DESIGNING SENSOR-DRIVEN ROBOTIC SYSTEMS*

Mohan M. Trivedi

Electrical and Computer Engineering Department
The University of Tennessee
Knoxville, TN 37996-2100

Extended Summary

Advanced robotic systems should be capable of performing complex tasks in highly unstructured and dynamic work environments. These systems will have to exhibit a high level of autonomy in operating in their complex work space. This can be accomplished by providing robots with sophisticated sensory capabilities for mapping the environment and abilities for task planning, control, and execution. Development of such systems capable of reliable operation in real-world environments is indeed a very challenging research task.

Development of intelligent robotic systems requires consideration of two different types of tasks. The first task deals with the design and development of individual components required in the system, whereas the second task is related to the proper integration of the individual components to form a complete system. Obviously, these two tasks are interrelated and successful development of a complete robotic system requires a *systems engineering* perspective. Specifications of the overall system must be utilized to guide the design of individual components and the framework for their integration.

Over the past several years, the main emphasis of research studies has been on the development of individual components which can be utilized in a larger robotic system. These studies have contributed in the development of useful image processing, analysis, and interpretation schemes and various robot control, path planning algorithms. Research studies with the primary focus on the development of complete robotic system have been comparatively much fewer in numbers. This may be due to the fact that such studies typically require extensive laboratory resources. Some of the noteworthy system development studies reported in the literature include, Autonomous Land Vehicle (ALV) project related works [1,2], automatic welding system developed at SRI [3], and a sheep shearing robot [4]. It should also be noted that whereas both theoretical and experimental approaches were utilized in the research associated with the individual component design, the main approach followed in system development research has been experimental. The complexity of most practical robotic scenarios required a systematic experimental research effort for system design and performance evaluation.

We describe research directed towards the development of an integrated robotic system capable of performing a variety of inspection and manipulation tasks autonomously. Most of the industrial robots currently in use utilize very limited or no external sensory feedback, a fact that limits their ability in performing complex tasks [5,6]. External sensory information derived from a variety of sensor modalities is critically important for robots operating in complex, unstructured and dynamic environments. Design of autonomous systems which effectively utilize multi–sensor inputs is a very challenging research task. It involves consideration of issues such as sensor modality selection, low level processing of sensor data, interpretation of information from a single as well as multiple sensory domains, decision making with noisy, uncertain or incomplete information and efficient and robust implementations for on–line operation of robotic systems. It should also be noted that in developing successful robotic solutions for a given problem, careful consideration of the specifications, requirements and constraints of a particular robotic work environment is essential.

* This work was supported by the DOE's University Program in Robotics for Advanced Reactors (Universities of Florida, Michigan, Tennessee, Texas, and the Oak Ridge National Laboratory) under grant DOE-DE-FG02-86NE37968.

In this presentation, we introduce a general framework for designing intelligent robotic systems. The system architecture consists of six basic modules: **Perception, Motor, Task Planner, Knowledge-Base, User Interface, and Supervisor.** The **Supervisor** module schedules (activates) each individual module and controls the overall flow of system operation. The module also monitors the operation of, and handles the interrupts generated by the **Perception**, and **Motor** modules. The **Task Planner**, given high-level user-specified task plans, generates the specific low-level task plans for manipulation and perception. The **Perception** module provides the sensory derived characterization of the robot's work environment. The **Perception** module also identifies and locates the tool required for the task. This module may utilize vision, range, tactile, force or any other types of sensors. The **Motor** module is responsible for positioning the sensors, grasping the tools, and the actual execution of a specified task. The **User Interface** module provides the necessary interface between the robot and its operator. This is essential in the development of system with provisions for human interaction, supervision and override of the robot operation. The **Knowledge-Base** module contains two components: a) long-term memory, in which information about the robot, sensors, and workspace, along with high-level, user-specified task plans, and general purpose low-level task plans are stored, b) short-term memory in which the current status of the objects, robot, and environment are stored.

Given the complexity of an intelligent robotic system, an important design consideration is that of generality. This can be accomplished by utilizing a design methodology and system architecture where differences in the types of sensors, robot hardware, work environment and task requirements can be systematically incorporated. Our eventual goal is to implement an autonomous robotic system which can accomplish various complex tasks such as inspection, manipulation and assembly. It would be to design the system in such a way that it should be as independent of a particular robot hardware configuration as possible.

The above concepts associated with the general architectural framework and the design of individual system components are utilized in developing and implementing two sensor-based robotic system prototypes. The first, is capable of a range of autonomous inspection and manipulation tasks involved with a control panel testbed (Figure 1). The second system, is capable of autonomous detection of a chemical spill, its localization in the world coordinates, its cleaning by using a vacuum cleaner attachment, and verification of the clean-up operation (Figure 2). These two systems are designed and implemented and are currently operational in our laboratory. The generality and robustness of the system performance is tested by successfully transporting system components to another research laboratory involving a different type of robot, sensors, and physical environment. Details associated with the various aspects of design and implementation of these robotic systems can be found in references [7] through [11].

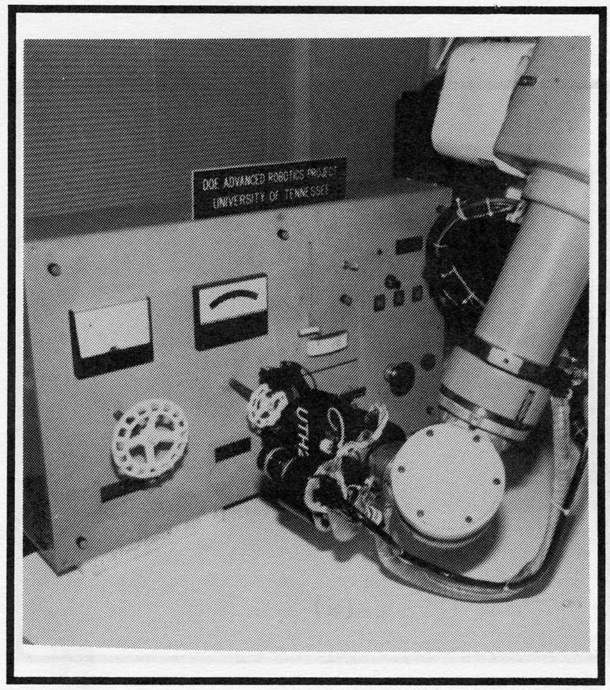

Figure 1: *A sensor-based robotic system for performing various inspection and manipulation tasks autonomously.*

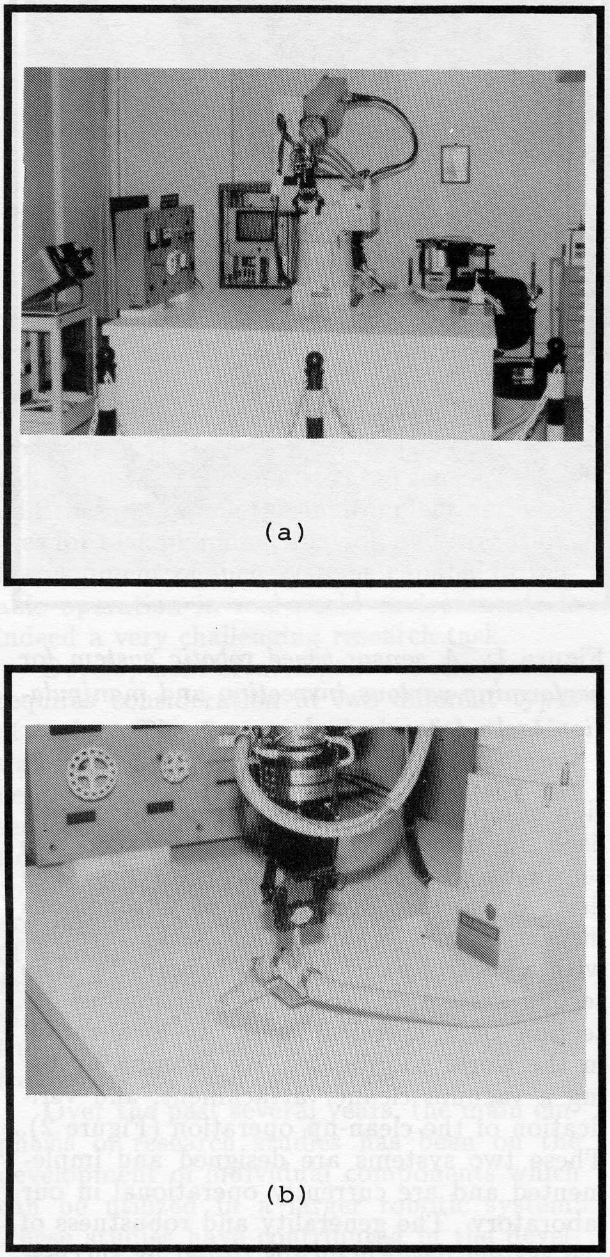

Figure 2: *A sensor-based robotic system for autonomous detection of spill and its clean-up. Part (a) shows the robot while acquiring images of the workspace and part (b) shows it during the execution of clean-up task.*

References

[1] C. Thorpe, M. H. Hebert, T. Kanade, and S. A. Shafer, "Vision and Navigation for the Carnegie-Mellon Navlab," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 10, no. 3, pp. 363–373, May 1988.

[2] M. A. Turk, D. G. Morgenthaler, K. D. Gremban, and M. Marra, "VITS-A Vision System for Autonomous Land Vehicle Navigation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 10, no. 3, pp. 342–361, May 1988.

[3] D. Nitzan, "Three-Dimensional Vision Structure for Robot Applications," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 10, no. 3, pp. 291–309, May 1988.

[4] J. P. Trevelyan, "Sensing and Control for Sheep-Shearing Robots," *IEEE Transaction on Robotics and Automation*, vol. 5, no. 6, pp. 716–727, December 1989.

[5] A. C. Kak and J. S. Albus, *Handbook of Industrial Robotics*, ch. Sensors for Intelligent Robots, pp. pp. 214–230. New York, NY: John Wiley & Sons, 1985.

[6] K. S. Fu, R. C. Gonzalez, and C. S. G. Lee, *Introduction to Robotics: Control, Sensing, Vision, and Intelligence*. New York, NY: McGraw-Hill, 1987.

[7] M. M. Trivedi, C. Chen, and S. B. Marapane, "A Vision System for Robotic Inspections," *IEEE Computer, Special Issue on Autonomous Intelligent Machines*, vol. 22, no. 6, pp. 91–97, June 1989.

[8] S. B. Marapane and M. M. Trivedi, "Region Based Stereo Analysis for Robotic Applications," *IEEE Transactions on Systems, Man, and Cybernetics, Special Issue on Computer Vision*, vol. SMC-19, no. 6, pp. 1447–1464, November 1989.

[9] M. M. Trivedi, M. A. Abidi, R. O. Eason, and R. C. Gonzalez, "Developing

Robotic Systems with Multiple Sensors," *IEEE Transactions on Systems, Man, and Cybernetics, Special Issue on Intelligent Systems and Unmanned Vehicles*, vol. SMC-20, no. 4, July 1990.

[10] C. Chen, M. M. Trivedi, and C. R. Bidlack, "Design and Implementation of an Autonomous Spill Cleaning Robotic System," in *Proceedings of the Applications of Artificial Intelligence VIII Conference*, (Orlando, FL), April 1990.

[11] H. Gadagkar and M. M. Trivedi, "Tactile Sensory Analysis for Robotic Applications," in *Proceedings of the Applications of Artificial Intelligence VIII Conference*, (Orlando, FL), April 1990.