ORTHOTIC MANIPULATORS

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Summary

Orthotic manipulators which resemble the structural configuration of the human arm are beginning to be used for many different applications in medical fields, as well as for industrial and scientific purposes. Science and industry are concerned chiefly with performance of tasks in environments that are hostile to man.

The foremost medical uses have been in the field of rehabilitation for restoration of arm function to paralyzed patients, and as therapeutic devices as an adjunct to the treatment of persons suffering neuromuscular damage. A unique feature of orthotic type manipulators is that their joint and segmental alignments resemble the human arm. Master/slave versions of these manipulators allow the person controlling them to duplicate his own arm motion by a mechanical arm located at a remote location.

Introduction

The investigation and developlent of externally-powered orthotic devices has spawned a unique family of teleoperators that are beginning to be used for many divergent purposes. The manipulator systems are unique because the externally-powered brace and/or powered slave device resembles the anatomical arm in terms of segmental length, joint alignment and range. The control hardware configuration in some cases (master/slave mode of operation) also is analogous to the human arm. The design concept differs from industrial machines in that the individual components of the device are expected to function at maximum capacity during normal operation of the device. This concept permits the fabrication of compact manipulators with a high performance (strength, speed, etc.) to weight ratio which is required if they are to be used as portable machines. Reliability is not sacrificed by the severe stressing of the components since they are operated on a low duty cycle.

Orthotic manipulators have two major uses: (1) To solve medical problems and (2) to perform tasks in hostile environments.

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The largest medical need for orthotic manipulators is in the field of rehabilitation, especially in orthotics. Motorized exoskeletal

Fig. 1.

braces provide partial return of arm and hand function [1, 2, 3] to severely paralyzed patients (Fig. 1).

Medical Applications

The control schemes most successful for orthotic applications have been switch configurations that allow sequential control of orthoses. The switch controls most commonly used are the unidirectional lever switch and the Rancho tongue switch (Fig. 2). Recently, pressure activated proportional controls [4] and myoelectric controls [5, 6, 7] have begun to be used functionally.

One significant medical application with great potential is the use of manipulators as an exercise therapy tool for re-educating the neuromuscular system of a patient who has sustained a cerebral vascular accident. The purpose of this type of therapy is to help patients regain control of velocity, and displacement in their upper-extremity motion. The method currently being investigated consists of programmed exercise therapy through multi-jointed electro-mechanical arm-and-hand brace structures which use external power. The basic manipulator design (Fig. 3) has seven bidirec-

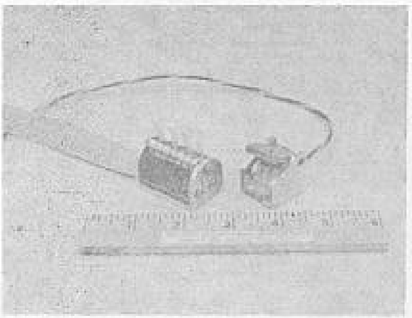


Fig. 2.

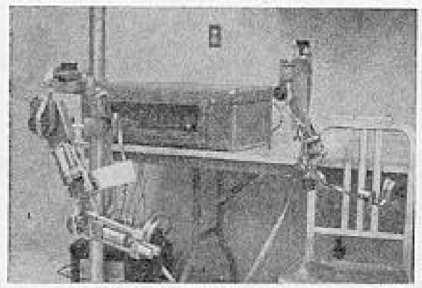


Fig. 3.

tional powered joints. The joints are (1) shoulder rotation about a vertical axis, (2) shoulder flexion and extension, (3) humeral rotation, (4) elbow flexion and extension, (5) forearm supination and pronation, (6) wrist flexion and extension, and (7) prehension. The brace produces motion through the anatomical range of the arm but its frequency response and strength do not equal those of the normal arm. The rotation velocity of the joints is limited to a maximum of approximately six revolutions per minute which adequately supplies the segmental displacement needed for most arm motions, but is not sufficient to simulate vigorous activity. The maximum pay load torque produced at the joints is 230 inch pounds. The devices are designed so they can be programmed to perform complex motions repetitively. In addition to this capacity, other modes of operation include: (1) Servo-boost of a specific motion pattern, (2) patient or therapist operated master/slave exercise control, (3) isokinetic exercises of specific motion patterns and (4) programmed motion.

1. *Servo-boost Operation*

The system (Fig. 4) is designed to act as a muscle amplifier that can be adjusted over a wide range of sensitivity. In operation, the exerciser brace is adjusted to restrict the patient to performing a specific motion pattern and it also acts as a proportional muscle magnifier as he attempts to produce the motion. In cases where the patient may have excessive muscle contraction strength, the brace can act as an attenuator.

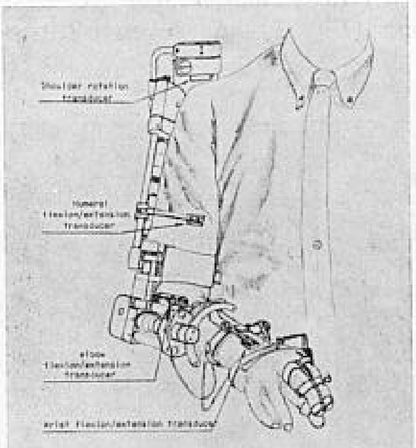


Fig. 4A *Transducer Arrangement For Servo-Boost Operation*

A transducer mounting arrangement is shown that will permit the control system to act as a muscle amplifier. The transducers are activated by relative motion between the patient's arm and the brace.

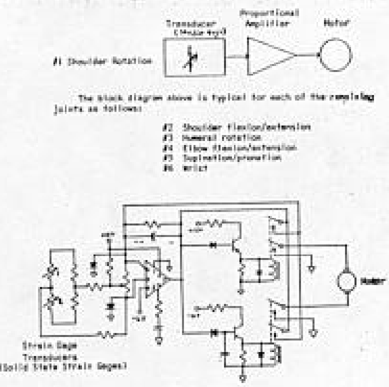


Fig. 4B *Servo Boost Circuit.*

Displacement of the transducer by the patient produces a frequency modulated signal that is fed to the relay driver circuit which in turn actuates the motor. Angular velocity of the motor is proportional to the pressure applied to the transducer.

2. *Master/Slave Exercise Control*

This is a master/slave operation from a controller brace (Fig. 5) that is an analog of the power exerciser. The master/slave mode of operation allows a therapist to exercise the patient by manipulating the controller brace or offers the option of permitting the patient to exercise one arm by operating the control brace with his opposite arm.

3. *Isokinetic Exercise Mode*

The patient may be exercised through specific motion patterns while exerting maximum contractions in an effort to produce these motions. The exerciser machine is set to limit the motion patterns to predetermined patterns and to maintain a constant speed of joint rotation regardless of the force being exerted by the patient (Fig. 6).

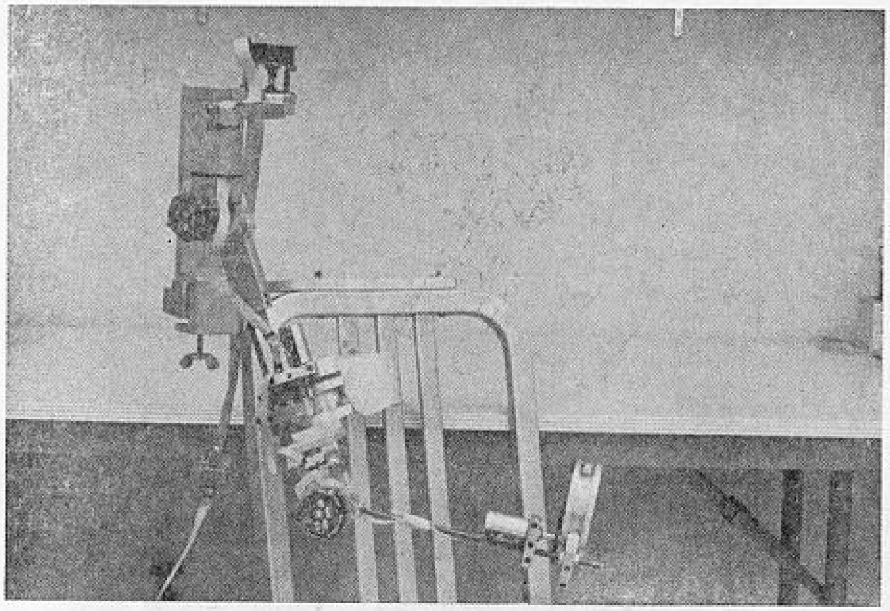


Fig. 5.

4. *Programmed Motion*

The patient may be exercised repetitively through programmed motions that were previously stored on magnetic tape. The control circuitry is described in Figures 7 and 8.

Scientific and Industrial Applications

The traditional use of remote manipulators is in the field of atomic energy. Of the approximately 3,000 manipulators that have been built, about 80% were purchased by atomic energy facilities [8]. Currently, there is a new surge of interest in the diversification of manipulator usage. The immediate uses will continue to be the performance of activities in environments that are hostile to man. Future uses will include the performance of tasks that are tedious or laborious to man, or which require physical strength greater than man can produce. The realization of the dream to accomplish these tasks without man's personal participation will not occur until the development of the manipulator has reached a high degree of sophistication. At the present time anthropomorphic manipulators are in the ebmryonic stage. Proprioceptive and other sensors are relatively crude. Manipulative dexterity and frequency response also are

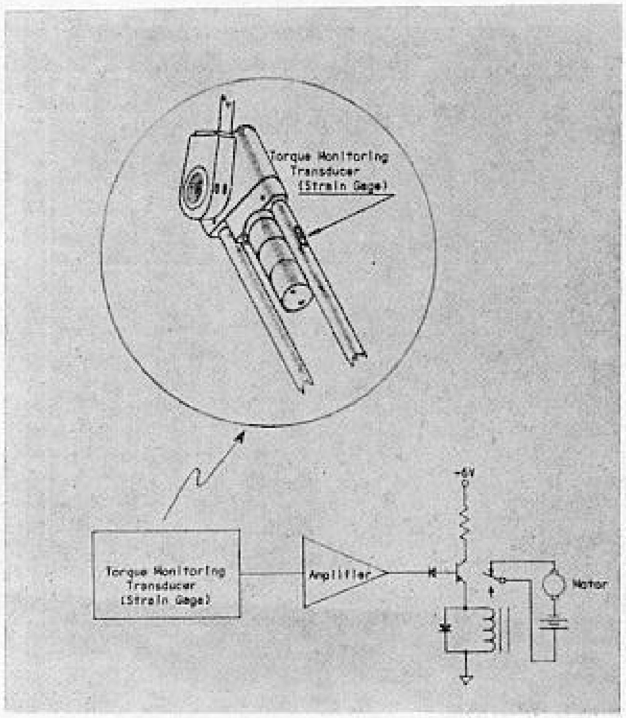


Fig. 6. *Isokinetic Exercise*

A strain gage is placed in the arm segment to detect the bending of the beam and is calibrated to reflect the torque applied at the joint. The output of the transducer is fed to an adjustable gain amplifier which drives a relay whose contacts open the arm motor leads when the relay is operated

inadequate. The immediate needs for manipulators are in outer space, underseas, and as rescue devices for retrieving human bodies or other object from fires, fields of heavy radiation or other environments unfriendly to man. Even though their quality of performance is low, manipulators can be successfully employed for these purposes. The high priority of the need to accomplish these tasks makes it reasonable to expend large amounts of time, money, and effort to extend man's physical limitations.

An orthotic master/slave type manipulator built by the authors, is being utilized by the United States Atomic Energy Commission as a rescue tool. Bilateral manipulators are mounted on a

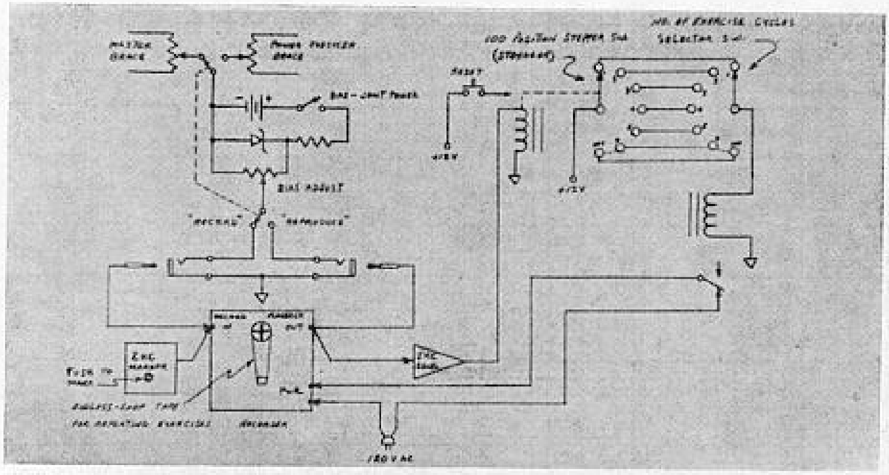
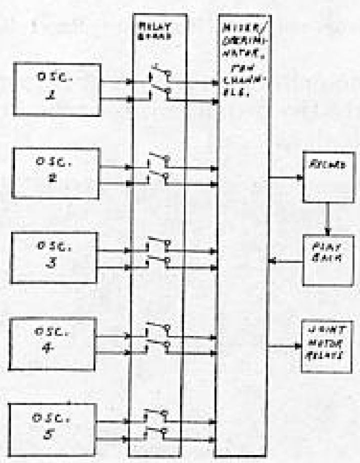


Fig. 7. *Programmed Motion Control System — Electrical Schematics.*

The desired motion patterns are recorded on a multi-channel endless loop tape recorder by manipulation of the master control brace. A 2KC marker is placed on the tape just prior to recording the motion. With each complete revolution of the tape, the marker signal is amplified by a selective amplifier which in turn advances a stepper switch one position. The contacts of the stepper switch are connected to a manually operated selector switch whose wiper is connected to a realy that cuts off the recorder. The number of exercise cycles can be preset by the positioning of the selector switch.



Oscillator sections 1 thru 5 are controlled by the respective joints of the master control brace (joints 1 thru 5). As the control brace is moved for programming a motion, those joints which are in motion switch the output of their oscillator to the mixer section. The mixer output is fed to a tape recorder which records the mixed signals. In the playback mode, the tape recorder output is fed to the discriminator which separates the various frequencies and feeds them to the proper relays for controlling the joints of the powered exercisor brace.

Fig. 8A *Arm exercisor control system* (Resonant Reed Relay)
Block diagram, ten channel mulitiplexer/discriminator

vehicle that can traverse terrain too rough for ordinary wheeled or track vehicles. The vehicle and teleoperator are remotely operated

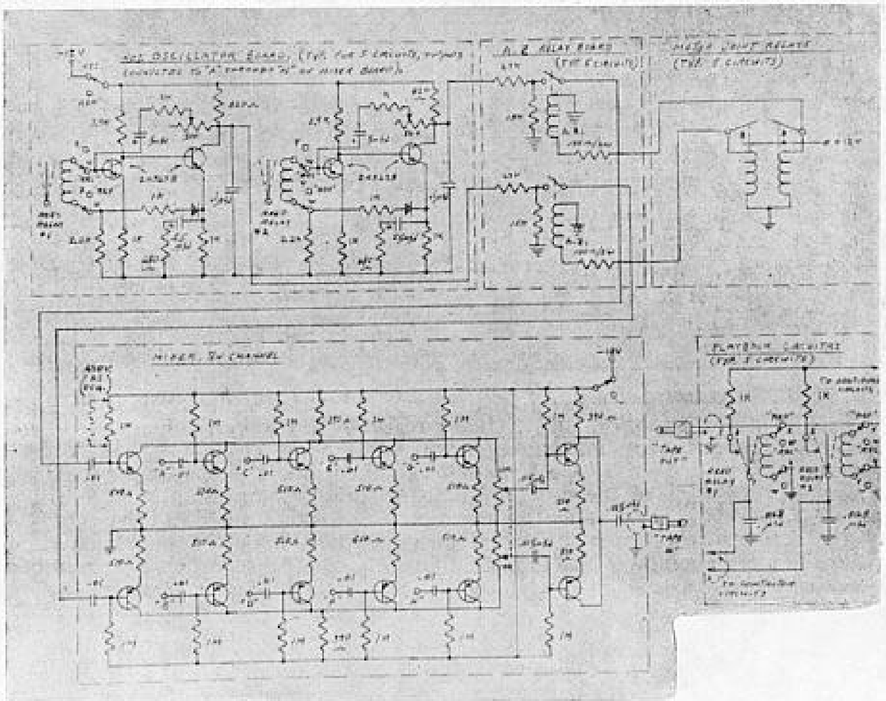


Fig. 8B *Schematic Diagram arm exercisor control* (Resonant Reed Relay)

by a 30-channel telemetry system. The primary purpose of this manipulator is to pick up or drag a body from dangerous areas subsequent to an accident (such as a gas leak or fire).

Fig. 9.

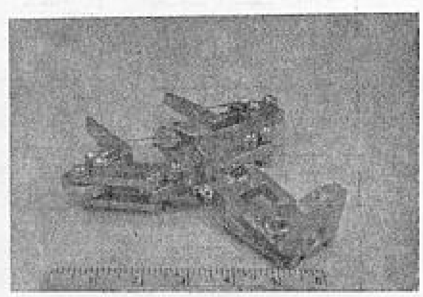


Fig. 10.

Another governmental agency, National Aeronautics Space Administration (NASA) is testing this manipulator to see if it is feasible to use it to perform tasks outside a space craft while it is in flight. In this case, the manipulator may make repairs on the external parts of the space craft or collect materials from space. This bilateral manipulator (Fig. 9) resembles the exercise device previously described except for its prehension devices which are parallel-jaw hooks (Fig. 10). The control schematic and assembly drawings are shown in Figure 11.

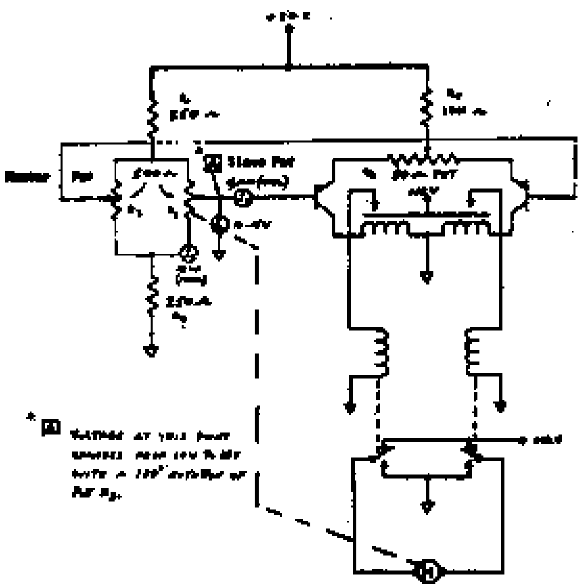


Fig. 11. Electrical Schematic — Remote Manipulator. (Single channel shown only.)

Conclusions

It is anticipated that the greatest gain to accrue from experience with these first orthotic manipulators will be delineation of the performance that is required from this type of device. The features found lacking in the pilot models will be incorporated in the design of future models. Major changes in joint ranges and alignment are not likely to occur as the result of future research. However, it is reasonable to expect that vast improvements in the control system will be made. Of particular importance will be the endowment of the machine with a semblance of man's visual, accoustical, proprioceptive, sense of smell, and other sensors.

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