DEVELOPMENT OF A FLEXIBLE TEST-BED FOR ROBOTICS, TELEMANIPULATION AND SERVICING RESEARCH

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Abstract

This paper describes the development of a flexible operation test-bed, based around a commercially available ASEA industrial robot. The test-bed was designed to investigate fundamental human factors issues concerned with the unique problems of robotic manipulation in the hostile environment of Space.

1. Introduction

The work to be described here forms part of a contract placed on British Aerospace Space and Communications Division at Stevenage by the European Space Agency, entitled "Teleoperation and Control." The study to be performed will be carried out by a team under the technical lead of the British Aerospace Sowerby Research Centre Human Factors Department, Filton. The remainder of the study team comprises of the United Kingdom Atomic Energy Authority Laboratories at Culham and Harwell.

The overall objective of this study is the development and delivery to the European Space Agency of a flexible (modular) teleoperation test-bed, based around a commercially available ASEA industrial robot, which will permit the experimental investigation of a variety of approaches to the control and supervision of robotic manipulation in Space. Experiments were designed to allow a comparative study of the control and display concepts in order to optimise and evaluate the use of sensor supplied feedback information to a human operator.

The experiments were designed with two mission models as a baseline:

Mission Model 1. The human operator is located on the ground whilst controlling a manipulator which is located on a free-flying servicing vehicle.

Mission Model 2. A human operator is located on the aft deck of the shuttle, controlling a manipulator servicing a payload in the cargo area.

In addition to providing information about the above scenarios, the project will address five overall objectives:

- To analyse specific MMI/human factors issues concerned with the unique problems of teleoperation.

- To provide data which will permit the optimisation of the man-machine interface before delivery of the experimental workstation to ESA.

- To provide results which may be used to formulate future research programmes, to determine the Human Computer Interaction requirements which can be satisfied in the short and long term and to determine possible roles for telepresence strategies.

- To provide results which may be applied in identifying options for the design of future workstations.

- To establish a test-bed facility and research programme which demonstrate a sound European capability in teleoperation workstation design and in research into remote handling and inspection in Low Earth Orbit (LEO).

2. Overall Test-Bed Concept

The development and use of an experimental test-bed stems from the need to establish a programme of experimentation and research into teleoperation in Space. It is important that in achieving this aim the test-bed should remain as flexible as possible. This allows the test-bed to be used both for future research programmes and for the development and implementation of new systems.

The programme of test-bed development has been driven by past theoretical research (e.g. Milgram et al, 1983; Sheppard et al, 1986) and by developments in the fields of the ESA crew workstation (CWS) and EUROSIM projects.

To obtain and maintain the maximum degree of flexibility, the test-bed was developed along modular lines. The modules were defined as follows:

- Subject control and display station
- Experimenter's control and display station
- Video system
- Robot system (ASEA IRb6)
- End-effector and sensors
- Task box and work area. (See Figure 1)

The requirements for the test-bed, workstation and video system were dictated by the nature of the experiments and pilot studies to be carried out using them. The pilot studies and experiments were concerned with the following issues:

- Time delay selection (Pilot Study 1)
- Control law optimisation (Pilot Study 2)
- Controller selection (Experiment 1)
- Feedback optimisation (Pilot Study 3)
- Comparison of feedback options (Experiment 2)

Since the test-bed is an evaluative and experimental tool its design and requirements for its construction were preceded by detailed assessments of the evaluative studies to be performed upon it.

3. Definition of Research and Experimentation

The main objective of the teleoperation and control study is to perform an experimental and comparative evaluation of a variety of concepts regarding the human operator's efficient use of control and feedback options. Previous research studies have been predominantly theoretical in their approaches to key human factors aspects of teleoperation in Space. Therefore, it is appropriate to address these issues from a practical perspective. Both quantitative and qualitative data will be collected in order to provide as complete an evaluation and analysis as possible.

Experimental Designs

The specific designs of the experiments have determined the hardware and software requirements for these investigations. However, the need for flexibility and modularity was not overlooked in this process so as to allow easy implementation of future developments and additions. It is important that there is a logical progression from one experiment to the next. For this reason, a number of pilot or optimisation studies will be undertaken. These will help the experimenters select or optimise the characteristics of the independent variables which will be used in the main experimental designs. This series of investigations places emphasis on both sensory and motor variables. The series of designs does not deal with these two key areas in isolation, but instead the emphasis of the designs will change from one area to the other as the experiments progress.

At the end of this series of investigations, the main sensory and motor factors which influence remote teleoperation will have been considered. The results of these studies will be fed directly into the development of the flexible teleoperation facility for ESA.

The experimental designs are outlined below:

Pilot Study 1. To identify from existing literature and preliminary experimentation, three time delays for use in Experiments 1 and 2.

One of the major areas of concern in the field of Space teleoperation is the performance penalties which are incurred by the human operator controlling systems in the presence of a transmission time delay. Some research has been performed, but this relates specifically to tracking tasks in the presence of a time delay. In the present investigation, consideration will be given to both tracking and pick-and-place tasks.

Three time delays will be considered for use in the main experiments:

(a) Human perceptual threshold. Identified as 60 milliseconds in Sheppard et al (1986).

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(b) Human control disruption (i.e. a time delay which produces 'stop and go' motions).

(c) Time delay for LEO: maximum delay likely to be experienced in a Space teleoperation system.

This pilot study will attempt to establish a representative time delay which will produce a human control disruption. Therefore, the result of this pilot study will be the specification of a control time delay which would interfere with all operators' ability to perform the tasks.

The third time delay which will be used in Experiments 1 and 2 will be representative of the time delay which would be experienced when controlling a task in LEO from the ground. This time delay will be identified from literature concerned with satellite/ground station communication links.

Pilot Study 2. To specify and compare control laws for a variety of control devices with the overall aim of selecting the most suitable control law for each device and to optimise the law more finely on the basis of this selection.

Three different joysticks and configurations have been selected for this pilot study. These joysticks will be used in the joystick comparison and evaluation study (Experiment 1), but the control law for each individual device must be optimised before the main study can be undertaken. The joysticks for which the control laws are to be optimised are as follows:

(a) 2x3 axis joysticks. Translational movements of the robot end-effector will be controlled by a three-axis horizontally mounted, whole-hand joystick. Rotational movements of the end-effector (hence changing the orientation of the end-effector at the same point in Space) will be controlled using a three-axis, vertically mounted, whole-hand joystick.

(b) Single multifunction joystick. This joystick will be used to control both translational and rotational movements. Selection of either translational or rotational modes will be made via a switch mounted on the joystick itself. The joystick chosen for this evaluation is the same as the rotational controller used in the previous configuration (a).

(c) DFVLR hand controller. This device is a ball controller capable of controlling six independent degrees of freedom. The controller is a force-torque device with only a perceptibly small degree of motion in each axis.

With these two pilot studies completed, Experiment 1 can commence.

Experiment 1. To evaluate and compare a variety of control devices for the task of remote handling in the presence of time delays and to provide data for subsequent designs.

In addition to the three joystick configurations discussed in the previous pilot study, a 'replica' controller, kinematically similar to the ASEA robot, will also be considered. All the devices will be compared using the control laws established in Pilot Study 1 (position control for the replica and optimised fixed or proportional rates for the other devices) and the independent variable of time delay (as in Pilot Study 1). (See Figure 2)

Performance measures of whole and part-task time along with whole and part-task accuracy will be taken. In addition to this quantitative data, certain qualitative data such as general operator strategies and workstation interaction difficulties will also be recorded.

The outcome of this experiment will be the specification of a controller which produces the most efficient performance of benchmark operations in the presence of time delays. In the event of interaction effects between controllers and time delays, then the controller deemed, in general, to be the most satisfactory will be selected for use in later experimentation.

Pilot Study 3. The optimisation of remote cameras, display configurations and remote lighting.

The aim of this pilot study is to optimise the various chosen methods of sensory feedback, feedback being the presentation of both visual and auditory information, moreover, to optimise the presentation of this information.

Issues to be addressed include the levels of ambient lighting in the experimental environment and the positioning of artificial lighting to meet human visual requirements and task requirements as outlined in Stone et al (1985).

This pilot study, in conjunction with the lighting, will also consider the positioning of the remote cameras. This will also be carried out to meet both human visual requirements and the requirements demanded by the task.

This pilot study, in contrast to the previous pilot studies, will be of a predominantly qualitative nature, where subjects' comments will be used to determine the optimal location of both lighting and camera configurations.

Experiment 2. The evaluation and comparison of a number of sensory feedback options in terms of their effect on operator performance.

This experiment will incorporate all the results of the previous pilot experiment studies. At this stage the controller or controllers will have been selected and the sensory information will have been optimised. Therefore, the experiment will encompass all that has been learnt from previous research and experimentation and will involve a fully configured task box and test-bed.

The options to be examined in the experiment will be:

(a) Visual feedback only. Only the remote cameras and lighting will be used.

(b) Visual feedback with force-torque display. In addition to the remote cameras, the subject will be provided with a graphics display of the forces and torques being exerted at the end-effector.

(c) Visual feedback with a proximity display. In this condition the subject will be provided with remote camera views plus the view from a proximity camera mounted on the wrist of the robot. (See Figure 3)

These conditions will be carried out under the three time-delay conditions mentioned earlier and a further condition of obscured/unobscured view of the task box. The obscured view will be achieved by degrading the image of one or more of the remote cameras, thereby forcing the subject to use one camera view more than another.

As in the previous experiment, performance measures of whole and part-task timings and accuracy will be taken.

4. Overview of Requirements for the Flexible Teleoperation Facility

From the outset of the study, it was a major priority that the design of the flexible teleoperation facility should be driven by the design of the experimental investigations to be carried out on it. Secondly, the design of the facility should be flexible such that future extensions and developments could be effectively carried out by ESTEC. This flexibility should permit development of the test-bed to such a level that it can be used ultimately as a development or training simulator, and possibly even as a back-up system to an operational ground-based Robotics Telemanipulation and Servicing (RTS) workstation.

Test-bed Requirements for Human Factors Experimentation

Once the experiments were designed and the general requirements for the modular components of the test-bed were broadly defined, it was appropriate to define these more rigidly:

- The robot system chosen for the test-bed is the ASEA IRb6. This choice was made for the sake of convenience as the test-bed will ultimately be based at ESTEC where it will be used with an ASEA IRb60 already situated there. More importantly, the robot should be available with six degrees of freedom. This requirement was made to ensure that operators would develop strategies that would be representative of strategies used by operators using a fully dextrous six degrees of freedom manipulator in LEO. Control of the degrees of freedom must be available in both control of individual degrees of freedom and of control of all six degrees simultaneously.

- The subject's control and display station was designed following ergonomic principles and to allow quick and efficient interfacing of the various joystick configurations. The displays and controls for the remote camera systems were also mounted on this workstation, again following ergonomic principles.

- With regard to the video system, this was designed to provide both worksite/task feedback and subject surveillance. With regard to the former, the following criteria were adhered to in order to ensure the satisfaction of human factors issues raised in Sheppard et al (1986). The system shall:

(a) Provide detailed and close-up views of the end-effector/task box interface for inspection and fine control.

(b) Provide global worksite and manipulator views to enhance the operator's notion of the orientation of the remote equipment relative to the worksite.

(c) Permit the efficient change of the remote views by the operator, both in terms of display quality and content.

(d) Permit symbolic or graphical representations of remote sensory data to be optimally displayed to the human operator, in a way which does not conflict with his perception of the video imagery.

5. Summary

This paper has described the development of a flexible (modular) teleoperation testbed, based around a commercially available ASEA industrial robot. The intention of the study to be carried out on the test-bed is to investigate fundamental human factors issues concerned with the control and sensory feedback problems of a remotely operated robot.

This paper discussed the experiments and investigations to be carried out on the test-bed and the philosophy behind the development of the test-bed using the design of the experiments as the principal driver. The components of the test-bed are described in detail along with the need for modularisation in order to maintain the degree of flexibility required of the test-bed to ensure efficient and trouble-free development in the future.

Acknowledgements

References

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Sheppard, J. et al. "Teleoperation and Control Study: Final Report." BAe Space and Communications Division, Stevenage, Report TP8268 (May 1986).

Stone, R. et al. "AERE Contract H2C 547430 ES: Human Factors Evaluation of the MA-23M Servomanipulator." BAe Report No. JS10561 (March 1986).
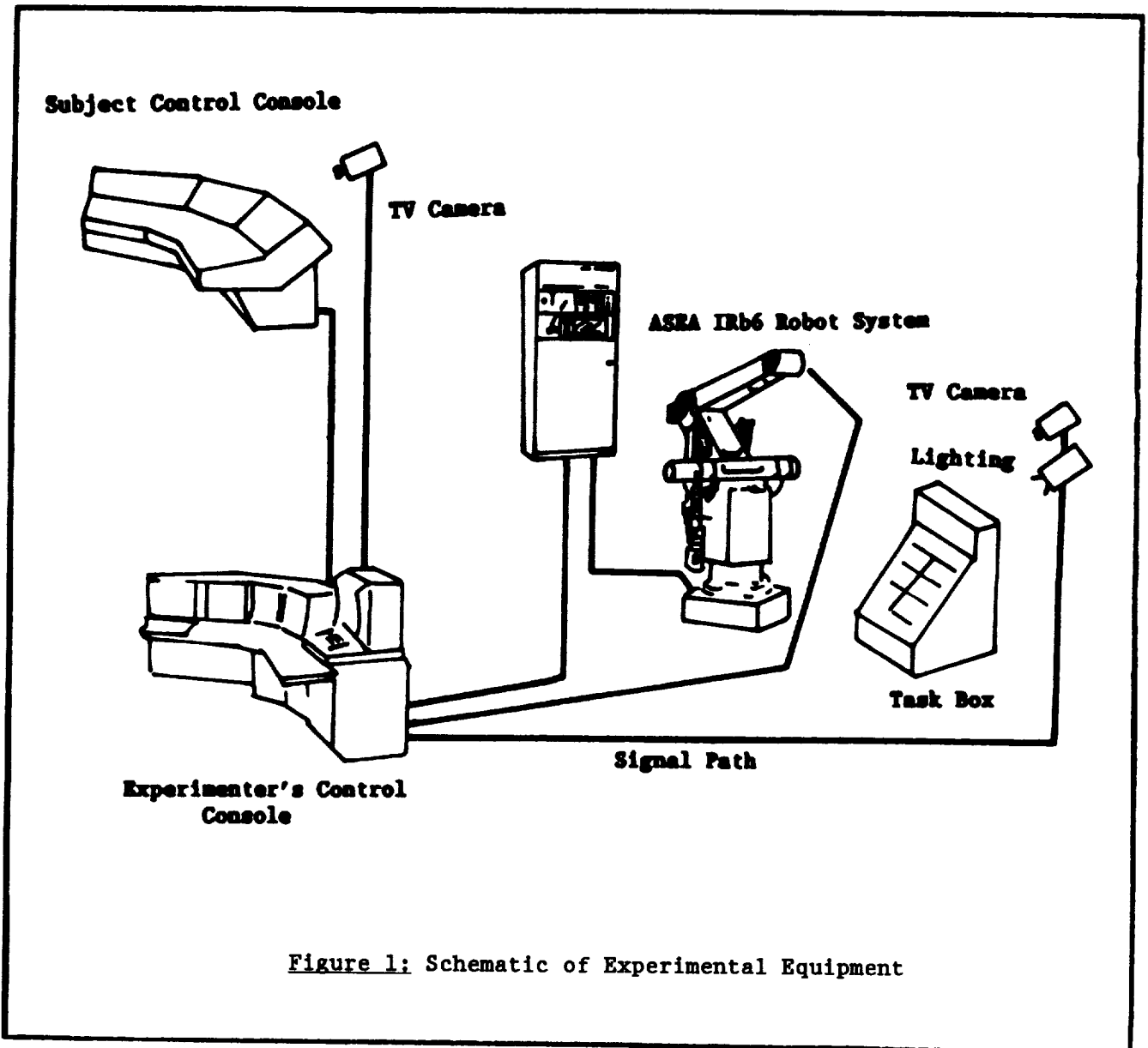
Subject Control Console

TV Camera

ASEA IRb6 Robot System

TV Camera

Lighting

Task Box

Experimenter's Control
Console

Signal Path

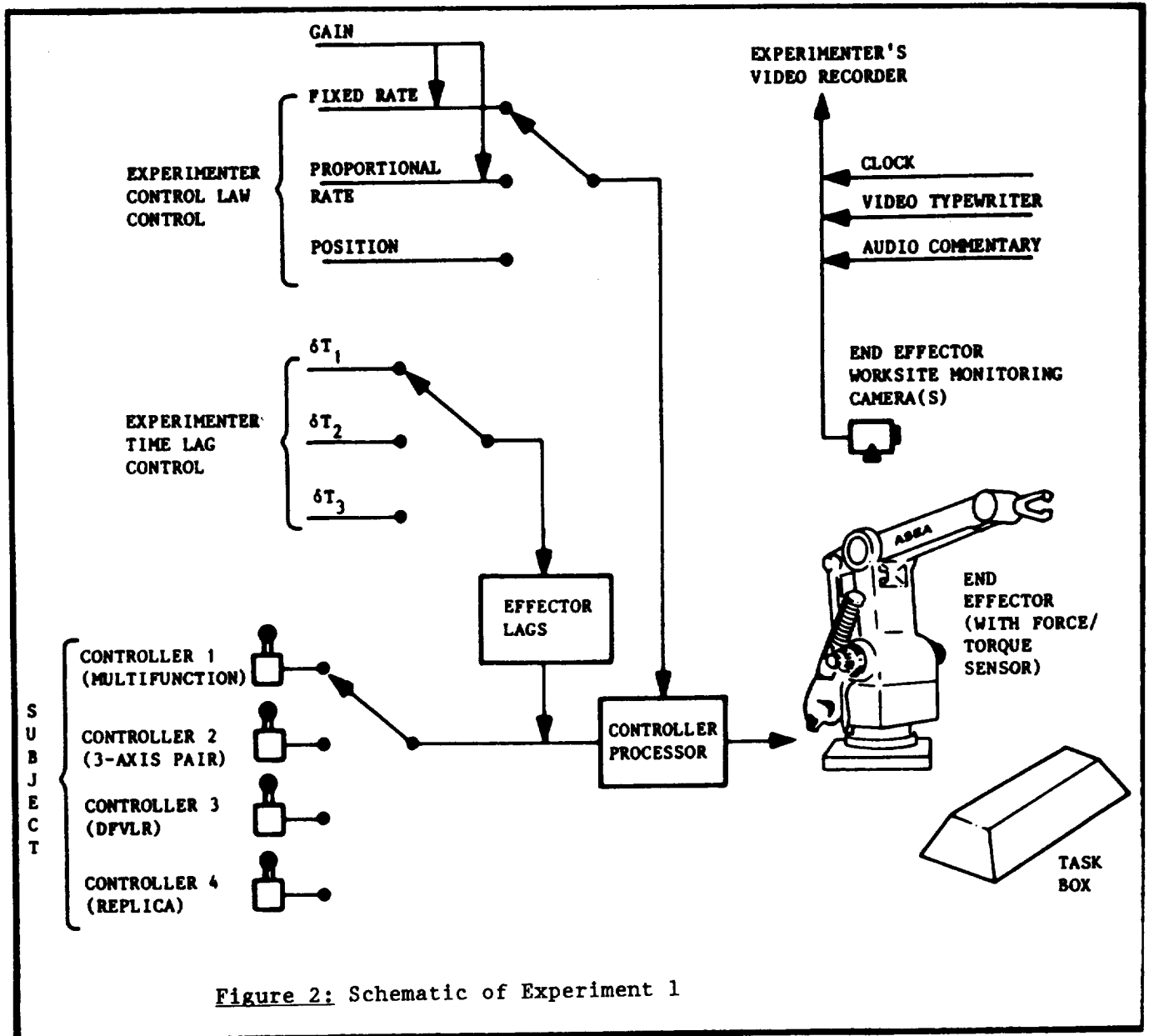Figure 1: Schematic of Experimental Equipment
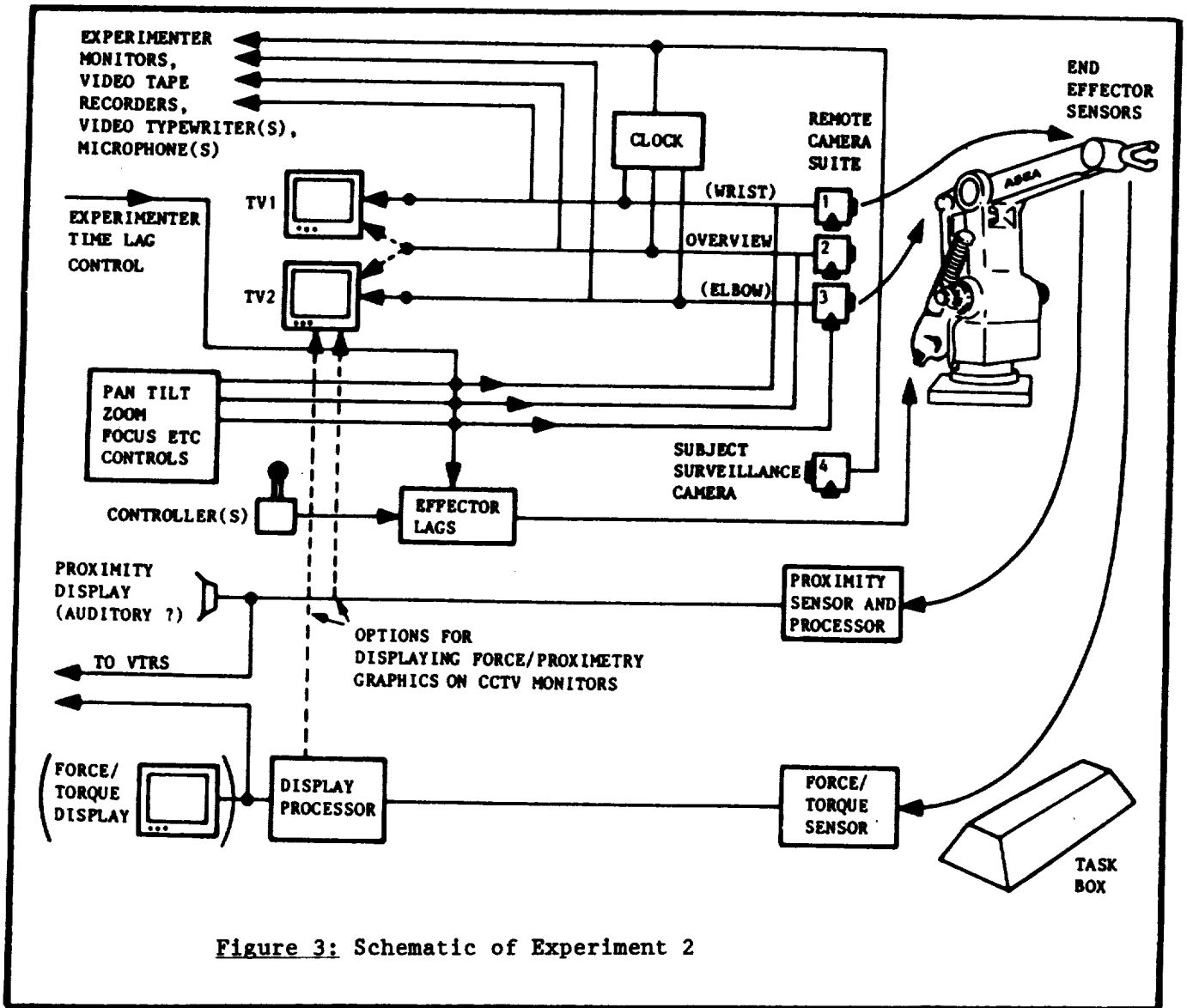
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Figure 2: Schematic of Experiment 1

Figure 3: Schematic of Experiment 2

TELEROBOT ARCHITECTURES