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# Applications of Intelligent Telerobotic Control*

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**Abstract** - The telerobotics laboratory at Lawrence Livermore National Laboratory is a facility for developing and testing new concepts in robotics controls. Research and development is being conducted in computer vision; adaptive control; software architectures for real-time, intelligent control; artificial neural networks; fuzzy logic controllers; telepresence; and path planning and collision avoidance.

The equipment in the telerobotics laboratory includes a six degree of freedom articulating robot arm with controller, gripper, and force and torque sensor; a 3D CAD workstation with software to model the work cell environment and simulate the robot dynamics; a six degree of freedom forceball for operator input to the telerobotics controller and the robot simulation; and a computer with a real-time operating system. Soon to be added are a 3D viewing system and a force reflecting hand controller.

This paper describes one of the research and development efforts currently in progress on this program.

## INTRODUCTION

The U. S. Department of Energy (DOE) is facing many challenging problems in its attempt to reduce the potential hazards to human beings and the environment in the handling of radioactive materials and the cleanup of radioactive waste. Robotics will play a major role in this effort. Lawrence Livermore National Laboratory (LLNL), which is managed by the University of California for the US DOE, has the lead role in DOE for the robotic effort in waste minimization.

One of the difficult problems to be solved is that of sorting hazardous waste. Currently this task is done by human operators using either mechanical remote manipulators or by reaching into a glove box using lead-lined gloves. Both of these methods require trained operators and are time consuming, and the latter exposes the operator to some level of radiation.

Robots currently using machine vision depend on recognizing parts from a known collection of possible shapes. In the application we are addressing, there is a collection of objects of random shapes and sizes which must be sorted into one of three categories: (1)

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metals, (2) flammable materials and (3) non-metallic, non-flammable materials. Collections of these materials have resulted from burying low-level radioactive waste from facilities processing radioactive material. The waste includes items such as operator's protective clothing, e.g. lab coats, gloves and booties; tools used in processing which have become obsolete; and cleanup materials, e.g. rags and paper towels. For decades, these items were simply buried in large containers. Many of these containers have begun to leak, and low level radioactive waste is seeping into the earth, approaching ground water supplies.

A major effort is being planned to excavate this buried waste and sort it into the three categories specified. The flammable material will be incinerated in a furnace with filters which trap any radioactive material in the gases formed. The metals will be cleaned and recycled. The remaining material will be fused into a glasslike substance and re-buried in containers which should not leak any radiation and require further excavation in the future.

In the following section, we will describe the hardware configuration in the telerobotics facility at LLNL which has been established to perform the research and development required to achieve the objective required by DOE to meet challenges such as the one just described. Next, we will describe one approach we are taking to solve this mixed waste sorting problem and discuss how artificial intelligence will be incorporated. We will finish with our conclusions

## TELEROBTICS APPLICATIONS LABORATORY

A telerobotics applications laboratory has been implemented at LLNL to perform research and development in the control of robots for handling hazardous material [1]. Figure 1 shows conceptually the components of an intelligent telerobotic system. We envision a system with considerable artificial intelligence, i.e. a system able to perform most tasks in the intelligent remote controller without the use of the operator. When a situation arises that the intelligent remote controller cannot handle, a message will be sent to the operator who will be in a supervisory mode. The operator will intervene in the upset condition. There will be a force reflecting hand controller and a 3D vision system to give the operator telepresence. The operator will assess the upset condition using the intelligent local controller which has an expert system, then correct the situation and return the operation to the intelligent remote controller.

The teleoperational capability is being developed on a Puma-based system as shown in Figure 2. When operating in the telerobotic mode, the key objectives are to provide the operator with telepresence and a means of conveying desired manipulation commands to the robot arm, gripper and tools. The specific functions needed to achieve these objectives are to translate operator manipulation commands into robot arm, gripper and tool movement; to present the operator with a stereo view of the workcell to provide orientation, depth perception, and object size and spacing proportions which will facilitate teleoperational hand-eye coordination; to assist the operator in manipulating the robot so that it does not collide with objects in the workcell; to supervise the transitions between autonomous and telerobotic modes of operation; and to model the workcell and simulate the robot dynamics to aid in tool design and off-line tool path planning and programming.

The telerobotic development system shown schematically in Figure 3 consists of the following elements: a Puma 562 six DOF robot ; the VAL II robot controller; a Sun workstation host running SunOS; a VME 68000 computer system running the VxWorks real-time operating system; a Silicon Graphics workstation running IGRIP, a CAD-based workcell modeling and robot dynamic simulation system; a MaxVideo20 module running

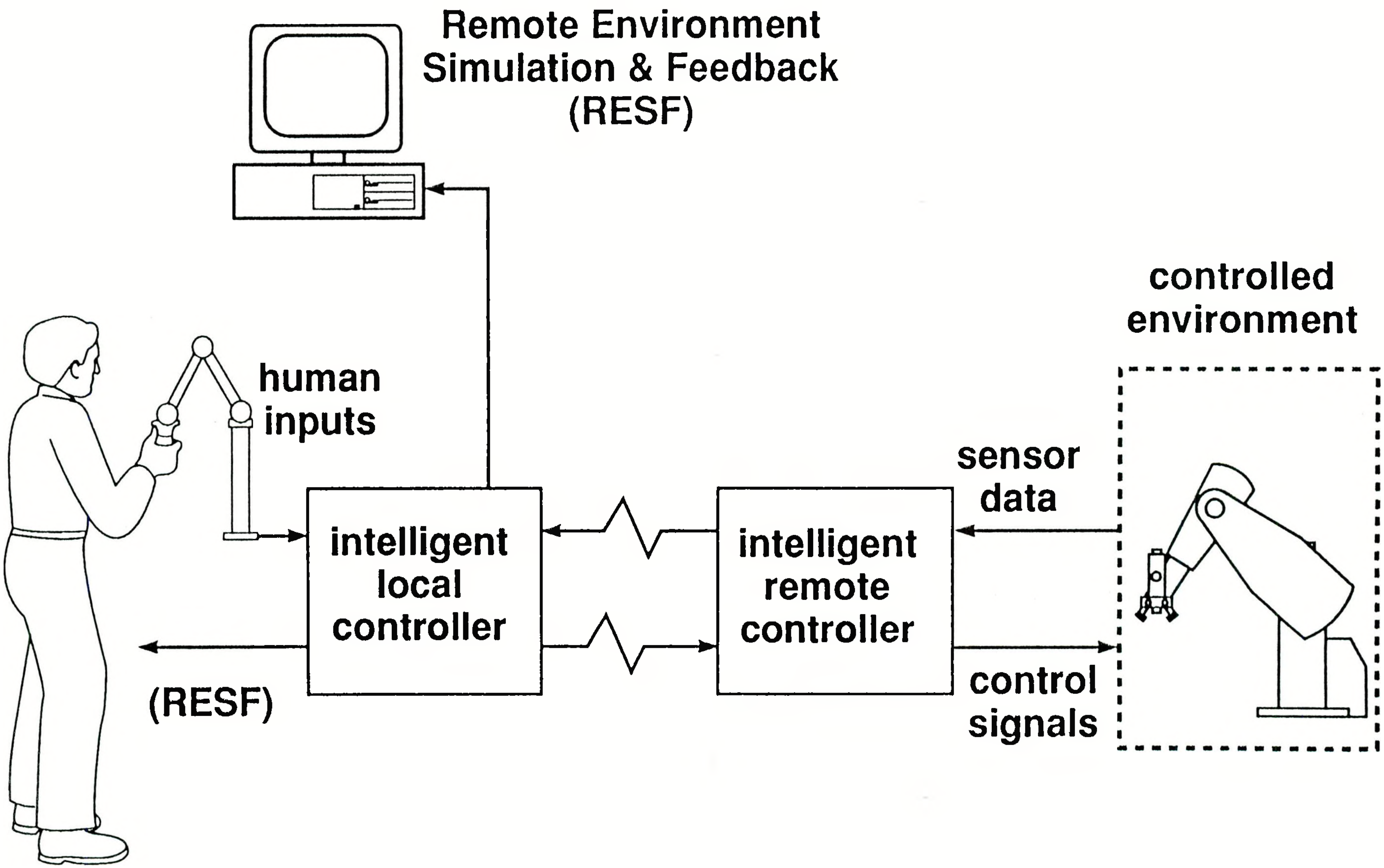


Fig. 1. Basic components of a teleautonomous system.

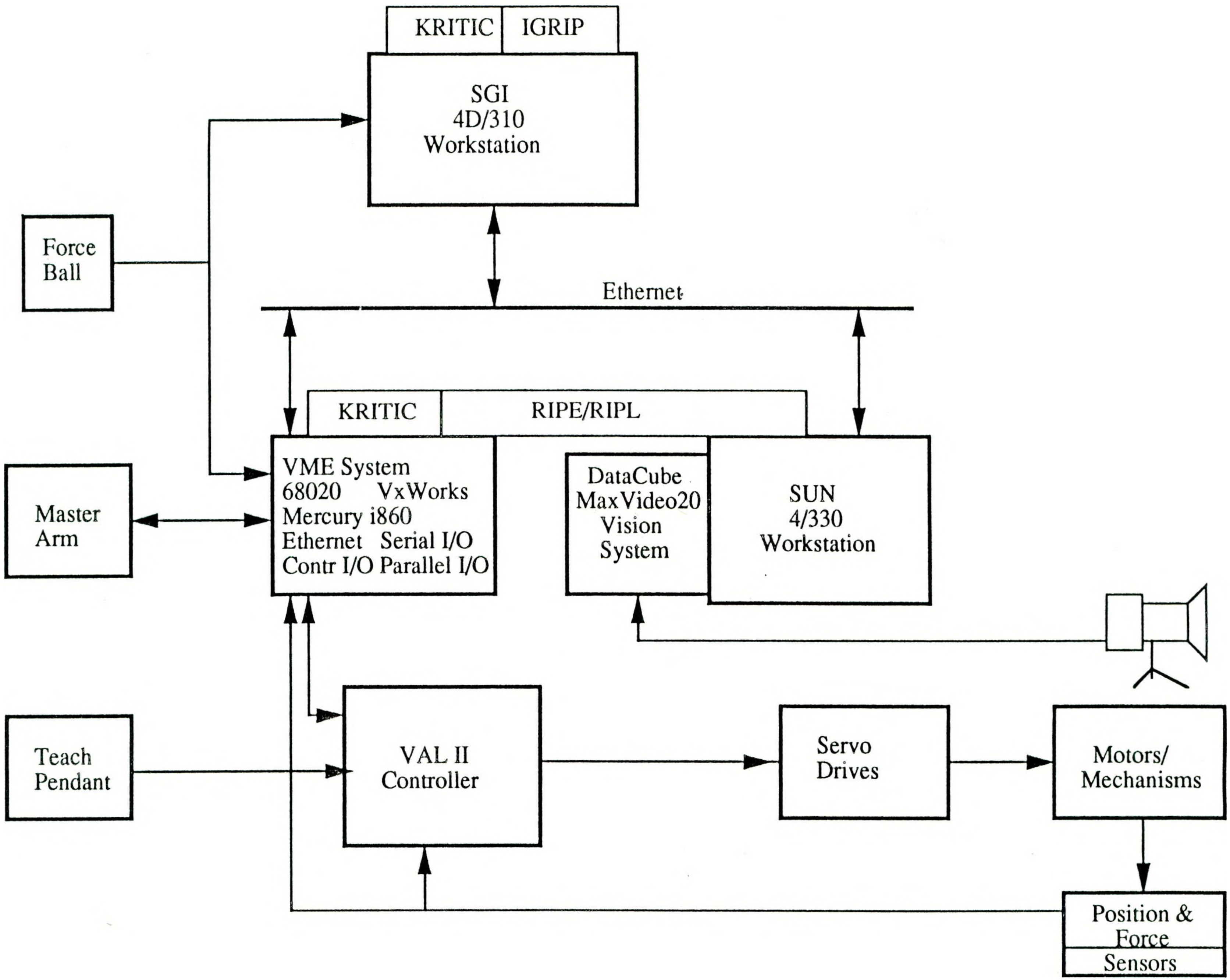


Fig. 2. Hardware configuration of Telerobotics Laboratory.

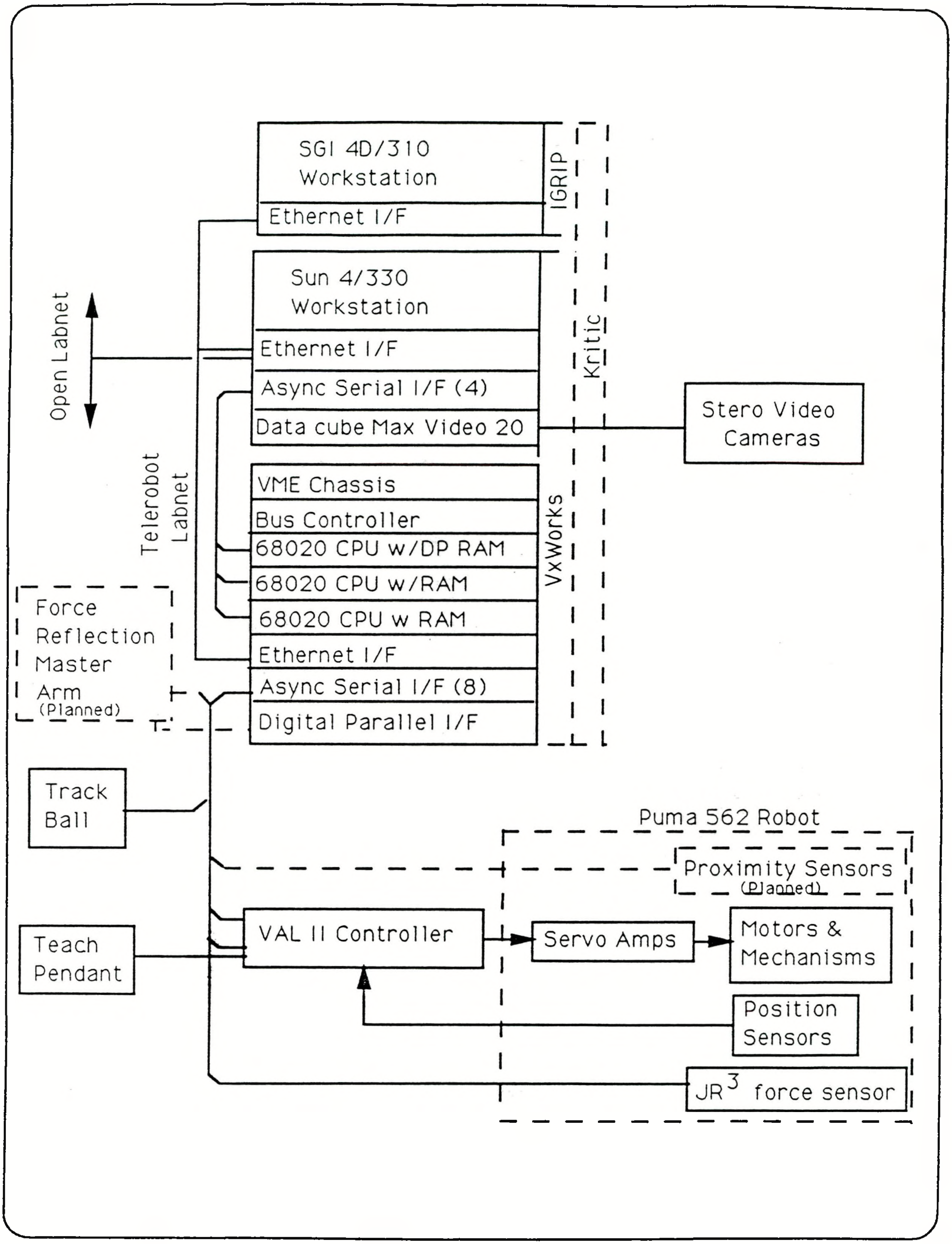


Fig. 3. Telerobotics application laboratory schematic.

ImageFlow which provides the machine vision interface with workcell stereo cameras; a Mercury i860 module to provide megaflop computational power; a JR3 force and torque sensor on the Puma wrist; the forceball and teach pendant operator input devices; and a Schilling force-reflection master arm operator input

The Sun, SGI and VME systems are networked together with ethernet. The VME system and VAL II, the robot controller, are linked together over an asynchronous serial line.

The telerobotic controller application software currently includes KRITIC, a collision avoidance program which imposes both trajectory and speed adjustments to the teleoperational commands to accommodate robot joint and singularity constraints, workcell constraints, and avoid proximity sensed workcell obstacles in the projected tool path, developed by Sandia National Laboratories Albuquerque [2]. As KRITIC does not have real-time workcell obstacle avoidance, it is planned to incorporate the Lockheed TIGER subsystem which does possess this capability [3].

The telerobotics applications is being used as a facility for research and development in a number of areas including computer vision; adaptive control; software architectures for real-time, intelligent control; artificial neural networks; fuzzy logic controllers; telepresence; and path planning and collision avoidance.

The following section describes one of the research activities.

## WASTE SORTING

The telerobotics applications laboratory is being used for research and development on the hazardous waste sorting problem described in the introduction. One approach we are pursuing is outlined in the diagram in Figure 4. The collection of 3D objects is represented by the cube at the upper left of the figure. Two cameras, which are capable of panning and tilting, take two views of the workspace. The two views are captured by the imaging system. Tokens are extracted from each of the two views. Registration of the corresponding tokens is performed, and a 3D model of the workspace is created in a CAD format such as the Initial Graphics Exchange Specification (IGES). A priority of selection of objects is performed. A path is planned to the next object in priority. The robot arm is moved to the object and posed for the grasp. The object is grasped and sorted into one of the three specified categories. A path is planned to the receptacle into which the object is to be placed, and the move is executed.

Much research must be done before these tasks can be carried out. The creation of the 3D model from the two camera views is one of the most challenging problems, and a research effort using neural networks is just underway. The use of fuzzy logic has been proposed for the priority of selection algorithm. The use of neural networks has been proposed for the path planning task. The pose and grasp are proposed to incorporate both neural networks and fuzzy logic.

At this point, we are too early in our project to report on the successes of artificial intelligence. We have a laboratory with a real-time controller, we have a difficult problem to solve, and we are in the process of implementing tools using artificial intelligence.

## SUMMARY AND CONCLUSIONS

An approach for using an intelligent telerobotic system has been described for the sorting of hazardous waste material. A telerobotic system has been developed and is being used for research and development of new concepts in robotic controls. Artificial intelligence will play an important role in the applications of this intelligent telerobotic system. The success of various approaches will be reported as the project proceeds.

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