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SENSING HUMAN HAND MOTIONS
FOR CONTROLLING DEXTEROUS ROBOTS

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ABSTRACT:

The Dexterous Hand Master™ (DHM) system is designed to control dexterous robot hands such as the UTAH/MIT and Stanford/JPL hands. It is the first commercially available device which makes it possible to accurately and comfortably track the complex motion of the human finger joints. The DHM is adaptable to a wide variety of human hand sizes and shapes, throughout their full range of motion.
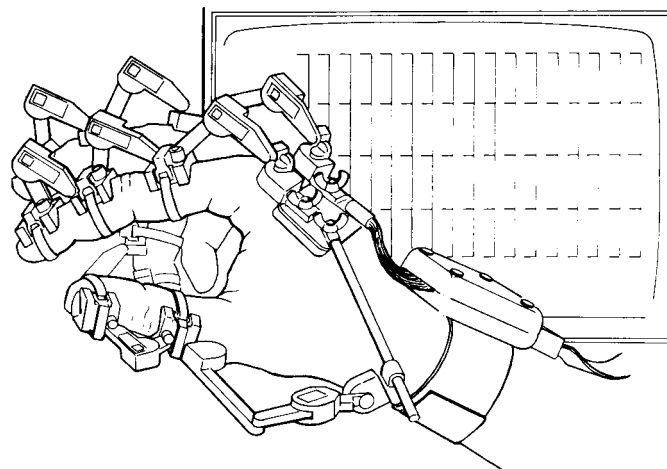
Figure 1- Dexterous Hand Master (DHM) system

BACKGROUND:

Laboratories around the country have begun to use dexterous robot hands such as the UTAH/MIT and the Stanford/JPL hands for robotic research applications. These hands are currently controlled through computer software, with little capability for teleoperation. As robotics technology has progressed, the dexterity of end-effectors has improved greatly, yet to make these dexterous hands widely and commercially applicable, an easy to use method for controlling them is required.

In January, we began a program to develop a sensing device capable of measuring human hand joint angles and translating them into position control commands. ADL selected an exoskeleton

design approach based on initial development work performed by Center for Engineering Design (CED) at the University of Utah in Salt Lake City, in conjunction with their dexterous robot hand program. Although their basic exoskeleton concept was viable for this application, several improvements were required to make this approach into a commercially available product.

With this starting point we developed a system which collects joint angle data on 16 finger joints, in real time, through the use of Hall Effect sensors and an AT compatible microcomputer. The result is a system which is accurate, light weight,

comfortable to use, and easily adjusted to fit a wide range of human hand sizes.(figure 1).

PROGRAM OBJECTIVE:

The goals of this program were to develop a system which could accurately transduce human joint motions and provide them as control signals to robots. In order to achieve this objective we set the following design goals to improve on the work of CED :

- Reduced Bulk,
- Reduced Weight,
- Improved Comfort,
- Improved Reliability,
- Improved Fit,
- Improved Attachment,
- Improved Resolution, and
- Addition of Calibration to Accommodate Hand Sizes.

SYSTEM DEVELOPMENT:

In order to achieve these goals we began with the selection of the sensor. The CED device, which was created primarily for testing the UTAH/MIT hand during development, used off the shelf potentiometers. Through experimentation with a variety of conventional, high precision, and conductive plastic potentiometers, we found that these sensors had the following disadvantages:

- Unacceptable levels of resistance to rotation (friction),
- Large package volume, and
- Signal output levels overly sensitive to noise, wear, and other environmental factors.

Therefore, we began considering other sensing methods and finally settled on Hall Effect sensors which had been successfully used for measurement of motion in other robotics applications (i.e. the UTAH/MIT hand, also developed at CED). A Hall Effect sensor is a small semiconductor device which changes its signal output voltage in proportion to the magnetic field it is experiencing. Its advantages include:

- non-contact measurements (no friction),
- small package,
- signal output not subject to many environmental influences, and
- available with amplification on the chip.

Using a magnet assembly designed by CED for the UTAH/MIT hand, we tested various Hall Effect sensors and selected a Honeywell product which featured built-in amplification and excellent temperature stability. We then experimentally determined the geometric relationship between the magnet and sensor which provided us with the desired response curve (figure 2). The important dimensions derived from these tests were the air-gap between the sensor and magnet faces, and the radial displacement of the magnet and sensor centerlines. In the proper configuration, the sensor output voltage will vary sinusoidally with the angular position of the magnet.

Once the sensor geometry was fixed, we moved on to the simultaneous development of the linkage mechanism and the electronics package. Through study of anthropomorphic data and experimental observations, we selected optimum linkage lengths for each joint of each finger. We built a single finger prototype using a planar linkage, with rigid attachment blocks, held to the fingers with Velcro™ straps. Extensive work with this prototype revealed three key problems:
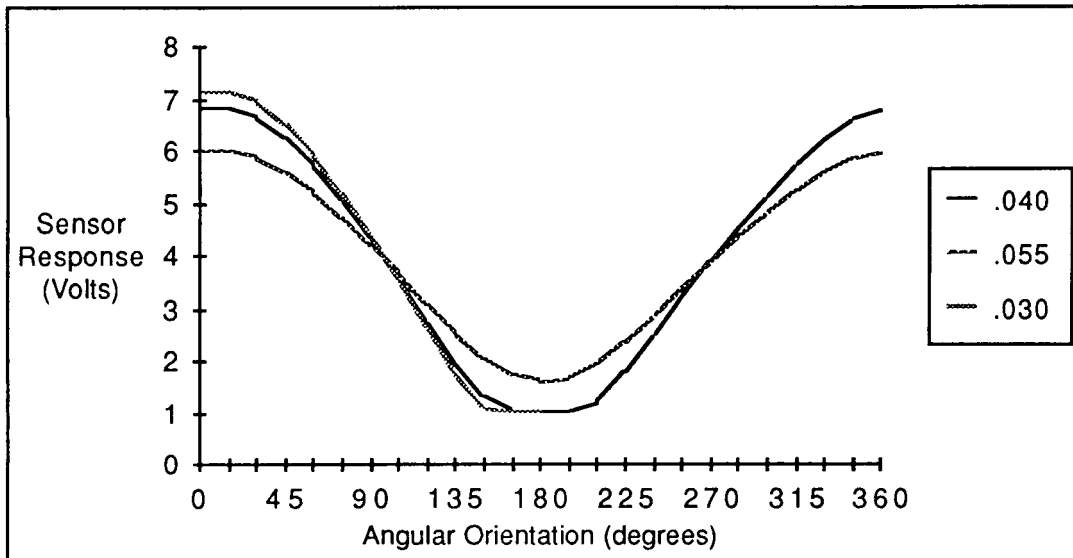
Figure 2- Hall Effect Sensor Response For Various Spacings

• Human fingers do not bend in a single plane (many people have noticeably crooked fingers),

• The relative orientation of the finger axes change continuously throughout the range of joint motion, and

• Finger segments grow and shrink substantially during bending,

The planar linkage therefore, was not acceptable because of its discomfort and tendency to shift at the attachment points. This led to pinching and measurement inaccuracy. Additionally, the solid attachment blocks would either flop about on the finger or restrict the range of motion of the finger depending on the angle of deflection (usually both).

We subsequently developed two features (figure 3) which eliminated these problems; the spring clip attachment, and the passive pivots. The spring clip allows a rigid strap (i.e. Velcro™) to change size as the finger bends, while keeping the attachment block firmly located on the finger segment. The passive pivot allows the finger to bend freely, while maintaining the integrity of the sensor measurement.

Once the finger mechanisms were completed, we began solving the more difficult problem of measuring the thumb angles. The design of the distal joint linkage for the thumb was copied from the finger designs. The main problem we encountered was the measurement of the two proximal joints of the thumb. We concluded was that it would not be possible to comfortably and repeatably secure an exoskeletal mechanism to the proximal link due to the large mass of soft tissue which makes up the base of the thumb and the unusual geometry of the joint itself. The solution we devised was to place two sensors on a linkage whose geometric relationship to the thumb joint motions was known. This solution requires a software algorithm which calculates both joint angles in real-time as a function of the two sensor inputs. In addition, we added another passive pivot to the thumb base to decouple several off - axis rotations which are not applicable to a robotic thumb command.
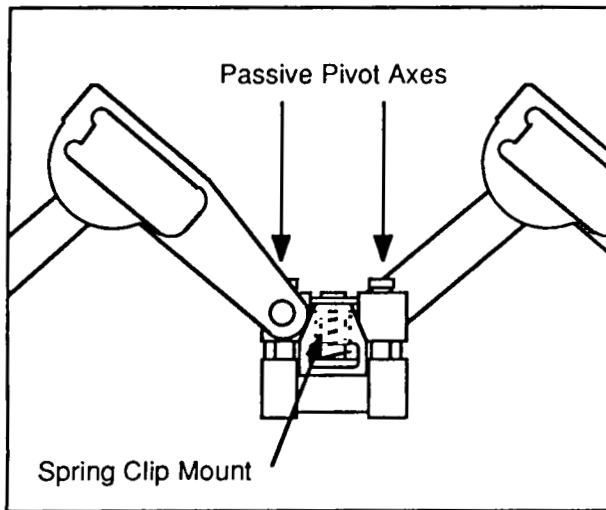
Figure 3- Linkage Design Features

The functional block diagram of the electronics is shown in figure 4. The electronics effort focussed on the development of an analog circuit interface board to drive the sensors, condition their output for the off-the-shelf A/D board, and perform certain additional tasks required during assembly of the devices. In addition, we developed software to collect the data from the A/D board, convert it into human joint angles, display the results, and transmit the joint angles through a serial port with an update rate of 100 Hz. The key element of the software is the hand calibration routine, which takes input from the user, combines it with fixed values from the sensor calibration and linkage geometries, and produces a set of look-up tables which map the sensor readings directly into human finger angles.

This combination of features allows an individual, regardless of hand size or shape, to place the device on their hand, perform the calibration, and get actual finger angles as a direct output. The calibration tables may be stored to allow the same individual to use the device again with a minimum amount of reconfiguration.
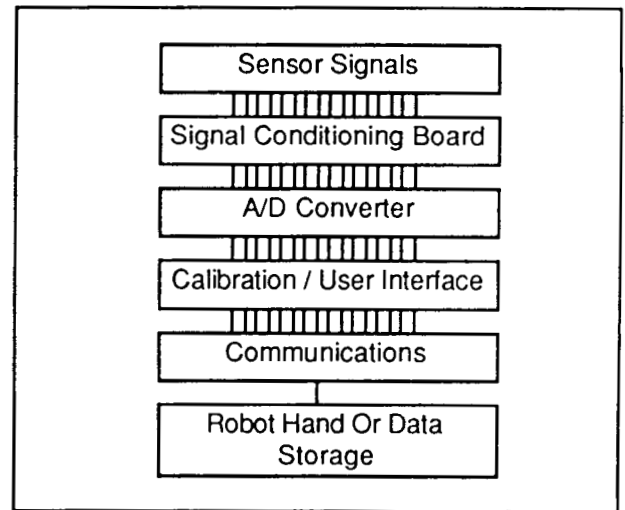

Figure 4- Electronics Block Diagram

SYSTEM DESCRIPTION:

The resulting system illustrated in figure 1 incorporates the following components:

- Exoskeleton - the mechanical structure which attaches the sensors to the human hand,

- Hall Effect sensors - 16 sensors, 4 per digit, 3 measure bending, 1 measures medial / lateral motion,

- Connection board - supplies power to the sensors, and returns their signals to the signal conditioning board,

- Signal conditioning board - conditions the signals for input to the A/D board,

- 12 bit, 16 channel A/D converter - creates digital representation of the analog sensor outputs,

- AT compatible micro-computer - provides data storage, date transmission, and calibration capabilities,

- RS422 serial port - transmits data at 19,200 baud for input to other computer systems, and

Proprietary software package - provides calibration, display, and communications functions.

CONCLUSIONS:

The Dexterous Hand Master system will allow users of dexterous robots to fully and rapidly understand which types of tasks can usefully be performed by these robots. It will also allow detailed study of the kinematics of the human hand, and the level of dexterity required to perform different tasks, which can enhance robotic applications. To date, four systems have been ordered, with three delivered. In the future we look anticipate developing more advanced versions of this technology featuring faster calibration routines, measurement of wrist joint angles and force reflection.

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1. Jacobsen, S.C., Iversen, E.K., Knutti, D.F., Johnson, R.T., & Biggers, K.B., "Design of the UTAH/MIT Dexterous Hand," Proceedings of the IEEE 1986 International Conference on Robotic and Automation, San Francisco, California.

2. Jacobsen, S.C., Wood J.E., Knutti, D.F., & Biggers, K.B., "The UTAH/MIT Dexterous Hand: Work in Progress," International Journal of Robotics Research, Vol. 3, No. 4, Winter 1984, pp21-50.