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14. ABSTRACT
Collaborating mobile robots equipped with WiFi transceivers are configured as a mobile ad-hoc network. Algorithms are developed to take advantage of the distributed processing capability inherent to multi-agent systems. The focus of this study was to determine the optimal amount of communication which allows the robots to share a sufficiently detailed global map, while keeping their processing time and energy usage to a minimum. A hardware testbed is described, which will be used to examine these trade-offs in an indoor laboratory-scale test

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Report Title

Cooperative Autonomous Robots for Reconnaissance

ABSTRACT

Collaborating mobile robots equipped with WiFi transceivers are configured as a mobile ad-hoc network. Algorithms are developed to take advantage of the distributed processing capability inherent to multi-agent systems. The focus of this study was to determine the optimal amount of communication which allows the robots to share a sufficiently detailed global map, while keeping their processing time and energy usage to a minimum. A hardware testbed is described, which will be used to examine these trade-offs in an indoor laboratory-scale test area.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 5.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 2

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 2

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Chris Wilson	0.25
FTE Equivalent:	**0.25**
Total Number:	**1**

Names of Post Doctorates

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Final Progress Report for Grant Number W911NF-06-1-0334

Report Date: 06 March 2009
Dates Covered: 1 January 2007 – 31 October 2007
Proposal Title: Cooperative Autonomous Robots for Reconnaissance
Grant Number: W911NF-06-1-0334
Author / Sole Investigator: Dr. Thaddeus Roppel
Performing Institution: Auburn University, 202 Samford Hall, Auburn, AL 36849-5320
Granting Agency: Army Research Office (ARO)
ARO Technical POC: Dr. David Chris Arney
ARO Contracting Official: Kathryn C. Terry kathy.terry@us.army.mil
Period of Performance: Original: 19 July 2006 – 18 March 2007,
Modified to: 1 January 2007 – 31 October 2007

Abstract—Collaborating mobile robots equipped with WiFi transceivers are configured as a mobile ad-hoc network. Algorithms are developed to take advantage of the distributed processing capability inherent to multi-agent systems. The focus of this study was to determine the optimal amount of communication which allows the robots to share a sufficiently detailed global map, while keeping their processing time and energy usage to a minimum. A hardware testbed is described, which will be used to examine these trade-offs in an indoor laboratory-scale test area.

Statement of the problem studied

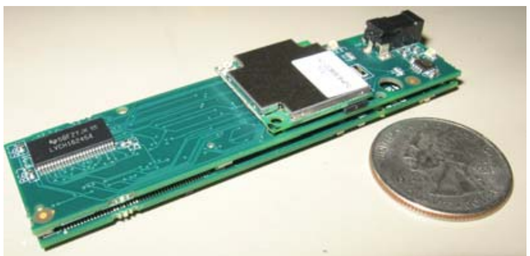
This work pertains to a network of mobile robots imbued with wireless communication capability. Simulation results prior to this award, detailed in Ref. 3, led us to understand that the productivity of such a network depends greatly on the details of the communication strategy. In particular, the quality of the data exchanged and how often it is exchanged are quite important. This award enabled the construction of a hardware testbed for studying these issues further and with greater realism.

Summary of the most important results

The most significant accomplishments are described in the following paragraphs A - D.

A. Construction of a physical testbed, consisting of a field of operation, six wireless-enabled robots, a quad-core server, and approximately 50,000 lines of code to serve as the operations backbone.

(a) Field of operations. The experiment is housed in an 8 ft. x 16 ft. field designed to mimic an indoor environment consisting of a hallway with three rooms on either side. The walls are 12" tall, and the top is open.



(b) Gumstix processor and wireless card with embedded linux. The Gumstix is a 400 MHz Intel XScale ARM-based processor with 64MB of RAM and 16MB Flash memory running embedded Linux 2.6.18 with the μClibc library

(c) Two of the six mobile robots. Sensors include sonar, IR, dual video, and contact (whiskers). Each robot is 7 inches in diameter and 12 inches tall.

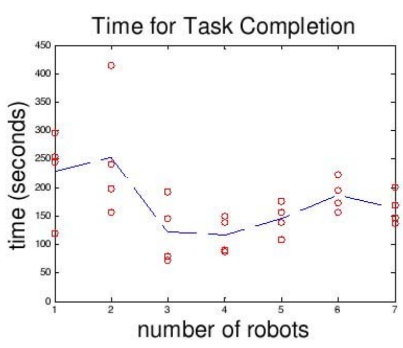
Figure 1. – Testbed for Wireless Collaborative Robotics. (a) Field of operations, (b) processor, (c) robots.

B. Development of global distributed path planning algorithms that are robust to sensor noise. An example of a typical planned path is shown in Fig. 2. The path planned is globally unique, but it is generated locally by each robot. All robots run the same algorithm using sensor data from all robots in the team. A key component of the research is to determine the optimal amount and type of data to share in order to get the best planned paths.

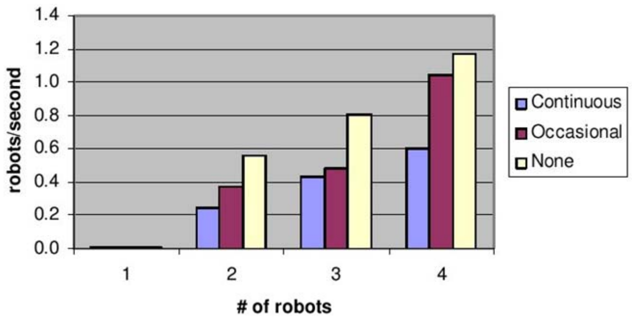
Figure 2. Path (red) planned collaboratively by six robots. Each robot contributes input to the global map based on its local sensor readings.

C. Sensor Fusion. The detailed results make it clear that no one sensor modality is sufficient for path planning and navigation. Robots without whiskers routinely run into walls. Sonar provides a broad view of the environment, but suffers from disastrous reflections at corners. IR has a narrower beam, but takes longer than sonar to perform an azimuthal scan, and suffers from specular reflection at smooth surfaces such as metal braces. We use "hacked" optical mice to provide inexpensive odometery. An optical mouse has an excellent camera / lens / processor built in. We mount two of these under the robot, aimed at the floor. Each mouse provides delta-x and delta-y output in a serial bit stream. Using this combined data, we can measure the robot's linear and rotational velocity to perform dead reckoning. However, as with all dead reckoning, errors accumulate and must be corrected.

D. Optimal Communication. In software simulation, it was determined that an optimal number of robots and an optimal communication interval existed. Some of these results are shown in Fig. 3. The tradeoff between communication interval and team performance (time to find a target) has not been firmly established for the corresponding hardware due to the greater complexities involved, but this is an area which our group continues to investigate.



(a) Task completion time vs. team size.



(b) The effect of communication interval on collaboration effectiveness (robots / second). With no data exchange (rightmost bar in each group), duplication of effort is maximum. With continuous data exchange (left-most bar in each group), collaboration is maximized, but so is resource utilization.

Figure 3. Simulation results for collaborating robots. (a) Effect of team size. (b) Effect of communication interval.

Publications, Presentations, Briefings and Follow-on Based on This Work

As we have presented this work in various venues, there has been a great deal of interest. Some of the more noteworthy occasions that we have had to present results are listed here in reverse chronological order.

- Funded collaboration with AMRDEC (TPOC is Mr. Grant Steele) and researchers at University of Virgina, Virginia Tech, and Polytechnic University through the Wireless Center for Advanced Technology (WICAT), funded through the NSF Industry/University Cooperative Research Centers (I/UCRC) program. July 2007 – ongoing.

- Christopher G. Wilson, "Hardware Testbed for Wireless Collaborative Robotics," Masters Thesis, Auburn University, May 2009.

- Christopher G. Wilson and Thaddeus Roppel, "Low-cost Wireless Mobile Ad-Hoc Network Robotic Testbed," accepted for Tridentcom 2009, The 5th International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities. April 2009

- Briefed Gen. Leslie Kenne on Cooperative Robotics, (Lt. Gen. Leslie F. Kenne is Deputy Chief of Staff for Warfighting Integration, Headquarters U.S. Air Force, Washington, D.C), November 4, 2008.

- C. Wilson, and T. Roppel, "Cooperative Robotics – Progress Report," WICAT (Wireless Center for Advanced Technology) Consortium Meeting, Brooklyn, NY, May 12-14, 2008,

- T. Roppel and D. Wilson, "Mobile Robots for Natural Disaster Search and Rescue," IEEE Spectrum Online, http://www.spectrum.ieee.org/video?id=340, March 2008.

- Wilson, C. and Roppel, T. "Wireless Communication for Robotics," presented at the 2007 Vodafone Symposium, March 2007, Auburn University, Alabama.

- *This poster won "best graduate student poster" award for Auburn. Venu Vereravalli from Univ. of Illinois (well known in wireless, NSF program manager, etc.) was very impressed and referred to the work in his keynote address the day following the poster session.*

- Pathfinder Exhibit in Huntsville, April 2007. Provided video, photos, and written material for College of Engineering poster.

- Numerous internal briefings and presentations to advisory boards, visitors, and students being recruited for College of Engineering scholarships.

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