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Annual Summary Report

University of Michigan 1993
SemiAutonomous Robots for Reactor Containments

1.0 Annual Summary Report

The University reported its progress on a quarterly basis through technology reports to DOE-HQ. The summary report is thus a compilation of the individual reports generated throughout the course of the year.

2.0 Focus for 1993

During 1993, the activity at the University was split into two primary groups. One group provided direct support for the development and testing of the RVIR vehicle. This effort culminated in a demonstration of the vehicle at ORNL during December. The second group of researchers focused attention on pushing the technology forward in the areas of radiation imaging, navigation, and sensing modalities. A major effort in technology transfer took place during this year. All of these efforts are reflected in the periodic progress reports which are attached.

3.0 Future Efforts in 1994

During 1994, our attention will change from the Nuclear Energy program to the Environmental Restoration and Waste Management office. The immediate needs of the Robotics Technology Development Program within the Office of Technology Development of EM drove this change in target applications. The University will be working closely with the national laboratories to further develop and transfer existing technologies to mobile platforms which are currently being designed and employed in seriously hazardous environments.

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MASTER

Summary Paragraph:

The University of Michigan conducted tests of various methods of place recognition for a mobile robot using sonar data taken during the robot's travels. The results identified one method as superior, but additional work remains to refine the approach for improved accuracy. Active efforts in technology transfer were initiated and resulted in collaborations with private industry. Preparations for the Remotec Andros have led to a new control architecture for this platform based on our earlier work with the multiple degree of freedom vehicle. Several radiation imaging algorithms were tested using data from one of the radiation cameras. The most sophisticated algorithm yielded outstanding fidelity, but at the cost of increased computing time. Two more doctoral students completed their studies.

Significant Accomplishments

Technology Transfer

During the past few months we have made increased efforts to transfer technology (developed under DOE) to the relevant industry.

Specifically, we focused on the Vector Field Histogram (VFH) method for obstacle avoidance, and the Error Eliminating Rapid Ultrasonic Firing (EERUF) method for noise rejection with ultrasonic sensors. While numerous manufacturers have shown their interest, additional efforts are required to bring these technologies to the attention of more manufacturers who could profit by employing our results. To increase the pool of potential candidates to use our technology, we categorize the potential clients of our technology into three groups:

- a. Autonomous Mobile Robots (e.g., Cybermotion, Denning, TRC, Cyberotics) Since obstacle avoidance is one of the most basic functions in any Autonomous Mobile Robot (AMR), all of the commercially available AMRs have some sort of obstacle avoidance system already built in. These manufacturers seem to shy away from the substantial development cost associated with redesigning their systems for the hardware requirements of our system, especially in view of the low sales volume of AMRs.
- b. Automated Guided Vehicles (e.g., Caterpillar) Automated Guided Vehicles (AGVs) typically follow guide wires embedded in the floor and have some primitive collision avoidance system. Usually they are unable to navigate around obstacles. In most cases, manufacturers of AGVs are not familiar enough with the problem of real-time obstacle avoidance in order to judge the performance of such systems.
- c. Remote Controlled Vehicles (e.g., Remotec) Remote Controlled Vehicles (RCVs) are even less autonomous than AGVs, and consequently the manufacturers interest and knowledge in the area of obstacle avoidance is typically minimal.

We estimate that the current sales volume (in units) of AGVs and RCVs is one to two orders of magnitude larger than that of AMRs.

After our mobile robot CARMEL won the Mobile Robot Competition in San Jose, California, in June 1992, we used the news reports and journal articles about this event to make manufacturers of AGVs and RCVs aware of our advanced technology. We produced a 10-minute video tape (see enclosed copy) with a format that is understandable and appealing to the technical level of the manufacturers.

Next, we compiled a list of about 30 AGV manufacturers and sent them our video tape, along with other technical material. Within one week after mailing out

these materials, we received phone calls from two AGV manufacturers. One of these manufacturers, Apogee Robotics, followed up with a letter and has begun the technology transfer process.

Currently, we are in the process of compiling a second mailing list, this time of manufacturers of RCVs. Based on a 1987 EPRI report we have identified only a few manufacturers of RCVs, listed in Appendix A. We are searching for additional companies and requesting assistance from the other team members and DOE in identifying additional manufacturers of Remote Controlled Vehicles.

Potential Benefits

We believe that our extra efforts in promoting technology transfer is well in line with the interests of DOE. Specifically, we believe that our effort will help:

- a. Improve the competitiveness of U.S. products on domestic and world markets, by incorporating best-of-its-kind technology.
- b. Spin-off technologies originally developed under DOE's Robotics for Advanced Reactors program to other areas of national interest. Specifically, manufacturing applications (in the case of AGVs and AMRs) is an area which is receiving increased attention from DOE as well as the ER&WM programs of DOE.
- c. Make our technology available for DOE applications sooner, that is, when DOE needs them as off-the-shelf products. Without our technology transfer efforts, manufacturers may be inclined to wait until clearly defined needs and markets are established before they begin to develop and incorporate the technologies that will meet these needs. Immediate interests in this technology are expected in the ER&WM programs of DOE.

In addition to the technology transfer to industry, there has been interest from within the DOE laboratory complex to benefit from the expertise developed under this project. For example, we recently were invited to LANL to describe our research efforts and results. The group we visited has two Cybermotion robots there. The first is to be used to do alpha-particle sweeps of the hallways of their plutonium facilities. The halls need to be swept every night to see if anyone has tracked radiation out of the facility and into public areas. Currently, people do the sweep, which involves moving an alpha detector along the floor at a distance of about 1/4 inch and a speed of no more than 1 inch per second. They also want this robot to be able to sweep a room if a radiation spill is detected. These are very application oriented tasks. The second Cybermotion is purely for research. They have a three year project to develop intelligent, perceiving, learning robots. They plan to use very advanced AI techniques like neural nets, black-boards, rule-based systems, etc. There is no specific task in mind for this research, it is pure, basic research in robotics, normally done at a university. They have requested the opportunity to visit our laboratories and continue the interactions.

Navigation

Experiments in Place Recognition

Background

Any mobile robot navigation system needs to be able to determine where it is. We are using a combination of sonar and vision sensing to construct unique place identifiers that can be matched to current sensor readings to determine the location of the robot. Sonar sensors are used to position the robot at specific places in the environment, these places are called *gateways*. An image is then taken at the gateway and vertical edges are extracted. The location of the edges along with their distance (determined by a simple stereo algorithm) and direction (i.e., is the edge a transition from dark to light or light to dark?) are stored in an abstracted 5 X 5 matrix grid. The size of the grid was selected by determining (experimentally) the error in position of the robot at a gateway and then calculating that error's effect on the location of an edge pixel. The orientation error at a gateway is a maximum of 3.5 degrees. Using a camera with a focal length of 4.8mm gives a displacement error of 47 pixels at 2m (less error at further distances). Doubling this to 94 pixels and then dividing that into the image size of 480 X 480 gives us a 5 X 5 abstraction grid in which errors in orientation should still cause an edge pixel to fall in the same cell of the abstraction grid over many runs.

Figure 1: Experimental space. The robot was stopped at each place and an image was taken in the direction of the cone. Drawing to scale, with the distance from D to G approximately 12m.

Experimental method

A mobile robot was stopped at 10 different places along two routes. The first route was from A to D and the second route was from E to J. All of these places were detected as gateways using a sonar sensing algorithm. Each route was traversed five times to allow for an abstraction grid to be built up; edges that were not seen

repeatedly were eliminated from the abstraction grids. Most of these runs were conducted under sonar control of the robot, although the final runs were performed manually.

At these 10 places, 12 images were taken and stored in the abstraction grids. Then a testing run was done, with the actual image at each of the ten locations compared against the stored maps. Four comparison methods were used:

Method 1: Abstraction grids were compared edge to edge, using the distance and direction of the edge as features. No partial matching of edges was allowed.

Method 2: Abstraction grids were compared pixel to pixel, using the distance and direction of each edge pixel. This allowed partial matching of edges.

Method 3: Abstraction grids were compared pixel to pixel, using only direction. This eliminated the expensive stereo matching algorithm.

Method 4: Abstraction grids were compared pixel to pixel, using only the presence or absence of an edge pixel. This allows for storing the abstraction grids as one bit matrices.

Experimental results

Testing showed that Method 1 gave a correct match 45% of the time, Method 2 was correct 72% of the time, Method 3 was correct 45% of the time and Method 4 was correct 18% of the time. Method 2 was also the only method that allowed for a threshold that separated matches from mismatches. Having a threshold means that the actual image would not have to be compared against all stored abstraction grids to find the closest match, but would only have to be compared until a match above the threshold was found. While a 72% correct match rate may seem low, the robot was operating in a real environment, with moving people, etc. There were instances when only weak vertical edges were available. Also, the robot will have more information about its location than just abstraction grid matching, such as information about where it came from and dead reckoning information.

Future work

Experiments on place recognition will continue. We want to examine the effect of different sizes of grids on place recognition. We also want to compare our sonar-based place detection with a control experiment using place detection based on distance traveled. All of these experiments are on the route to developing an sophisticated navigation system for mobile robots.

Locomotion

We received local approval for the purchase of a Remotec Andros and submitted the order. This will mean common vehicles will be located at Florida, ORNL, and Michigan. We purchased the necessary hardware to begin turning this platform into an intelligent machine, similar to CARMEL, with onboard computing, sensing, and remote communications. We have developed a control architecture for the platform which takes advantage of our earlier work using the multiple degree of freedom robot. We have discussed this architecture with ORNL (Judd Jones) and presented the material to Florida (during the student conference) for their consideration. A brief schematic of this architecture is enclosed. We shall continue our work in preparing for the Remotec platform over the coming months.

Radiation Imaging

During this past reporting period, the radiation imaging group graduated two more doctoral students. This consummates our work in the wavelength shifting of BaF and our fundamental studies on CsI as a radiation detector coupled to photodiodes for imaging applications. Although additional areas of investigation were identified, our efforts have already shifted to the development of a mechanically collimated camera using these results.

With two working prototype cameras, attention has also been directed to the image reconstruction problem. During this reporting period, we have explored applying the algebraic reconstruction (ART), simultaneous iterative reconstruction (SIRT), filtered backprojection, and the maximum likelihood (ML) techniques to our image reconstruction problem. An image of two known point sources was taken and the data was used as input to these routines. The results showed the ML produced a superior image with outstanding fidelity, but at a cost of over five hours of Cray processing time. Further work has led to improvements which cut the processing time by an order of magnitude. We are currently looking at ways of blending the speed of the simpler algorithms with the sophistication of the ML approach in order to produce more real-time images for practical applications.

*) Minimum configuration

***) maximum configuration

Fig. 2

University of Michigan integrated low-level motor controller with radio control and ultrasonic sensor obstacle avoidance.

Fig. 3 Completely wireless run-time and "debug-time" control system.

1st iteration

2nd iteration

5th iteration

7th iteration

10th iteration

20th iteration

Fig. 4. Radiation Image of 2 point sources using ML method.

Submitted papers

David Kortenkamp, "Giving Mobile Robots Cognitive Maps", to appear in Second International Symposium on Intelligent Robotics, Bangalore, India, January 1993.

David Kortenkamp, *et al*, "Winning the AAAI Robot Competition: A Case Study in Integrated Mobile Robot Design", Submitted to *IEEE Expert*, December, 1992.

Clare Congdon, M. Huber and D. Kortenkamp, *et al*, "CARMEL vs. Flakey: A Comparison of Two Winners", to appear in *AI Magazine*, Spring Issue, 1993.

Eric Chown, S. Kaplan and D. Kortenkamp, "Prototypes, Location and Associative Networks (PLAN): Towards a Unified Theory of Cognitive Mapping", submitted to *The Journal of Cognitive Science*, September 1992.

Presentations

David Kortenkamp, "A Directional Spreading Activation Network for Mobile Robot Navigation", Presented at Second International Conference on Simulation of Adaptive Behavior, Honolulu, Hawaii, December 1992.

Johann Borenstein attended a meeting in Washington, on January 7th, 1993. In this meeting the four Universities and ORNL presented their programs to John Williams, Deputy Director of the DOE program for Advanced Reactors. The meeting also kicked off the Team's involvement in the MHTGR program.

David Kortenkamp visited Los Alamos National Laboratory on January 13-15 to give an invited talk on mobile robotics research to their nuclear materials technologies group.

Terry Weymouth, David Kortenkamp, and Arun Hampapur participated in the project's student conference held at the University of Florida, January 27-29, 1993, and presented four papers on our work.

Problems Noted.

None.

APPENDIX A:
LIST OF MANUFACTURERS ADDRESSED IN VIDEO PROMOTION

Automated Guided Vehicles

1. A. G. V. PRODUCTS, INC.
2. AERO-GO INC.
3. AMERICAN SOLVING, INC.
4. APOGEE ROBOTICS
5. BOSH MATERIAL HANDLING
6. BT SYSTEMS, INC.
7. CHARDAN INDUSTRIES, INC.
8. CONTROL ENGINEERING COMPANY
9. CUSTOM TECHNOLOGIES, INC.
10. EATON-KENWAY, INC.
11. EIMELDINGEN CORP.
12. EISENMANN CORPORATION
13. ELWELL PARKER ELECTRIC CO
14. FMC CORPORATION
15. FREDENHAGEN INC.
16. GRIMSLEY & GRIMSLEY, INC.
17. HYSTER COMPANY
18. INTERLAKE MATERIAL HANDLING DIV.
19. LUCAS ASSEMBLY & TEST SYSTEMS
20. MENTOR AGVS, INC.
21. MILLER EDGE, INC.
22. MODULAR AUTOMATION CORP.
23. MANNESMAN - DEMAG, MATERIAL HANDLING SYSTEMS
24. LITTON AUTOMATED VEHICLES
25. MUNCK AUTOMATION TECHNOLOGIES, INC.
26. PRIME-MOVER COMPANY
27. ROBERTS CORP., A CROSS & TRECKER CO.
28. ROBOTIC SYSTEMS, INC.
29. THE RAYMOND CORP.
30. TRANSLOGIC CORPORATION

Remote Control Vehicles

1. AUTOMATION TECHNOLOGY CORP.
2. GCA/PAR CORPORATION, INDUSTRIAL SYSTEMS GROUP
3. PENTEK, INC.
4. STANDARD MANUFACTURING COMPANY, INC.
5. ODETICS
6. ROBOTIC SYSTEMS INTERNATIONAL, LTD.

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