Real-time Cooperative Behavior for Tactical Mobile Robot Teams

September 10, 1998
Ronald C. Arkin and Thomas R. Collins
Georgia Tech
Objectives

- Build upon previous work with multiagent robotic behaviors for UGV DEMO II
- Develop platform-independent robotic communication and control strategies for MOUT scenarios
- Provide usability-tested mission specification interface
- Facilitate integration with part B contractors
Technology Thrust Areas

• Fault-tolerant multi-robot behaviors
  – Provide the enabling set of robust behaviors needed for TMR missions

• Communication minimization and planning
  – Enhance the performance of multiagent systems

• Mission specification and user interface system
  – Ensure that system is usable by military personnel

• Real-time requirements
  – Improve reliability, predictability, and timeliness
Technical Background

• Brief overview of aspects covered previously (at kickoff)
  – Reactive schema-based control
    • Mechanism for generating behaviors
  – Reactive group behaviors
    • Increasing effectiveness through cooperation
  – Team teleautonomy
    • Multiple robots under control of single operator
  – *Missionlab* system
    • The usability-tested robot programming toolset
Reactive Schema-based Control

- Reactive control
  - A widely-accepted technique for real-time response
  - Closely ties perception to action without deliberation
  - Displays emergent behavior

- Reactive schema-based control
  - Biological basis, using motor schemas and perceptual schemas
  - No requirement for arbitration
    - Fuses potentially-conflicting inputs with vector summation
  - Dynamic instantiation (and deinstantiation) of behaviors
  - Reconfigurable under the direction of a deliberative and/or learning component
Reactive Group Behaviors

• Prior effort has focused on formation behaviors
  – Derived from military requirements
  – Implemented within the motor-schema framework
  – Vector driving each agent toward its formation position
  – No explicit communication required

• MOUT scenarios will require formation behaviors in conjunction with explicit communication
  – Targeting
  – Newly-acquired map information
  – Threat identification and hiding
  – Cooperation, including. Point-man/cover-man role switching
Team Teleautonomy

- In typical MOUT scenarios, operators will always want the ability to override robot autonomy
  - Utilize real-time feedback, not necessarily provided directly to robot
  - *Teleautonomy* allows operator to direct robots while still allowing them to perform local navigation and low-level tasks
  - *Team* teleautonomy incorporates formation control
    - Commander directs the group, not the individual robots
- Supports the “moving interface” (of human-robot capabilities) referred to by DARPA/TTO
- Reduces *cognitive overload* on operators
Missionlab

- Objective:
  - To empower robot commanders to specify, evaluate, and execute military missions
**Missionlab System**

- Recursively build missions from reusable elements
  - Behaviors, behavioral assemblages (robots), teams of robots
- Generalizable to other robot control methods
  - Code generators for two architectures already
- Different levels of functionality for different user types
  - Novice user works with “useful” assemblages
  - Sophisticated user may develop new behaviors and assemblages
What **MissionLab** is

- a mission specification tool
- a platform-independent robot interface
- a robot configuration tool
- a robot-to-robot communication mechanism
- a mission simulation environment
- a usability-tested human interface
- a mission execution monitor
- a bridge between simulation and execution
What *MissionLab* is not

- a mission planner
- a terrain visualization tool
- a sensor suite

*MissionLab is designed to work with other technology components to build complete multiagent systems:
- robotic platforms
- workstations, laptops, etc.
- sensors and device drivers
- high-level mission planners
- communication hardware and software*
Interfacing to *MissionLab*

- **CDL - Configuration Description Language**
  - normally generated by the graphical Configuration Editor (*cfgedit*)
  - allows delayed binding (architecture- and robot-independent)
- **CNL - Configuration Network Language**
  - only produced when bound to the AuRA architecture
  - hybrid dataflow language
- **C++ / LISP**
  - runtime code generated for AuRA robots and UGV Demo II
Progress to date

- Staffing
- Equipment acquisition
- Demonstration scenarios
- Enabling behaviors and robot configuration
- Mission overlays
- Simulations
Program staffing

- Postdoctoral position remains vacant
  - no suitable candidates on the horizon
- Hiring additional GRAs (5 total, instead of 3)
  - double up on tasks where required
  - support operational issues (equipment, system administration)
  - increase management load on PIs
Equipment acquisition

- DARPA specs for terrain traversal limit robot choices
  - 4 Pioneer-AT “Outlaw” robots ordered (not yet delivered)
- 3 development computers ordered and received
  - serve also as mobile operator control units (laptops)
- Hummer deployment vehicle already available
Budgetary and Schedule Risks

- Staffing profile behind schedule, but compensated in September
- Equipment purchases within budgetary expectations
- No unmanageable risks at this time
Demonstration scenarios

• Interim use - for initial demonstrations until TMR scenarios are provided
• Based on USMC MOUT manual
• Two scenarios
  – Outdoor building-to-building transport of two 4-robot fire squads using bounding overwatch
  – Room-to-room clearing
Enabling behaviors

- Initial scenario requires wall-hugging of robot teams
- *move-to-goal* motor schema used in conjunction with nearby walls as intermediate, weaker goals
- Mission waypoints act as stronger goals
- *avoid-static-obstacle* motor schema maintains robot-wall and robot-robot separation
- Vector field shows robot driving force if placed at an arbitrary point (here for *avoid-static-obstacle*)
Enabling behaviors (cont’d)

• Combination of goal & obstacle behaviors produces a stable standoff distance from obstacles
• A wall appears as a series of obstacles (e.g. sonar readings)
• Complete mission by adding two group behaviors:
  – column formation behavior for low-profile wall-following
  – wedge formation for open-area traversal
Reactive schema wall-following

- Simple scenario with one goal (mission waypoint) & one wall
- Three figures show combination of schemas to produce resultant behavior
  - attractive goal only
  - goal plus repulsive wall
  - goal plus wall-following
Mission overlays

- Overlays are renditions of mission environment
  - mainly for simulation
    - *MissionLab* generates simulated sensor readings based on overlay entities
- Overlay of downtown Atlanta created for outdoor scenario
- Overlay of Mobile Robot Lab wing of building created for indoor scenario
Live Demonstrations

- Executed in *MissionLab* environment
  - Building-to-building movement with bounding overwatch
  - Room-to-room clearing
### Program Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault-tolerant multi-robot behaviors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design behaviors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement behaviors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulate behaviors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test behaviors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication minimization and planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design protocols</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop tools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrate with MissionLab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission specification and user interface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validate Linux implementation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Determine new specification requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement new language features</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhance configuration editor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-time requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify technologies, tools, and methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establish metrics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop automated implementations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrate resource management technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire initial robot platforms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire development computers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/integrate software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire robot controllers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire/integrate robot sensors/comm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire additional robots and computers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/integrate software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2K compliance verification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop final integrated demonstrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information exchange/reviews</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start of Work Meeting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robotic concept of use available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quarterly IPRs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final IPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deliverables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Status Report / A001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly Cost Report / A004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsystem Specifications / A002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstration Plan / A006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report (draft) / A005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report / A005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface Control Doc. (draft) / A005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface Control Doc. / A005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software / A007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9/17</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10/19</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6/15</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>6/1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plans

- Take robot delivery and configure as required
- Develop low-level software for Pioneer interface
- Ramp up communication, real-time tasks
- Full demonstrations with simulation and real robots
- Web site enhancements (pending government direction)
  - operation of *MissionLab & JavaBots* simulations
  - team teleautonomy over the net
For further information . . .

• Mobile Robot Laboratory Web site
  – http://www.cc.gatech.edu/ai/robot-lab/

• PDF versions of pertinent papers
  – http://www.cc.gatech.edu/ai/robot-lab/tmr/archive.htm
    • Cooperative Multiagent Robotic Systems
    • Behavior-based Formation Control for Multi-robot Teams
    • Multiagent Teleautonomous Control
    • Communication in Reactive Multiagent Robotic Systems
    • Evaluating the Usability of Robot Programming Toolsets
    • Multiagent Mission Specification and Execution

• Contact information
  • Ron Arkin: arkin@cc.gatech.edu  404-894-8209
  • Tom Collins: tom.collins@gtri.gatech.edu  404-894-2509