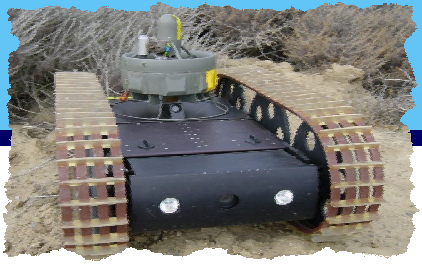
MARSUPIAL ROBOTS





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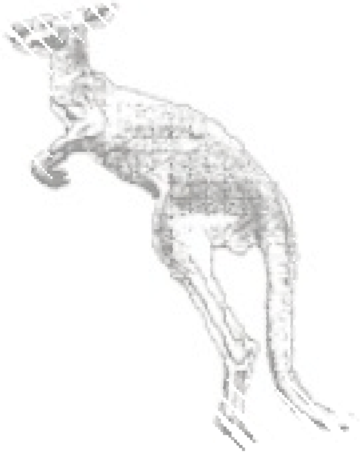
About the Paper

- Author:
  - Robin R. Murphy, USF
- Published in:
  - “Robot Teams: From Diversity to Polymorphism”, edited by Balch and Parker
  - A. K. Peters, Ltd, 2002



Problems Addressed

- How can teams of robots work together to reach and sense target areas?
- How can teams cooperate to maintain and distribute sensing?
- Urban Search and Rescue (USAR)
  - Collapsed man-made structures with no controlled lighting, treacherous and rugged terrains
  - Practical Issues: build robots with limited power supply and cost, but with adequate communication capabilities

Solution: Marsupial Robot Teams

- Biologically inspired: pouched animals
- One mother robot transports/supports one or more daughter robots
- Advantages to daughters from mother
  - Rapid, energy efficient transport to target area
  - Protection during transport
  - Shelter from environmental conditions
  - Power recharge, battery/fuel swapping

Solution: Marsupial Robot Teams (cont.)

- Advantages to daughters from mother (cont.)
  - Processing station – analysis of sample materials
  - Proxy Processing
  - Communication relay, etc.
  - Result: cost and complexity of daughter reduced
- Advantages to mother
  - Surrogate sensing - “eyes in the back of the head”

Marsupials in Robotics

- Natural motivation for studying heterogeneous societies
  - Measuring and representing heterogeneity in humans and robots
  - Planning, allocating, optimizing task assignments
- Tradeoffs between centralized and distributed control
- Adapting roles within control schemes
- Fault tolerance: daughter lost, mother missing
- Distributed sensing and sensor fusion
- Physical cooperation and cooperative mobility

Heterogeneity

- Marsupial teams are highly heterogeneous
  1. Physical heterogeneity
  2. Cognitive heterogeneity
     - Typically: human as cognitive agent for robot
     - Mother as "middle" level for cogn. capability
  3. Behavioral heterogeneity
     - Robots may dynamically change their behaviors
     - Mother-daughter relationships studied

Cognitive Heterogeneity

- Incidental
  - Mother only relays data and commands, no contribution to processing
- Perceptive
  - Mother provides external sensor viewpoint to supplement daughter's sensors (large improvements)
- Proxy
  - Mother provides distributed off-line processing for daughter using her cognitive abilities
- Hierarchical
  - Mother as a middle manager

Behavioral Heterogeneity

- Courier
  - Transporting daughters to/from mission sites
- Coach
  - Mother providing perceptive or hierarchical cognitive support to daughters
  - Studies completed in USF confirm the importance of coaching
- Manager
  - Mother having complete control over the daughters
  - Providing directions or deliberation continuously or on demand
- Messenger
  - Mother as communication relay between daughters and humans

Behavioral Heterogeneity: Courier

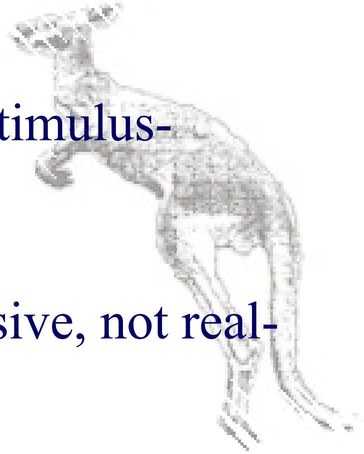
- Courier role involves
  - Deploy – getting the daughters out in the mission target area
  - Docking – getting the daughters back
    - Mother-centric: mother perceives daughters and moves to pick them up
    - Daughter-centric: daughter perceives and moves to mother
    - Combined: both agents move simultaneously (not considered in paper due to slow vision processing)

When to Deploy

- Heuristics generated from earlier work using empirical data (105 data points over 7 scenarios collected, individual navigation time via tele-operation compared with marsupial team time)
- Deploy daughters if:
  - Mother is blocked, and goal region is within tether (or communication) distance constraints
  - Mother cannot make direct progress but daughter can, and daughter is within tether constraints
  - Mother is within the tether constraints of the goal region, and $\frac{mother\_travel\_time}{daughter\_power\_consumption}$ is high

Docking (Single Agent)

- Single Agent Docking – One agent moving to the other using its local behavior (egocentric docking)
- **Local sensing** – each mobile robot perceives through her own on-board sensors
  - Advantage: little or no communication, stealthy
- **Centralized Sensing** – "see through the eyes of the other"
  - Advantage: more accurate vision
  - Disadvantage: High cost in communication bandwidth, decreased stealthiness (not considered)
- Programming approaches
  - Behavioral – mimicking encapsulation of reflexive stimulus-response behaviors in animals
  - Visually guided – visual serving and optic flow
  - Control-theoretic – path planning algorithms (expensive, not real-time, etc.)

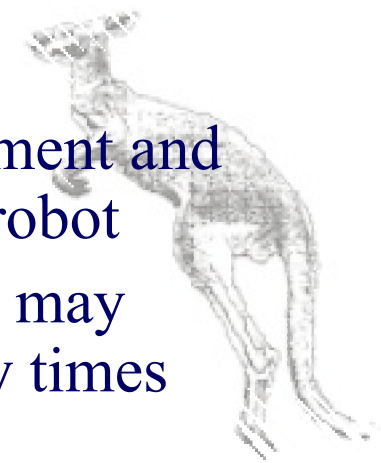


Docking (Distributed Multiagent)

- Distributed Multiagent Docking – how can multiple daughters dock efficiently?
- Simple approach: single agent docking conducted n times (n=number of daughters)
- Cooperative sensing – agents share sensory information
  - Ecocentric docking – non-docking daughter broadcasts a view of the mother and daughter
  - Landmark based (not considered)
- Distributed sensing – external global view of where the daughter is relative to mother is used
  - Communication/computation intensive, but may speed up multiple agent docking

Docking (Active Cooperative)

- Societal Cooperation
  - A centralized controller imposes order
    - High in communication
    - Coaching is good alternative, reduces communication and sensing requirements
  - Each distributed agent is given societal rules and can follow them without communication
  - Each distributed agent follows societal rules but may communicate with other agents
- Cascaded sensing
  - One robot senses something in the environment and reacts to it, then another robot reacts to 1st robot
  - Can be combined with distributed docking, may dramatically improve docking and recovery times



Manager, Coach, Messenger: MaintainLOS

- Mother needs to be in perceptual range of the daughter for:
  - Coach: providing recommendations based on a global perspective
  - Messenger: serving as communication relay
  - Manager: adequately commanding the daughter to conduct missions under her supervisory control

MaintainLOS: Distributed Localization

- Distributed Localization: how mother can perceive a daughter and estimate its relative distance?
  - Visual tracking of daughters
    - Challenge: how to identify and track in real time
    - 1 approach: use uniquely colored landmark on daughter
  - Spherical Coordinate Transform (SCT)
    - Color segmenter developed for medical applications
    - Average pixel error: 1.5, avg distance error: 6.3 cm
    - Real time tracking system using only Pentium class proc.

Experiments: Marsupials in the Field

- Marsupialism demonstrated in 2 domains: USAR and MOUT
- Coaching illustrated at the 2000 AAAI Mobile Robot Competition: finding most victims in a fixed period of time
  - Team: iRobot ATRV mother and iRobot daughter
  - Robots and the tele-operator given different set of responsibilities
  - Two robots cooperating in victim-detection and navigation
  - Results: Heterogeneously cooperating USF team found %209 more victims than same robots working independently

Related Work

- NASA’s Jet Propulsion Laboratory
  - Expanding work with rovers and FIDO project
- University of Southern California
  - UAV-UGV marsupial team: autonomous helicopter deploying tele-operated RC car for surveillance
- University of Minneapolis
  - RAPTOR marsupial system: mother carries a Gatlin gun type launcher for deploying small mobile robots
- iRobot
- Idaho National Energy and Engineering Laboratory, DOE

Summary and Contributions

- Marsupial Robot Team: 3 types of heterogeneity
- Physical: Mother, Daughter
- Cognitive: Incidental, Perceptive, Proxy, Hierarchical
- Behavioral
  - Courier
    - Deploy
    - Docking: Single Agent, Distributed Multiagent, Active Cooperative
  - Coach, Messenger, Manager: MaintainLOS
- Experiments illustrate significant contributions of marsupial robots to domains such as USAR

Thanks for listening!

Questions