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Consolidated Fuel Reprocessing Program

ADVANCED TELEOPERATION IN NUCLEAR APPLICATIONS

W. R. Hamel
Instrumentation and Controls Division

M. J. Feldman
Fuel Recycle Division

H. L. Martin
Instrumentation and Controls Division

Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37831

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DISCLAIMER

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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

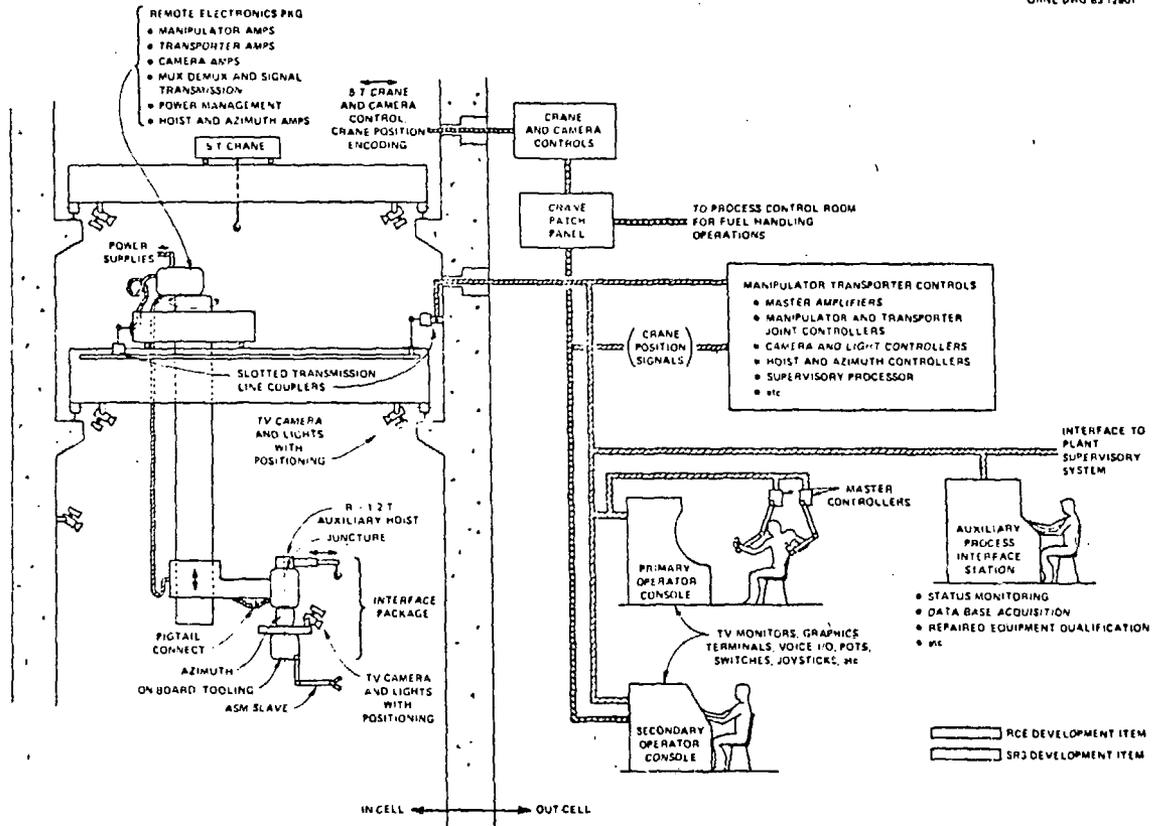servomanipulator slave arms and several other development components

have begun.

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

REMOTE ELECTRONICS PKG
- MANIPULATOR AMPS
- TRANSPORTER AMPS
- CAMERA AMPS
- MUX DEMUX AND SIGNAL TRANSMISSION
- POWER MANAGEMENT
- HOIST AND AZIMUTH AMPS

5 T CRANE

POWER SUPPLIES

SLOTTED TRANSMISSION LINE COUPLERS

TV CAMERA AND LIGHTS WITH POSITIONING

R 12 T AUXILIARY HOIST JUNCTURE

INTERFACE PACKAGE

PIGTAIL CONNECT

AZIMUTH
ON BOARD TOOLING
ASM SLAVE

TV CAMERA AND LIGHTS WITH POSITIONING

5 T CRANE AND CAMERA CONTROL CRANE POSITION ENCODING

CRANE AND CAMERA CONTROLS

CRANE PATCH PANEL

TO PROCESS CONTROL ROOM FOR FUEL HANDLING OPERATIONS

CRANE POSITION SIGNALS

MANIPULATOR TRANSPORTER CONTROLS
- MASTER AMPLIFIERS
- MANIPULATOR AND TRANSPORTER JOINT CONTROLLERS
- CAMERA AND LIGHT CONTROLLERS
- HOIST AND AZIMUTH CONTROLLERS
- SUPERVISORY PROCESSOR
- etc

MASTER CONTROLLERS

INTERFACE TO PLANT SUPERVISORY SYSTEM

PRIMARY OPERATOR CONSOLE

AUXILIARY PROCESS INTERFACE STATION

- STATUS MONITORING
- DATA BASE ACQUISITION
- REPAIRED EQUIPMENT QUALIFICATION
- etc

TV MONITORS, GRAPHICS TERMINALS, VOICE I/O, POTS, SWITCHES, JOYSTICKS, etc

SECONDARY OPERATOR CONSOLE

RCE DEVELOPMENT ITEM
SRJ DEVELOPMENT ITEM

IN CELL ← → OUT CELL

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
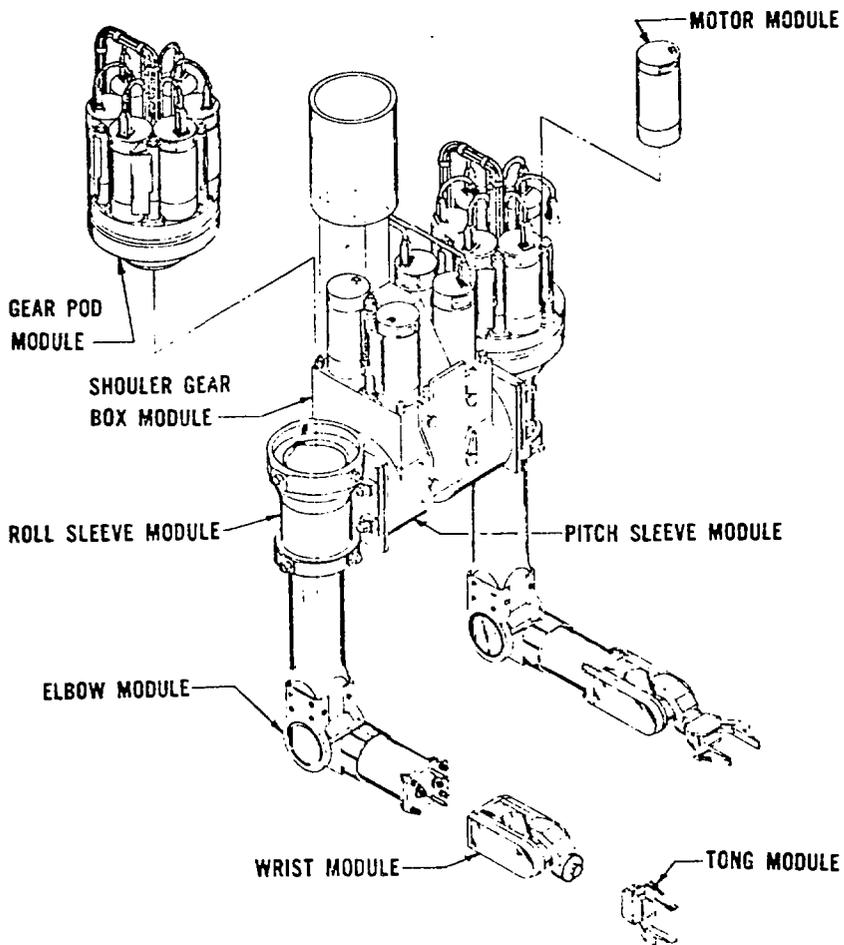
MOTOR MODULE

GEAR POD
MODULE

SHOULER GEAR
BOX MODULE

ROLL SLEEVE MODULE

PITCH SLEEVE MODULE

ELBOW MODULE

WRIST MODULE

TONG MODULE

Fig 2 The advanced
Servo-manipulator

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 arrange-

ment 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]

SHOULDER PITCH
AXIS VERTICAL
ADJUSTMENT
COLUMN

SHOULDER
ROLL

SHOULDER
PITCH
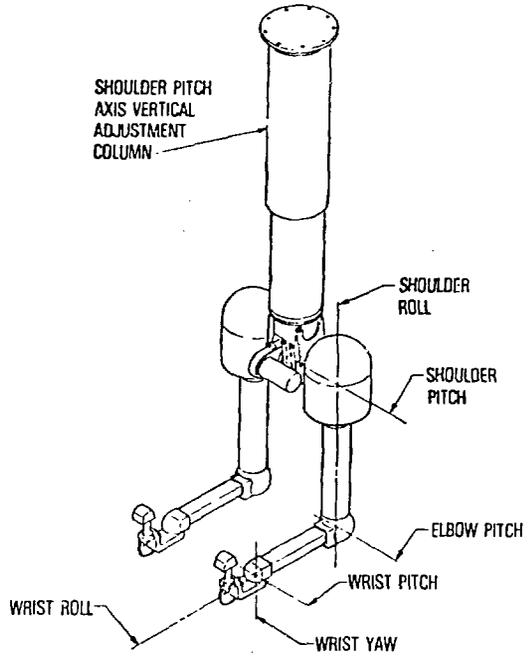
ELBOW PITCH

WRIST PITCH

WRIST ROLL

WRIST YAW

Fig. 3 Dual arm
Master Controller

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 counter-balancing 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
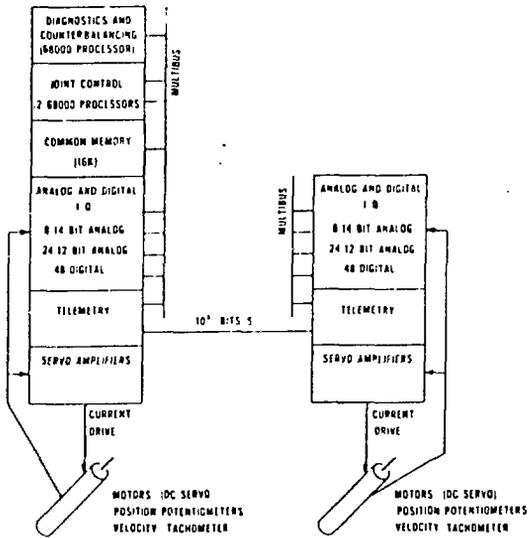
Fig. 4   Control System Architecture

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 elec-
tronically 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 t 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 in early 1985. The entire system
will be assembled and under test next year.
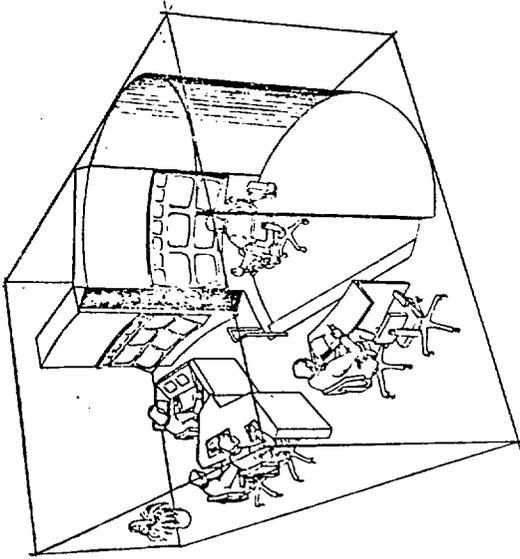
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Fig. 5 Operator
control station

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

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