N89-19881

A MULTI-SENSOR SYSTEM FOR ROBOTICS PROXIMITY OPERATIONS

J.B. Cheatham, C.K. Wu, P.L. Weiland
Rice University
Mechanical Engineering & Materials Science
Houston, Texas 77251-1892

T.F. Cleghorn
NASA/Johnson Space Center - FM 7
Houston, Texas 77058

ABSTRACT

Robots without sensors can perform only simple repetitive tasks and cannot cope with unplanned events. A multi-sensor system is needed for a robot to locate a target, move into its neighborhood and perform operations in contact with the object. This paper describes systems that can be used for such tasks.

INTRODUCTION

An integrated robotic system capable of performing tasks in which the target is in an arbitrary location and orientation is described in this paper. This system consists of a PUMA 560 robot manipulator, a vision system with a camera mounted over the robotic work area, a force/moment sensor, a laser range finder, and an infrared proximity sensor. Two laboratory experiments were performed successfully using this system. One experiment simulates a simple industrial assembly task and the other permits battery replacement in a model of the Solarmax satellite. In the first experiment, the vision system is used to locate randomly placed parts. In the second, a laser range finder is combined with the infrared proximity sensor to locate the satellite model. These two 'visual' systems provide redundant information about an unknown environment. This redundancy can be used to check or confirm the visual information provided by either system. Fine motion control is achieved by employing the force/moment transducer and the infrared proximity sensor.

Sensors are monitored and controlled by an expert system written in CLIPS (C Language Integrated Production System). CLIPS is a rule-based language written in C. All rules are sequenced by a priority rating. The priority rating is set by the rule ordering method [1] which arranges all rules in one long priority list. The rule with the highest priority, appearing earliest in the list, is triggered first.

SYSTEM OVERVIEW

The RTX robot, manufactured by UMI, is a six degree-of-freedom robot with five revolute axes and one translational axis. This manipulator is operated under program control using the C language. Belt drives are used for the shoulder, elbow and yaw joints and bevel gears for the roll and pitch axes. Accuracy of repetitive movements is within 0.5 mm.

Figure 1 depicts the system configuration. The PUMA 560 is an industrial grade, six degree-of-freedom robot. This manipulator can be operated interactively or under program control using the VAL II language. A NAMCO Lasernet scanner attached to the first joint of the PUMA provides a vertical search arc of 90 degrees to a distance of twenty feet. Rotating this device about the vertical first joint of the PUMA effectively provides a complete search of the robot's workspace.

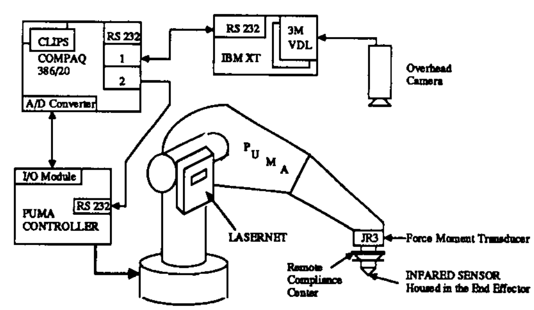

Figure 1. System configuration

A specially designed tape that reflects incoming light back at the incident angle is attached to the target. The returning pulse is detected by the Lasernet, which signals that the target has been located. An infrared proximity sensor, built into the end effector, determines the target orientation by examining a known surface of the target.

A JR3 force/moment transducer, mounted on the end effector of the PUMA, provides a means for controlling the motion of the robot while maneuvering the objects. The JR3, an industrial grade force/moment measuring device [2], consists of a six degree-of-freedom force sensor and an electronics enclosure that contains a 12-bit analog to digital converter. Resolution of the force measurements is 1 part out of 4096 of the full scale, (+/- 25 lbs along the x and y axis, +/- 50 lbs along the z-axis, and +/- 75 in- lbs for moments). The digital data output from the A/D board is transferred to the PUMA controller via the direct memory access (DMA) bus. A VAL II subroutine, provided by the JR3 company, can be called in a program for measuring the forces and moments exerted on the end effector.

A 3M vision development language (VDL) system with a camera mounted over the robotic work area provides a high-speed vision development workstation for an IBM XT computer. This system includes a 512 x 512 x 8 digitizer with two 256 Kbyte frame buffers and a signal processing board for image acquisition and processing. A wide variety of vision algorithms can be implemented interactively using macros, programmed with a command interpreter called VDL-BASIC, or programmed using C language supported by a C command subroutine library. Work described in this paper use the C programming capabilities.

INTELLIGENT VISION-ASSISTED ASSEMBLY TASK

The first experiment simulates an assembly task involving two robots. A number of objects of various sizes and shapes are randomly placed in the work area (see Figure 2). A camera over the work area captures images of the objects and data relating to the images are passed from the vision system to the expert system for identification. One by one the objects are retrieved by the RTX robot and placed in a position for use by a PUMA 560 robot in an assembly task. The objects are picked up by the Puma and inserted into holes of the proper sizes and shapes under force- moment control.

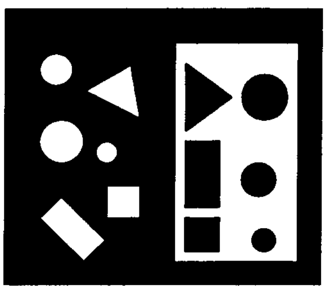

Figure 2. Top view of the objects and receptacle

An overhead camera connected to the 3M VDL vision system provides digitized images of the unknown targets. The vision program consists of a calibration subroutine, an image acquisition subroutine, a target extraction subroutine, and a properties measurement subroutine. Video images of the objects are digitized and thresholded into binary images by the image acquisition routine. Targets are represented as white objects on a black background in the binary image. The target extraction routine searches the binary image for a single white object and encloses the object within a window. The contour of the windowed object is then traced and the locations of the corners are determined [3]. This procedure is repeated for all objects in the viewing plane.

Processed vision data are transmitted from the vision system to the expert system on a Compaq 386 through an asynchronous communication line. The CLIPS program analyzes the vision data and determines the shapes, sizes and locations of the objects. This program consists of rules to identify the objects and to sort the targets by their geometric properties. It then transmits the position data to the RTX.

The RTX is programmed in C to perform the disk retrieval task. Center of gravity and orientation data of an object are developed by the expert system program. These data provide the necessary information for the RTX to pick up the object and move it to a predefined location. Upon completion of this task the control program is notified of the task completion and the RTX returns to its home position. The PUMA 560, programmed in VAL II, is instructed by the expert system program to retrieve the disk and move it to the taught position for the assembly work station. Insertion of the object is accomplished using force/moment feedback provided by the JR3 transducer. After successfully inserting an object a signal is transmitted from the PUMA to the expert system program. This process is repeated for the remaining objects. Upon completion of the insertion of the last object, both robots return to home positions.

BATTERY REPLACEMENT IN A SATELLITE MODEL

The goal of the second experiment is to develop a procedure for changing batteries in a satellite. A PUMA robot is programmed to perform this task autonomously. The robot carries a tray with tools and fresh batteries in a known position with respect to the robot. The location and orientation of the satellite containing the battery compartment is unknown.

An essential part of this experiment is to locate the satellite model without using the vision system. A scanning laser range finder is used to locate a reflective material attached to the target and to determine the coordinates of the object. A proximity sensor, which is housed in the end effector (see Figure 3), is then used to determine the orientation of the target. This system provides an alternative means of acquiring positioning information and is relatively inexpensive compared with a vision system [4].

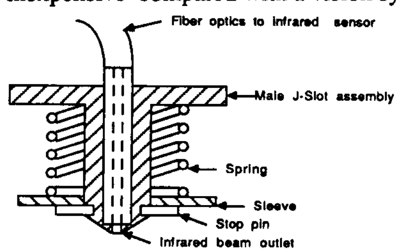

Figure 3. Infrared sensor housed in an Interchangeable end effector

The Lasernet senses only its reflected light. Commercially available reflective tape can reflect incident light back to the origin at angles up to 70 degree from the surface normal. However, variations in this angle are observed. The width of the target must be known for the Lasernet data to be used in determining distance. An object in a horizontal plane can readily be located by using a flat, circular reflective tape. As the object's orientation becomes more complex, so does the target selection. Ideally, a spherical target will provide the most uniform projection at any orientation. In this experiment, a spherical reflective target was constructed out of the reflective tape adhered to a golf ball.

During operation, the PUMA rotates the Lasernet about its first joint searching for the spherical target attached to the satellite. When the target is located the Lasernet sends a signal to the PUMA which records its first joint angle. The location of the spherical target is then computed from the range and angle data from the Lasernet and the PUMA's first joint angle [4].

Once the spherical reflector has been located, the IR proximity sensor is used to conduct a search for a smaller circular reflector (see Figure 4). The proximity sensor receives a reflected "on" signal within 2 cm of the aluminum plate on the satellite model and up to 50 cm from the reflective tape targets. The end effector is moved in a circular search pattern of radius equal to the known distance from the sphere. By locating the two reflective targets a line is defined on which the satellite model is located. The proximity sensor is then moved midway between the reflectors and lowered to detect the object's surface. A search for the edges of the aluminum plate defines it's orientation. The sensor receives a positive impulse while over the surface, but loses the signal as it crosses over the edge. The orientation of the satellite model is found by tracing one of the edges. A false edge is used to determine which edge is found. A non-reflective strip is placed down the length of the object. When first seen by the sensor it appears as an edge. The sensor will continue onward after the 'edge' is found and regain contact with the surface. This on-off-on signal will signify the location of the false edge. Knowing these points the orientation of the object can be established.

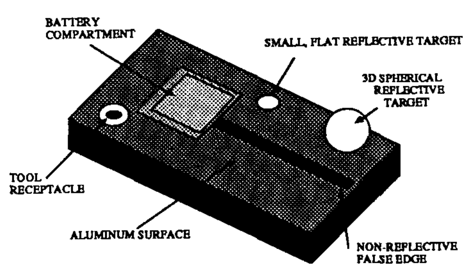

Figure 4. Object/Target Configuration

Once the location of the satellite model is completely determined, the battery replacement task may proceed. The PUMA engages an electric cover actuator to turn a power screw which opens and closes the door over the battery compartment. A J-Slot type assembly is used to pick up both the battery packs and the electric cover actuator [5]. Figure 5 depicts the electric actuator with the J-Slot. The retrieval and insertion of batteries into the battery compartment are performed under position and force control using the JR3 sensor.

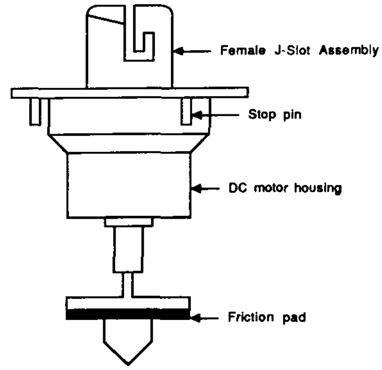

Figure 5. Electric actuator with J-Slot assembly

CONCLUSIONS

Two systems have been described that can be used for robot proximity operations. A vision system combined with a force sensor has been used to locate and identify objects then retrieve and insert them into receptacles of appropriate size and shape. An expert system written in CLIPS interprets the vision data and sends instructions to two robots used in the assembly task.

The second system used a laser range finder, an infrared proximity sensor, a force/moment transducer and special reflective targets to locate a satellite model and replace a battery pack in the model. A combination of both system can provide redundancy that could permit improved reliability for space robotics activities.

ACKNOWLEDGMENTS

The authors appreciate support of this work by NASA/JSC under Grant NAG-208 and RICIS contract NCC9-16.

References

[1] Giarratano, J.C., CLIPS User's Guide, A. I. Section, NASA/JSC, Houston, September, 1986.

[2] JR3, Universal Force/Moment Sensor System, Operational Manual, JR3, Inc., Woodland, CA, 1985.

[3] Cheatham, J.B., Wu, C.K., Chen, Y.C. and Cleghorn, T.F., "Interpretation of Robot Vision Images via An Expert System", ASME International Computers in Engineering Conference, San Francisco, CA, 1988.

[4] Cheatham, J.B., Weiland, P.L. and Wu, C.K., "A Sensor System for Determining Position and Orientation of Robot Targets", 3rd International Conference on CAD/CAM Robotics and Factories of the Future, Southfield, MICH, 1988.

[5] Armstrong, A., Dunn, P., Hekma-Wierda, D., Hodge, A. and Howard, D., Design, Construction and Implementation of a Robotic System for Replacing Batteries, Senior Design Project Report, MEMS Dept., Rice Univ., May, 1987.