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ADVANCED TELEOPERATION IN NUCLEAR APPLICATIONS

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ABSTRACT

A new generation of integrated remote maintenance systems is being developed to meet the needs of future nuclear fuel reprocessing at the Oak Ridge National Laboratory. Development activities cover all aspects of an advanced teleoperated maintenance system with particular emphasis on a new force-reflecting servomanipulator concept. The new manipulator, called the advanced servomanipulator, is microprocessor controlled and is designed to achieve force-reflection performance near that of mechanical master/slave manipulators. The advanced servomanipulator uses a gear-drive transmission which permits modularization for remote maintainability (by other advanced servomanipulators) and increases reliability. Human factors analysis has been used to develop an improved man/machine interface concept based upon colorgraphic displays and menu-driven touch screens. Initial test and evaluation of two advanced servomanipulator slave arms and several other development components have begun.

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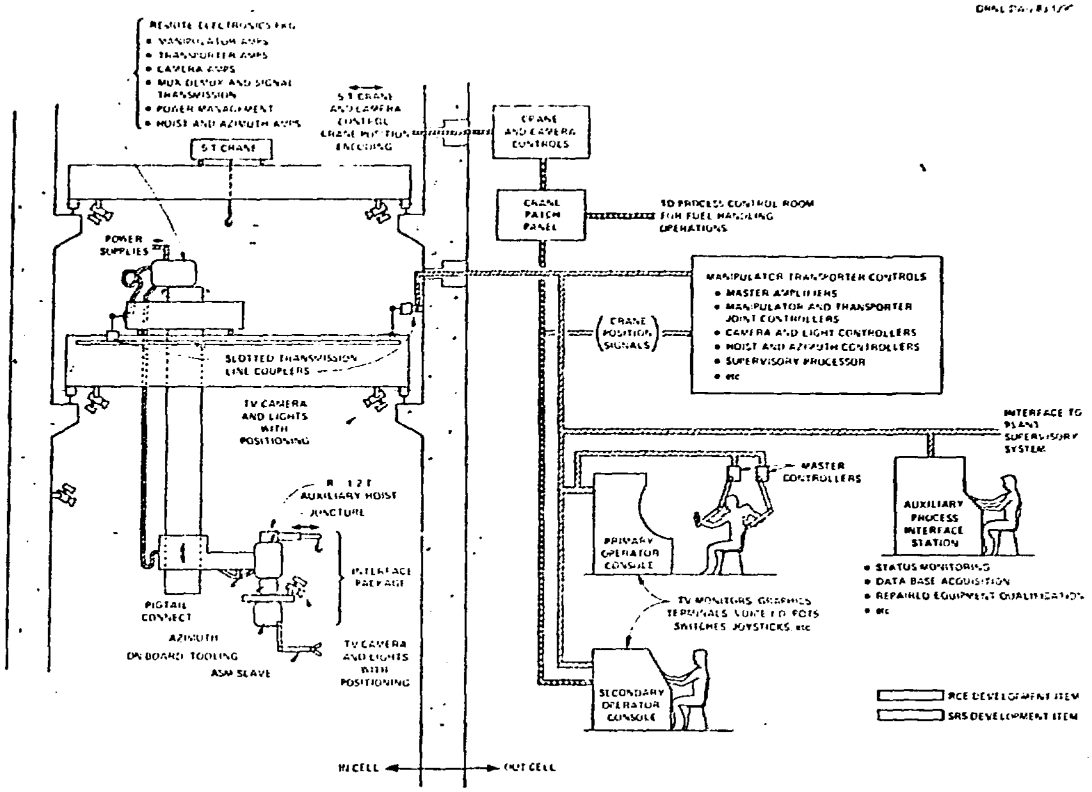
INTRODUCTION

In the Consolidated Fuel Reprocessing Program at the Oak Ridge National Laboratory (ORNL), a significant development program in the area of advanced telemanipulation for nuclear fuel reprocessing has existed for the past five years.[1] Development activities are applying modern technology to new concepts for remote manipulators, television viewing systems, and man/machine interface. The general objectives of this work are to increase the range of admissible work tasks to include delicate and complex tasks, and to improve the effective work efficiency of the overall remote handling system.

Remote operations have been used in various nuclear applications beginning forty years ago in the Manhattan Project. Very important progress has been made in all aspects of remote operations and maintenance from the design of remote equipment handling features through the development of force-reflecting mechanical master/slave manipulators.[2] Unfortunately, the earlier work stagnated after the initial development of the force-reflecting electronic servomanipulator in the 1960s, and until recently remote handling development activities have been limited. A new generation of remote handling systems is now under comprehensive development at ORNL to meet future challenges in advanced teleoperator-based maintenance of complex radioactive chemical and mechanical processing equipment.

DESCRIPTION OF AN ADVANCED TELEOPERATOR MAINTENANCE SYSTEM

A fully integrated advanced maintenance system, Fig. 1, is under development. It encompasses the transporter which provides mobility, an advanced innovative servomanipulator which perform dexterous work, a



MAINTENANCE SYSTEM SCHEMATIC

special manipulator master controller, an integrated operator control station, and the first time use of extensive active electronics in the high radiation environment.

The Advanced Servomanipulator

The Advanced Servomanipulator (ASM), shown in Fig. 2, is an entirely new force-reflecting electronic servomanipulator based upon a mechanical drive concept using gears and torque tubes rather than metal tendon (tapes) drives.[3] It is anticipated that the gear-driven ASM will be substantially more reliable than earlier designs; but most importantly, the ASM has been segmented into working modules which can be replaced remotely (by another ASM) for in situ repair. Consequently, the ASM represents the first known remotely maintainable servomanipulator. There are eight different types of modules each of which are within the manipulator's basic 23-kg capacity.

In more traditional elbows-up manipulator configuration, the elbows are above the lower-arm segment. However, another important innovation of the ASM is its anthropomorphic (human-like) stance, shown in Fig. 2, where the manipulator's normal elbow position is in alignment with the lower arm segment. This stance was selected because it reduces the obstruction that the manipulator lower arm creates for horizontal reaching and above the shoulder television camera viewing of the end-effector region. The manipulator's neutral position aligns the centerline of the lower arm link and the end-effector roll axis. It is critically important that end-effectors have an uncoupled roll motion so that pure rotations for threading, twisting, and other such common actions can be accomplished straightforwardly by the operator. To avoid

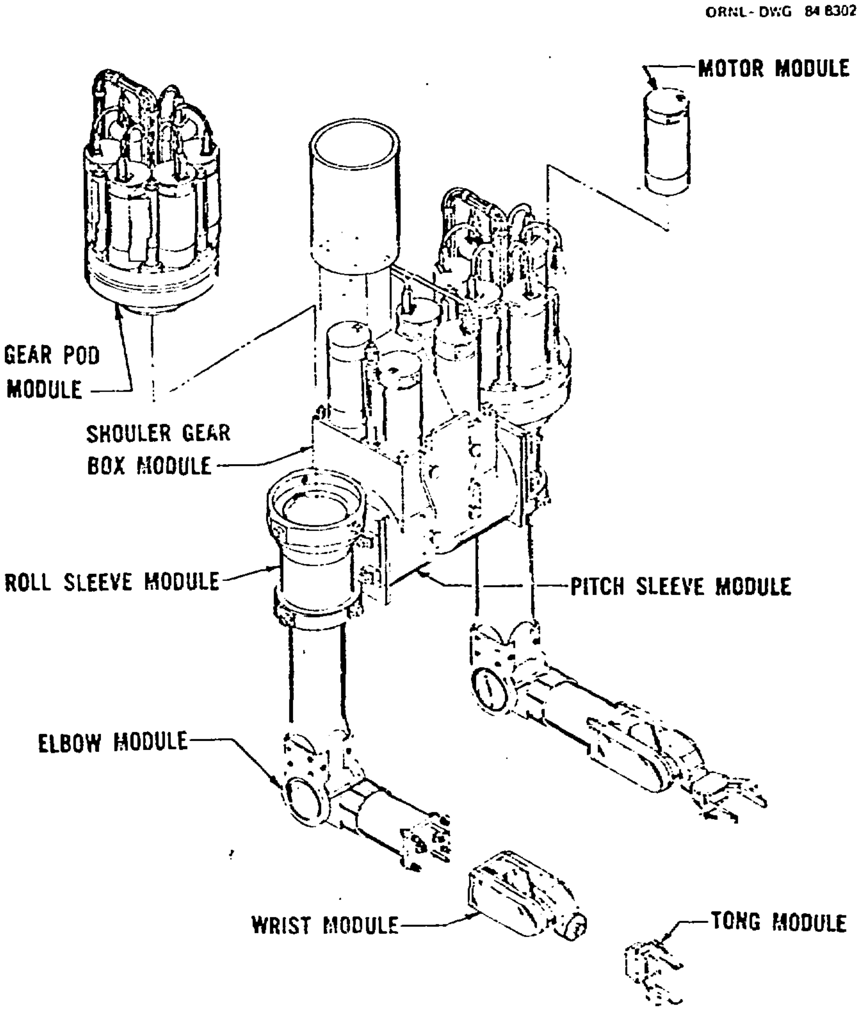


Fig. 2 The original
servomanipulator

the roll-roll singularity, it was not possible to use the lower arm axis for wrist roll orientation as is done in elbows-up designs. A unique four degrees-of-freedom wrist mechanism was developed for the ASM which provides intersecting orthogonal pitch, yaw, and roll axes.[3] The wrist is mechanically compact and backdriveable in all axes including the grip action. The design is kinematically ideal for teleoperation since all of its singularities are at the extremities of the ranges of motion.

Master Controller

The ASM gear drives facilitate manipulator modularization, but also increase inertia and friction. Increased inertia and friction degrade the quality of the force reflection (sense of feel), which has been shown to be critically important to complex teleoperation. To offset the deleterious effects of the ASM slave manipulator gear drives, a specially designed kinematic-replica master controller has been designed for ORNL by the Jet Propulsion Laboratory.[4] Since this device will not be located in the remote environment, it has been designed using a stranded-cable force transmission system to reduce overall system friction and inertia. Graphite composites and other weight minimization techniques are also being used. The design is shown in Fig. 3.

Controls and Electronics

To accomplish force reflection, the position servomechanisms of the slave and master manipulators must be integrated in a bilateral arrangement in one-to-one joint correspondence. And, to achieve dynamic operation compatible with normal human operation, mechanical natural frequencies should be near 10 Hz. Many advantages can be gained through digital implementation of the servomanipulator control system.[5]

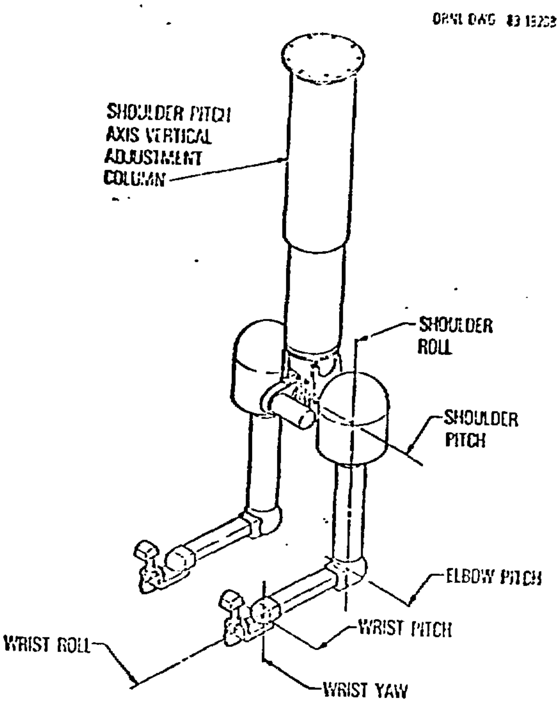


Fig. 3 Dual Arm Master Controller

ORNL-DWG 83-13453

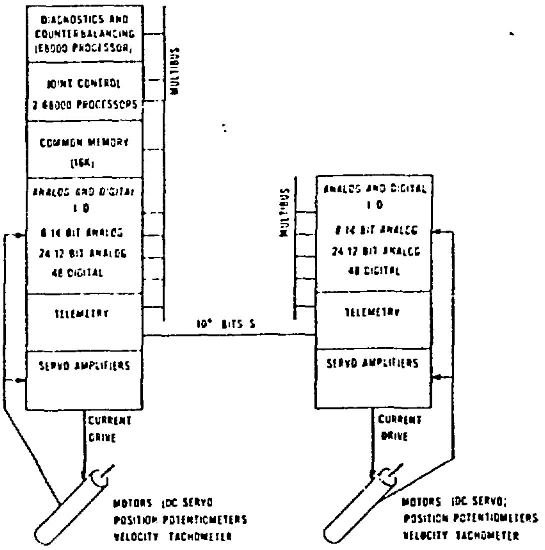


Fig. 7 Control
System Architecture

Improvements include reduced cable handling through serial multiplexing, higher gain servotuning possible through reduced noise, stable calibration because of reduced drift, on-line diagnostics, and "friendly" man/machine interface controls and displays.

The ASM control system utilizes a tightly coupled distributed processor network which is based upon the IEEE-796 Multibus backplane and the Motorola MC68000 16-bit microprocessor.[6] The architecture of the control system is shown in Fig. 4. Note that separate processors are used for servocontrol, electronic counterbalancing (to remove static weight of the slave manipulator arms from the operator), and system integration. These processors are actually single-board microcomputers which dialogue through a multiport common memory. The sampling frequency for the overall system is approximately 100 Hz. All software is done in the FORTH language, which was selected for its speed of execution, memory efficiency, and inherent dictionary structure. FORTH is a very effective real-time microcomputer language particularly well-suited for control applications.[7]

The ASM presents several significant challenges in control system performance. Various techniques to compensate for the increased inertia and friction of the gear-drive systems have been developed on a single-axis breadboard mockup and will be evaluated in the development units. To date, joint interaction effects have not been considered. As depicted in Fig. 2, the ASM does not incorporate mechanical static-weight counterbalancing but will use electronic counterbalancing for gravity compensation. A dedicated MC-68000 is used to calculate the real-time center of gravity locations of the manipulator links based on joint positions. These results are then transformed to a centralized motor drive reference frame where the required nulling torques can be added to each motor drive axis.

Operator Control Station

A considerable amount of effort has been devoted to the development of an effective operator control station design using human factors engineering and specific experimental results.[8,9] To distribute the workload, a two-operator team approach will be used, as shown in Fig. 5. This will allow the manipulator operator's entire attention to be devoted to intense manipulator tasks. The secondary operator will control peripheral functions including television camera selection, positioning, and lighting and transporter movement. The two operators will be equally qualified so that they can interchange work positions to reduce fatigue in longer work tasks. The operator station is electronically designed as a Multibus-node extension of the overall ASM network. The principal display medium will be colorgraphic video monitor screens which are menu-driven from either touch screens at the secondary console or cursor control switches on the ASM master controller handles. The control station is being designed to provide a maximum of adaptability for operator physical size and accommodation of control/display preferences (possible through software).

STATUS OF DEVELOPMENT ACTIVITIES

Two development units of the advanced servomanipulator have been completed and are in the initial stages of design testing. Design of the ASM master controller has been completed, and fabrication of two development units will be completed early in 1985. The entire system will be assembled and under test next year.

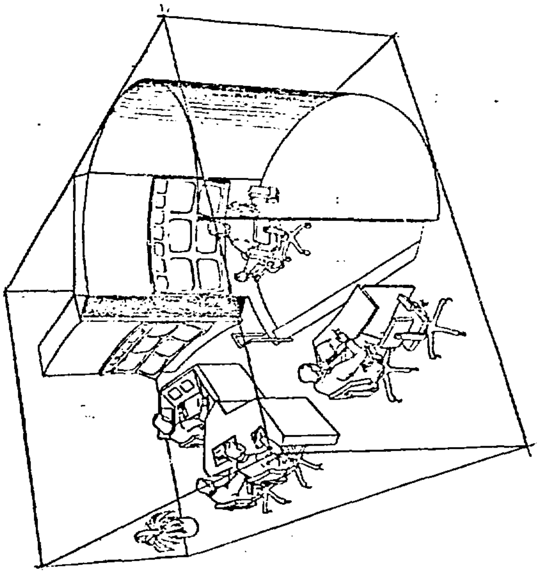


Fig 5 Operator
Control Station

Fig 6

SUMMARY

A new generation of remote maintenance system is being developed to meet the needs of future nuclear fuel reprocessing. Development activities cover all aspects of an advanced integrated maintenance system with particular emphasis on a new force-reflecting servomanipulator concept. The new servomanipulator is microprocessor controlled and is based upon gear force transmission, which permits modularization for remote maintainability and increased reliability. Human factors analysis has been used to develop an improved man/machine interface concept based upon colorgraphic displays. Initial test and evaluation of several development components have begun.

ACKNOWLEDGMENTS

The activities summarized here are the results of work performed by a rather large development team. The authors acknowledge the contribution of their colleagues in general and specifically the leadership roles of D. P. Kuban, Dr. Margaret M. Clarke, and J. N. Herndon.

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