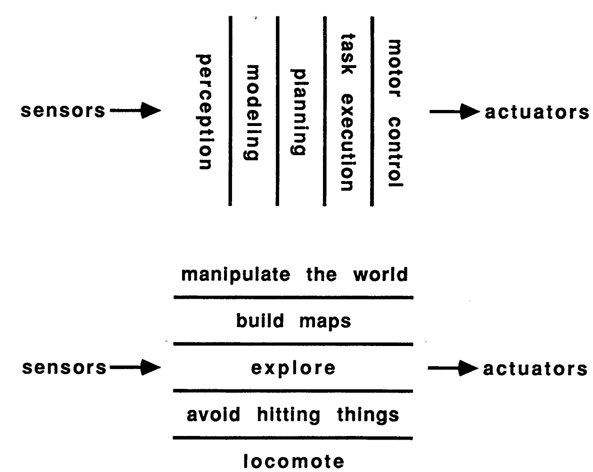
▶ Pipe Mobility

External Pipe Inspection

- tethers limit motion, add mass and complexity
- lack of high bandwidth communication necessitates on board computation

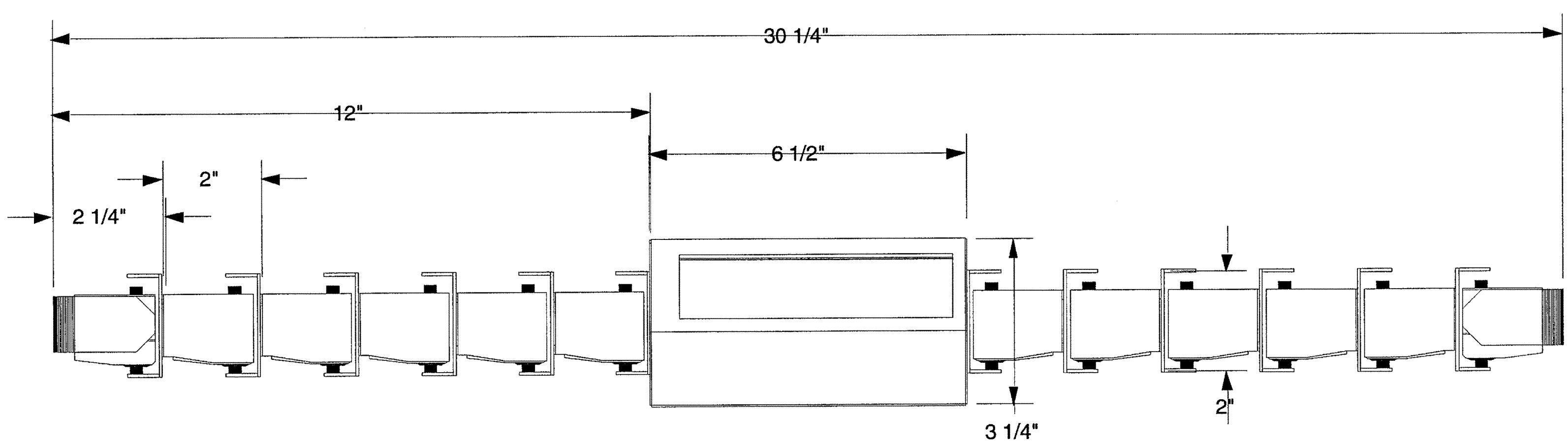
Behavior Control

- low compute power
- easily adapts to environment variability
- handles sparse, noisy sensor data
- Brooks 1986

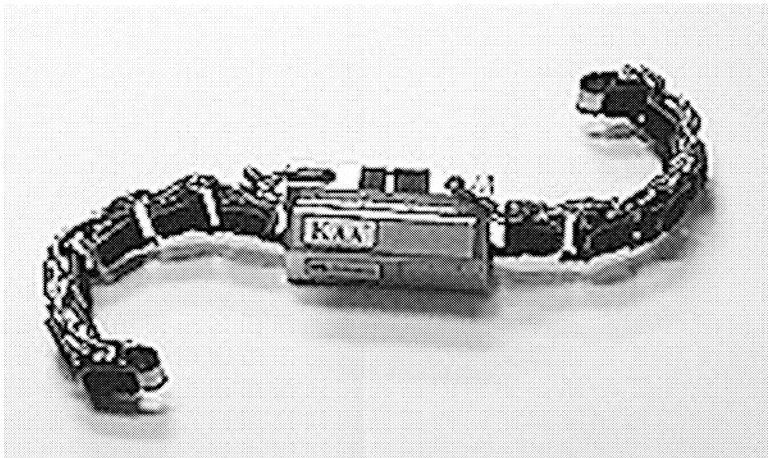


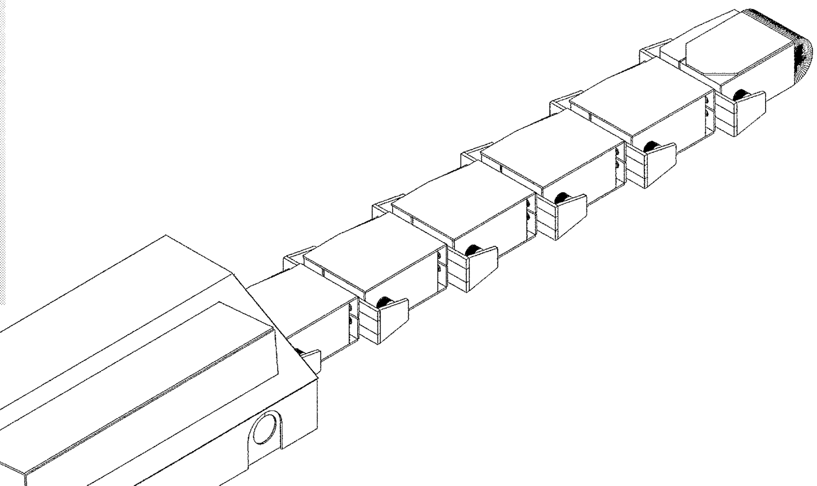
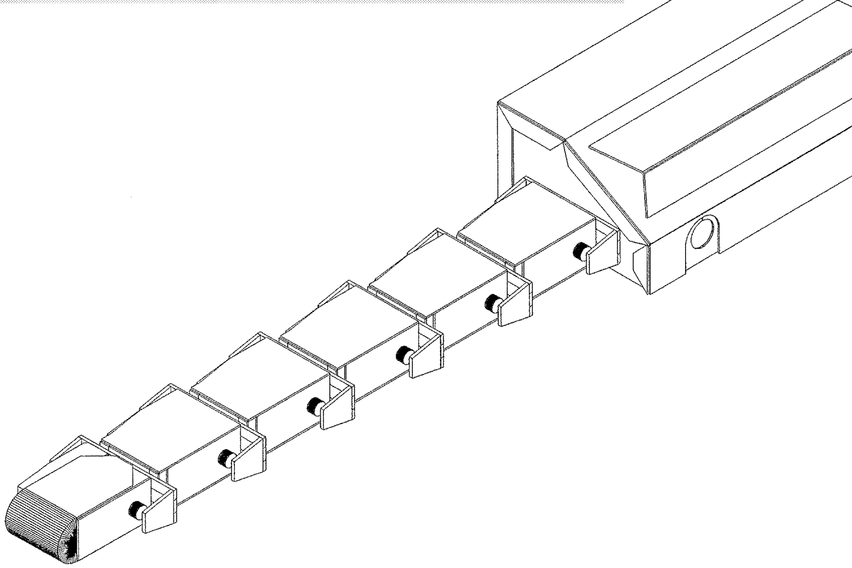
▶ Mechanical System

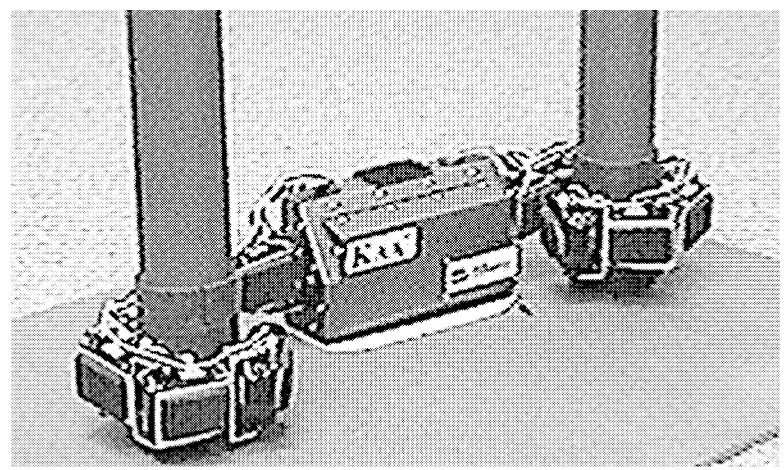
- thirteen links
- robot length is 30 inches, 0.75 meters
- twelve planar degrees of freedom
- each side of central link is a 6 DOF arm
- servo motor and driving electronics are contained in each link
- final link on each arm is terminated in a rounded finger tip



▶ Complete System





▶ Electronic System

Computation

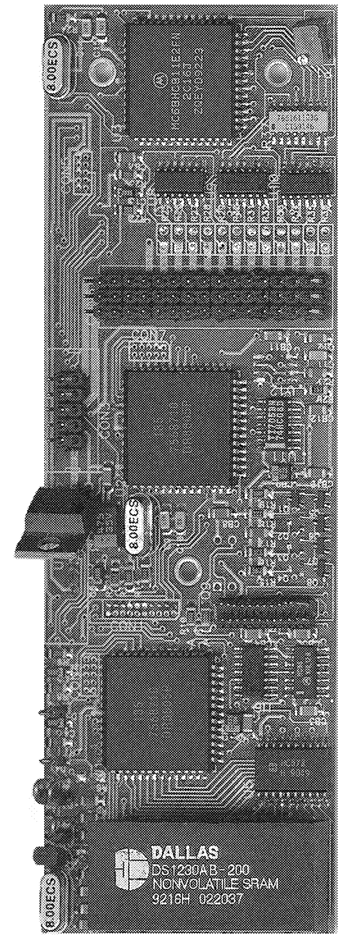
- three, 8 bit, 1 MIP Motorola 6811 microprocessors, networked
- 1 for servo control - 2K code space
- 1 for behavior control - 34K code space
- 1 for IR control - 2K code space (recent addition)

Completely Autonomous

- central body link contains power and computation

Sensing

- motor torque on each joint
- IR proximity on finger tips (recent addition)



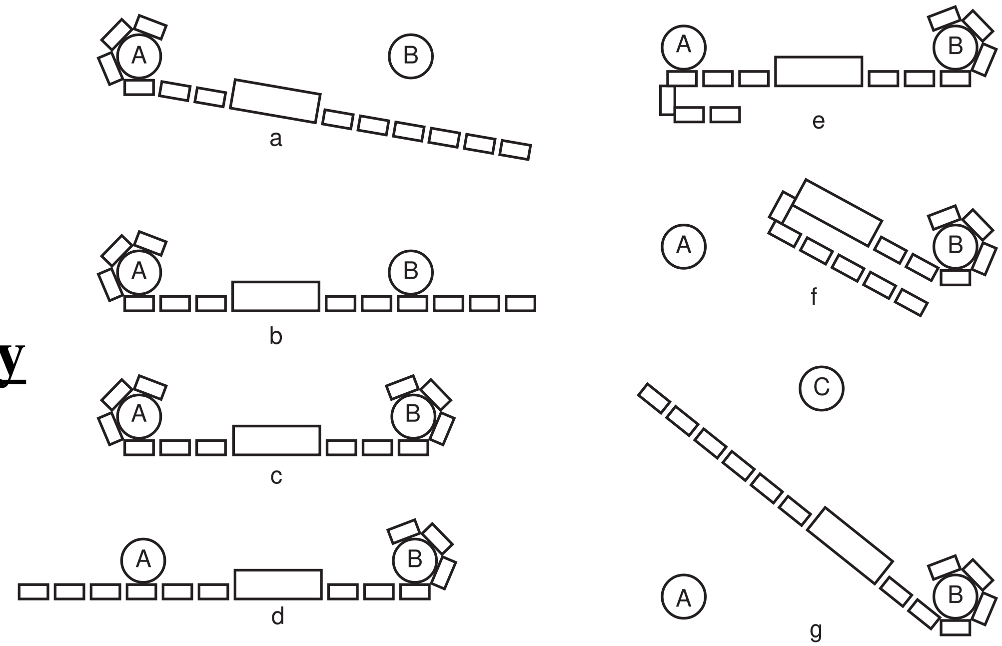
Significant Behaviors

Grasping

- whole arm manipulation

Constrained Space Mobility

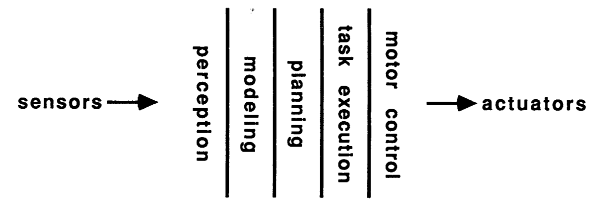
- folding
- unfolding

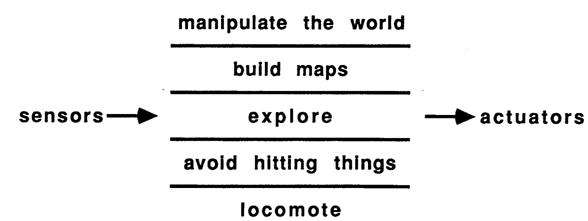


Control Architecture

Behavior Control

- Brooks 1986
- overall task decomposed into subtasks which link sensing to actuation
- programmed in custom language specifically designed to create many small processes which communicate via a message passing paradigm



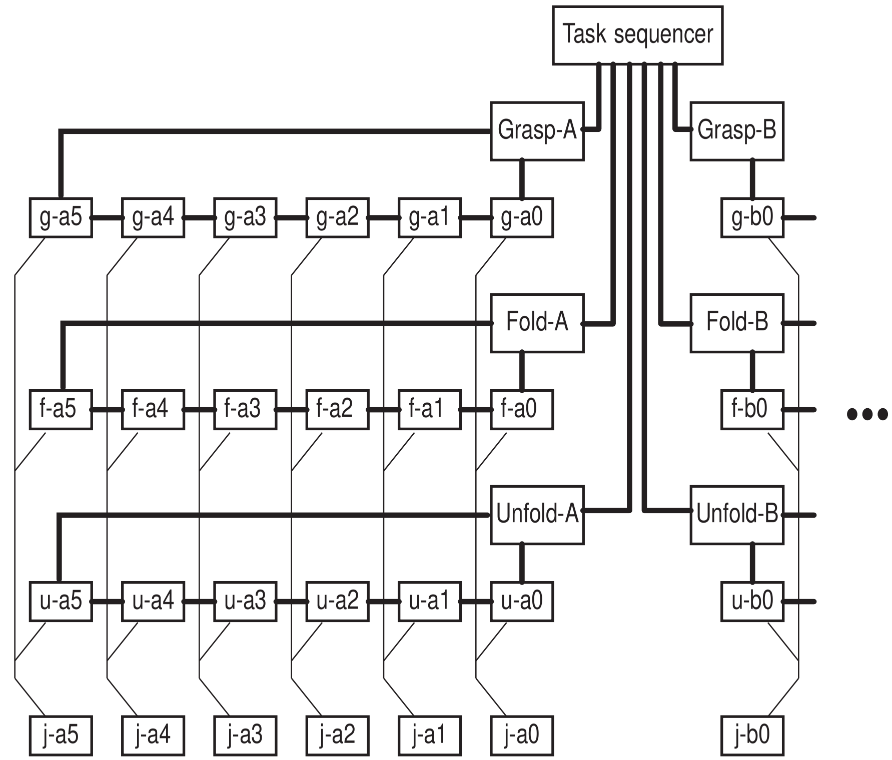


Organization

- a set of processes associated with each joint which make up a module
- communications mostly between processes in a single module and between modules on physically adjacent links

Control System Organization

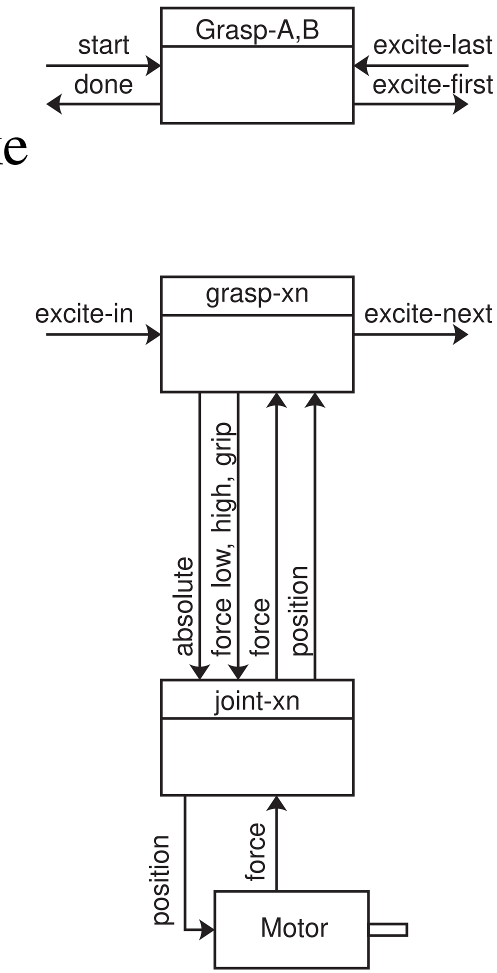
- behaviors organized by task - one set for grasping, one for folding, one for unfolding
- each side of the robot - A and B - is controlled by a separate set of behaviors
- a specific set of processes is assoicated with each link of the arm



Grasping

Key Points

- can grip objects of various sizes and shapes
- arm swings out and wraps around the object like an elephant's trunk
- force servoing helps to maintain a grip on the object
- Pettinato and Stephanou 1989



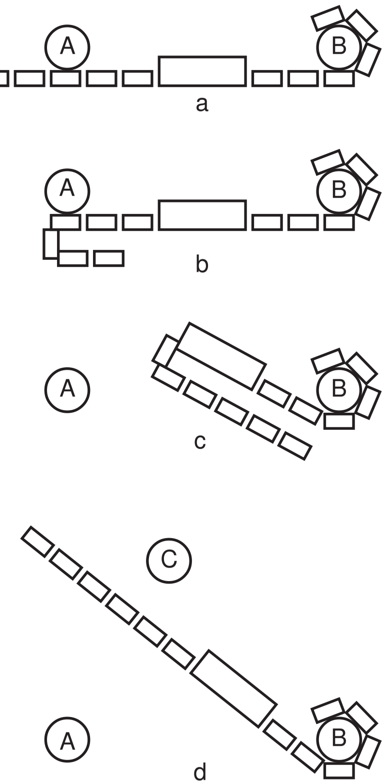
Sequence

1) arm straight
2) activation wave begins at central links and moves outward
3) activated link moves in direction of grasp
4) motion continues until motion limit or force sense
5) joint enters force servo mode and passes activation onto next outward link

▶ Folding and Unfolding

Key Points

- can deploy the robot in a narrow space
- arm folds in on itself and can unfurl into the desired space



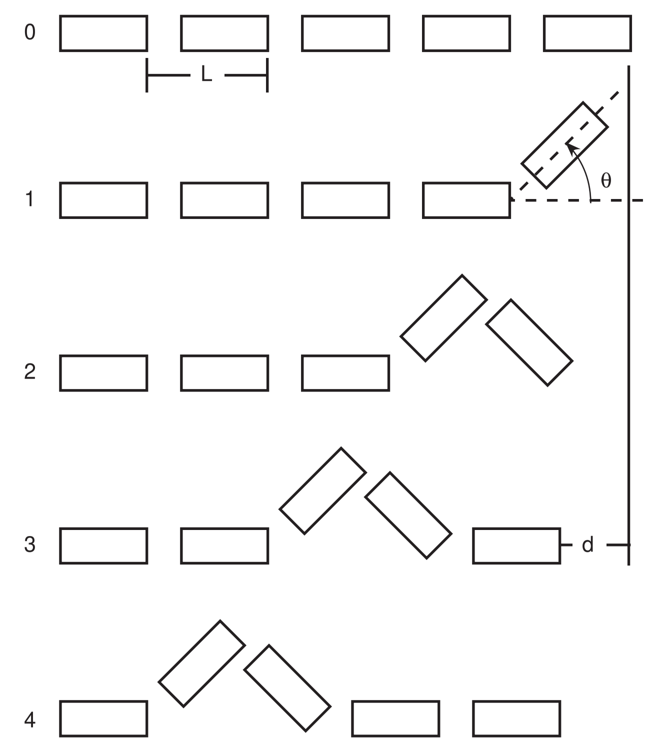
Sequence

1) the folding activation wave begins at the outer most joint and is passed inwards
2) the straighten activation begins at the outer most joint and is passed inwards
3) folding motion for a joint begins when activated and ends when a position limit is reached, then is passed on
4) straighten motion for a joint begins when activated and the arm tip senses a force, it ends on a position limit, then is passed on
5) when both waves have finished propagating, a single link is put into force servo mode

▶ Wave Locomotion

Key Points

- Chirikjian and Burdick 1991
- can locomote without legs or wheels
- stationary wave of varying amplitude
- traveling wave of constant amplitude
- degrees of freedom re-oriented so axes of rotation are parallel to the plane of the ground



Sequence

1) move joint n to angle +q
2) move joint n to angle -2θ while activating behavior controlling joint n+1
3) move joint n to angle +θ
4) return joint n to the zero angle

Conclusions and Future Work

Conclusions

- developed a functional completely autonomous robot
- developed behaviors for grasping and constrained space mobility
- developed behaviors for locomotion along a plane
- behavior control provided for robust control in a semi-structured environment with only tactile sensing

Future Work

- add two degrees of freedom perpenduclar to the others to allow motion out of plane
- utilize IR's on finger tips to scan for free space and avoid obstacles while executing the planar mobility behavior