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Paper Session II-B - Sensor Data Display For Telerobotic Systems

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SENSOR DATA DISPLAY FOR TELEROBOTIC SYSTEMS

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ABSTRACT

Future earth orbiting, lunar and planetary missions will require the performance of tasks that are beyond human capability or are in an environment where human entry would be too costly or too hostile. These tasks will be candidates for performance by telerobotic systems whereby an electro-mechanical manipulator device performs the task in the remote hostile environment and the operator controlling or supervising the task remains at a work station in a safe location. Efficient operator participation in a telerobotic task occurs only when operators experience "telepresence", that is they "feel" that they are present at the remote site in making the various decisions to control the task. Telepresence is therefore enhanced by presenting to operators the various inputs, for example visual, tactile, and force/torque information, that they would receive if they were actually present at the remote site.

This paper addresses the problem of enhancing telepresence by displaying telerobotic sensor information to operators at their work stations. The paper is divided into four sections. First, a discussion is presented on some of the problems of displaying data from remote tasks. Second, an effort at Rockwell International to identify requirements for operator friendly display of data from telerobotic sensors, is described. Third, work performed at Rockwell's Robotic Facility is addressed. This work involves the integration of various sensors on a telerobotic device, and the design and implementation of operator friendly data display which adheres to the guidelines described above. Lastly, our future research plans and objectives in this area are discussed.

1. SOME PROBLEMS WITH SENSOR DISPLAYS FROM REMOTE TASKS

In a typical teleoperated space task, a human operator located in a work station uses a manipulator master to control an on-orbit slave performing a remote task. To do this, the operator needs continuous data about the task and about the work environment. Various cameras and sensors on the slave, or in its immediate locale, capture these data which are then presented to the operator through a communication link to the work station.

While remote task performance is often a very useful and necessary way to accomplish tasks in a remote hostile environment, the very remoteness of the task often results in two major difficulties from the point of view of the operator. First, there is some degradation of information presented to the operators, and second, there are difficulties with their perception of this information. In the first instance, no sensor can pick up the richness of data that the operator would experience in a "hands-on" operation where texture, temperature, slip and force would be perceived together with the sense of vision and sound as a single experience. Nuances, "just noticeable differences" that the operator might have been aware of, may be lost in data acquisition, transmission and reformatting. In the second instance, operators at a work station often receive information through an unnatural sense modality. Again, in a "hands-on situation", the sensory receptors in the hands and arm are the main recipients of touch, temperature and force stimulation. However, present technology does not allow us to readily present these data to the operators' hands when a task is being performed remotely although efforts are underway to do this. The senses of hearing and vision are therefore the two next best candidates to present sensor data, bringing with them a new set of problems. Most humans do not have a sense of absolute pitch and can usually distinguish no more than four or five absolute, (rather than comparative), differences in frequency. Thus while sound is useful for caution, warning, alarm and for "yes - no" information it would not be useful for continuous data such as changes in force as a task progresses. Sound has the additional drawback that operators are already receiving auditory stimulation from the background noise, equipment, and speech of colleagues in the control room. The only present solution is therefore to present continuous data visually, using computer generated alpha numeric or graphic displays. This brings the additional problem that the operators' eyes are probably fully occupied with TV screens or written procedures. The displays must therefore be designed to provide the necessary information in a format that does not overburden the operators' visual perceptual capabilities, and is also readily available, simple, and easy to understand. However the two major difficulties still remain. Much of the richness of the information will be lost. And the information is still presented in an unnatural mode, that is, information which in a "hands-on" task would naturally be sensed by the hands is now allocated to the sense of vision and must be interpreted and integrated by the operator to make a unitary concept of "what is out there".

2. REQUIREMENTS FOR OPERATOR FRIENDLY DISPLAYS

An effort was undertaken at Rockwell to expand existing literature on guidelines for visual and auditory displays, and to develop guidelines for the display of information from telerobotic sensors. References 1 through 9 are

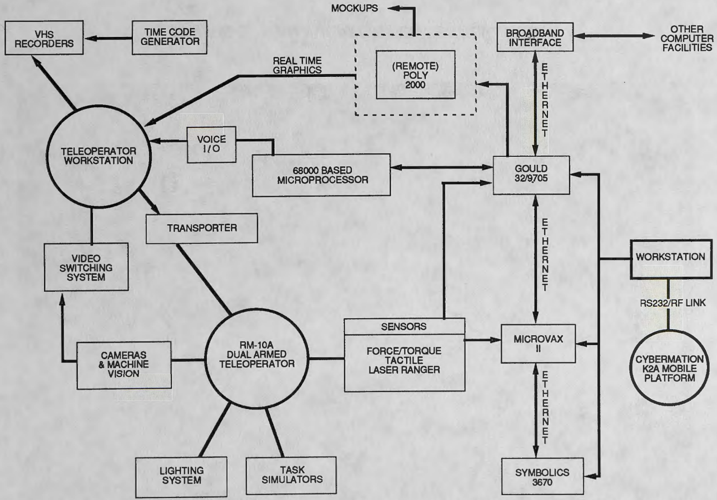


FIGURE 1. ROCKWELL ROBOTICS FACILITY

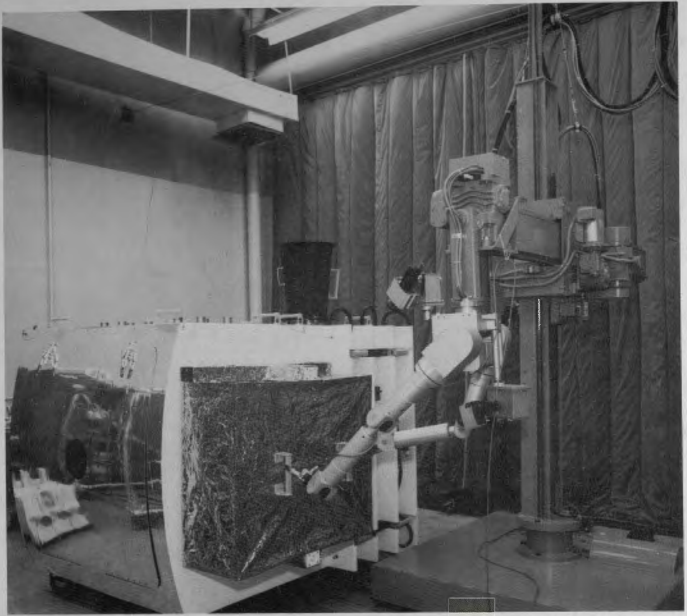


FIGURE 2. MANIPULATOR SLAVE TASK AREA

FIGURE 3. MANIPULATOR MASTER WORKSTATION

examples of the kinds of data that were reviewed. Reference 10 presents the suggested guidelines for sensor displays and covers three areas of concern: telerobotic work stations, visual displays, and auditory presentation of information. A few examples from the document are given below.

> Displays must be presented in an immediately usable form: data conversion by operators wastes time and can lead to errors. For example, operators can understand a cartoon of the slave arms which changes from green to yellow when safety limits are approached, faster than they can understand a table of joints, angles and force vectors.
> Data shall adhere to convention as regards format, direction of data flow and units of measurement.
> Metric and imperial units shall not be mixed. Display formats shall be consistent from one display to another.
> If operators need a historical perspective to understand the sensor display, a separate smaller display window may be used on the primary display .
> Colors shall be chosen on the basis of conventional association, for example, red for unsafe load conditions, yellow or orange for caution in handling, green for normal loads and white for neutral information.

3. IMPLEMENTATION OF OPERATOR FRIENDLY SENSOR DISPLAYS

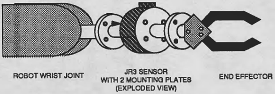
Sensor displays were next designed and implemented to meet the guidelines developed in Reference 10. The Rockwell Robotics Laboratory was the locus of this work and is described below:

LABORATORY DESCRIPTION

The Robotics Laboratory is housed in Building 4 in the Rockwell Space Transportation Systems Division in Downey, California. A block diagram of the laboratory's main features is shown in Figure 1. A REMOTEC RM 10A master slave manipulator is complemented in its slave area (Figure 2), by remote cameras and force/torque, tactile and laser ranger sensors and by a fully equipped operator work station in its master area, (Figure 3). Data processing is provided by a Symbolics 3670, a MICROVAX II and by a Gould 32/9705. A Poly 2000 provides a remote graphic interface between the Gould and the operator work station.

SENSORS

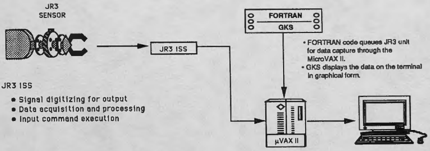
A JR3 Force-Torque Sensor, manufactured by JR3 Inc., is mounted on the wrist of the RM 10-A slave. The sensor has a diameter of 6 in., height of 1.5 in., and weight of 8 lbs. Contained within its housing are foil strain gauges whose electrical resistances change as loads are applied to the wrist. This change in resistance is transduced into force and torque



JR3 FORCE-TORQUE SENSOR

- Six degrees of freedom
- Wrist mounted
- Sends electrical signals by strain gauges to ISS.
- Detects damaging overloads
- Compact for minimal effect on robot's work envelope
- dia = 3.00", ht = 1.25", wt = 3. lbs

FIGURE 4. CLOSE UP OF JR3 FORCE-TORQUE SENSOR



- FORTRAN code queues JR3 unit for data capture through the MicroVAX II.
- GKS displays the data on the terminal in graphical form.

JR3 ISS

- Signal digitizing for output
- Data acquisition and processing
- Input command execution

FIGURE 5. SENSOR INTEGRATION INTERFACES

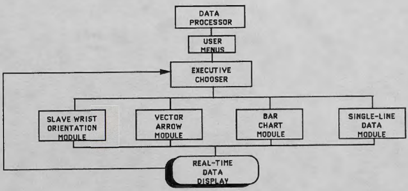
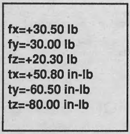
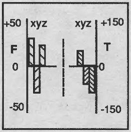


FIGURE 6. SENSOR INTEGRATION INTERFACES

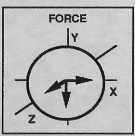


fx=+30.50 lb
fy=-30.00 lb
fz=+20.30 lb
tx=+50.80 in-lb
ty=-60.50 in-lb
tz=-80.00 in-lb

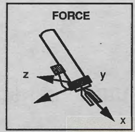
NUMERICAL MEASUREMENT



BAR CHART



VECTOR ARROW



SLAVE-WRIST
ORIENTATION

FIGURE 7. FOUR DISPLAYS OF SAME DATA

data in the x, y, and z directions. Maximum loads that the JR3 can sense are forces of 50-100 lbs and torques of 100 in-lbs. The mechanical interface of the JR3 sensor to the arm is through a 9-pin sensor cable connected to the JR3 Intelligence Support System (ISS), which allows for command inputs and data transmission. The ISS is powered by an electrical box and can be connected to any external device by means of an RS-232 cable. The JR3 sensor, its integration interfaces and a real-time data flow chart are shown in Figures 4, 5 and 6 respectively.

As the slave applies forces to task objects, the sensors' strain gages change resistance and send excited voltages through the sensor cable to the ISS, which amplifies, filters and digitizes the signals. The ISS also processes command inputs. An RS-232 and a communication protocol provide the interface between the ISS and the MicroVAX II host computer. Displays are generated in real time.

The Graphical Kernal System (GKS), the new international graphics programming standard, displays the force and torque data pictorially. GKS is a library of run-time subroutines that are linked to the FORTRAN '77 programming language. This package provides a full set of output primitives basic to building graphics programs. These output primitives can be elaborated by attribute, transformation, and segment functions.

SENSOR DISPLAYS

Using Reference 10 as a guide, four formats have been designed to display JR3 force/torque data: numerical measurement; bar chart; vector arrows; and slave wrist orientation. The formats are presented in Figure 7. The first format, numerical measurement, presents only quantitative values while the other three present the same data as a chart, diagram or cartoon. Operators can choose the format they prefer through a "user menu". The "numerical measurement" format probably requires more cognitive processing by the operator but would be useful when operators need to know the absolute values of the forces exerted at the slave. The other formats, particularly the "slave wrist orientation" are designed to help operators interpret the data by giving directional and overload cues. All formats adhere to the referenced guidelines as regards labelling, symbol size, format, color and so on. For example, all displays are green for normal operating conditions, become yellow when overload is approached, and red when overload occurs. Each of the formats is further described below.

NUMERICAL MEASUREMENT

This format gives force and torque numerical values in each three dimensional axis. Numbers are rounded upwards to whole numbers. Force torque vectors are displayed by letter symbols rather than graphically, which may have the disadvantage of requiring more interpretation on the part of the operator.

BAR CHART

A horizontal line represents an at-rest position. A set of three bars coded green denotes force values in x, y, and z directions. Similarly torque values are coded by yellow bars. The vertical axes show easily readable unit intervals. Difficulties that were overcome in generating the bar chart display include specifying GKS parameters so that the desired display is generated, for example, implicit regenerations were suppressed so that the display background would remain constant during continuous data refreshment, and only the bars would change.

VECTOR ARROW

Green force or torque vector arrows increase or decrease as loads on the sensor change. A red circle around the vectors marks the area of overload which operators must avoid. The display has the advantage of depicting the x, y and z planes and area of overload in an immediately understandable manner. It has the disadvantage of not displaying numerical values.

SLAVE WRIST ORIENTATION

Arrows on a cartoon of the slave wrist indicate the direction of force and moment loading. Numerical values are not displayed but the cartoon is very easy to understand and directly relates to the scene at the remote work site.

4. FUTURE TECHNOLOGY NEEDS

Our research work will continue to emphasize the presentation of sensor data to the operator through means other than by direct mechanical feedback techniques or by electronic force reflecting master arms. As robotics technology moves towards more autonomous operations and supervisory control, efforts must be directed towards removing the operator from the control loop. This will entail reducing operator reliance on sensory feedback to control tasks, and instead developing techniques for presenting large amount of data to operators as they supervise tasks.

Our future approach will build on our past accomplishments and focus on integration and display of force/torque and tactile sensor data into one user friendly format. This will consist of at least twenty four different measurements for two arms which will be updated continuously. Simultaneous presentation of these data in parallel with images from video cameras, and with data describing system health would push human visual perception beyond its limits. Voice input/output techniques will be employed to help overcome this problem. For example, voice input will be used to control camera pan and tilt motion, to access system health data and to request display screens. Voice output will be used for directing operator attention to critical items such as excessive force and torques at the manipulator arm wrist. Finally the capabilities developed will be used to perform laboratory testing to evaluate the different sensor display and control options.

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