A COORDINATED, PROPORTIONAL MOTION CONTROLLER FOR AN UPPER-EXTREMITY ORTHOTIC DEVICE

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Summary

Upper-Extremity Orthotic devices presently being used have required the patient control each joint of the splint structure from a separate on-off control site. The disadvantages of this type of control are (1) the patient must relate anatomical joint movements to the desired motion of the terminus, (2) coordinated motion of the joints is difficult since multiple sites must be actuated simultaneously, (3) on-off control does not permit smooth or fine positioning of the terminus and in general leads to a hunting situation for final positioning.

The control system described uses proportional control and a mechanical coordinate converter to achieve smooth coordinated motion of the splint structure.

Preliminary results of studies to determine the feasibility of using eye motion to control azimuth and elevation are included.

Introduction

Significant efforts have been made in the design of powered orthoses for upper extremities. The critical problem remaining is the development of a control system to obtain smooth coordinated motion of these splint structures with the limited control sites available. The research reported here has as its goal the development of variable speed operation and coordinated motion of the splint structure joints using volitional control [1], [2].

Variable speed control is important to enable reasonably high speeds to be used for gross motions and slow speeds used for fine control. Automatic coordination of joint motion is essential if motion of the hand is to be controlled directly. Volitional control is considered essential if the flexibility of the orthotic device is to be capitalized upon.

The particular orthotic device being used in the investigation is the Rancho Electric Arm [3]. This powered splint structure has

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seven degrees-of-freedom (joint motions) shown in Figure 1. These seven degrees-of-freedom require seven signals if volitional control is to be realized.

The most critical factor in the successful control of an externally powered upper-extremity orthotic or prosthetic device is the information channel from the user to the device. The degree of satisfactory function to be realized depends directly and fundamentally upon the adequacy of available control signals.

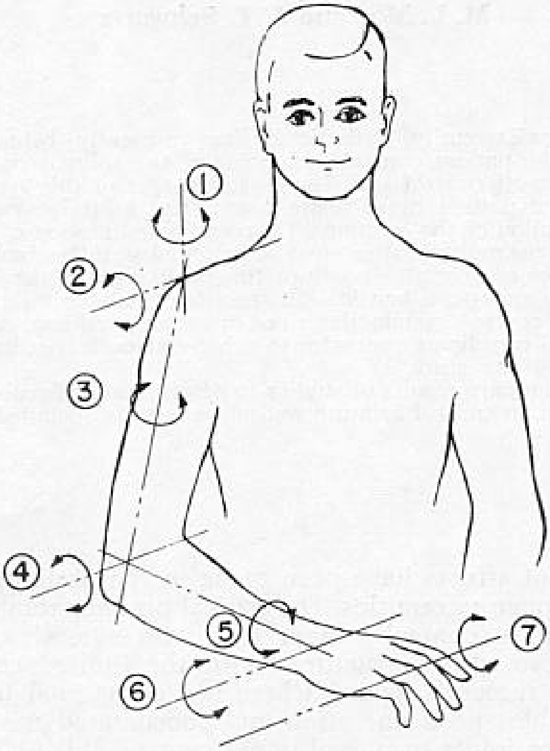

Fig. 1. The seven degrees-of-freedom of the Rancho Electric Arm

Sensory feedback is also needed. This feedback is usually visual but in some cases, proprioceptive feedback is available. Since visual feedback is sufficient for satisfactory function, the feedback link will not be discussed further.

Source of Control Signals

The possible sources of control signals are numerous. The Rancho Tongue Control [3] is an especially reliable source of on-off signals. Myoelectric control has also been reported [4], [5], [6]. If a variable speed control system is to be used, it is essential that continuous bi-directional signals with reasonable dynamic range be obtained. Also, the amount of training will be minimized if there is a close relationship between the source of the control signal and the resulting motion.

One source of continuous bi-directional signals is the strain gauge tongue transducer. The transducer consists of a base block with seven plug-in beams. The base block with three beams removed is shown in Figure 2. A single beam is shown in Figure 3. Each beam has a semiconductor strain gauge on both the top and bottom sides connected in a standard strain gauge bridge arrangement. The patient pushes up on the beam with his tongue to get a signal of one polarity and pushes down to get the other polarity. With the seven beams a signal is available to control each degree-of-freedom for volitional control.

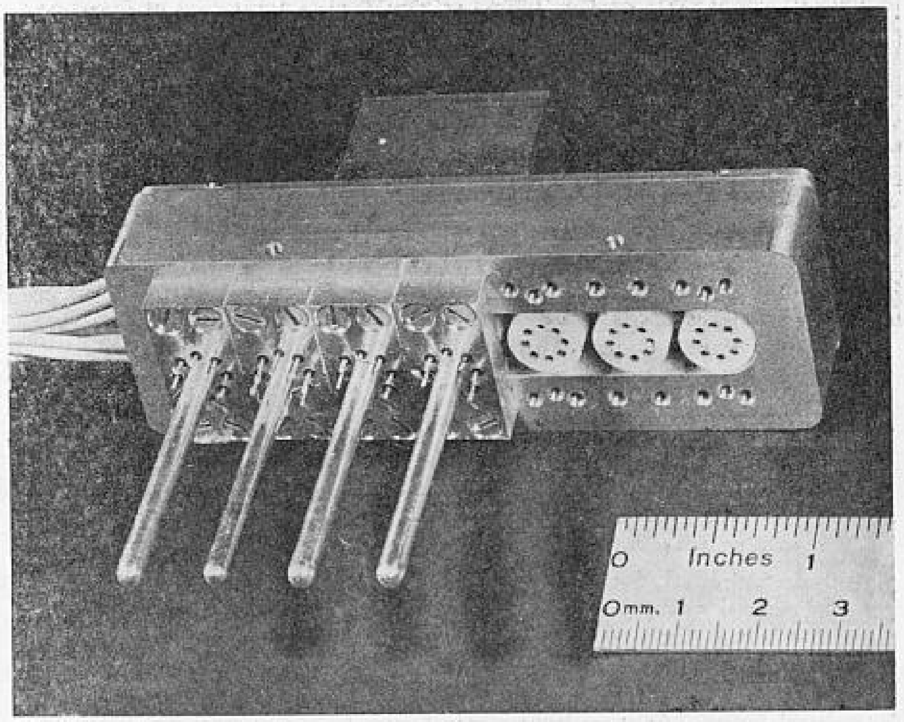

Fig. 2. Strain gauge tongue transducer with three beams removed

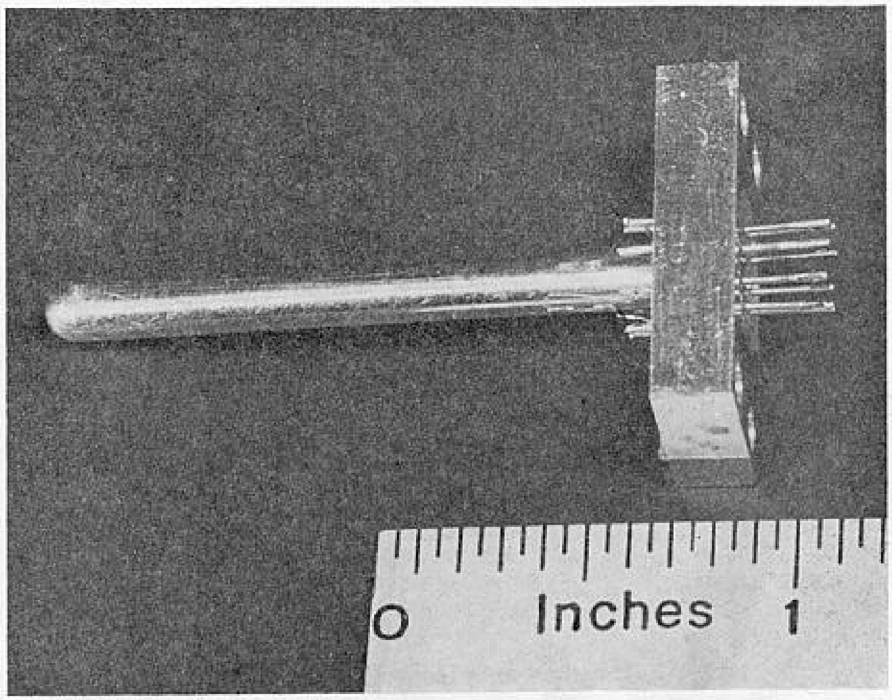

Fig. 3. Plug-in beam for strain gauge tongue transducer

Variable Speed Control

The Rancho Electric Arm uses constant speed permanent magnet DC motors to power the joints. A variable speed control system in which the speed of each joint is proportional to a variable signal was needed. Such a control system will be termed a *proportional* control system.

Both linear voltage amplification and variable frequency pulse modulation were considered as possible methods of obtaining proportional control of the DC motors. Tests of the motors on the Rancho Electric Arm indicated that, while some control could be obtained with either method, the pulse method permitted a greater range of speeds as well as simple circuitry.

The circuit diagram of the proportional motor control system is shown in Figure 4. A Fairchild UA702C wideband DC differential amplifier is used in an integrator configuration with a resistor in parallel with the integrating capacitor. The resistor produces a dead zone so that if the inputs differ by less than 2.4 mv, the relays that drive the motor are not activated. When either relay is activated, one set of contacts discharges the integrating capacitor and the other set pulses the motor with a 12 volt pulse of 20 ms duration.

The magnitude of the input signal determines the rate at which the integrator output builds up after the capacitor is discharged,

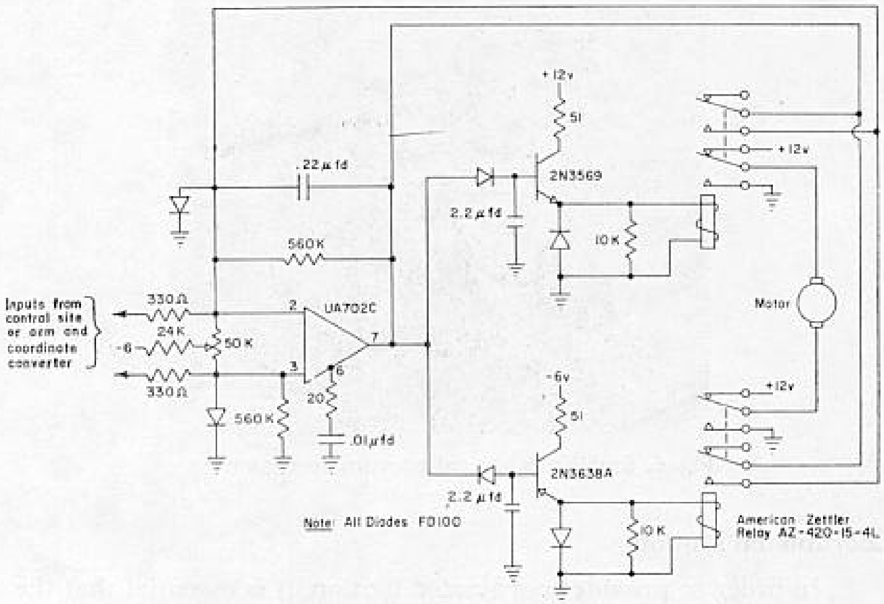

Fig. 4. Schematic of motor controller circuit

and hence the frequency of the pulses activating the motor and thus the motor speed. An electronic unit containing all the circuits to drive the Rancho Electric Arm is shown in Figure 5.

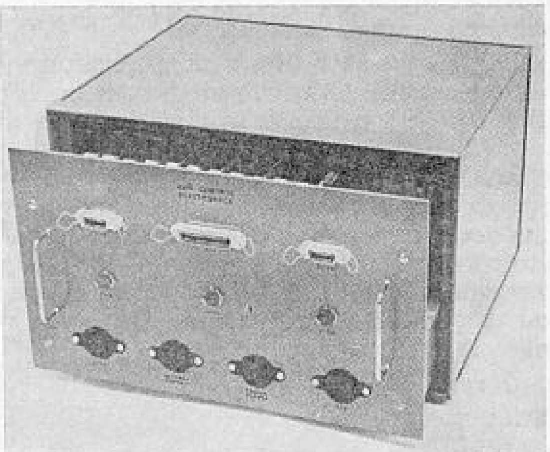

Fig. 5. Electronic unit

A similar technique has also been developed for control of an electropneumatic valve for a system powered by McKibben muscles [7].

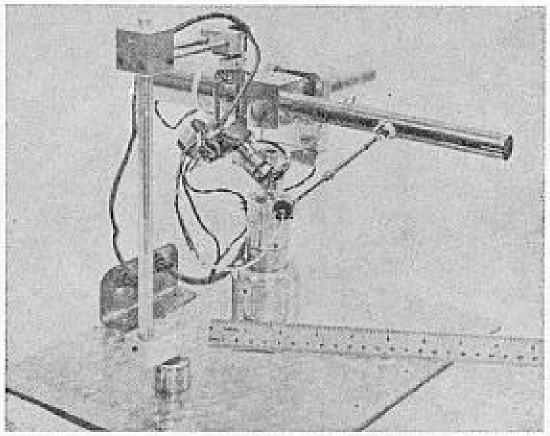

Fig. 6. Small mechanical coordinate converter

Coordinated Motion

In order to provide coordinated motion, it is essential that the patient be relieved from the task of directly controlling each joint of the splint structure. To accomplish this, a small mechanical coordinate converter, shown in Figure 6, has been developed to permit the patient to control the speed and direction of motion of the terminus of the splint structure with azimuth, elevation, and range rate commands. The coordinate converter processes these commands and provides signals to control the splint structure joints to produce coordinated motion.

The coordinate converter uses a miniature mechanical analog of the orthotic device. The terminus of the analog is attached to a rod representing a position vector in spherical coordinates. When the rod is moved under control of the input signals, it forces the joints of the analog to assume values that satisfy the desired position in space. The position of the analog joints and splint structure joints are compared electrically and the splint structure joints moved to correspond to the position of the analog's joints. In this mode of operation four beams of the strain gauge tongue transducer are used to control the coordinate converter, one beam for each of the following rate commands:

1) Azimuth rate, $\dot{\Theta}$
2) Elevation rate, $\dot{\Phi}$
3) Range rate, r
4) Elbow elevation rate, $\dot{\gamma}$

The coordinate converter in turn controls the following four motions of the splint structure:

1) Rotation of shoulder about vertical axis, γ_1
2) Shoulder flexion/extension, γ_2
3) Humeral rotation, γ_3
4) Elbow flexion/extension, γ_4

These are the first four degrees-of-freedom shown in Figure 1. A block diagram of the system is shown in Figure 7.

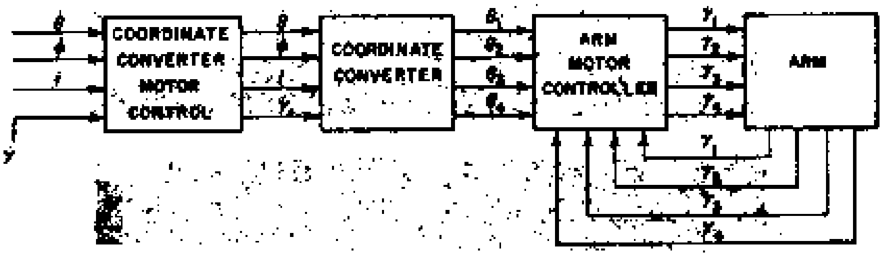

Fig. 7. Control system block diagram

It should be emphasized that the coordinate converter does not change the total number of signals required to control the orthosis; it permits action resulting from an input signal to be more complex. For example, without the coordinate converter, one signal would be used to control elbow flexion; with the coordinate converter, one signal controls the movement of the hand in range, toward and away from the mouth. This motion requires elbow flexion, shoulder flexion, and rotation of the shoulder about the vertical axis in a coordinated manner to get straight line motion toward or away from the mouth.

The last three degrees-of-freedom shown in Figure 1 that correspond to the operation of the hand splint are each controlled directly by a beam of the strain gauge tongue transducer, thus are not controlled by the coordinate converter. Additional details on the operation of the coordinate converter are given elsewhere [1].

Preliminary tests on four patients indicate that the coordinate converter substantially reduces the skill required by the patient to obtain coordinated motion. The utility of the coordinate converter will increase as additional useful control sites are developed.

Control Using Eye Motion

The possibility of using the eye as a control mechanism has been discussed for some time [8], [9]. In severely disabled quadriplegics this control site is especially valuable since impairment of eye motion is rare and smooth control over a wide dynamic range is feasible. It also appears quite natural to use horizontal and vertical eye motion to control azimuth and elevation of the splint structure. In this mode of control the patient first points his head

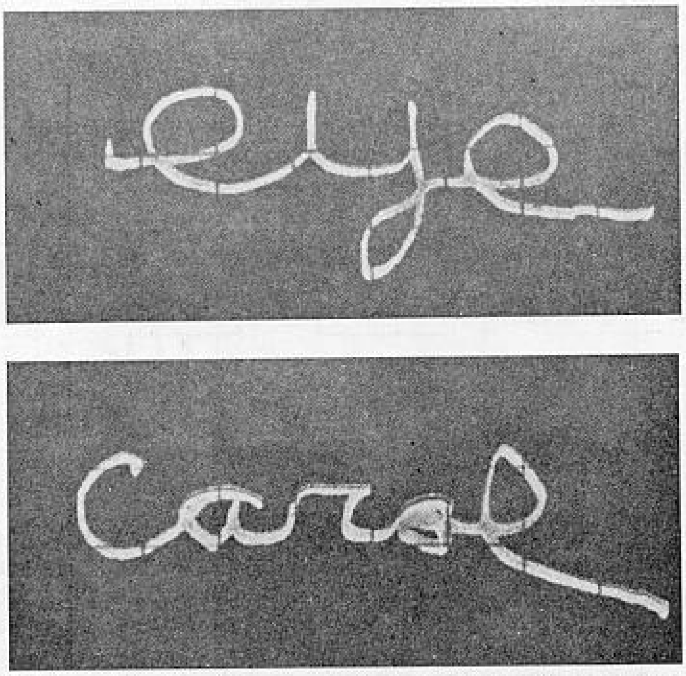

Fig. 8. "Eye writing" on the screen of a storage oscilloscope produced by electrical signals from EOG transducers

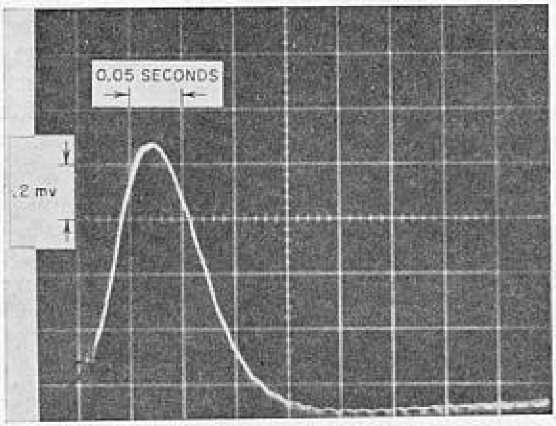

Fig. 9. EOG pulse produced by an eye blink

and direction of gaze toward his hand. Then, while looking at his hand, he turns his head to the right or left, up or down or some combination thereof. The hand is automatically driven in the direction of head motion with a speed proportional to the amount of head motion. This approach makes use of the natural coordination of hand and hand motion, shown in recent studies [10] to simplify the control task.

Preliminary tests have shown that it is quite easy to "write" with the eyes as shown in Figure 8. Thus, it certainly is possible to use the eyes for some tasks. However, many problems remain to be solved before clinical use of eye control will be realized. If electro-oculographic signals are used to measure eye position, there is some problem with drift which can be minimized with proper electrodes [11]. Eyelid movement is a problem [12], [13], blinks are one manifestation of this problem. The electrical pulses produced by eye

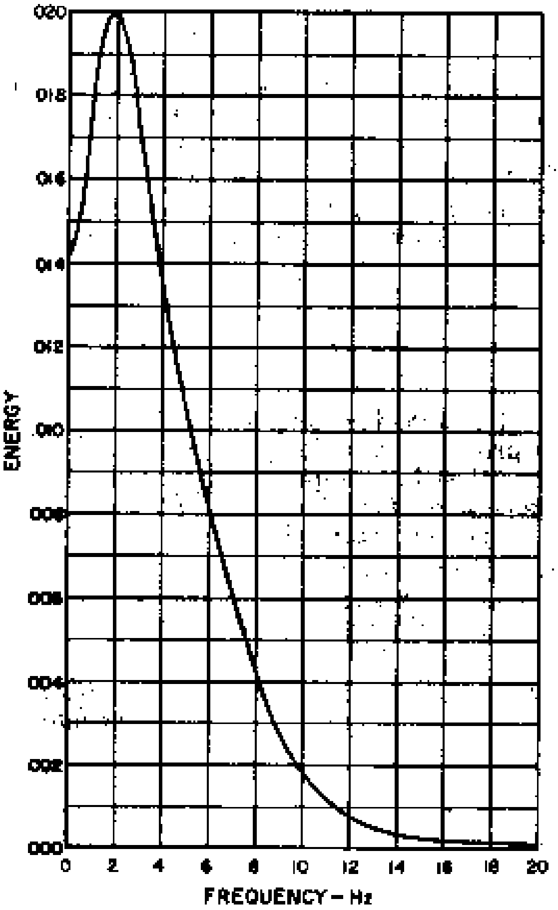

Fig. 10. Frequency spectrum of eye blink shown in Figure 9.

blinks are quite varied. The pulse shown in Figure 9 is a typical example of one of the more difficult pulses to filter since it contains considerable energy at low frequencies. This pulse was obtained from electrodes placed above and below the eye. A spectral analysis of the pulse produced the energy spectrum shown in Figure 10. It will be noted that most of the energy of the pulse occurs below 10 hertz. Since the useful control signal from the eye will generally be below 0.25 hertz, considerable but not complete, electrical filtering of the blink is possible. In addition, filtering is inherent in the mechanical structure of the orthotic device.

Another problem which must be considered is that of delays in the control system. Studies have shown that delays of 0.5 second can seriously degrade system performance when a human is in the loop [14]. Thus, every effort must be made to provide a reasonable bandwidth for the system. Development of an electronic coordinate converter will help alleviate this problem.

Other techniques for measuring eye motion being considered include infrared reflection techniques [15] and an impedance method [16].

Conclusions

The control system for the Rancho Electric Arm which has been described provides variable speed control of all joints and coordination of the first four joints. This coordination simplifies the control task since *direction* of motion of the terminus instead of rotation of joints can be specified.

The design of the system is general enough to permit its use with any continuous bi-direction electric signals obtained from useful control sites, although the system has been used primarily with strain gauge tongue transducers.

Ocular control shows promise although additional tests are needed to determine the physiological and psychological effects of its use.

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