High-FIVE

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Abstract

Robots have all along been slave to their programmers. They are told to build, weld, carry, retrieve, grasp, rotate, recognize, and move many different objects they interact with. The human hand is the master of all tools. The hand is able to grasp any object within a reasonable size and manipulate it as the brain sees fit. Equipping a robot with human like hands expands its capability, thereby increasing the expectations of its master, the programmer. High-FIVE is not intended to be the final answer towards a robotic human hand, but yet a simpler step along that path. High-FIVE is equipped with four fingers, thumb, wrist, and forearm. It performs in two distinctly different modes. The first and foremost is a remote controlled mode where its operator’s hand is inside of a sensor-laced glove. Movements made by the user are mimicked in real time by High-FIVE. A secondary mode enables the robot to interact with its environment. Whether it is a screwdriver, baseball, or block, High-FIVE should be able to decide what type of elementary object it is dealing with (i.e. sphere, block, or cylinder) and grasp it accordingly. Other behaviors include friend or foe recognition, dangerous temperature response, and a light follower. Through diverse operational modes, robust construction, and simple programming code, High-FIVE is dynamic, durable, and most of all cheap. Just as computers dominated the end of the 20th century, robots will dominate the 21st century and beyond. Let’s give them hands!

Executive Summary

High-FIVE is an autonomous robotic human hand that responds according to its environment. There are two modes of operation in which High-FIVE is comfortable in working in. In autonomous mode, he responds mostly to forces applied by the environment to specific areas of his hand. For example, if High-FIVE were in a business setting a coworker might shake High-FIVE's hand after a job well done. In response to this peaceful gesture, the robotic hand squeezes the coworker's hand. The second mode of operation is the remote controlled mode where the robotic hand is entirely under the operation of the user who wears a sensory glove. Under this mode, the user is able to move all four of fingers and thumb. Having two modes of operation enables High-FIVE to be a well-rounded robot.

The fingers and thumb have three degrees of freedom (dof). They are constructed from bicycle chain, hot glue, nut/bolt assy., springs, and hard plastic tubing. The palm is made from nylon, wood, hot glue, nut/bolt assy., aluminum, and hard plastic tubing. The palm was milled from one piece of nylon. Aluminum, nylon, nut/bolt assy., and wood have been implemented in the construction of the forearm. Lastly, the control box houses the MSCC11, two 6ea. AA battery packs, four mode control switches, one reset button, and one run/download switch. The face of the control box is removed by way of two removable hinges.

The entire cost of the project was roughly \$260 ±10%. The ±10% is projected for the reason that some of the parts were free and some were surplus. This does not take the force sensing resistors into consideration since all seven of them were given away free as samples.

High-FIVE was entered into the Second Annual University of Florida Biomedical Engineering Design Competition earlier this year in March of 2000 as a Multifingered Prosthetic Human Hand. At that point only four fingers were attached to the palm. High-FIVE came in third place after having competed against one Virginia Polytech team, six Duke teams, and one UF team.

Introduction

Ever since my parents took me to Walt Disney World I have been fascinated by animatronics and the ability to recreate the human form with life like dynamics. For the past two year prior to taking EEL5666 I continued that wonder and amazement in my sketchbook designing fingers and their actuation mechanisms. After have taken EEL4744, Microprocessor Applications, I realize the infinite uses that a microprocessor has and decided to take a first step towards creating an artificial human being by designing and building a multifingered human hand. The main focus of this project is to design and build a multiple fingered controllable robotic human hand with the ability to switch between remote control and autonomous control. The cost should be kept to a minimum and the system should be durable and robust.

The topics of discussion will flow in a general manner. A breakdown of the integrated system is discussed first and is followed by a description of the platform. One of the key areas in which a great deal of time was spent was the actual physical design and actuation. Sensors and behaviors will follow actuation and mechanical design.

Integrated System

System Description

High-FIVE can be broken down in to three separate areas: Central Processing Unit (CPU) also known as the microprocessor, Remote Control Sensory Glove, and Robotic Human Hand. Below in illustration 01, a functional flowchart reveals how High-FIVE interacts with its user and the environment in remote control mode and autonomous mode respectively.

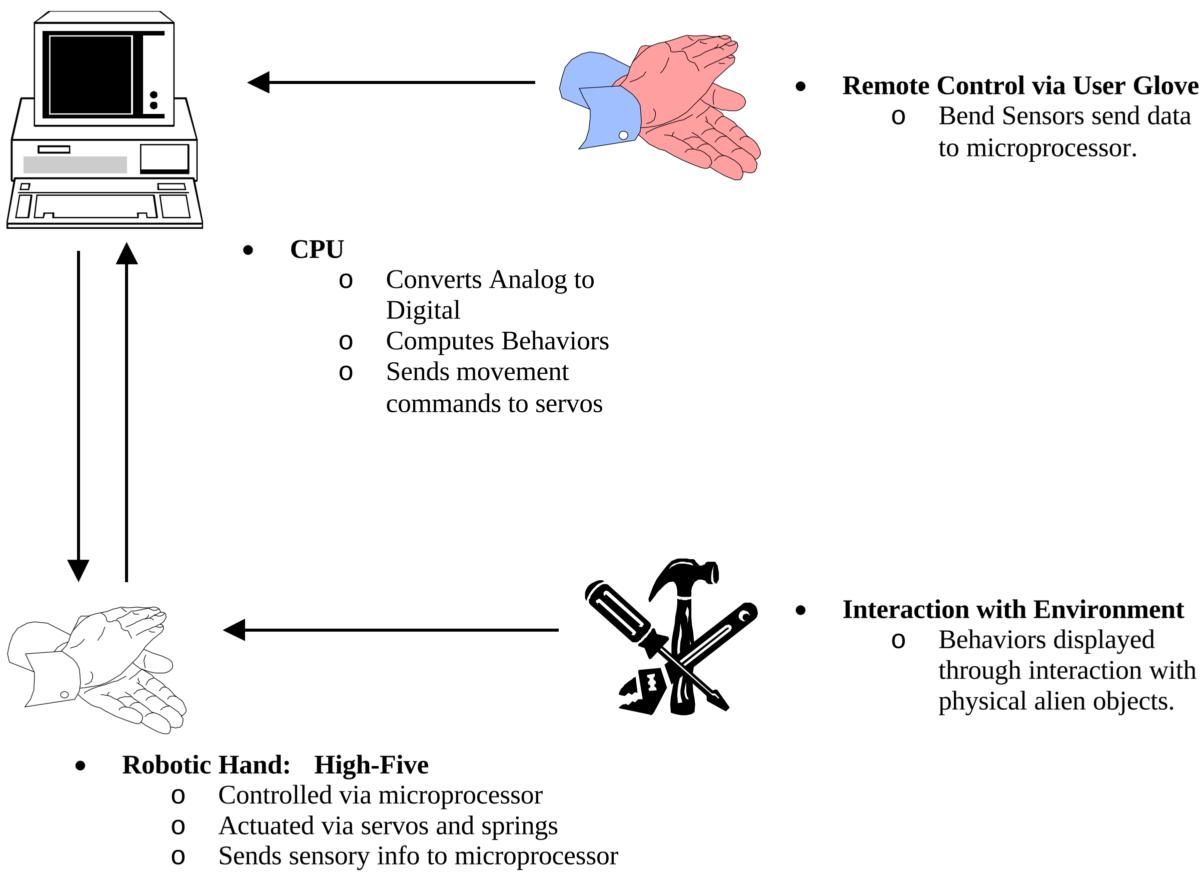


Illustration 01
Functional flowchart revealing how High-FIVE interacts with its user and the environment. Top right hand corner depicts the robots CPU. The colored hands represent the users hand with control glove. Black and white hands represent the robot.

Theory of Operation

Two modes of operation enable High-FIVE to be versatile without regard to its environment.

- **Autonomous Mode**
  While in the *Interaction with Environment* mode, High-FIVE displays all of its behaviors depending on what comes into contact with it.

- **Remote Control Mode**
  High-FIVE does not display any of its behaviors while in *Remote Control* mode. As stated, this mode of operation enables the robot to be controlled remotely through the use of an operator's glove. The glove is equipped with bend sensors along the fingers allowing analog positioning data to be passed to the robot's microprocessor. Positioning (angular rotation) information is then sent from the microprocessor to servos within High-FIVE's forearm. The servos actuate the fingers and thumb according to the movements of the user's hand.

Block Diagram

Below in illustration 02, a diagram describing the system operation is more detail.

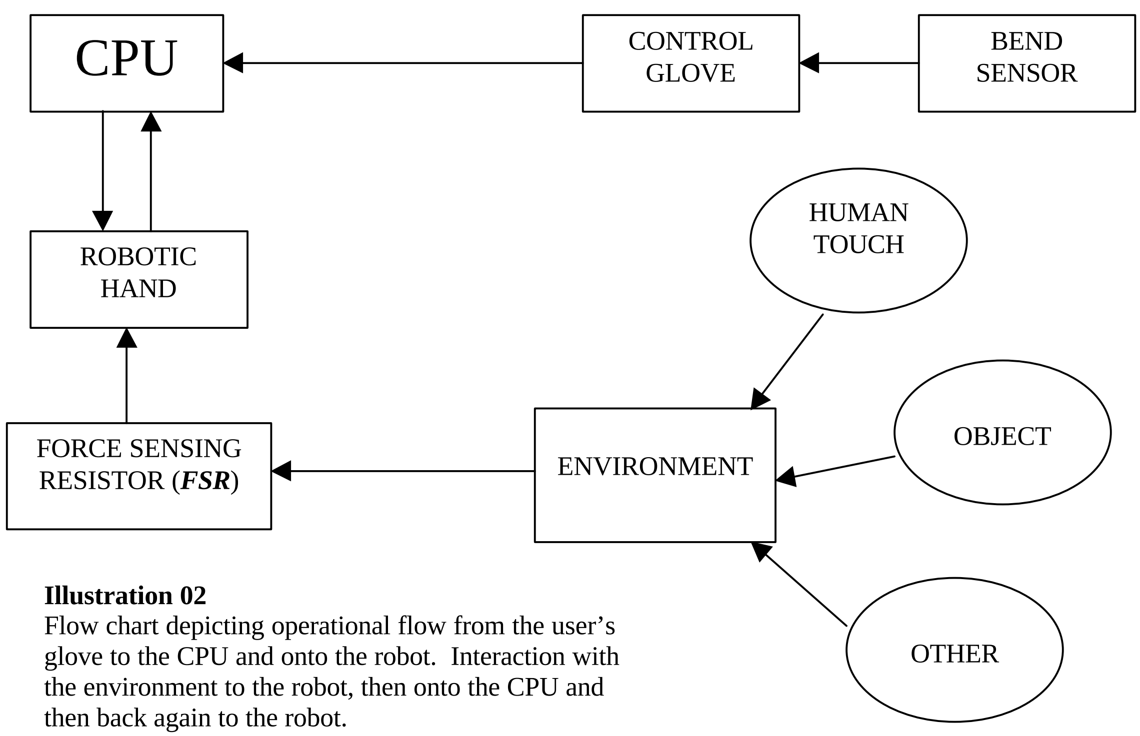


Illustration 02
Flow chart depicting operational flow from the user's glove to the CPU and onto the robot. Interaction with the environment to the robot, then onto the CPU and then back again to the robot.

Platform

Scope and Objective

One of the primary objectives concerning the physical aspects of High-FIVE is its appearance to represent the form of the human hand. High-FIVE needs to be robust with respect to the mechanics within its dynamic joints. The structure should be durable enough to interact with many small objects that a human hand might come into contact with throughout a typical day.

Specification

- **Palm**
  The palm houses the servo for the thumb. Two 1.5” X 1.5” *FSRs* are located on the ventral side of the palm for interaction with the environment. It is constructed from nylon and wood. A silicon skin to protect the FSRs covers the surface of the ventral side.

- **Fingers**
  The human hand has four fingers, so to does High-FIVE. Its fingers will be comprised of three joints; distal interphalangeal, proximal inter-phalangeal, and metacarpo-phalangeal joint. They are made from bicycle chain, springs, yellow plastic tubes, and hot glue. Two 0.5” in diameter *FSR*s are located on both the index and the middle finger.

- **Thumb**
  This finger is much more complicated than the other four. High-Five’s thumb exhibits only one-axis of motion. This results in a false resemblance of the human hand’s functionality with respect to its opposable thumb. However, High-FIVE operates very well with out this feature. Like the fingers, the thumb will also be made of bicycle chain, springs, yellow plastic tubes, and hot glue.

- **Wrist**
  Two-axis of motion is desirable. However, the wrist of High-FIVE is static. Future work will include a working wrist.

Design

Palm and Thumb

The palm was milled from a block of nylon approximately 5" X 4" X 1". The slots shown at the top of the palm in figure 01 are for attachment of the proximal ends of the fingers. The servo shown actuates the thumb.

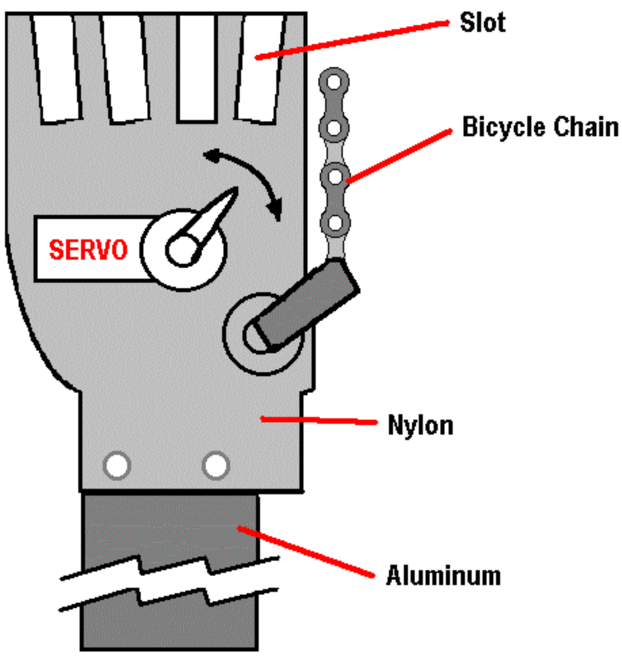


Figure 01 Palm made from nylon. Thumb built from ball-and-socket joint of table leg.

Fingers

The figure below is a representation of the index finger.

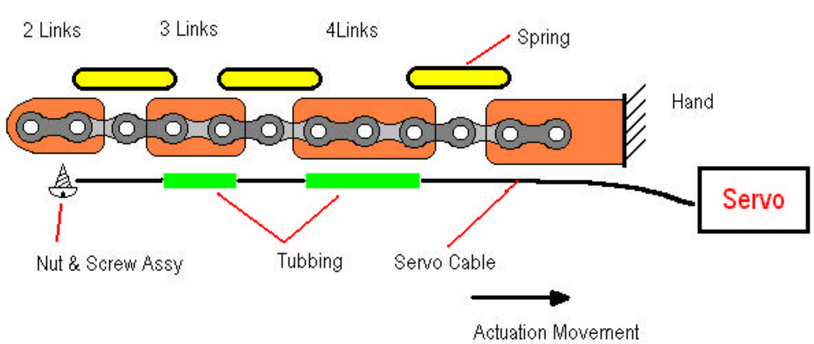


Figure 02

Lessons Learned

- **Palm / Silicone Skin**
  On the ventral side of the palm is a silicone "skin". The "skin", which I have called it, describes a texture that is soft, rubbery, and gives resistance when pushing an object across its surface. My initial attempt was with an "almond" colored silicone. I used a caulk gun to apply the silicone across a plate of aluminum. I though I would be able to remove the hardened silicone, but it only stuck to the aluminum. It was later found that almond colored silicone doesn't stick to paper. Clear silicone adheres to just about everything, so I applied it to a piece of clear plastic from the inside of a notebook and did not remove the silicone from the clear plastic. Index cards work well for spreading the caulk. The top eighth inch of silicone dries while the remaining silicone beneath it remains unhardened.

- **Fingers**
  The springs that span across the joints of the hand were all hand made. The installation process was a rigorous one for the reason that the points of installation had to be reheated so that the hot glue would melt. The fingers took the majority of the construction time. A better construction method should have been taken. A design that didn't involve hot glue would have given more leeway with respect to time management and design constraints.

- **Thumb**
  The thumb has two springs similar to the other fingers, one across the interphalangeal joint and the other across the metacarpo-phalangeal joint. The metacarpal bone of the thumb was constructed from a leg "ball and socket" base from a table.

Actuation

Mechanical Dynamics

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.

In order to minimize the complexity of the robotic hand design, I decided to implement the multiple hinge joints of a bicycle chain as synovial joints in the hand. A bicycle chain provides greater movement in one plane with very little lateral movement.

Bicycle chain links are welded together at various joints in order to simulate varying lengths of phalangeal bones. Figure 03 is an enlarged bicycle chain link with measurements in inches. A link is considered one pin-to-pin measurement of 0.50 inches.

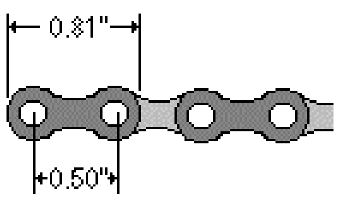


Figure 03 Three bicycle chain links.

For example, as shown in figure 04, the phalangeal bone in the first row of the index finger, phalanx 1, consists of four links measuring 2.00 inches (50.80 mm) similar to that of an adult male measuring 1.75 inches (44.45 mm). The other phalangeal bones of the fingers and the two of the thumb are designed in the same manner as the index finger. The illustration below shows the index finger made from varying lengths of bicycle chain. (See table 01 for measurements.)

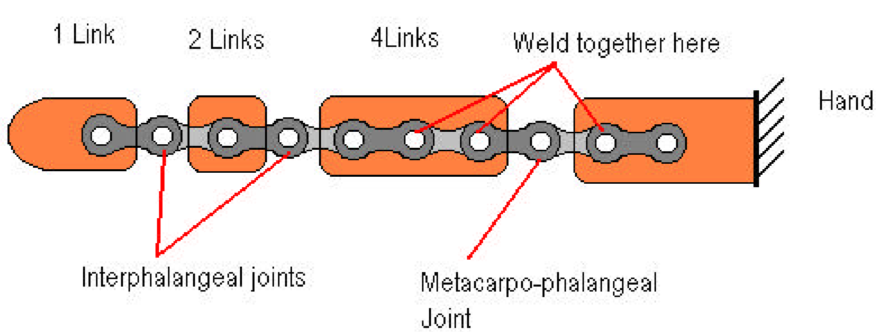


Figure 04 Representation of index finger with interphalangeal and metacarpo-phalangeal joints.

Phalangeal Lengths

	Index (inch)	Middle (inch)	Ring (inch)	Pinky (inch)
Phalanx 1	1.75	2.00	1.75	1.47
Phalanx 2	1.00	1.25	1.13	0.88
Phalanx 3	1.00	1.13	1.13	1.00
Total Length	3.75	4.38	4.00	3.35

	Thumb (inch)
Metacarpal	1.47
Phalanx 1	0.88
Phalanx 2	1.00
Total Length	3.35

Links Used

	Index (inch)	Middle (inch)	Ring (inch)	Pinky (inch)
Phalanx 1	2.00	2.00	2.00	1.50
Phalanx 2	1.00	1.50	1.00	1.00
Phalanx 3	0.50	1.00	0.50	0.50
Total Length	3.50	4.50	3.50	3.00
Total Links	**7**	**9**	**7**	**6**

	Thumb (inch)
Phalanx 1	1.00
Phalanx 2	1.00
Total Length	2.00
Total Links	**4**

Table 1 Measurements of human and robotic phalanges in units of inches.

Fingers

The most difficult part of the hand to mimic is the complex and unique features of its fingers. The thumb 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 metacarpo-phalangeal 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. In order to recreate the capability of the thumb, we have decided to use a more complex ball-and-socket joint. The “ball” of the ball-and-socket joint is located at the carpal extremity of the metacarpal. The metacarpal is made from the threaded end of the ball-and-socket joint. The phalanges are made of bicycle chain links of varying lengths. The other fingers of the hand are made similarly from bicycle chain.

Joints of the Fingers and Thumb

Metacarpo-phalangeal and interphalangeal joints are subject to constraints dependent upon their purpose. Metacarpo-phalangeal joints of the fingers move in the following motions: flexion, extension, adduction, abduction, and circumduction. It is very important to note that the lateral movements of the fingers are limited to a greater degree unlike that of the thumb.

Springs of varying strengths are used for the motion of extension and to limit the range of extension. The ends of the spring(s) are attached to what may be called the extremities of the phalange(s) and/or metacarpal.

After having observed that flexion in the normal manner of the distal interphalangeal joint does not exist without flexion of the proximal interphalangeal joint, a weaker spring was installed on the proximal and a stronger spring on the distal. Doing so ensures that the proximal interphalangeal joint closes before or at the same time as the distal interphalangeal joint.

Force and Torque Calculations at Finger Joints

Using pennies as a mass standard, twisty ties and small plastic sandwich bags, measurements have been made. The mass of a penny is 0.0025Kg and won't be changing any time soon. The bags were attached at ends of each particular moment arm of the finger (the ends of the phalangeal bones).

Joint Dynamics

US one cent

Mass (kg)	0.0025
Gravity (m/s^2)	9.8

Note: 1inch = 25.4mm

Equations

Force	(Newtons)	F = m*g
Torque	(Newton*Meters)	T = F*d

LIMIT:

OVER EXTENTION LIMIT

Joint	Pennies	Mass (kg)	Force (N)	Distance (inches)	(meters)	Torque (Nm)
Jmp	150	0.38	3.68	2.00	0.051	0.19
Jipp	50	0.13	1.23	1.25	0.032	0.04
Jipd	70	0.18	1.72	1.00	0.025	0.04

CONTRACTION LIMIT

Joint	Pennies	Mass (kg)	Force (N)	Distance (inches)	(meters)	Torque (Nm)
Jmp	30	0.08	0.74	2.00	0.051	0.04
Jipp	40	0.10	0.98	1.25	0.032	0.03
Jipd	30	0.08	0.74	1.00	0.025	0.02

Joints	
Jmp	Metacarpo-phalangeal Joint
Jipp	Interphalangeal Proximal Joint
Jipd	Interphalangeal Distal Joint

Table 02 Force and Torque measurements of the joints of the finger.

Mechanical Dynamics

See figure 05 for contraction and extension description of the finger.

A Extension
B Contraction
C Full Contraction

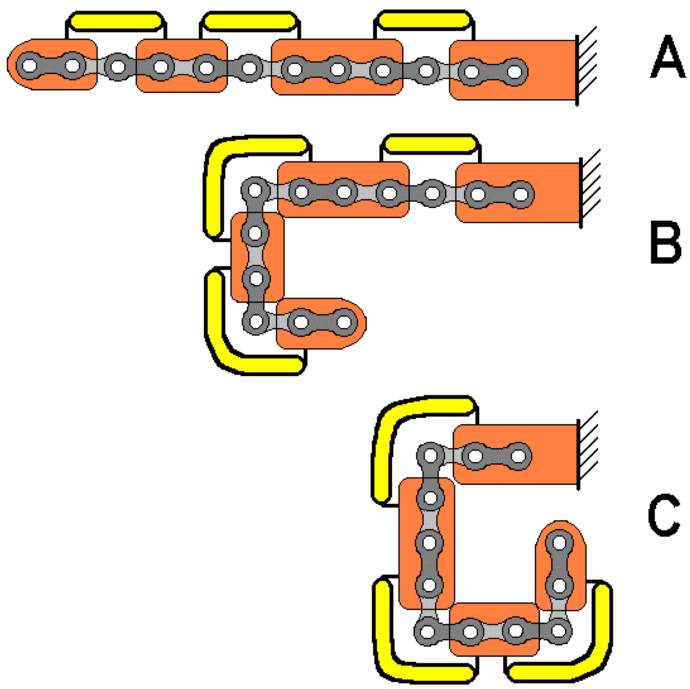


Figure 05 Finger extension and contraction.

Characteristics of Servos

Six 40oz.-in servos control the pinky, ring, middle, and index fingers. One servo of the same size controls the thumb from within the palm. The size of these servos is $1^{20}/_{32}$ x $^{25}/_{32}$ x $1^{24}/_{32}$ inches (length x width x height).

Sensors

Bend Sensor (A.K.A. Flex Sensor)

Sensor

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

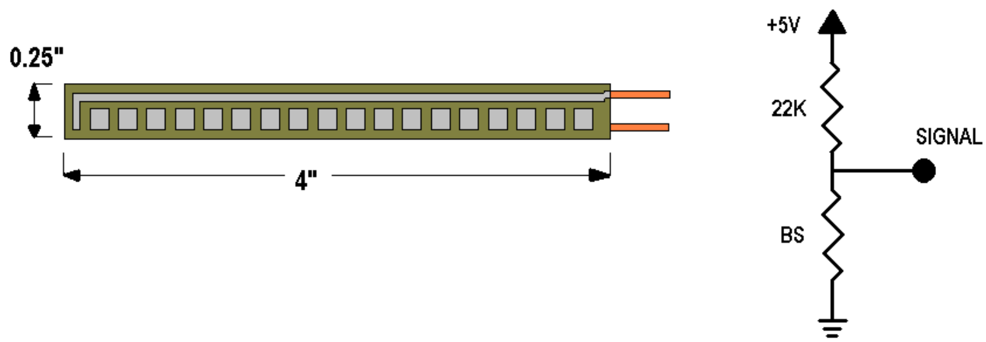
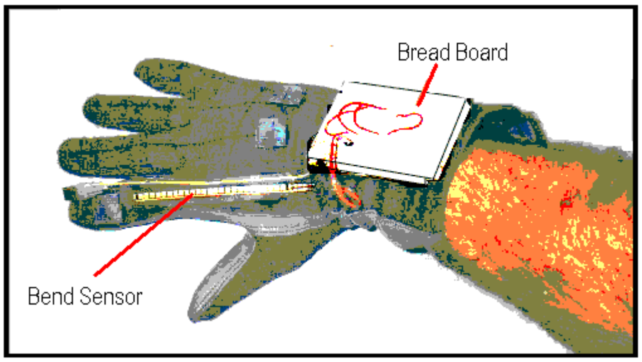


Figure 06 Bend sensor depicted above (actual size).

When unbent at 0°, it has a nominal resistance of 12 kΩ. As it is bent more and more, the resistance increases up to approximately 30 kΩ 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

Glove

The bend sensors are mounted on a glove. The glove is a military issued "Summer Flyers Glove", made from heat resistant material and leather. Bend sensors are attached to the dorsal side of the glove at specified points. These specified locations are the prominences of the knuckles during metacarpo-phalangeal and third row to second row interphalangeal articulation. The interactive glove was initially equipped with a breadboard located on the dorsal side of the forearm to aid in the ease of prototyping. Picture 01 below shows the glove, a bend sensor, and the prototype board being worn by a hand.



Picture 01 Glove displayed on hand.

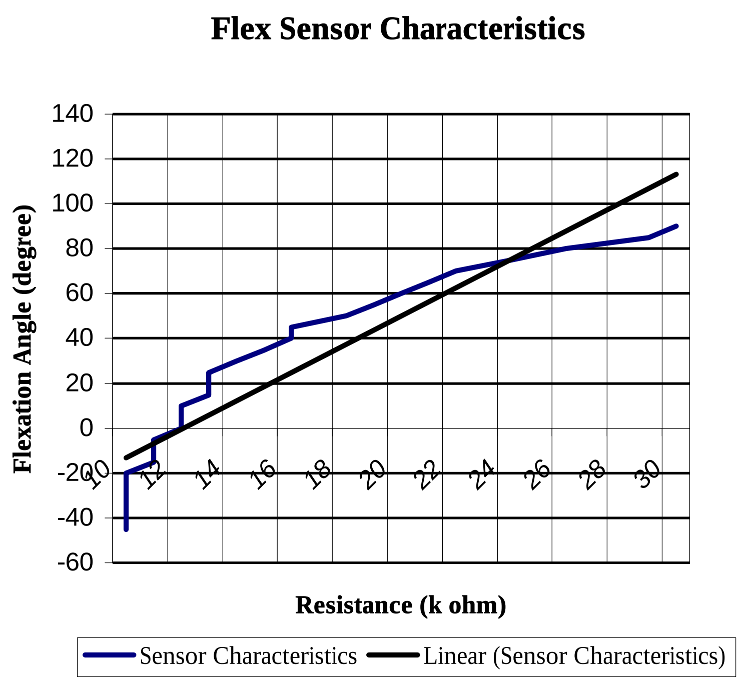
The prototype breadboard was removed and replaced by inline circuitry. The bend sensors are readily attached and removed by way of Velcro.

Statistical data is represented below. Data from the bend sensor was collected in the following manner. First, the terminal end of the sensor is attached to an arbitrary cup of 2.5" radius. Second, a digital multimeter is attached the terminals to read resistance values. Third, the bend sensor is bent at 5° intervals, from -45° to +90°. Lastly the data was recorded in MSExcel, creating a table and a graph that are shown below in D&G 01.

FLEX SENSOR Vendor info: Abrams Gentile Entertainment
(A.K.A. - Bend Sensor)

Size: 4"X0.25"X0.031"
The flex sensor changes resistance when bent. Data has been collected which shows that it is almost linear when bent. This means that as the sensor is bent its resistance changes smoothly and regularly. See data and graph, D&G 01 below.

Angle	Resistance
-45	10.5
-40	10.6
-35	10.7
-30	10.8
-25	10.8
-20	10.9
-15	11
-10	11.3
-5	11.5
0	12
5	12.3
10	12.6
15	13
20	13.5
25	13.9
30	14.6
35	15.1
40	16
45	16.8
50	18
55	19
60	20.1
65	21
70	22.5
75	24.2
80	26.1
85	29.2
90	30.3



D&G 01 Bend sensor characteristics

Force Sensing Resistor (FSR)

A second sensor will be mounted on the tip of each finger. This sensor is 0.5” in diameter and drops in resistance when force is applied. This “force reading” comes in the form of increasing the surface area of contact between the upper layer array and the lower layer array of the force sensing resistor. For example, as pressure is applied with the fingertips of the human hand to the active surface of the *FSR*, the upper layer approaches the lower layer. As more pressure is applied, the contact area within the active area is increased, thereby increasing the conductivity from one terminal to the other. When conductivity is increased, the resistance decreases. After having implemented the FSRs in my design, I am very pleased with the smoothness of their response. If I didn’t know about these sensors my project would have been a flop with respect to the autonomous issue. All seven were donated to me as free samples from Interlink Electronics (interlinkelectronics.com) CA, USA.

The weaknesses of the *FSR* are its delicate structure, unreliable values and inability ability to be mounted easily. Its properties along with its weaknesses are discussed below.

Delicate Structure

Due to the size and purpose, the 0.5” diameter *FSR* poses some robustness problems. As seen in figure 07, the 0.5” dia. *FSR* is very small. This particular sensor will be mounted on the tips of the fingers of High-FIVE to sense force applied.

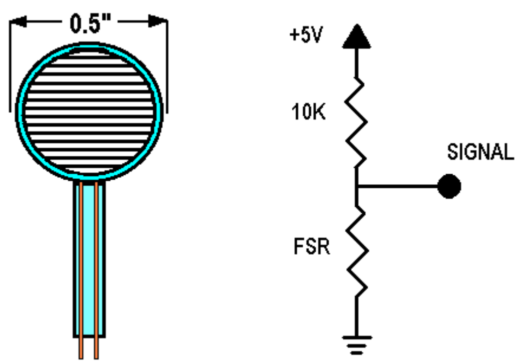


Figure 07 Approximate size of 0.5” dia. *FSR*.

Unreliable Values

Although only one round of testing has been performed, it is predicted that continuous force sensing data will remain somewhat sporadic. However, it is noted that data collection with a certain “type of skin” has shown to be less rampant, data was less scattered. Below in D&G 02, note that at 20 pennies (0.050 Kg), a threshold was passed. Any value less than 20 pennies resulted in infinite resistance.

<u>Data Collection Results</u>

As seen in the D&G 02, the characteristics are quite linear between 17.6 N and 8.5 N of force.

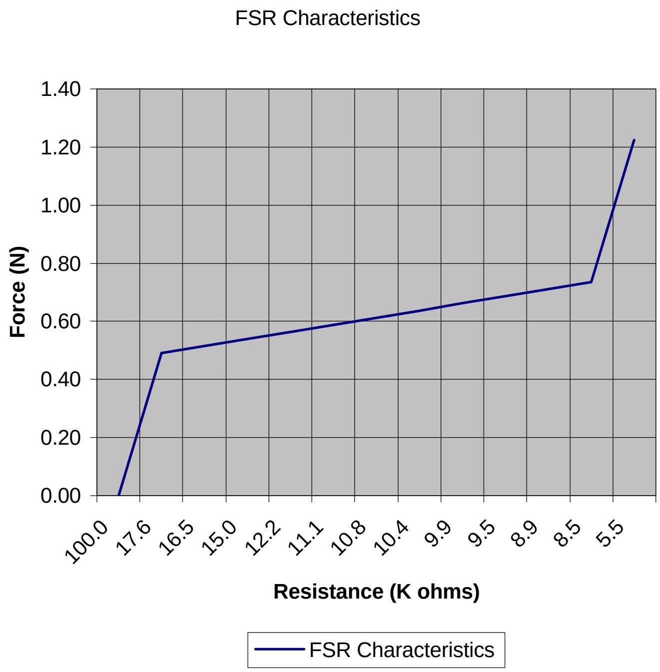
Force Sensing Resistor (*FSR*)

US one cent

Mass (kg)

Gravity (m/s^2)

Pennies	Mass (Kg)
0	0.000
20	0.050
21	0.053
22	0.055
23	0.058
24	0.060
25	0.063
26	0.065
27	0.068
28	0.070
29	0.073
30	0.075
50	0.125



D&G 02 Force calculations using pennies and a 0.5" dia. *FSR*.

However, the geometry of the surface applied to the surface of the *FSR* plays a major part in determining the resistance at the terminals. The geometry is discussed in the following section.

<u>Types of Skin</u>

In order to recreate a life-like human hand a texture that might resemble that of the human hand needs to be implemented on the surface of High-FIVE. Silicone is being used not only to give the robot a realistic texture but also a dynamic sense of touch that improves its force sensor readings. Below in figure 08 are a few examples of skins that were tested. The figure at the top was implemented using hot glue; this design was used.

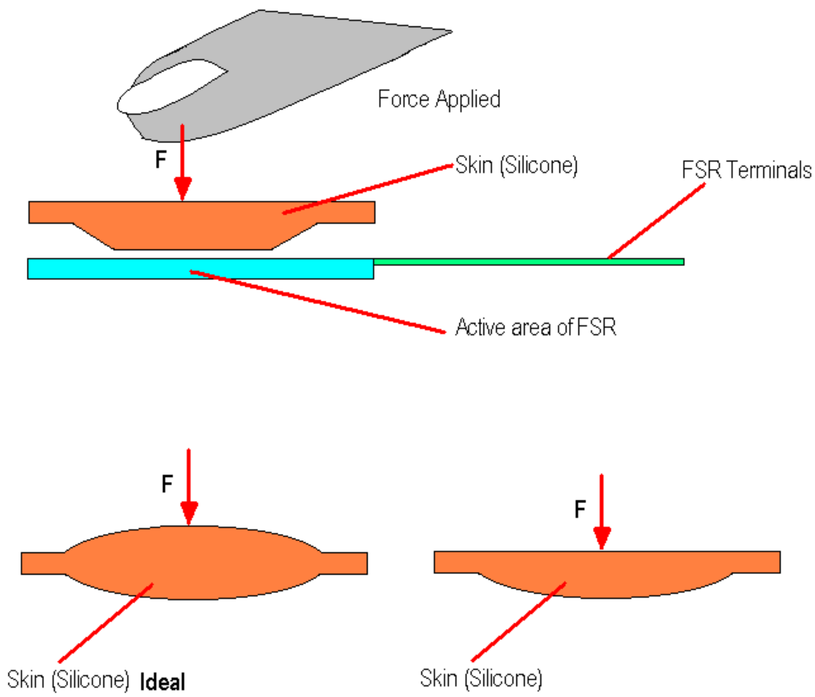


Figure 08 Types of skins used while testing *FSR*.

Hard to Mount

Because of its size, the 0.5" dia. sensor was difficult to mount on the tips of the fingers. A mounting bracket might be created, housing the sensor and the skin. The entire bracket would be then mounted on to the fingertips. The 1.5" X 1.5" square *FSR* was mounted on the inner and outer ventral side of the palm and are removable by way of Velcro.

Behaviors

Interaction with Environment

- **Squeeze My Hand**
  Small objects such as tennis balls and 2inch blocks are recognizable by the final form of High-FIVE's fingers.

- **Force Finger**
  An important aspect of artificial intelligence is how well a robot interacts with humans. By touching the tips of the middle and ring finger, High-FIVE makes a peace sign. On the other hand, if you touch the middle finger, an angry fist will form.

- **In My Hand**
  High-FIVE doesn't like temperatures that might melt its skin. Upon sensing a predetermined temperature threshold, High-FIVE moves its fingers back away from hot objects.

Conclusion

In summary, attainable goals were set and were fulfilled. Since the highest priority was set on High-FIVE's remote control system I was able to continue on with the project after realizing that my final goal was within reach. Once the force sensing resistors were incorporated the behaviors were readily changed and re-administered to the microprocessor. With expanded memory, High-FIVE would be able to perform may behaviors well beyond the required amount.

Appendices

Program Code

When downloaded, dday.c is approximately 1850 bytes. The MSCC11 can hold up to 2000 bytes of information in its ROM.

```
/*****************************************************************/
/*  Peach, Jack                 04/22/00   4:30am
            */
/*          High-FIVE           EEL5666            SP00
            */
/*
                                                   */
/*          c:\ICCTJ\examples\dday.c
            */
/*          Switch between Remote and Autonomous modes (4 Behavors)          */
/*
                                                   */
/*****************************************************************/

void main()
{

/*******  Initialization  *******************************************/
            init_analog();
            init_servos();
/*****************************************************************/

while(1)
 {

/********  Variables for Equations  *********************************/
int         A,      /*      A = ((20 * fs1a) + 7000);     /*Fmin=400          Fmax=3800     */
            B,
            C,
            D,      /*      D = ((20 * fs2b) + 7000);     /*Fmin=400          Fmax=3800     */
            E,      /*      E = ((20 * fs3a) + 7000);     /*Fmin=400          Fmax=3800     */
            F,
            X;      /*      X = ((20 * fs1b) + 7000);     /*Fmin=400          Fmax=3800     */
/********  End Equations  *******************************************/

/********  Force Sensing Resistor (FS)  *****************************/
int         FS1,    /* Thumb(tip) -> PE0  */
            FS2B,   /* Index(tip) -> PE1  */
            FS2A,   /*              (mid) -> PE2       */
            FS3B,   /* Middle(tip)-> PE3  */
            FS3A,   /*              (mid) -> PE4       */
            FS1B,   /* Palm(inner)-> PE5  */
            FS1A,   /*    (outer)-> PE6   */
            MODEs;  /* Switch between Remote and Autonomous MODEs    *********/

/*          Inverted Force Sensing readings */
int         fs1,
            fs2b,
            fs2a,
```

```
		fs3b,
		fs3a,
		fs1b,
		fs1a;
/**********************************************************************/

/******* Bend Sensors (BS) ****************************************/
int BS4A_0,			/* Ring	(base)	-> PE0*/
		BS4B_1,		/* Ring&Pinky		-> PE1*/
		BS3A_2,		/* Middle (base)-> PE2*/
		BS3B_3,		/* Middle (mid)		-> PE3*/
		BS2A_4,		/* Index (base)		-> PE4*/
		BS2B_5,		/* Index (mid)		-> PE5*/
		BS1_6;		/* Thumb (base)		-> PE6*/

/******* Inverted Bend Sensor readings ****************************/
int		bs4a,
		bs4b,
		bs3a,
		bs3b,
		bs2a,
		bs2b,
		bs1;
/**********************************************************************/

/******* Get Sensory Signals (FSR & BS) ****************************/
/*		Take continuous Force Sensor readings from robot hand.		*********/
		FS1A = analog(0);	/* Outer Palm		*/
		FS1B = analog(1);	/* Inner Plam		*/
		FS3A = analog(2);	/* Middle (mid)		*/
		FS3B = analog(3);	/* Middle (tip)		*/
		FS2A = analog(4);	/* Index (mid)		*/
		FS2B = analog(5);	/* Index (tip)		*/
		FS1 = analog(6);	/* Thumb (tip)		*/

		MODEs = analog(7); /* Switch between Remote and Autonomous MODEs*/

		fs1a = (-FS1A);
		fs1b = (-FS1B);
		fs3a = (-FS3A);
		fs3b = (-FS3B);
		fs2a = (-FS2A);
		fs2b = (-FS2B);
		fs1 = (-FS1);

/*		Take continuous Bend Sensor readings from sensory glove.*********/
		BS4A_0 = analog(0);
		BS4B_1 = analog(1);
		BS3A_2 = analog(2);
		BS3B_3 = analog(3);
		BS2A_4 = analog(4);
		BS2B_5 = analog(5);
		BS1_6 = analog(6);

/*		Inverted Bend Sensors readings ***********************************/
		bs4a = (-BS4A_0);
		bs4b = (-BS4B_1);
		bs3a = (-BS3A_2);
		bs3b = (-BS3B_3);
		bs2a = (-BS2A_4);
		bs2b = (-BS2B_5);
		bs1 = (-BS1_6);
```

```
/*******  Equations  ************************************************/
            A = ((20 * fs1a) + 7000);       /*Fmin=400                  Fmax=3800                      */
            D = ((20 * fs2b) + 7000);       /*Fmin=400                  Fmax=3800                      */
            X = ((20 * fs1b) + 7000);       /*Fmin=400                  Fmax=3800                      */
            E = ((20 * fs3a) + 7000);       /*Fmin=400                  Fmax=3800                      */
/*********************************************************************/

/*********************************************************************/

/********    ***    ***********************************************/
/*****              ********************************************/
/****  REMOTE CONTROL MODE  ******************************************/
/*****              ********************************************/
/********    ***    ***********************************************/


if (MODEs > 100)      /* If MODEs is LOW then the Remote mode is                  */
                                          /*  selected.
                            */
 {
            servo(0, ((12 * BS4A_0) + 1700));         /* Move S4A                              */
            servo(1, ((12 * BS4B_1) + 2000));         /* Move S4B                              */
            servo(2, ((12 * BS3A_2) + 1500));         /* Move S3A                              */
            servo(3, ((12 * BS3B_3) + 1000));         /* Move S3B                              */
            servo(4, ((12 * BS2A_4) + 2000));         /* Move S2A                              */
            servo(5, ((12 * BS2B_5) - 200));  /* Move S2B                        */
            servo(6, ((12 * BS1_6) - 500));           /* Move S1                                        */
 }

/********   ***   ***************************************************/
/*****            ************************************************/
/****  AUTONOMOUS MODE  **********************************************/
/*****            ************************************************/
/********   ***   ***************************************************/


/***              ********************************************/
/***** BEHAVIOR NUMBER 1 *********************************************/
/***              ********************************************/
/*          DESCRIPTION:
                            */
/*
                                          */
/*          THE GOAL:
                                    */
/*          All fingers contract depending on the force applied to the INNER*/
/*           PALM.  If the human hand squeezes High-FIVE's hand tightly,    */
/*           then High-FIVE will squeeze back with the same force if not    */
/*           more.
                                    */
/*********************************************************************/

else if (X > 3000)      /*  3000 is a predetermined threshold                  */
                                          /*  NOTE: A=((20*fs1a)+7000)
            */
                                          /*  Where Fmin=400 and Fmax=3800
            */
                                          /*          These values are equ to servo positions    */
 {
            servo(0,((15 * fs1b) + 5500));
```

```
            servo(1,((12 * fs1b) + 6000));
            servo(2,((10 * fs1b) + 5500));
            servo(3,((10 * fs1b) + 5500));
            servo(4,((10 * fs1b) + 5500));
            servo(5,((8 * fs1b) + 5000));
            servo(6,((8 * FS1B) + 500));
 }


/***                  ******************************************/
/***** BEHAVIOR NUMBER 2 ********************************************/
/***                  ******************************************/
/*
                                                            */
/*          THE GOAL:
                                                 */
/*          All fingers contract depending on the force applied to the OUTER*/
/*           PALM FSR (fs1a).  If the force is great enough to over come a    */
/*           predetermined threshod, then the fingers will contract auto-     */
/*           matically and hold until fs1b (Inner Palm FSR) is sensed              */
/*******************************************************************/

else if (A > 3000)      /*  3000 is a predetermined threshold                    */
                                                 /*  NOTE: A=((20*fs1a)+7000)
            */
                                                 /*  Where Fmin=400 and Fmax=3800
            */
                                                 /*           These values are equ to servo positions      */
 {
            B = (0);
 do
  {
             B = B + (1);
             C = (B + 8000);
             F = (-B);
             servo (0, (C / (4)));   /* Ring Metocarpo-phalangeal                        */
             servo (1, ((C / (4)) + 900));       /* Ring Interphalangeal                        */
             servo (2, ((C / (4)) + 600));       /* Middle Metocarpo-phalangeal  */
             servo (3, ((C / (4)) + 900));       /* Middle Interphalangeal               */
             servo (4, ((C / (4)) + 600));       /* Index Metocarpo-phalangeal   */
             servo (5, ((C / (4)) + 900));       /* Index Interphalangeal                */
             servo (6, ((F / (4)) + 3000));      /* Index Interphalangeal          */
            }
 while (B < 7000);

/*******  Return fingers to Extension  ****************************/
             servo (0, 2500);      /* Ring Metocarpo-phalangeal                        */
             servo (1, 3000);      /* Ring Interphalangeal                                          */
             servo (2, 3000);      /* Middle Metocarpo-phalangeal                      */
             servo (3, 3000);      /* Middle Interphalangeal                                 */
             servo (4, 3000);      /* Index Metocarpo-phalangeal                       */
             servo (5, 3000);      /* Index Interphalangeal                                  */
             servo (6, 2000);      /* Index Interphalangeal                                  */
 }


/***                  ******************************************/
/***** BEHAVIOR NUMBER 3 ********************************************/
/***                  ******************************************/
/*          DESCRIPTION:
                                   */
/*          The Index Finger contract depending on the force applied to the    */
```

```
/*              tip of the Index Finger (fs2b).                                          */
/*
                                                  */
/*          THE GOAL:
                                           */
/*          High-FIVE's Index Finger will respond with a                                  */
/*           force equaling the force applied to it by a human Index Finger       */
/*           after passing a predetermined threshold.                                     */
/**********************************************************************/
else if (D > 2200)      /*  2200 is a predetermined threshold                    */
                                                  /*  NOTE: D=((20*fs2b)+7000)
            */
                                                  /*  Where Fmin=400 and Fmax=3800
            */
                                                  /*          These values are equ to servo positions     */
  {
            servo (4, ((20 * fs2b) + 8500));    /* Index Metocarpo-phalangeal*/
            servo (5, ((20 * fs2b) + 8500));    /* Index Interphalangeal         */
  }

/***                   ******************************************/
/***** BEHAVIOR NUMBER 4 ********************************************/
/***                   ******************************************/
/*          DESCRIPTION:
                                     */
/*           An "OK" signal is given when force is applied to the FSR at the*/
/*           base of the Index Finger (fs3a).                                             */
/*
                                                  */
/*          THE GOAL:
                                           */
/*           High-FIVE's Pinky, Ring, and Middle Fingers will remain              */
/*           extended while the Thumb and Index Fingers are       contracted        */
/*           making an "OK" sign
            */
/**********************************************************************/

else if (E > 2200)      /*  2200 is a predetermined threshold                    */
                                                  /*  NOTE: E=(20*fs3a)+7000
            */
                                                  /*  Where Fmin=400 and Fmax=3800
            */
                                                  /*          These values are equ to servo positions     */
            {
            B = (0);
  do
   {
              B = B + (1);
              C = (B + 8000);
              F = (-B);
              servo (4, ((C / (4)) + 600));       /* Middle Metocarpo-phalangeal  */
              servo (5, ((C / (4)) + 900));       /* Middle Interphalangeal              */
              servo (6, ((F / (4)) + 3000));      /* Index Interphalangeal         */
            }
  while (B < 7000);

   }
 }
}
/*** End Main *******************************************************/
```