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Supporting Robotics Technology Requirements Through Research in Intelligent Machines*

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Supporting Robotics Technology Requirements Through Research in Intelligent Machines[1]

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Summary

"Safer, better, cheaper" are recurring themes in many robot development efforts. Significant improvements are being accomplished with existing technology, but basic research sets the foundations for future improvements and breakthrough discoveries. Advanced robots represent systems that integrate the three basic functions of sensing, reasoning, and acting (locomotion and manipulation) into one functional unit. Depending on the application requirements, some of these functions are implemented at a more or less advanced level than others. For example, some navigation tasks can be accomplished with purely reactive control and do not require sophisticated reasoning and planning methodologies.

Robotics work at the Oak Ridge National Laboratory (ORNL) spans the spectrum from basic research to application-specific development and rapid prototyping of systems. This presentation summarizes recent highlights of the robotics research activities at ORNL.

Intelligent Sensors and Sensor Fusion

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Range imaging devices form a critical component of any advanced robotic or remote system. These devices provide the 3D environmental information required for metrology, topographic mapping, remote inspections, and object identification. The two main classes of presently available technologies for range sensing are triagulation based and time-of-flight based. The former class includes the structured-light and synchronized scanner approaches. The latter group of technologies contains three types of imaging laser radar - pulsed, frequency-modulated and amplitude-modulated CW laser radars.

A central focus with CESAR during the past eight years has been *sensor fusion* with *imaging laser radar*. Specific research problems which have been addressed include:

(1) *Sensor Modeling*
(2) *Calibration*
(3) *Registration*
(4) *Navigation*
(5) *Image Reconstruction*

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(6) *Scene Segmentation*
(7) *Topographic Mapping*

Imaging laser radar systems which have been studied to a lesser or greater extent within CESAR are:

(1) *Odetics AM Laser Rangefinder*
(2) *Perceptron AM Laser Rangefinder*
(3) *MTI Structured Light System*
(4) *Coleman FM Coherent Laser Radar*

There have been several recent projects in multisensor fusion. In the first project, registered range and reflectance images were acquired using the Odetics and Perceptron AM laser radars. These were fused in order to segment the scene. In the second project, Perceptron AM laser radar images were fused with MTI structured light data for topographic mapping.

Scene Segmentation - Segmentation is frequently a crucial step in analyzing and interpreting image data acquired by a variety of automated systems ranging from indoor mobile robots to orbital satellites. In one recent project, our goal was to partition indoor scenes into regions corresponding to the meaningful surfaces in the 3D environment. This was accomplished by transforming the camera data into three sets of images, encoding depth, albedo and surface orientation, and constructing a probabilistic model for their fusion. The objective of the probabilistic modeling was the reconstruction of the individual surfaces, by removing noise and artifacts while preserving and strengthening surface boundaries. The results of segmenting a laboratory scene are shown below.

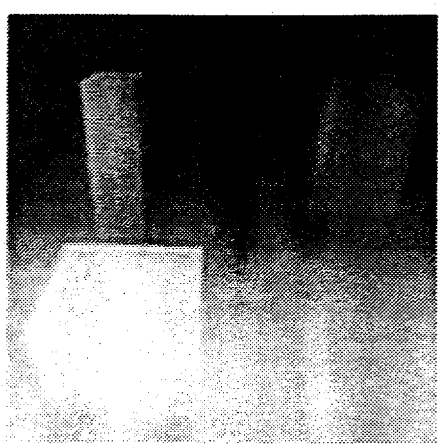

Figure 1. Range image.

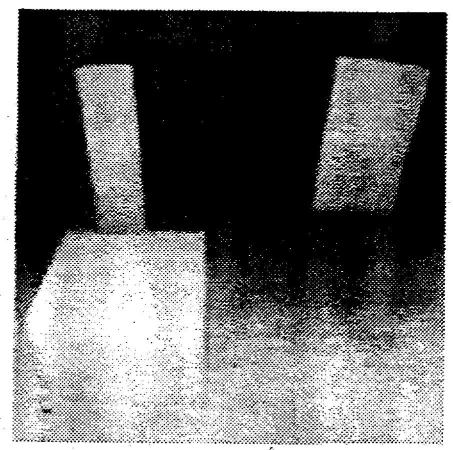

Figure 2. Reflectance image.

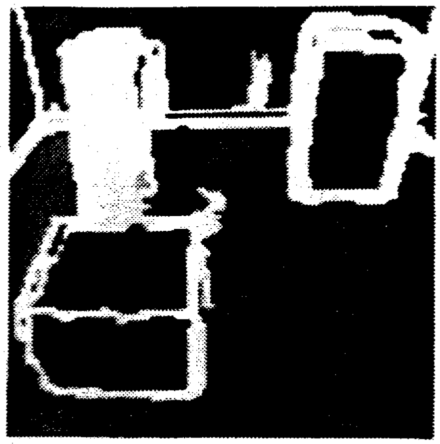

Figure 3. Segmented laboratory scene.

Topographic Mapping - The task was to integrate together imaging laser radar and structured light data from two different locations into an internally self-consistent and reliable world model. This work was undertaken as part of the Environmental Restoration and Waste Management Program. The scene for this fusion task was that of a mockup of an underground storage tank. Specific subtasks included sensor modeling, calibration, registration, world modeling, data fusion and visualization. A mechanical camera model was developed, and a procedure for registering the images was devised. The probabilistic model was then used to fuse the data together. Several visualization tools enabled the viewer to examine the resulting 3D scene. The next two figures show results of the recent USTID activities carried out in June at Hanford, Washington.

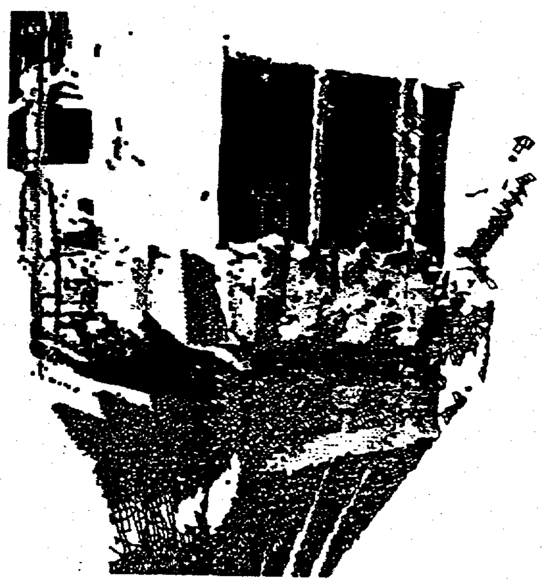

Figure 4. Fused range image of underground storage tank mockup.

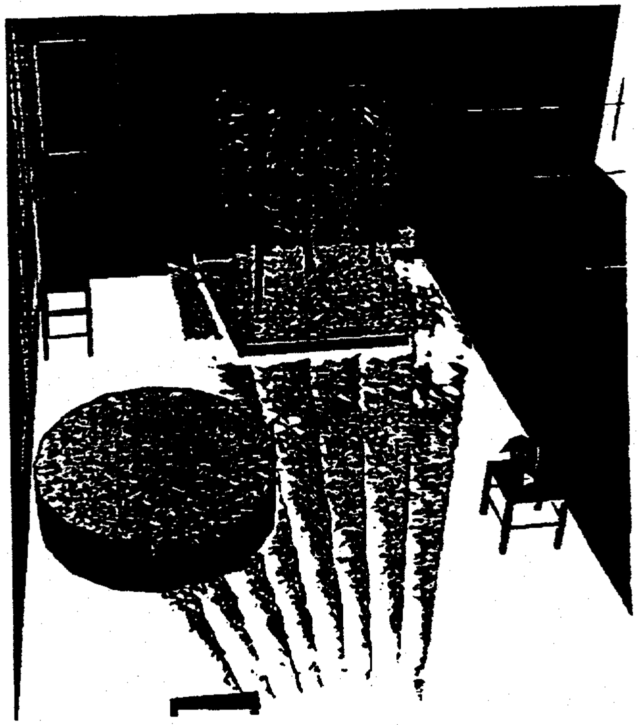

Figure 5. Fused data in 3D database.

Practical Learning Algorithms for Robots
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Several of the difficult problems in sensor-based robotic systems are due to the errors and imprecisions in sensor readings and command executions. These errors and inaccuracies are predominantly system specific and, in general, cannot be characterized by simple models. Complex models are likely to require intractable solutions both computationally and analytically. If the robot systems are readily available, empirical data can be collected by sensing objects and environments with known parameters and executing commands in known configurations. This empirical (or experimental) data can be utilized to infer information about the error characteristics of the sensors and the motion primitives of the system. For example, if we find after a number of trials that a particular mobile robot is bearing to the right by a certain amount, suitable off-set can be added to every motion command to account for the error. This very simple example illustrates the spirit of empirical estimation. In general, however, the error process could be extremely complicated in practical systems, and the degree of difficulty in handling these errors is likely to increase with the next generation of robots.

We investigate general empirical estimation methods to infer from experimental data; this paradigm is intended to complement the techniques that do not employ empirical data rather than replace them. Before the system is put into operation, we collect empirical data and train the system such that mapping from sensor data to the parameter space can be inferred. We address the problems of handling sensor data, and controlling and navigating mechanisms by taking advantage of the empirical data. In the area of sensor processing, we concentrate on sensor fusion, in particular on the problem of estimating fusion rules based on empirical data. We are among the first to propose general methods for obtaining fusion rules based on empirical data. In terms of the robot motion planning and control, we are working on sensor-based methods that make use of both the terrain model and sensor information to navigate. Our experimental examples include the following:

(a) Recognition of doorways using ultrasonic and infrared data: For navigating in indoor environments, a robot was required to identify and pass through a door which is only two inches larger than the robot itself. The ultrasonic sensors are unreliable in measuring the distances to objects, particularly around the corners and doors. The infrared readings yielded only binary information (i.e., within or out of sensor range). The robot was trained to detect the door based on empirical data from an array of ultrasonic and infrared sensors. The robot could successfully navigate through the door after a number of learning trials in which it was told when the door was detected or missed.

(b) Glassware identification using laser range images: In this project, glassware was located and identified to be subsequently manipulated by a robot arm. The workspace is a chemistry laboratory, with a known set of glassware objects. The sensor system consists of a laser range camera. Since light rays go through the glassware, surface fits to the sensor readings had no resemblance to the surface of the glassware. Based on empirical data, we were able to successfully train a system that included a neural network to identify the glassware.

A New Family of Omnidirectional and Holonomic Wheeled Platforms for Mobile Robots
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The concepts for a new family of holonomic wheeled platforms have been developed and tested in prototype hardware. The platforms feature full omnidirectionality with simultaneous and independent rotational and translational motion capabilities. This characteristic results from use of the orthogonal wheel assembly (Figure 1).

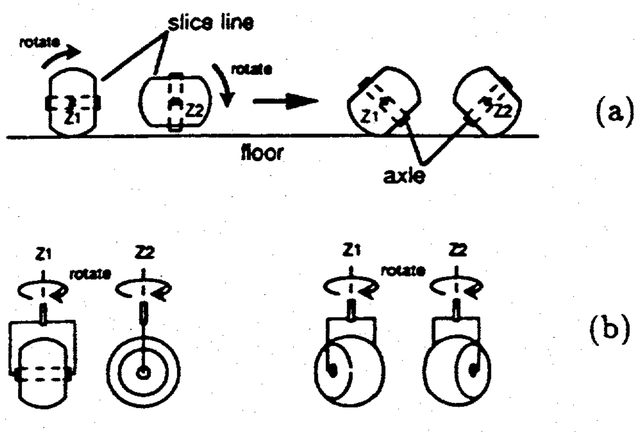

Figure 1. Schematic of the basic orthogonal-wheels operating principle: (a) end-view, (b) top-view.

The basic operating principle of the orthogonal wheel concept is illustrated in Figure 1. The major components are two spheres of equal diameter which have been sliced to resemble wide, rounded-tire wheels, such as those that can be found on most ATV's (All Terrain Vehicles). The axle of each wheel is perpendicular to the sliced surfaces and is mounted using ball bearings so that the wheel is freewheeling around its axle. Through a bracket which is holding the extremities of the wheel axle, each wheel can be driven to roll on its portion of spherical surface, rotating around an axis Z perpendicular to the wheel axle. When these axes (Z_1 and Z_2, coming out of the figure plane in Figure 1a) are maintained parallel and at a constant distance from each other, and when the wheel rotations around these axes are synchronized, contact with the ground can be assured by at least one wheel, while allowing enough space for the brackets holding the wheel axles to clear the ground. The end-view sketch in Figure 1a shows the simplest configuration consisting of two identical wheels with 90° rolling surfaces on each and axles offset by 90°, rotating at the same angular velocity.

When the wheels are rotating in synchronized fashion, they are driven in the direction perpendicular to the Z axes. In the meantime, whatever wheel is in contact with the ground can roll freely in the direction parallel to Z, therefore allowing the entire wheel assembly to move freely in that direction. The two (or more) wheels do not necessarily need to be close to each other, although from a practical point of view, their proximity will minimize drive train and assembly parts.

Heterogeneous Mobile Robot Cooperation

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A key driving force in the development of mobile robotic systems is their potential for reducing the need for human presence in dangerous applications, such as the cleanup of toxic waste, nuclear power plant decommissioning, planetary exploration, fire-fighting, search and rescue missions, and security, surveillance, or reconnaissance tasks; or in repetitive types of tasks, such as automated manufacturing, construction, or industrial/household maintenance. The nature of many of these challenging work environments requires the robotic systems to work fully autonomously in achieving human-supplied goals. One approach to designing these autonomous systems is to develop a single robot that can accomplish all of the goals of a given application. However, the complexity of many environments or missions may require a mixture of robotic capabilities that is too extensive to design into a single robot, thus requiring the capabilities to be distributed functionally across robots. Other missions may be distributed either spatially or temporally, again requiring a distributed robotic solution. Even for applications that are not inherently distributed, multiple robot teams can offer many advantages over single robot solutions, such as increased fault tolerance and reliability through redundancy, and increased efficiency and flexibility through parallelism. In some instances, it may actually be easier or cheaper to design cooperative teams of robots to perform a given mission than it would be to employ a single robot.

At CESAR, we are investigating the topic of cooperation among heterogeneous mobile robots by exploring a number of key issues in cooperative team design and cooperative control. To date, little previous research has addressed the general issues of cooperation that provide guidelines for the design of the appropriate cooperative team for any given set of requirements. Thus, the cooperative robotics research community does not have the tools necessary to adequately characterize the performance of cooperative systems. Such a characterization would be a significant step towards the commercialization of cooperative systems, as it would facilitate the design of the appropriate cooperative team for a given application. Our research in CESAR is thus examining this issue of cooperative design by investigating cooperative robotic issues such as the following:

- Determining the appropriate distribution of capabilities across robot team members for a given application.
- Quantifying the overall system capability versus the system complexity.

- Ascertaining the most appropriate control strategy for a given robot team applied to a given application so as to maximize efficiency, fault tolerance, reliability, and/or flexibility.
- Determining tradeoffs in control strategies in terms of desirable traits, such as efficiency versus fault tolerance.

An understanding of the factors that influence the relative performances of various approaches to cooperative control will enable not only an evaluation of existing methodologies, but will also aid in the design of new cooperative control approaches.

Simulation of Manipulators and Automated Machinery
Technical Contract: R. Kress, tel: 615-574-2468, e-mail: kressrl@ornl.gov

The development of a simulation environment for the modeling of robotic manipulators is considered as one of the core competencies of the Robotics & Process Systems Division at Oak Ridge National Laboratory. Simulation includes the modeling of kinematics, dynamics, sensors, actuators, control systems, operators, and environments. Models will be used for manipulator design, proposal evaluation, control system design and analysis, graphical preview of proposed motions, safety system development, and training. Of particular interest is the development of models for robotic manipulators having at least one flexible link. As a first application, models have been developed for the Pacific Northwest Laboratories' Flexible Beam Test Bed which is a one-Degree-Of-Freedom, flexible arm with a hydraulic base actuator. Initial results show good agreement between model and experiment.

Selective Equipment Removal System
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The Selective Equipment Removal System has been designed as a generic and re configurable remote manipulation platform to demonstrate and to evaluate mobile telerobotic concepts suitable for performing selective decontamination and dismantlement functions. Both radioactive and hazardous chemical environments dictate that human presence should be minimized in many of these activities. In addition, robotic deployment of large and heavy tools should improve safety of operation by limiting human proximity to tooling. Monotonous, repetitive, and high precision activities should also benefit by robotic completion. The Selective Equipment Retrieval System consists of a remote manipulation platform, the Dual Arm Work Module, and specialized tools for example, hydraulic cutting devices.

Swing-Free Control for Cranes
Technical Contract: J. Jansen, tel: 615-574-8154, e-mail: jansenjf@ornl.gov

When suspended payloads are moved, pendulum-like oscillations are naturally introduced because of the fundamental physics of the system. Motion of objects using overhead cranes is a prime example of this phenomenon. This presents a problem any time a crane is used; however, the problem is exacerbated when expensive delicate objects are moved, when objects are to be moved in cluttered and/or hazardous environments, and when objects are to be placed in tight locations. Damped oscillation (Or swing-free) control algorithms have been demonstrated over the past several years for laboratory-scale robotic systems and on dc motor-driven overhead cranes. Most overhead cranes presently in use in industry are driven by ac induction motors; consequently, Oak Ridge National Laboratory has implemented damped oscillation crane control on one of its existing facility ac induction motor-driven overhead cranes. The purpose of this test has been to determine feasibility, to work out control and interfacing specifications, and to establish the capability of newly available ac motor control hardware with respect to use in damped oscillation controlled systems. Flux vector inverter drives are used in the initial demonstration to investigate their acceptability for damped oscillation crane control. Motor performance and restrictions are also examined. Control hardware uses a standard VME bus/Motorola 680X0-based CPU boards/UNIX/VxWorks hardware and software environment; however, smaller, cheaper, and more simple embedded controller designs are also being considered to make the technology more attractive for general industrial use. Results of the demonstration indicate that damped oscillation control is feasible for ac motor-driven overhead systems using industrial-grade hardware. Sensor-based damped oscillation control is also possible to remove oscillations introduced by external forcing functions.