Human shadowing robotic hand with haptic feedback

ABSTRACT

We have built a robotic hand that returns haptic feedback i.e. a sense of touch to the user. In this project the force applied by the object on the robotic hand will be actively measured and transmitted to the user's hand giving a sense of haptic feedback.

The project consists of two separate entities: the glove and the robotic hand. The glove is worn by the user over the hand, which allows him or her to control the robotic hand's motion in real time. In this way, the user can perform specific tasks, such as grasping an object. The glove is never in contact with any object other than the user's hand. The design does not only allow the user to control the robotic hand remotely, but it also allows the user to actively feel what and when the robotic hand has something in its grasp. Thus, the overall design of our product allows the user to control the robotic hand and retain his or her sense of touch even though there is nothing physically in the user's hand. The final design was not completely functional with wireless as expected; however, the wired version performed perfectly.

INTRODUCTION

The dexterity of the human hand enables us to perform a number of useful everyday tasks such as actively exploring surfaces and grasping and moving objects. Today, technology is advancing and catering to the rapidly increasing human needs. The work done to meet these needs makes life easier every day, and such studies are concentrated in robotic arm studies. Robotic arms work with an outside user or by performing predetermined commands. These are used nowadays in every part of the industry, specifically medical. They contribute in reducing manpower and increasing precision. To make the concept of these robotic arms more fascinating and useful, the concept of haptics is also added. Haptics refers to the sense of touch, which is astonishingly acute and gives us a sense of presence. While rapid progress has been made on the input side (display and sensing technologies), haptic interfaces providing physical feedback to the hand lag in their fidelity. Traditionally, haptic feedback was achieved by connecting vibration motors to the fingertips, but a buzz cannot be mistaken for touch. So, we have attached servo motors to the gloves which pull the string connected to the fingertips and provide a braking mechanism.

Haptic Components of Grasping

The perceptual mechanisms behind the experience of holding an object or exploring the shape and texture of its surface is composed of kinesthetic and cutaneous components [10]. Kinesthetic feedback is based on larger scale forces while cutaneous stimuli are felt by the pressure receptors in the skin, typically in the fingertips. During object manipulation, the typical cycle starts when type 1 fast receptors in the fingertips are excited for about 1 second, indicating the contact boundary of an object [11]. After initial contact, kinesthetic forces are transmitted through the joints and muscles, informing us of relative limb and finger positions through the sense of proprioception.

Kinesthetic and cutaneous channels work in tandem to provide an accurate sensation of touch [12] that also acts as a feedback loop to accurately control the grasping force exerted on an object [13].

PROBLEM STATEMENT

To make a mechanical arm which mimics a real human hand and, also provides haptic feedback.

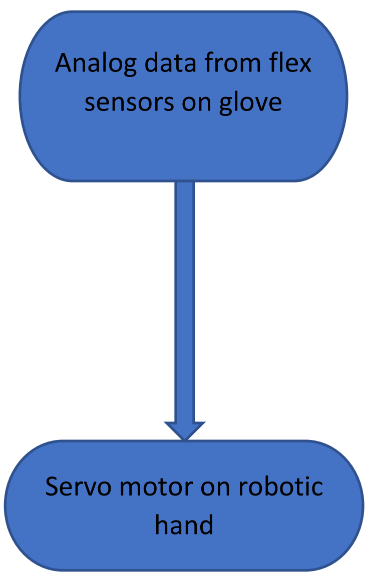
SYSTEM OVERVIEW

Our approach to this problem statement was to build two entities which would communicate wirelessly with each other such that the glove controlled by the user would control the movement of the robotic hand whereas the force applied on the robotic hand while grasping an object is converted to a means for obtaining haptic feedback on the user's end.

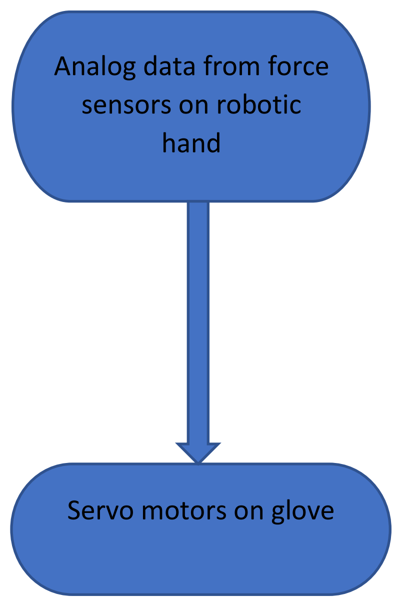
For the first part of solution, initially it was proposed to use a rotary potentiometer which rotates the potentiometer when the user bends their fingers and when the finger is at rest, the potentiometer returns to its rest state due reverse pulley action caused by the thread connecting the fingertip of glove and the potentiometer. This solution was replaced by a simple use of flex sensor which would achieve the same objective (measure the extent of the finger bent and show it in terms of changing variable value) in a much easier mechanism. With the changing values from flex sensor, the servo motor (9g) on the robotic hand begins rotating (in our project, the extent ranged till 170 degrees rotation for readings till 1700 flex). As the servo motor rotates, the thread winds or unwinds on a spindle attached to the servo's shaft which closes or opens the robotic finger using a string pulley system.

For the second part of solution, we agreed upon using force sensors at the fingertips of the robotic hand which measures the changing force applied on the fingertips by the object held in the robot's hand which gives us the idea of intensity of touch. With the changing values from the force sensors, the servo motor connected to the glove rotates such that it pulls back the fingers of the user giving a feel of touch which changes with changing intensity of force. The greater the force, more would be the angle through which the servo rotates.

To sum it all up:



Mechanism for moving the robotic hand.



Mechanism to achieve haptic feedback.

HARDWARE AND SOFTWARE REQUIREMENTS

For the robotic hand:

The fingers were 3D printed using stl files of the design [1]. The material used to 3D print all the parts was PLA.

The fingers were mounted on a ply piece, for required support. In all six 2mm screws and bolts were used to properly fix the joints. Also, it is advisable to file the fingers at the joints to get better movement.

One force sensor was used per finger, which was stuck to the inner side of the robotic finger.

Each finger housed a thread, which would wind/unwind on a spindle which closes or opens the finger using string pulley mechanism. The pulley would rotate due to the servo motor. Hence, in all two servo motors were used for the robotic hand and were mounted on the ply piece.

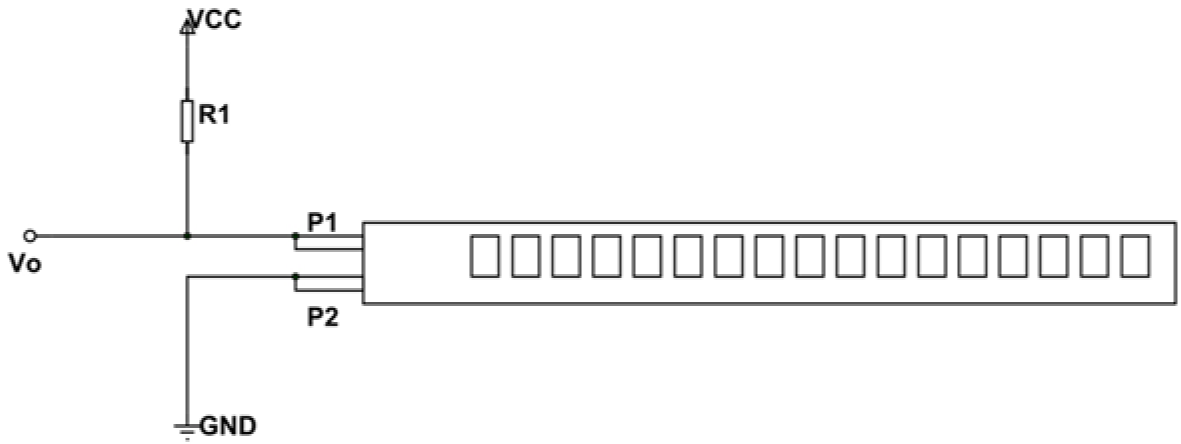
For the glove:

Along each finger a flex sensor was attached using an adhesive. For the haptic feedback, strings were tied to the user's finger which would wind/unwind on the spindle mounted on a servo motor. Hence, two servo motors were used on the glove. These servo motors were attached to the base of the glove.

Working of the flex sensor:

Flex sensor is basically a variable resistor whose terminal resistance increases when the sensor is bent. So, this sensor resistance increases depends on surface linearity. One side of the sensor is printed with a polymer ink that has conductive particles embedded in it. When the sensor is straight, the particles give the ink a resistance of about 30k Ohms. When the sensor is bent away from the ink, the conductive particles move further apart, increasing this resistance (to about 50k-70K Ohms when the sensor is bent to 90°.

As shown above figure, when the surface of flex sensor is completely linear it will be having its nominal resistance. When it is bent 45º angle the flex sensor resistance increases to twice as before. And when the bent is 90º the resistance could go as high as four times the nominal resistance. So, the resistance across the terminals rises linearly with bent angle. For convenience we convert this resistance parameter to voltage parameter. For that we are going to use voltage divider circuit. A typical voltage divider circuit is shown below.



As shown in figure, R1 is a constant resistance and the flex sensor acts as a variable resistance. Vo being output voltage and also the voltage across the flex sensor.

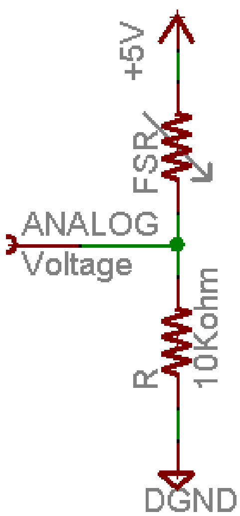
Here,
Vo = VCC *(Rx/ (R1+Rx)).
Rx – resistance of the flex sensor

Now, when the flex sensor is bent the terminal resistance increases. This increase also appears in the circuit. With that the drop across the flex sensor increases so is Vo. So, with increase in bent of flex sensor Vo voltage increases almost linearly. With that we have voltage parameter representing the flex also increasing.

We can then take this voltage parameter and feed it to ADC [GPIO pin 34,35] to get the digital value which can be used conveniently. With these values obtained, then mapping is done to find the precise angle by which the servo has to be rotated to mimic the flex in the actual finger to the robotic fingers [14].

Working of the force sensor:

Force sensing resistor can be defined as a special type of resistor whose resistance can be varied by varying the force or pressure applied to it. Its working is opposite of the flex sensor, here as the force increases the resistance decreases. The force sensing resistor is generally supplied as a polymer sheet or ink which is applied as screen printing. Both the electrically conducting and non-conducting particles are present on this sensing film. If force is applied to a surface of sensing film, then the particles touches the conducting electrodes and thus resistance of the film changes. The circuit diagram of a FSR voltage divider is shown below:

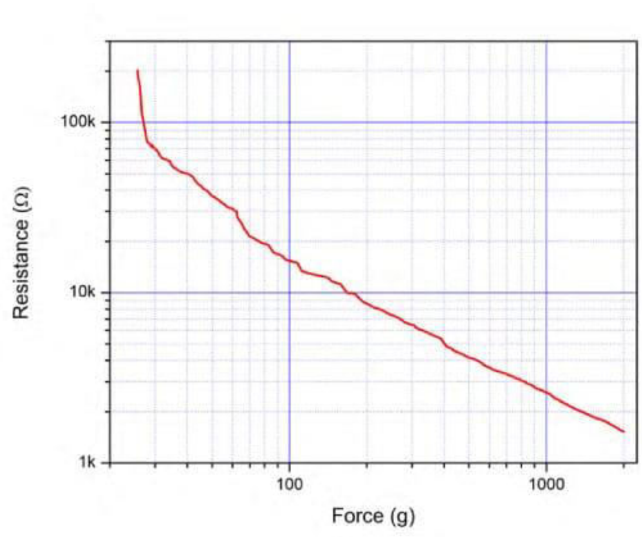


The easiest way to measure a resistance of FSR is to connect one terminal to power and the other to a pull-down resistor to ground. Then the point between the fixed pull-down resistor and the variable FSR resistor is connected to the analogue input of a microcontroller. As the resistance of the FSR decreases the total resistance of the FSR and the pull-down resistor decreases from about 100Kohm to 10Kohm. That means the current flowing through both resistors increases which in turn causes the voltage across the fixed 10K resistor to increase.

This, method takes somewhat linear resistivity but does not provide linear voltage. That's because the voltage equation is:

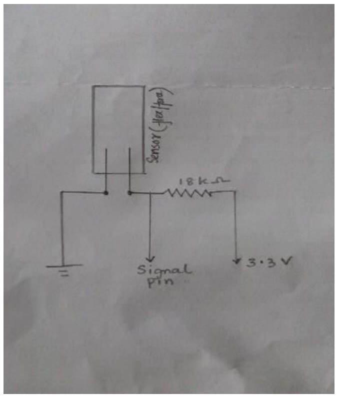
Vo = Vcc * (R / (R + FSR))

That is, the voltage is proportional to the inverse of the FSR resistance.



The readings from the analogue pin[GPIO pin 36,39] are then mapped [14] depending on the force exerted and servos on the glove are rotated accordingly for haptic feedback.

The connection for each sensor (force or flex) is the same. One terminal of the sensor was connected to ground, the other terminal was connected to a 1.8 kilo-ohm resistor and the other end of the resistor was connected to 3.3V. A third connection was made from the terminal-resistor junction to the microcontroller pin. This acted as the signal output. It is as shown below:



All these connections are made through a development board used for microcontroller - ESP32. Code flashed on the microcontroller to achieve control is also included as github file along with this paper [14].

This whole project is supplied with 3.3 V through the ESP32 and uses signal pins 18,19,21,22 for servo motors and pins 34,35,36,39 for both the sensors.

OUTPUT AND CONCLUSION:

Hence by experimenting on different ideas to achieve the objective of this problem statement, we were successful to build a two-finger robotic hand model which mimics the finger flexing of the user through the glove worn by him or her, in real time almost instantaneously without any lag and was able to perceive haptic feedback at the user's end.

This project is still at a stage which has room for improvisation and modification to achieve more accurate results and more compact design.

FUTURE PROSPECTS

We have currently presented a two-finger model mounted on a wooden base which are controlled by flex sensors in the glove. These fingers mirrored, the glove wearer's fine motor skills in real time. We plan to complete the model by printing the other fingers, the palm and the arm [1]. This will ensure better movement and grasping capability of the robotic hand. This is achieved by making the wrist rotating by servo control and the thumb can be made opposing [2]by joining it to the palm with a bolt. This ensures that thumb has more degrees of freedom. Also, the arm will provide as a bed for the servos and all the wiring will be well hidden. Further to mimic human touch, we can incorporate Paeno-HASEL actuators [8], which gives soft robotic touch. This would further allow the robotic hand to also grasp objects which are fragile and easily breakable like an egg.

Haptic feedback has been synonymous with vibrating motors but a buzz can never be mistaken for touching a real object. So, for haptics we attached to the back of the glove fingertips with string and the other end of the string to the servos, which were attached to the base of the glove and based on the feedback from the force sensors, the angle of the servo was set. This mechanism acted like a brake and prevented the user's fingers to go any further. In the future, we plan to replace these servos with electrostatic brakes [3,5]to get the same braking effect. This method would ensure precise and better control than the previous used servo-method.

These braking methods only stops the motion of the hand but does not bring about the perception of touch. For that, we will have to use microfluidic skin [4] which will be attached inside the gloves, pressing against the finger muscles. The microfluidic skin is a flexible, silicon-based textile containing an array of pneumatic actuators and microfluidic air channels. This would give cutaneous and kinesthetic haptic feedback to the user.

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