iRehab: Advancements in a novel system to analyse and improve the accuracy of finger dexterity in patients with impaired hand function

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Abstract

To rehabilitate the hand, accurate quantification of skill can be used to rank the patient against agreed norms and help to develop more targeted rehabilitation programs. Current tools can be expensive, cumbersome and test only a few aspects of hand skill. This project will attempt to further develop a prototype system created in 2009 by Barnes. The system uses an application on an Apple iPhone™ or iPod® in conjunction with a force transducer to capture the contact force data and present it in an informative and beneficial format acceptable to both the clinician and patient. The advancement to the project in this work has enabled a wireless communication system between the iPod®, force transducer and host PC as well as reducing the size of the force transducer and its housing. An additional two tests have been incorporated, the system now has four fully integrated tests that can help to improve the rehabilitation of the hand.
Winthrop Professor John Dell  
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Dear Professor Dell  

I am pleased to submit this thesis, entitled “iRehab: Advancements in a novel system to analyse and improve the accuracy of finger dexterity in patients with impaired hand function”, as part of the requirement for the Degree Bachelor of Engineering.  

Yours Sincerely  

David Smith  
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Contents

1. CHAPTER 1 -INTRODUCTION AND LITERATURE REVIEW .................. 1
   1.1. INTRODUCTION AND PROJECT OBJECTIVES ................................. 1
   1.2. SYSTEM DIAGRAM ..................................................................... 2
   1.3. REVIEW OF CURRENT LITERATURE ............................................ 3
   1.4. UPDATED SYSTEM OUTCOMES AND DESIGN AIMS ....................... 8

2. CHAPTER 2- DESIGN AND DEVELOPMENT ................................... 10
   2.1. DESIGN AND DEVELOPMENT CRITERIA ..................................... 10
   2.2. COMMUNICATION SYSTEM CRITERIA ......................................... 10
   2.3. COMMUNICATIONS SYSTEM POSSIBLE SOLUTIONS ..................... 11
   2.4. iPod® WIRELESS CAPABILITIES .......................................... 12
   2.5. FORCE TRANSDUCER DESIGN CRITERIA .................................. 12
   2.6. POSSIBLE SOLUTIONS .............................................................. 13
   2.7. FORCE TRANSDUCER CHOICE ................................................ 13
   2.8. ARDUINO MICROCONTROLLER .............................................. 14
   2.9. INTERFACING THE FORCE TRANSDUCER WITH THE MICROCONTROLLER .... 14
   2.10. MICROCONTROLLER WIRELESS MODULE .............................. 16
   2.11. COMMUNICATION SYSTEM ACTUAL CHOICE ............................ 16
   2.12. DATA ACCESS, RETRIEVAL AND STORAGE .............................. 17
   2.13. WEB SERVER INTRICACIES .................................................. 17
   2.14. NEW AND UPDATED TASK DESCRIPTIONS ............................... 18
       2.14.1. Sequences ...................................................................... 18
       2.14.2. Tracing ........................................................................... 19
   2.15. SOFTWARE TESTS ................................................................. 20
   2.16. DEVICE HOUSING CRITERIA ................................................ 20
   2.17. DEVICE HOUSING DESIGN AND CONSTRUCTION .................... 21
   2.18. SAFETY ............................................................................... 22
       2.18.1. Safety of the force transducer and housing ....................... 23
       2.18.2. Safety of the application .................................................. 24
       2.18.3. Safety of the communication system ............................... 24
   2.19. FINAL SYSTEM ...................................................................... 25

3. CHAPTER 3- RESULTS AND DISCUSSION .................................... 26
   3.1. PERFORMANCE OF THE WIRELESS COMMUNICATION SYSTEM ......... 26
       3.1.1. Web Server Data Processing ............................................... 26
3.1.2. iPod® communication ................................................................. 26
3.1.3. Microcontroller with Wireless Module Communication and ADC .......... 26
3.2. Development of the new and upgraded tests within the iRehab Application ........................................................................................................ 27
3.3. Performance of new Force Transducer: FlexiForce® sensor response and characteristics................................................................. 27
  3.3.1. Impulse Response ........................................................................ 27
  3.3.2. Calibration Curve ....................................................................... 28
  3.3.3. Sequential tapping at speed .......................................................... 29
  3.3.4. Repeatability ................................................................................ 30
  3.3.5. Noise Sensitivity ......................................................................... 32
  3.3.6. Conditioning ................................................................................ 33
3.4. Ethics Approval Update ..................................................................... 33
3.5. Observations of users and clinicians .................................................. 34
3.6. Cost Analysis .................................................................................... 34
3.7. Limitations during development and the final system ......................... 36
  3.7.1. Application .................................................................................. 36
  3.7.2. Force Transducer ........................................................................ 37
  3.7.3. User Feedback Group ................................................................. 37
4. Chapter 4- Conclusions ..................................................................... 38
  4.1. Reflection upon original objectives, aims and future work ............... 38
    4.1.1. Project Aims ............................................................................. 38
    4.1.2. Project Objectives .................................................................... 39
REFERENCES ..................................................................................... 40
APPENDICES ...................................................................................... 43
Chapter 1 - Introduction and Literature Review

1. **CHAPTER 1 - INTRODUCTION AND LITERATURE REVIEW**

1.1. **INTRODUCTION AND PROJECT OBJECTIVES**

The Australian Neuromuscular Research Institute (ANRI) expressed the need for a system that could evaluate manual dexterity. Such a system would need to provide an accurate assessment of hand and finger motor skills. This assessment would then be used to track a patient’s current rehabilitation program and help clinicians to design more specialised programs.

Barnes (2009) explored possible solutions to create a system to meet these needs. Barnes developed a system where the patient would be guided to perform certain movements with his/her fingers using one or both hands, the application will analyse the accuracy and time between movements whilst a force transducer captures the force of the actions, saving a report on the patient’s performance. The system has two main components being an iPhone™ or iPod® and a force transducer. For the remainder of this work only an iPod® will be considered, however this system is applicable to both. The iPod® runs the application and the force transducer to measure the pressure applied to the iPod®.

At the completion of Barnes’ work there were still significant areas of development that needed to be accomplished. This thesis details the further development completed on the above system to bring it another step closer to being an effective assessment and rehabilitation tool. The system is to be used by clinicians to enable them to further assess finger dexterity and the contact force of patients with impaired hand function. The system would then also be made available to the patient to use as a rehabilitation tool with continuous feedback in between clinician visits to encourage the use of the system and enhance their recovery. To achieve this, the system needs to be easy to use and able to give simple and effective feedback to the patient whilst being small and portable. This thesis aims to specifically develop these objectives to create an effective communication system between the iPod® and the force transducer to allow more effective patient feedback. Whilst developing a new force transducer system to allow the complete system to be encapsulated in a small, portable and ergonomic housing. The application will also be updated and expanded taking into account feedback from clinical trials completed by Barnes.
This thesis will first present a critical analysis on the work completed by Barnes and how it compares to other rehabilitation systems that are being used commercially or are still in development. It will specifically analyse the use of certain rehabilitation exercises and how they are extremely important in day-to-day life. Chapter Two details the design and development of the updated force transducer, the housing for the complete system, the new and updated tests in the application and the communication system between the or iPod® and the force transducer. Chapter Three presents the results of the testing completed on the system along with an analysis and discussion on the limited user feedback provided, as well as some of the limitations of the current system and prospects for the future.

Presented in this thesis is a detailed review of the steps taken to produce the updated prototype system. These steps include the research and feasibility studies completed to allow the development of the mechanical, electrical and software design used to present the updated prototype system. Finally analysing the performance of the system including both its failings and key developments to continue the opportunity for future work on the system that has opportunity to help many people that live day to day with impaired hand functions.

### 1.2. SYSTEM DIAGRAM

The new communications system implemented in this project demonstrates the interconnection of devices within the current system, which is shown in **Figure 1-1**. The communication system is initiated by a user starting a test, after which the iPod® sends data wirelessly to the host PC running a web server. Subsequently the PC wirelessly informs (synchronises) the microcontroller to start recording and time stamp the data coming from the force transducer. Once the patient has completed the test the iPod® sends a stop request to the web server which relays that request that stops the microcontroller from posting any further data from the force transducer. The data from the force transducer is stored in a CSV format whilst the data from the iPod® is stored in a XML format. Once this is completed the iPod® then posts the test data that it has stored to the web server, which the microcontroller also does. The web server then collates the data from the iPod® and the force transducer/microcontroller. Once collated/parsed, the data is then displayed in a table and graphically on a web page for both the patient and clinician to see and analyse.
1.3. REVIEW OF CURRENT LITERATURE

The design, development and construction of an initial prototype system completed by Barnes aimed to develop a software application to act as a Graphical User Interface (GUI) for the system as well as to design and construct a force transducer to capture the impact force of a user completing a test. This prototype system was designed based
upon the rehabilitation needs of patients and in turn other rehabilitation tools currently available to clinicians and patients or still in the development stage. A critical analysis of a series of the prototype’s limitations including a comparison with other manufactured systems will be completed to give a better understanding of what it needed to further the system to be closer to production.

A key limitation of the current system is the communication between the iPod® and the force transducer, this problem then increases when you want to view the patient data on a PC to analyse it. The problem stems from both the iPod® and force transducer; in the case of the iPod® currently there is only one complicated and time consuming method to remove data. This involves physically plugging the iPod® via a serial to USB cable into a Mac running the iOS Software Development Kit (SDK) that can be downloaded from the Apple developers web page once you have paid $99 US to become a registered Apple Developer (Apple® 2010a). When completed you can then follow a long and complicated process to access and download files that have been stored within the app running on the iPod®. Once you have the files on your PC you then also require software to be able to read and display a XML file in a manner that is able to be read by the untrained user.

Currently in the case of the force transducer the microcontroller must be physically connected via a USB cable to a Mac or PC running a Matlab® program. The Matlab program then needs to be manually controlled as to when to start and stop recording the data. This exercise makes running a simple test on the app quite intensive for the clinician and virtually impossible for the patient to solely run the test. This process is a significant downfall of the current system as it has been shown that patients with portable rehabilitation recover faster and more successfully than patients who are only able to use the system under supervision of a clinician (Yuxiang et al. 2006).

There has been a significant increase in the use of robotics and other technologies in recent times due to advancements in technology that keep within budget and introduce new possibilities. This has been mainly due to the fact that robots can now precisely track and record trajectories of a patient as well as calculate joint forces as they complete a test (Huang & Krakauer 2009). It is also due to the fact that robots can complete repetitive tasks with minimal fatigue, which will help a clinician significantly in patient treatment and analysis(Hesse 2007).
Although there is not a large range of portable rehabilitation devices for hand therapy patients, there is still a large range of devices that are used in a clinical environment that to an extent effectively communicate between their multiple components to reveal the results generated.

**Figure 1-2** shows four hand rehabilitation devices currently in use around the world. The devices all use hard wired serial communication between the tests apparatus and the PC to view the results generated from the test. Many advantages and disadvantages can been seen in the use of this connection style, some of which are listed below.

Advantages included:
- Very cheap, most sorts of cable used are extremely cheap;
- Reliable, a hard wired system has a lot less availability for disturbances; and
- Simple software, as the PC can normally directly communicate with the external testing rig, the communication protocols are a lot less intensive.

Disadvantages include:
- Portability, most of the devices seen in **Figure 1-2** are all very cumbersome and would be very time consuming to disassemble, move and reassemble;
- Patient testing, again as the tests are not portable the patient needs to come to the test not have the test taken to the patient, in some cases this can be extremely troublesome; and
- Cables can become very intrusive, in **Figure 1-2** (D) you can see the cyber glove is covered in cable which are connected to a PC.
Assessing many aspects of hand skill in the one system is something that is rarely seen in most rehabilitation devices and if it is they are extremely expensive and cumbersome. **Figure 1-3** shows the AutoCITE system that was developed in 2004. The system incorporates a computer and eight task devices arranged on a modified cabinet. The system is well known for its capabilities but it is also quite easy to see a series of issues that the procurement and use of this system can raise.
The use of a person’s hand to complete day-to-day tasks is extremely important to an individual’s quality of life. High level tasks like writing and typing is something most people take for granted. The key goal for a patient with impaired hand functions is regaining the capability to write and type again. To do this patients start with very simple tests like the one seen in Figure 1-4, where a patient uses a touch screen to tap letters and shapes in a pre-determined order.
A new test was developed in this thesis that is a step towards enabling a cost effective rehabilitation method targeted towards writing. The test has been developed based on older style paper and pencil cancellation tests (Rabuffetti et al. 2002), as well as new tracing letter exercises implemented as part of the AutoCITE system (Lum et al. 2004).

These tests are both based around repeatedly attempting the similar exercises with increasing difficulty based upon the user’s skill and previous attempts. It has been shown that the act of repeating specific actions is an effective rehabilitation method used in a range of systems presently used (Krakauer 2006; Willmann et al. 2007).

Comparing the act of repeating an action and attempting to draw leads to the conclusion that there can be a test developed that can use this theory. The user can be guided through a series of increasingly difficult tracing actions, starting from simply tracing a line to then a square, a circle and eventually to alphanumeric characters. The implementation of this tracing task into a device that could be low cost and portable would allow sufferers to have a new and exciting means of rehabilitation. Ultimately if the task could be taken for simply being asked to trace a pattern on a blank background to importing this idea to a simple graphical game it would make the user experience even greater and in turn increase their chance of a better recovery.

1.4. **Updated System Outcomes and Design Aims**

The objectives of the prototype system (code name: iRehab) have been set to overcome the limitations of the current system and to achieve improved outcomes. These outcomes are to create a system that is

- Low cost;
- Small and portable;
- Assess many aspects of hand skill;
- Provide quantitative and meaningful data to clinicians; and
- For the system to be novel and appealing to potential users.

To further what has already been achieved this project aims to:

- Develop a connection between the iPod®, force transducer/external microprocessor and a host PC;
- Develop a new more compact force transducer system and design a new housing;
- Upgrade the existing system; and
- Develop new tests in the application in consultation with an occupational therapist with the aim to test these on patients with a range of disabilities.
2. CHAPTER 2- DESIGN AND DEVELOPMENT

2.1. DESIGN AND DEVELOPMENT CRITERIA

As stated earlier this project has three main aims with the first being to develop a communications system between the iPod®, force transducer/external microprocessor and a host PC to view the results. One of the key limitations in the prototype system developed by Barnes was that there was no simple way of retrieving the data from the app and force transducer and displaying it in a simple yet informative manner. This was mainly due to the fact that the app and the force transducer never communicated and the data was manually compiled on a PC to then be analysed later. The aim then was to create a communications system that enabled the app and force transducer to communicate, then send all of the data to a PC to display it. The criteria and possible solutions to this problem are discussed in Chapters 2.2 - 2.4.

The second aim was to develop a new force transducer system and a housing for it. This aim was set out due to feedback received during system trials completed by Barnes, a large percentage of users believed that the housing was very large and bulky which made completing some of the tests increasingly difficult. The criteria and possible solutions to this problem are discussed in Chapters 2.5 - 2.7.

The final aim was to further develop the existing tests in the application as well as create new tests using the feedback that was received during the system trials previously completed. It was decided to develop two of the existing tests as well as create one new test so that there was a total of four fully functioning tests. These tests are further discussed in Chapter 2.14.

2.2. COMMUNICATION SYSTEM CRITERIA

For the system to be used effectively the data collected by both the iPod® and the force transducer needs to be easily available, with this in mind a communication system needs to be developed with the following criteria:

- Seamless communication between the devices, simple to use for both the clinician and the patient;
Chapter 2 - Design and Development

- Fast transfer speeds, no large delays for data transfer; and
- Must remain a low cost.

Currently the iPod® stores each test completed in its own file in XML format, listing the patient and test details briefly in the name of that file and then expanded in full within the file. This file doesn’t exceed 10kB in size and the file format of the force data to be sent is yet to be determined, with this in mind data transfer speeds should be analysed accordingly.

2.3. COMMUNICATIONS SYSTEM POSSIBLE SOLUTIONS

The analysis of possible solutions for the communication system is largely dependent on the iPod® as this is the device in the system that has the most constraints on its capabilities. The iPod® has five possibilities for external communication with some being quite obvious and others being quite obscure.

The first obscure option involved using a series of light sensors to read a binary signal produced on the screen by a series of small black or white squares in the corner of the screen. The second involved using the audio out/microphone in port and sending data via audio files to and from the microcontroller. Both of these options were rejected due to their complexity and large risk factors.

The two most obvious and widely used connections in mass production of external iPod® accessories are either the 30-pin serial dock connection or the Bluetooth® 2.1 connection. Both of these connections are more than capable of the data transfer speeds needed and could have been successfully implemented in conjunction with the force transducer. The issue that become apparent with both of these connections is that the use of them is not provided to every registered Apple® Developer. To use these connections you must also be a participant of the Made For iPod® (MFi) licensing program (Apple® 2010b). The MFi program is the only way individuals or companies can gain access to the relevant libraries. With multi-million dollar companies like Boss and JBL being a part of the same licensing program it is understandable that the cost of the program is out of reach of the independent developer and obviously rejected as a viable solution.
Although the iPod® largely controls the choice of communication system there is still the possibility of using a different system for the microcontroller. As there are far few limitations on the microcontroller, there is a massive array of options that could be used. Almost all of these would involve the use of one of the many forms of serial communication available or a Bluetooth connection, all of which are unavailable on the iPod® and have been rejected. There are also many options involving the use of obscure forms of communication that were previously discussed and rejected for the same reasons. The option of removing the microcontroller all together and sending an analogue signal of some type to an external receiver was also researched. This was rejected as it added a lot of complexities to the system without a large cost saving.

2.4. iPod® Wireless Capabilities

All iPod® Touch generations have an in built wireless module capable of connecting to a range of Wireless Local Area Networks (WLAN) using 802.11b/g/n protocols. All three protocols connect at a frequency of 2.4GHz and have a bandwidth of 20MHz. The minimum connection speed that could be enabled across the protocols is 5.5Mbit/s meaning that it would take ~2 milliseconds to send a large XML file from the iPod® to a host PC which is well within the criteria.

Programming for the iPod® to send data through the wireless connection involves using the standard Hypertext Transfer Protocol (HTTP). HTTP functions as a request-response protocol where the iPod® would act as a client to a server running on a host PC. Where the iPod® can submit a request to post data to the server, the server then reads in this data and sends a response to say that the data has been received. This protocol can be used to send data to signal the start and finish of a test as well as the test data itself. Hence a wireless connection meets all of the design criteria and will be developed to connect the three devices.

2.5. Force Transducer Design Criteria

The force transducer was to be redesigned with the following criteria:
A significant reduction in size was needed in volume as well as more importantly the vertical axis; maintain accuracy and dynamic range; and low cost.

2.6. POSSIBLE SOLUTIONS

Various solutions were considered to satisfy the design criteria, most obviously reducing the size of the cantilever load cell setup used previously. Problems that could be encountered reducing the size would be that the fabrication of the load cell would get more expensive as the tolerances would get very small. Also to reduce the size of the load cell and strain gauge setup the standard error increases, it can increase so much that at a point the measurements are almost worthless (Lang & Chou 1998). Both of these problems directly impact the criteria, which should be avoided. Many prefabricated load cells are available that are smaller and still maintain the dynamic ranged and accuracy needed but as before as the size of the setup is decreased the cost significantly increases which is not achieving the criteria.

2.7. FORCE TRANSDUCER CHOICE

A FlexiForce® Force Sensor manufactured by Tekscan was chosen, due to its size and low cost. The force sensor is versatile, durable and only 0.203mm thick with a 9mm sensing area that is able to sense forces between 0 – 110N with a response time of less than 5 milliseconds with an accuracy of 1%. The sensor uses a proprietary piezoresistive material in between two silver plates and flexible polyester. As a force is applied to the sensor a strain affect is applied to the material causing a change in the inter-atomic spacing this in turn changes the resistance across the sensor (Tekscan 2010b). With no load applied there is a resistance of ~5MΩ, when a force is applied the resistance decreases inversely proportional to the force applied down to ~10KΩ when ~100N is present.

Figure 2-1: FlexiForce® Force Sensor manufactured by Tekscan (Tekscan 2010a).
2.8. **Arduino Microcontroller**

A microcontroller is used to accept force transducer data as well as make this data available to a host PC to be viewed. The microcontroller used was an Arduino Due Milanove, manufactured in Italy. The microcontroller can be pre-programmed and powered from either mains power or a battery pack. Once a program is preloaded to the microcontroller it can be powered up at any point and automatically runs through the setup for that program, and then continuously runs the given loop. The use of an Arduino microcontroller was advantageous due to the large amount of libraries easily available for communication with external devices.

2.9. **Interfacing the Force Transducer with the Microcontroller**

As the force sensors acts as a variable resistor it was chosen to place the sensor in a voltage divider circuit seen in Figure 2-2. This was powered by a 16-bit analogue to digital converter (ADC) LTC2470. Chosen was an external 16-bit ADC over the 10-bit ADC available on board the microcontroller as it was found previously that the 10-bit converter did not provide sufficient range for the force output.

*Figure 2-2: Circuit schematic showing section A: Force Transducer placed in a voltage divider configuration. B: Analogue to Digital Converter ADC. C: Interface with the microcontroller.*

This circuit was layed out on to a printed circuit board using Eagle CAD, the layout seen in Figure 2-3.
The ADC is powered by a 5V output available on the microcontroller board, this supply is also in parallel with two capacitors to reduce ripple in the supply. The ADC outputs 1.25V at the REFOUT pin that is placed across the force transducer and a 1MΩ resistor. As the force applied to the force transducer varies so will the resistance of the force transducer, this will vary the voltage received by the ADC. This analogue voltage signal will then be converted to an integer and sent to the microcontroller. The flow and range of these signals and data can be seen in Figure 2-4.

The microcontroller and ADC communicate via a Serial Peripheral Interface (SPI), SPI is known as a de facto standard as there is a lack of a formal standard with a wide variety of protocol options used. The protocol evident on the LTC2470 uses 4 communication lines three being inputs to and one being an output from the ADC (Linear 2010). The three inputs are the Chip Select (CS), Serial Clock (SCK) and Serial Data In (SDI), for the Serial Data Out (SDO) to output a 16-bit integer the CS that is normally high is set low along with the SDI and the SDO outputs the most significant
bit to the least changing from one bit to the next on a rising edge seen on the SCK. Once all 16-bits have been sent CS is set high again to signal the end of that transmission.

2.10. **MICROCONTROLLER WIRELESS MODULE**

To enable the microcontroller to wirelessly communicate with the host PC a WiFly GSX 802.11b/g Serial Module manufactured Roving Networks was connected. This module is mounted on a proto board along with an SC16IS750 SPI-to-UART chip that is used to allow faster transmission speeds between the microcontroller and the WiFly module. Both the WiFly module and SPI-to UART ship are powered by the regulated 3.3V output present on the microcontroller board. The proto board as a whole is known as a WiFly Shield, the microcontroller communicates with the WiFly Shield again using SPI with four digital communication pins. This wireless module was chosen for its low cost and availability of simple communication libraries between itself and the microcontroller used.

The main file to run the microcontroller can be found in Appendix A.

2.11. **COMMUNICATION SYSTEM ACTUAL CHOICE**

With both the iPod® and force transducer/microprocessor now having wireless capabilities they then need to both connect to a server of some type to allow data communication. In this thesis this has only been done on a local basis whereby a host PC (laptop) is used as an access point that both the iPod® and microcontroller can automatically associate themselves with. This laptop is then running a web server that both devices can communicate with.

A web server is a computer program that handles content such as web pages using HTTP over the Internet. In this case the web server will handle the data sent from both the iPod® and microcontroller, then delivering this in the form of a Hypertext Markup Language (HTML) document to be viewed by a web browser. As stated earlier this is only running locally so the web page will only be able to be viewed on the laptop running the web server.
2.12. **DATA ACCESS, RETRIEVAL AND STORAGE**

The web server handles the data being sent to it by first identifying whether it has come from the iPod® or the microcontroller. If the data is from the iPod® then it knows that this will be in XML format. Extensible Markup Language (XML) is a widely used format, used for encoding documents in a machine-readable format. The web server will then read in the XML file and store it in its root directory. A similar process occurs with the data from the microcontroller except the data is stored in a CSV format listing the force reading in Newtons and a time stamp. A comma-separated values (CSV) file is a commonly used simple text format for a database table where each record is on one line with each element separated by a comma. In this case each line will have a force reading in Newtons and a time stamp separated by a comma. Once both files have been read in and stored in the root directory, a request can then be placed by the opening of a specified web page to open these files and display them onto the web page. At this stage this has only been completed at a very elementary level but in the future has the potential to be developed significantly.

2.13. **WEB SERVER INTRICACIES**

It was chosen to write the web server in Python™ due to its steady learning curve as the author had no experience in the area, but most importantly its strong and easily accessible math libraries. Python™ is an interpreted, interactive, object-orientated programming language that aims to combine remarkable power with very clear syntax (Python™ 2010). Version 2.6.5 was used as this was the most recent version available at the time, during the year updates have been released and Python is running at version 3.1.2. The web server is run through one main python file that handles all of the post and get requests from the iPod® or microcontroller, this can be found in Appendix B. There is then a series of helper files that allows for smoother processing of the data to be sent, received or displayed.
2.14. **NEW AND UPDATED TASK DESCRIPTIONS**

At the beginning of 2009 the *app* ran three tests, a Single Finger Tap Test, Sequence Test and a Pinching Test. These tests were developed based on theories and techniques that have been previously tested and analysed. Another common testing technique seen in other formats is a tracing test where a patient is asked to trace a certain shape. As the patient’s skill increases so would the difficulty of the trace. It has been decided that this would be the next innovative test to implement into the current *app*.

After testing had taken place last year, feedback was given both from the patient and from the clinician present. Some valuable feedback from the clinician was that the patients suffering from Parkinson’s disease or a stroke can often also have a significant cognitive disability. This makes not only completing the hand and finger movements very difficult but also conceptualising the movement that they must make or need to remember to make after previous movement. With this in mind the current format of the sequences test where the patient had to remember a sequence and then repeat it, was not suitable. To update the test to better suit the patients needs it was decided with consult with the clinician to only show one step of the sequence at a time and then randomly select the next button to press.

2.14.1. **Sequences**

The updated sequences test flow can be seen from left to right in **Figure 2-5** below. To prepare to complete the test the patient should comfortably have their finger from left to right aligned with the respective numbered buttons. The patient must then initiate the test by pressing the “START TEST” button. Then only one of the four buttons will remain highlighted and the patient must press that button as fast as possible with the respective finger. Once either that button or another button is pressed a different button will become highlighted. This process will be repeated a number of times depending on the patients skill level ranging from 5 – 20 times. Once this is completed the patient will be informed that the test is finished and they will be able to view their results as seen in the screenshot on the right of **Figure 2-5**.
The test now gives more accurate feedback in regards to the reaction time of each finger as well as the error rate. This is more valuable than just a time to complete a set sequence which was the only feedback previously received.

![Figure 2-5: Sequence Test](image)

2.14.2. Tracing

A tracing test has been developed to allow patients to attempt to trace a line and eventually a shape or even character on the screen. The test initially presents the patient with a simple vertical line that they are asked to trace. Once the patient has completed the test they are given feedback as to how they completed the test. The case in Figure 2-6 shows a patient that has attempted to trace a line from the top to the bottom of the screen. In this attempt the patient completed the test in 13.46 seconds with an average error of 40.69%. The percentage error is calculated by the amount of the line drawn outside an acceptable area over the length of the trace. To uncontrollably stutter is a common symptom of Parkinson’s patients, this test also calculates the number of times the patient stuttered by counting the number of times they trace backwards and then forwards again, in the case of the test in Figure 2-6 it was three.
2.15. **SOFTWARE TESTS**

Both the *app* and microcontroller program have been tested by the author. They were put through a series of pass/fail tests to ensure they would remain stable and correctly handle any unexpected user inputs to the system.

2.16. **DEVICE HOUSING CRITERIA**

The device housing used in the 2009 prototype was not designed at all and was merely an off the shelf PVC box to enclose and protect the individual components for testing purposes. This lack of design ignored the need for effective component placement and securing within the box whilst also ignoring any ergonomics in the design. Key feedback that was received from patient testing in 2009 was that the iPod® was raised far too high above the table surface; where the housing was placed on which made completing the exercises increasingly difficult. With these deficiencies and feedback considered the design criteria for the new housing included:

- Effectively using the space within the housing to store components to intern reduce the size;
- Reducing the height of the housing as much as possible mainly constrained around the force transducer; and
• Increasing the ergonomics of the housing to allow for a better patient experience.

2.17. DEVICE HOUSING DESIGN AND CONSTRUCTION

The housing was initially modelled in Solidworks® taking into account the size and mounting of the previously discussed components. These included the force sensor, ADC circuit, microcontroller with the WiFly Sheild mounted and finally the iPod® to be mounted above the force sensor. These drawings can be seen in Figure 2-7 (A)-(C) showing the placement of each of the components in (A) through to the complete housing with ergonomic ramp in (C).

These drawings were then discussed with Vera Riley a Senior Occupational Therapist at Sir Charles Gairdner Hospital who the Author has worked closely with throughout the program, with any designs that needed to be analysed on a clinical use basis. In Figure 2-7 (C) there is a jigsaw shaped key that lines up the ramp with the housing in three configurations. This was initially designed so that the ramp would be in a set position depending on the orientation of the test that was currently being completed on the app. After consultation it was decided to remove this key for a number of reasons all related to the ergonomic customisation of the system for different patients. If the ramp was set at only one distance from the iPod® it would make it hard for different patients with smaller or larger hands to all get the same comfortable resting position which is one of the mains aims of the housing redesign. As you can see in Figure 2-7 (F) the ramp is now a standalone piece that can be moved into whatever position the patient finds most comfortable and intern making the rehabilitation exercise more enjoyable for the patient.

The new system can be seen in Figure 2-7 (D) – (F) measuring 220x120x50mm without the ramp. This is 40mm shorter than the previous housing and 35% of the volume. The ramp measures 225x100x50mm with the incline at 15°, which was decided in consultation with the therapist.
2.18. **SAFETY**

Engineering projects in all forms involve hazards with varying risks that can in some cases be very harmful. As such, safety should always be a primary concern for engineers and how they deal with it can often determine the success or failure of a project on many levels.

During the design, construction and testing phases of the project a large portion of time was spent in the UWA mechanical engineering laboratories to complete these tasks.
Potential hazards were identified early in the project, at this stage measures were put in place to reduce or even eradicate potential consequences from the identified hazards.

A safety induction was conducted by Adrian Keating for both G19 and G55 where several hazards were identified. Included in the induction training was an understanding on how to use a large range of equipment present in the room, once completed with the induction manual available in the respective labs at all times the risk of many incidents occurring was greatly reduced. The laboratories were also regularly checked to maintain and ensure all emergency equipment was present. Appropriate clothing including closed in shoes was worn at all times in the labs as well as equipment such as safety glasses when particular tasks were taking place that they were necessary for, such as printed circuit board construction and soldering.

2.18.1. Safety of the force transducer and housing

The safety of the force transducer and it casing is paramount as it will be used in patient testing at a hospital. The design of the housing has been completed so that all electrical components are enclosed, as well as all corners and edges being sanded down so that there are no sharp objects present in or around the housing.

Enclosed within the housing are three electrical circuits with two being externally manufactured and one needing design and construction in the printed circuit board laboratory in G55. Approval of the circuit design was first received before the construction was commenced. Constructing the board had two main phases being the fabrication of the printed circuit board (PCB) and the soldering of components to it, both with significant risks.

The process of making the PCB involved the use of concentrated and potentially dangerous chemicals to etch the PCB, it was ensured that these chemicals were appropriately labelled and stored to avoid confusion and misuse. The process also commences with the use of ultraviolet (UV) light in the photolithographic phase of design. Furthermore, prior to even beginning the process a number checks must be performed including checking to see if the UV lights are switched off prior to switching the light box on, and checking the operation diary for any problems encountered in past
usage. It is also essential to check the heater in the etching tank, as it is prone to breaking with poor handling and can lead to electrocution if not handled correctly whilst broken. As a part of the safety induction completed all personnel working in the laboratory were trained in the safety procedures to exercise if an unforeseen event occurred. This included the location and how to use emergency showers and eyewash stations as well as the nearest first aid station and officer.

No injuries or incidents occurred during the projects lifecycle. If one had occurred, an incident report form would have been completed and filed with the UWA safety office so that the problem could be investigated and resolved through the correct channels.

2.18.2. Safety of the application

Throughout the design and development of the new and upgraded tests that were analysed and reviewed by both Vera Riley and Gary Thickbroom. This was done not only to give feedback about their rehabilitation benefits but also the consequences and implications they may inflict on the patient. A brief on the tests was then also submitted for Human Ethics approval which was required for patient trials. These precautions were taken to significantly reduce the risk of completing the tests having any adverse effects on the patient. This is crucial because if there was to be any unexpected issues that caused any injuries to a patient this would significantly affect the current progress of the project as well as having massive implications on the future of it.

2.18.3. Safety of the communication system

When designing the communication system a consideration that was not previously discussed was its use within a hospital environment initially for testing and eventually for clinical use. Hospitals have a large array of equipment running at all times that can be extremely sensitive to unwanted disturbances, it is quite common for wireless devices operating at undesired frequencies to impact the use of this equipment. It was only recently in 2009 that the use of mobiles phones was officially allowed within hospitals (2009). With this in mind the use of an accepted wireless frequency that was accepted in hospitals was crucial. This made the use of any non-standard
communication frequencies and protocol very difficult. With this in mind it added to the reasons why a wireless 802.11 protocol was an effective and good choice as the form of communication.

2.19. **Final System**

*Figure 2-8: Final System*

*Figure 2-8* shows the final system that was constructed, you can clearly see how both circuits are mounted to the MDF base as well as the iPod® in its holder.
3. **CHAPTER 3- RESULTS AND DISCUSSION**

3.1. **PERFORMANCE OF THE WIRELESS COMMUNICATION SYSTEM**

3.1.1. *Web Server Data Processing*

The task of creating a web server proved to be quite challenging with not only having to learn a new programming language in Python™ but also having to understand the correct protocol for completing POST and GET requests which is how data is prompted to be sent. The development of this web server in limited time has limited the functionality, whereby it can only run locally. The advantage of using such a system though is that to expand the server to run globally over the internet does not mean writing a new program but continuing to add power and control to the current one.

3.1.2. *iPod® communication*

With the iPod® being constrained in its communication abilities to now be able to receive the test data on a PC from the iPod® wirelessly is a key achievement in the project objectives. To empower the iPod® with the ability to send the data did not come natively to the iPod® or the author. The process of this development ran with a “let’s give it a go and crash the iPod®” approach as each level of the code was developed; it was soon found that another lower level was needed to either complete the transfer itself or to stabilise it. The one area where the iPod® was natively helpful came in simply creating the connection with a wireless network to send the data over, unlike the microcontroller that proved troublesome.

3.1.3. *Microcontroller with Wireless Module Communication and ADC*

The learning curve and the amount of publically available libraries for the Arduino microcontroller made development of the communication system for itself into an achievable experience from one that had the potential to be extremely time consuming. Although there was a large array of available libraries for the WiFly Shield used, their reliability was to be questioned at times. The issue faced with the microcontroller connecting a network is that it must be pre-programmed, which meant that all of the
networks details must be previously known and entered in the right encryption format. Although the microcontroller has the ability to automatically scan for networks and automatically connect to available networks that are not password protected, it is now days very rare for networks not to be password protected.

The ADC used provided a detailed guide as to how it communicates with the microcontroller bit by bit, this made its inclusion simple and effective.

### 3.2. Development of the New and Upgraded Tests within the iRehab Application

The initial task of understanding the current state of the iRehab app proved to be extremely time consuming. The process was hindered by first having to learn a new language based around similar principles object orientate C programming but with a large amount of intricacies. With this learning curve in place this limited the amount of work that could be done expanding the app to incorporate more tests and features. The involvement of an experienced iOS programmer would be extremely beneficial to this project; to allow for more development and less learning throughout the project.

### 3.3. Performance of New Force Transducer: FlexiForce® Sensor Response and Characteristics

With the aim of reducing the size of the system a new force transducer was chosen to be used. To meet the overall objectives and design criteria the force transducer must be able to accurately and repeatedly determine the amount of force exerted onto the iPod® and output an associated value. In doing this it must be able to handle and capture quickly reoccurring successive taps realised in the single finger-tapping test.

#### 3.3.1. Impulse Response

The system in 2009 used a load cell to measure the force which presented a multitude of problems attempting to dampen the system as the load cell could bounce and in turn it would appear as there was a negative force applied. It was thought that the use of the
new force sensor could alleviate these issues as there was no possibility of a false negative appearing. An example of how the system responds to a large instantaneous impact is seen in Figure 3-1. It takes 0.04s to reach its peak at 2.98N but it takes a further 0.26s to drop to 10% of the peak value. Theoretically this means that if measurements of a tap using these constraints were used, input frequencies above 3.3Hz would not be captured accurately.

Tekscan claims the FlexiForce sensor has a response time <5μs, with more work required into the analysis of this and why this system is not realising this speed. Due to time constraints a reduction in this delay was not considered but will need to be analysed in future work.

![Impulse Response](image)

*Figure 3-1: Impulse Response for the new system.*

### 3.3.2. Calibration Curve

Tekscan claim that the linearity error of Flexiforce® sensor is ±3%, to test this and find a relationship between the force applied and the voltage seen across the divider circuit a calibration curve was needed. For this test various masses were added to the sensor and the digital output from the ADC was recorded. The minimum and maximum weights applied were 0.1085kg (the weight of the iPod® plus its holder) to 1.085kg respectively. The results are shown in Figure 3-2. It was chosen not to set linear trend line to
have a y intercept of 0 as there would always be a force of at least the iPod® and its holder during any test. The ADC output shows a linear relationship with Output = 29910 * Applied Weight – 3936, with a $R^2$ value of 0.991.

![Calibration Curve](image.png)

**Figure 3-2:** Calibration curve between the applied weights and the output from the ADC.

Calibration of the sensor shows a strong linear relationship between the applied weight and the output from the ADC. It must be noted that the output of the ADC is correlated to an applied weight that has been at rest on the sensor for 20s prior to reading being taken. This process will be quite different to when the force is applied in the form of a tap with is duration to last approximately 0.2s. With the output from the ADC correlated to the applied force each integer corresponds to an increase in the force applied of approximately 0.329N.

### 3.3.3. Sequential tapping at speed

The ability of the force transducer to accurately capture a series of sequential taps at high frequency is crucial to its design. The response of a control patient tapping as fast as possible and discounting the amount of force they were applying to increase the number of taps possible is seen in **Figure 3-3.** This figure realises an issues that was
discussed in section 3.3.1 where the time delay for the system to return to steady state after a tap is less than the time between taps at speed.

![Sequential Tapping at Speed](image)

*Figure 3-3: Sequential tapping by a control patient with 62 taps seen in 10s.*

Some of the possible implications that this delay could be causing can be rejected from analysing these results. A key problem of the delay would be if the force that was applied was compounded with the previous force. For example if one tap peaks at 2N and starts its slow decent to steady state but before it reaches steady state another new tap of 2N is applied. Would the peak of this new tap be 2N or would it be a sum of residual previous tap plus the new 2N tap. It can be seen from Figure 3-3 that if this effect is present then it is insignificant and can be neglected as an issue for altering the peak values but could still make it increasing hard for peak detection.

3.3.4. Repeatability

A repeatability test was conducted to determine and analyse the repeatability of the system to accurately record and output the same value for the same applied force. This
involved placing a 600g weight on and off the system 6 times in succession. The results are shown in Figure 3-4.

![Figure 3-4](image-url)  
**Figure 3-4:** Repeatability of the system with a 600g weight applied 6 times over a 1 minute period.

It can be clearly seen that the same applied load does not result in exactly the same result each time, including the fact that there is a delay in the response returning to steady state after the weight is removed as discussed earlier. The fluctuating results are caused by only using one force sensor. It means that a force applied to the iPod® outside a central region is not accurately reflected by the force reading, as not all of the force is directly translated to the sensor, this is demonstrated in Figure 3-5.

![Figure 3-5](image-url)  
**Figure 3-5:** Force diagram showing how forces are captured inaccurately.
This issue was identified by the author, due to the fact that sensors were purchased overseas there was insufficient time to order more parts to implement a redesigned system seen in Figure 3-6.

![Figure 3-6: Modified design to implemented four sensors to stabilise system.](image)

The redesigned system would implement four sensors instead of one, each being located in one of the four corners. This would mean that a force placed anywhere on the iPod® would be able to be reliably measured.

### 3.3.5. Noise Sensitivity

Electric noise is a characteristic present in all electrical circuits, in most cases it can be identified and reduced. The system was designed with that in mind where all connects have been made using ribbon cable so that any background electromagnetic noise is minimised as well as having a series of 0.1μF and 10μF located at multiple points throughout the ADC circuit to smooth out the voltages supplied at the respective points. The noise present in the system with these design measures implemented can be seen in Figure 3-7 where a 350g weight is place on the sensor for a period of 16 seconds. The force reading over that time varies over a range of 0.046N which is 1.3% of the average force reading of 3.45N seen over that period. The standard deviation of the force readings seen over the period is 0.0087N which is a insignificant 0.25% of the average. With this in mind it can be noted that from a electrical design perspective the noise in the system has been dealt with successfully.

The system is also quite sensitive to vibrations present in its environment, these can be hard to avoid when the system is placed on a table that is been tapped continuously to
complete the test. This noise will be quite hard to deal with as implementing any sort of filtering system will significantly impact on the measurement of the peak force during testing.

![Noise with 350g weight applied](image)

**Figure 3-7: Noise in the system with a 350g weight applied**

### 3.3.6. Conditioning

The system may go through periods of inactivity throughout its life cycle which have the potential to alter the properties of the sensor. It is recommended by Tekscan that prior to each use the sensor is conditioned by placing a weight greater than 110% of the test weights and leaving it for 20 seconds and then removing the weight (Tekscan 2010a). This process should be completed 5 times, in the case of this project it can be completed with a weight ranging from 1kg to 2kg.

### 3.4. Ethics Approval Update

It was intended that patient testing was to be conducted with the new and upgraded tests within the *app* as part of the entirely new force transducer, housing and communication system. To do this the Human Ethics approval which was granted for the previous prototype system needed to be updated to include the new information as well as listing
the Author as being able to conduct the testing. This was completed, however due to delays getting the Authors name listed on the approval it was not granted until the 15th of October leaving not enough time for official testing. This was very disappointing for the Author as patient recruitment had already begun. Continued patient testing with detailed feedback is crucial for the continual development and improvement of the prototype system. The updated approval letter can be found in Appendix C with reference number RA/4/1/2487.

3.5. OBSERVATIONS OF USERS AND CLINICIANS

Although no official patient testing was conducted the author worked closely with Vera Riley a Senior Occupation Therapist at Sir Charles Gairdner Hospital throughout the project. Invaluable feedback was provided throughout all stages of the project initiating with a detailed review of the previous prototype and what key areas needed immediate further development. Finally through to feedback on the prototype system constructed in this thesis as well as the new and upgraded tests. It was noted that the improvements in the size of the housing were significant and will definitely impact the running of the tests working towards making the most enjoyable patient experience possible whilst maintaining the most efficient clinical testing possible. The new tracing test was also of significant interest because as discussed in section 1.3 there is almost endless possibilities for development that can be catered for patients on all levels. With this feedback about the tracing test implement, the further development of this test should be a key focus in the future.

3.6. COST ANALYSIS

One of the objectives of this prototype system is to remain low cost. A detailed list of the costs involved in the development and construction of the upgraded prototype system are listed in Table 3-1.
### Chapter 3 - Results and discussion

#### Table 3-1: Cost Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Source</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>iOS Developer Registration</td>
<td>*US $99</td>
<td>developer.apple.com</td>
<td>Yearly subscription</td>
</tr>
<tr>
<td>8 GB iPod® Touch</td>
<td>AU $289</td>
<td>store.apple.com/au</td>
<td></td>
</tr>
<tr>
<td>Cost to distribute</td>
<td>Free</td>
<td>developer.apple.com</td>
<td>Included in registration</td>
</tr>
<tr>
<td>Cost to buy iRehab</td>
<td>Free</td>
<td>apple.com</td>
<td>A cost can be set in the future with Apple taking 30%</td>
</tr>
<tr>
<td>Tekscan FlexiForce Sensor</td>
<td>*US $14</td>
<td>sparkfun.com</td>
<td>One used in this project but four needed in future</td>
</tr>
<tr>
<td>Microcontroller (Arduino) plus WiFly Shield</td>
<td>*US $68</td>
<td>sparkfun.com</td>
<td></td>
</tr>
<tr>
<td>ADC plus additional components and PCB</td>
<td>AU $15</td>
<td>farnell.com.au</td>
<td></td>
</tr>
<tr>
<td>Housing Materials including mounting circuits</td>
<td>AU $15</td>
<td>bunnings.com.au</td>
<td>Materials purchased instore at Bunnings Warehouse</td>
</tr>
<tr>
<td>iPod® Holder</td>
<td>AU $10</td>
<td>jbhifi.com.au</td>
<td>Holder purchased instore at JB Hi-Fi</td>
</tr>
<tr>
<td>*Assuming an exchange rate of 1AUD = 0.95USD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost to develop iRehab and construct new force transducer with one sensor</td>
<td>AU ~$225</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost to develop iRehab and construct new force transducer with four sensors</td>
<td>AU ~$269</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost for the Force Sensing Docking Station with four sensors</td>
<td>AU ~$165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost for a user to purchase an iPod® with iRehab and a Docking Station</td>
<td>AU ~$454</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Once you are a iOS registered developer with Apple it is free to submit and sell an *app* on the Apple App Store that currently has over 200,000 *apps* available worldwide. In this process the developer can choose to have their *app* free to download or they can set
a price with the minimum being AU $1.19, with no maximum the most expensive apps currently only go up to AU $100. Once the price has been set the app can be sold worldwide with Apple taking 30% of the selling price.

There are two costs shown in Table 3-1 to develop iRehab and construct the new force transducer as one represents the system that has currently been constructed with only the one sensor present. The second cost represents the value to slightly modify the system to incorporate four sensors so that the force can accurately be captured at any point on the iPod®.

The cost to purchase a brand new iPod® Touch has been included in the final cost but it should be noted that there have been over 120 million iOS devices capable of running iRehab sold worldwide as at the end of September 2010. With this in mind a large percentage of developed countries population would have access to an iOS device. This would mean that they would not have to purchase an iPod® to run the app, which would reduce the cost to only $165, which is significantly cheaper.

3.7. LIMITATIONS DURING DEVELOPMENT AND THE FINAL SYSTEM

In the initial phases of the project a list of aims seen in section 1.4 were set out to be achieved through-out the project. These aims were all met to an extent but were not achieved to the initial high standard that was set out. Due to this and other choices that were made there are a series of limitations still placed on the entire prototype system.

3.7.1. Application

The application has currently been developed so that any iOS capable devices, including an iPod®, iPhone™ and an iPad will accept the app. Although these devices cover a large percentage of market share within their industries there are also other operating systems and devices available which may bring added benefits to the project. At the initial stage of choosing to use an iPod® in 2009 the Android operating system (OS) by Google was still very much in the development stage which limited its capabilities. In the two years since then the Andrdiod OS has grown exponentially and is now an
Chapter 3- Results and discussion

extremely capable OS that should be considered for this project in the future (Google 2010a). The reasons why are mainly based around the operating systems open source structure which could aid in connecting external devices like the force transducer as well as the distribution of the app to clinicians for testing.

The porting of the app to the Android OS could be completed as a standalone project with the addition of a feedback system to allow users to easily give opinions of the app. It is free to download and use the Android Software Development Kit (Google 2010b).

3.7.2. Force Transducer

The main limitations of the force transducer have been mentioned throughout its analysis and include only using one sensor and the delay to reach steady state. It was chosen to only use one sensor in the initial design due to the unknown about the sensor as the author had no experience in its use and implementation. It can now be seen that although there is still some unknowns about the sensor, if four sensors were to be implemented into the design then it could be a viable solution at an acceptable price.

3.7.3. User Feedback Group

The app and the tests on it require large amounts of continual feedback to ensure their development. With this in mind it should be a key goal in the next stages of the project to distribute the app to a larger population. There are a number of issues raised mainly due to Apple’s very strict distribution policies and procedures. It would be ideal to have a beta version of the app available to download through a protected web page that the author could inform targeted audiences about for them to then use the app and give feedback. The problem here is that there is no middle step like this available with the distribution onto the app store, the app can either be locally added to a limited number of devices or has to be completed and available to download on the app store.

As previously discussed the porting of the app to the Android OS could significantly assist in the distribution of a beta release for use and feedback. As a limited distribution of the app via a secured web page to a limited target audience would be possible.
Chapter 4 - Conclusions

4. CHAPTER 4- CONCLUSIONS

4.1. REFLECTION UPON ORIGINAL OBJECTIVES, AIMS AND FUTURE WORK

The system has undergone significant redevelopment in line with the overall project objectives and more specifically the aims of this project. The achievement of the aims of this project and the furthering of the project objectives are discussed below:

4.1.1. Project Aims

**Develop a connection between the iPhone™ or iPod®, force transducer/external microprocessor and a host PC:** A system has been designed for wireless communication between the components that allows the user to wirelessly complete a test and the results can be displayed on an external host PC. In the future this needs to be developed to be a global system so that the test can be wirelessly completed without the need of a host computer, then the results could be seen by logging into a webpage displaying all patient results.

**Develop a new more compact force transducer and design a new housing:** A new more compact force transducer has been introduced enabling a smaller housing to be constructed. In future a new base for the iPod® utilising four sensors needs to be incorporated to enable a much more accurate and repeatable force reading. Also the prototype housing could be redesigned so that it would be easier to mass produce so that the housing can be easily produced and distributed to potential customers.

**Upgrade existing and develop new tests in the application in consult with an occupational therapist and test these on a range of patients:** The existing sequences test has been upgraded and a new tracing test has been implemented. Testing of these is yet to be completed. The future for the app development is relatively endless; as the app is used by more users there will be increased feedback to develop more tests. One key step that could be taken is to start integrating difficulty levels into all of the tests so that they can be made available for patients at both extremes of hand disabilities suffering from different conditions.
4.1.2. **Project Objectives**

**Low Cost:** iRehab still has the potential to be available free for clinicians and patients in its development stage; however the distribution during this stage still needs to be finetuned. The new force transducer and its housing have remained at a low cost and at a single unit construction estimate is slightly cheaper. The existing load cell design was quoted at AU $170 with the new FlexiForce® design quoted at AU $165, both of these costs are excluding labour which would need to be taken into consideration when determining a sell price for the unit. With the goal to design a housing for mass production this should only bring down the cost of the unit.

**Small and portable:** The new force transducer and housing is significantly smaller than the previous prototype, with a global communication system implemented it has the potential to be completely non reliant and easily portable.

**Assess many aspects of hand skill:** With the implementation of the new and upgraded tests this has improved and added the assessment of many aspects of hand skill. In future with more detailed feedback the current tests can be further developed along with new tests.

**Provides quantitative and meaningful data to clinicians:** The data presented from completing the new tracing test presents quantitative information about the patient’s finger movements to clinicians. The information can be used to assess and measure this skill and allow the clinician to better prescribe rehabilitation exercise to further the patients development.

**For the system to be novel and appealing to potential users:** With the new communication system in effect and the housing now less cumbersome the idea of completing a task on an app on an iPod® sitting in the docking station and being provided with the amount of feedback possible is extremely exciting. With rehabilitation sometimes being a daunting task the opportunity to be presented with a system that is far less intimidating than what is currently available is a great step in providing a better rehabilitation process to patients.
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Appendices

Appendix A: Arduino Program

```c
#include "WiFly.h"
#include "Credentials.h"

#define CS 3
#define SDI 4
#define SCK 5
#define SDO 6

unsigned int readvalue;
char readvaluestring[6];

byte server[] = { 10, 0, 2, 1 }; 

Client client(server, 15628);

void setup() {
    // set pin modes
    pinMode(CS, OUTPUT);
    pinMode(SDI, OUTPUT);
    pinMode(SCK, OUTPUT);
    pinMode(SDO, INPUT);
    // disable device to start with
    digitalWrite(CS, HIGH);
    digitalWrite(SCK, LOW);
    digitalWrite(SDI, LOW);

    Serial.begin(9600);
    Serial.println("serial.begin");

    WiFly.begin();
    Serial.println("WiFly.begin");

    if (!WiFly.join(ssid, passphrase)) {
        Serial.println("Association failed.");
        while (1) {
            // Hang on failure.
        }
    }

    Serial.println("connecting...");

    if (client.connect()) {
        Serial.println("connected");
    }
}
```

-43-
unsigned int read_adc(){
  int tempbit = 0;
  unsigned int adcvalue = 0;

  //initiate read
  digitalWrite(CS, LOW);
  delayMicroseconds(1);

  //read bits from adc
  for (int i=0; i<16; i++){
    digitalWrite(SCK, HIGH);
    delayMicroseconds(1);
    tempbit = digitalRead(SDO);

    adcvalue+=tempbit<<(15-i);

    //cycle clock
    digitalWrite(SCK, LOW);
    delayMicroseconds(1);
  }
  digitalWrite(CS, HIGH);
  return adcvalue;
}

void loop() {
  readvalue = read_adc();
  Serial.println(" ");
  Serial.println(readvalue);
  sprintf(readvaluestring, "%d", readvalue);
  Serial.println(readvaluestring);

  if (client.connected()) {
    client.write(readvalue);
    client.flush();
  } else {
    client.connect();
  }
}
Appendices

Appendix B: Web Server programs written in Python

Header file that handles iPod XML file transfer

```python
import sys

from BaseHTTPServer import BaseHTTPRequestHandler, HTTPServer
import cgi
import cgitb
from os import curdir, sep
sys.path.append(curdir + sep + 'pages')
from index import IndexPage
from list import ListPage
from form import FormPage

class HTTPRequestHandler(BaseHTTPRequestHandler):
    """Class to handle all HTTP Requests""

    def do_GET(self):
        """Method that handles all GET requests""
        try:
            # takes the url and splits it into page (first parameter) and
            # extra parameters (ie, the rest) in a dictionary. /
            path = self.path.strip('/')
            request = path.split('/', 1)
            page = request[0]
            parameters = {}
            if len(request) > 1:
                extras = request[1].split('/')
                i = 0
                while i < len(extras):
                    parameters[extras[i]] = extras[i+1]
                    i += 2
            if page == 'index' or page == '':
                IndexPage(self, parameters)
            elif page == 'list':
                ListPage(self, parameters)
            elif page == 'form':
                FormPage(self, parameters)
            else:
                raise Exception('URL doesn\'t match a page')
        except Exception as e:
            print e
        self.send_error(404, 'File Not Found: %s' % self.path)

    def do_POST(self):
```

-45-
try:
    print self.headers
    ctype, pdict = cgi.parse_header(self.headers.getheader('content-type'))
    length = int(self.headers.getheader('content-length'))
    print ctype
    print length
    if ctype == 'multipart/form-data':
        print "Multipart data"
        body = cgi.parse_multipart(self.rfile, pdict)
        outputFile = open("something.xml", "w")
        outputFile.write(body['uploaded'][0])
        outputFile.close()
    elif ctype == 'application/x-www-form-urlencoded':
        print "Form data"
        qs = self.rfile.read(length)
        print "Finished reading from socket"
        body = cgi.parse_qs(qs, keep_blank_values=1)
    else:
        print "Other data"
        body = {} # Unknown content-type
        # throw away additional data [see bug #427345]
        while select.select([self.rfile._sock], [], [], 0)[0]:
            if not self.rfile._sock.recv(1):
                break
        print "printing parameters"
        print body
        print "printed parameters"

    parameters = {}
    FormPage(self, parameters)
except Exception as e:
    print e

def main():
    """Main application loop""
    try:
        server = HTTPServer(("", 8080), HTTPRequestHandler)
        print 'Starting Webserver'
        server.serve_forever()
    except KeyboardInterrupt:
        print 'Closing server'
        server.socket.close()

if __name__ == '__main__':
    main()
Header file that handles microcontroller CSV file transfer

```python
import socket
import csv
import time

TCP_PORT = 15628
BUFFER_SIZE = 10

csvOutput = csv.writer(open('blah.csv', 'w'), delimiter=',')

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
s.bind((socket.gethostname(), TCP_PORT))
s.listen(1)

conn, addr = s.accept()
print 'Connection address:', addr
while 1:
    data = conn.recv(BUFFER_SIZE)
    if not data: break
    number = int(data, 2)
    print "received data:", number
    csvOutput.writerow([time.time(), number])
conn.close()
```
Appendix C: Approval letter from the UWA ethics committee to continue user trials.

Our Ref: RA/4/1/2487

Professor Adrian Keating
Mechanical & Chemical Engineering (School of)
MBDP: M050

Dear Professor Keating

HUMAN RESEARCH ETHICS OFFICE – ETHICS APPROVAL RENEWED

Exploring the feasibility of using a software application on the iPhone to assess hand motor skill and act as a rehabilitation device

Student(s): David William Smith, Alison Margaret Barnes

Thank you for submitting your Progress Report for the above project. The report is satisfactory and ethics approval for the project has been renewed.
You will receive a request for your next progress report approximately one month before the next renewal date of 01 September 2011.
If you have any queries, please do not hesitate to contact the Human Research Ethics Office (HREO) on (08) 6488 3703.
Please ensure that you quote the file reference – RA/4/1/2487 – and the associated project title in all future correspondence.

Yours sincerely

Kate Kirk
Secretary
Human Ethics Research Committee