

Teleoperated Anthropomorphic Hand

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Abstract- As we push the limit on exploration of uninhabitable environments, human explorers have been increasingly replaced by robots. We have attempted to give these robot explorers a human advantage. To accomplish this task a multifingered ten degree of freedom robot hand has been constructed. The robot's actions are dynamically controlled by actuator cables attached to radial servomechanisms. Its functions consist of simple grasp/release operations and contraction/extension of specified digits according to the operator's desires. These operations are directed exclusively through the operator's sensory glove, which are fed to a microprocessor and then on to the servomechanisms. Through simple yet seemingly complex design and control, a multifingered robotic hand has been implemented with minimal cost to demonstrate its potential use in the field of robot exploration.

Key words – Robotic hand, telepresence, manipulator arm, anthropomorphic hand

Introduction

The focus throughout this project has been to build a low cost and highly durable multiple degree of freedom (DOF) anthropomorphic hand. Ideally, if the robot's mechanics were robust, students in following years would be able to experiment and improve the hand. Therefore, the center of attention has been placed on its mechanics and dynamics. Additionally, this project builds upon an earlier robot hand design from the spring of 2000. That project entailed a seven DOF robotic hand being controlled much like this project. An entirely new design has been

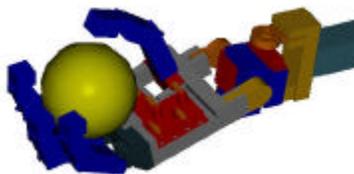


Figure 01 Ten DOF robot hand.

implemented to reduce weight and improve dynamic control.

1 Integrated System

1.1 System Block Diagram

The flow of digital signals to and from the microprocessor is shown below in *figure 02*.

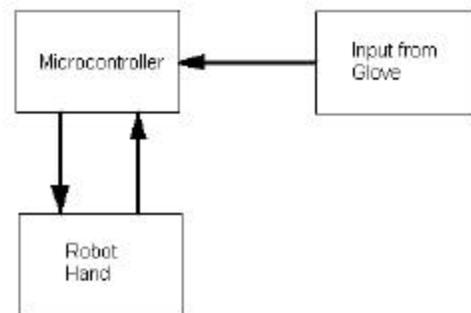


Figure 02 Basic system flow diagram.

1.2 Operation

A user securely puts on the cyber-wear input devices and power-ups the control system. The servos controlling the 10 DOF rotate to their initial position. The robot arm moves in unison with the user's arm as he/she moves his/her wrist and fingers. The result is real-time telepresence manipulator hand dynamically moving in unison with the motions of its operator.

2 Components

2.1 Cyber-wear

2.1.1 Description

The control system of the robot arm is based on a control system devised such that the robot arm will mimic the users motions. In order to do this the users must wear a sensor-laced glove that senses angles of bending across his/her joints. The glove is described as cyber-wear.

2.1.2 Construction

The cyber-wear is comprised of a military issue "summer flyers" glove converted into a sensory glove containing 10 sensors. The glove is made for an adult's hand, yet many young operators have used it as well. On an adult, the tight fit makes it ideal for tracking the hand's movements.

The glove is equipped with bend-sensors across particular articulations of the fingers and wrist. These bend-sensors are attached by way of Velcro; allowing for the sensors to be moved if necessary. These specified locations are the prominences of the knuckles during metacarpo-phalangeal and third row to second row interphalangeal articulation

as shown below in *figure 03*. Bend-sensor circuitry and signals are discussed in *Sensors*.

2.1.3 Lessons Learned

The placement of the bend-sensor is very important when trying to yield a voltage range. When placed across the top of the glove (dorsal side) the sensors respond with a small range of voltage differential. A better method was implemented. Attaching the bend-sensors on the belly (ventral side) of the finger articulations resulted in a wider voltage range. A wider voltage range increases the articulation resolution. This improvement wasn't made until the second generation of High-FIVE.

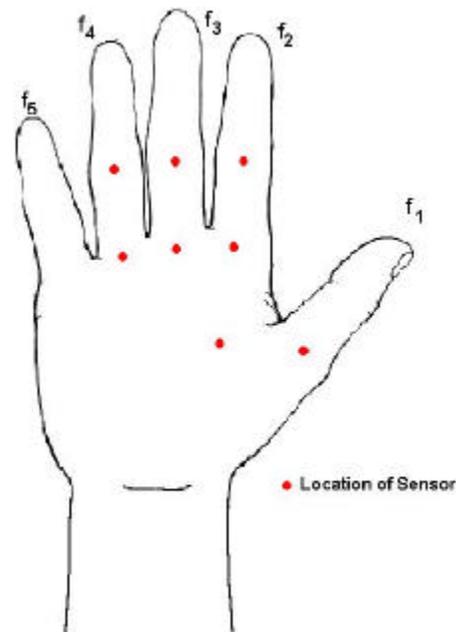


Figure 03 Location of sensors on the sensory glove

2.2 Robot Hand

2.2.1 Description

In trying to keep with the form and function of the human arm, the robot has been designed with three fingers, one thumb and two-axis wrist. Through

experience with the first generation, it was found that three fingers would be sufficient over four. A fourth finger could very easily be added. However, this addition would increase the overall size and weight of the hand. A four-fingered hand may have benefits over a three-fingered hand such as increase dexterity. This has yet to be determined.

2.2.2 Construction

Nylon, urethane, and aluminum were used in conjunction with various adhesives and original manufacturing techniques during the building process. Materials used and their methods are discussed in the reading below.

Manufacturing Process

A unique procedure was employed in the making of the three fingers and the thumb. Design and time constraints led us to pursue a six step manufacturing process that promoted part replication and rapid turnover time. The *first* step was to design the three “phalangeal bones” of the finger and machine them from aluminum. Consider these “bones” as links of a serial link manipulator. *Secondly*, the links are mounted to an aluminum plate and then enclosed in a box such that one side is the aluminum plate. Step *three*, on the top of the box there is an opening so that silicone can be poured into the box. The silicone is a two part 1:1 mixture that allows for approximately seven minutes of preparation and solidifies after four hours. Step *four*, after curing; the aluminum plate is removed revealing a void where the links were. Step *five*, a 1:1 mixture of urethane is then poured into the voids and the top is sealed; the urethane hardens in approximately a half an hour. Lastly, the castings are

removed and are ready for assembly and use.

This method allowed us to clone as many fingers as we needed and to make them with some precision of accuracy comparable to the original. Machining the fingers would have taken weeks as opposed to only a few hours. Additionally, the cured urethane was found to be suitable for further machining if needed. It is much lighter than aluminum and at least half as light as nylon of which the palm is constructed.

2.3 Control System

2.3.1 Description

Two different types of control have been implemented into the control system. The least complex is an open-loop where a direct reading is taken from a bend-sensor from the cyber-wear and manipulated to yield a value used to control the servo. The second form of control has an added advantage by way of feedback. The two types of control are discussed below along with other essential control elements.

2.3.2 Control Loop

Open-Loop Control

Simply put, open-loop control is direct control of an operation. The robotic arm is directly controlled by the cyber-wear. The advantage of this is the mere fact it's easier to implement and debug. Open-loop control was the first form of control used to operate the robot to ensure its mechanical robustness and performance.

Closed-Loop Control

Similar to a cruise control system in an automobile, the robot's fingers, have bend-sensors imbedded within them that

form a closed-loop control system which tracks the motion of the user's glove. The computer constantly updates and compares the signals from the glove to the signals imbedded within the links. If the robot's feedback bend-sensor signal is less or greater than the user's glove, the servo will either retract or release the actuator cable. This process continues until the "angle of bending" across the robot's finger is the proportionally close to the "angle of bending" across the user's joint. Closed-loop control using bend-sensors enables some precision of a finger's location at a minimized cost.

2.3.2 Lessons Learned

As discussed earlier, two servomotors control each finger. One actuates the joint proximal to the palm (SERVO A); the other controls the two distal joints (SERVO B). A problem presented itself when SERVO A retracts pulling in its actuator cable and SERVO B's actuator cable. The actual problem comes in to play when SERVO B tries to retract, pulling in the slack created by SERVO A. This meant that SERVO B wasn't able to articulate the two distal joints properly. This problem was solved by actuation both servos when SERVO A was actuated; whereby removing the slack so that SERVO B could function as designed.

3 Actuation

3.1 Mechanics

3.1.1 Description

In trying to mimic the opposability of the human hand, two servos have been implemented in such a way to enable the thumb to rotate from the index finger to

When considering replicating the mechanics behind a machine as fascinating and as complex as the human hand and wrist, minimization and localization of degrees of freedom is key. A total of ten degrees of freedom (D.O.F.) have been implemented from the robot's wrist to the fingers.

Forearm and Wrist

The forearm is made of 1" square tubing. The wrist attaches securely to the forearm via a setscrew. The wrist was designed after a universal joint, which allow pitch and yaw motion. The two servomotors that power the wrist have an added feature. Servo-savers were attached to the heads of the servos so that if the hand were disturbed by and unforeseen force or impact, minimal damage would be done to the wrist servos.

Thumb

The most difficult part of the hand to mimic is the complex and unique features of its thumb. It is unlike that of its neighbors. It has one less phalange, uses its metacarpal for more than just part of the palm, and functions in a two-axis plane. Although metacarpophalangeal articulations of the fingers are similar to that of the thumb, they do not have the ability of circumduction of the magnitude that of the thumb. The articular surfaces of the metacarpal and carpal bones of the thumb form a saddle joint that enables the thumb to have greater degree of movement.

the third finger and contract, closing its grip on an object. See *figure04* below. The thumb is mounted approximately 20° from the perpendicular servo head. The "contraction" servo equipped with a

rotor arm was placed on the dorsal side of the palm, allowing an actuator cable to be strung through the thumb. When actuated, the thumb contracts, while a spring holds the thumb in extension. The thumb is made from urethane, molded in the process discussed earlier.

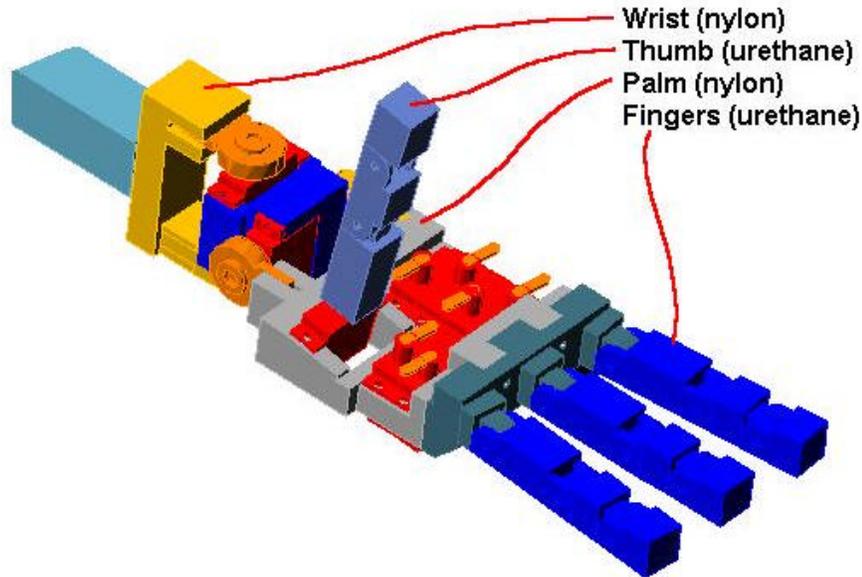


Figure 04 Graphical rendering of the physical attributes (ventral side). Note the servo-savers on at the wrist. The springs that keep the links in extension are on the dorsal side (not shown).

Fingers

The motion of our body is allowed by joints or articulations – the sites where two or more bones meet. Joints of the hand are synovial joints – the articulating bones are separated by a fluid-containing joint cavity.

The robot's fingers are made from the same urethane that the thumb is made from and are connected by roll pins. They are kept in extension with the help of a spring similar to the thumb's spring. See *figure 04* above.

One of the key elements of this project was the mechanics and control of the fingers. Each finger has three D.O.F., but only two are controlled. This element of having control over two D.O.F. for each finger allows for a more intense manipulation of an object. The most proximal joint of the finger is directly controlled, as is a coupling motion of the two distal joints.

To allow for a more precise measurement of the angle of bending across the robot's knuckles, bend-sensors are placed across the controlled articulations of the fingers. This

presents a feedback system such that the robot's fingers will be held in check throughout their motion. This form of control was expressed in detail under *Control System*.

3.2 Articulation

Prominent features of the hand are its individual finger and joint manipulation. Individual joint manipulation is allowed by driving a finger with two actuators. As stated earlier, one controls the metacarpal-phalangeal joint and the other actuator controls the two distal interphalangeal joints. After having observed that flexion in the normal manner of the distal interphalangeal joint does not exist without flexion of the proximal interphalangeal joint in our own finger, shims were placed between the proximal interphalangeal links. Doing so ensures that the proximal interphalangeal joint closes before or at the same time as the distal interphalangeal joint. In short, the shims give a mechanical advantage to the proximal interphalangeal joint.

As shown in *figure 05*, the fingers are controlled by two servos for greater command. In the following, we will describe articulations of the finger.

Flexation occurs at the metacarpophalangeal joint of the finger by means of the microprocessor signaling servo **B** to move a specified amount depending on the bend sensor placed across the corresponding joint of the hand. When servo **B** rotates the actuator cable contracts and the joint rotates. This process of contraction is depicted in step 4 of *figure 05*.

Flexation at the interphalangeal joint is dependent upon servo **B**. Servo **B** supplies actuations to both of the interphalangeal joints. This process of contraction is depicted in steps 2 through 3 of *figure 05*.

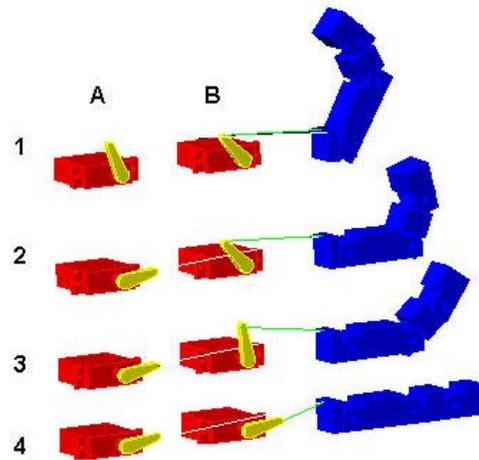


Figure 05 Animated sequence of finger articulation.

A spring extends over the joints on the dorsal side. The end of actuator cable **B** is attached to the middle of distal link. The end of actuator cable **A** is attached to the middle of the proximal link.

Extension of the finger is caused by the reverse action of the servo(s) whereby causing the actuator cable(s) to release. The release of the tension applied by the servo(s) cause the spring to return to their static position. The cable and spring system is considered to be a reverse biased system, where angular motion is dependent upon the tension applied to the cable.

The second and third fingers are designed in the exact same fashion as the index finger is.

4 Electronics

4.1 Microprocessor

The microprocessor used is the MC68HC11E9 produced by Motorola. Its general description is termed by what follows:

- Advanced 8-bit micro controller
- 2 MHz bus speed
- On-chip 12K bytes ROM
- On-chip 512 bytes EEPROM
- On-chip 512 bytes RAM
- Expanded 64 K bytes RAM
- Eight-channel analog-to-digital converter (8-bit resolution)

Two microprocessors have been used to control the fingers, thumb, and wrist.

4.2 Sensors

4.2.1 Bend Sensor

Bend sensors, also known as flex sensors, are four inches long by one-quarter inch wide by one-sixty fourths inches thick.

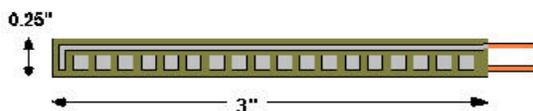


Figure 06 Bend sensor depicted above (approx. size).

When unbent at 0° , it has a nominal resistance of $4k\Omega$. As it is bent more and more, the resistance increases up to approximately $50k\Omega$ at 90° . Since these sensors display resistance values that vary linearly with the angle of bending, we are able to control flexing of the fingers.

4.1.2 Sensor Circuitry

A voltage divider circuit was used to send a usable voltage signal to the A-to-D converter of the MSCC11, PortE0-E7.

4.3 Servos Characteristics

Eight Hi-TECH 81MG 40oz.-in servos control the first, second, and third fingers as well as the thumb. (length x width x height).

4.4 Software

The programming language used to control High-FIVE is Interactive C Compiler produced by Image Craft Inc. and Christine, Copyright © 1994-1998. The control of the flow of the program is based upon while, if, then, else statements.

5 Conclusion

We demonstrated that with readily available sensors and servomotors, a multiple-fingered robotic hand can be constructed at minimal cost. The ten degree of freedom manipulator hand is dynamically controlled by an operator's sensory glove. Its high operability and durability demonstrate its potential use in the field of robot exploration.