Real-time Cooperative Behavior for Tactical Mobile Robot Teams

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Overview

- Ft. Sam Houston results and lessons learned
  - additional sensor integration
  - usability enhancements
  - experimental data
  - new behaviors
- Honeywell Real-Time Advisor
- Usability studies
  - test scenarios
  - procedures and plans
- Linux 6.x port

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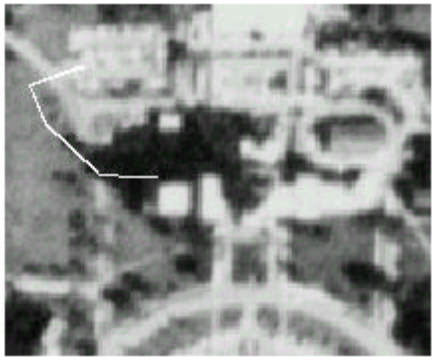
Ft. Sam Demonstration Overview

- Multiphase building approach and assessment
  - Deployment and cross-country phase
    - Waypoint following with satellite photo underlay
    - Demonstrated in July at Ft. Sam
  - Stair climbing phase
  - Interior assessment phase
    - Room-to-room assessment completed in simulation and at Ft. Sam in both July and September
    - Resulted in development of relevant TMR behaviors

HAZMAT Assessment: Phase 1



- Deployment to northwest of building
- Waypoint following using DGPS, augmented by odometry
- Performed with Pioneer, ending at loading dock ramp
- DGPS completely integrated
  - DGPS base station set up and broadcasting data (RTK - single carrier phase)
  - Pioneer knows its position with accuracy up to 20 cm
- Long-term impact
  - Point-and-click go-to's in configuration editor
  - UTM positioning capability

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HAZMAT Assessment: Phase 2

- Received Urbie from pool
- Integrated MissionLab on Urbie
  - CORBA-level interface of RWI Mobility
    - basic "goto" and obstacle avoidance functionality
    - have not yet addressed novel locomotion capabilities of platform
- Completion of a hardware demonstration of this phase pending government direction
  - could complement other efforts already completed by JPL and Penn
  - would add behavioral and perceptual schemas to MissionLab

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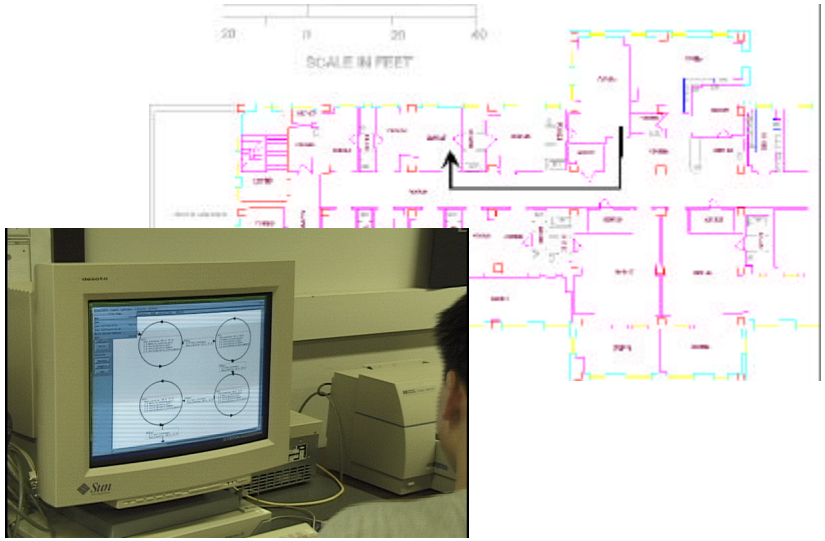
HAZMAT Assessment: Phase 3



- Demonstrated on second floor in July and first floor in October
- Simulation used actual architectural CAD data from hospital
- Repositioning of Pioneer sonar sensors provided better obstacle avoidance
- Pioneer implementation of visual servoing fully integrated in MissionLab
- Low-cost IR sensors added to Pioneer for reliable door entry

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Ft. Sam Experimental Data

- Data logged during a series of October trial runs (after setup complete and prior to final preparation for demo)
- Metrics included
  - number of operator commands required
  - time required to complete states and entire mission
  - distance covered
  - speed (average and maximum)
  - number of collisions
  - success of assessment mission
- Descriptions and subjective assessments also exist for other factors
  - communication links (frequency, technology, range, protocols)
  - test conditions
  - task complexity

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Results - Successful Runs

- 5 of 12 logged runs were completely successful
- Nearly all later runs were successful (~30)
- Speeds, mission lengths similar for all logged runs

Trial Number	1	2	6	10	12
Status	successful	successful	successful	successful	successful
Number of Planned Tasks in the Mission	13	14	14	14	14
Number of Tasks Actually Executed	13	14	14	14	14
Number of Collision During the Mission	0	0	0	0	0
Reason for Failure	N/A	N/A	N/A	N/A	N/A
Number of Commands Sent from Console	1 (start)	1 (start)	1 (start)	1 (start)	1 (start)
Number of Data-Set Collected	431	664	558	578	578
Total Length of Time the Robot Ran (sec)	114.88	146.84	148.04	138.34	142.44
Avg. Time Cycle on Data Collection (sec)	0.27	0.22	0.27	0.24	0.25
Avg. Time for Each Task Completed (sec)	8.84	10.49	10.57	9.88	10.17
Total Distance the Robot Traveled (m)	16.44	16.54	16.75	16.39	16.55
Max. Speed the Robot Ran (m/s)	0.20	0.20	0.20	0.20	0.20
Avg. Speed the Robot Ran (m/s)	0.17	0.12	0.14	0.14	0.14

Results - Failures

- Includes onsite debugging (three failures)
- Minimal sensors resulted in one collision and two misalignments
- Operator error caused one failure during specification

Trial Number	3	4	5	7	8	9	11
Status	failed	failed	failed	failed	failed	failed	failed
Number of Planned Tasks in the Mission	14	14	14	14	14	14	14
Number of Tasks Actually Executed	12	12	12	8	9	9	6
Number of Collision During the Mission	0	0	0	0	0	0	1
Reason for Failure	bug*	bug*	bug*	calibration error**	bad alignment***	bad alignment***	init. position****
Number of Commands Sent from Console	2 (start, abort)	2 (start, abort)	2 (start, abort)	2 (start, abort)	2 (start, abort)	2 (start, abort)	2 (start, abort)
Number of Data-Set Collected	659	646	751	467	299	511	205
Total Length of Time the Robot Ran (sec)	133.13	134.64	140.64	92.56	77.69	101.85	59.47
Avg. Time Cycle on Data Collection (sec)	0.20	0.21	0.19	0.20	0.26	0.20	0.29
Avg. Time for Each Task Completed (sec)	11.09	11.22	11.72	11.57	8.63	11.32	9.91
Total Distance the Robot Traveled (m)	16.53	16.72	16.28	15.11	9.62	16.52	8.35
Max. Speed the Robot Ran (m/s)	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Avg. Speed the Robot Ran (m/s)	0.12	0.12	0.11	0.18	0.15	0.17	0.12
Note							
* A buffer for mail message was declared smaller than it was required by actual message.							
** User-defined parameters for "AlignWithDoorway" were specified incorrectly.							
*** The robot could not align properly with the doorway.							
**** The robot was started from the postion where it could not recover from heading wrong direction.							

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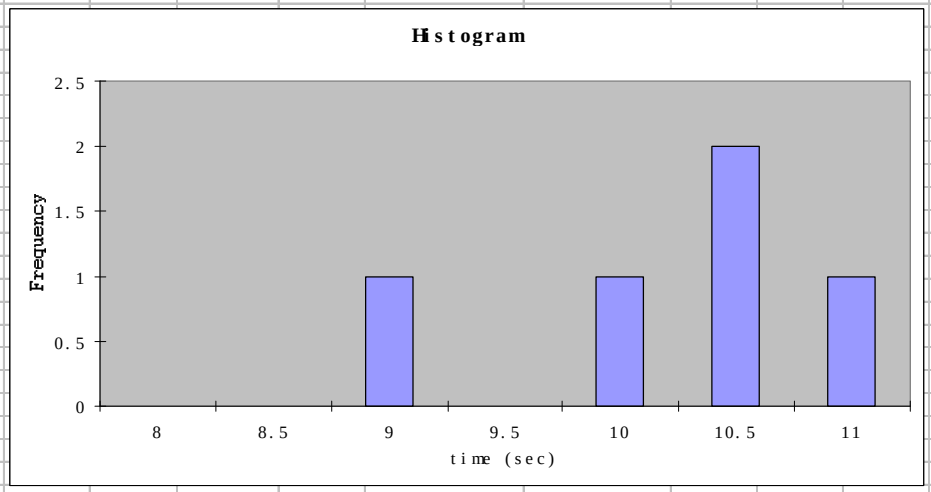
Time per Task

- Statistical significance is marginal, but . . .
- Tends to indicate that tasks are of similar granularity

Bin	*Frequency*
8	0
8.5	0
9	1
9.5	0
10	1
10.5	2
11	1

Mean	9.99
Standard Error	0.31
Median	10.17
Standard Deviation	0.70
Sample Variance	0.49
Range	1.74
Minimum	8.84
Maximum	10.57
Count	5



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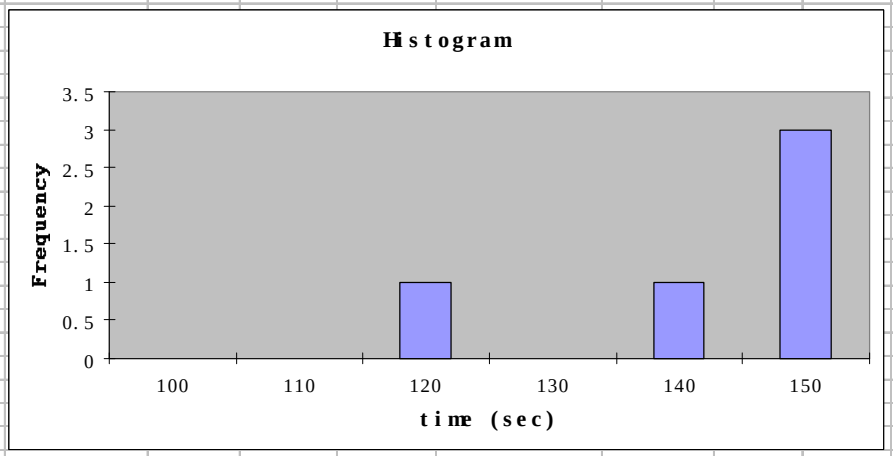
Mission Execution Time

- Average speed similar, so total execution times are similar
- Short run was prior to the addition of one more state

Bin	Frequency
100	0
110	0
120	1
130	0
140	1
150	3

Mean	138.10
Standard Error	6.05
Median	142.44
Standard Deviation	13.54
Sample Variance	183.30
Range	33.16
Minimum	114.88
Maximum	148.04
Count	5



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New or Enhanced Behaviors

- Resulted from Fort Sam experiments
- Most are still in developmental stages and will support usability studies

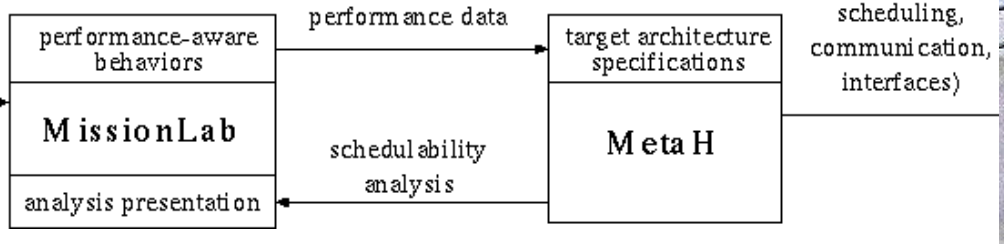
- Behavioral States
  - ApproachAndTest
  - EnterDoorway
  - GoTo_Outdoor
  - LookFor
  - Mark(positive/negative)
  - MoveDownHallway
  - PutDown
  - ReverseDirection
  - Standby
  - Survey
  - TestObject
  - AlignWithDoorway
- Triggers
  - TestPositive
  - TestNegative
  - InRoom
  - InHallway
  - DetectDoorway
  - DetectHall
  - DetectAlternateHallway
  - NotHolding
  - DirectionReversed
  - SurveyComplete
  - EndOfHall
  - Proceed

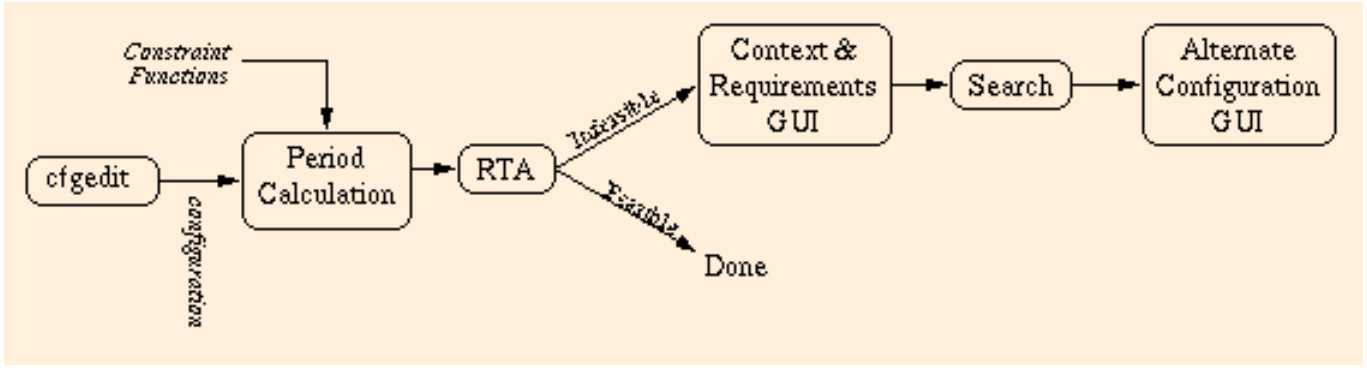
Ft. Sam Lessons Learned

- Laser rangefinder will facilitate progress with demonstrations similar to indoor HAZMAT scenario
- Improvements in behaviors
- Usability enhancements
  - Pop-up window showing current robot state
  - Ability to hide detailed information in states while in CfgEdit
  - Default triggers are tailored to the behavioral state
- Need for closed-loop motor control monitoring on Pioneers, especially during startup
  - Failure occurred during full demonstration
  - Single bit of information provided by Pioneer was wrong
  - Solution implemented as a new "standby" state

Real-Time Behavioral Specification

- Honeywell Technology Center's RT-MLab adds real-time analysis
  - ensures computation feasibility for arbitrary configuration
  - intelligently advises user how to change configuration to meet computation limitations





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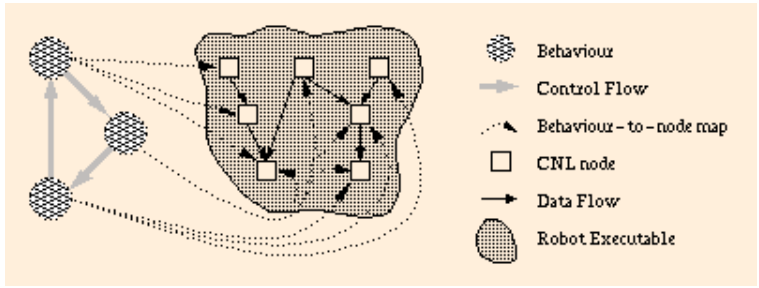
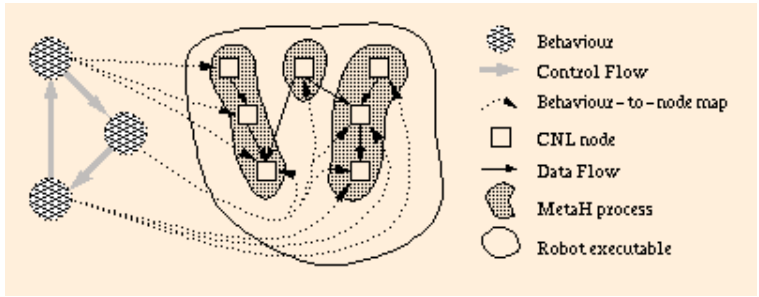
MetaH Implementation



Normal MissionLab



RT-MissionLab

- CNL nodes grouped into MetaH processes according to rate (priority)
- In a feasible implementation, processes can be serviced with guaranteed schedules
- User interface remains unchanged, except for "Analyze" capability

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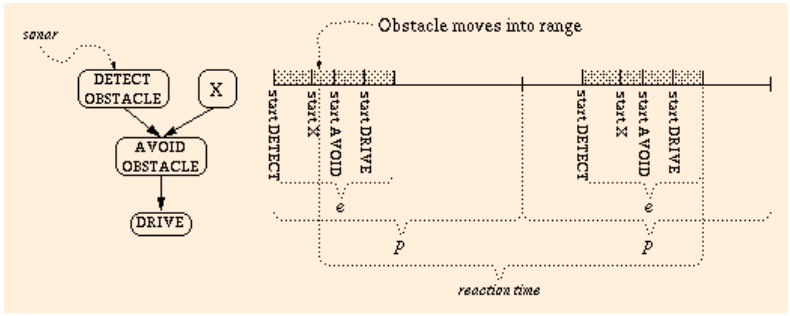
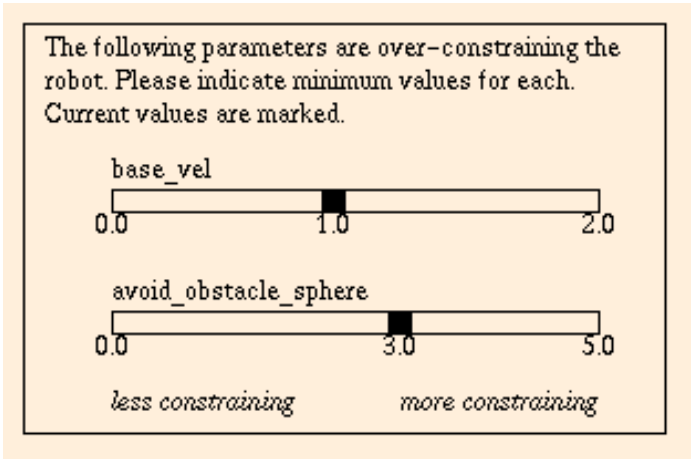
Real-Time Advisor



A feasible executable



One possible operator aid

- Sensor rates and "reaction time" determine processing period
- User-specified behaviors may result in infeasible robot executables
- Real-time constraints may be met by
  - slowing robot (increasing reaction time)
  - reducing sensor rates
  - adopting alternate behavioral ensembles

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Usability Study Objectives

- To validate that average users are capable of generating effective robotic missions for TMR scenarios using *MissionLab*
- To provide effective methodologies that evaluate the performance of TMR systems from an end-user's perspective
- To provide methods and tools in support of cognitive modeling of the interaction of users with TMR systems
- To create meaningful TMR applications that can serve as prototypical tasks for the research community
- To suggest refinements to the *MissionLab* GUI

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Usability

- A combination of:
  - ease of learning,
  - high speed of user task performance,
  - low user error rate,
  - subjective user satisfaction,
  - user retention over time,

    (Schneiderman 92)

Usability Requirements

- Understanding the users' abilities and goals through user and task analysis
- Involving the user in participatory design where feasible
- Preventing user errors
- Optimizing user operations
- Keeping the locus of control with the user
- Assisting the user to get started

(Hix93)

Experimental Testbed

- I-Observe (Interaction, OBServation, Evaluation, Recording and Visualization Environment) interface usability evaluation environment, consisting of:
  - Logging tools
  - Analysis tools
  - Visualization tools

Usability Lab

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TMR Usability Experiments

- Four robotic scenarios
  - Hostage counter-terrorism (room searching/clearing)
    - single robot
  - Hospital approach
    - single robot
    - tests map interface for placing waypoints
  - Airport incursion
    - multiple robots, also with map interface
  - Anti-tank scenario
    - multiple robots
    - more complex robot sensing and interaction
- Test subjects will specify missions using Configuration Editor
- Analysis of verbal protocol of participants speaking aloud to provide information to improve interface

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Experimental Procedures

- Administered by third party
- Uniform introduction to toolset provided to participants
- Participants given one task at a time
- Left alone in the usability lab to complete
- Observed via one-way glass and video camera

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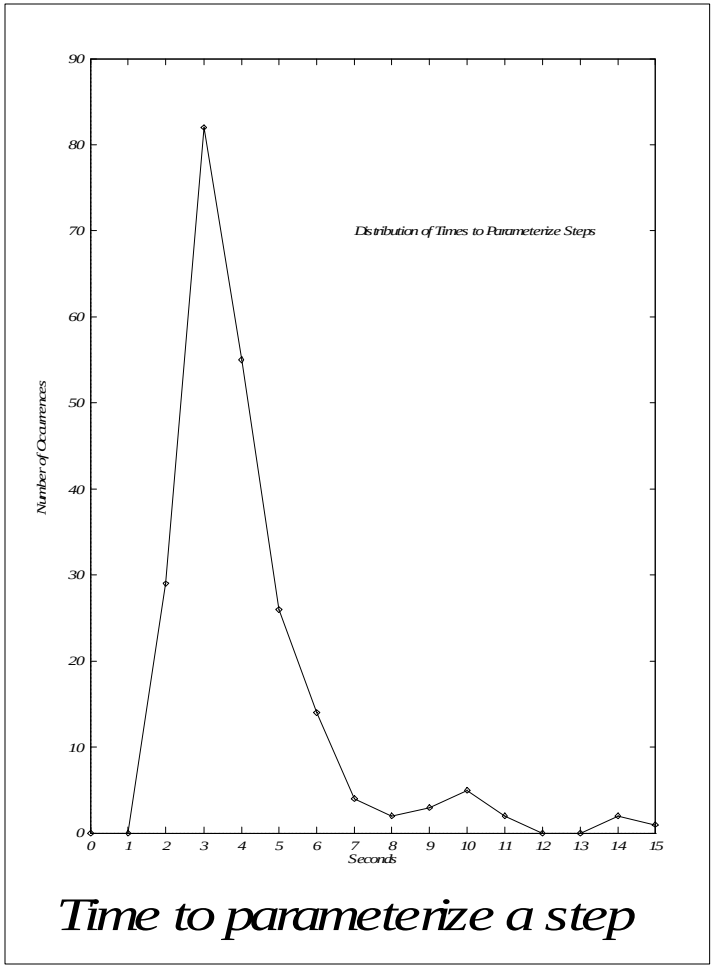
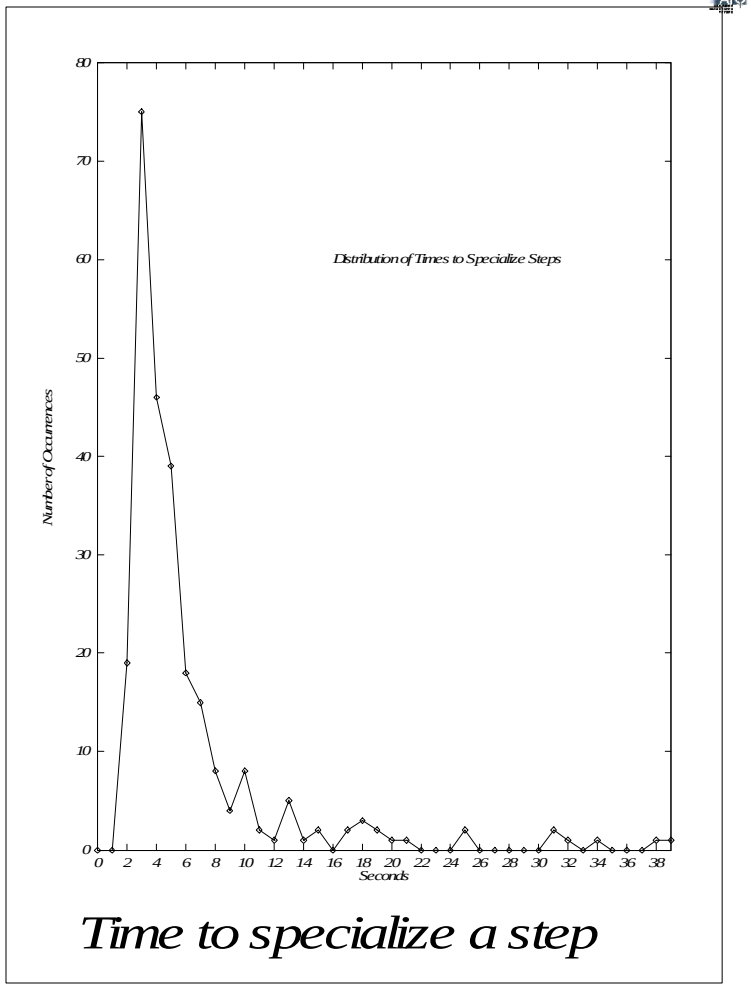
Example Results



Time to parameterize a step



Time to specialize a step

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Usability Study Schedule

- Completion of scenarios and behaviors - mid February
- Preliminary simulation studies - late February
- Refinement of scenarios and behaviors - March/April
- Full studies - summer
- Analysis - late summer

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MissionLab port to Linux 6.0/6.1

- Necessary to make MissionLab available to a wider user community
- Previously postponed due to demonstration activity
- Became higher priority in November
- Variety of minor porting issues
- Now 99.9% complete -- looking for obscure bugs, and available for use by other performers

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Linux Porting Issues

- New kernel and new library interfaces after version 4.2
- New gcc compiler in version 6.0 (egcs becomes gcc)
- Corresponding upgrades of included packages
  - Cthreads
  - IPT, including removal of TCX vestiges
- Testing and verification
  - Most existing simulations have been tested
  - Real robot tests just underway

Onboard Hardware Developments

- Needed smaller computer for Pioneer ATs
  - Acquired Libretto 110 & installed Linux 6.1
  - Four PCMCIA slots and all essential features in a much smaller form factor (even with docking station)
  - Machine used as part of Linux port validation process
- Preferred a smaller, faster commlink
  - Acquired Nokia 802.11 Ethernet adapters and access point
  - PCMCIA card, no external antenna required
  - Configured Linux-WLAN driver (supports variety of 802.11 adapters)
  - 2 Mbits/sec over distances comparable to both Ft. Sam demos
  - Eliminates need for PPP over serial modems, but this feature is still available for long range missions

ARL acoustic sensor

- Conceptual phase of acoustic sensor integration with *MissionLab*
- Considering relevant perceptual schemas
  - Sniper detection
  - Speech identification and other human sounds
  - Road condition/type
  - Robotic platform health
  - Vehicle classification
- Related behavioral schemas
  - Take cover
  - Evade
  - Divert attention
  - Minimize activity
  - Maximize sensitivity
  - Dock and hitch-hike

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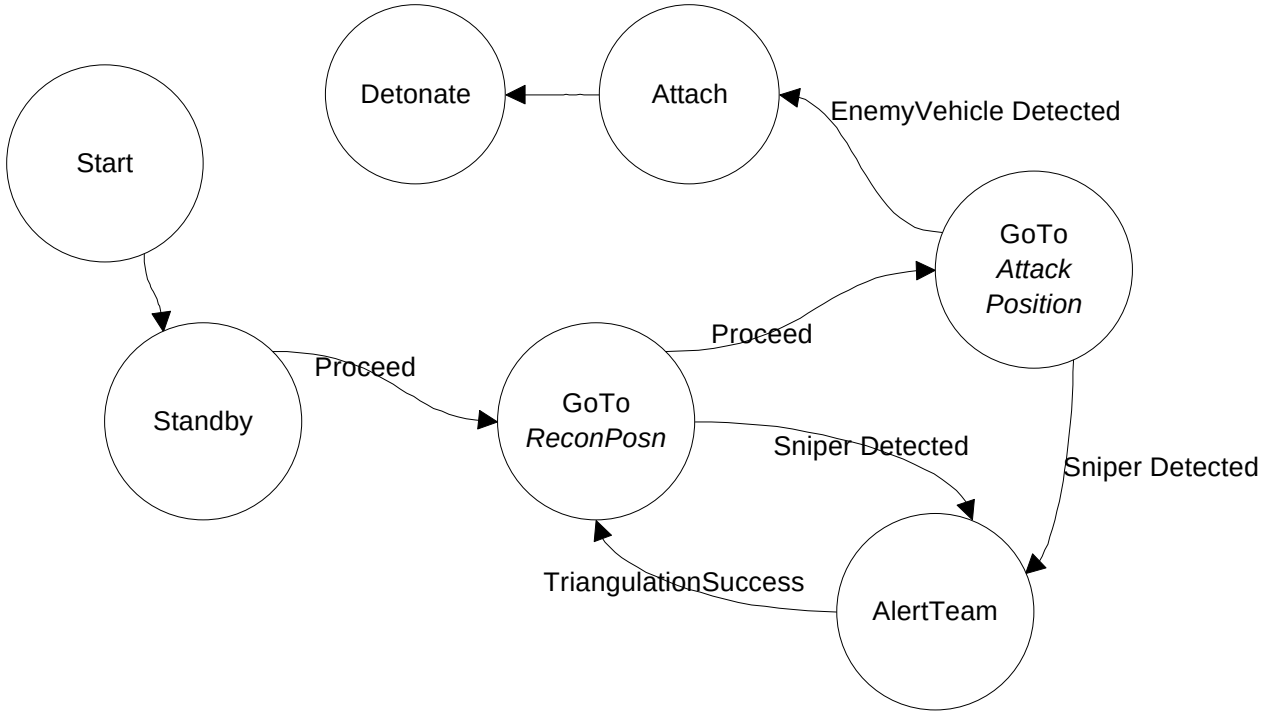
Notional Acoustic Sensor Mission



- Cross exposed terrain after brief recon
- Wait for enemy vehicle at opportunistic roadside point
- Use other robot team members to triangulate snipers and restart recon
- Attach and destroy

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For further information . . .

- Mobile Robot Laboratory Web site
  - http://www.cc.gatech.edu/ai/robot-lab/
  - http://www.cc.gatech.edu/ai/robot-lab/tmr
- PDF versions of pertinent papers
  - http://www.cc.gatech.edu/ai/robot-lab/tmr/archive.htm
- Videos
  - http://www.cc.gatech.edu/ai/robot-lab/tmr/videos.htm
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