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NUCLEAR TELEROBOTICS AND DEXTROUS CONTROLLERS

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ABSTRACT: Two new fields of development at AEA Technology's Harwell Laboratory are described, covering telerobotics and hand controllers for the nuclear industry. The first development describes the production of a Nuclear Engineered Advanced Telerobot (NEATER) for applications in decommissioning and waste handling. It is a re-engineered industrial robot based on the Staubli-Unimation PUMA 762 clean room manipulator. The second development described concerns dextrous hand controllers which can be used to control the motion of a telerobotic manipulator end effector as it moves in space and contacts surfaces and workpieces. Several input devices have been investigated for characteristics such as user-friendliness, compactness and cost effectiveness. Servo control of bilateral systems has been examined to optimize end point bilateral control.

1. INTRODUCTION

The nuclear industry relies on a variety of systems for remote handling that has changed little over the years. In comparison, automation has dramatically improved efficiency in conventional industries, and the industrial robot has allowed a flexible approach to be taken to assembly operations. There are similar pressures to apply more advanced remote handling techniques in the nuclear industry, but uncertainty in task definitions and their precise description makes fixed automation difficult to apply, except in regular near-production plants such as re-processing or waste processing. Even in these applications, non-repetitive tasks occur, and the skill of human operators to adapting the use of manipulators to many different constraints is an important feature of the operational life of the facility. If the processes involved in nuclear facilities had no radiation hazard, industrial robots would feature in the tasks carried out. The corollary is that if a radiation-tolerant robot existed, it would be immeediately useful to the industry. The uncertainty associated with some tasks would still need the human intervention and interruption of robotic operation, and so for effective application of industrial robotics to nuclear plant to occur, operators must be able to augment the functionality of the robot controller, providing man-in the loop or telerobotic control. This paper describes how two developments at AEA Technology's Harwell Laboatory have provided solutions to the problems that had prevented the application of industrial robotics to nuclear plant processes. Working with an established robot manufacturer, a radiation-tolerant version of a commercially available industrial robot has been produced, that is easy to maintain and decontaminate, and is tolerant to high levels of radiation (10^6Gy). Telerobotic control of the robot is accomplished by using a microprocessor based input controller which conditions commands from joysticks or other input devices such as force balls. The input devices are usually configured for control of the tool or end effector, and the input controller takes care of the kinematic transformation of the appropriate co-ordinate system used by the robot controller.

The Nuclear Engineered Advanced Telerobot (NEATER) and the appropriate choice of input devices working through the input controller provide the necessary means of widespread application of industrial robot practice throughout the nuclear industry.

2. APPLICATION AREAS

The majority of remote handling operations in nuclear plant are carried out by master-slave manipulators, power manipulators, cranes and special purpose machines. In general, except for low radiation environments, robots are not used because radiation soon damages sensors, cabling and any electronics. Many tasks would now be carried out using industrial robots if the radiation hazard was removed, and the corollary is that a radiation-tolerant robot would be immediately useful to the industry. Uncertainty in tasks and their precise description and the complexity of non-repetitive operations are other factors that preclude strict robotic operation of manipulators, and make some reliance on the skills of human operators essential. Telerobotic control is therefore required. Our approach has been to make as much use as possible of the industrial robotic controller, but condition operator commands for tool deployment before they are sent to the standard robot controller. This provides a more robust system design because the development effort already incorporated in the robot controller is made available to the overall product, and is not lost to the customer. The resulting system produces an easy-to-use interface for the operator, and supports either pure robotic operations or hybrid telerobotic/robotic operations.

The mainstream applications for NEATER are thought to lie in the areas of decommissioning and waste management. However, because of the flexibility of application of the machine, it is envisaged that it may be also applied to:

- fuel fabrication (including Mox fuels)
- filter changing
- waste drum handling
- inspection, monitoring and assay
- swabbing at any contamination level
- posting and bagging operations
- decontamination
- routine manipulation and tool deployment
- decommissioning (from gloveboxes to reactors)

3. FUNCTIONAL REQUIREMENTS

The design was envisaged as a two-stage process. Initially the robot design would be re-worked with the robot manufacturer Staubli-Unimation to produce a machine that was easy to service, had high reliability with the attendant long service intervals, use as many industrially sourced components as possible, and potentially was of low cost. The design of the PUMA 762 clean room robot, and the good surface finish of this machine, meant that it would be potentially easy to decontaminate. The production of a prototype machine would allow many radiation-tolerant components to be included and tested for their compatibility of operation. Longer lead time developments would be added on to the prototype machine in the second stage to bring its anticipated radiation-tolerance to beyond 10^4Gy. Radiation testing of components and sub-systems has been carried out at Harwell and the results have been fed back into the design and manufacturing process.

A maintenance review of the machine was carried out to establish a procedure for dealing with failures of a contaminated machine. The review identified the benefit of having a removeable forearm (equivalent to a detachable wrist in a conventional master-slave manipulator). A weight reduction of 100 kg was also possible, which would ease the burden on in-cell handling equiment, by simply making the base in two pieces which could be remotely mated in-cell, if a plinth was not available. Split-ring seals were added at major joints to increase the sealing efficiency and allow the use of a free-running pressurised decontamination wash down, prior to maintenance.

Basic performance parameters of the machine are unchanged. It has the same load capacity as the 762 PUMA and the same reach. However it was realised that variants were required to cover the vast range of potential nuclear environments. The machine can be configured to suit three main combinations of activity and contamination.

1) A basic radiation tolerant version of the clean room PUMA without modularity or improved sealing, for high radiation, low contamination applications (for example in waste drum handling or swabbing) - designated PUMA 762N (N for nuclear).

2) A modular version, with improved seals but not highly radiation-tolerant, for applications where decontamination is necessary but radiation levels are low (for example in replacement or assistance to pressurised-suit operations) - designated PUMA 762M (M for modular).

3) A radiation-tolerant decontaminable version, which can be used in the most extreme environments, with modularity to help maintenance-designated PUMA 762NM (nuclear and modular).

The prototype NEATER at Harwell began as Version 2, with modularity, improved seals and some radiation-tolerant components. It is now being brought to a target tolerance of 10^6Gy, (Version 3) by the addition of specially re-designed radiation-tolerant encoders, and has already been exercised for over 1000 hours without failure. Fig 1 shows NEATER in the Robotics Demonstration Facility at Harwell engaged in non-active trials of telerobotic glovebox size reduction.

4. SPECIFICATION OF PRODUCTION NEATERS

As mentioned, the 20 kg capacity of the 762 PUMA is available in the NEATER design at a top speed of 0.4 ms^{-1}. At 1 ms^{-1} this is reduced to 12 kg. An increased reach version, the 761 PUMA, is also available in all three nuclear environment versions.

The final specification for the most advanced model, the 762NM is summarised as:

Load Capacity:	20 kg at a reach of 1.4m
Maximum Velocity:	0.4ms^{-1} (20 kg) or 1.0ms^{-1} (12 kg)

Repeatability (robotic operation):	± 0.2 mm
Operational Temperature:	10-50°C
Radiation Tolerance:	10^6Gy (100Mrad) integrated dose anticipated before major overhaul - based on sub-system and component test irradiations.
Contamination Protection:	double seals on all axes and covers including grease packed labyrinth seals on axes 1-4 and wrist gaiter on axes 5 and 6
Modularity:	splittable at elbow (joint 3) and at base
Maintainability:	all bolts, fixings and electrical inter-connects designed for remote assembly/disassembly
Weight:	whole robot: 568 kg forearm only: 66 kg base stand: 112 kg

5. MASTER COMMAND INPUT DEVICE(S)

Command input devices for teleoperations fall into two distinct categories. The majority of the designs are based on a master arm which is kinematically either a replica or a scaled replica of the slave manipulator. The other kind of input device, sometimes called a general purpose hand controller, is geometrically dissimilar to the slave arm. Operator preferences seem to vary from one industry to another. For example, operators in the nuclear industry have higherto preferred to use a kinematically similar master arm to control a slave manipulator, perhaps influenced by their experience of handling mechanical master-slave manipulators. By contrast D Yeorger (2) for example, notes that operators in the offshore industry have a great dislike of anthropomorphic master arm type input devices with large coverage volume, as these tend to cause fatigue in prolonged operations.

At Harwell Laboratory, we decided to investigate both options, initially for use with Harwell's Hydraulic Manipulator and more recently for the upgraded PUMA 760N - NEATER Robot. The independent hydraulic slave manipulator, which is derived from an earlier hydro-mechanical master-slave system has a payload capacity of 35 kg in its entire workspace and a direct vertical life of 350 kg, Fig 2. The proposed kinematic arrangement of the master arm is shown in Fig 3. Force reflecting characteristics are added along each degree of freedom to enhance the overall teleoperator performance. Different kinds of drive arrangements and control system implementations have been analysed by both simulation studies and experimental evaluations, initially for a single axis system (3). Results have shown that stable bilateral performance can be established using electric force feedback actuators within the master arm. Fig 4 shows typical simulated time responses of the system using a position-to-position servo system. It can be seen that backdriveability is provided to the hydraulic servo drive by the use of an inner pressure feedback loop. The experimentl results shown in Fig 5 also indicate the achievaqble bilateral coupling stiffness between the master and the slave joints using the simpler position-to-position bilateral control scheme.

In order to add teleoperation capabilities to the NEATER Robot, it was decided to initiate a new development project to investigate the feasibility and ramifications of a general purpose hand controller for bilateral control(4). By general purpose, it is meant that the input command device shall be capable of co-ordinating and controlling the remote manipulator's end effector as the operator desires; for example, in a tool co-ordinate frame, world co-ordinate frame, inclined planes etc. Since the kinematics and dynamics are dissimilar between the hand controller and the manipulator, the implementation of the unilateral and bilateral control system essentially requires the computer to deal with these disparities - joint travel limits, singularities etc.

The first phase of the project is involved in the development of a user-friendly input device mechanism. Characteristics such as compactness, cost effectiveness etc, are of significant importance to widen the scope of its use and thus improve performance. The use of two 3 degrees of freedom joysticks, CAE's 6-axis joystick and DFVLR's 6-axis force/torque ball demonstrated that unilateral end point control of the NEATER Robot (4) could be achieved cost effectively. However, some tasks require the end-point force/torque information to be communicated back to the operator for successful completion of these tasks.

In order to add force reflection to a 6-axis joystick, it is necessary that the joystick is displaceable over a reasonable range of movement. This has led to the development of a 6-axis displaceable joystick based on the parallel link kinematics of the Stewart platform, Fig 6. The mechanism design is compact and easy to service and maintain. It has the potential to be a cheap and versatile input device for teleoperations, and in its basic form, can be used as a compound joystick.

6. CONCLUSIONS

The development programme has lasted two years and has resulted in a commercially available telerobot which can be easily used in a variety of nuclear applications. The short development timescale was possible because of the co-operation of an established robot manufacturer, and the ability to test, specify and re-engineer radiation-tolerant components at Harwell. The use of the prototype machine in active trials is anticipated within AEA Technology's Decommissioning and Radwaste programme, following the conclusion of inactive proving trials.

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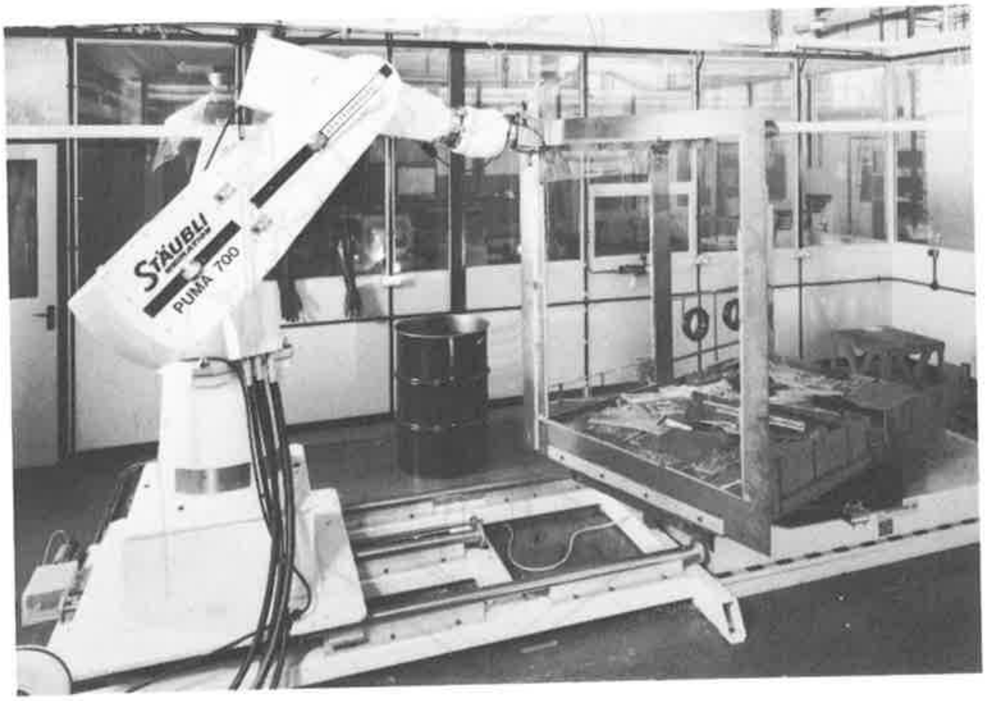
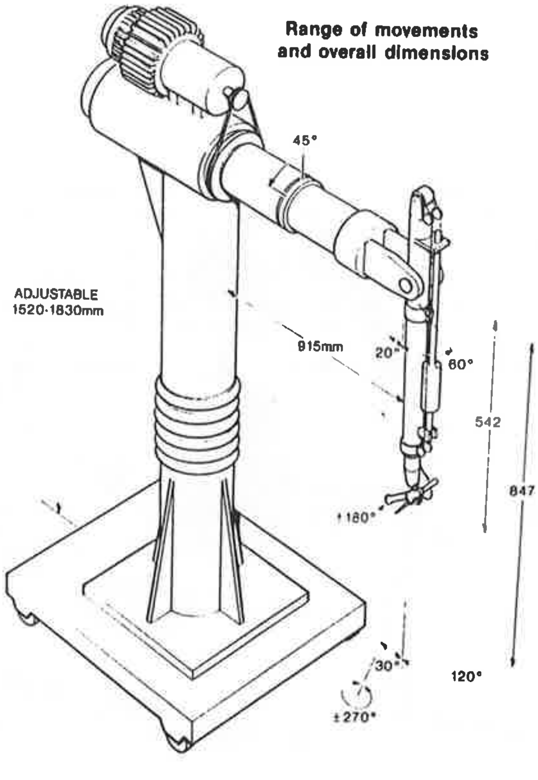


FIGURE 1 - NEATER being used to continue non-active trials of telerobotic size reduction of gloveboxes



Range of movements
and overall dimensions
45°
ADJUSTABLE
1520-1830mm
915mm
20°
60°
542
847
±180°
30°
120°
±270°

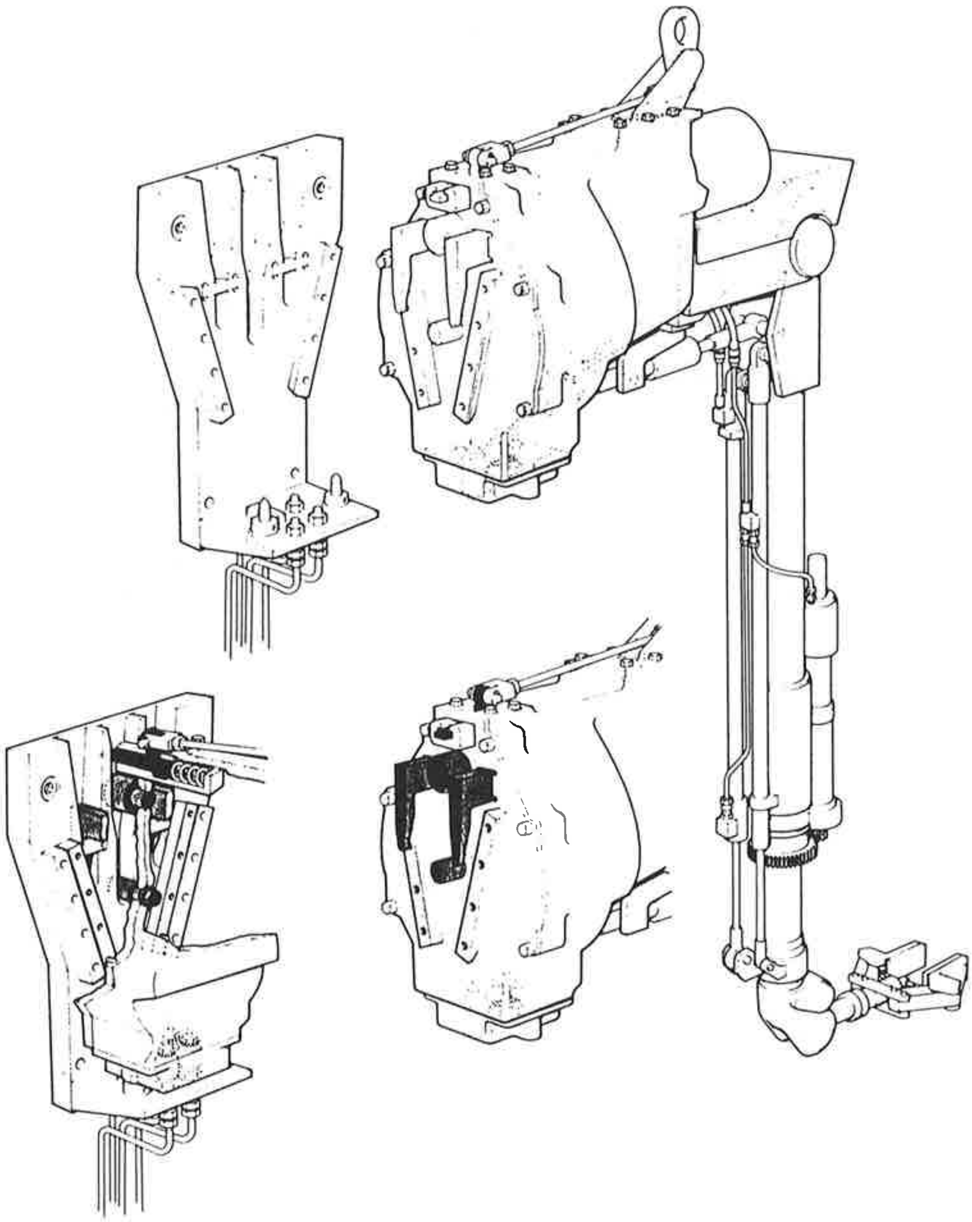


FIGURE 2 - The Harwell Hydraulic Manipulator

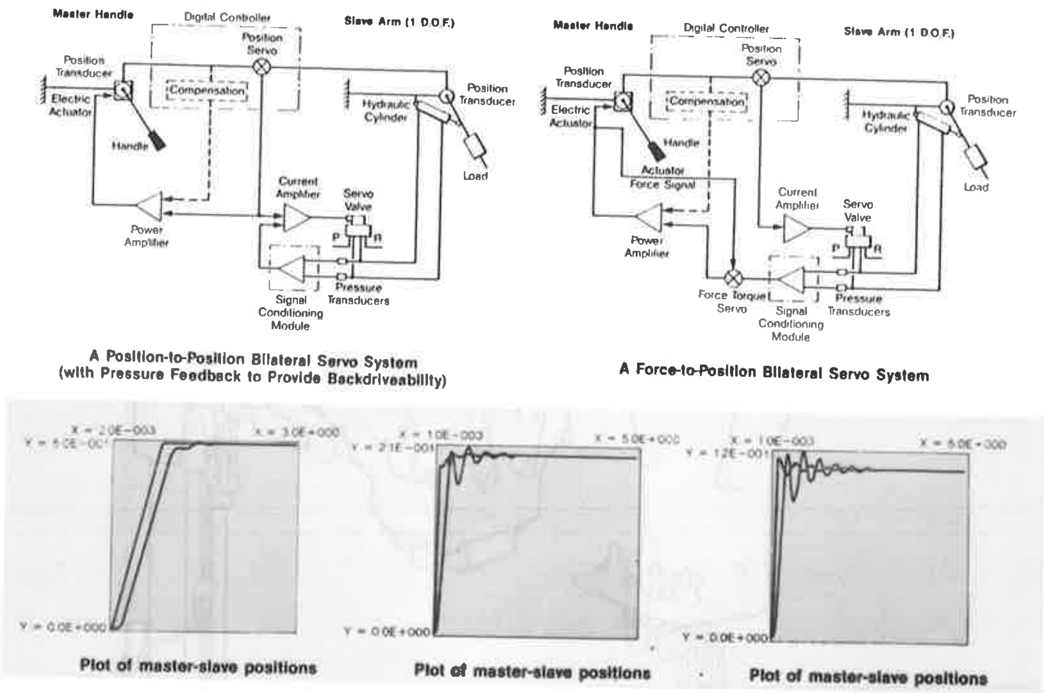


FIGURE 4 - Simulation of the Bilateral Servo Systems

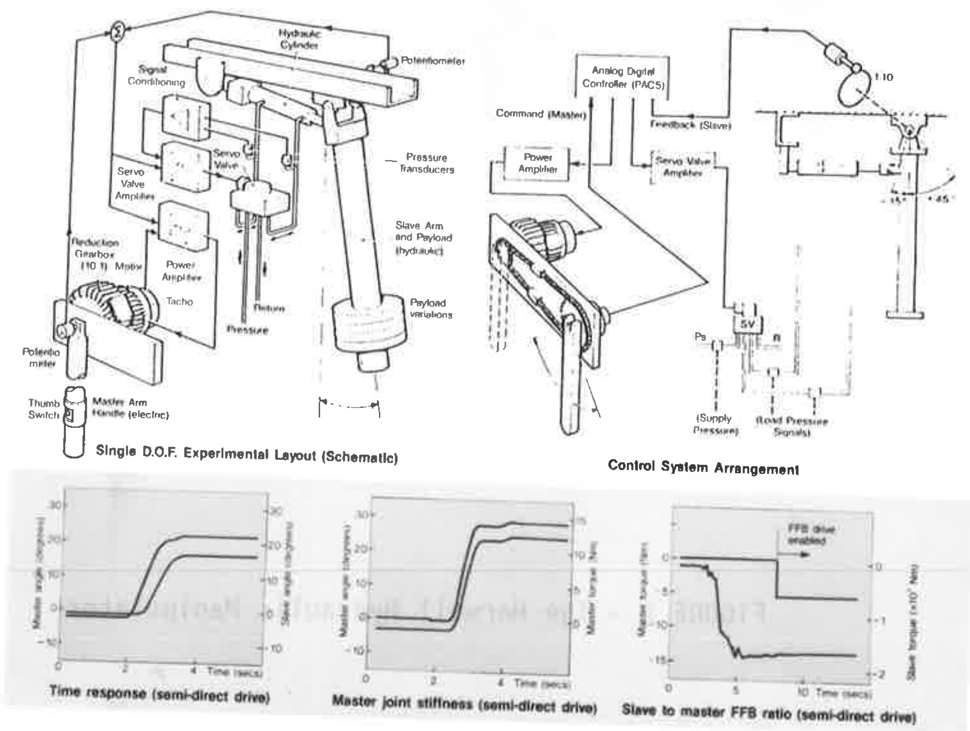


FIGURE 5 - The Experimental Rig and Some of the Results

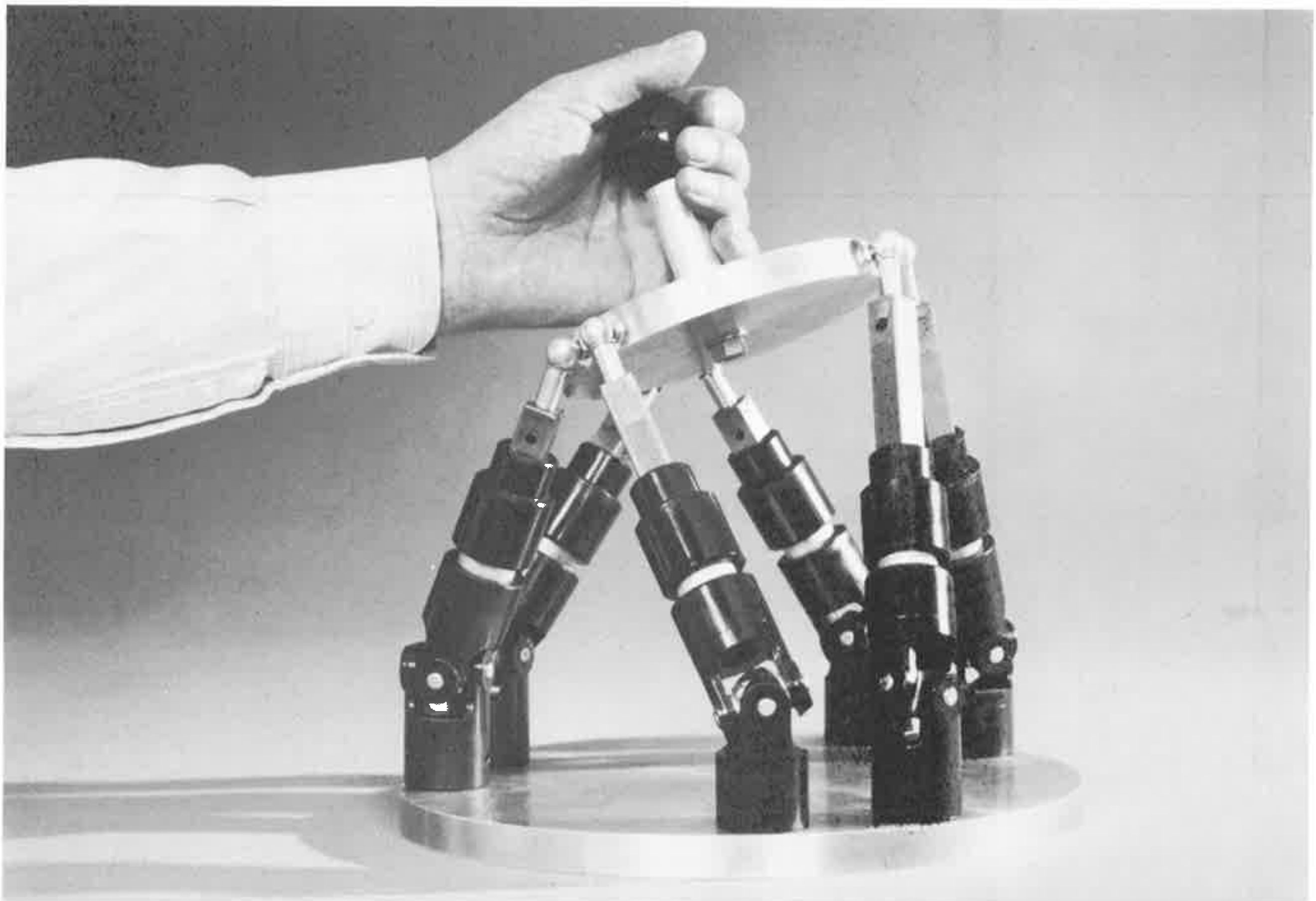


FIGURE 6 - A Hand Controller based on the Stewart Platform

Preliminary Program

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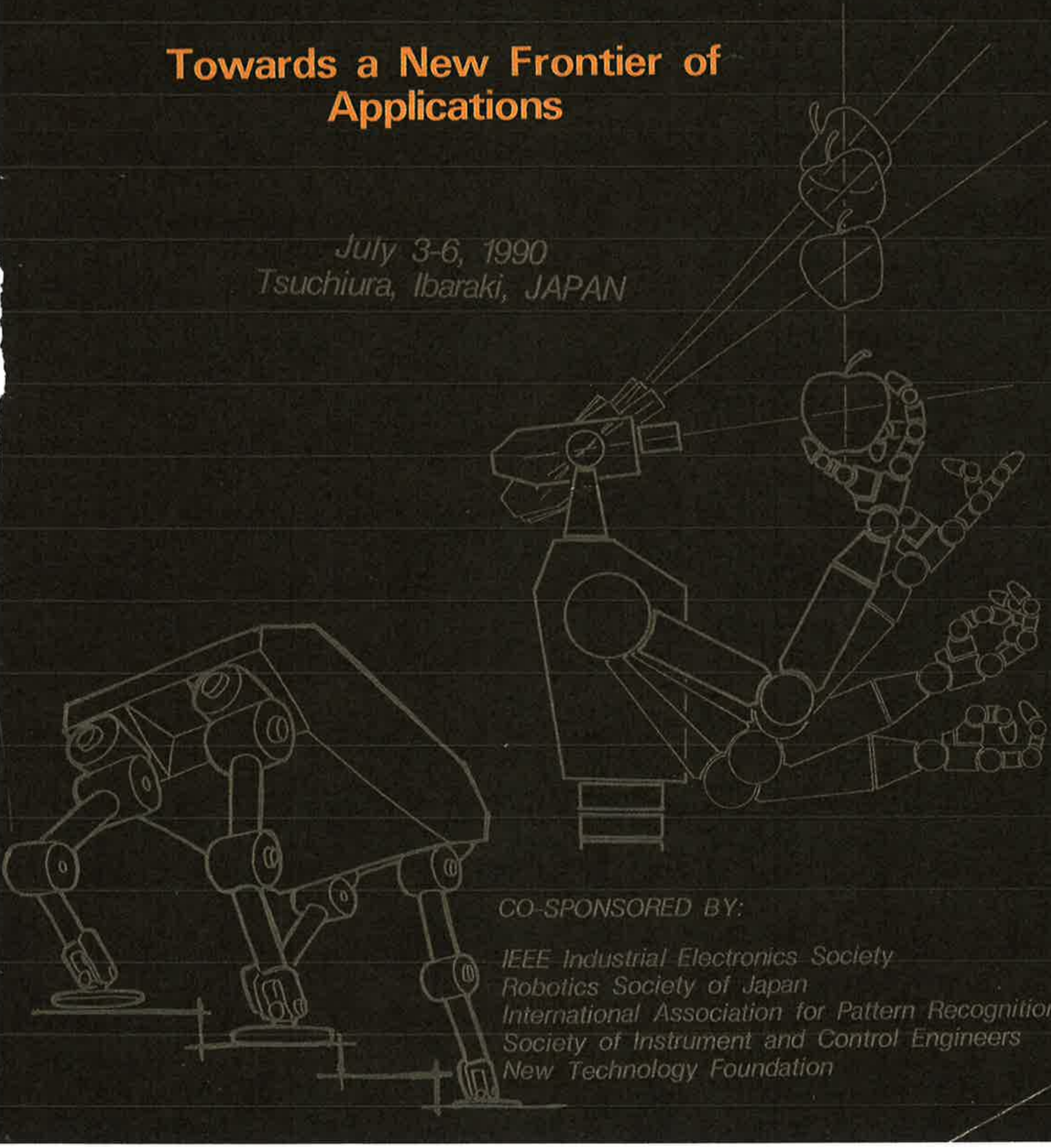

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