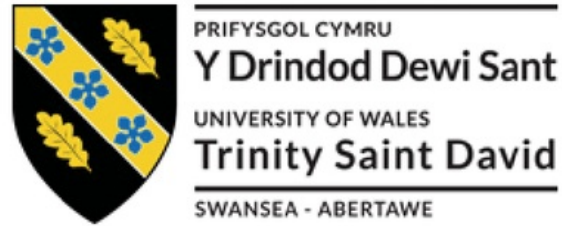


ScottPiperMajorProject

by Scott Piper

FILE	17537_SCOTT_PIPER_SCOTTPIPERMAJORPROJECT_78227_1320664374.DOCX (429.12K)		
TIME SUBMITTED	21-APR-2016 08:03AM	WORD COUNT	6074
SUBMISSION ID	56173044	CHARACTER COUNT	37936



BEng Computer Systems & Engineering

An Investigation into the use of telepresence technologies as a means of controlling robotic devices

By

Scott Piper

Supervisor: John Rees

Second Marker: Gary Jones

Project Submitted as part of the requirements for the award of
BEng (Hons) Computer Systems and Electronics

April 2016

Abstract

This report contains the efforts by the author to provide a comprehensive presentation of telepresence technologies and the components that go into assembling such devices, in particular the manners of control and feedback present therein. The report was undertaken with the hopes of constructing a device that would allow the user to operate a robotic arm using only the movements of a human hand.

Throughout the report is a step by step process from which the final proof-of-concept design was built including the research into microcontrollers and their relevance to the project.

Also contained in the report are the results of the project; the research conducted was thorough but could have been improved and the final construction worked well as a proof-of-concept but could have benefited from better time management and become a much more in depth construction.

DECLARATION

I, ... declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

Signed :

Date :

FORM OF CONSENT

I hereby consent that my Project, submitted in candidature for the degree, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

Signed :

Date :

Table of Contents

Abstract	1
1. Introduction	6
1.1 Aims and Objectives.....	6
1.1.1 Aims.....	6
1.1.2 Objectives.....	6
1.2 What does telepresence/teleoperation mean?.....	7
1.2.1 What is the difference between them?	7
1.3 How does this apply to the project?	8
2. Research.....	9
2.1 Control	9
2.1.1 Analogue	9
2.1.2 Motion Tracking	10
2.1.3 Myoelectric	10
2.1.4 Neurological	11
2.1.5 Conclusion	12
2.2 Feedback	12
2.2.1 Haptic	13
2.2.2 Auditory	14
2.2.3 Visual	14
2.2.5 Conclusion	14
2.3 Microcontroller	14
2.4 Wireless.....	15
3. Methodology.....	17
3.1 Research Methodology	17
3.2 Development Methodology.....	17
3.3 Time Scale	18
4. Design.....	19

4.1 Part list	19
4.2 Block diagram.....	19
4.3 Flowchart	19
4.4 Proteus Design	20
5. Implementation	22
5.1 Breadboard construction	22
6. Analysis and Testing	23
7. Future Improvements	24
7.1 3D Printing	24
7.2 Implants/Body Hacking	24
8. Evaluation.....	25
References	26
9. Bibliography	27

1. Introduction

The main intention of this project is to provide an in depth look at the methods of control utilised in telepresence and teleoperation technologies, and in the control of robotic devices; to this end this report will cover the extensive research into two fields:

- Control: There are a wide array of control methods, from standard analogue devices like joysticks to complex motion tracking devices, a section of this report will cover a number of these methods in detail and find a method suitable for use in a device to be constructed as a show piece for the project.
- Feedback: Feedback is an important part of any control system, whether it's a flashing light that says the device is operating properly or a buzzer that sounds when the operation fails; a section of this report will cover research into a number of methods of feedback used in telepresence devices and whether or not any of them can be utilised in this project.

The secondary aim of this project is to produce a device that is capable of using the movement of a human being to control a device over a fair distance; specifically the hope is to mirror the movements of a human hand with a robotic counterpart, whether this is possible within the time allotted is yet to be seen but at the end of the project there should be a working prototype or proof of concept available for presentation.

1.1 Aims and Objectives

To better complete the project it's important to set out a number of aims and objective in order to set out a clear path of progress from conception to completion.

1.1.1 Aims

- To produce a report exploring the use of telepresence and teleoperation technology and construct a prototype or proof-of-concept device to display some knowledge of the researched material.

1.1.2 Objectives

The first set of objective pertain to the research of telepresence technologies:

- Information will be gathered on the methods of control that fall under the umbrella of this projects aim
- Further information will be gathered on how feedback can be implemented into telepresence devices for ease of use by operator
- A conclusion will be drawn from the presented materials as to what are the best materials to utilise in the proposed construction

The Second set of objectives refer to the construction of the proposed prototype/proof-of-concept device, objectives marked '(Optional)' are possible further expansions of the construction dependant on time and component limitations:

- From the conclusions of the research a concept should be outlined and a block diagram produced in order to provide a suitable plan
- A list of suitable/relevant part should be assembled
- Find a suitable/available microcontroller for use in the construction
- Order and assemble the parts into a device that will allow the operator to translate the movements of a human hand into some form of output
- (Optional) Attach the output signals to a device; maybe a pre-built robotic hand or a remote control vehicle
- (Optional) Implement the feedback research into the final design.
- (Optional) Add further parts to the circuit in order to make it operate wirelessly; without the end device, whether it's an arm or vehicle, being directly attached to the control section of the project.

1.2 What does telepresence/teleoperation mean?

The word telepresence refers to an array of technologies that provide the user with a feeling of being present, or having an effect, usually via some form of telerobotics, at some place or area other than their actual location.

Telepresence activities usually require that a users' senses be provided with some sort of stimuli so they are given the feeling of being in another location. Users may also be given the ability to affect something in the remote location. In these cases, the user's position, movements, actions, voice, etc. can be tracked, transmitted and duplicated in the remote location to bring about this effect.

Teleoperation is used to indicate the operation of a machine across a fair distance. It is essentially a more academic term for remote control in that it appears more commonly in academic, technical, and research environments. It tends to be associated, more often than not, with robotics, but can still be applied wide range of occasions where a user is operating a device/machine from a distance. Bomb disposal robots are a common example of teleoperation machines.

1.2.1 What is the difference between them?

Teleoperation tends to be a word more commonly apparent in research or technical environs when referring to the operation of a device at a distance, whereas telepresence is not as commonly used and can refer to a wide array of interaction or existence that includes some sort of remote component.

1.3 How does this apply to the project?

The proposed construction, if enough time is allotted, would be a sort of combination of the two fields; using a control device to operate a robotic hand/arm at a distance could be termed as teleoperation, and being able to manipulate objects from a distance using that system would fall under the telepresence umbrella.

2. Research

As implied by this chapter's title it is entirely comprised of the research conducted in the pursuit of gaining sufficient knowledge/understanding of fields relevant to the project as a whole. This chapter is broken down into four sections;

- Control: This section contains the research into a number of control methods previously used in a number of telepresence/teleoperation projects
- Feedback: This section covers a few different feedback methods/technologies that could be applied to the project and their use in other incidents
- Microcontroller: This section is less in depth in terms of research as it compiles the consideration of a number of microcontrollers and or processors that could be useful for the project
- Wireless: The last section in this chapter covers a number of wireless technologies that, if time permits, can be implemented into the final construction

2.1 Control

The first section of this chapter covers a number different control methods that could be used in this or future projects. There was brief consideration towards the use of accelerometers for the purposes of detecting the movement of a hand, but after some brief research and, under some advisement from colleagues, it seemed that they would be too complex a device to utilise on such a simple project.

2.1.1 Analogue

For the purposes of this section analogue is a catch all term and covers everything from joysticks to sensors with an analogue output. For the purposes of this section when referring to a 'controller' the author is referring to a pre-made device, such as those present in most games consoles, that can be interfaced with a computer or robotic system.

First off is a discussion of the standard control method for most telepresence/teleoperation devices; which would be a controller and/or joystick. Both joysticks and controllers are quite commonly used as they are probably the most intuitive control device for a user to get to grips with as they are so prevalent in this field.

The next 'analogue' method is one that actually fits the name; variable resistors; by placing variable resistors on a glove that an operator can then wear it would be possible for a properly constructed system to read the position of the users fingers based on the voltage drop across said resistor which can then be used to perform a prearranged instruction. There are two types of resistor that could be used for this purpose:

- A standard variable resistor that changes resistance when the dial on top is turned; this could be modified slightly in order to attach to the side of a finger and rotate as the finger bends. This could be implemented onto either with each knuckle in the finger or onto the sections between knuckles
- The other resistor type is less cumbersome and already used for these purposes; a flex sensor is a flexible variable resistor that looks like a flat rectangle and changes resistance as it bends, it wouldn't have the accuracy of sensors along the knuckles but would work fine to detect how much bend is in a finger, if properly attached to it

2.1.2 Motion Tracking

There have been great strides in motion tracking software in recent years, mostly from the video game market but the devices are just as impressive all the same. Here's a brief rundown of a few motion tracking devices currently being used for experimentation by researchers:

- Microsoft Kinect: The Microsoft Kinect was released as a mediocre video game peripheral but quickly became popular among researchers and hobbyists. The Kinect provides a relatively cheap motion tracking system that, with some minor adjustments by owner, has been used in a number of projects, the most impressive of which is a project by Microsoft Research Cambridge that allows surgeons in theatre to make use of the Kinect for touchless manipulation of medical scans on the fly. (1)
- HTC Vive & Oculus Rift: The recent advancements in virtual reality technologies have also come with their own interesting uses, the oculus rift has been utilised in a number of different telepresence projects including its use in combination with the Microsoft Kinect by NASA for experiments in controlling their 'Robonaut' device that is installed in the space station; NASA combined the tracking in both systems, that being the positional tracking of the Kinect and the rotational tracking of the Oculus, and used the devices to provide their operator with a first person point of view from which to work, which allowed their operator to perform simple tasks with both an actual robotic arm and a simulated robonaut.

2.1.3 Myoelectric

Myoelectric control pertains to the use of a series of electrodes placed onto the operator/users skin, more commonly than not on the arm, in order to pick up the electrical impulses that pass through the arm when it receives an instruction from the brain.

Myoelectric signals are rarely used for anything beyond prosthesis; other than a few hobbyists it seems that if researchers want to utilise the electric signals within the body as a means of control then they more often than not take those signals from the brain.

There have been some interesting projects that utilise myoelectric signals however; it has become relatively common for people to implant themselves with small chips or devices, more often than not they are simply RFID chip used for experimentation, but a number of people have implanted chips in their arms that use the myoelectric signals that run through then arm as a power source. Any other implant that uses arm movement as a control signal is usually attached directly to a bundle of nerves in the arm that carry the signal in order to get a better connection.

There are always some ethical concerns when attaching things to humans, these concerns will be discussed more thoroughly in the next section as neurological control methods tend to share the same concerns.

2.1.4 Neurological

Similar to myoelectric control, when attempting to make use of brainwaves to control a device a user, more often than not, must place a number of electrodes around their head; ideally the user would attach these electrodes to the scalp directly for better conductivity but there have been advancements in the development of technologies that don't need such a connection.

Some more advanced Neurological sensors have been developed by a company called Emotiv with the express purpose of providing high quality raw EEG signals for use in research applications, the sensors themselves do not need to be attached to the scalp or brain and come attached in a sort of array on a halo like device. The products they produce seem to be of a high quality but as with most high quality products have a steep entry fee; the cheapest device they offer costing \$299.

Neurological control devices are more often than not referred to as Brain-computer Interfaces (BCI) as that's what they are commonly made up of; a series of electrodes connected to the brain in some manner feeding the brainwaves they sense into a computer for extrapolation into whatever set instruction the operator is aiming for.

There have been a number of incredible projects to come from the development of BCIs:

- While working with a team from reading university Professor Kevin Warwick, affectionately nicknamed as 'Captain Cyborg', had an array of electrodes implanted directly into his nervous system; the implanted array provided a signal that was detailed enough that a robotic arm built by a colleague of Warwick's was able to mimic the movement of his arm.

- Recently a news article has come to light of how, with the use of a brain implant and a polymer gel sleeve(that holds 130 electrodes on it) a quadriplegic man was able to once more instruct his hand in how to move using the relevant signals in his brain, this time bypassing his damaged spinal cord and allowing him to grasp with his hand and even move his forearm to a degree

As with myoelectric devices BCIs come with a number of ethical considerations, namely that attaching anything to the body of a human being requires they're express permission along with a properly written form for the lawyers. There's also the case that, implantation being the best source of a signal, a universities ethical committee is unlikely to allow students to perform brain surgery on one another for the purposes of a project.

2.1.5 Conclusion

In terms of this project it is important to set achievable goals; in this regard it seems that using either myoelectric or neurological sensors as the source for the control signal would present a number of problems:

1. Both methods would require a large amount of software coding to translate the relevant signals into the desired instructions.
2. Both methods make use of electrodes as non-invasive sensors which can be unreliable dependant on the subject's physical state; if they're sweaty or have some kind of skin condition it could interfere with the systems.
3. For clearer signals invasive sensors would be required, like needles or implants. This brings up several ethical issues; it's generally unacceptable to stab a colleague in pursuit of a simple test.
4. Even a small number of suitable electrodes can be relatively expensive; costing is important in large scale project and saving money were possible is preferable.

In conclusion it would be easier on development time and cost to use a method covered in the 'Analogue' section, in particular the use of a variable resistor would be quite simple to implement and as such the piece constructed as of the end of this project will most likely make use of flex sensors like those discussed. The control devices/techniques discussed in that section appear to be more expensive than using either myoelectric or neurological sensors.

2.2 Feedback

This section of the research chapter is meant to cover the various types of feedback that could be utilised in telepresence technologies.

2.2.1 Haptic

Haptic feedback is meant to the user to receive a sense of touch by returning forces, motions or vibrations to the user from the connection. This feedback, though mechanical in nature, can be utilised to present virtual objects in computerised simulations, to help the user control such objects, or to enhance the users control of specific devices or machines, as in telerobotics. Such devices may also make use of tactile sensors in order to measure the forces that the user exerts in their use of the interface.

A great number of researchers have been known to define three different sensory systems associated with what we define as the sense of touch; cutaneous, kinesthetic, and haptic. (2) (3) Any sense that are mediated by cutaneous and/or kinesthetic are commonly referred to as tactual perception. The human sense of touch is often classified into two different fields; active and passive, with "haptic" being commonly associated to active touch in order for a person to recognize or communicate with objects.

Developments in haptic technology have made great strides in allowing researchers to understand how the human sense of touch works by providing the creation of controlled haptic virtual objects.

A group of students at Stanford University have been able to use a series of tactile sensors and haptic feedback to provide an amputee with something similar to a sense of touch through a prosthetic arm.

2.2.1.1 Pressure Sensors

Pressure sensors are, as the name suggests, sensors that measure the pressure places upon them. There are a number of different choices when considering them; a pre-built pressure sensor can be bought from between eight and twenty pounds, however, through the use of some conductive fabrics and a basic understanding of piezoelectric concepts it wouldn't be hard to construct a pressure sensor to specific measurements for use in this project.

Piezoelectricity refers to an electric charge that commonly builds in several specific solid material, e.g. certain crystals, some ceramics, and some biological matter, when said materials are placed under some mechanical stress. The word itself literally means electricity that is produced as a result of pressure

2.2.1.2 Strain gauge

A lecturer, upon discussion of pressure sensors, suggested that some research into strain gauges may be useful, their advice proved useful as strain gauges appear to be quit robust at measuring the pressure they are under thought they do seem to be more commonly used for large loads like buildings and trucks and may not be the right kind of component to implement in this circuit.

2.2.2 Auditory

For certain operations it could be satisfactory for the device to make a sound or alarm noise as a manner of feedback, for example; if the operation is completed as intended then the system could return a small chime to the user, and if the operation encounters a problem or fails in its task then a buzzer could signify the fault.

As it stands auditory feedback is simply not appropriate for this project because of its simplicity and relatively vague results; there is no indication of what went wrong unless you specifically attach a sound to it, and even then there are any number of things that could go wrong that may not have been considered.

2.2.3 Visual

The majority of telepresence devices make use of visual feedback, as the majority of them are built with the purpose of communication across great distances and a great many of these devices are mobile; it helps to see where you're going when controlling a moving object.

The same can be said for teleoperation devices such as drones or bomb disposal robots; many are affixed with some form of camera that feeds back to a head mounted or hand held display for better control over the device.

2.2.4 Conclusion

If any form of feedback were to be implemented it would probably be some sort of haptic feedback; the auditory feedback, as discussed in its section, is too unreliable in this sort of operation, and visual feedback would be a complication unto itself with extra software development time piled on to for the programming of an LCD, although the use of one or several LED as indicators could be beneficial in the long run.

So as stated if time allows the project should have some form of haptic feedback included hopefully in the form of pressure sensors on the robotic device that feed back to relevant vibrating motors in the control device.

2.3 Microcontroller

In terms of controlling the device it was recommended by a number of lecturers that the project should incorporate a microcontroller of some sort, in particular the PIC microchip series was recommended.

If the project was to make use of a more complex input signal it would probably be more appropriate to use a more complex device to interpret the signals, for example; if the project was to utilise either myoelectric or neurological control it would probably need to make use of a raspberry pi or PC104 type device, or maybe even a computer itself.

With the relative simplicity of the signal input it's apparent that the recommended PIC microcontroller would be sufficient or if necessary an Arduino system could be implemented.

For the sake of this project it will move forward with a PIC microcontroller as suggested because of their availability and because a lot of the equipment available on the university premises are better suited for the simulation and implementation of a Pic based system.

A microcontroller was selected using the microchip websites selector; the only real requirement for this system was that it be able to handle the CCS program; the result was the selection of the PIC18F2620, which was then purchased for the later construction. However when the PIC was received it was discovered that the wrong format of PIC had been purchased for the purposes of prototyping; an surface mount variant was purchased in the place of the required through-hole component that could sit on a breadboard

2.4 Wireless

For the purposes of this project the most appropriate form of wireless connection would have to use either radio frequency or Bluetooth signals to pass the information between the control device and device the user wishes to operate.

Bluetooth is a standard for wireless technology used in the transference of data across short distances by making use of short-wavelength UHF radio waves in the ISM band with a range from 2.4 to 2.485 GHZ. Bluetooth can be utilised from either fixed or mobile devices and is sometimes used within a buildings personal area network (PAN). Bluetooth is a relatively new technology but it can still be utilised to great effect although the software necessary to properly utilise a Bluetooth module could prove too complex for such project as this.

Radio waves are probably the most commonly used form of wireless communication which means that there are a lot of helpful sources when searching for problems to solutions, the biggest problems would have to be:

- a. The government regulation on radio frequencies; meaning that unless a project makes use of a pre-authorized set of modules or similar device then it could run the creator into a fair amount of trouble.
- b. With the prevalence of radio signals the interference encountered in the project could prove untenable in any kind of long rang project, though there are most likely five solutions to every problem to occur.

Even with the apparent flaws radio transmission would still be the most preferred form of wireless operation if the opportunity should occur; it would prove less complex to implement than a Bluetooth module, and any interference problems would, in the case of a project this size, only come from the projects of a colleague and as such be relatively simple to resolve.

3. Methodology

This chapter is meant to serve as a guide so that others could follow the instructions herein and construct a report of similar quality or formatting.

3.1 Research Methodology

Before the project began all of the students on this course were advised that having not been provided a research methods module the previous year would mean that they were not fully informed on various research methodology, that being said, the primary methodology for this project was to make full use of the resources available:

- The Universities online library provided a comprehensive list of all the books available within the physical library itself along with the digital/eBook versions of several of those books.
- The Universities library also provided a list of databases that operate similarly to their own online library in that they hold a wide array of journals, eBooks, and other such research materials within them
- As with any and all problems in life google is always a useful tool; in particular there are a number of tricks to optimally searching google for relevant articles/journals and the like, there are even some settings that can help in the base search engine.

3.2 Development Methodology

For this project the development was broken down into sections or steps that would need to be undertaken in order to end up with a complete device/report by the time of the deadline, they are as follows:

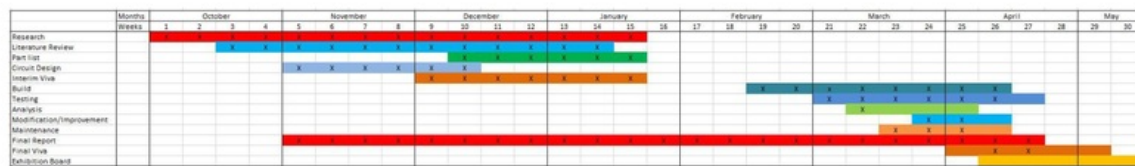
1. Conduct research into all relevant fields, discussed more in depth in the previous section
2. Use the information gathered from the research to construct an idea of the components necessary for the project
3. Draw up some preliminary designs of the circuit making use of items like block diagrams to get a grasp of how it fits together
4. Draw up a flow chart or something similar to provide a simple breakdown of how the code is supposed to operate
5. Make use of a program like Proteus in order to simulate the circuit, code and all
6. Assemble list of parts from the simulation and requisition them, either from online stockists or the establishments storerooms
7. Construct the parts on a breadboard in order to properly test the circuit design

8. Once the design has been completed, should time allow, there may be chances to improve upon or expand it
9. On the appropriate deadline the design and all relevant materials should be submitted to the proper entities

Should all of these steps be followed in a timely and efficient manner, it will result in a reasonably decent report along with a working item to be presented for submission to the project supervisor.

3.3 Time Scale

This section contains a Gantt chart that is meant to be representative of the time expended for this project, cells marked with an 'X' are actions that have been completed whereas the empty cells represent as of yet uncompleted actions:



4. Design

This chapter is meant to display the step by step process of the projects design and as such features conceptual diagrams, such as a block diagram and flowchart, alongside simulation screenshots and photographs of the finished product.

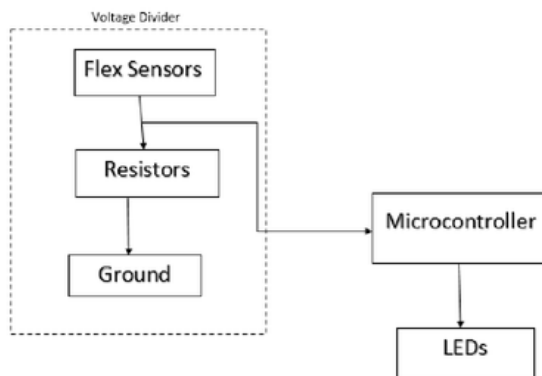
4.1 Part list

This small section contains a list of parts and pricing for the final device assembly:

Component	Quantity	Pricing(£)
Flex Sensor	3	36.29
22K Resistor	3	(Provided from University stores)
PIC18F2620	1	4.73
PIC16F887	1	(Provided from University stores)
LED	6	(Provided from University stores)

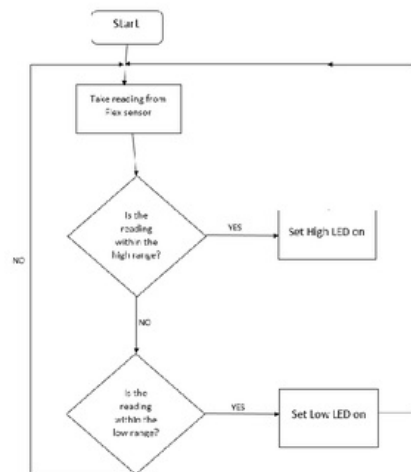
4.2 Block diagram

Featured in this section is a simplistic block diagram of the circuit as it stands; as a proof of concept piece:



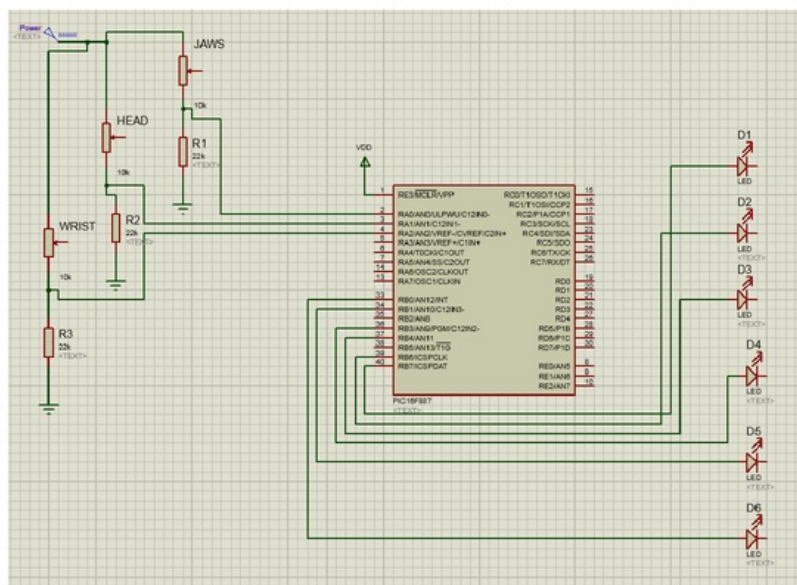
4.3 Flowchart

This section of the chapter provides a small diagram that is meant to show the process that the program runs through:



4.4 Proteus Design

Below is a screenshot from the simulation constructed within Proteus, this was done to ensure that the code worked properly before it is burned onto the PIC:



As is shown here the flex sensors are placed in a voltage divider layout with some 22k resistors, the voltage is then fed, from in-between the two components, into three analogue ports on the PIC. Seeing as this is a proof of concept piece the PIC is then to measure the incoming voltages and determine if they are within two different ranges, if the voltage is in the higher rang then the first LED associated with that resistor

lights up, and if the voltage is in the lower range the second LED lights up. If the voltage falls outside of the two set ranges or the flex sensors lay flat then nothing happens.

The components are associated as follows:

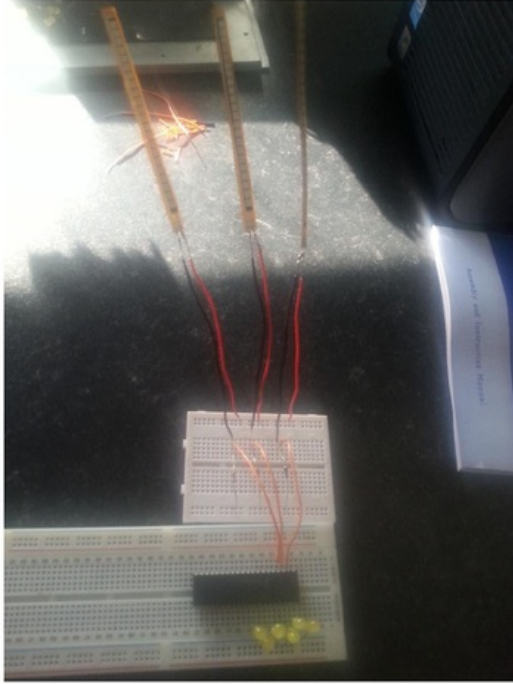
- The JAWS sensor feeds into AN0 (analogue port 0) and outputs from either RB7 & LED D1, or RB6 & LED D2.
- The HEAD sensor feeds into AN1 (analogue port 1) and outputs from either RB4 & LED D3, or RB3 & LED D4
- The WRIST sensor feeds into AN2 (analogue port 2) and outputs from either RB1 & LED D5, or RB0 & LED D6

5. Implementation

This chapter is meant to present how the research conducted in chapter two is implemented into the final construction of the proof-of-concept device described previously.

5.1 Breadboard construction

Below is a photograph of the design constructed on a breadboard for testing and demonstration purposes:



The photograph provided shows the flex sensors have been soldered onto wires, red represents the signal and black the ground, for ease assembly; the points already on the sensors are too small to be attached to the board and used properly. The wires from the sensors then feed into the board with the proper resistors attached, from there the orange wires connect between the voltage divider section and the microcontroller. On the other side of the microcontroller are the LEDs discussed in the previous section.

6. Analysis and Testing

At this point in the report it was hoped that the device would be fully assembled and working and also allow for more improvement upon the design such as the completion of several of the optional objectives. In terms of the construction; it is more or less complete in so far as it fulfils its proof-of-concept purpose; when the flex sensors are bent to within the specified range the relevant LED lights up. As of the time of this writing however the program hasn't been burned onto the PIC microcontroller and as such no real in depth testing could be performed.

7. Future Improvements

This Chapter is meant to contain a number of future improvements or developments that could be made on the project if it was taken further.

7.1 3D Printing

With modern advancements in 3D printing it would be possible to, with the appropriate materials, print the device almost in full, from the flex sensors to the mounting for the glove, dependant on the materials and/or specialised equipment necessary such an operation could prove to be rather expensive.

7.2 Implants/Body Hacking

3D printing isn't the only thing to have advanced in the modern ages crave for technology; implanted microchips are becoming more and more common, whether it's a simple RFID chip used to open doors or tiny programmable circuit that could, with the relevant signals, operate a robotic arm over a reasonable distance, and as hobbyists become more involved there are only bound to be more developments

8. Evaluation

The project on the whole seems to have been a relative success in terms of achieving the set aims and objectives:

- The aim appears to have been properly achieved even if not all of the objectives were
- Information on control methods has been gathered in spades and has provided the author with a reasonably competent knowledge of the subject matter
- The same could be said of the research on feedback; though none of it was properly utilised in the final construction the research itself was interesting.
- The proper components were selected based on the research conducted as shown in the design chapter
- Both a block diagram and flow chart were drawn up in order to properly facilitate the design and construction of the final product

None of the optional objectives were achieved, more than likely this was because of poor timing on the part of the author.

There are a number of things that could have been done differently in order to construct a more complete/satisfactory report:

- Time could have been managed more carefully
- The research could have been done in a more in depth manner
- Better care could have been taken in the selection of parts
- It would have been preferable for the final construction to include a connection to a robotic device of some sort, alongside some form of feedback

References

1. **Gantenbein, Douglas.** Kinect Launches a Surgical Revolution. *Microsoft Research*. [Online] Microsoft, 7 June 2012. [Cited: 16 April 2016.] <http://research.microsoft.com/en-us/news/features/touchlessurgery-060712.aspx>.
2. *Tactual discrimination of softness.* **Srinivasan, M. A., & LaMotte, R. H.** 1998, *Journal of Neurophysiology*, pp. 73, 88–101.
3. *Compliance discrimination of deformable objects by squeezing with one and two fingers.* **Freyberger, F. K. B., & Färber, B.** Paris : EuroHaptics 2006, 2006.

9. Bibliography

1. **Hollister, Sean.** Robot hand hits 20WPM, nearly ready to embrace infinite monkey theorem. *engadget*. [Online] February 20, 2011. <http://www.engadget.com/2011/02/20/robot-hand-hits-20wpm-nearly-ready-to-embrace-infinite-monkey-t/>.
2. **T.R. Darr, J.D. Cox, E. Sumner, Magnus Persson, Piyoosh Mukhija, S.J Manderson.** Robotics. *Wikibooks*. [Online] July 25, 2015. https://en.wikibooks.org/wiki/Robotics/Print_version.
3. **Dimension Engineering LLC.** A beginner's guide to accelerometers. *Dimension Engineering*. [Online] Dimension Engineering LLC. [Cited: November 29, 2015.] <http://www.dimensionengineering.com/info/accelerometers>.
4. **Woodford, Chris.** How strain gauges work. *Explainthatstuff*. [Online] March 5, 2016. [Cited: March 8, 2016.] <http://www.explainthatstuff.com/straingauge.html>.
5. **Barnes, Donald Michael.** *System for robotic control of imaging data having a steerable gimbal mounted spectral sensor and methods. US 6422508 B1* United States of America, April 5, 2000.
6. **Marks, Paul.** Mind-meld brain power is best for steering spaceships. *New Scientist*. [Online] RELX Group, February 20, 2013. [Cited: January 5, 2016.] <https://www.newscientist.com/article/mg21729025-600-mind-meld-brain-power-is-best-for-steering-spaceships/#.Ui7uX0CpfV4>.
7. **Stevens, Greg.** The military paves the way for super-humanitarian cyborgs. *Second Nexus*. [Online] Second Nexus, March 16, 2016. [Cited: March 20, 2016.] http://secondnexus.com/technology-and-innovation/military-humanitarian-cyborgs/?utm_content=inf_10_1164_2&tse_id=INF_58c47f47d9154c94acd1981a0ed18325.
8. **Duhaime-Ross, Arielle.** A paralyzed man's brain implant let him move his fingers to play a guitar video game. *The Verge*. [Online] Vox Media, April 13, 2016. [Cited: April 18, 2016.] <http://www.theverge.com/2016/4/13/11420394/quadruplegic-brain-chip-implant-move-fingers-batelle-neurolife>.
9. *Proportional Myoelectric Control of Robots: Muscle Synergy Development Drives Performance Enhancement, Retainment, and Generalization.* **Mark Ison, Panagiotis Artemiadis.** 2, Arizona : March, 2015, Vol. 3.
10. **SRI International.** Telepresence Surgery. *SRI International*. [Online] SRI International, 2016. [Cited: March 20, 2016.] <https://www.sri.com/work/timeline/telepresence-surgery>.
11. **Top 10 Robotic Kinect Hacks.** *IEEE Spectrum*. [Online] IEEE Spectrum, March 7, 2011. [Cited: November 26, 2015.] <http://spectrum.ieee.org/automaton/robotics/diy/top-10-robotic-kinect-hacks>.
12. **Renstrom, Joelle.** NASA Scientists Control Robotic Arm With Kinect And Oculus Rift. *Giant Freaking Robot*. [Online] Giant Freaking Robot, January 2, 2014. [Cited: November 22, 2015.] <http://www.giantfreakinrobot.com/sci/nasa-scientists-control-robotic-arm-kinect-oculus-rift.html>.

13. What is haptic feedback? *Precision Microdrives*. [Online] Precision Microdrives Limited, 2015. [Cited: March 25, 2016.] <http://www.precisionmicrodrives.com/haptics-haptic-feedback-vibration-alerting/haptic-feedback-in-detail/an-introduction-to-haptic-feedback>.
14. *Compliance discrimination of deformable objects by squeezing with one and two fingers*. Freyberger, F. K. B., & Färber, B. Paris : EuroHaptics 2006, 2006.
15. *Tactual discrimination of softness*. Srinivasan, M. A., & LaMotte, R. H. 1998, *Journal of Neurophysiology*, pp. 73, 88–101.