Reconfigurable Robots, Part I

February 27, 2003

Class Meeting 14
There are Several Types of Reconfigurable Robots

- **Minimal-capability modules:**
  - (1) Chain-type links (rolling track, spider, snake, etc.)
  - (2) Lattices, matrices (for stair climbing, object support, etc.)

- **(3) Connectable robots:**

- **(4) Modular, plug-and-play components:**
Objective: Obtain function from shape, allowing modules to (re)connect to form shapes that achieve desired purpose

• Earliest research focused on reconfigurable/cellular robotics:
  – CEBOT: Fukuda (Univ. of Tokyo)

• Two main types of current research:
  – (1) Chain-type linkable appendages
  – (2) Lattices/matrices
Example of (1) Chain-Type Reconfigurable Robots:
Polybot: Yim, Xerox

- **Polypod:**
  - Bi-unit modular robot
  - Consists of exactly two types of modules repeated many times
  - Repetition makes manufacturing easier and cheaper
  - Dynamic reconfigurability enables robot to be versatile and reconfigurable

Spider gait
Earthworm gait
Movies of PolyBot
(Mark Yim, Xerox PARC)

- Stair Climbing
- Tricycle pedaling
- Porous material climbing
Example of (1) Chain-Type Reconfigurable Robots: CONRO: Castano, et al., USC/ISI

- **Goal**: development of taskable reconfigurable robot
- **Composition**: identical modules programmable for altering its topology
- **Base topology**: simply connected, as in a snake
- **More complex topology**: includes appendages
- **Each module**: CPU, memory, battery, micro-motor plus sensors
- **Major challenges**: packaging, power, cooling, programming and program control.
Movies of CONRO
USC Information Science Institute

Rolling tracks

Sidewinder snake

Caterpillar
Example of (2) Lattice-Type Reconfigurable Robots: Robotic Molecule: Rus, Dartmouth

- The Molecule:
  - 4 degrees-of-freedom
  - Can aggregate with other identical modules to form 3D dynamic structures.
Movie of Crystalline Robot Simulation
Rus et al., Dartmouth

(dogcouch.mov)
Example of (2) Lattice-Type Reconfigurable Robots: Miniature Modular Machine using Shape Memory Alloy, Yoshida, MEL, Japan

- Objective: Develop reconfigurable system for reaching variety of hard-to-reach areas

Basic unit
Example of (3) Connectable Robots for Reconfiguration, Linked Mobility: Hirose et al., Tokyo

• Challenging new area with potentially high payoff
  – Broad cross-domain application
    • Modular RRs where sub-sets of modules may operate independently or combine as circumstance necessitates
    • Cooperative object transport
    • Reconnaissance
  – Manually-linked mobility has been demonstrated, but not autonomous reconfiguration

• Possibility to increase the capabilities of existing multi-robot systems
  – e.g. navigate previously inaccessible terrain
Example of (4) Modular Plug-and-Play, Manually Reconfigurable Robots: Millibot, Khosla et al, CMU

- Objective: Develop small (5-10cm) modular robots capable of surveillance and reconnaissance
Movie of Millibots (CMU)

Local cooperation for formation control
Our Primary Focus: Minimal Capability Modules

- Chain-Type reconfigurable robots
- Lattice/Matrix-Type reconfigurable robots
Student Paper Presentation

• “Hormone-Inspired Adaptive Communication and Distributed Control for CONRO Self-Reconfigurable Robots”, by Shen et al.,

• Presented by Maureen Chandra
Dynamic reconfiguration from a sidewinder to a quadruped
More Movies of CONRO (con’t.)
USC Information Science Institute

Dynamic reconfiguration from caterpillar to spider and back
More Movies of CONRO (con’t.)
USC Information Science Institute

Reactive caterpillar and quadraped
More Movies of CONRO (con’t.)
USC Information Science Institute

Six legged insect
Key Issues Addressed in CONRO

(1) Adaptive communication

(2) Collaboration between physically coupled modules

Solution must be:
- Dynamic: to deal with changes in network topology
- Asynchronous: to compensate for lack of global clocks
- Scalable: to support shape-changing
- Reliable: to recover from local damages
Hormone Inspiration in CONRO

• “Hormone” signal:
  – Propagates through entire network
  – Causes different modules to react differently based upon:
    • Local receptors
    • Topology connections
    • State information
  – No specific destination
  – May have a lifetime
Communication Makes use of Topology Definitions

- Local topology determined by how CONRO modules are inter-connected
  - Back
  - Front
  - Right
  - Left

- Depending on connections, topology type given a name:
  - T0, T1, ..., T31

- Modules continually verify their current local topology through “probing” hormones
Adaptive and Distributed Control Protocol

• Use of a Rulebase for various types of moves
• Modules decide what to do based upon:
  – Local topology
  – Local state information (e.g., timer, motor and sensor states)
  – Received hormone messages
• Rulebase inputs:
  – Module type
  – Local timer
  – Received hormone data
• Rulebase outputs:
  – Action for module to perform
  – Hormone for module to send
Various CONRO Rule Based Developed

• Rulebases for:
  – Caterpillar move
  – Legged walk
  – Rolling track
  – Etc.

• Rulebases developed manually; unclear how to automate this (perhaps GAs?)
Next Time…

• **Topic:**
  – Reconfigurable Robots, Part II (Lattice-type robots)