University of Southern Queensland

Faculty of Engineering and Surveying

The Design and Construction of an Exercise Device for Use in Physiotherapy of the Arm

A Dissertation submitted by

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Courses ENG4111 and ENG4112 Research Project

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ABSTRACT

This project set out to develop a low cost, in-home robotic rehabilitation device for stroke patients suffering arm paralysis. The forecast increase in stroke caused by obesity and the aging population will place more strain on social services and resources. There is a requirement to move away from traditional therapy with the alternative being computer-based rehabilitation devices that allow patients to exercise in the comfort and safety of their homes.

This project has researched stroke and its debilitating effects along with rehabilitation goals and techniques. This research revealed the potential to introduce a low cost robotic rehabilitation device. The project conceptualised, designed and manufactured a device that simulates most of the natural range of motion of the arm. The device is linked to a computer and offers an on-screen representation of the patient's movements.

Testing has shown that the device has great potential in the medical world and will offer stroke patients a more accessible rehabilitation technique. With some refinement of the design and improved software, the device will be ready for clinical testing. All of this work aims to help the patient return to normal everyday living sooner making them less dependent on social services, friends and family.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Date

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I would like to thank my project supervisor, Dr Selvan Pather for his valued help and reliable guidance over the last year, and the USQ workshop for constructing this device.

To my friends and family, thankyou for your support and patience throughout my degree.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

CIMT: Constraint Induced Movement Therapy

DOF: Degree of freedom

DOFs: Degrees of freedom

FEA: Finite element analysis

RRD: Robotic rehabilitation device

ROM: Range of motion/movement

ROMs: Ranges of motion/movement

Chapter 1 INTRODUCTION

1.1 Introduction

Robotics and electronics have proven very beneficial in almost all industries and areas of human life. There has been much research conducted recently into the use of robotic devices for stroke rehabilitation. They are showing great promise in restoring movement and strength to a patient's paralysed limbs after suffering a stroke.

This dissertation discusses how rehabilitation can greatly improve a sufferer's quality of life. The advantages of using robotic rehabilitation over traditional methods are important drivers for this design. The dissertation documents the design and construction of a computer-based device to help rehabilitate a patient's upper limbs.

This chapter discusses the project motivation, objectives and methodology as well as outlining the structure of the dissertation.

1.2 Motivation

Stroke is a leading cause of disability and devastates the lives of sufferers as well as their friends and family. One of the common side effects of stroke is paralysis of one or more limbs. The limitations caused by the paralysis, and thus the quality of life of the patient can be greatly improved with rehabilitation, but there are some problems with the current techniques. It can be difficult for patients to receive enough therapy to improve their condition because of its high expense, the need to travel and a lack of therapists. An inexpensive robotic device that can be used in the home has the potential to help many less fortunate sufferers regain movement and strength in their arm, thus reducing their reliance on others. Family and friends are usually left with the heavy strain of looking after stroke victims so helping stroke patients also helps their carers.

The aim of this project is to design and manufacture an effective yet inexpensive robotic device that can be used for rehabilitating stroke survivors who have arm paralysis. It is intended that the device will be purchased by the patient and kept in their home so that they can use it at any time. It will not replace physiotherapists completely; instead it will supplement their work to achieve better results for the patients.

1.3 Project Objectives

In order to guide the project, a list of objectives has been devised. They have been arranged in order of when they will be achieved and are shown below;

1. Research how stroke affects movement and motor skills. Research current rehabilitation methods and their success.
2. Research available joystick style equipment and their mechanisms, and determine whether they could be suitable for this device.
3. Create concepts and investigate the strengths and weaknesses of each concept.
4. Prepare design for construction
5. Investigate and design electronics and control.
6. Test the design and evaluate its performance.

As time permits:

7. Investigate and design force feedback components.
8. Perform clinical testing and provide professional feedback.

The methodology needed to ensure these objectives are achieved in a timely fashion will be discussed next.

1.4 Methodology

Research will be conducted into stroke and its effects on the human body. This project focuses on the paralysis of the arm and how this reduces the patient’s independence and quality of life. The benefits of rehabilitating arm paralysis and the currently used methods will be investigated. The possibility of using robotic rehabilitation devices will be explored and some recently developed devices will be discussed. Arm movements and ranges of motion will be examined.

Using the background information, the constraints and requirements of the device will be determined. Some concepts for the structure will be devised and critiqued. Position monitoring systems will be considered at this point, but designed in detail later. The best concept will be designed, components drafted and drawings given to the workshop for construction. Parts to be outsourced will be specified and ordered through USQ. Once built, the structural part of the device will be tested and evaluated and changes may be made if necessary.

The position sensing of the device will then be designed in detail. The parts will be fitted to the device along with any electronics that are required. The electrical circuit will be designed and implemented. The software and interface needed to make the position of the device visible on a computer screen will then be developed.

The device will be evaluated as an overall stroke rehabilitation tool. Problems will be identified, possible solutions/modifications will be suggested and the future work needed will be outlined.

1.5 Overview of Dissertation

This section outlines the information that is included in this dissertation. The chapters and their content are listed below;

Chapter 2, *Background,* investigates stroke and its effects along with rehabilitation objectives and techniques. It also introduces robotic rehabilitation and looks at some of the recently developed devices.

Before design can begin, the requirements of the device and the design constraints need to be known. Chapter 3, *Design Constraints and Requirements,* contains this information.

Chapter 4, *Concept Development,* covers some of the concepts that were devised and shows which concept was chosen to be designed.

In chapter 5, *Final Design and Manufacture of Prototype*, the design process and the workings of the device are documented. Included in this chapter is the design of the mechanical structure and the electronics.

The development and operation of the software and interface is detailed in chapter 6, *Software and Interface*.

Chapter 7, *Evaluation and Testing of Design*, will look at the functionality of the design and identify any problems that were found. It will also cover the range of movement and accuracy testing.

Finally, a summary of the achievements that have been made and the future work that can be done on this project will be included in chapter 8, *Conclusions and Future Work.*

1.6 Conclusion

The need for a better stroke rehabilitation technique has sparked research into using robotic devices for physical therapy. An effective device could help patients recover from their paralysis much better than traditional techniques, making them less dependent on carers and giving them better quality of life. This chapter has set out the project objectives and methodology.

Chapter 2 BACKGROUND

2.1 Introduction

The following chapter discusses the information found while conducting a literature review on stroke. The topics include stroke and its effects, rehabilitation goals and techniques, neuroplasticity and muscle development. The research then moves onto robotic rehabilitation and its effectiveness, and some of the recently developed devices. An understanding of stroke and rehabilitation was necessary to design a device that meets the needs of the patients.

2.2 Stroke

Stroke (also known as cerebrovascular disease) occurs when the supply of blood to the brain is suddenly disrupted. (National Stroke Foundation, 2007). Blood flows to the brain by a network of blood vessels called arteries, and is responsible for transporting oxygen and nutrients to brain cells. When the blood flow is cut off, the brain cells don't receive the supplies they need and die. Depending on the extent of the stroke, and the length of time before medical help is received, part of the brain can become permanently damaged. This damaged part is referred to as an infarct. The part of the body that the infarct controlled, will no longer work properly, or not at all.

2.3 Stroke Statistics

The National Stroke Foundation (2010), have listed a number of statistics on their website. The ones that are useful for this report are listed below;

- Stroke is Australia's second single greatest killer after coronary heart disease and a leading cause of disability.
- In the next ten years more than half a million people will suffer a stroke.
- About 88 per cent of stroke survivors live at home and most have a disability.
- Close to 20 per cent of all strokes occur to people under 55 years old.

The numbers presented here show the significant effect that stroke has on society. The Australian Bureau of Statistics constantly reports an ageing population which will correlate to an increased number of stroke sufferers in coming years.

2.4 Types of Stroke

There are two main types of stroke; ischemic and hemorrhagic, and they are classified by the way the blood flow to the brain is interrupted.

An Ischemic stroke (Figure 2.1) occurs when an artery to the brain is blocked either by a blood clot that has formed at the site of the blockage (cerebral thrombosis) or at another location in the body (cerebral embolism). These blood clots are formed because of a build up of fatty deposits on the blood vessel walls.

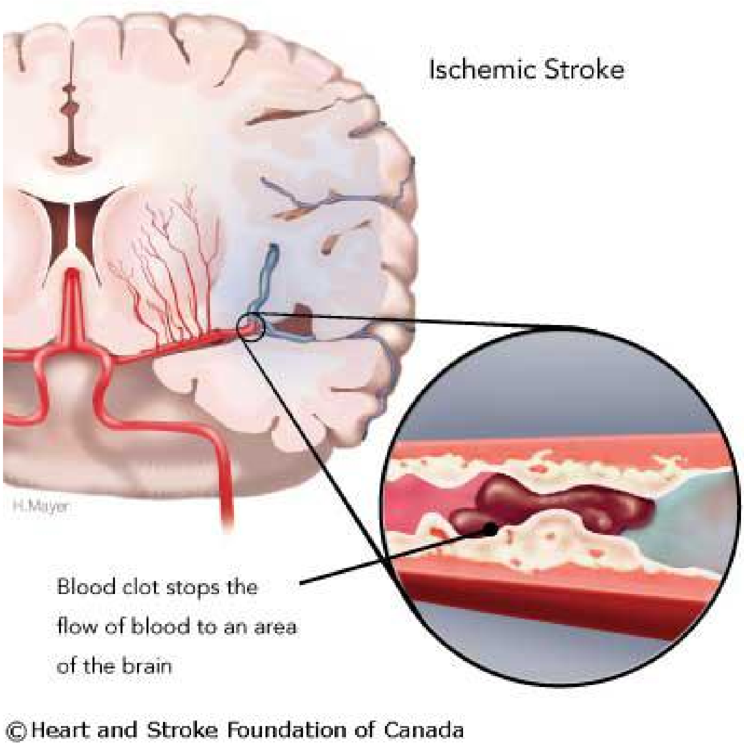

Figure 2.1 An Ischemic Stroke occurs when an artery to the brain is blocked by a blood clot (Source: Heart and Stroke Foundation of Canada, 2008)

A hemorrhagic stroke (Figure 2.2) occurs when a blood vessel ruptures and bleeds into the brain. According to the American Heart Association (2010) thirteen per cent of all strokes are hemorrhagic strokes. When the weakened blood vessel ruptures, the blood pools and presses on the nearby brain tissue, killing brain cells. The blood vessel can rupture inside the brain, known as an intracerebral hemorrhage or on the outside of the brain, a subarachnoid hemorrhage.

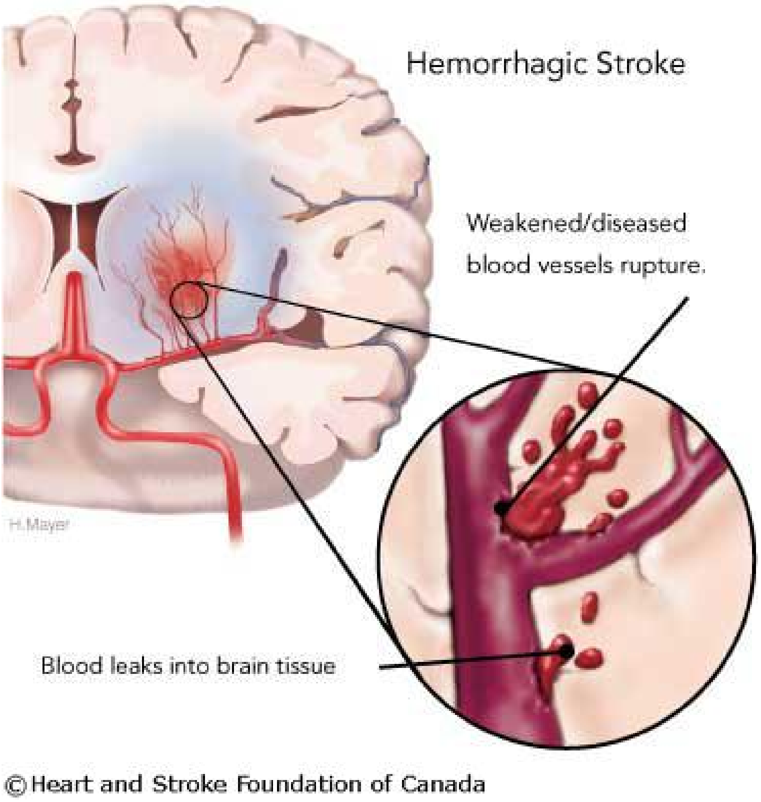

Figure 2.2: A Hemorrhagic Stroke occurs when a blood vessel ruptures and bleeds into the brain. (Source: Heart and Stroke Foundation of Canada, 2008)

2.5 Effects of Stroke

Each stroke is different, and the effects depend on the size of the stroke and where in the brain it occurs. The American Heart Association (2010) lists some of the common disabilities caused by stroke including problems with;

- the senses (eyesight, touch, awareness of the body);
- motor activity (in the arms or legs);

- speaking and understanding speech;
- eating;
- sexuality;
- behaviour, thinking, emotions; and
- weakness or paralysis of the body (hemiplegia).

If the stroke occurs in the right hemisphere of the brain, it can cause paralysis of the left hand side of the body and problems with depth perception. Patients can experience loss of judgement and act impulsively, suffer short term memory loss and visually neglect the space on the left side of their body (left side neglect).

If the stroke occurs in the left hemisphere, it can cause paralysis of the right hand side of the body, speech and language problems as well as behavioural and memory problems. In the opposite way to right hand hemisphere stroke sufferers having an impulsive behaviour and losing their sensible judgement, left hand hemisphere patients may have a slow behaviour and not be able to finish tasks because of it.

Patients who have a stroke in their brain stem lose the part of the brain that controls breathing, blood pressure and heart rate. They can experience problems with these functions as well as paralysis, vision impairment, difficulty swallowing and hearing and speech problems.

Strokes that occur in the cerebellum can cause loss of coordination and balance, dizziness, nausea and vomiting. (Brain Foundation, 2010)

Generally stroke can have a devastating effect on one’s personality. It can cause the patient to become distressed, irritated, depressed, overly emotional or to feel helpless. It can make what were once simple tasks very complicated and this can be difficult to come to terms with for some sufferers.

It is possible for these side effects to improve or even disappear after the stroke, but again, this will depend on the severity of the stroke, and the rehabilitation that is received. This will be discussed further in the next section.

2.6 Rehabilitation

The Pocket Macquarie Dictionary (1989, p. 873) defines ‘rehabilitate’ as, *to educate and help (a person affected by an accident or disease) to take up normal activities again.* The following section discusses the reason for rehabilitation, the currently used techniques and the issues associated with them.

2.6.1 Reason for Rehabilitation

Stroke can drastically reduce a person’s quality of life because of its debilitating side-effects. The type and amount of rehabilitation required depends on the severity of the stroke and what parts of the body it has affected. In Australia, rehabilitation can be received in hospital, at home, or as an outpatient (National Stroke Foundation, 2007). Rehabilitation needs to start as soon as possible after the stroke, and can be within 2 days of the attack if the patient is stable (Brain Foundation, 2010). There are several rehabilitation techniques and these will be discussed in the following sections.

A rehabilitation team can consist of some or all of the following people; doctors, nurses, dieticians, occupational therapists, physiotherapists, psychologists, social workers and speech pathologists (National Stroke Foundation, 2007) Obviously, the professionals involved will depend on the problems the patient experiences.

2.6.2 Rehabilitation Goals

The aim of rehabilitation is to help the patient regain as much independence as possible (Heart and Stroke Foundation of Canada, 2009) and to improve the patient’s quality of life after the stroke. It helps to learn skills that have been lost or if this isn’t possible, patients will be taught new skills to cope with the changes to their lifestyle (National Stroke Foundation, 2007). The rehabilitation goals will depend on the severity of the stroke, and its effects on the patients. For a stroke that has caused speech problems, rehabilitation will focus on helping the patient to communicate. If the stroke has caused paralysis to one or both sides of the body, rehabilitation will focus on getting the patient to re-learn movements and regain muscle strength. This could mean the difference between a patient being able to open a bottle themselves, and having to rely on someone else to do it. Rehabilitation can last for months or years depending on the person.

Recovery is usually greatest in the first couple of months after the stroke and then gradually plateaus, but small gains can be experienced long after the stroke (Brain Foundation, 2010).

2.6.3 Neuroplasticity

Neuroplasticity is the brain's ability to reorganize itself by forming new neural connections throughout life (MedicineNet.com, 2004). Humans are always learning new skills, and experiencing new things. The human brain is able to adapt to these things by training different neurons to control different parts of the body and remember different things. Neuroplasticity is the saving grace of the damaged or disabled brain; without it, lost functions could never be regained, nor could disabled processes ever hope to be improved (MemoryZine, 2009). After a stroke, parts of the brain can be damaged and the function that these parts controlled will be lost. However, because of neuroplasticity, a different part of the brain can be trained to take over the lost functions. For example, if the left side of the brain is damaged from stroke causing paralysis of the right side of the body, the right side of the brain can be trained to control the bodily functions. Retraining the brain takes time and constant repetition of the task.

Carey (2007) listed the principles of retraining a damaged brain based on perceptual learning and neural plasticity theories. They are;

- repeated practice of specific stimuli;
- attentive exploration;
- vision occlusion;
- motivating, meaningful tasks;
- use of anticipation trials and imagery;
- feedback on accuracy, method of exploration and summary feedback;
- calibration of sensation within and across modalities; and
- progression from easy to more difficult discriminations.

2.6.4 Muscle Development

Muscle atrophy is the wasting of muscles resulting from disuse, or disease (also called neurogenic atrophy). Disuse is generally related to things like decreased activity as aging occurs or suffering an injury that prevents use of a body part for some time. Muscle atrophy caused by stroke falls under the disease category as the inability to move is caused by the problems with the nerves that supply the muscles.

The most common form of treatment for muscle atrophy is an exercise program designed by a physical therapist. However, in order to exercise the limbs, the patient must first be able to use them. Muscle development would be the final stage of stroke rehabilitation and can only begin once the patient has regained movement in the affected limb. (MD Guidelines, 2010)

2.6.5 Current Rehabilitation Techniques

The majority of rehabilitation received is currently through physical therapy. Another recently developed technique called Constraint Induced Movement Therapy is also being more widely used. These will be discussed further below.

2.6.5.1 Rehabilitation by Physical Therapy

As discussed earlier, there are many professionals that can be involved with the rehabilitation process. This report is mainly concerned with trying to recover the movement of the patient’s arm, which is presently done by a physiotherapist. This section will only discuss the techniques used by a physiotherapist to regain movement of a limb.

In Australia, physical therapy is currently the most widely used technique for recovering limb movement. It is the most accessible treatment and offers reasonable results. Physiotherapy can include some or all of the following;

- practicing day to day activities like rolling in bed, standing up, walking and using legs and arms;
- exercises to improve strength, sensation, coordination and fitness;
- stretching or supporting muscles to reduce their stiffness or pain; and

- choosing to limit the use of the patient’s good limb to encourage use of the affected limb.

(National Stroke foundation, 2008)

The therapy program depends on the patient and will be determined by medical professionals. The exercises will change over time as the needs of the patient change.

2.6.5.2 Constraint Induced Movement Therapy

Constraint Induced Movement Therapy (CIMT) or CI Therapy is a fairly new technique developed by Edward Taub. It involves constraining the unaffected arm with a sling and forcing the use of the affected arm for day to day activities. Usually after a stroke that causes arm paralysis, the patient will neglect using the affected arm and hence never regain any movement of it. CIMT utilises the theory of neuroplasticity and retrains the brain to move the impaired arm.

Taub & Guswatte (2006) give the three main components of CIMT. They are; repetitive, task-oriented training of the impaired arm for several hours a day for 10-15 days, constraining patients to use the impaired arm during waking hours and applying a package of behavioural messages designed to transfer gains in a clinical setting to the real world. Over the last 20 years, a large body of evidence has accumulated to support the efficacy of CI therapy for hemiparesis subsequent to chronic stroke (Taub & Guswatte, 2006).

Following on from the research into CIMT, a need to automate the treatment has been recognised, to try and make it administrable in the home. This is necessary to reduce the amount of one-on-one physical therapy required, in turn reducing the cost of such a beneficial treatment and making it more easily available for the wider community. This has led to the development of Automated Constraint Induced Therapy Extension (AutoCITE), a workstation that can train the patients to carry out a set of movements which will help them regain use of their arm. The workstation consists of eight tasks which address the movement of the shoulder, elbow, hand and wrist. The eight tasks shown in Figure 2.3 are; reaching, peg board, supination/pronation, threading, tracing, object-flipping, fingertapping and arc-and-rings. A computer records the patient's 'score' for each task and compares his or her scores during the training.

Figure 2.3: The eight tasks performed at the Auto CITE workstation are reaching, peg board, supination/pronation, threading, tracing, object-flipping, fingertapping and arc-and-rings

2.6.5.3 Issues with Current Rehabilitation Techniques

There are number of problems associated with current stroke rehabilitation techniques, mainly physical therapy. DeAngelis (2010) reported that less than ten percent of people who had suffered a stroke were still receiving occupational or physical therapy within two years of their attack. This is because therapy is a very expensive and time consuming treatment. In order to reap significant benefits from physical therapy, the patient must frequently see a physiotherapist. This can be difficult for some patients who live a significant distance from the clinic or must rely on family or friends to drive them. These factors cause great inconvenience and place a lot of pressure on the patient and their family.

Another major problem with physical therapy is that the patient might be showing promise of independence within the hospital or facility but once they get home, the skills don't transfer and the patient must still rely on family or friends. If the skills do transfer, they usually aren't reinforced when the patient returns home and can eventually be lost. (DeAngelis, 2010)

Stroke rehabilitation will usually involve practicing repetitive movements. This can be boring for both the therapist and the patient, causing them to lose interest in what they are doing.

2.6.6 Measuring Rehabilitation Progress

An important part of any rehabilitation program is monitoring the progress of the patient in order to address problems with certain areas. It is paramount that the patient moves forward with their disability and not backwards which sometimes happens because of lack of motivation or improper treatment.

There is a variety of tests and scales that are used by therapists to monitor the progress of a patient. They can be a measure of range and speed of movement, or a subjective rating of a patient’s ability to perform tasks. The Manual Muscle Test involves a therapist testing the strength of a limb. The Fugl-Meyer assessment consists of a therapist noting the general use, reflex, range of motion (ROM), balance, sensation and other behaviours associated with the affected limb.

2.7 Robotic Assisted Rehabilitation

Robotic rehabilitation has been an active field of research since the 1990s (Celik et al. 2010). Restoring arm movement after a stroke usually requires teaching specific movements then constantly repeating them. This sort of work can easily be done by a robotic device. It is important to note that a robot will not necessarily replace a therapist but will probably supplement their treatment. Some different types of robotic devices have been created and tested, and studies have shown that they give results similar to or better than physical therapy.

2.7.1 Advantages

There are numerous advantages of using robotic devices to aid in rehabilitating paralysed limbs including the following;

- It relieves the need for one on one time with a physiotherapist as the device can guide the patient through the exercises instead of the therapist.

- An in-home device relieves the need for travelling to a physiotherapist and allows the patient to do the exercises whenever he or she can.
- Robotic devices are consistent and objective when assessing and guiding a patient.
- With the use of games or activities, robotic devices can make the rehabilitation more fun and exciting.
- Correct movements can be forced by locking certain degrees of freedom (DOFs). Exercise programs can be developed as required by therapists.
- With the aid of force feedback, the nature of the device can be changed from resistive, to neutral to assistive more accurately and consistently than by a therapist.

However there are some limitations with robotic devices and these need to be discussed as well.

2.7.2 Limitations

The limitations associated with robotic rehabilitation are;

- Exercises that can be done on a robotic device may not correlate directly to activities of everyday living such as opening a jar (Casadio et al. 2009).
- Robotic devices do not have give the human interaction of one on one therapy.
- There is not yet a correlation between robotic measurements and patient progress. (Celik et al, 2008)

Research has shown that the advantages of robotic assisted rehabilitation outweigh the limitations and that robotic devices have a very important role in the society.

2.7.3 Recently Developed Devices

There is a lot of research being conducted into using robotic assisted rehabilitation and several different devices have been designed. Some devices have been put into a clinical situation and initial testing has been conducted. Three of the recently developed devices will be discussed here.

2.7.3.1 T-WREX

The T-WREX or the Therapy Wilmington Robotic Exoskeleton shown in Figure 2.4 is a weight reducing structure that has been designed to support an arm weakened by paralysis. The structure counterbalances the weight of the entire arm without the use of actuators to enable the user to move around easily and not have to support their bodyweight. It offers approximately two thirds of the full ROM of an average arm and has five DOFs. The amount of support the device gives can be varied by adding or removing rubber bands.

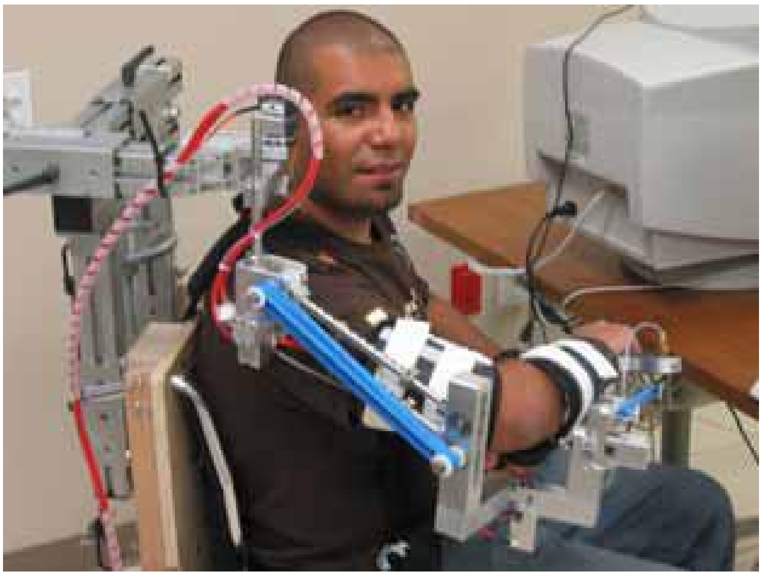

Figure 2.4: The T-WREX is an weight reducing structure that has been designed to support an arm weakened by paralysis (Source: Housman et al, 2007)

2.7.3.2 HOWARD

The HOWARD, or the Hand-Wrist Assisting Robotic Device shown in Figure 2.5 was designed to help stroke sufferers regain strength and use of their hand. The patient's hand is strapped in HOWARD, which is linked to a computer screen. The device takes the patient through a series of exercises and with the help of force feedback, can help him or her move their hand when needed. The HOWARD has been designed to help patients re-learn hand movement and control.

Figure 2.5: The HOWARD was designed to help stroke sufferers regain strength and the use of their hand (Source: redOrbit, 2007)

2.7.3.3 MIT-Manus

The MIT-Manus (Figure 2.6) is a robotic rehabilitation device developed by the Massachusetts Institute of Technology. It initially had two DOFs and could move in 2D horizontal plane. A wrist attachment with three DOFs was later added to exercise the wrist as well. The initial device was completed in 1991 and it has been worked on since. It is now a highly functional device that is coupled to a computer and uses force feedback to assist or resist patient movements. The computer displays the position and movements of the handle and provides exercises for the patient.

Clinical testing has been conducted with this device (without the wrist attachment) at the Burke Rehabilitation Hospital in New York and the results were quite promising. Patients showed reduced movement impairment in their elbows and shoulders. (Krebs et al, 2007)

Figure 2.6: The MIT-Manus is a highly function robotic rehabilitation device with 5 DOFs to exercise the shoulder, elbow and wrist (Source: Garrett, 2009)

2.8 Interview with Jude Wilson – Physiotherapist

In June 2010, a casual interview was conducted with Jude Wilson, a physiotherapist who was worked with stroke patients, to obtain a clinical opinion of the device in mind. Jude's overall view was that the device was good idea and would definitely be a valuable tool for stroke rehabilitation. Jude also brought up some points that reinforced the literature found in other research material.

- The device needs to provide functional movements that correlate to everyday living.
- The best way to regain movement is by repeating movements over and over again.
- Patients are currently not getting enough therapy to reap the benefits of rehabilitation.
- The orientation of the patient is important, that is whether they are performing tasks sitting, lying or standing.
- The orientation of the movements, that is whether they patient needs to move against gravity, with gravity or neutrally.

Jude was a helpful reference as the opinions and ideas of someone who has worked directly with patients are very valuable in the design process.

2.9 Conclusion

Stroke is a leading cause of disability and one of its effects is paralysis in the limbs. This causes sufferers to lose their ability to do simple, everyday tasks and hence makes them very dependent on others. Rehabilitation aims to reverse this paralysis, and help the patient re-learn movements, increase muscle strength and improve motor skills. This is currently done by physical therapy, but new advances in robotic therapy are making it a very attractive technique for rehabilitation.

Chapter 3 DESIGN CONSTRAINTS AND REQUIREMENTS

3.1 Introduction

The following chapter covers the requirements of a fully functional robotic rehabilitation device that is ready for production and sale. Not all of these requirements will necessarily be met in this project, but they will be considered and developed as future work. The constraints need to be established early so that a suitable device is designed. The most important feature of the intended device is its home-based nature. This suggests a low cost, small and effective design.

3.2 Requirements of a Robotic Rehabilitation Device

The following section lists the major requirements of a robotic rehabilitation device (RRD). Each one will be addressed in detail.

3.2.1 Size, Form & Portability

It is intended that the RRD to be designed will be owned by a patient and kept in his or her home. It could also be kept at a physiotherapy clinic for use during appointments. It should be easily accessible and set-up should be quick and simple so as to not create another tedious task. The device could be kept on a computer desk with a computer and be set up at all times (Figure 3.1). This gives a rough idea of how big the device can be, but a quantitative maximum size window would be approximately 500 mm wide, 1000 mm deep and 1500 mm high. One would assume that the only times the device would be moved is if the room needs to be rearranged or if the patient is moving house, meaning portability isn't a major issue. The form of the device should be so that it can be clamped to a desk in a safe manner, and be ergonomically sound.

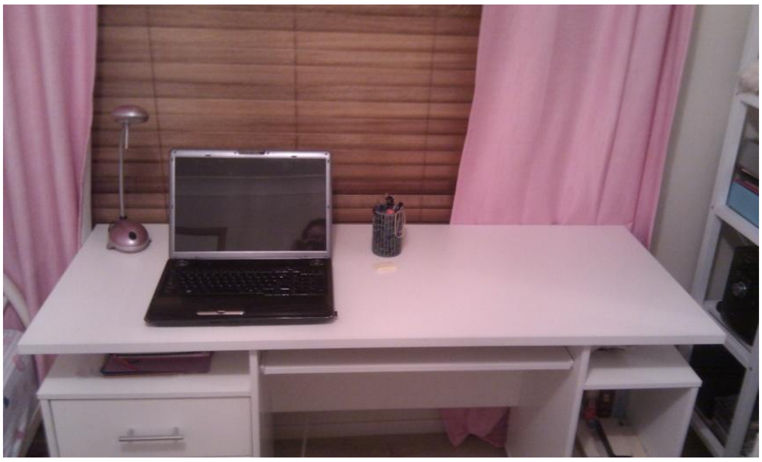

Figure 3.1: It is envisioned that the device will be kept on a medium sized desk next to a computer. This image shows the relative size that the device could occupy compared to a laptop

3.2.2 Movement

The RRD will need to have movements that mirror the human arm. The particular movements will be discussed more in a later section but the mechanisms controlling these movements will be discussed here. The device will be made up of mechanical joints, either linear or rotational, that will need to be smooth and consistent. They should be precise and repeatable and be as neutral as possible, so quality manufacturing and design will be required.

3.2.3 Cost

It is intended that this device will be owned by the patient. To make this realistic, the device needs to be cheap relative to therapy costs and the results that it gives. There is a fair scope for price, depending on the final design and its application. By owning this device, the patient reduces the amount of therapy they need and can use the money they are saving to buy a RRD.

3.2.4 Position Monitoring

One of the requirements of the device is that it can track the patient’s movement at all times. The movement and position of the patient will be used in the computer software to monitor their progress and to give them objectives to complete. It will also be necessary for adapting force feedback to the device.

3.2.5 Force Feedback

It is desirable to have force feedback on a RRD, in order to take patients through the whole range of rehabilitation; teaching movements, refining motor skills and increasing strength. Assuming a patient has lost nearly all of their movement, they will need to first learn movements without having to apply force, and then once this is done, they will need to learn to move their own body weight. From here, they can keep building muscle and move heavier and heavier objects. There are many ways in which force feedback could be used to increase the effectiveness of this device. It could be used to replicate gravitational forces, simulate friction, obstacles etc.

3.2.6 Lockable movements

It is necessary that certain DOFs can be locked, to focus on particular movements. A physiotherapist would devise a suitable routine, locking and unlocking DOFs as required. Certain arm muscles and movements could be targeted depending on the patient and their condition.

3.2.7 Measuring Movement & Progress

The reason for rehabilitation is to help patients improve and progress. In order for a physio to help the patient, they need to know where the patient is up to and which areas need improvement. It is important that the device can map progress over time. It could do this by measuring strength, ROM, speed, reaction times, accuracy etc.

3.2.8 3D Games

One of the objectives of creating this device is to make rehabilitation more exciting and keep patients interested. This can be done by getting patients to use the device to play games on the computer. There are endless possibilities for interface software and it will probably be limited by the electronic hardware. The device will act like a generic joystick being used to play a computer game, just with a larger ROM.

3.3 Design Constraints

It should be noted that the device to be designed is not supposed to be a completed, fully functioning device. This device is a proof of concept prototype only and may not fulfil all of the requirements of one that is ready for production. Low cost and simple mechanisms will be pursued to prove that concepts will or will not work and determine how they can be developed.

For this project, the main design constraints that will be considered are size, movement, lockable movements, position monitoring, cost and adaptability of force feedback. The proof of concept device will be refined as future work to meet the remaining requirements.

One of aims of this project is to test the ease of which the wide ROM of the shoulder and arm can be captured and it will be sufficient to test this in two dimensions and not three. Therefore the major movements of the device will be kept to a single two dimensional plane. This may mean one of the shoulder's DOFs will not be included in the device's movements however simplicity will be maintained while testing the concept of using a RRD.

The biomechanics of the human arm need to be examined so that a suitable ROM can be established for the device.

3.4 Movement of the Human Arm

The human arm is a very flexible and useful tool. This section will introduce the basic structure and mechanics of the human arm in order to understand its ROM.

3.4.1 Basic Anatomy

Human anatomy is quite complex when the body is considered as a complete working system, however for the purpose of this project, movement of the human arm will be simplified in order to understand how a rehabilitation device should work.

A joint is where two or more bones touch and/or articulate. The human arm gets its dexterity from its three main ‘freely movable’ joints; the shoulder, elbow and wrist (Figure 3.2). The bones that make up a freely movable joint are held together by bands of tissue called ligaments.

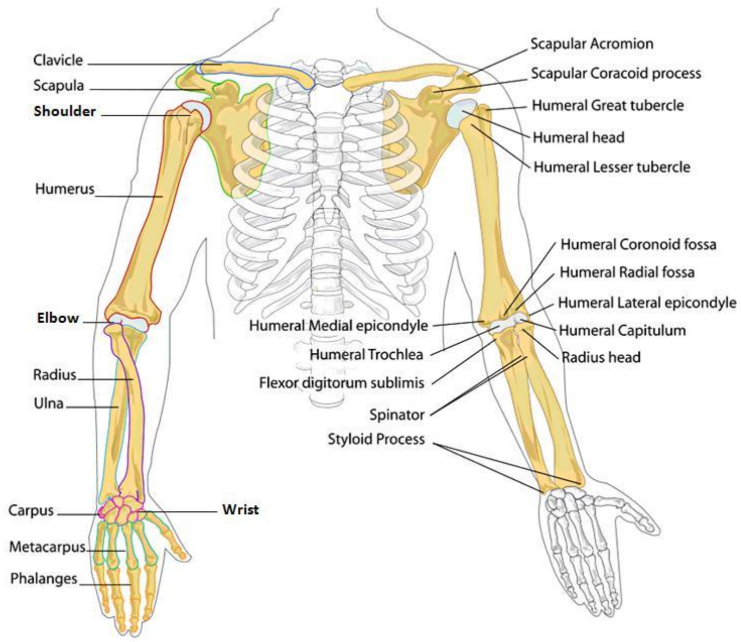

Figure 3.2: Bone Structure of the Human Arm (Source: Wikipedia, 2010)

Movement is given to the joint by a muscle or group of muscles that are attached to a bone on both sides of the joint. When given a signal from the brain, a muscle contracts, pulling the bones of a joint together in one direction. To move in the other direction, an opposing set of muscles on the opposite side of the joint need to contract. Take for instance the elbow joint, which is referred to as a hinge joint. It has one degree of freedom (DOF), flexion (this will be discussed further in the next section). The elbow joint has 3 main bones. Joining the shoulder and elbow is the Humerus, and joining the wrist are the Radius and Ulna. Looking at Figure 3.3, which is a side on view of the elbow at 90 degrees, it can be seen that the Radius and Ulna can pivot up or down relative to the Humerus. If the biceps muscle contracts and becomes shorter, it will pull the Radius and Ulna up. Similarly, if the triceps muscle, which attaches to the opposite side of the bones contracts; it will pull the Radius and Ulna down. Nerves in the arm receive signals from the brain and tell the muscles when to contract, and when to relax.

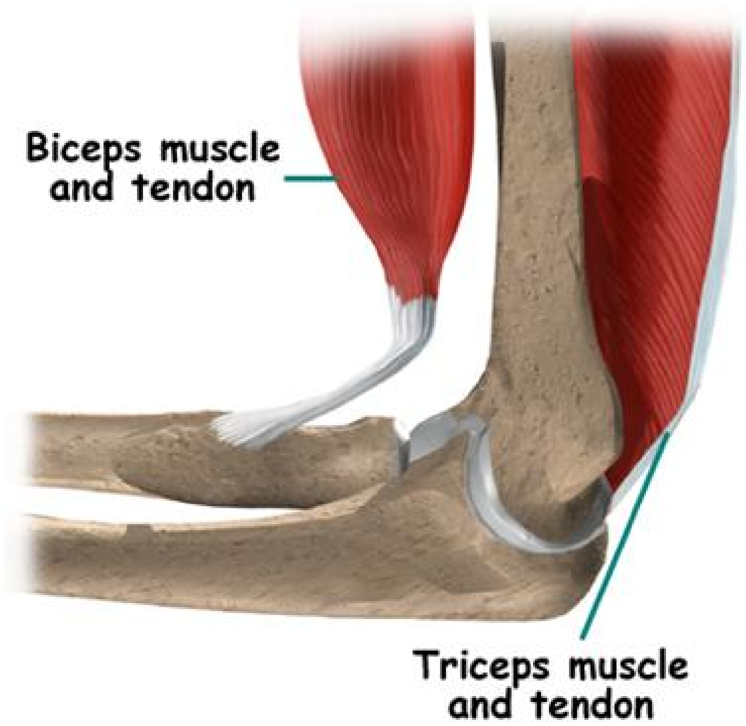

Figure 3.3: Side on view of the human elbow joint (Source: Medical Multimedia Group, 2001)

3.4.2 Degrees of Freedom

The shoulder is a ball and socket joint. It has three DOFs; shoulder flexion/extension, shoulder adduction/abduction and shoulder rotation – lateral/medial shown in Figure 3.4.

The elbow (Figure 3.5) is a hinge joint. It has one DOF; elbow flexion.

The wrist (Figure 3.6) is a more complicated joint. It is a form of gliding joint known as the ellipsoid joint. Hamill & Knutzen describe the wrist as having two DOFs; wrist flexion/extension and wrist adduction/abduction. A third degree, which is commonly included in the wrist joint, is forearm supination/pronation.

The human arm as a whole has a total of seven DOFs, which can all be used simultaneously.

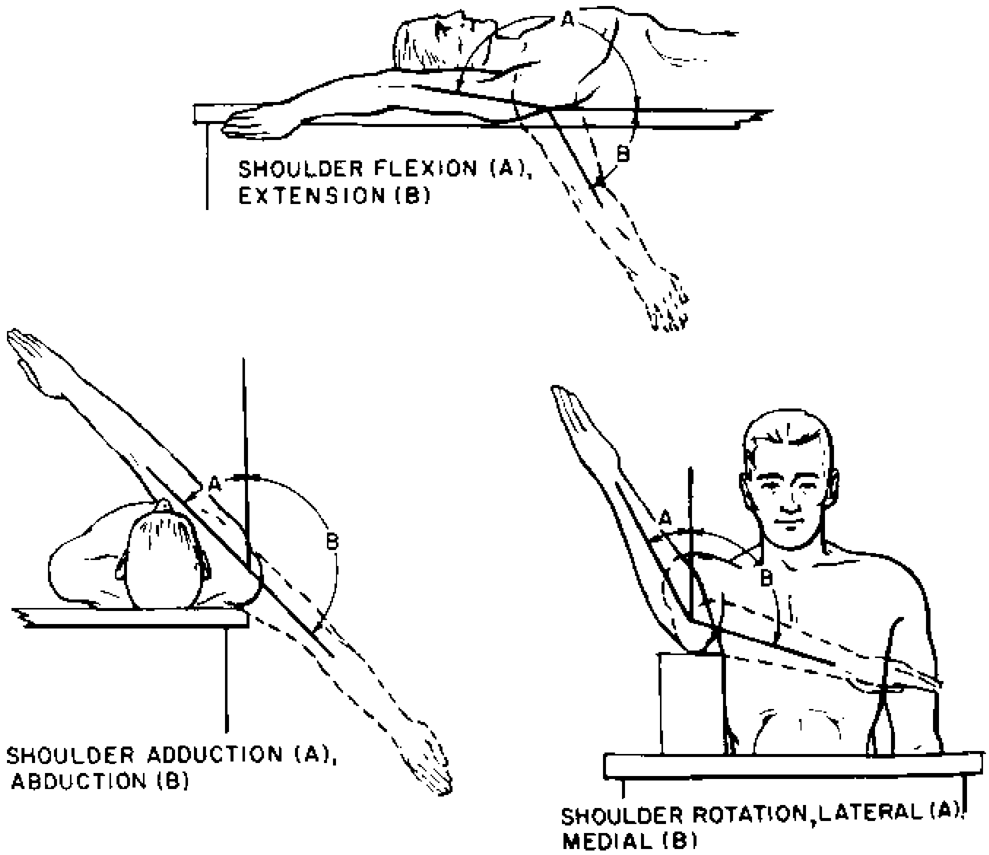

Figure 3.4: The three shoulder DOFs (Source: Hamill & Knutzen, 1995)

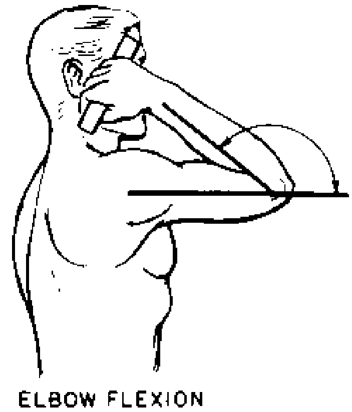

Figure 3.5: Elbow DOF (Source: Hamill & Knutzen, 1995)

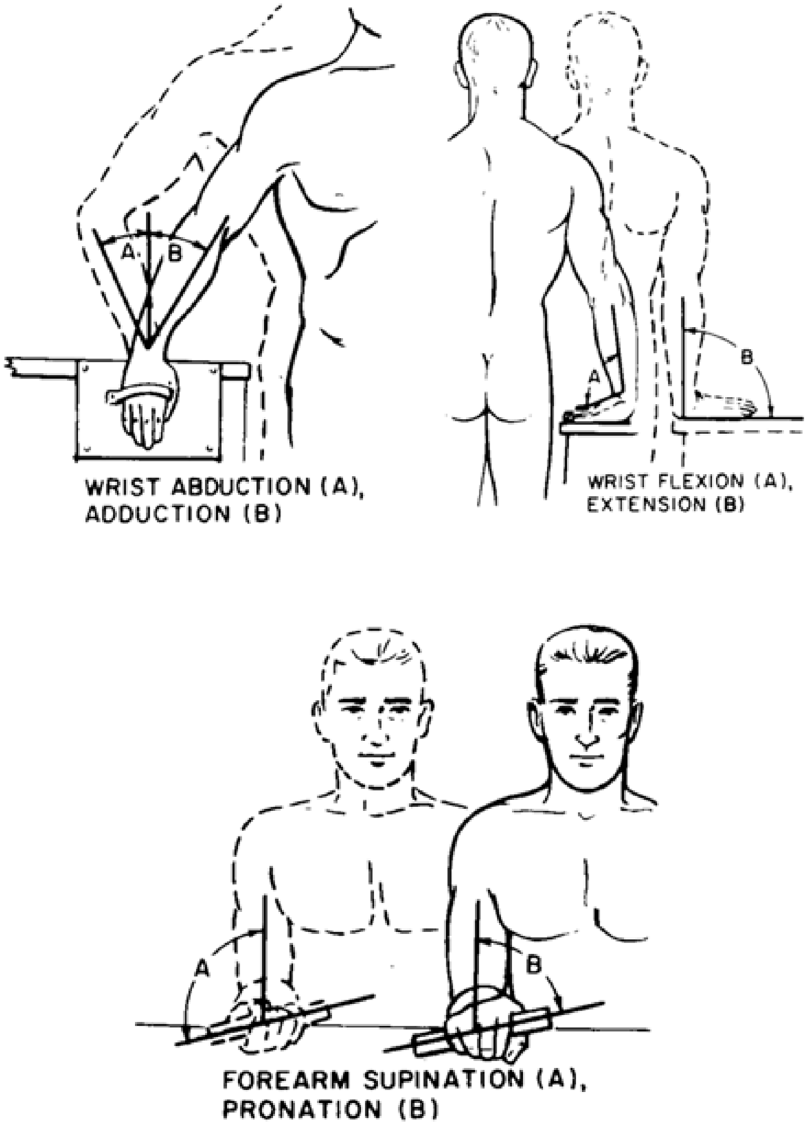

Figure 3.6: The three wrist DOFs (Source: Hamill & Knutzen, 1995)

3.4.3 Range of Motion

Table 3.1 shows the ROMS of each of the arm's DOFs. These values are average ranges of the male air force personnel, who are usually in peak physical condition, and would have more movement than the average person.

Table 3.1: Ranges of Motion of the seven DOFs of the arm (Source: Adapted from Woodson et al. 1992)

Movement	Range of Motion (degrees)
Shoulder Flexion	188
Shoulder Extension	61
Shoulder Adduction	48
Shoulder Abduction	134
Shoulder Rotation – Lateral	34
Shoulder Rotation – Medial	97
Elbow Flexion	142
Forearm Supination	113
Forearm Pronation	77
Wrist Flexion	90
Wrist Extension	99
Wrist Adduction	27
Wrist Abduction	47

3.5 Conclusion

An ideal device needs to have the following features and characteristics;

- be small enough to fit in the patient's home;
- covers the movement of a human arm;
- has a position monitoring system;
- movements can be locked;
- progress can be monitored;
- has 3D games;
- low cost; and
- has force feedback.

However, the device that will be constructed for this project will only address the need to; be small, be low cost, cover most of the human arm movement, have a position monitoring system and have lockable movements. The DOFs and the ROM of the human arm have been investigated and concept design can begin.

Chapter 4 CONCEPT DEVELOPMENT

4.1 Introduction

The idea of using a presently available hand control device and modifying it to meet the requirements discussed in chapter 3 was investigated to save manufacturing costs. A device that met these meets was not found, so several concepts for a new RRD were devised. This chapter discusses the various conceptual designs and how they were critiqued to find the best options for both the structure and the position monitoring system.

4.2 Presently Available Hand Control Devices

A good way of reducing cost is to use commercially available parts instead of designing and constructing them. This section investigates joysticks and hand control devices that are on the market, and their applicability to the required device.

4.2.1 Joystick

Joysticks for computer gaming have been around for years but they are always being developed to increase the authenticity of the playing experience. Joysticks are also used to control various sorts of machinery, aeroplanes, remote controlled devices and many other things. Figure 4.1 and Figure 4.2 show joysticks from a Caterpillar Skid Steer Loader, and a common gaming joystick respectively.

Figure 4.1: Caterpillar Skid Steer Loader control joystick (Caterpillar, 2010)

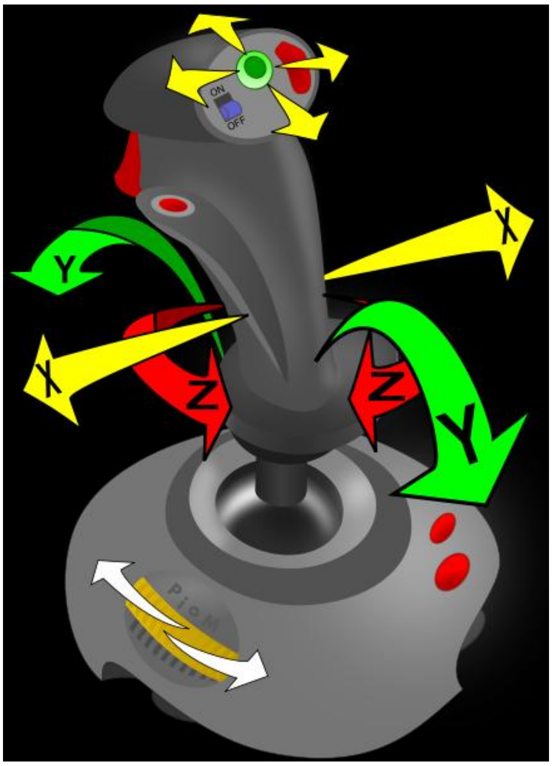

Figure 4.2: A common gaming joystick (Wikipedia, 2010)

The Caterpillar joystick has 2 DOFs and several buttons which are pushed with the thumb. It can move side to side and backwards and forwards. Many industrial joysticks electronically control hydraulic systems. They are often proportional, meaning the amount the joystick is moved is relative to the amount of function that is performed. For example, if the forward movement of the joystick is used for moving the machine forward, when the joystick is moved a small amount, the forward speed will be low, but if the joystick is moved all the way forward, the machine will move at maximum speed.

The gaming joystick pictured has 3 DOFs as well as several other buttons. It can move side to side, backward and forward and the handle can also rotate in the Z axis. Gaming joysticks usually offer any combination of the X and Y movements, for example, diagonally forward. Some joysticks have a form of force feedback built into them. It is usually quite simple, and gives resistance to movement, or a vibration sensation.

Suitability of a Joystick

Joysticks can offer the three DOFs of the wrist but unfortunately not those of the elbow and shoulder. The 'force feedback' does not offer the assistive and resistive forces over the full ROM that is required for a RRD. It would be very hard to add force feedback to commercially available joysticks because they are not very easy to modify. Joysticks that are robust enough for this application are available and might be similar to the one pictured in the skid steer loader. Overall, a joystick is not suitable for a RRD because it would not be easy enough to adapt it to a design and would require too much modification to make it worthwhile.

4.2.2 Stewart Platform (Hexapod)

A Stewart Platform (Figure 4.3) is a parallel kinematic mechanism consisting of two plates joined by six actuators. The movable plate or platform can travel in 6 axes; 3 translational and 3 rotational. Being a parallel mechanism, all of the actuators work in parallel with each other, that is, they all move the platform simultaneously. This gives the device very smooth, accurate, precise movements. Stewart Platforms or Hexapods as they are sometimes called are available in many sizes, capacities, accuracies and ROMs. They can be hydraulically, pneumatically, mechanically or electrically controlled and are used for anything from assembly machines to CNC machining and surgical equipment to flight simulator bases (Figure 4.4). As an example, Physik Instrumente (2010) make and sell hexapods with capacities from 5 kg to 1000 kg and up to 200 mm travel in the X and Y axis. This is just a small range of the current market though.

For the purpose of a RRD, a handle could be attached to the moving plate, so that a patients hand can control the position of, for example, a cursor on a computer screen.

Suitability of a Stewart Platform

A Stewart Platform would be able to offer all of the DOFs required for a RRD however it would be very difficult to lock certain ones if required. As stated, Stewart Platforms would be ideal in terms of precision and smoothness however this corresponds to their high cost. They also have a limited range of travel. A Stewart Platform would be quite adaptable in terms of mounting, programming and adapting force feedback however their high cost, limited ROM and inability to lock movements makes them unsuitable for this application.

Figure 4.3: A small Stewart Platform (Hexapod) (Source: Physik Instrumente, 2009)

Figure 4.4: A flight simulator base using a hexapod arrangement (Source: Atallah, 2000)

4.2.3 Haptic Devices

Haptic devices are those that can transfer the sensation of touch from a virtual, computer based world to the user. Haptic devices are used in situations where a user requires feedback from a system to make the experience more realistic for a variety of reasons. This is very difficult thing to do, and is currently being extensively researched. Typically, the haptic device will use programmed actuators to exert a force or vibration on the user simultaneously with an action on a computer screen or in a virtual world in an attempt to make it seem more real. The particular model shown in Figure 4.5 is made by SensAble Technologies, and has 6 DOFs. It is being used for training surgeons as shown in Figure 4.6. The reason for using one of these haptics devices is that the student feels like he or she is cutting into a real human body and the different tissues with different textures require various cutting forces.

Suitability of Haptic Devices

It might be possible to use a haptic device to cover all of the required DOFs of the arm. Their limitations and advantages are similar to those of a Stewart platform, in that they are precise and smooth, but there is difficulty in locking particular movements. They can be purchased with force feedback and software but are expensive and may be difficult to adapt to.

Figure 4.5: Haptics Device that can be used to train surgeons (SensAble Technologies, 2010)

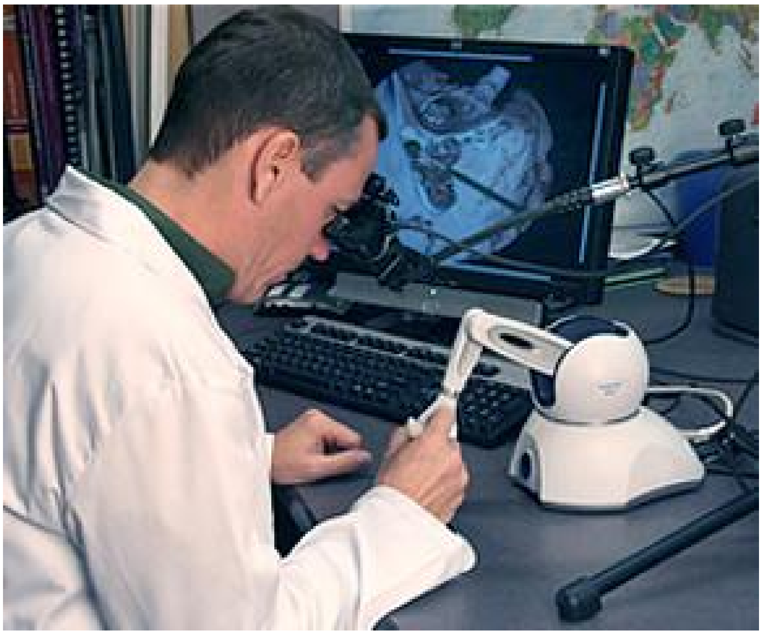

Figure 4.6: A Haptics Device being used to train a surgeon (Lyons, 2009)

4.2.4 Conclusion

None of these commercially available products are idea for an RRD. They all offer inviting features, but have limitations that make them unsuitable. The main problem is that none of them offer the ROM that is required to exercise the whole human arm. Cost also precludes the Haptic devices and Stewart Platform. From this research, it was concluded that a new device needed to be designed to meet the needs of this particular application. Concepts were developed and will be discussed in the following sections.

4.3 Previous Work at USQ

Blythe Garratt was a final year Bachelor of Mechatronic Engineering at USQ Toowoomba campus in 2009. His final year project is titled *”The Development of a Wrist Rehabilitation Device for Movement Therapy”* and its focus was the design and development of a therapy device to assist physiotherapists in the rehabilitation of a patient’s wrist strength and motor control which have been impaired by stroke. His work is similar to that being done in this project however Garratt only looked at rehabilitation of the wrist. His work proved successful as he designed and constructed a device which captures natural human wrist movement over a large and complex ROM with a mechanical structure that is well suited to the biomechanical behaviour of the wrist (Garratt, 2009).

Garratt’s wrist device (Figure 4.7) consists of a mechanical structure, electronics, and interface software. It is available to me and I have been encouraged to use it in my design if possible. No better options have been found so at this stage, so the wrist device will be attached onto a structure that will accommodate for elbow flexion, shoulder flexion/extension and shoulder rotation.

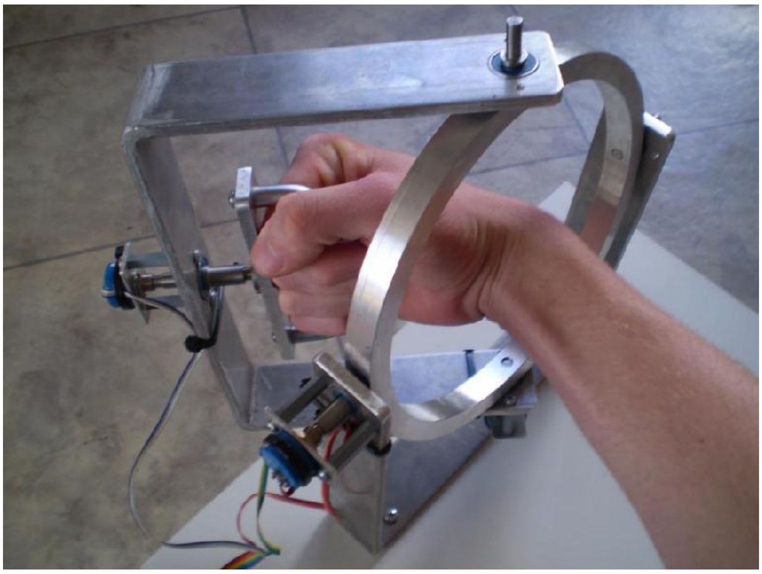

Figure 4.7: Blythe Garrett's device designed as a USQ final year project (Source: Garrett, 2009)

4.4 Concepts of Structure

A system of joints will be needed to cover the six of seven DOFs of the arm, and for simplicity, these have been broken up into the wrist and shoulder /elbow parts. The shoulder /elbow structure has been conceptualised as a standalone assembly and the wrist device will be attached to it. The patient will hold or be strapped to a handle that is part of the wrist assembly.

4.4.1 Concept 1 – Cables and Pulleys

This design pictured in Figure 4.8, uses a simple cable and pulley system to support the patients arm while they hold the handle. The handle is connected to one end of the cable and the weight block is connected to the other end. The handle is free to move in any direction possible and its weight is counterbalanced by the weight block. The pulleys would be attached to the ceiling or a high shelf of some sort, or a structure may be provided to support them.

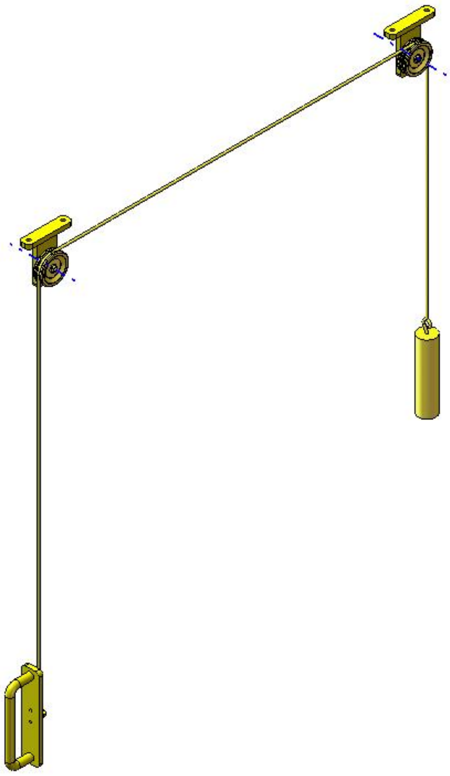

Figure 4.8: Concept 1 uses cables and pulleys to provide movement to a handle

Strengths

- it is a very simple design involving few parts.

Weaknesses

- position monitoring would be very difficult;
- adding force feedback would be virtually impossible; and
- there is no way to limit or lock movements.

4.4.2 Concept 2 – Lever Arms

This design (Figure 4.9) uses rotational joints to provide translation of the hand in the horizontal and vertical directions of a 2D plane. There is three joints separated by linkage bars, with one end fixed to the base, and the other attached to the wrist assembly. The vertical and horizontal translations will correspond to shoulder flexion/extension and elbow flexion respectively. Blythe's wrist device can be attached to the face plate shown in the model. The joints would have ball bearings for minimal friction and be as precise as practical. The base plate would be clamped to a desk and the patient would sit in a height adjustable chair in front of it.

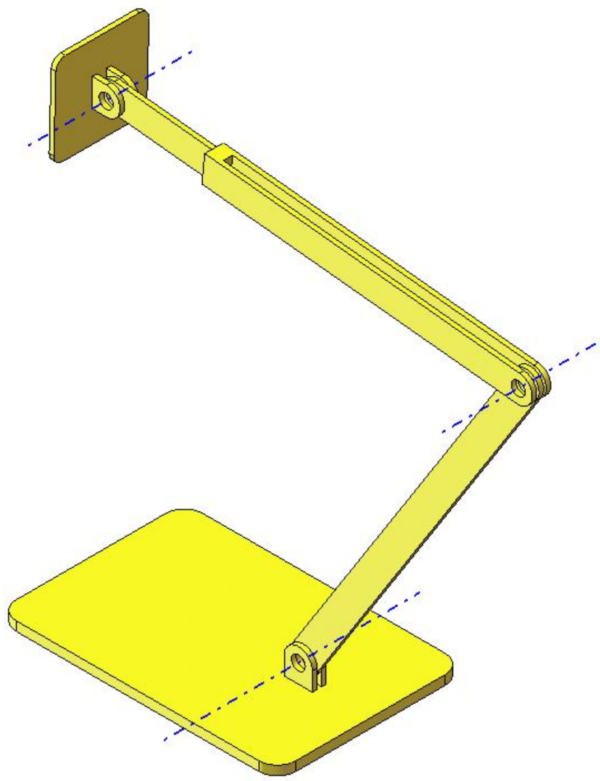

Figure 4.9: Concept 2 uses rotational joints to provide horizontal and vertical movement

Strengths

- it wouldn't require any expensive parts except ball bearings;
- has limited precision manufacturing;
- it is a simple design; and
- it offers easy mounting of wrist device.

Weaknesses

- without complex guides, there is no way to limit or lock movement in certain directions;

- position monitoring is certainly possible but could become complex depending on the system used;
- force feedback would be difficult to adapt as each joint depends on the other one; and
- possible buckling and rigidity problems.

4.4.3 Concept 3 – Linear Shafts

This design (Figure 4.10) consists of a central bearing block that can move up and down on two vertical shafts. There is a third shaft that can move horizontally in and out of the bearing block. This combination gives horizontal and vertical translation in a 2D plane, which corresponds to shoulder flexion/extension and elbow flexion. The wrist device would be attached to the end of the horizontal shaft, and provide the three wrist movements and shoulder rotation. The design would incorporate a locking mechanism for the vertical and horizontal movements. As with concept 1, the base plate would be clamped to a desk and the patient would sit in a chair to operate the device.

Strengths

- it would give very precise movements in both directions, providing it is well manufactured;
- easy to fit a locking mechanism, or even a movement limiting mechanism; and
- device could be very robust with appropriate material selection.

Weaknesses

- some quality machining required; and
- expensive linear motion system may be required.

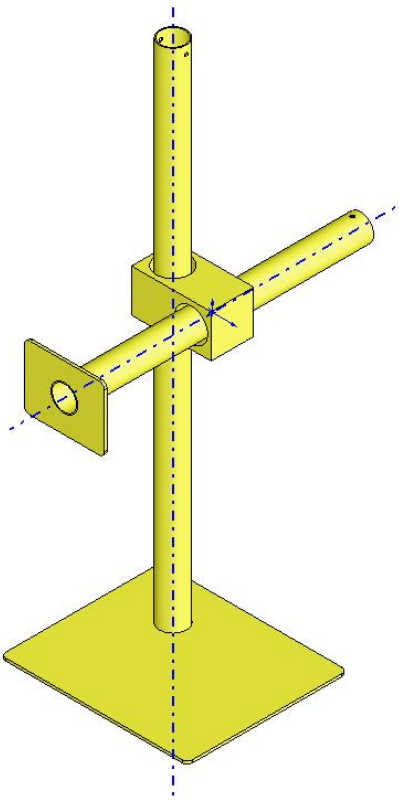

Figure 4.10: Concept 3 uses linear movement along 2 axes to cover the required ROM

4.5 Concepts of Position Monitoring

Position monitoring is an essential part of a RRD. It needs to be accurate and reliable in order to control software and correctly assess patient's progress. It should be noted here that in previous work, potentiometers have been used for position monitoring of rotating components.

4.5.1 Concept 1 – Potentiometers

A potentiometer (Figure 4.11), usually called a 'pot' is a simple electronic component that is used as a rheostat or variable resistor. As shown in Figure 4.12, they consist of a resistive element that has a cylindrical shape. A wiper is connected to the input shaft and contacts on the resistive element. A voltage drop across the element can be used to calculate the amount of rotation of the input shaft.

Potentiometers can be single turn, which gives slightly less than 360^{o} of rotation or up to about 20 turn, offering about 7200^{o} of rotation. For standard applications, their resistance can range anywhere from 1 Ω, to 5 MΩ.

Potentiometers can have a linear or logarithmic taper. In linear potentiometers, the output voltage is linearly proportional to the position of the wiper. They are used in applications like position control where the output needs to be linear. Logarithmic potentiometers have a logarithmic output and are used for things like audio volume control.

Figure 4.11: A multi-turn potentiometer (RS Online, 2010)

Strengths

- fairly inexpensive;
- easy to implement;
- easy to use in a circuit and retrieve signals from;
- have been proven in previous work; and
- are fairly accurate and precise if high quality potentiometers are used.

Weaknesses

- offer rotation which needs to be converted to linear movement if necessary.

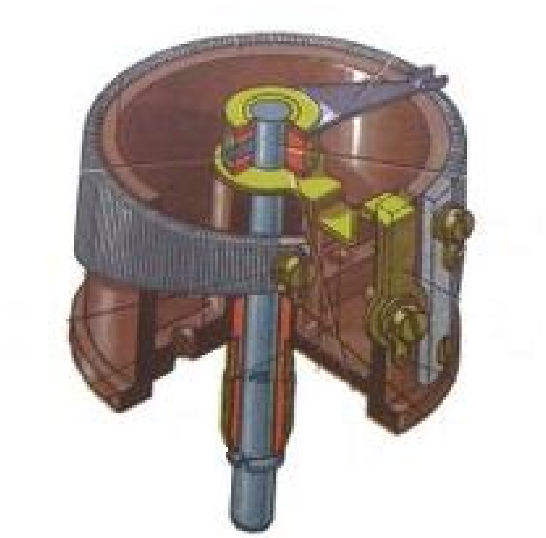

Figure 4.12: Potentiometer Construction (Wikipedia, 2010)

4.5.2 Concept 2 – Linear Encoders

Linear encoders are used to detect position in a linear axis and utilize properties including optical, magnetic, inductive, capacitive and eddy current. Most of them, including the one shown in Figure 4.13 work by using a readhead to measure a certain aforementioned property, whether it be light, magnetic field etc along a strip or shaft, and then give an output which can be used to determine the position of the readhead relative to a fixed point.

Encoders can be either incremental or absolute. An absolute encoder gives a unique signal for each position, whereas an incremental encoder only gives a change in position between increments and calculations need to be done to determine position.

Linear encoders are used for a variety of applications from digital callipers to high precision machining tools.

Figure 4.13: A type of Digital Encoder (Digiball, 2006)

Strengths

- inherently monitor linear position; and
- precise and accurate.

Weaknesses

- expensive;
- mounting needs to be very precise; and
- don’t always have an infinite/ customisable length.

4.6 Conclusion

It was found that there were no presently available hand control devices that suited this application. A new device needed to be designed so concepts were devised. There were three ideas for the structure and two for position monitoring and the strengths and weaknesses of each were discussed. The concepts that were chosen for detailed design will be discussed more in the following chapter.

Chapter 5 FINAL DESIGN AND MANUFACTURE OF PROTOTYPE

5.1 Introduction

This chapter includes all of the processes undertaken to produce a design that could meet the requirements discussed in earlier sections. It is arranged in an order that reflects the design process as best as possible. It includes the design of the structure, as well as the position monitoring system that it supports and the electronics. Background on engineering theory is included where necessary to help the reader understand various decisions that were made. A discussion on the design of each part in the device assembly has been included.

5.2 Choosing a Design

The design that best met the requirements of a RRD was chosen and its design was pursued. Firstly the structure was chosen, and concept 3 stood out because of several features. These included; the inherent ease to add movement locking mechanisms to the device and attach the wrist assembly, the precise and repeatable movements offered, and its possible robustness. The cost of the main components was thought to be low enough for this application so was neglected as a weakness.

As mentioned earlier, it was also confirmed that using the wrist device and attaching it to the structure was the best option. The wrist rotation DOF will be used for shoulder rotation as well.

Once the structure was chosen, the position monitoring system had to be investigated. It was now known that the device would offer direct linear movement, so the position monitoring had to suit this. Although linear encoders would work quite well, potentiometers were chosen because of their lower costs and proven abilities. The fact potentiometers had already been used and their effectiveness had already been proved also played a part in the decision. Their weakness of only providing rotary motion was deemed unimportant.

5.3 Design of Structure

The design of the structure involved sizing the device, choosing a motion system, selecting shafts, selecting bearings, and detailed design. Each of these steps will be discussed in detail in this section.

5.3.1 Sizing

The first step in the design process was to look at the ROM of the shoulder and elbow and determine how large the structure needed to be to cover this movement.

As stated in chapter 3, the average value for angle A in Figure 5.1 – shoulder flexion is 188^o and angle B – shoulder extension is 61^o. Similarly, elbow flexion, shown in Figure 5.2 is 142^o. Using these angles and the average length of the arm, it is possible to find the ROM in terms of lengths, not angles. For the 95th percentile, SAA HB59 (1994) gives the distance between the shoulder and knuckles of a British male as 715 mm, and the distance between the shoulder and elbow as 355 mm.

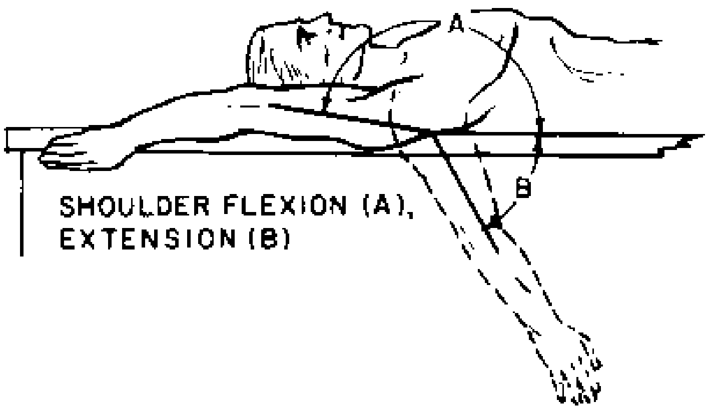

Figure 5.1: Shoulder flexion and extension (Source: Hamill & Knutzen, 1995)

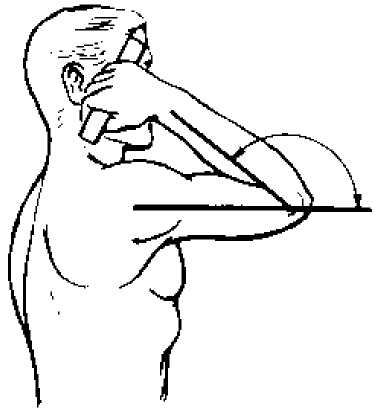

Figure 5.2: Elbow flexion (Source: Hamill & Knutzen, 1995)

Using this information, a sketch of the arm at full stretch was drawn (Figure 5.3) to show the extents of movement. It can be seen that the device would need a vertical ROM of 1430 mm and a horizontal range of 1340 mm. This was deemed to be too large for a proof of concept device because of the extra material that would be required and hence higher costs, higher weight and possible difficulty in position monitoring. It was also preferable to keep the patient's hand and arm in front of them as this movement was thought to be more important and more useful for a stroke sufferer.

The sketch was hence changed to Figure 5.4. As seen, the horizontal ROM has been decreased to 715 mm and the vertical movement to 1408 mm. This was still too large for a proof of concept device, so combining shoulder and elbow movements into one axis was investigated. For example, if the forearm is held horizontal and moved in and out, there is elbow flexion as well as shoulder flexion/extension.

The sketch then became that in Figure 5.5. The full elbow flexion of 142^{o} and shoulder extension of 61^{o} have both been covered and the shoulder flexion of 188^{o} has almost been covered. The vertical displacement has been reduced to 923 mm which seems reasonable for this device. However, the horizontal displacement of 715 mm remains too large.

Figure 5.6 and Figure 5.7 show the final sketches of the arm, with a 923 x 510 mm ROM. This covers almost all of the movement of a human shoulder and elbow however it doesn't cover it all in one configuration. Figure 5.6 represents a scenario where the device handle is fully retracted in the horizontal direction and the handle is held with elbow fully flexed. The handle is pushed inwards horizontally 510 mm. There isn't enough range to fully straighten the arm unless the handle is raised vertically by flexing the shoulder. In Figure 5.7 the handle is fully extended with the arm straight. When it is retracted 510 mm, the elbow isn't fully flexed. So it can be seen that there is an infinite number of movement configurations, with the ROM depending on the starting position. It was decided that constructing a proof of concept device with this ROM would offer a sufficient working envelope with a low enough cost.

At this point it wasn't known how the ends of the horizontal and vertical shafts would be attached, and what obstacles would be present to reduce the ROM. Approximately 40 mm was added to the horizontal range and approximately 80 mm was added to the vertical range to account for this. That brought the design range to 1000 x 550 mm.

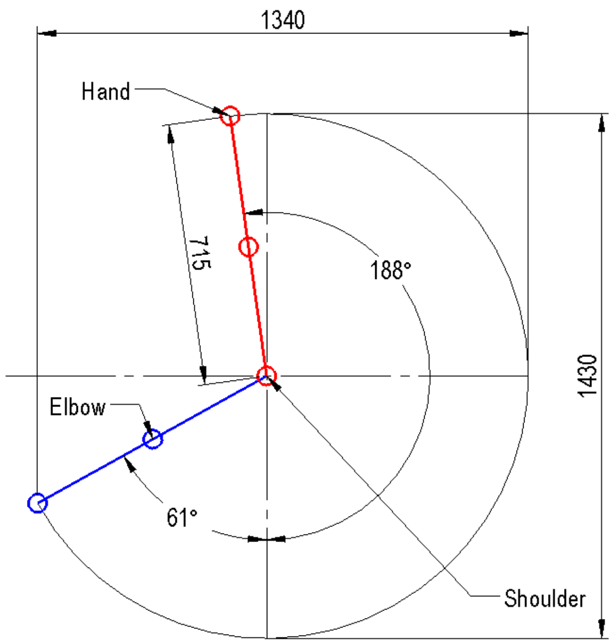

Figure 5.3: ROM with Arm Fully Stretched

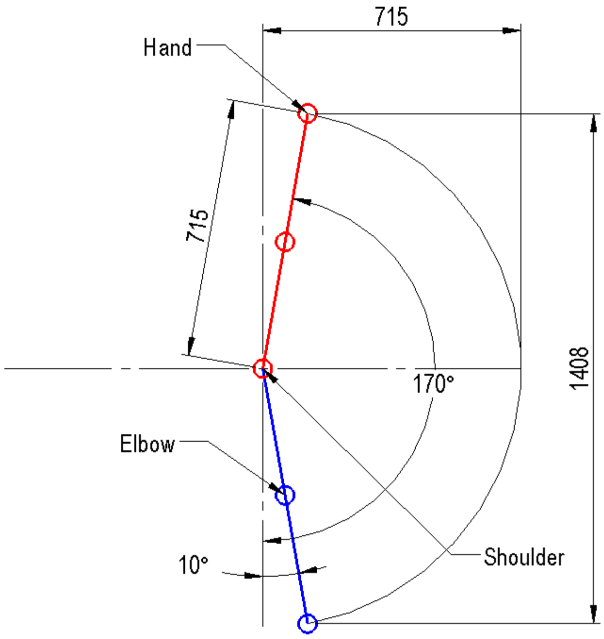

Figure 5.4: ROM reduced by keeping the arm in front of the body

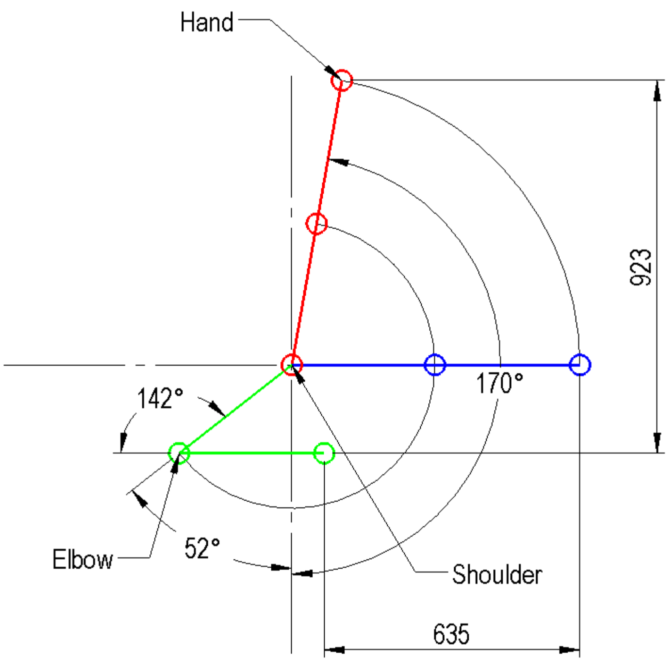

Figure 5.5: ROM reduced again by allowing combined shoulder and elbow movements

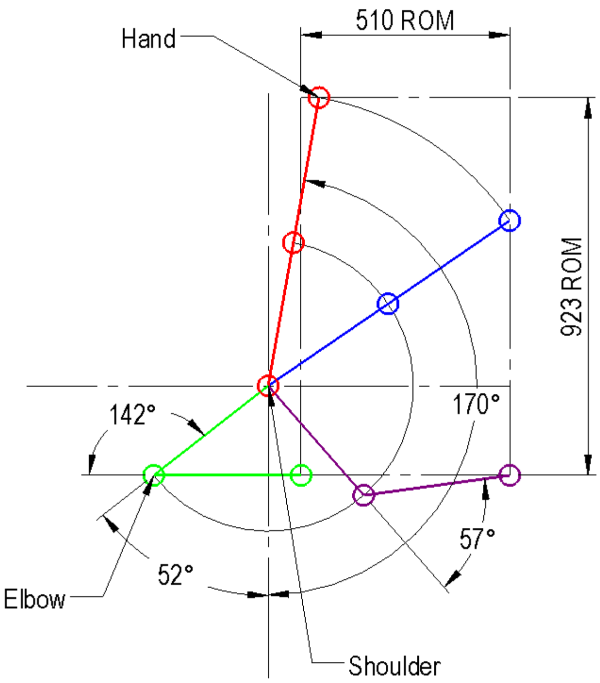

Figure 5.6: Final design ROM – scenario 1

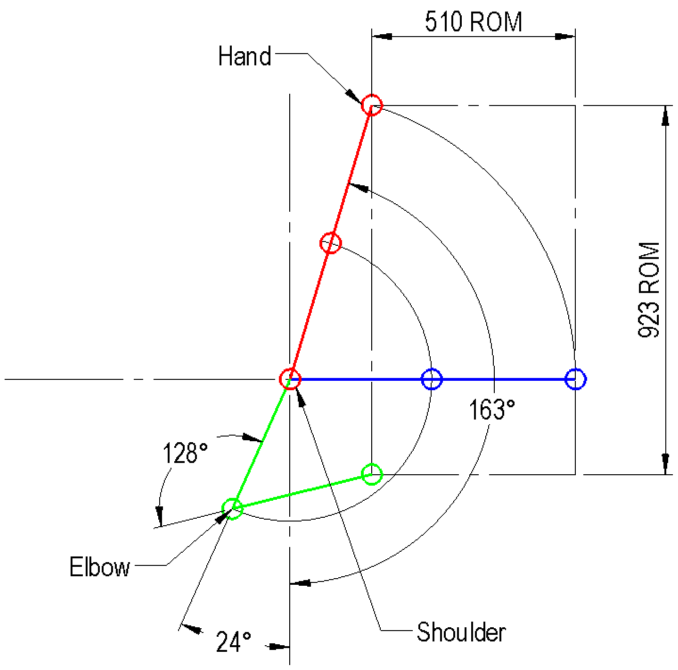

Figure 5.7: Final design ROM – scenario 2

5.3.2 Motion System

The next step after sizing the device was to determine how the motion would be achieved. The initial concept was based on round shafts, but this wasn't the only available option. There are many linear motion technologies available on the market, from nylon bushes to linear bearings to wheel and track arrangements. Powered devices such as hydraulic and pneumatic cylinders and power screws could also be considered.

In choosing a motion mechanism, force feedback fitment still needed to be considered even though it wouldn't be implemented in this project. A requirement of the mechanism was that a position monitoring system could be fitted.

The SKF linear motion website (2010) was consulted, and several technologies existed there. They are listed below and shown in Figure 5.8 to Figure 5.10

- Ball and roller screws – High efficiency 'power screws' used when rotational movement needs to be converted to linear movement. They come with rolling elements between the screw shaft and the nut.
- Dry sliding bushes – Composite material cylindrical bushes used for rotational and oscillating movements under radial loads. They are used where space is limited and they don't need lubrication.
- Linear ball bearings and precision shafts – Essentially bushes with recirculating ball tracks for low friction smooth running. They can handle radial loads and moments about their axis. Precision shaft is available for the linear ball bearings to run on.
- Rail guiding systems – There are a variety of rail guiding systems available. The standard guides have a carriage containing rolling bearings to give it linear movement on a rail. Precision rail guides can be purchased with a combination of rolling elements to suit certain applications.

Figure 5.8: Linear bearings and precision shaft (Source: SKF, 2010)

Figure 5.9: Ball and roller screw (Source: SKF, 2010)

Figure 5.10: One style of rail guiding system (Source: SKF, 2010)

Ball and roller screws were immediately discarded as an option because they convert an input rotational motion to linear motion well, but aren't designed to take a linear input motion.

Linear bearings and dry sliding bushes were considered next. A discussion into whether or not the motion system can tolerate 'off centre' loads or moment loads is required here. Figure 5.11 shows a generic shaft and block arrangement, where the block is to slide up and down the shaft when a load is applied. If a suitable bearing surface isn't used in this situation, the off-centre load will cause the block to 'grab' on the shaft, and dig into the material. The more load that is applied, the more the block will dig into the shaft. For this reason, dry bushes have been ruled out because they aren't really designed for extra smooth, frictionless motion nor will they work when an off-centre load or moment is applied.

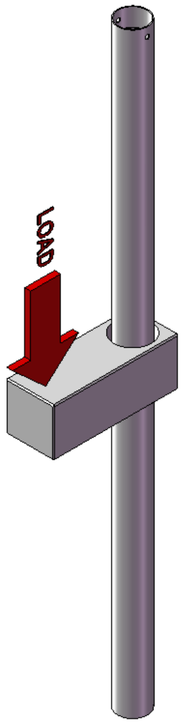

Figure 5.11: Example of an 'off centre load', where the load is applied at a distance from the axis of movement

With the other options discarded, linear ball bearings or rail guiding systems were left to choose from. Both options seemed very good for this application so a table of features was created, and the quality of each feature offered by the two systems was listed.

It can be seen from the table that the linear bearings are the better option because they are; more customisable, the shafts can be used as the structure, the length of the shafts and hence the ROM is infinite and the price is more suited to a low cost RRD. As stated, both systems were good options and rails may have worked well, but for this design, linear bearings were considered.

Table 5.1: Comparison of features of linear bearings and rail guiding systems

Feature	Linear Bearings	Rail Guiding System
Mounting	Very customisable	Reasonably customisable
Load Carrying capacity	Sufficient	Sufficient
Can Rails or shafts be used as structure	Yes	Probably not
Is length of shaft or rail infinite	Yes	No
Price	Fairly low	Higher
Number required	3	3
Easy of fitment	Fairly easy, machining required	Fairly easy, machining required

5.3.3 General Structure

It was already known that the general structure would offer linear motion in two axes, horizontal and vertical. The original concept consisted of a single horizontal shaft, a bearing block with two linear bearings and a single vertical shaft. This was not going to be a sufficient design as there was nothing to stop the shafts rotating around each other. It was decided that two vertical shafts guiding the bearing block would be needed. There would then be a single horizontal shaft running through the bearing block between the vertical shafts. This design has been 3D modelled in Figure 5.20.

5.3.4 Shaft Selection

As stated earlier, linear ball bearings were chosen as the motion system and they would run on circular shafts. The shafts were also required to be the main structure of the device. They needed to be stiff enough to inhibit flexing and buckling, but light enough to retain portability and keep the device neutral until force feedback could be added.

There were three options available for the main shafts; precision solid shaft, steel tube or aluminium tube. There are several characteristics of a material that need to be considered, including; stiffness, density, cost, availability and hardness. In many situations, this one included, a balance of these properties is required, so a compromise in one or more may be necessary. The first property to be discussed is stiffness and deflection.

5.3.4.1 Stress and Deflection

Deflection is the displacement of a material when subject to a load, and was the main concern for this device. It was imperative that the shafts remained straight and stiff to ensure the linear bearings worked properly and the structure would offer precise, accurate movements.

Deflection in a material is related to the stress within it by the following formulae, where E is the modulus of elasticity, σ is stress, ε is strain, d/x is the deflection of a material over its initial dimension, M is moment of force, y is distance from the neutral axis and I is second moment of area.

$$E = \frac{s}{e}$$

(5.1)

Where

$$e = \frac{d}{x}$$

(5.2)

And

$$s = \frac{My}{I}$$

(5.3)

Figure 5.12 shows a round cantilever experiencing a side load. The variables mentioned in the previous formulae are displayed in this figure.

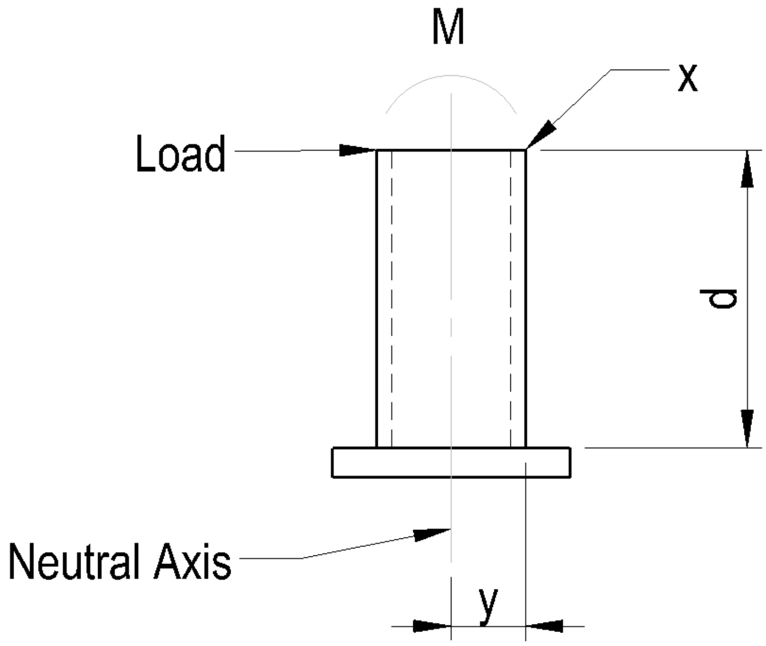

Figure 5.12: Illustration of a round cantilever experiencing a side load

Formulae for deflection of beams were used to estimate the size and material combination required to keep the structure within acceptable bending limits. To do this, the structure was simplified to that shown in Figure 5.13 with a fixed base and fixed joint where the horizontal shaft meets the bearing block.

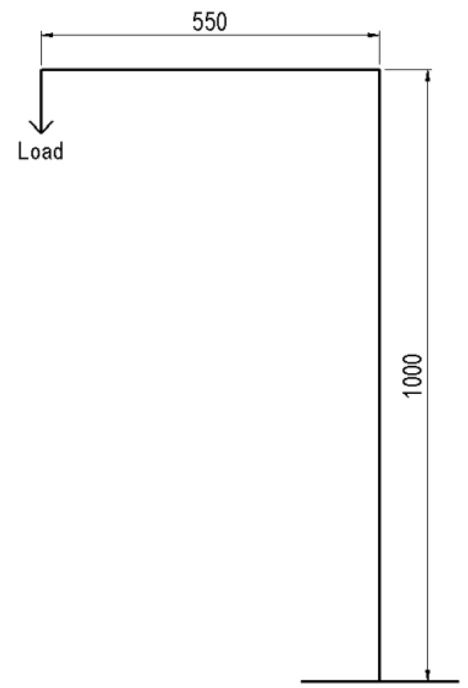

Figure 5.13: Simplified model of structure

Firstly, the two vertical shafts can be treated as one shaft taking half the load that is actually experienced. Secondly, it becomes very difficult to quickly calculate the deflection when two perpendicular beams are combined. Instead, the horizontal shaft was treated as a cantilever beam, fixed at the bearing block and experiencing a point load at the end. The vertical shaft was treated as another cantilever beam fixed at the base experiencing a moment caused by the load at a distance from the shaft. Figure 5.14 shows the formula required for the horizontal shaft, and Figure 5.15 shows the formula for the vertical shaft.

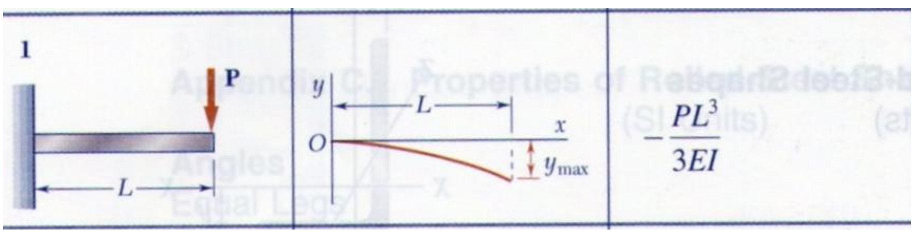

Figure 5.14: Deflection formula for a beam under a point load
(Source: Beer et al. 2004)

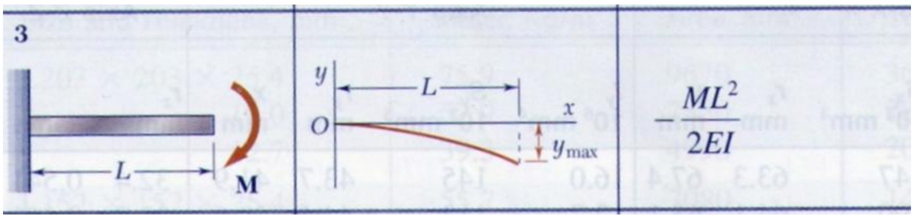

Figure 5.15: Deflection formula for a cantilever beam under a moment load (Source: Beer et al. 2004)

There are two properties in these formulae which can be varied, depending on the material and its cross sectional shape. They are *E,* the modulus of elasticity and *I*, the second moment of area.

The second moment of area of a cross section is its resistance to bending and deflection. The higher the value, the more resistive the cross section is. Each cross section has a different formula for calculating second moment of area, the general formula for a circular cross section being;

$$I_{xx} = \frac{pr^4}{4}$$

(5.4)

And a hollow circular section;

$$I_{xx} = \frac{p}{4}(r_o{}^4 - r_i{}^4)$$

(5.5)

See Figure 5.16 for the definitions of *r, r_i* and *r_o.*

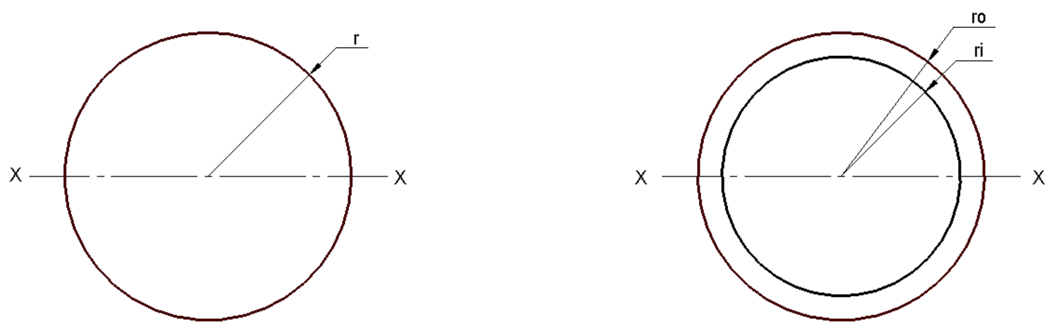

Figure 5.16: Dimensions for moments of area for a solid and hollow circular cross section

The modulus of elasticity describes the tendency of a material to deform elastically. The higher the *E* value, the less likely it is to deform. The values for carbon steel and aluminium are shown in

Table 5.2.

Table 5.2: Properties of steel, aluminium and precision shaft

Material	Approximate Modulus of Elasticity (GPa)	Density (kg/m^3)	Hardness
Carbon steel	200	7900	110
Aluminium	69	2700	60
Precision Shaft	-	-	466+

In normal use, the device would only see a few kilograms, or about thirty newtons of load at the handle. However, stroke patients who have paralysis in their arms may also be lacking control of their torso. This could mean they ‘hang’ off the handle forcing it to support some of their body weight as well. The RRD will be designed to have around 5 mm off deflection in either the horizontal or vertical shafts when loaded with 20 kg or 200 N.

The deflection equations in Figure 5.14 and Figure 5.15 can be used to find a combination of *E* and *I* to withstand the desired loading.

For the horizontal shaft;

$$\begin{aligned} EI &= \frac{-PL^3}{3d} \\ &= \frac{-200\times 550^3}{3\times 5} \\ &= -2.22\times 10^9 \end{aligned} \tag{5.6}$$

For the vertical shaft;

$$\begin{aligned} EI &= \frac{-ML^2}{2\times d} \\ &= \frac{0.5\times 200\times 550\times 1000^2}{2\times 5} \\ &= -5.5\times 10^9 \end{aligned} \tag{5.7}$$

The vertical shaft will suffer the most deflection so the material needs to be specified to tolerate this higher value. Table 5.3 shows the *I* value required for the two possible materials, and the corresponding diameter of tube and solid shaft that gives this *I*.

Table 5.3: Shaft diameters required for sound steel and aluminium structures

Material	I (mm^4)	Tube diameter - 3 mm wall (mm)	Solid Shaft diameter (mm)
Steel	27 500	32	27
Aluminium	79 710	44	36

The bearings are available through SKF with 30, 40 and 50 mm inside diameters. The approximate size of shaft was now known, so some other material properties were investigated.

5.3.4.2 Density and mass

The densities of steel and aluminium are shown in

Table 5.2 and it can be seen that a certain volume of steel would be approximately three times heavier than that same volume of aluminium. This was a big factor in choosing between the two materials, with the other major factors being surface hardness and availability.

5.3.4.3 Surface Hardness

The hardness of a material describes its resistance to plastic deformation when a load is applied to it. Linear ball bearings have a number of very hard balls in them that run on the shaft surface and recirculate throughout the bearing. This means that the surface they are running on also has to be quite hard, preferably harder than the balls, so that they cannot mark or scratch the shaft surface. The higher the loads that the bearing is withstanding, the more likely the balls are to dig into the shaft so the harder it needs to be. Unfortunately it is not easy to find a very hard material that is light weight and cheap, especially thin walled tube. There are various methods of describing hardness, with Brinnell hardness being a common one. The approximate hardness of some common steel and aluminium alloys as well as SKF's precision shaft is shown in

Table 5.2. It is obvious that the steel and aluminium have much lower hardness than the precision shaft, however for the light loads that the device will be seeing, it was thought that aluminium or steel would be sufficient.

5.3.4.4 Availability

Availability was the next thing to be investigated. Linear bearings require an exact size shaft to run on. As an example the precision shaft that SKF sells for a 50 mm linear bearing is toleranced between 49.981 – 50.000 mm. For optimum results, the shaft to be used for this device should also be within this. Unfortunately, thin walled steel tube is not readily available at this size. It is sold as ‘50 mm OD’ but is actually about 48.3 mm. Unfortunately, this was the case with 40 mm tube as well. Thick walled cylinder tube was available, but was too heavy, and defeated the purpose of using tube. This only left aluminium, which was available in 50 mm. The alloy 6061 T6 was preferred, but this was not available, so 6061 T4 was the remaining option.

5.3.4.5 Corrosion Resistance

Because the linear bearings were to run on the shafts, their surface could not be painted for rust prevention. Aluminium has a natural resistance to corrosion unlike steel which will rust over time. Steel can be chrome plated to prevent rusting but this is an extra manufacturing process and cost. Precision shaft contains alloying elements that resist corrosion.

5.3.4.6 Final selection

The three options for the shafts were steel tube, aluminium tube and precision shaft. Precision shaft was ruled out early because of its high mass however its hardness suited the application much better than the other two materials. Steel tube was unavailable in the required sizes so it was not a viable option either. Aluminium was the remaining material, and offered some good characteristics including its low density, natural corrosion resistance and good machinability. Its lack of hardness was its main downfall but was deemed negligible for this application.

5.3.4.7 Finite Element Analysis

A solid model of a 50 mm OD x 3 mm wall tube structure was created and a simple finite element analysis (FEA) was conducted to verify that the stress and strain in the shafts would be low enough. The results are shown in Figure 5.17 and Figure 5.18. The maximum deflection of 6.3 mm at the handle was a little higher than the expected 5 mm, however it was still acceptable as it actually represented the combine deflection. The stress was very low throughout the structure with the maximum being about 20 MPa. 6061 T4 aluminium has a yield stress of about 110 MPa, so the structure was sound in that regard. With the shafts selected and verified, it was time to order the bearings and start the detailed design.

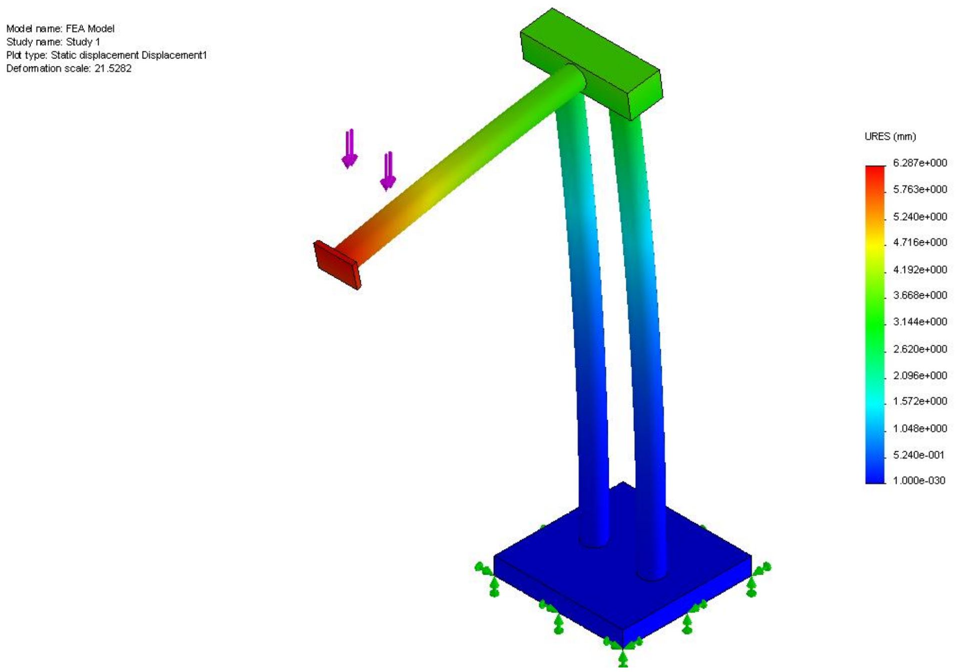

Figure 5.17: Deflection of aluminium tube structure

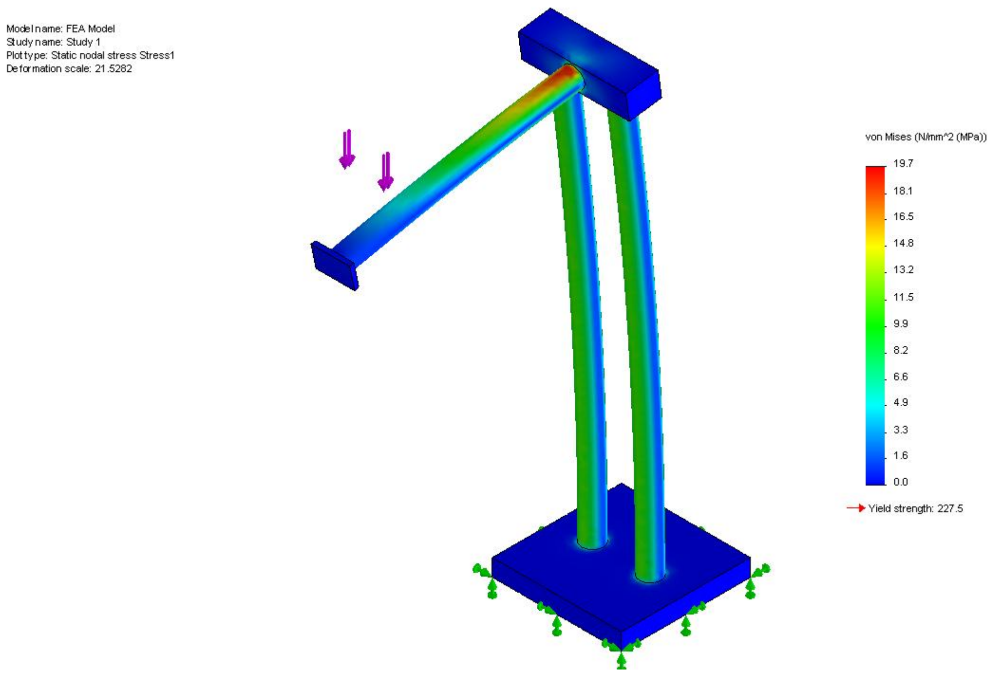

Figure 5.18: Stress in aluminium tube structure

5.3.5 Bearing Selection

The linear bearings required were to have a 50 mm inside diameter and be able to tolerate the loads necessary. SKF was consulted initially, and quoted approximately $240 per bearing. This meant the bearings alone would cost $720. At this point the idea of linear bearings was being questioned because of this unexpected high cost. BSC Motion Technology were then called and they quoted $86 per sealed bearing. This was much more acceptable and the bearings were purchased. A schematic of the bearing is shown in Figure 5.19. These bearings are rated to a radial load of approximately 6500 N, which is much higher than necessary.

Bearing

Dimensions			Reference	Variance	
Shaft Diameter	OD	Length		P	PP
6	12	22	KH0622	•	•
8	15	24	KH0824	•	•
10	17	26	KH1026	•	•
12	19	28	KH1228	•	•
14	21	28	KH1428	•	•
16	24	30	KH1630	•	•
20	28	30	KH2030	•	•
25	35	40	KH2540	•	•
30	40	50	KH3050	•	•
40	52	60	KH4060	•	•
50	62	70	KH5070	•	•

Variances: P = 1 seal PP = 2 seals

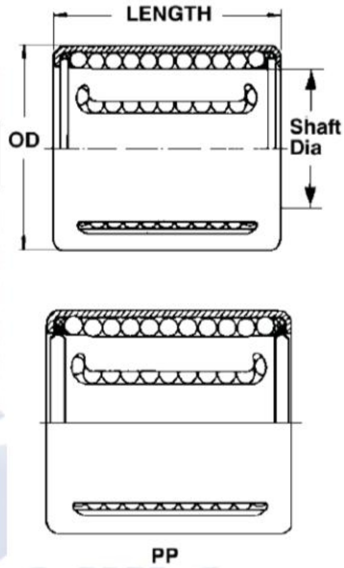

Figure 5.19: Linear Bearing schematic (Source: adapted from BSC, 2009)

5.3.6 Detailed Design

Once the general size and structure had been determined, it was possible to begin detailed design. Figure 5.20 shows a 3D model of the completed assembly of the RRD and Figure 5.21 shows this model in exploded view. It will be referred to throughout the following section.

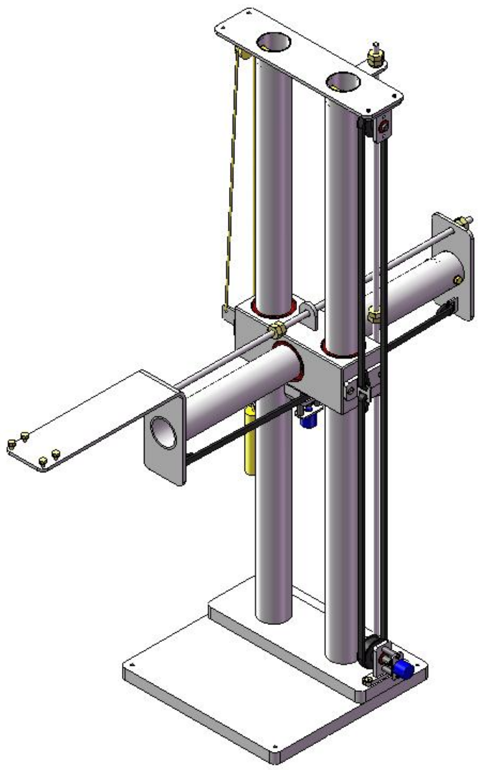

Figure 5.20: 3D model of assembled RRD.

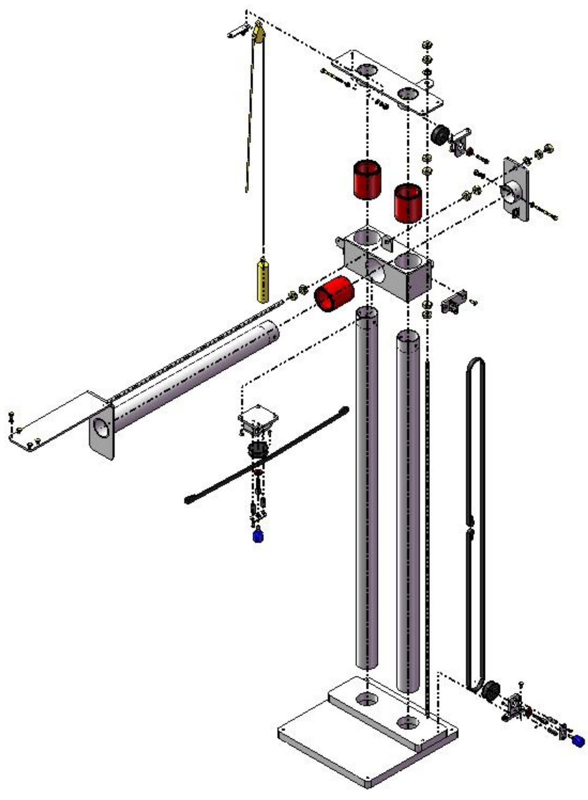

Figure 5.21: 3D model of exploded RRD assembly.

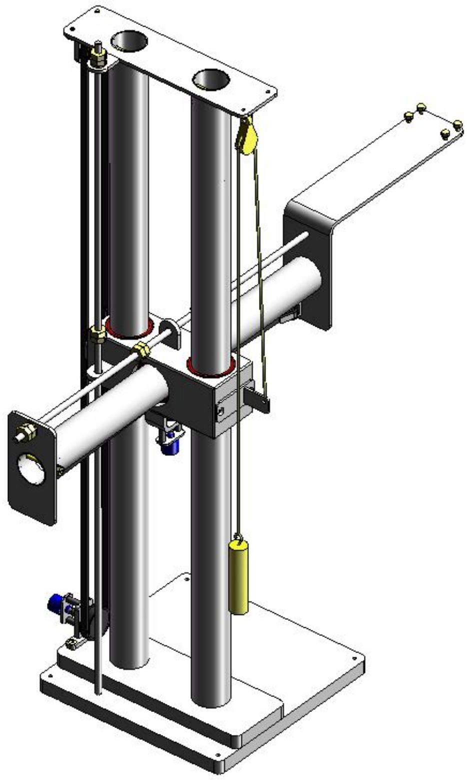

Figure 5.22: 3D model of assembled RRD from rear.

The first components to be designed were the bearing block, the base, the shafts, the top bar and the end bar. The rest of the parts were designed while the aforementioned parts were being constructed to save time. All major parts were made from aluminium to maintain consistency, weldability and low weight.

The base is shown in Figure 5.23 and was made from two pieces of 20 mm aluminium plate. The two plates were welded together then two 50 mm holes were machined through them both. These holes were tightly toleranced so that the two vertical shafts could be pressed into them. The combined depth of the two plates meant that the shafts would stand parallel and square to the base. This was necessary because of the precise nature of the linear bearings. It would not have been good enough to simply weld the two tubes to a base plate because it would be impossible to position them accurately enough and expect the linear bearings to run properly. Four through holes were drilled in the corners of the base to allow for fixing the device to a bench or desk. Two tapped M5x0.8 holes were added to attach the vertical pulley holder.

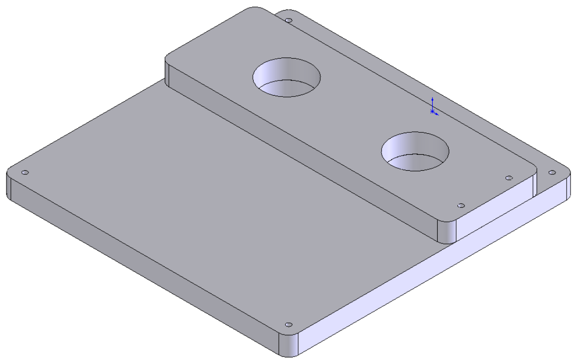

Figure 5.23: 3D model of Base; made from two piece of 20 mm aluminium plate

The two vertical shafts (Figure 5.24) were very simple being just a piece of 50 mm ODx3 mm wall aluminium tube cut to 995 mm. The inside of the top end of the shaft was machined out to Ø47 mm, 30 mm deep and a 7 mm hole was drilled through so that the top bar could be bolted on.

Figure 5.24: 3D model of Vertical Shaft; made from 50 OD x 3 mm wall aluminium tube.

The bearing block (Figure 5.25) was a piece of aluminium 80x80x209, and had three tightly toleranced holes to house the 3 linear bearings. It was sized so that enough material was kept between the bearings, and between the bearings and the outer surfaces. Tabs made from 6 mm aluminium flat were welded on for the threaded rod locking bars to run through. M5x0.8 tapped holes were added either side and underneath to attach the cable holder, vertical belt holder and horizontal pulley holder.

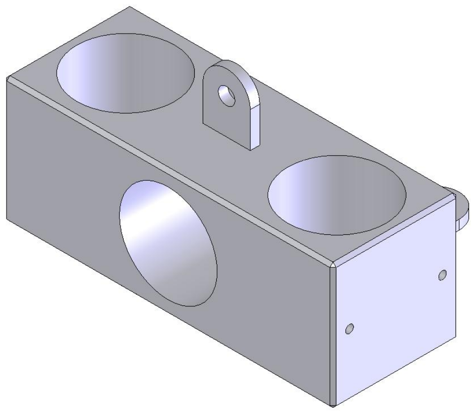

Figure 5.25: 3D model of Bearing Block; made from an 80 x 80 mm aluminium block.

The top bar (Figure 5.26) was then designed to stop the bearing block travelling too far and coming off the top of the vertical shafts and also to keep the shafts aligned. It consisted of a flat plate with two pieces of aluminium tube welded to it at the same centre distance as the vertical shafts. The tube was machined down to 47 mm to fit in the machined end of the shafts, and they also had a 7 mm hole through them to put a bolt in. It had M5x0.8 holes both sides to attach the vertical pulley holder and the vertical cable pulley holder. It also had a tab welded on for the vertical threaded rod to be fixed to.

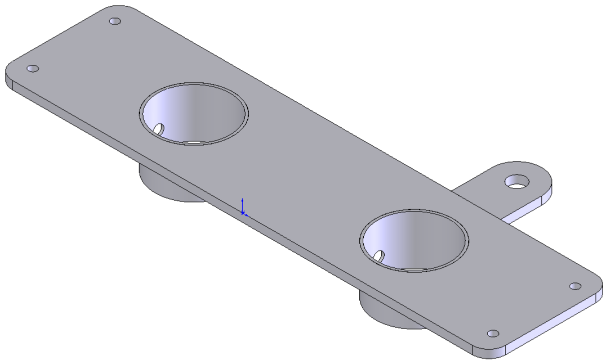

Figure 5.26: 3D model of Top Bar; made from aluminium plate and tube.

The end bar (Figure 5.27) was very similar to the top bar, but only had one tube to fit in the horizontal shaft. It had a hole for the horizontal threaded rod to be fixed to it, and a tab at the bottom for the horizontal timing belt to be looped through.

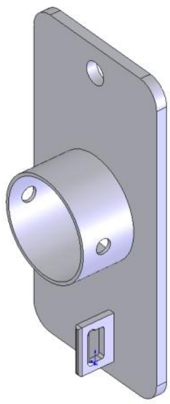

Figure 5.27: 3D model of End Bar; made from aluminium plate and tube.

The horizontal shaft (Figure 5.28) was the final major component and was very similar to the vertical shafts except that it had an attachment welded to one end for the wrist device to be bolted to. This was simply a bent piece of 6 mm flat aluminium with 4 holes in it. There was another tab welded to this piece of flat for the other end of the horizontal timing belt to loop through. -

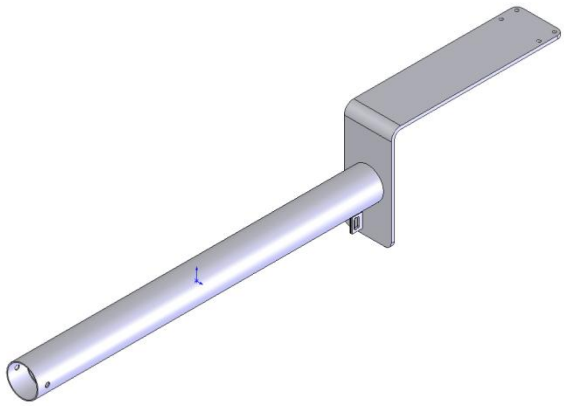

Figure 5.28: 3D model of Horizontal Shaft; made from aluminium plate and tube.

-

The M10 horizontal and vertical threaded rods, which are visible in Figure 5.20, were also cut to length. This concluded the structural design and the device was ready for the position monitoring system.

5.4 Design of Position Monitoring system

Once the design of the structure was complete, detailed design of the position monitoring began. At this point it was known that rubber belts and gears would be used to drive potentiometers, as it was necessary to design the structure with the mounting of these components in mind. The discussion on choosing a position monitoring system will be included in this section for ease of reference.

5.4.1 Choosing a System

It had already been decided that potentiometers would be used as the position monitoring system, but there still needed to be a way of converting the rotational motion of the potentiometers to linear motion in the horizontal and vertical axes.

Two ideas were being considered; using a rack and pinion system or a belt and pulley system shown in Figure 5.29 and Figure 5.30 respectively. For the rack and pinion system, the potentiometer would be fixed to the moving part, and its shaft would be fixed in the gear. The rack would be attached to the structure and as it moves linearly, the gear would turn, rotating the pot shaft, and varying the signal.

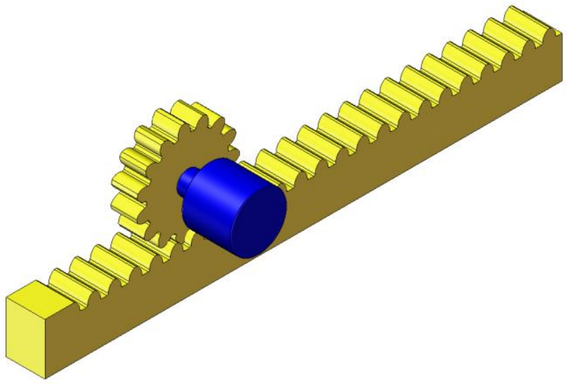

Figure 5.29: Example of using a rack and pinion to drive a potentiometer.

The second idea was using a belt and pulley system. This system was chosen and is fully modelled in Figure 5.20. For the vertical axis, the two ends of a miniature timing belt were attached to the bearing block, and looped around two gears, one at the top of the structure and the other at the bottom. The potentiometer was attached to the gear at the bottom and as the bearing block moves up and down it pulls the belt around, rotating the gears and turning the pot. The horizontal axis used the same principle, but instead the bearing block is fixed so the belt was attached to either end of the horizontal shaft. The gear was mounted on the underside of the bearing block and rotates when the belt is pulled in either direction relative to the bearing block.

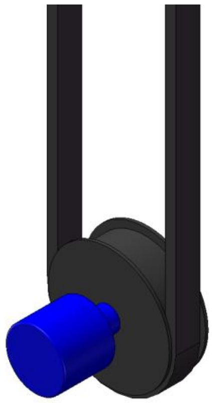

Figure 5.30: Example of using a gear and belt to drive a potentiometer.

The belt and pulley system was the better option because it seemed to be easier to fit, and easier to customise. If the rack and pinion idea was used, it may have been necessary to machine a rack out of metal to ensure it was strong and stiff enough. This would be expensive and time consuming.

Once the monitoring system was finalised, design began for mounting the gears and attaching the belts. Some modifications were made to the major components to fit the new parts and these were discussed earlier.

5.4.2 Gear and Belt Selection

The components that would determine the design of the position monitoring were the potentiometers (which will be discussed later) and the timing belts and gears. Local hobby shops were consulted first for the latter, but did not stock anything suitable, so a search on the internet was conducted to find a supplier. There were several businesses listed, and one that looked ideal was Hobby & Engineering Supplies PTY LTD (HES). They stocked continuous lengths of timing belt, and a variety of gears to suit.

The best size of the pulleys and timing belt wasn't easily identified at this point. The main constraints were that the gears would fit where they were intended to, and that the number of turns associated with a full movement would not be more than that of the potentiometer. After some quick calculations, it was decided that a 10 turn potentiometer would be the most suitable for the larger vertical movement, and to keep consistency, for the horizontal movement as well. The gears and belts also had to be strong enough and not slip on each other so that they could be driven by a force feedback motor if need be.

For a 10 turn pot, covering 1000 mm of linear travel, the minimum radius of pulley is;

$$
\begin{aligned}
r &= \frac{x}{q} \\
&= \frac{1000}{2p} \\
&= 15.9\,\text{mm} \\
f &= 31.8\,\text{mm}
\end{aligned}
\tag{5.8}
$$

The space on the underside of the bearing block would be the limiting factor in terms of pulley size. The maximum was estimated to be 68 mm. Also, because of the design the vertical pulleys would obstruct the bearing block at the extremities of the device and limit the ROM. This meant that the pulley was to be as small as possible. From here, the potentiometer and pulley mounting arrangement were modelled and it was concluded that the potentiometer would determine the size of the mounting bracket, not the pulley. A 40 mm diameter pulley would match the size of the bracket so this was used as an ‘in between’ size and allowed for and increase or decrease if required.

The other pulley and belt dimension to be determined was the width. There was no determining factor for this so 9 mm was chosen as it was thought to match the size of the device. The parts were ordered and detailed design could begin.

5.4.3 Detailed Design

Brackets were needed to hold the gears at the top and bottom of the device for the vertical belt and also the gear on the bearing block for the horizontal belt. The vertical pulley holder was used for both the top and the bottom brackets and its assembly is shown in Figure 5.31.

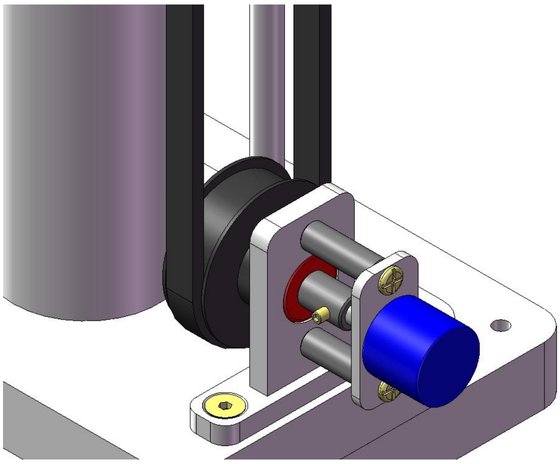

Figure 5.31: 3D model of the assembly of the bottom Vertical Pulley Holder and other components.

The Vertical Pulley Holder (Figure 5.32) is a ‘T’ section made from 6 mm flat aluminium. It was intended to be made from two pieces welded together but the workshop decided it would be easier to machine it out of one piece. This resulted in a neat, accurate shape. The bracket has a 19 mm hole for a ball bearing (red part in Figure 5.31), and two 4.5 mm holes for M4 screws to mount the potentiometer. There were also 2 countersunk holes for M5 socket head cap screws to attach the bracket to the device.

The potentiometer pulley shaft (Figure 5.33) was pushed through the bearing, and a circlip put in the groove. The gear was put on the end, and its grub screw tightened on the flat area of the shaft. The potentiometer was fixed to the potentiometer mounting plate (Figure 5.34) by its nut then followed by the two spacer bars. This sub-assembly was then screwed to the vertical pulley holder.

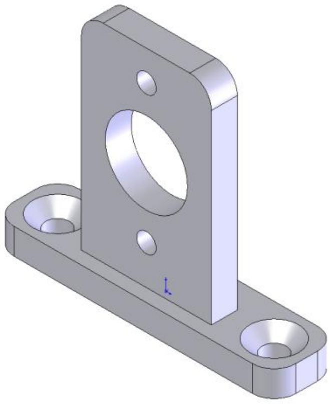

Figure 5.32: 3D model of Vertical Pulley Holder; made from aluminium plate,

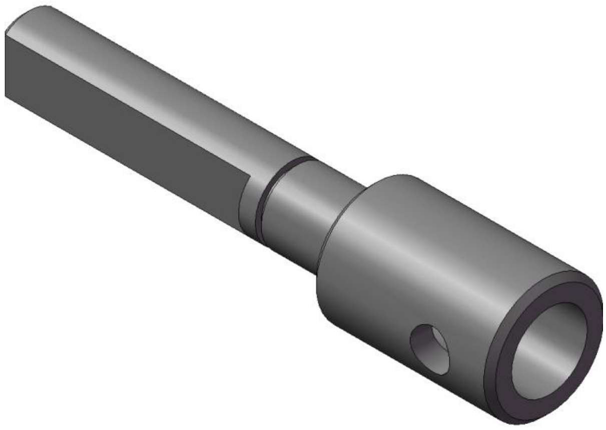

Figure 5.33: 3D model of Potentiometer Pulley Shaft; made from steel bar.

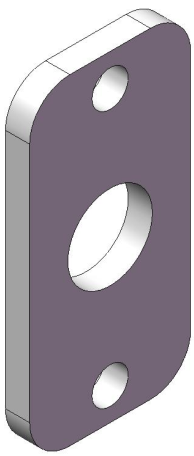

Figure 5.34: 3D model of Potentiometer Mounting Plate; made from aluminium plate.

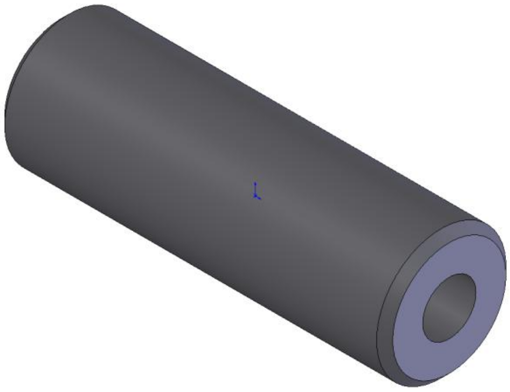

Figure 5.35: 3D model of Spacer Bar; made from steel bar.

Another bracket was needed to attach the ends of the timing belt to the bearing block. It is shown in Figure 5.36 and is made from a piece of 3 mm aluminium welded to a piece of 6 mm aluminium. There are two countersunk holes for M5 mounting screws, and 2 slots for each end of the belt to loop through. Smooth edges were required to prevent unnecessary wearing of the rubber belt.

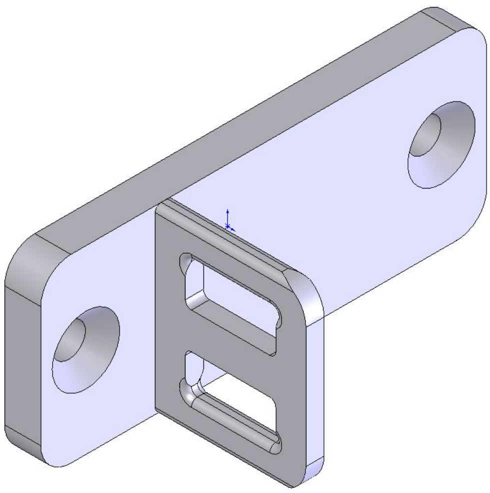

Figure 5.36: 3D model of the Vertical Belt Holder; made from aluminium plate.

The bearing and potentiometer mounting for the horizontal pulley holder was similar to that for the vertical pulley holder, with the main difference being the orientation and mounting of the bracket to the bearing block. The assembly is shown in Figure 5.37 and the pulley holder is shown in Figure 5.38. It is made up of a bent piece of

6 mm flat aluminium welded to another piece of 6 mm flat aluminium. There are four M5 countersunk holes for mounting screws. The assembly was a bit more complicated for this pulley holder because the pulley had to be positioned as the shaft was being pushed through the bearing. The spacer bars had to be screwed on first, as the pulley covered the screw heads.

The horizontal belt was fitted by attaching each end to the tabs on the horizontal shaft and end bar as discussed earlier.

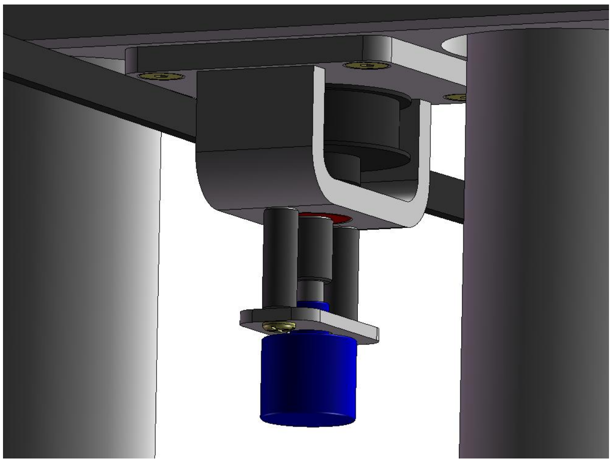

Figure 5.37: 3D model of the assembly of the Horizontal Pulley Holder and other components.

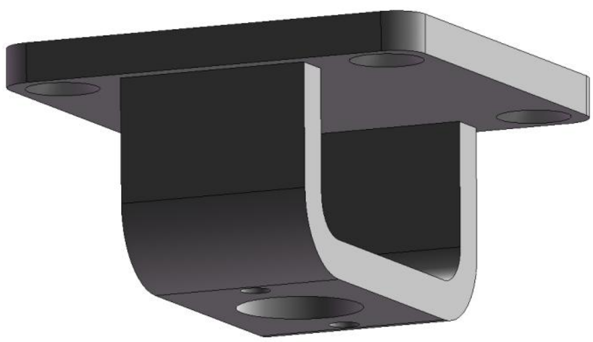

Figure 5.38: 3D model of horizontal pulley holder; made from aluminium plate.

5.5 Weight Block (Counterweight)

The weight block was the last part of the device to be added, and was used to neutralise the vertical weight of the moving components. Once the device was assembled, a set of kitchen scales were positioned under the bearing block. The horizontal shaft was lowered until the full weight of the moving components was being supported by the scales and a reading was taken. Six 20 mm steel concrete reinforcing bars were welded together and then cut to length so that they weighed approximately the same as the moving components. A hole was drilled through the block of bars, before a 3 mm steel cable was looped through and swaged.

Two brackets were then made from 3 mm steel. The vertical cable pulley holder (Figure 5.39) consisted of two pieces welded together with 2 countersunk holes for M5 screws to attach the bracket to the top bar. There was one M4 tapped hole added to the smaller piece to screw the pulley on.

The vertical cable holder Figure 5.40 was a similar bracket. It was another 'T' shaped arrangement with two countersunk M5 holes to attach the bracket to the bearing block. A 5 mm hole was drilled through the smaller piece to loop the cable through. Ideally, these parts would have been made from aluminium, but they weren't made by the workshop, and steel was the only material available.

The assembly of these components can be seen in Figure 5.22 and it shows how the cable was put on an angle from the bearing block to the top bar so that the weight block wouldn't clash on its way up and down.

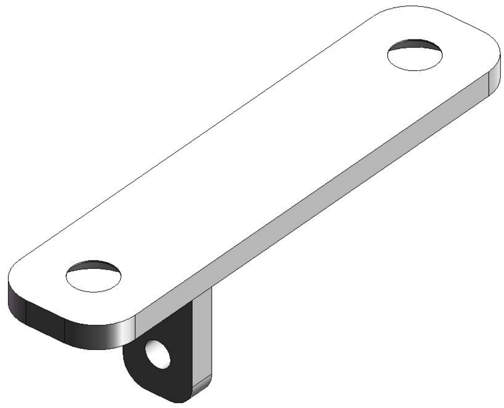

Figure 5.39: 3D model of Vertical Cable Pulley Holder; made from steel plate.

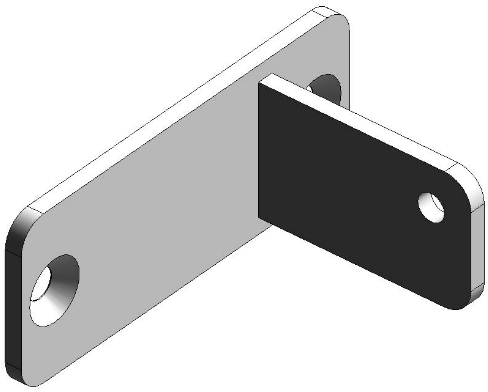

Figure 5.40: 3D model of Vertical Cable Holder; made from steel plate.

5.6 Design of Electronics

At this point, it was known that the circuit and interface software that was designed in previous work would be re-used and modified to accommodate for the extra two potentiometers. Being a mechanical based project, no extra research into improving the electronics of the device was conducted.

5.6.1 Microcontroller and Development Board

The microcontroller used was the PIC16F877A Figure 5.41. Its features include;

- maximum clock speed of 20MHz;
- 33 Input/output (IO) pins;
- 10-bit, 8 channel Analogue to Digital Converter (ADC);
- 8K flash program memory;
- 256 bytes of EEPROM data memory;
- two 8-bit and one 16-bit timer;
- universal Synchronous Asynchronous Receiver Transmitter (USART) module; and
- two pulse width modulation (PWM) modules.

(Garrett, 2009)

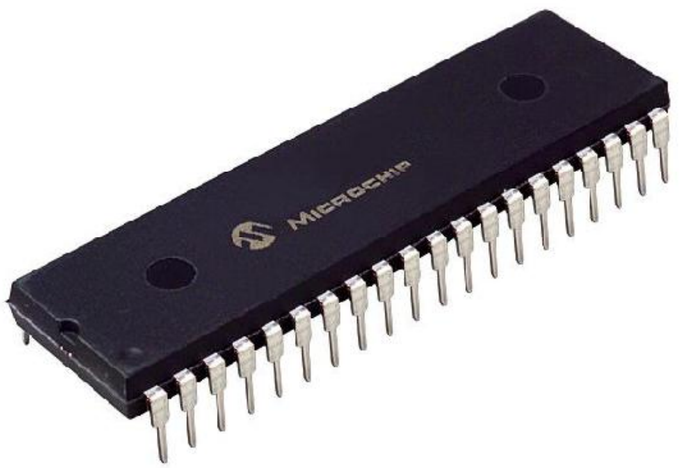

Figure 5.41: PIC16F877A microcontroller used for the RRD (Source: Garrett, 2009)

The development board used was the PIC-MT-USB by Olimex (Figure 5.42). Its features include;

- two 10 pin expansion headers for unused ports;
- 16 general purpose IO pins accessible;
- 20 MHz crystal on board;

- serial communication via RS232 → USB embedded integrated circuit;
- in Circuit Serial Programming (ICSP) capability;
- alphanumeric display 2x16 LCD with backlight;
- two push buttons, hardware debounced;
- bi-colour LED; and
- power supply taken by USB port

(Garrett, 2009)

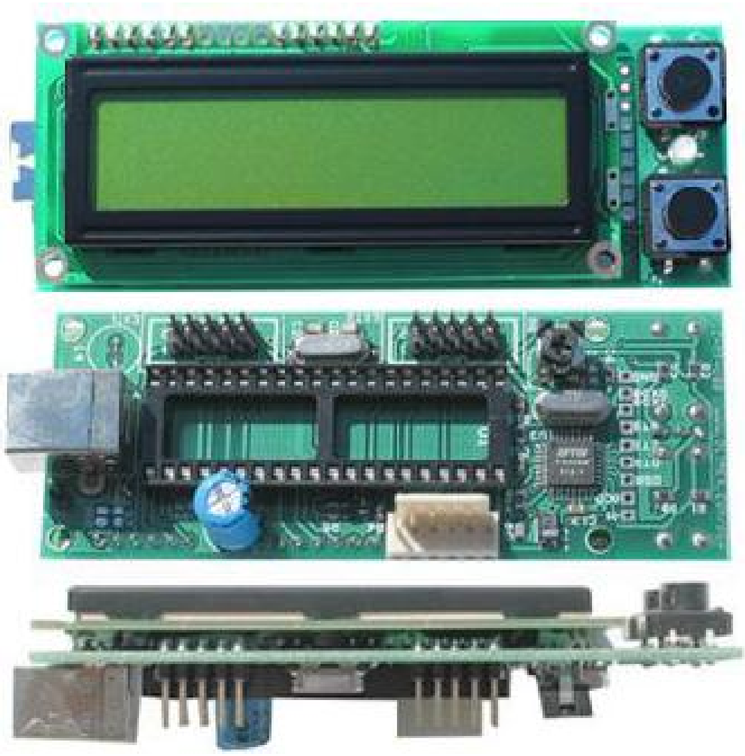

Figure 5.42: Olimex PIC-MT-USB development board used for the RRD (Source: Garrett, 2009).

A full discussion on why this microcontroller and development board were chosen has been included in future work and will not be re-written in this dissertation.

5.6.2 Potentiometers

The wrist device uses precision potentiometers with a resistance of 10 kΩ made by Bourns. These potentiometers have been found to be highly precise and reasonably accurate, so the same potentiometers were to be used, but in a 10 turn configuration.

The features of these potentiometers include;

- 340° electrical angle without mechanical stops.
- Essentially infinite resolution.
- Highly linear (±2%).
- High rotational life (10 million rotations).
- Exceptional quality and rugged construction

(Garrett, 2009)

The potentiometers, pictured in Figure 5.43 were ordered from RS online.

Figure 5.43: Bourns 10 turn potentiometer

5.6.3 Circuitry

The previously used circuit had already been proven effective so it was to be re-used. Two more of the microcontroller's channels were to be used for the extra two potentiometers. The previous circuit board consisted of two ten-pin headers and a 6-pin header to join the development board. A third 9-pin header was used to join the potentiometer wires. Each potentiometer needed three wires, one for power, one for ground and one for signal. The power and ground were provided by the development board through one of the 10-pin headers. The signal from the potentiometer was put through a simple resistor-capacitor filter circuit (Figure 5.44) then to the other 10-pin header which joined to the microcontrollers analogue input ports.

However the board wasn't designed with expansion in mind, so a new one had to be made. For this project, it was envisioned that all 8 of the converter's channels would be used at some stage, so a 25 wire ribbon cable and 25 pin plugs were used for the potentiometer wiring. 10 wires were left unused but the circuit board, pictured in Figure 5.45, was arranged so that the extra ports could be used in the future.

The same reset button was used, as well as the ribbon cable and header arrangement between the extension ports of the development board.

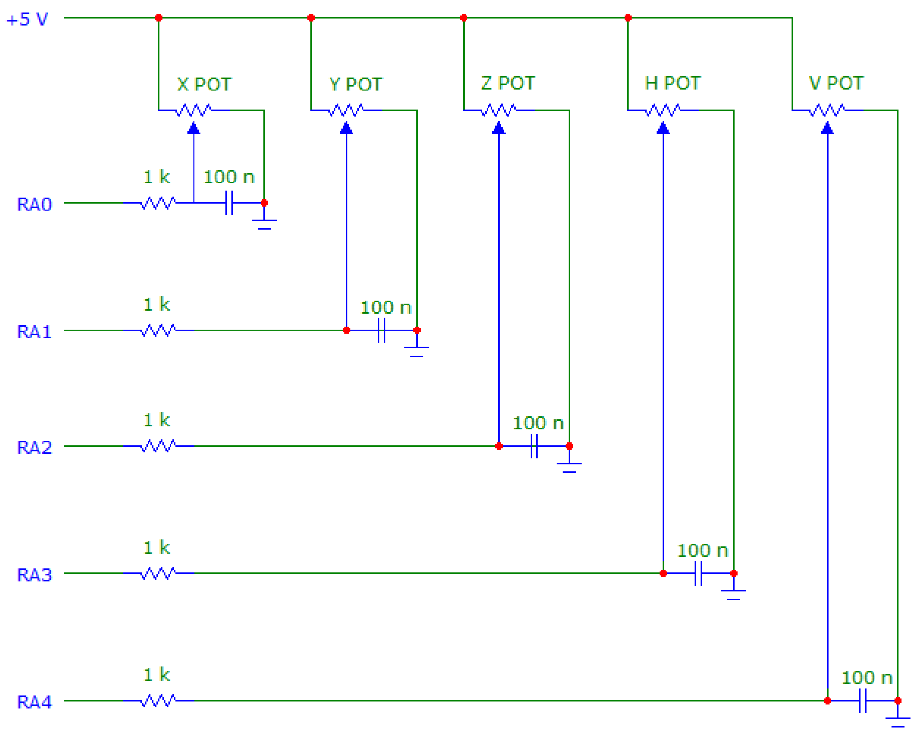

Figure 5.44: Resistor-capacitor filter circuit.

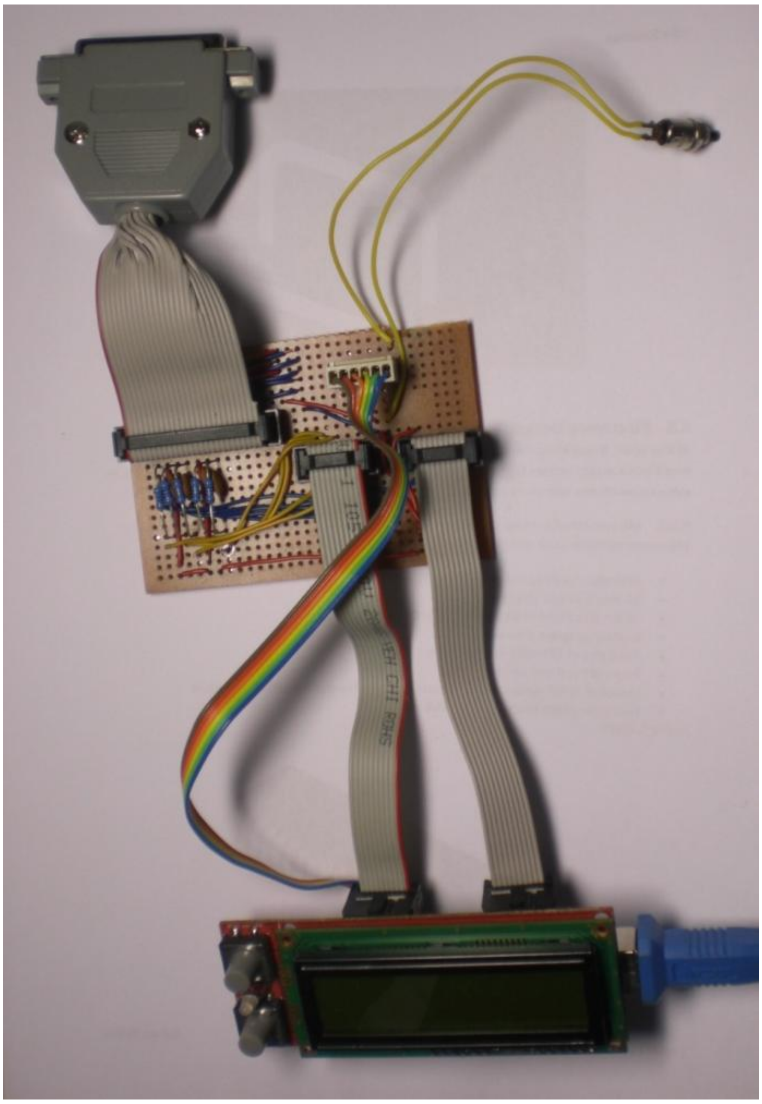

Figure 5.45: Photograph of the circuitry used for the position monitoring system.

5.7 Conclusion

A complete device was successfully designed and constructed. Linear bearings and round shafts were used to provide linear movement in 2 axes, horizontal and vertical. These correspond to shoulder and elbow movements and account for numerous combinations of these. A rehabilitation device for the wrist designed in previous work was attached to the horizontal shaft to provide the wrist movements and shoulder rotation. Once the parts and assemblies were modelled in 3D using

Solidworks, 2D engineering drawings were produced and given to the USQ workshop for production.

Potentiometers coupled to rotating gear and belt arrangements were used for position monitoring. Electrical design was undertaken, and the necessary circuitry and components were soldered onto a printed circuit board. The software used to link the device with a computer is discussed in the following chapter and testing and evaluation of the device will follow that.

Chapter 6 DEVELOPMENT OF SOFTWARE AND INTERFACE

6.1 Introduction

Functioning software was essential for linking the device to a computer and providing a quality interface to show the position of the handle on the screen. There is two parts to the system; the microcontroller software which ensures the position of the potentiometers can be sent to the computer, and the computer software which takes the position readings and displays them in a useful fashion on the screen. This chapter outlines the operation of the software and the work required in developing it.

6.2 Interface

An interface had been developed in previous work, but needed to be changed to accommodate the extra DOFs. A full explanation of the interface system can be viewed in his dissertation, and only a brief outline will be given here.

6.2.1 Microcontroller Software

As before, Oshonsoft PIC Simulator Integrated Development Environment (IDE) was used for coding.

The microcontroller software's role is to is to do the following

- perform analogue to digital conversions on the potentiometer output voltages every 20ms;
- convert this raw data to angular position in each axis;
- display the data in raw or converted form on an LCD screen;
- output the data serially to the RS232□USB chip on the development board;
- allow the user to press buttons to change menus and calibrate the device; and
- store the calibration data and last menu state in EEPROM and recall this on power up.

A flowchart of the system is shown in Figure 6.1.

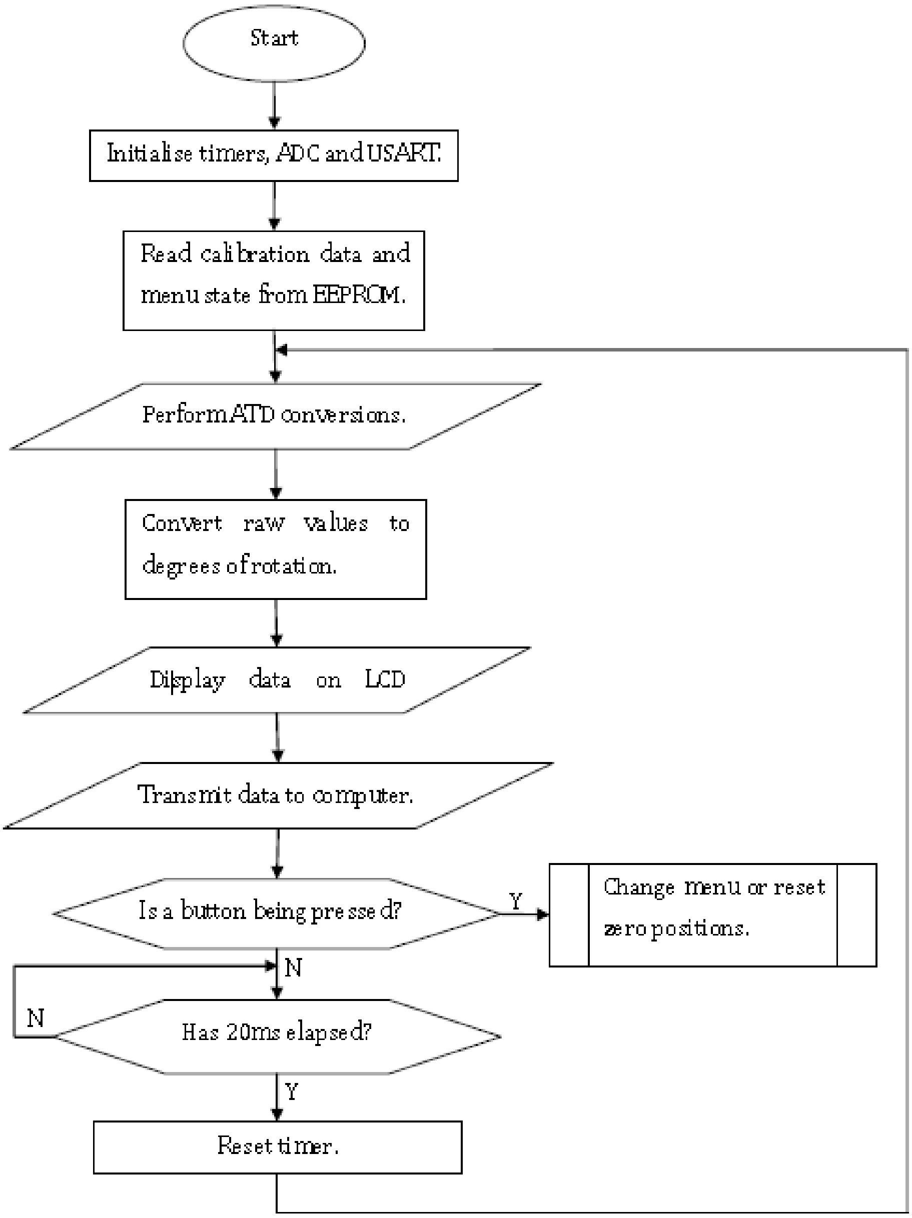

Figure 6.1: Flowchart of the microcontroller software.

(Garrett, 2009)

There were now five potentiometers, X, Y, Z, H and V and these were wired into ports AN0, AN1, AN2, AN3 and AN4 of the microcontroller. Each channel receives an analogue signal from its corresponding potentiometer every 20 ms, or at a rate of

50 Hz and converts it to a digital number. These numbers range from 0 to 1023 and are directly proportional to the position of the potentiometer.

The functions performed by the built in LCD screen and push buttons have been left unchanged, however the screen needed to be rearranged to provide enough space for five values, not three.

The bottom button is used for calibrating the device, that is, setting a zero position. This would usually be done when a new patient begins using the device or if the device is locked in a certain position for a specific exercise.

The top button toggles between display modes; raw mode, relative mode and rotation mode. Raw mode displays the raw, unaltered ADC values while relative mode displays the ADC values relative to the calibrated values. Rotation mode displays the angle that the potentiometers have rotated relative to the calibrated values.

Calculating the three values that get displayed should be discussed here. Let the raw ADC value, calibration value and relative value be RAW, CAL and REL respectively. Also, let θ be the angle of rotation.

$$REL = RAW - CAL \tag{6.1}$$

For the single turn potentiometers;

$$q = \frac{REL}{1023} \times 360^{\circ} \tag{6.2}$$

For the 10 turn potentiometers;

$$q = \frac{REL}{1023} \times 3600^{\circ} \tag{6.3}$$

Figure 6.2: Photograph of the LCD screen in rotation mode showing the relative angel of each of the potentiometers.

6.2.2 Computer Software

The computer software was also based on previous work and was developed in Microsoft Visual Basic 2008 Express Edition. The requirements of the computer program are;

- log patient movement;
- objectively assess and record patient condition;
- display movement of the wrist on the screen;
- provide visual stimulus in the form of computer games to exercise the wrist through an appropriate ROM;
- allow the therapist to specify maximum limits of wrist motion; and
- include playback tools for evaluation by a therapist.

This project will only focus on logging patient movement. It does not aim to produce an interface of high quality or high functionality, but merely an on-screen representation of the 6 movements. This will be enough to prove the concept of the RRD.

Previously, the software drew a grid with a central cross in the 2-dimensional window and placed a crosshair within it. The middle of the screen corresponded to the calibrated position of the device. The *x* coordinate, *y* coordinate and rotation of the cross hair corresponded to the flexion/extension, abduction/adduction and rotation of the wrist of the wrist respectively.

Two more DOFs which reflected the horizontal and vertical position of the wrist/arm were to be added. For horizontal movement, that is the wrist moving in and out, the screen was to appear like it was moving backwards and forwards. This was done by zooming the grid and central cross in as the handle was pulled towards the user, and zooming it out as the handle was pushed away from the user.

As the handle was moved up and down in the vertical direction, the central cross was to move up and down, while keeping the three wrist movements relative to it. This indicated the wrist moving up and down vertically while still using the *y* position as the abduction/adduction of the wrist. This meant that the wrist movements could no longer take up the whole screen, but had to be scaled down to allow for the vertical position as well. The position of the central cross ranged from ¼ to ¾ of the height of the screen. A full wrist flexion/extension or abduction/adduction corresponded to ¼ of the screen. This meant that the crosshair would always stay on the screen.

Figure 6.3 shows the interface screen immediately after the device has been calibrated. All axes read zero, and all visual indicators are central. Figure 6.4 show the interface when the arm is pushed away from the body and lowered, with the wrist extended, abducted and rotated. Figure 6.5 shows the other extreme where the arm is pulled towards the body and raised, with the wrist flexed, adducted and rotated.

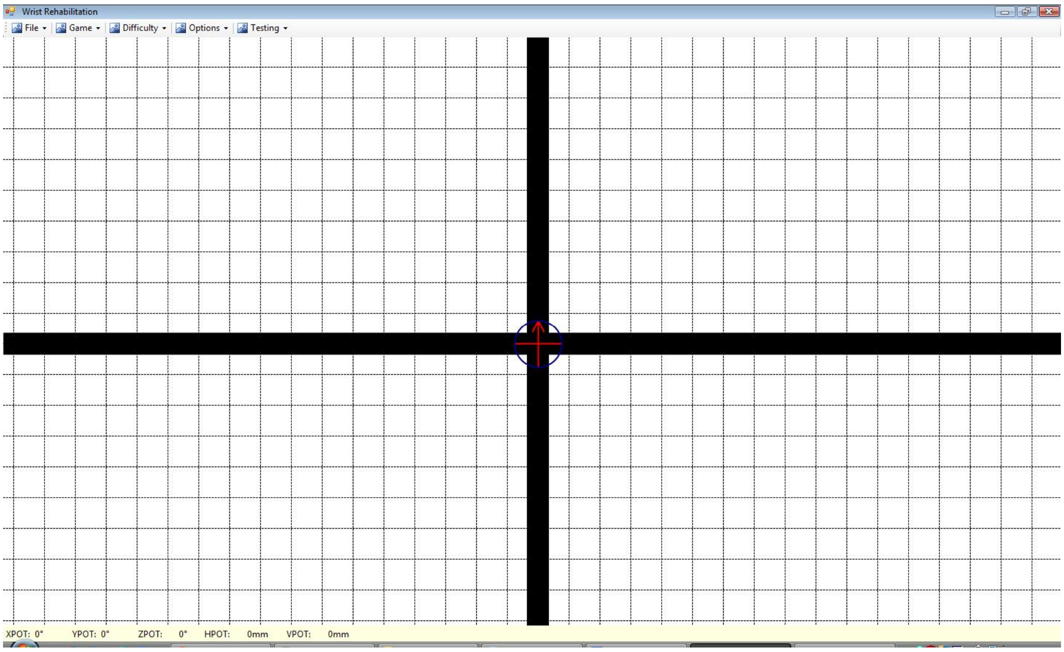

Figure 6.3: Image of the interface screen immediately after device has been calibrated.

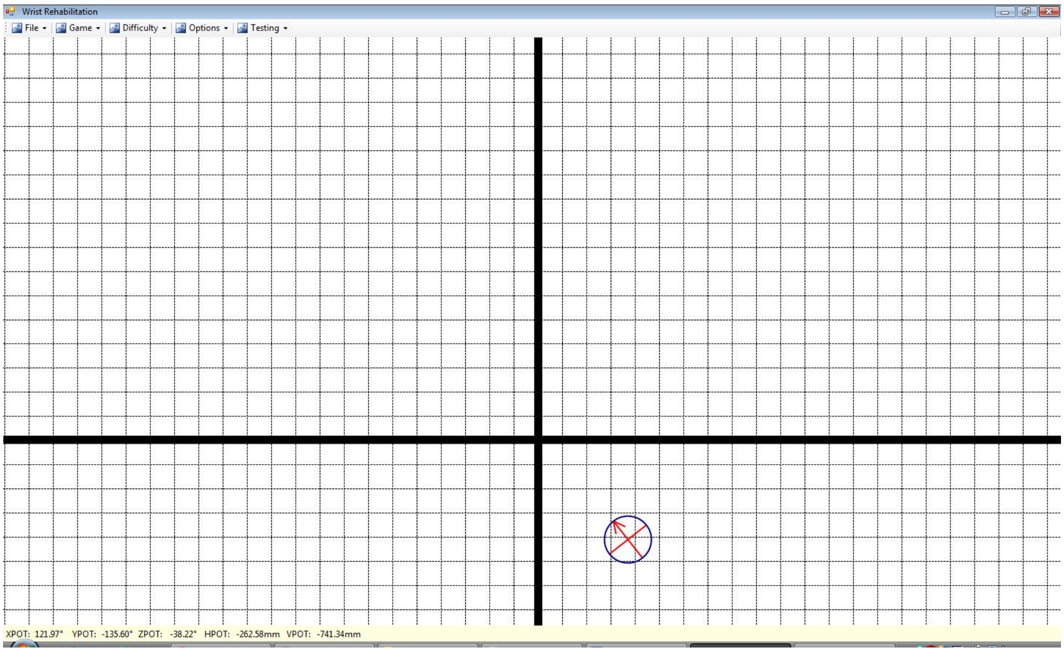

Figure 6.4: Image of the interface screen when arm is pushed away from the body and lowered, with the wrist extended, abducted and rotated.

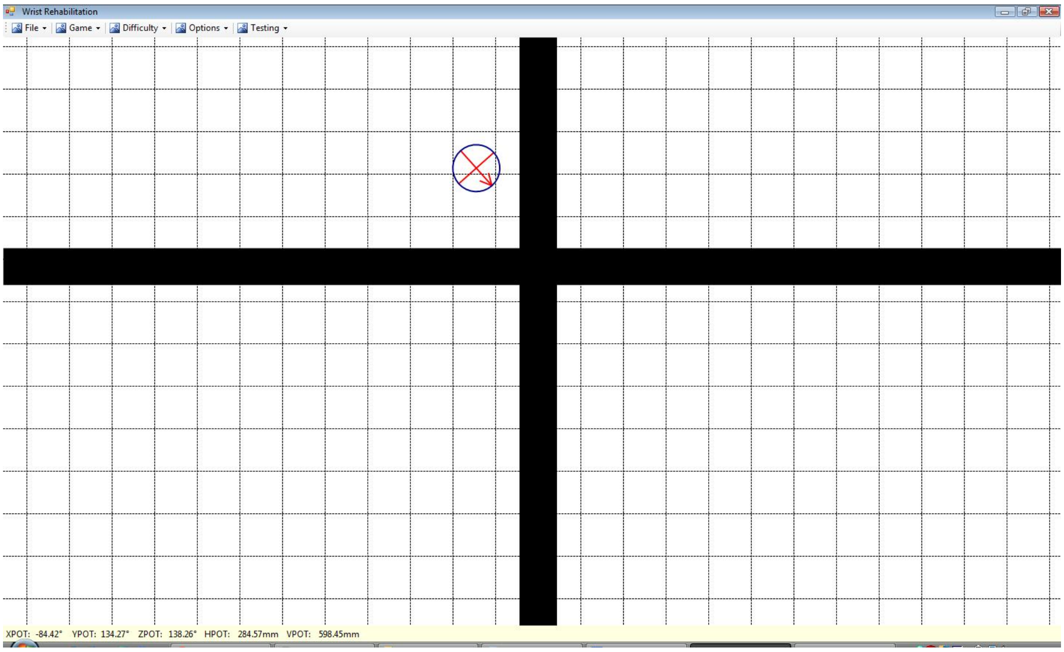

Figure 6.5: Image of the interface screen when arm is pulled towards the body and raised, with the wrist flexed, adducted and rotated.

6.3 Conclusion

A simple interface was created for the RRD by updating software developed in a previous USQ project. The interface shows the position of the device handle in 5 axes, by 5 different on screen variables. The microcontroller reads the positions of the potentiometers, displays them in useful formats on the development board's LCD screen and sends them via USB to the computer. Software for the microcontroller was written in PIC Simulator made by Oshonsoft. Using Microsoft Visual Basic, the computer then calculates the actual position of the device and displays it on the screen in both numeric form, and pictorial form.

The software for this device only logs patient movement and does not fulfil any of the other requirements of a fully functioning device. However this covers the scope of the project as the remaining requirements of the software were to be left as future work.

Chapter 7 EVALUATION AND TESTING OF DESIGN

7.1 Introduction

Evaluation and testing is an important step in any design task. Both qualitative and quantitative testing was done on the device to determine its suitability as a stroke rehabilitation tool. The ROM, accuracy and precision of the device were tested as well as the general functioning of the components. This chapter discusses the results and findings of the testing and gives some suggestions for improvement where necessary.

7.2 Structure

Manufacture and assembly of the structure proceeded quite well however the device did not work as well as expected. There were a few issues with the device and these will be discussed below.

7.2.1 Problem with linear bearing joints

The linear bearing joints were very sticky and rough and would only work when the moving force was applied directly through the axis of movement. This was very unhelpful as it made the vertical movement virtually useless because the handle was never going to be directly in line with the vertical shafts. The horizontal movement was also much too rough for this application.

Causes

Several observations were made while testing the device. The aluminium tubes were very loose and 'sloppy' in the linear bearings where they were supposed to be very tight and rigid. The horizontal shaft was fully extended and moved around to test the play in the joints. A movement of 10 mm from side to side, and up and down was measured at the end of the horizontal shaft. There was also some visible marking and wear on the aluminium tubes. The third observation was that the further the force was from the axis of movement, the harder it was to move the device.

Due to time constraints, the exact cause of the problem is not known. There is two likely causes and they are; the aluminium is too soft for the balls of the linear bearings to run on and they are ‘digging’ into the tubes or that the aluminium tubes are undersize and the linear bearings are too sloppy to work properly. A third unlikely but possible cause is that the machined housing for the linear bearings is not the correct size, and the press fit is too tight.

Solutions

There are several fixes for this problem. One which would combat both possible causes is coating the surface of the tubes with a hard substance by a process such as hard chroming or hard anodising. These processes could add from a couple of microns to tenths of a millimetre to the diameter of the tube as required. They would also offer a much harder surface that the balls wouldn’t be able to dig into and grab on.

Another, more drastic solution would be to redesign the device using smaller, solid precision shafts. This is not the ideal solution as discussed throughout the design chapter because of the added weight. However, looking at the design now, downsizing the shafts would mean that other components could be downsized as well, making this option more viable. Linear bearings could also be replaced with another linear motion system.

7.2.2 Horizontal Shaft Rotation

The horizontal axis only has one linear bearing as opposed to the vertical, which has two. The horizontal shaft has nothing to align it, and is free to rotate about its linear axis as well as move in a linear direction. With the current design, the horizontal threaded rod for the locking mechanism is stopping the shaft from rotating. This is not ideal as the threaded rod passing through the locking tab creates extra friction and roughness is in the movement.

Causes

There is no guidance system for the horizontal shaft.

Solutions

Another linear bearing could be added above, below or to the side of the current horizontal bearing. Another option would be to add a round bar parallel to the horizontal shaft and another tab on the bearing block with a bush in it for the bar to travel in.

7.2.3 Top Bar Bending

As shown in Figure 7.1, the top bar has bent on one side because of the weight block hanging off of it. It hasn't caused any other damage to the device, or stopped the weight block moving, but isn't desirable.

Causes

Weight block is too heavy for the structure of the top bar.

Solutions

One option is to lower the mass of the moving components, so the size and mass of the weight block can be reduced. Another option is to make the top bar stronger so it can hold the mass of the weight block.

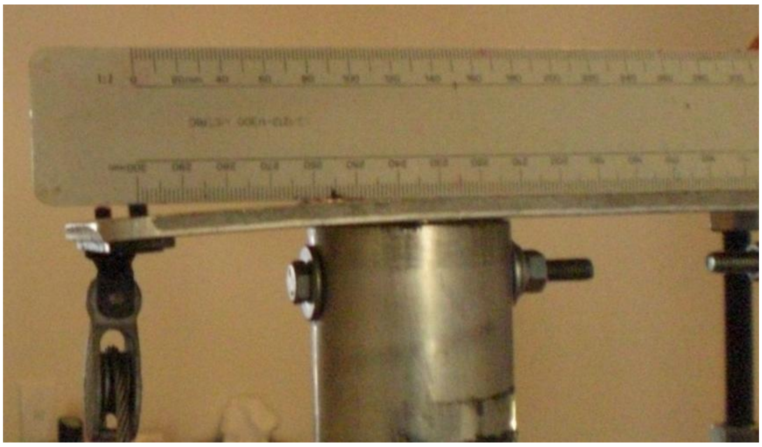

Figure 7.1: Photograph showing the bending that the top bar has experienced.

7.2.4 Changes to Wrist Device Mounting

To combat the problem with the linear bearings, it was thought that moving the wrist device and hence the handle as close to the vertical shafts as possible may make it easier to move the horizontal shaft up and down. The bent piece on the end of the horizontal shaft was cut off, and the wrist device was bolted directly to the flat on the end of the horizontal shaft. Figure 7.2 shows the new mounting arrangement.

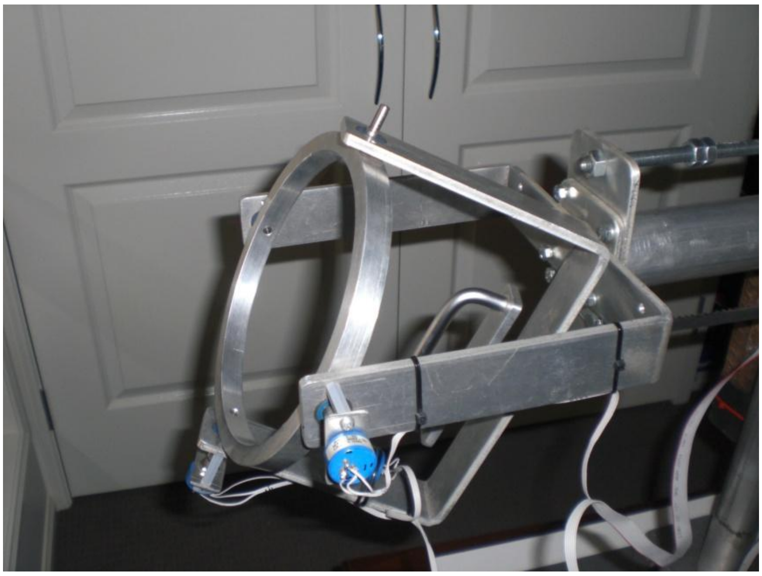

Figure 7.2: Photograph of new wrist device mounting arrangement.

By doing this, the orientation of the wrist device was changed, and it was no longer mounted as it was designed to be. Unfortunately the ROM of the wrist abduction/adduction and flexion/extension was impeded.

Table 7.1 shows the approximate reduction to the ROM after the changes.

Table 7.1: ROM of wrist device after mounting changes.

Movement	Original ROM	ROM after changes
Adduction	48°	40°
Abduction	Unlimited	40°
Flexion	80°	40°
Extensions	80°	40°
Forearm pronation	Unlimited	Unlimited
Forearm Suppination	Unlimited	Unlimited

7.3 Range of Motion

The ROM of the device was determined simply by measuring the distance between a pair of datum points on the device at its four extremities; maximum vertical, minimum vertical, maximum horizontal and minimum horizontal. Photos were taken with the tape measure in view for records. The photographs are shown in Figure 7.3 to Figure 7.6.

Figure 7.3: Maximum vertical measurement.

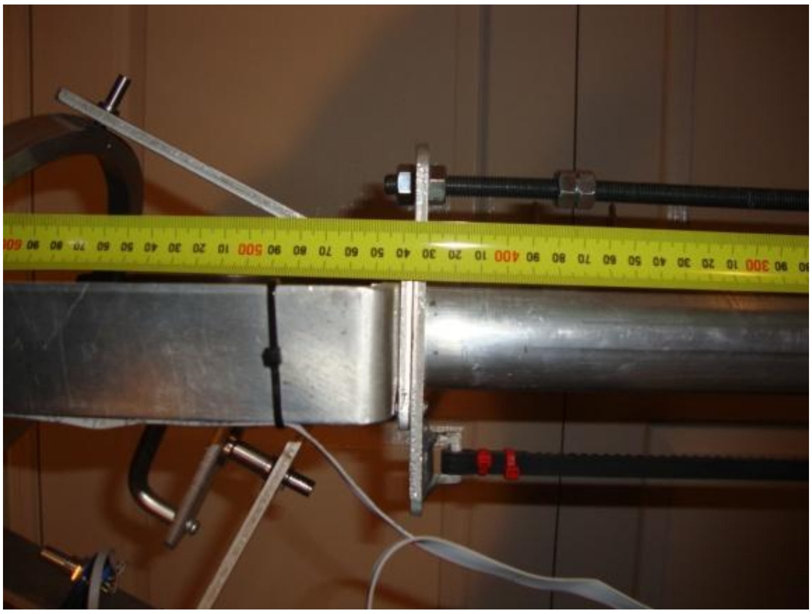

Figure 7.4: Maximum horizontal measurement.

Figure 7.5: Minimum vertical measurement.

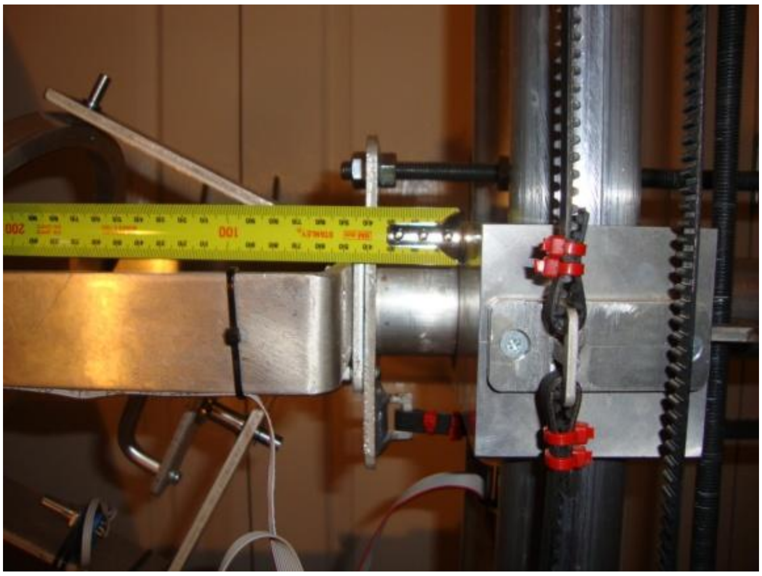

Figure 7.6: Minimum Horizontal measurement

Table 7.2 shows the measurements taken and the difference between them. This difference corresponds to the ROM of the device. The desired range was 923 x 510 mm and approximately 80% of this has actually been achieved in both directions. This was mainly due to the unforeseen size of the position monitoring system, and locking mechanisms. This could be easily fixed by increasing the size of the shafts by the required dimension.

Table 7.2: Measurements taken to deduce ROM

Axis	Minimum (mm)	Maximum (mm)	Achieved ROM (mm) (Max-Min)	Desired ROM (mm)
Horizontal	36	431	395	510
Vertical	88	828	740	923

Some experimenting was done to determine the ROM that the human arm would experience using the device in the 740 x 395 mm window. As stated earlier, there is infinite number of combinations of using shoulder movements and elbow movements together, so this is difficult to quantitatively measure. Some photographs (Figure 7.7 to Figure 7.12) have been taken as examples of the possible movements.

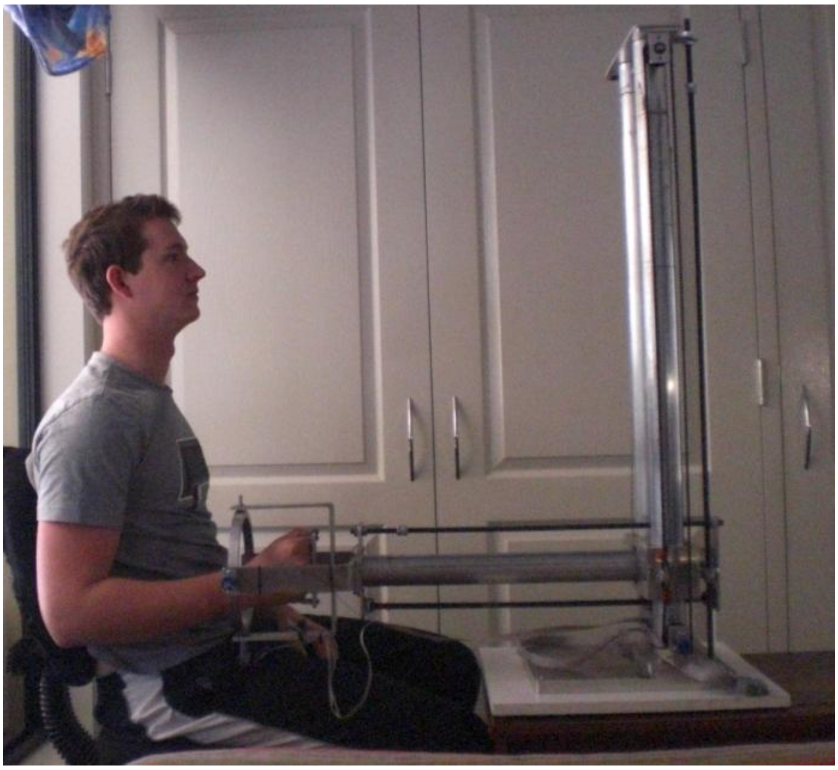

Figure 7.7: Position 1

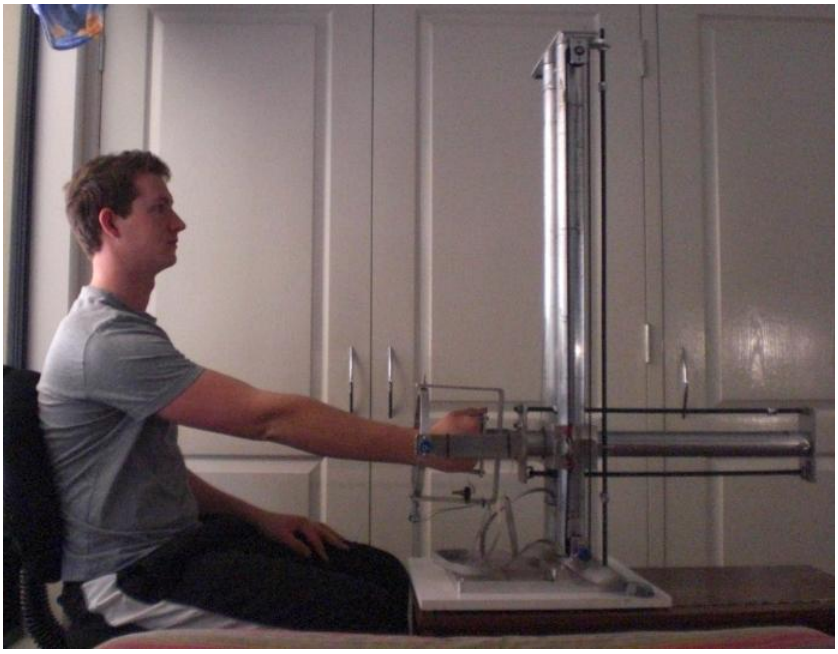

Figure 7.8: Position 2

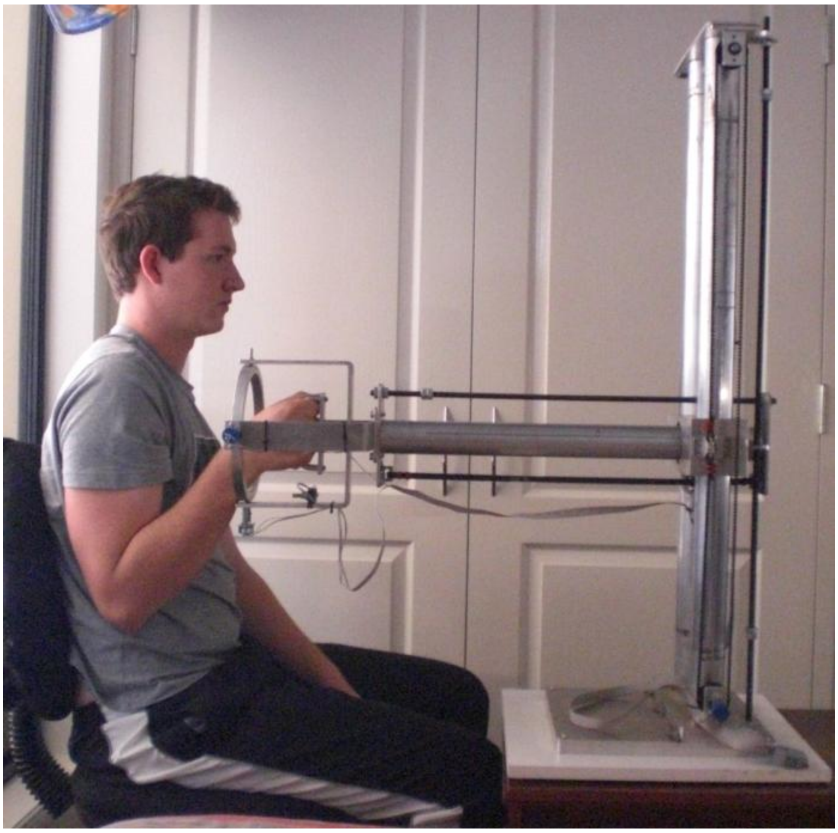

Figure 7.9: Position 3

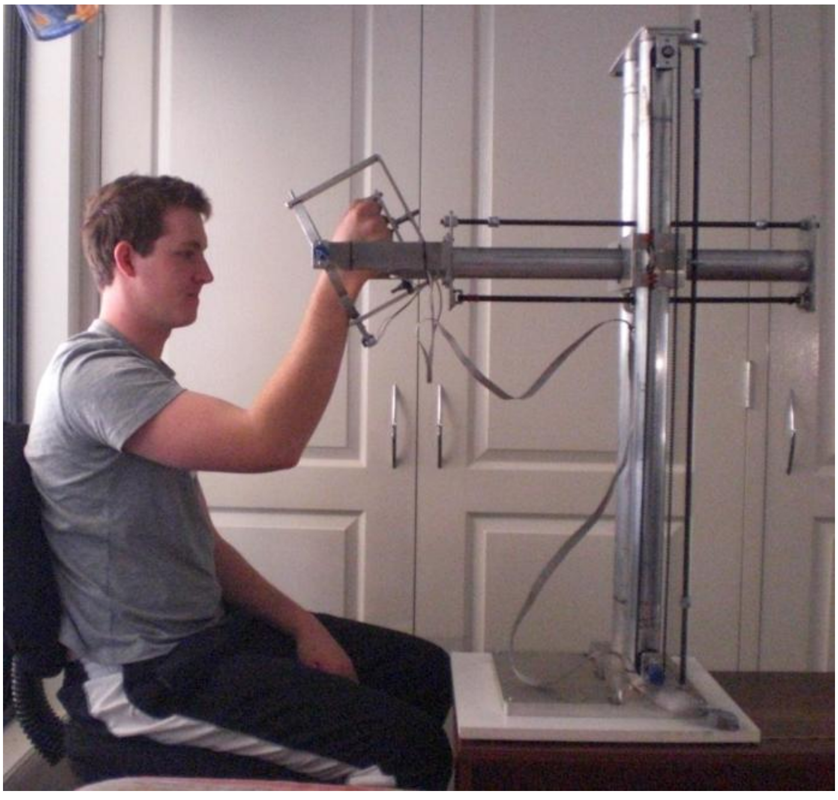

Figure 7.10: Position 4

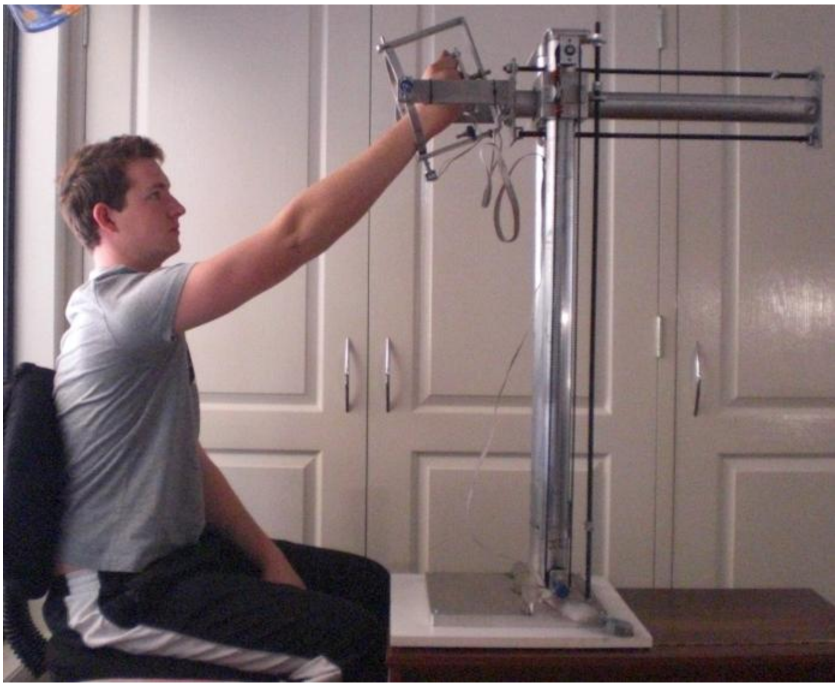

Figure 7.11: Position 5

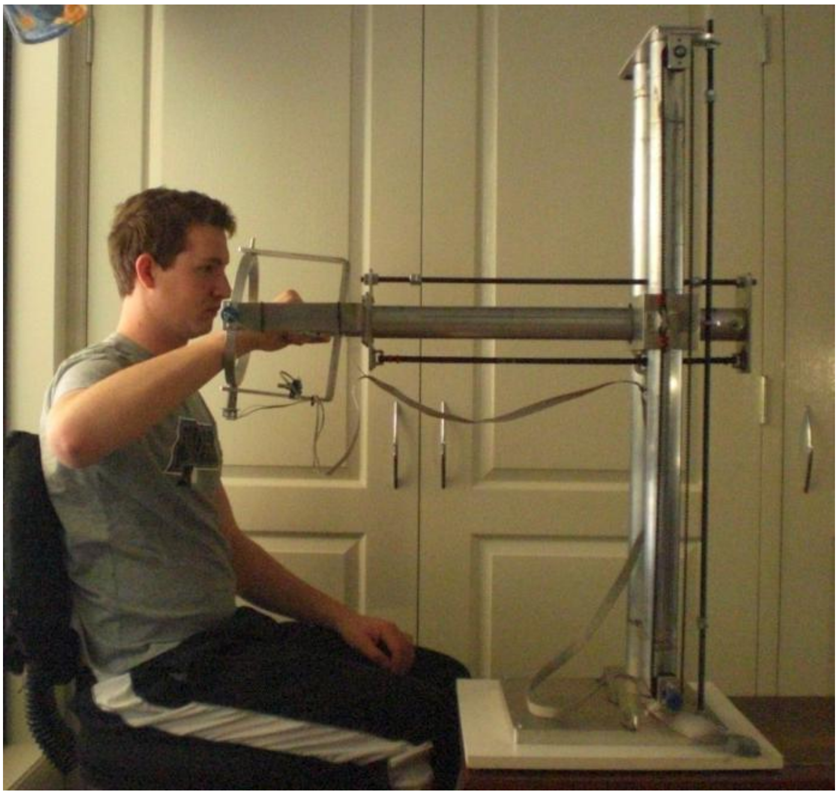

Figure 7.12: Position 6

7.4 Position Monitoring System

The position monitoring system has worked very well. It is robust and of high quality so is very reliable. There were a couple of minor issues with some components that can be easily fixed.

7.4.1 Grub Screw holes Stripped

One issue was that the grub screws in the potentiometer pulley shafts were too big for the thickness of material that was holding them and the threads were stripped (Figure 7.13).

Causes

The specified grub screws were too big.

Solutions

Smaller grub screws need to be used; perhaps a M2 or M3 thread would be better.

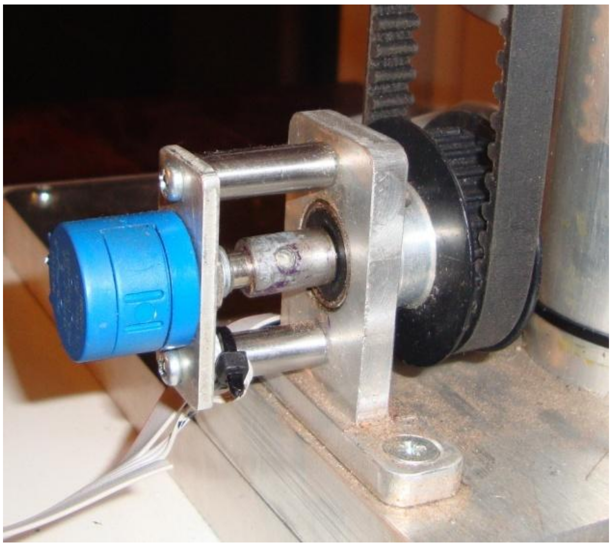

Figure 7.13: Photograph of potentiometer mounting arrangement, specifically noting the lack of grub screw in the hole.

7.4.2 Wasted Range of Motion

As mentioned in a previous section, the position monitoring components did finish being larger and take up more room than expected.

Causes

Unfortunately, manufacture of the structure had already started before the position monitoring system was fully designed. The extra components took up more room than originally expected and hence reduced the ROM of the device.

Solutions

The size of the structure needs to be increased slightly to account for the reduced ROM.

7.4.3 Testing

Other than the couple of issues discussed, the position monitoring system worked very well. Some testing was done to determine the precision and accuracy of the device. For each axis, the locking nuts were set to the extremities of the device. The handle was moved to one extremity then to the other and this was repeated 10 times. The position was read from the software and recorded at each extremity for each trial. These readings were compared with the physical measurement taken with the tape measure. Table 7.3 and Table 7.4 show the results.

Table 7.3: Results for Horizontal Axis Testing

Results for Horizontal Axis (mm) – Physical Range = 0 – 395 mm								
Trial	**Min**		**Min Error**	**Max**		**Max Error**	**Range**	**Range Error**
	Physical	**Software**		**Physical**	**Software**			
1	0	0	0	395	393.27	1.73	393.27	1.73
2	0	0	0	395	393.27	1.73	393.27	1.73
3	0	0	0	395	393.27	1.73	393.27	1.73
4	0	0	0	395	393.27	1.73	393.27	1.73
5	0	0	0	395	393.27	1.73	393.27	1.73
6	0	0	0	395	393.27	1.73	393.27	1.73
7	0	0	0	395	393.27	1.73	393.27	1.73
8	0	0	0	395	393.27	1.73	393.27	1.73
9	0	0	0	395	393.27	1.73	393.27	1.73
10	0	0	0	395	392.04	2.96	392.04	2.96
Max Error			**0**			**2.96**		**2.96**

Table 7.4: Results for Horizontal Axis Testing

Results for Horizontal Axis (mm) – Physical Range = 0 – 740 mm								
Trial	**Min**		**Min Error**	**Max**		**Max Error**	**Range**	**Range Error**
	Physical	**Software**		**Physical**	**Software**			
1	0	0	0	740	741.34	1.34	741.34	1.34
2	0	0	0	740	741.34	1.34	741.34	1.34
3	0	-1.22	1.22	740	741.34	1.34	742.56	2.53
4	0	-1.22	1.22	740	740.12	0.12	741.34	1.34
5	0	-1.22	1.22	740	740.12	0.12	741.34	1.34
6	0	-1.22	1.22	740	738.90	1.10	740.12	0.12
7	0	-2.44	2.44	740	738.90	1.10	741.34	1.34
8	0	-2.44	2.44	740	738.90	1.10	741.34	1.34
9	0	-2.44	2.44	740	738.90	1.10	741.34	1.34
10	0	-2.44	2.44	740	738.90	1.10	741.34	1.34
Max Error			**2.44**			**1.34**		**2.53**

The horizontal axis seems a little more consistent than the vertical. The range of the vertical movement seemed to stay fairly constant; however the minimum and maximum values were changing. Lack of time meant that further testing to find the cause of this wasn't possible.

The horizontal axis offered very high precision, with 9 out of 10 trials giving the same measurement. Its electronic measurement of 393.27 mm as opposed to the measured 395 mm equates to an error of 0.5% which is quite good.

The vertical axis was not as precise, with some variance in the readings. The maximum error in the measurement was about 0.4%, with the maximum variance in the range being 2.53 mm. In both axes, there was an error in the range of approximately 2-3 mm. The device was deemed accurate and precise enough for the proof of concept application.

7.5 Software and Interface

There wasn't really a method of quantitatively testing the software. The only check that was done was to make sure correct on-screen function was corresponding to the device movements and this was happening as desired.

7.6 Effectiveness of Device

At this stage there has been no form of clinical testing conducted with the device. It has not been assessed by any medical professionals, so the only evaluation of effectiveness of the device will be the opinion of the author.

Currently, the device would not be very effective as a stroke rehabilitation tool because of the poor performance of the linear bearings. The movements are too rough for use by someone with impaired motor skills and coordination. However, with this problem fixed, and some general refinement of the design, the device shows very good potential as a RRD. A little more work with the software would mean a simple game could be developed to complete the proof of concept device.

7.7 Conclusion

There were some problems with the device, the main one being that the linear bearings were not functioning as desired. This would have been fixed if time permitted, instead it will be left as future work. The ROM was a little less than expected as space was lost to the position monitoring components. The position monitoring system worked well, and was quite accurate and precise. The software and interface was very simple but functioned as it was designed to.

Chapter 8 CONCLUSIONS AND FUTURE WORK

8.1 Introduction

This project has included researching stroke and its effects, rehabilitating arm paralysis and current rehabilitation techniques. Robotic rehabilitation was investigated as a technique and after it was found to be very promising, a low cost robotic rehabilitation device was designed and constructed. The device was tested and evaluated and the problems were noted. The project has resulted in a step towards the design of a fully functioning robotic rehabilitation device.

This chapter discusses the achievements made by this project and explains the future work required to make the device ready for clinical testing. Figure 8.1 shows the designed robotic rehabilitation device 3D model.

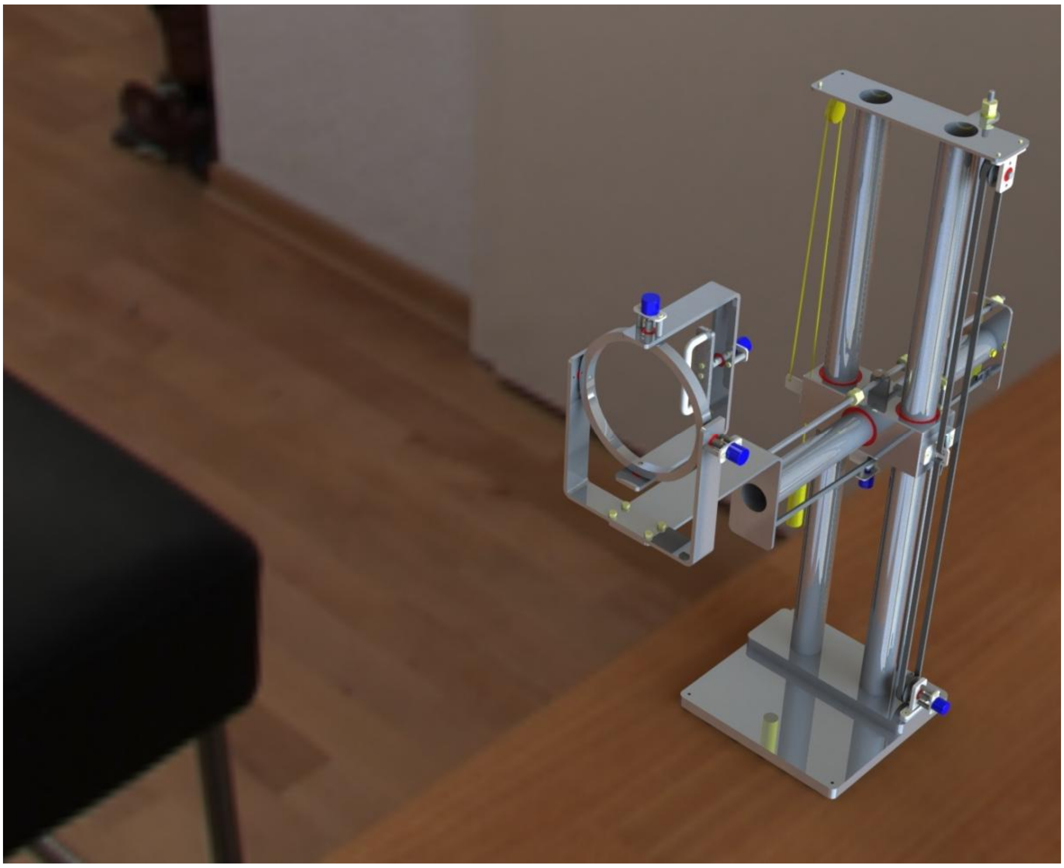

Figure 8.1: 3D model of the robotic rehabilitation device ready to be used

-

8.2 Achievements

The project objectives that were established at the beginning of the project will be revisited in this section and the achievements will be discussed.

The first objective was to *research how stroke affects movement and motor skills and to research current rehabilitation methods and their success.* This was accomplished by thoroughly researching stroke and its effects. It was found that stroke was a leading cause of disability, one of its effects being paralysis of the limbs. Research was conducted into rehabilitation and the problems that patients currently experience. The necessary steps to regaining movement were understood so that a suitable device could be developed. Robotic assisted therapy was found to be very promising in rehabilitating limb paralysis and some recently developed devices were discovered. All of this research was documented in chapter 2. It was obvious that a low cost device would be very beneficial to stroke patients.

Once objective 1 was completed, the requirements of a robotic rehabilitation device were determined and recorded in chapter 3. This was not an explicit objective but was necessary so that a suitable device could be designed. The next objective, *Research available joystick style equipment and their mechanisms, and determine whether they could be suitable for this device,* was completed. Chapter 4 explains that this proved unfruitful as the requirements of the device didn't match anything presently on the market and a completely new design was needed.

Creating concepts and investigating the strengths and weaknesses of each concept began. Several designs, shown in chapter 4, were investigated for both the structure and the position monitoring system. The best structure type was chosen first, and designed in detail so that the position monitoring system could be investigated further and then decided upon.

Chapter 5 details the full design process from specifying a motion system to mounting the potentiometers as per the *prepare design for construction* objective. All of the parts and assemblies were modelled using Solidworks, then detailed on 2D drawings so that the USQ workshop could build the device. The structure was designed first with position monitoring in mind. Potentiometers coupled to a gear and belt system were used for locating the device. The mounting of these parts was determined once the layout of the structure was known, and more parts were designed and constructed as required. The electronic circuitry needed to link the potentiometers to the computer was then designed and made. The microprocessor software and computer software were developed using Oshonsoft's PIC Simulator and Microsoft Visual Basic respectively. This fulfilled the *investigate and design electronics and control* objective.

Test the design and evaluate its performance was the next objective. The findings from this are included in chapter 7 and show that there were a couple of problems with the design however it was successful as a proof of concept device. The linear bearing joints did not perform as well as desired because of the roughness and stickiness of the motion. The position monitoring system, however, performed very well with errors in precision and accuracy of fractions of a percent.

Time didn't permit the addition of force feedback to the device. The device was intended to be neutral for the time being, but this was only moderately achieved due to the friction in the linear bearings. The device was not ready for clinical testing at this point either. This left *investigate and design force feedback components* and *perform clinical testing and provide professional feedback* as objectives to achieve in future work.

8.3 Future Work

The requirements of a robotic rehabilitation device were outlined in chapter 3. It was also stated that not all of the requirement could be addressed in this project. There is quite a bit of work necessary to get the project to the point where it can be clinically tested. The future work needed will be divided into four areas; structure, wrist device, force feedback and software.

8.3.1 Structure

The size and shape of the device is quite good and it easily fits on a desk beside a computer. There are some changes to the structure that would make the device a better a tool for stroke rehabilitation.

The final DOF of the shoulder, abduction/adduction, needs to be accommodated for in the device. It is believed this could be quite complex and would need to be done carefully so that the device doesn't become too large or heavy.

The linear bearing joints also need to be improved. At this stage, they are much too rough and the device can only be moved when the load is applied along the axis of movement. Chapter 7 gives some possible solutions to this problem.

The ROM of the device was reduced by the position monitoring components. The device either needs to be bigger, or a slight redesign is needed to move the obstructions out of the way of the moving components.

An enclosure for the moving components would be beneficial in making the device safer and more aesthetically pleasing. This would be needed before the device could be sold commercially.

8.3.2 Wrist Device

The wrist device designed in a previous project was attached to the end of the horizontal shaft of the device. It was not designed to be mounted in this way, and thus its ROM has been impeded. Work needs to be done to correct this and will probably entail designing a new wrist device that is better incorporated into the rest of the device.

There is also no method of locking the movements of the wrist device. Locking mechanisms need to be added and should be addressed if any redesign is done.

One other improvement that can be made to the wrist device is including a soft handle (Garrett, 2009).

8.3.3 Force Feedback

An attempt was made to make the device neutral by adding a weight block that counteracted the mass of the moving components. This would have been successful if the joints had minimal friction. However, a neutral device isn't able to move the patient’s hand for them to teach them movements, nor is it able to increase the strength of the arm by resisting motion.

A variable force feedback system would make the device much more flexible in that it could be used as an assistive, neutral or resistive rehabilitation tool. These three steps are very important in the rehabilitation process.

The device has been designed with force feedback in mind. Each axis of the wrist device has shafts for coupling electric motors to. The gears used for the horizontal and vertical position monitoring have also been designed so that that motors can be added without too much modification.

8.3.4 Electronics and Software

Several improvements to the electronics were recognized by Garrett (2009). They included;

- replacing the ribbon cable connecting the potentiometers with shielded computer cable to avoid interference;
- using a printed circuit board for the interfacing circuit;
- mounting electrical hardware in a neat box;
- investigation into using machine vision in calculating the position of the device; and
- possible improvements to accuracy of sensing before feedback can be added.

More robust wiring and a method of keeping the wires protected as the components move around will also be necessary on a commercial device.

The software requires quite a bit of work. It is currently very simple and merely shows the position of the wrist. There needs to be much better on-screen view, preferably in 3 dimensions and games or scenarios need to be created. One of the requirements of such a device is the ability to map and record progress to identify weak and strong areas. A program to do this also needs to be developed. This work will probably need to be left as an entire project for a software engineer.

8.4 Conclusion

This dissertation details the design and construction of an exercise device for use in therapy of the arm. The proof of concept device that has been designed and constructed meets the majority of the objectives set at the beginning of the project. Six out of the seven DOFs of the arm have been captured by rotational and linear movements. The position of the hand is tracked using potentiometers and displayed visually on a computer screen.

The device shows the potential to be developed as an effective computer based exercise device to assist in the rehabilitation of arm movement in stroke patients. Stroke recovery depends upon frequent, repetitive exercise. This device offers the advantage of being a cheap, home based therapy technique that allows patients to exercise whenever they can. All of this work aims to help the patient return to normal everyday living sooner, making them less dependent on social services, friends and family.

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Appendix A PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR: Jake Salomon

TOPIC: THE DESIGN AND CONSTRUCTION OF AN EXERCISE DEVICE FOR USE IN PHYSIOTHERAPY OF THE LOWER ARM

SUPERVISOR: Dr Selvan Pather

PROJECT AIM: To design and construct a device that can be used by stroke patients to help restore movement and motor skills to the lower arm.

PROGRAMME: Issue A, 16 March 2010

1. Research how stroke affects movement and motor skills. Research current rehabilitation methods and their success.
2. Research available joystick style equipment and their mechanisms, and determine whether they could be suitable for this device.
3. Create concepts and investigate the strengths and weaknesses of each concept.
4. Decide on a design to be constructed and tested.
5. Prepare design for construction
6. Investigate and design electronics and control.
7. Test the design and evaluate its performance.

As time permits:

8. Investigate and design force feedback components.
9. Perform clinical testing and provide professional feedback.

AGREED: ____________________(student) ____________________(supervisor)

Date: / / 2010 Date: / / 2010

Examiner/Co-examiner: ____________________

Appendix B CODE LISTING

Appendix C contains two pieces of code; the microcontroller code developed in Oshonsoft's PIC Simulator and the Computer code developed in Microsoft Visual Basic.

B1 Microcontroller Code

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'This software is designed for use with the wrist rehabilitation'
'device.  The purpose of the software is to read analogue       '
'voltages on the pots, update the LCD display and send the data '
'to the computer.                                               '
'Author: Jake Salomon                                           '
'Year:   2010                                                   '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Define CONF_WORD = 0x3f72
Define CLOCK_FREQUENCY = 20

'Define lcd display data lines
Define LCD_BITS = 4
Define LCD_DREG = PORTD
Define LCD_DBIT = 4
Define LCD_RSREG = PORTD
Define LCD_RSBIT = 0
Define LCD_RWREG = PORTD
Define LCD_RWBIT = 1
Define LCD_EREG = PORTD
Define LCD_EBIT = 2
Define LCD_READ_BUSY_FLAG = 1

'Define variable types
'Raw adc values
Dim xraw As Word
Dim yraw As Word
Dim zraw As Word
Dim hraw As Word
Dim vraw As Word
'Relative values
Dim xrel As Word
Dim yrel As Word
Dim zrel As Word
Dim hrel As Word
Dim vrel As Word
'Calibration values
Dim xset As Word
Dim yset As Word
Dim zset As Word
Dim hset As Word
Dim vset As Word
'Angle values
Dim xangle As Long
Dim yangle As Long
Dim zangle As Long
Dim hangle As Long
Dim vangle As Long
'Display mode
Dim mode As Byte
'Positive flags
Dim xpos As Bit
```

```
Dim ypos As Bit
Dim zpos As Bit
Dim hpos As Bit
Dim vpos As Bit
'Button flags
Dim but1_pressed As Bit
Dim but2_pressed As Bit
'Timer value
Dim timer1 As Word
timer1 = 40536  'for 20ms delay

'Define symbols
Symbol but1 = PORTB.5  'button 1
Symbol but2 = PORTB.4  'button 2
Symbol green_led = PORTB.2  'green led
Symbol red_led = PORTB.1  'red led
Symbol backlight = PORTD.3  'lcd backlight

'Start of program
start:
AllDigital
'Initialise lcd and custom characters
Lcdinit
Lcddefchar  0,  0x1c,  0x14,  0x1c,  0x00,  0x00,  0x00,  0x00,  0x00
'degree symbol
'Initialise analogue port
ADCON1 = %10000000
'Initialise ports
TRISA = %11111111
TRISB = %11111001
TRISC = %10111111
TRISD = %00000000
'Set Timer registers
T1CON = %00100001
'Set interupt registers
INTCON.TMR0IE = 0  'no interrupt on timer0
INTCON.GIE = 0  'disable global interrupt
Hseropen 56000  'initialise serial communication
green_led = 1  'turn green led on
red_led = 0  'turn red led off
'Print splash screen to LCD
backlight = 1
Lcdcmdout LcdClear
Lcdout "Arm Therapy"
Lcdcmdout LcdLine2Home
Lcdout "Device  JMS 2010"
WaitMs 3000
'main program
      Gosub restore  'restore calibration values and menu state
main:
      While PIR1.TMR1IF = 0
      Wend
      TMR1H = timer1.HB
      TMR1L = timer1.LB
      PIR1.TMR1IF = 0  'reset timer flag
      Gosub measure  'perform ADC conversions
      Gosub convert
      Gosub buttons  'check if buttons are pressed
      Gosub display  'print results to lcd
      Gosub serial  'send data to computer
      Goto main  'start again
End

restore:
'Restore zero settings and display mode from EEPROM
Read 0, xset.HB
Read 1, xset.LB
Read 2, yset.HB
Read 3, yset.LB
```

```
Read 4, zset.HB
Read 5, zset.LB
Read 6, hset.HB
Read 7, hset.LB
Read 8, vset.HB
Read 9, vset.LB
Read 10, mode  'was read 6
'check that data is valid or use defaults
If mode > 2 Then
mode = 0
Endif
If xset > 1024 Then
xset = 0
Endif
If yset > 1024 Then
yset = 0
Endif
If zset > 1024 Then
zset = 0
Endif
If hset > 1024 Then
hset = 0
Endif
If vset > 1024 Then
vset = 0
Endif
Return
'Perform analogue to digital conversions
measure:
      zraw = 0
      xraw = 0
      yraw = 0
      hraw = 0
      vraw = 0
      Adcin 1, xraw   'x and y are wired incorrectly on device. the
wrong wires are going to the pots.
      Adcin 0, yraw
      Adcin 2, zraw
      Adcin 3, hraw
      Adcin 4, vraw
Return
'Send data serially to computer
serial:
      Hserout "x"
      If xpos = 0 Then
      Hserout "-"
      Endif
      Hserout #xrel, "y"
      If ypos = 0 Then
      Hserout "-"
      Endif
      Hserout #yrel, "z"
      If zpos = 0 Then
      Hserout "-"
      Endif
      Hserout #zrel, "h"
      If hpos = 0 Then
      Hserout "-"
      Endif
      Hserout #hrel, "v"
      If vpos = 0 Then
      Hserout "-"
      Endif
      Hserout #vrel, Lf
Return
'Update lcd display
display:
      Lcdcmdout LcdClear  'clear the lcd
      'Print menu options
```

```
      Lcdcmdout LcdLine1Pos(16)
      Lcdout "M"
      Lcdcmdout LcdLine2Pos(16)
      Lcdout "S"
      Lcdcmdout LcdLine1Home
      Select Case mode
      'Display the raw adc values
      Case 0
            Lcdout "X", #xraw
            Lcdcmdout LcdLine1Pos(6)
            Lcdout "Y", #yraw
            Lcdcmdout LcdLine1Pos(11)
            Lcdout "Z", #zraw
            Lcdcmdout LcdLine2Home
            Lcdout "H", #hraw
            Lcdcmdout LcdLine2Pos(6)
            Lcdout "V", #vraw

      'Display the raw difference from the zero position
      Case 1
            Lcdout "X"
            If xpos = 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #xraw
            Lcdcmdout LcdLine1Pos(6)
            Lcdout "Y"
            If ypos = 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #yraw
            Lcdcmdout LcdLine1Pos(11)
            Lcdout "Z"
            If zpos = 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #zraw
            Lcdcmdout LcdLine2Home
            Lcdout "H"
            If hpos = 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #hraw
            Lcdcmdout LcdLine2Pos(6)
            Lcdout "V"
            If vpos = 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #vraw

      'Display the angle in degrees from zero position
      Case 2
            'Convert raw adc values to angle
            Lcdout "X"
            If xpos = 0 And xangle > 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
```

```
            Lcdout #xangle.LW, 0
            Lcdcmdout LcdLine1Pos(6)
            Lcdout "Y"
            If ypos = 0 And yangle > 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #yangle.LW, 0
            Lcdcmdout LcdLine1Pos(11)
            Lcdout "Z"
            If zpos = 0 And zangle > 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #zangle.LW, 0
            Lcdcmdout LcdLine2Home
            Lcdout "H"
            If hpos = 0 And hangle > 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #hangle.LW, 0
            Lcdcmdout LcdLine2Pos(8)
            Lcdout "V"
            If vpos = 0 And vangle > 0 Then
            Lcdout "-"
            Else
'Lcdout " "
            Endif
            Lcdout #vangle.LW, 0
      EndSelect
      Toggle green_led
      Toggle red_led
Return
'Poll the buttons
buttons:
      If but1 = 0 Then  'check if button is down
            but1_pressed = 1
            Else  'button not being pressed
            If but1_pressed = 1 Then  'button has been released
                  mode = mode + 1
                  mode = mode Mod 3
                  but1_pressed = 0  'reset button status
            Endif
      Endif
      If but2 = 0 Then  'check if button is down
            but2_pressed = 1
            Else 'button not being pressed
            If but2_pressed = 1 Then  'button has been released
                  xset = xraw
                  yset = yraw
                  zset = zraw
                  hset = hraw
                  vset = vraw
                  Write 0, xset.HB
                  Write 1, xset.LB
                  Write 2, yset.HB
                  Write 3, yset.LB
                  Write 4, zset.HB
                  Write 5, zset.LB
                  Write 6, hset.HB
                  Write 7, hset.LB
                  Write 8, vset.HB
                  Write 9, vset.LB
                  Write 10, mode
                  but2_pressed = 0  'reset button status
```

```
            Endif
      Endif
Return
'Convert raw results to rotations
convert:
      xrel = xraw - xset
      yrel = yraw - yset
      zrel = zraw - zset
      hrel = hraw - hset
      vrel = vraw - vset
      If xrel > 1024 Then
                  xrel = 65535 - xrel + 1
                  xpos = 0
            Else
                  xpos = 1
      Endif
      If yrel > 1024 Then
                  yrel = 65535 - yrel + 1
                  ypos = 0
            Else
                  ypos = 1
      Endif
      If zrel > 1024 Then
                  zrel = 65535 - zrel + 1
                  zpos = 0
            Else
                  zpos = 1
      Endif
      If hrel > 1024 Then
                  hrel = 65535 - hrel + 1
                  hpos = 0
            Else
                  hpos = 1
      Endif
      If vrel > 1024 Then
                  vrel = 65535 - vrel + 1
                  vpos = 0
            Else
                  vpos = 1
      Endif
      xangle = 340 * xrel / 1023
      yangle = 340 * yrel / 1023
      zangle = 340 * zrel / 1023
      hangle = 3600 * hrel / 1023
      vangle = 3600 * vrel / 1023
Return
```

B2 Computer Code – Main Application

```
Imports Microsoft.VisualBasic.PowerPacks
Imports System.Math
Public Class MainApplication
    Dim screensize As Size
    Dim relative = False
    Dim grid = True
    Dim gameon = False
    Dim testing = False
    Dim newtarget = True
    Dim gotocenter = True
    Dim xtarget As Integer
    Dim ytarget As Integer
    Dim targetrad As Integer = 16
    Dim target_ext As Integer = 40
    Dim target_flex As Integer = 40
    Dim target_add As Integer = 28
    Dim target_abd As Integer = 12
    Dim righthand As Boolean = True
    Dim coneext(180) As Decimal
    Dim coneflex(180) As Decimal
    Dim maxabs(180) As Decimal
    Dim minabs(180) As Decimal
    Dim maxcurve(180) As Point
    Dim mincurve(180) As Point


    Private Sub MainApplication_Load(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles MyBase.Load
        'Maximise window
        Me.WindowState = FormWindowState.Maximized
        Me.ResizeRedraw = True
        Me.SetStyle(ControlStyles.AllPaintingInWmPaint, True)
        Me.DoubleBuffered = True
        Me.SetStyle(ControlStyles.OptimizedDoubleBuffer, True)
        screensize = Me.Size
        RS232COM.Show()
    End Sub

    Private Sub MainApplication_Paint(ByVal sender As Object, ByVal
e As System.Windows.Forms.PaintEventArgs) Handles Me.Paint
        Dim xpos As Decimal
        Dim ypos As Decimal
        Dim zpos As Decimal
        Dim hpos As Decimal
        Dim vpos As Decimal
        Dim hposlinear As Decimal
        Dim vposlinear As Decimal
        Dim extension As Decimal
        Dim abduction As Decimal
        Dim pronation As Decimal
        Dim horizontal As Decimal
        Dim vertical As Decimal
        Dim numberlines As Decimal
        Dim xtran As Decimal
        Dim ytran As Decimal
        Dim scalefactor As Integer
        Dim verticaloffsetfactor As Integer
        Dim linefactor As Integer
```

```
        Dim arrow = My.Resources.myarrow
        Dim gridpen As New Pen(Color.Black, 1)
        gridpen.DashStyle = Drawing2D.DashStyle.Dash
        Dim line As Integer
        Dim point1 As Point
        Dim point2 As Point
        Dim point1cross As Point
        Dim point2cross As Point

        scalefactor = screensize.Width / 1000
        verticaloffsetfactor = screensize.Height / 400
        xpos = Val(RS232COM.xPOT.Text) * 340 / 1023
        ypos = Val(RS232COM.yPOT.Text) * 340 / 1023
        zpos = Val(RS232COM.zPOT.Text) * 340 / 1023
        hpos = Val(RS232COM.hPOT.Text) * 3600 / 1023
        hposlinear = hpos * PI / 180 * (39.77 / 2)
        vpos = Val(RS232COM.vPOT.Text) * 3600 / 1023
        vposlinear = vpos * PI / 180 * (39.77 / 2)

        'Calculate onscreen translations
        If relative = True Then
            If righthand = True Then
                extension = xpos * Cos(zpos * PI / 180) - ypos *
Sin(zpos * PI / 180)
                abduction = ypos * Cos(zpos * PI / 180) - xpos *
Sin(zpos * PI / 180)
                pronation = zpos
            Else
                extension = -xpos * Cos(zpos * PI / 180) + ypos *
Sin(zpos * PI / 180)
                abduction = ypos * Cos(zpos * PI / 180) + xpos *
Sin(zpos * PI / 180)
                pronation = -zpos
            End If

            xtran = screensize.Width / 2 + extension * scalefactor
            ytran = screensize.Height / 2 - abduction * scalefactor
            xlabel.Text = Round(abduction, 2) & "°"
            ylabel.Text = Round(extension, 2) & "°"
            zlabel.Text = Round(zpos, 2) & "°"
        Else
            xtran = screensize.Width / 2 + xpos * scalefactor
            ytran = screensize.Height / 2 - ypos * scalefactor
            xlabel.Text = Round(xpos, 2) & "°"
            ylabel.Text = Round(ypos, 2) & "°"
            zlabel.Text = Round(zpos, 2) & "°"
        End If

        hlabel.Text = Round(hposlinear, 2) & "mm"
        vlabel.Text = Round(vposlinear, 2) & "mm"

        numberlines = 35 - Round(25 * hpos / 2132, 0)
        linefactor = screensize.Width / numberlines
        horizontal = 30 + (28 * hpos / 1138)
        vertical = (vpos / 3600) * (screensize.Height / 4)

        'Draw grid if selected
        If grid = True Then
            'Draw vertical grid lines
            For line = -Round(numberlines / 2, 0) To
Round(numberlines / 2, 0)
```

```
                point1.X = screensize.Width / 2 - linefactor * line
                point1.Y = 0
                point2.X = point1.X
                point2.Y = screensize.Height
                If line = 0 Then
                    e.Graphics.DrawLine(New Pen(Color.Black,
horizontal), point1, point2)
                Else
                    e.Graphics.DrawLine(gridpen, point1, point2)
                End If
            Next line
            'Draw horizontal grid lines
            For line = -Round(numberlines / 2, 0) To
Round(numberlines / 2, 0)
                point1.X = 0
                point1.Y = screensize.Height / 2 - linefactor * line
                point2.X = screensize.Width
                point2.Y = point1.Y
                'If line = 0 Then
                'e.Graphics.DrawLine(New Pen(Color.Black, 40),
point1, point2)
                'Else
                e.Graphics.DrawLine(gridpen, point1, point2)
                'End If
            Next line
        End If

        'Enable high quality antialiasing
        e.Graphics.SmoothingMode = Drawing2D.SmoothingMode.AntiAlias

        'Render game graphics
        If gameon = True Then
            If newtarget = True Then
                If gotocenter = True Then
                    xtarget = screensize.Width / 2
                    ytarget = screensize.Height / 2
                Else
                    'Generate a random target within maximum motion
ranges
                    xtarget = (screensize.Width / 2) - scalefactor *
(CInt(Int(((target_ext + target_flex) * Rnd()) + 1)) - target_flex)
                    ytarget = (screensize.Height / 2) - scalefactor
* (CInt(Int(((target_abd + target_add) * Rnd()) + 1)) - target_add)
                End If
                newtarget = False
            End If
            e.Graphics.DrawEllipse(New Pen(Color.Green, 3), xtarget
- targetrad, ytarget - targetrad, targetrad * 2, targetrad * 2)
            If (xtran - xtarget) ^ 2 + (ytran - ytarget) ^ 2 <
targetrad ^ 2 Then
                newtarget = True
                gotocenter = Not (gotocenter)
            End If
        End If

        'Range of mode testing
        If testing = True Then
            'Record maximum and minimum abduction for each degree of
extension
            If abduction > maxabs(CInt(extension) + 90) Then
                maxabs(CInt(extension) + 90) = abduction
```

```
            ElseIf abduction < minabs(CInt(extension) + 90) Then
                minabs(CInt(extension) + 90) = abduction
            End If
            For i = 0 To 180
                maxcurve(i) = New Point(screensize.Width / 2 + (i -
90) * scalefactor, screensize.Height / 2 - CInt(maxabs(i)) *
scalefactor)
                mincurve(i) = New Point(screensize.Width / 2 + (i -
90) * scalefactor, screensize.Height / 2 - CInt(minabs(i)) *
scalefactor)
            Next

            'Plot the cone of circumduction
            e.Graphics.DrawPolygon(New Pen(Color.Black, 3),
maxcurve)
            e.Graphics.DrawPolygon(New Pen(Color.Black, 3),
mincurve)
        End If

        'Draw Crosshair at correct position
        point1cross.X = 0
        point1cross.Y = screensize.Height / 2 - vertical
        point2cross.X = screensize.Width
        point2cross.Y = point1cross.Y
        e.Graphics.DrawLine(New Pen(Color.Black, horizontal),
point1cross, point2cross)

        'Transform target image from top left pixel
        e.Graphics.TranslateTransform(xtran, (-vertical + ytran))
        e.Graphics.RotateTransform(zpos)

        'Draw target image at correct position
        e.Graphics.DrawLine(New Pen(Color.Red, 2), -32, 0, 32, 0)
        e.Graphics.DrawLine(New Pen(Color.Red, 2), 0, -32, 0, 32)
        e.Graphics.DrawLine(New Pen(Color.Red, 2), 0, -32, 8, -16)
        e.Graphics.DrawLine(New Pen(Color.Red, 2), 0, -32, -8, -16)
        e.Graphics.DrawEllipse(New Pen(Color.DarkBlue, 2), -32, -32,
64, 64)

    End Sub

    Private Sub MainApplication_Resize(ByVal sender As Object, ByVal
e As System.EventArgs) Handles Me.Resize
        screensize = Me.Size
    End Sub

    Private Sub ExitToolStripMenuItem1_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
ExitToolStripMenuItem1.Click
        RS232COM.Close()
        Me.Close()
    End Sub

    Private Sub PlayToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
PlayToolStripMenuItem.Click
        gameon = True
        PlayToolStripMenuItem.Checked = True
        FreeMove_TSM.Checked = False
    End Sub
```

```vb
    Private Sub StopToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
StopToolStripMenuItem.Click
        gameon = False
        PlayToolStripMenuItem.Checked = False
    End Sub

    Private Sub Easy_TSM_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles Easy_TSM.Click
        targetrad = 32
        Easy_TSM.Checked = True
        Medium_TSM.Checked = False
        Hard_TSM.Checked = False
    End Sub

    Private Sub Medium_TSM_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Medium_TSM.Click
        targetrad = 16
        Easy_TSM.Checked = False
        Medium_TSM.Checked = True
        Hard_TSM.Checked = False
    End Sub

    Private Sub Hard_TSM_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles Hard_TSM.Click
        targetrad = 8
        Easy_TSM.Checked = False
        Medium_TSM.Checked = False
        Hard_TSM.Checked = True
    End Sub

    Private Sub Flexion_Text_Enter(ByVal sender As Object, ByVal e
As System.EventArgs) Handles Flexion_Text.Enter
        target_flex = Flexion_Text.Text
    End Sub

    Private Sub Ext_text_Enter(ByVal sender As Object, ByVal e As
System.EventArgs) Handles Ext_text.Enter
        target_ext = Ext_text.Text
    End Sub

    Private Sub Adb_Text_Enter(ByVal sender As Object, ByVal e As
System.EventArgs) Handles Adb_Text.Enter
        target_abd = Adb_Text.Text
    End Sub

    Private Sub Add_Text_Enter(ByVal sender As Object, ByVal e As
System.EventArgs) Handles Add_Text.Enter
        target_abd = Add_Text.Text
    End Sub

    Private Sub RHand_TSM_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles RHand_TSM.Click
        RHand_TSM.Checked = True
        LHand_TSM.Checked = False
        righthand = True
    End Sub

    Private Sub LHand_TSM_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles LHand_TSM.Click
```

```
        RHand_TSM.Checked = False
        LHand_TSM.Checked = True
        righthand = False
    End Sub

    Private Sub FreeMove_TSM_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles FreeMove_TSM.Click
        gameon = False
        testing = False
        PlayToolStripMenuItem.Checked = False
        FreeMove_TSM.Checked = True
    End Sub

    Private Sub RangeOfMotionToolStripMenuItem1_Click(ByVal sender
As System.Object, ByVal e As System.EventArgs) Handles
RangeOfMotionToolStripMenuItem1.Click
        testing = True
        gameon = False
        RangeOfMotionToolStripMenuItem1.Checked = True
        PlayToolStripMenuItem.Checked = False
        FreeMove_TSM.Checked = False

    End Sub

    Private Sub OnToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
OnToolStripMenuItem.Click
        OnToolStripMenuItem.Checked = True
        OffToolStripMenuItem.Checked = False
        grid = True
        Refresh()
    End Sub

    Private Sub OffToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
OffToolStripMenuItem.Click
        OnToolStripMenuItem.Checked = False
        OffToolStripMenuItem.Checked = True
        grid = False
        Refresh()
    End Sub

    Private Sub WristToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
WristToolStripMenuItem.Click
        WristToolStripMenuItem.Checked = True
        DeviceToolStripMenuItem.Checked = False
        ssxlabel.Text = "Abduction:"
        ssylabel.Text = "Extension:"
        sszlabel.Text = "Pronation:"
        sshlabel.Text = "Horizontal:"
        ssvlabel.Text = "Vertical:"
        relative = True
    End Sub

    Private Sub DeviceToolStripMenuItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
DeviceToolStripMenuItem.Click
        WristToolStripMenuItem.Checked = False
        DeviceToolStripMenuItem.Checked = True
        ssxlabel.Text = "XPOT:"
```

```
        ssylabel.Text = "YPOT:"
        sszlabel.Text = "ZPOT:"
        sshlabel.Text = "HPOT:"
        ssvlabel.Text = "VPOT:"
        relative = False
    End Sub


    Private Sub hlabel_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles hlabel.Click

    End Sub
End Class
```

B3 Computer Code - RS232COM

```
Public Class RS232COM
    Dim WithEvents serialPort As New IO.Ports.SerialPort


    Private Sub RS232COM_FormClosing(ByVal sender As Object, ByVal e
As System.Windows.Forms.FormClosingEventArgs) Handles Me.FormClosing
        If serialPort.IsOpen = True Then
            serialPort.Close()
        End If
    End Sub


    Private Sub RS232(ByVal sender As System.Object, ByVal e As
System.EventArgs) _
    Handles MyBase.Load
        'If serial port is active close it so transfer protocols can
be established
        If serialPort.IsOpen Then
            serialPort.Close()
        End If
        'Define transfer protocols
        While serialPort.IsOpen = 0
            Try
                serialPort.PortName = "COM4"
                serialPort.BaudRate = 56000
                serialPort.Parity = IO.Ports.Parity.None
                serialPort.DataBits = 8
                serialPort.StopBits = IO.Ports.StopBits.One
                serialPort.ReadTimeout = 200
                serialPort.Open()
            Catch ex As Exception
                MsgBox("Please connect device and press OK.")
            End Try
        End While
    End Sub

    Private Sub DataReceived(ByVal sender As Object, ByVal e As
System.IO.Ports.SerialDataReceivedEventArgs) Handles
serialPort.DataReceived
        'Get data sentence from COM1 port
```

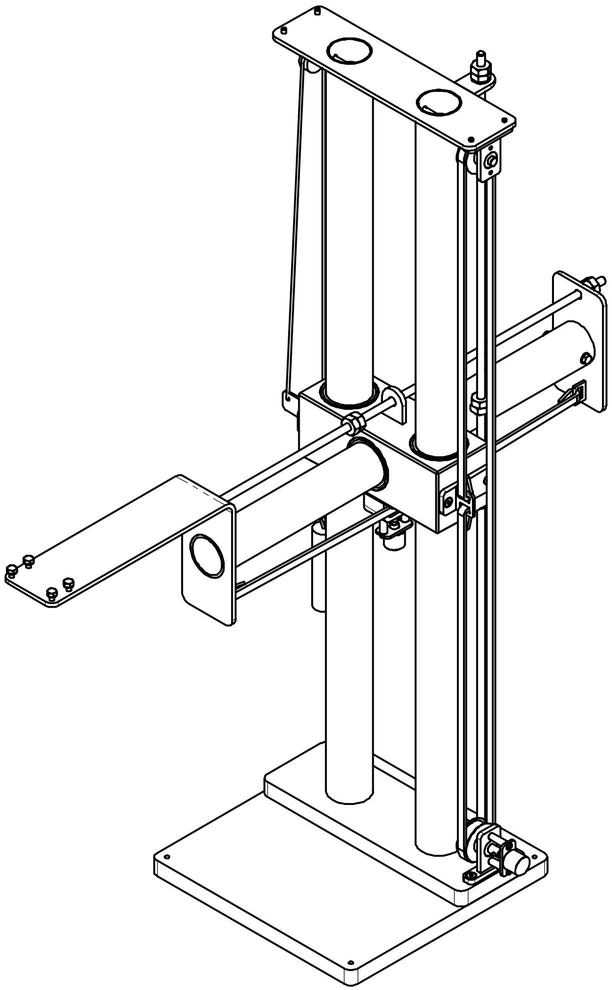
```
        Dim Buffer As String
        Try
            Buffer = serialPort.ReadLine()
            Me.BeginInvoke(New StringSubPointer(AddressOf Display),
serialPort.ReadLine())
        Catch ex As Exception
        End Try

    End Sub

    Public Delegate Sub StringSubPointer(ByVal Buffer As String)
    Public Sub Display(ByVal Buffer As String)
        Dim x_char_pos As Byte
        Dim y_char_pos As Byte
        Dim z_char_pos As Byte
        Dim h_char_pos As Byte
        Dim v_char_pos As Byte
        Dim num_chars As Byte
        'Determine length of string and positions of marker
characters
        num_chars = Buffer.Length
        x_char_pos = Buffer.IndexOf("x")
        y_char_pos = Buffer.IndexOf("y")
        z_char_pos = Buffer.IndexOf("z")
        h_char_pos = Buffer.IndexOf("h")
        v_char_pos = Buffer.IndexOf("v")
        'Check that the data string is valid
        If x_char_pos = 0 And (x_char_pos < y_char_pos < z_char_pos
< h_char_pos < v_char_pos) Then
            ReceiveData.Text = Buffer
            xPOT.Text = Buffer.Substring(x_char_pos + 1, y_char_pos
- x_char_pos - 1)
            yPOT.Text = Buffer.Substring(y_char_pos + 1, z_char_pos
- y_char_pos - 1)
            zPOT.Text = Buffer.Substring(z_char_pos + 1, h_char_pos
- z_char_pos - 1)
            hPOT.Text = Buffer.Substring(h_char_pos + 1, v_char_pos
- h_char_pos - 1)
            vPOT.Text = Buffer.Substring(v_char_pos + 1, num_chars -
v_char_pos - 1)
            MainApplication.Refresh()
        Else
            ReceiveData.Text = "ERROR"
        End If
    End Sub

    '   Private Sub Label5_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles Label5.Click '?????

    'End Sub
End Class
```

Appendix C DETAIL DRAWINGS

Appendix B contains the 2D details drawings of the part assemblies required for construction by the USQ Workshop. The drawings were created in Solidworks by the author and reflect the initial construction of the device. The drawings have been scaled down from A3 to fit in the appendices.

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY	TITLE
1	1	Base
2	1	Bearing Block
3	1	Horizontal Shaft
4	3	Linear Bearing
5	1	Top Bar
6	1	End Bar
7	2	Vertical Shaft
8	3	Timing Gear
9	1	Horizontal Pulley Holder
10	3	Ball Bearing
11	1	Horizontal Belt
12	2	Vertical Pulley Holder
13	1	Vertical Belt Holder
14	1	Vertical Belt
35	2	Potentiometer Pulley Shaft
16	1	Pulley Shaft
17	2	Potentiometer
18	2	Potentiometer Mounting Plate
19	4	Spacer Bar
20	12	M10 Nut
21	3	M6x60 HHB
22	3	M6 Nut
23	6	M6 Flat Washer
24	2	M12 Spring Washer
25	7	M6 Spring Washer
26	4	M6 x 10 HHB
27	14	M5 x 10 SHCS
28	8	M4 x 10 Button Head Screw
29	2	M4 Grub Screw
30	1	Vertical Cable Holder
31	1	Vertical Cable Pulley Holder
32	1	Cable Pulley
33	1	Weight Cable
34	1	Weight Block



ISOMETRIC ASSEMBLED VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. FINISH CODE: U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2µm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY, NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	B0	REPLACED ITS 7 & 10 WITH 27 & 32, ADDED ITS 13 TO 34	JMS	-	-	27/08/10	-
	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

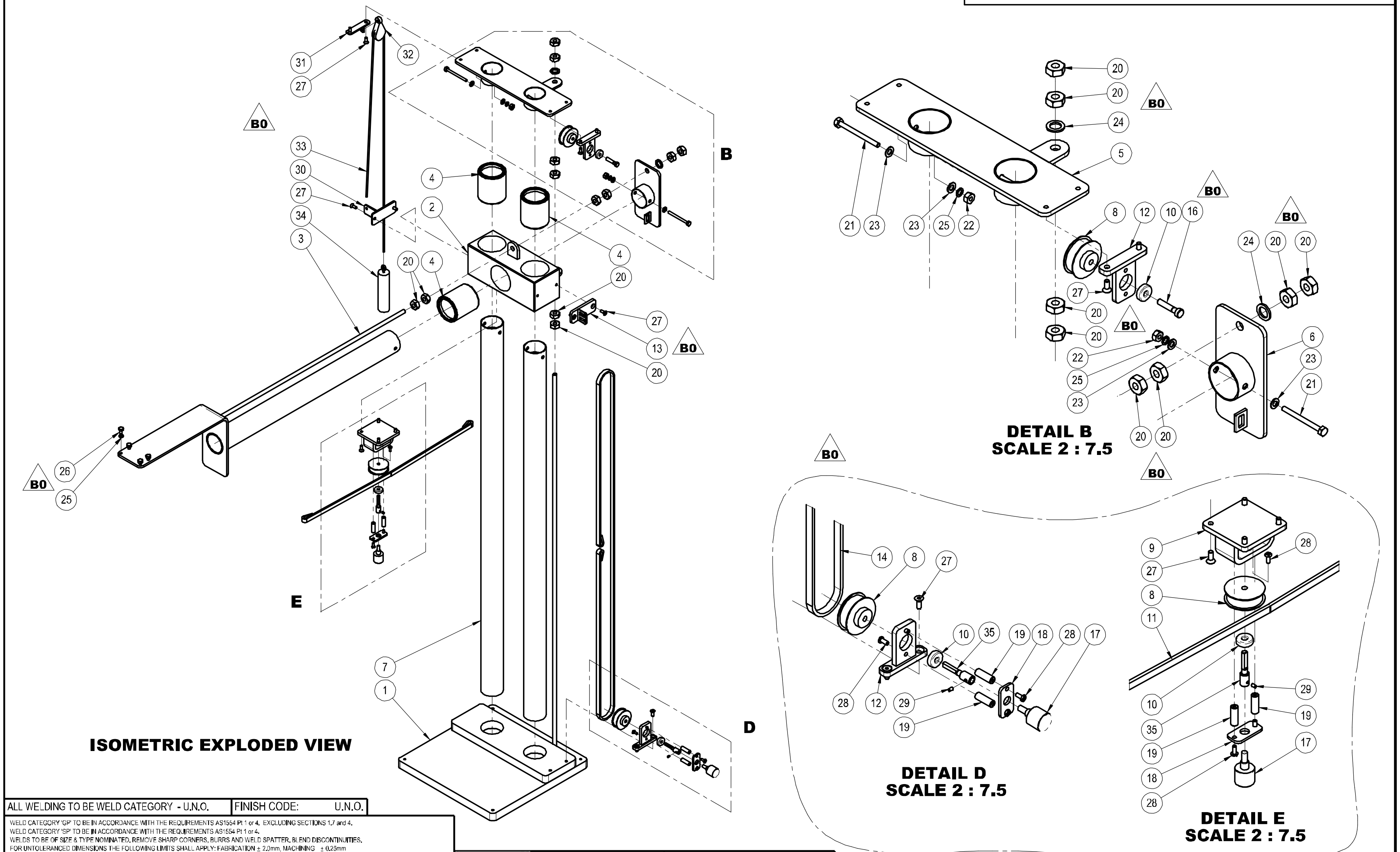
SCALE	1:5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Stroke Rehabilitation Device

SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Stroke Rehabilitation Device

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK



ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED, REMOVE SHARP CORNERS, BURRS AND WELD SPATTER, BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	B0	REPLACED ITS 7 & 10 WITH 27 & 32, ADDED ITS 13 TO 31	JMS	-	-	27/08/10	-
	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: kg

Russell Mineral Equipment Pty Ltd

DO NOT SCALE
IF IN DOUBT - ASK

STAMP POSITION SHOWN BY NOTE, AND CONTAINS PROJECT & PART NUMBER, 8mm HIGH

SCALE	1:5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Stroke Rehabilitation Device

SHEET 2 of 2

3rd ANGLE PROJECTION U.N.O. | A3

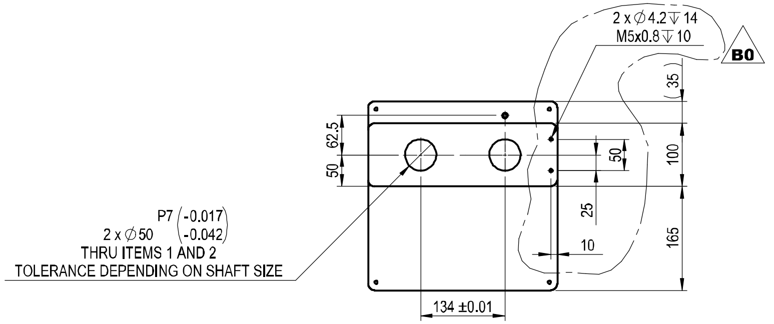
DRAWING STATUS
PRELIMINARY

RME Drawing Number | REV

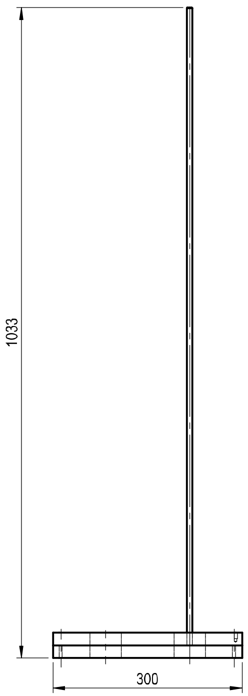
Stroke Rehabilitation Device

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

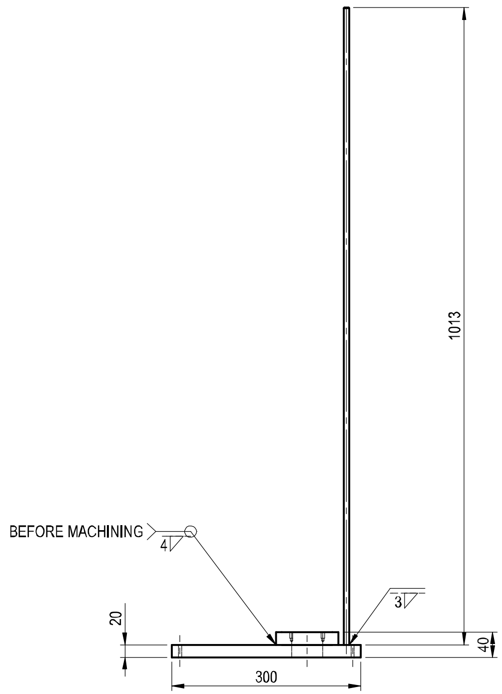
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 20mm ALUMINIUM	300 x 100
2	1	PLATE - 20mm ALUMINIUM	300 x 300
3	1	THREADED ROD - M10 STEEL	1013



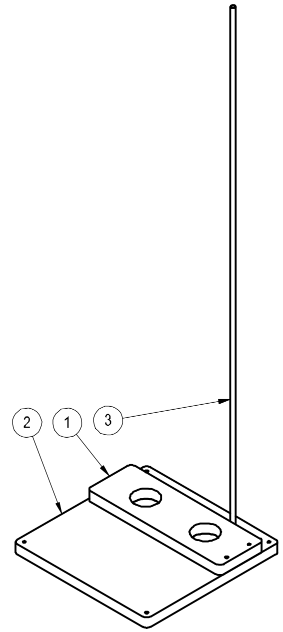
TOP VIEW



FRONT VIEW



SIDE VIEW



ISOMETRIC VIEW

ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 2 x M5 HOLES TO ITEM 1	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 18.1kg

**DO NOT SCALE
IF IN DOUBT - ASK**

Jake Salomon

USQ Toowoomba Campus

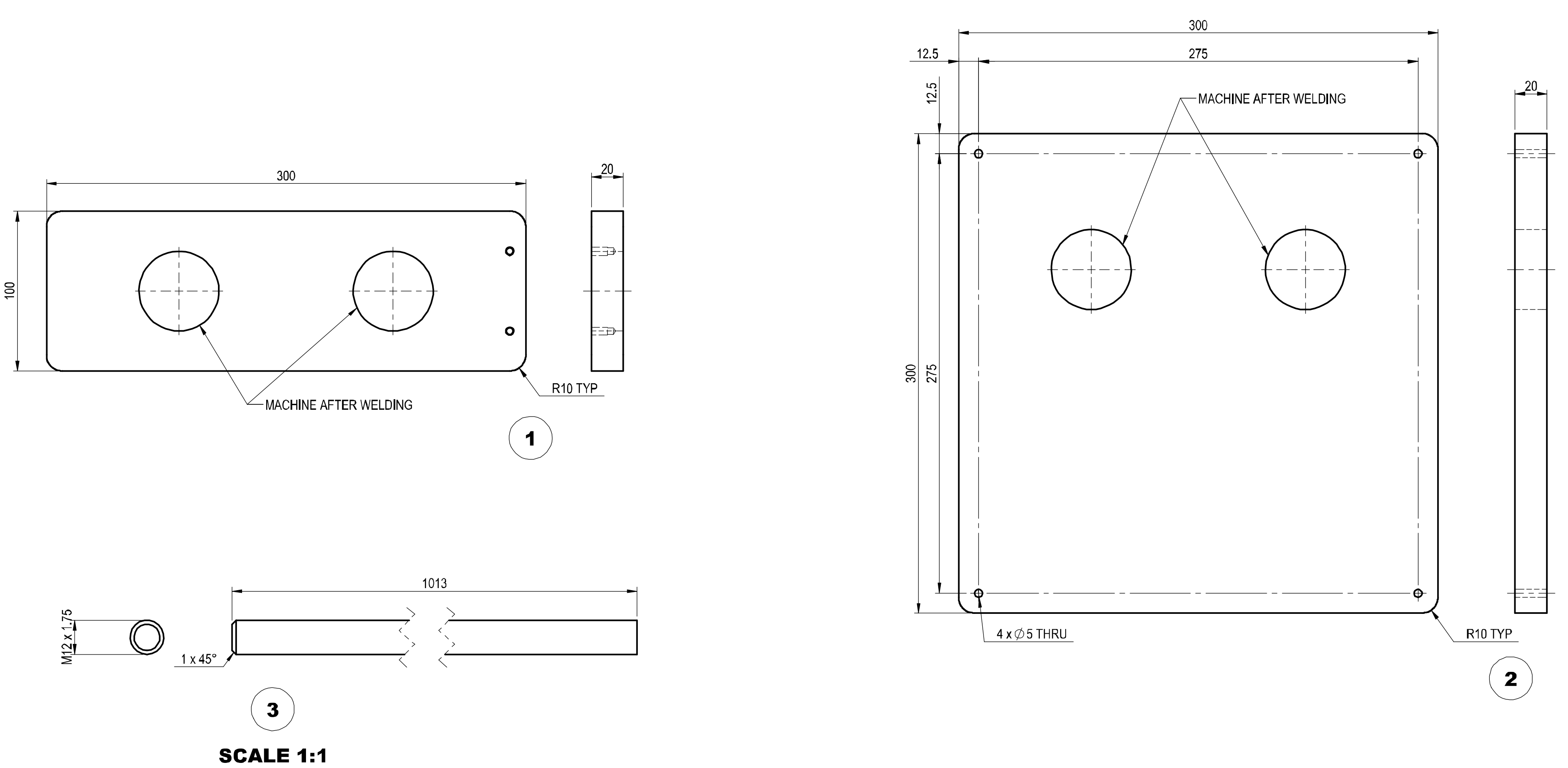
SCALE	1:7.5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Base

SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. | A3
DRAWING STATUS
PRELIMINARY
Drawing Number | REV
Base | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK



ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
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ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 2 x M5 HOLES T0 ITEM 1	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 18.1kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:2.5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Base

SHEET 2 of 2

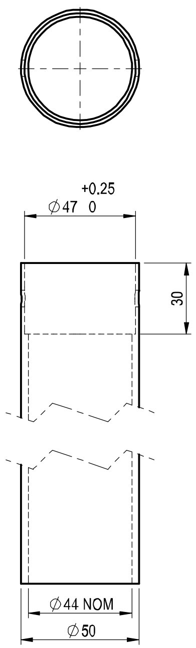
3rd ANGLE PROJECTION U.N.O. A3

DRAWING STATUS
PRELIMINARY

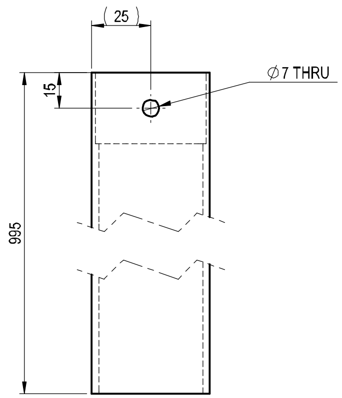
Drawing Number: **Base** REV: P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

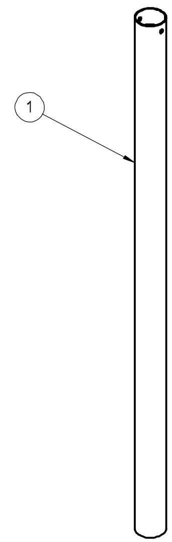
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PIPE - 50mm OD x 3mm ALUMINIUM	995



FRONT VIEW



SIDE VIEW



ISOMETRIC VIEW
SCALE 1:7.5

ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 3.4kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:7.5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

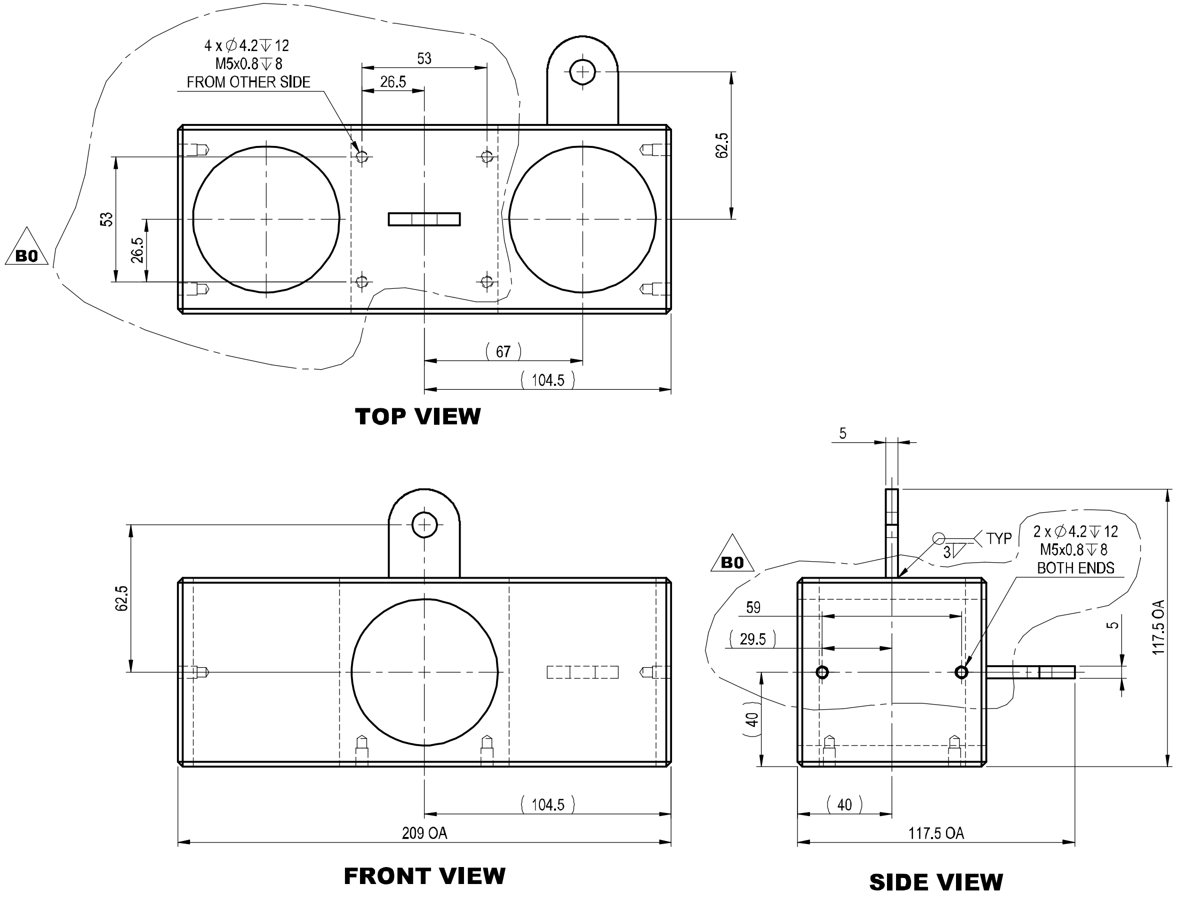
Vertical Shaft

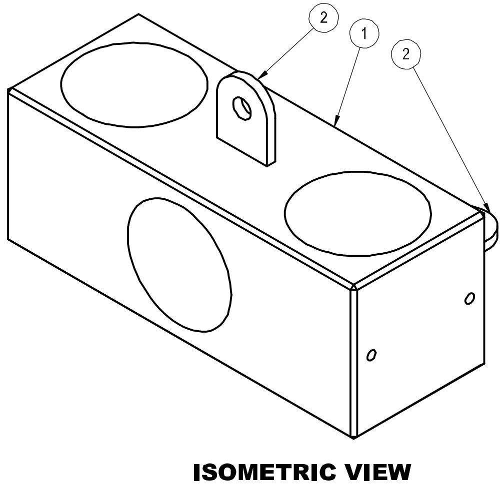
SHEET 1 of 1

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Vertical Shaft P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	SQUARE BAR - 80mm x 80mm ALUMINIUM	209
2	2	PLATE - 5mm ALUMINIUM	37.5 x 30





ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
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ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY, NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 8 x M5 HOLES	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 4.9kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

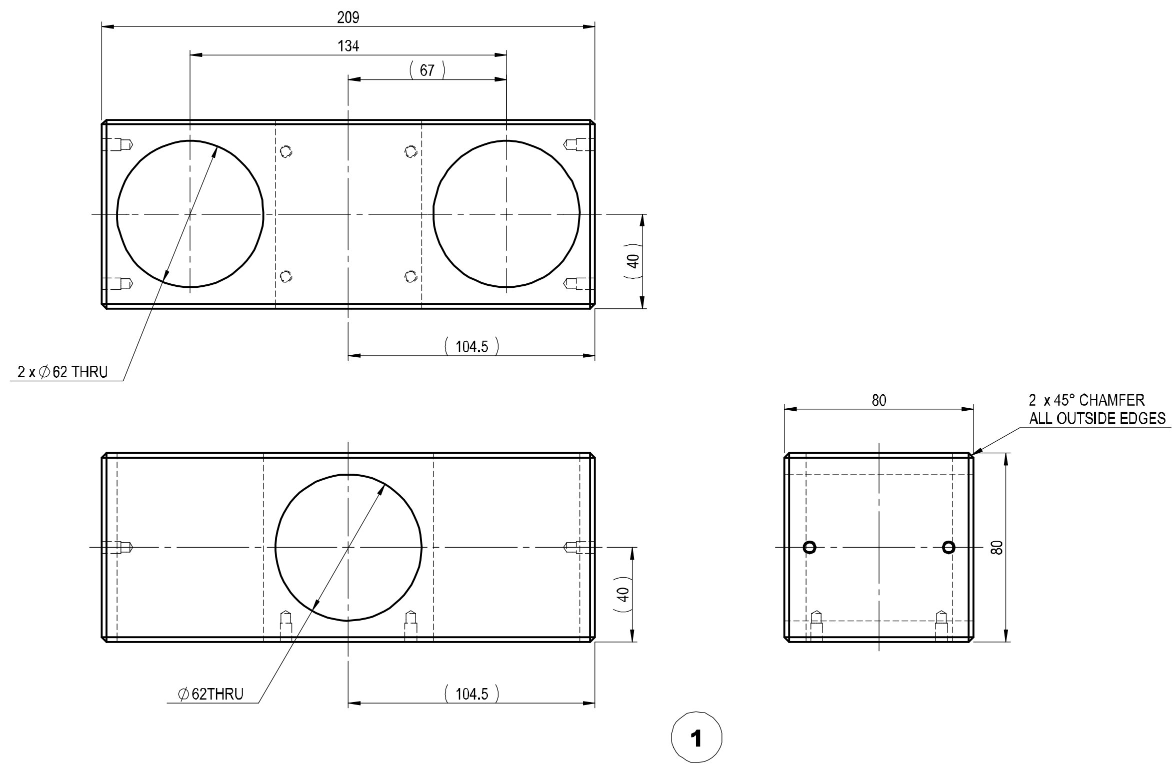
SCALE	1:2 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

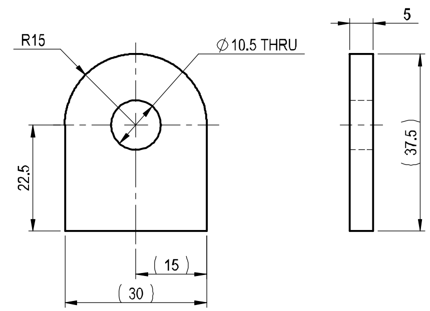
Bearing Block

SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. | A3
DRAWING STATUS
PRELIMINARY
Drawing Number | REV
Bearing Block | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK





SCALE 1:1

ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY, NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 8 x M5 HOLES	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 4.9kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:2 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Bearing Block

SHEET 2 of 2

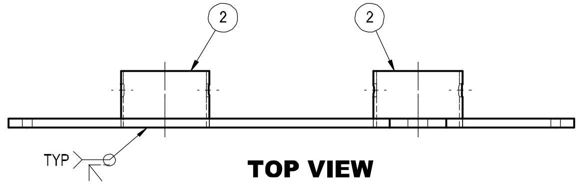
3rd ANGLE PROJECTION U.N.O. | A3

DRAWING STATUS
PRELIMINARY

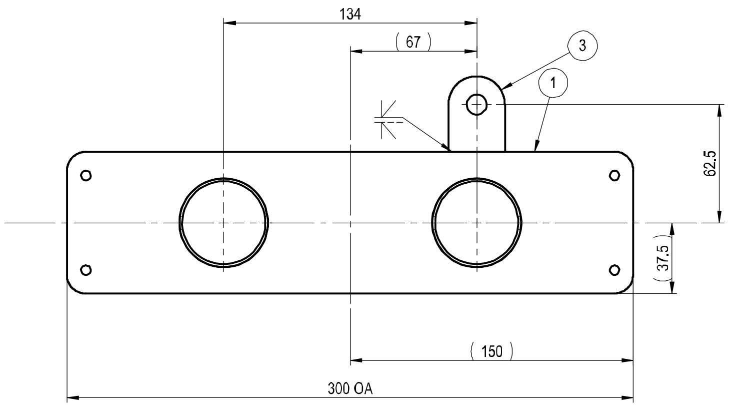
Drawing Number | REV
Bearing Block | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

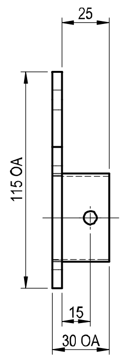
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 5mm ALUMINIUM	300 x 75
2	2	PIPE - 50 x 3mm WALL ALUMINIUM	30
3	1	PLATE - 5mm ALUMINIUM	40 x 30



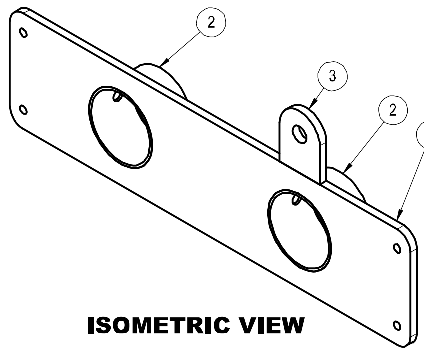
TOP VIEW



FRONT VIEW



SIDE VIEW



ISOMETRIC VIEW

ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 4 x M5 HOLES TO ITEM 1	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.9kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:2.5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Top Bar

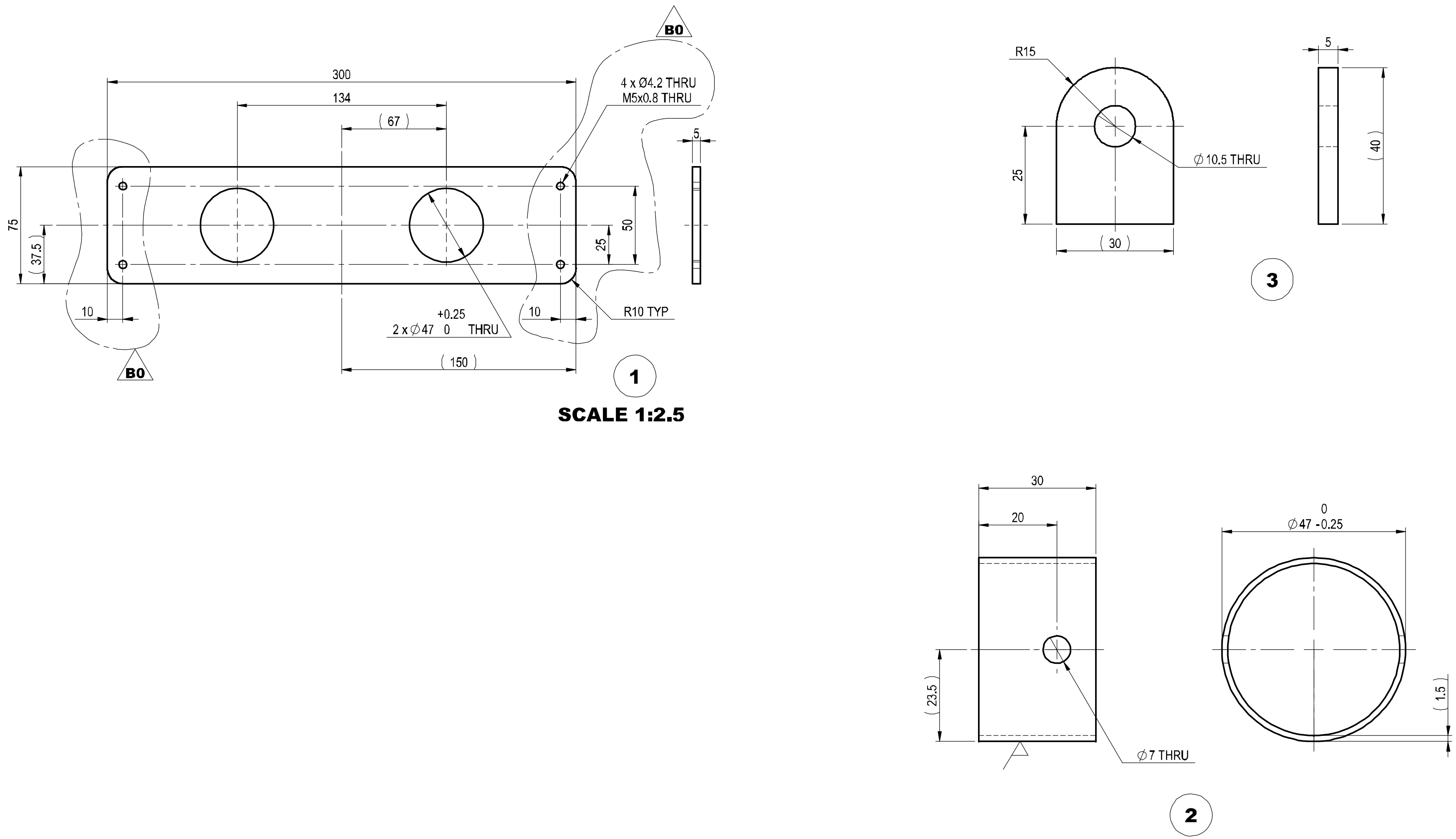
SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. | A3

DRAWING STATUS
PRELIMINARY

Drawing Number: **Top Bar** | REV: P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK



ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED 4 x M5 HOLES TO ITEM 1	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.9kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Top Bar

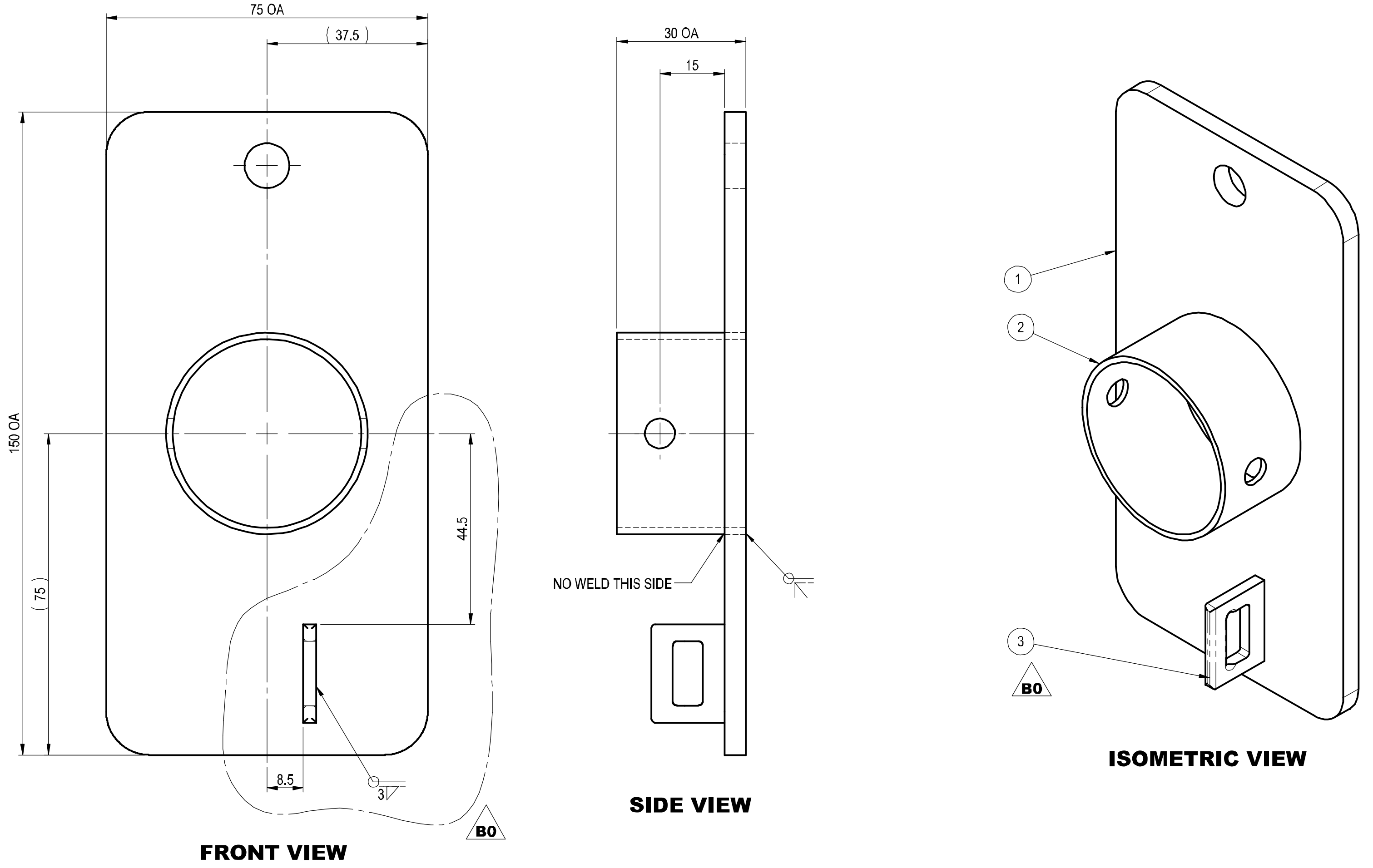
SHEET 2 of 2

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Top Bar P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 5mm ALUMINIUM	150 x 75
2	1	PIPE - 50 x 3mm WALL ALUMINIUM	30
3	1	PLATE - 3mm ALUMINIUM	23 x 17

B0



ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED ITEM 3	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.4kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

End Bar

SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. | A3

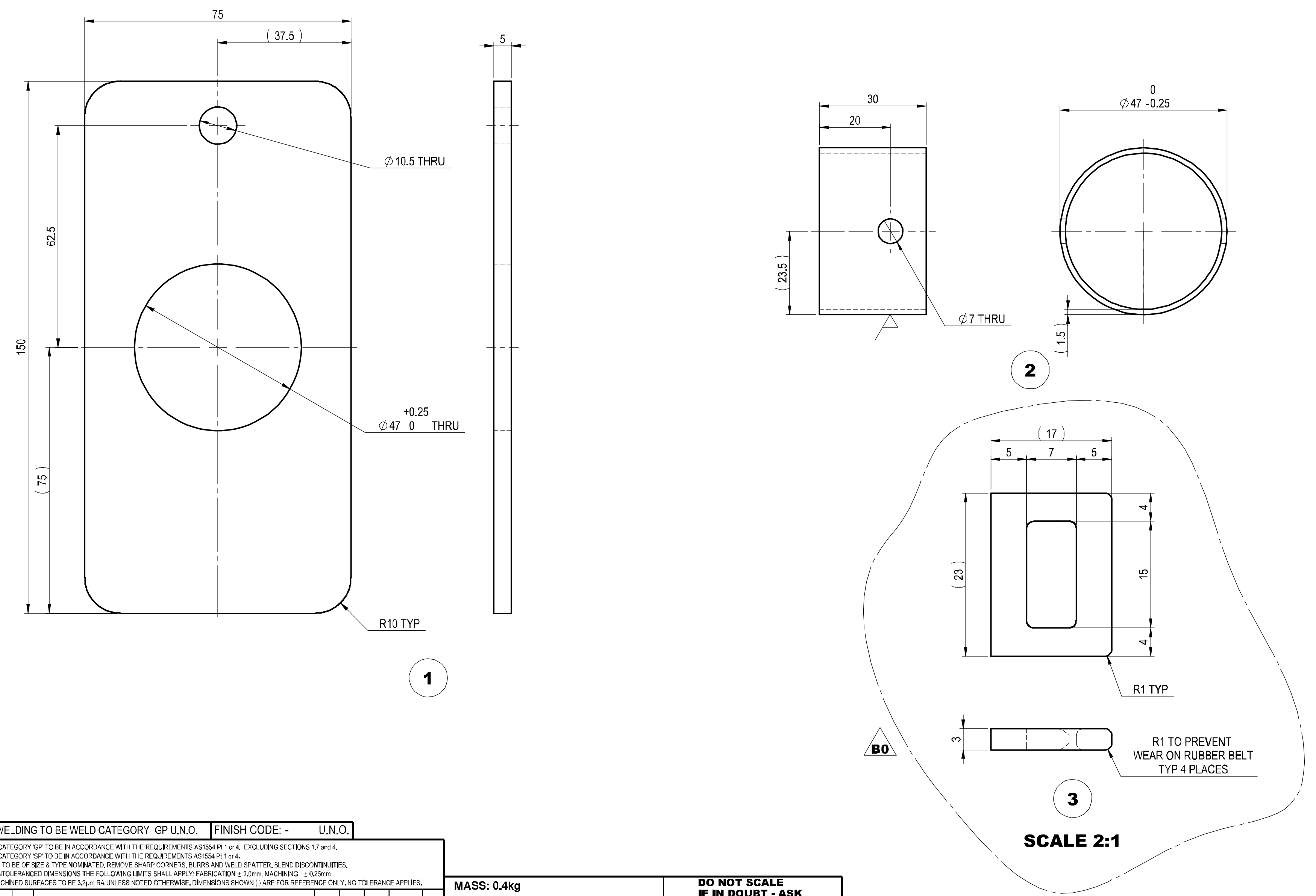
DRAWING STATUS

PRELIMINARY

Drawing Number | REV

End Bar | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK



ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED ITEM 3	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.4kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

End Bar

SHEET 2 of 2

3rd ANGLE PROJECTION U.N.O. | A3

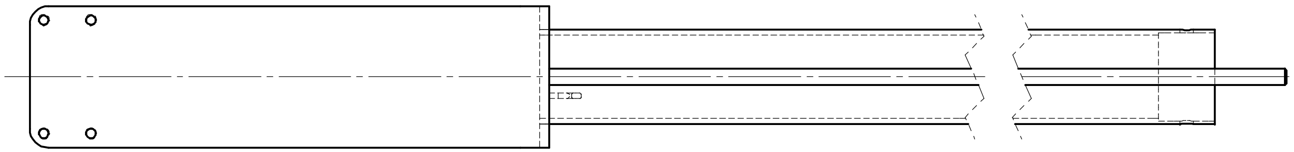
DRAWING STATUS
PRELIMINARY

Drawing Number | REV
End Bar | P9

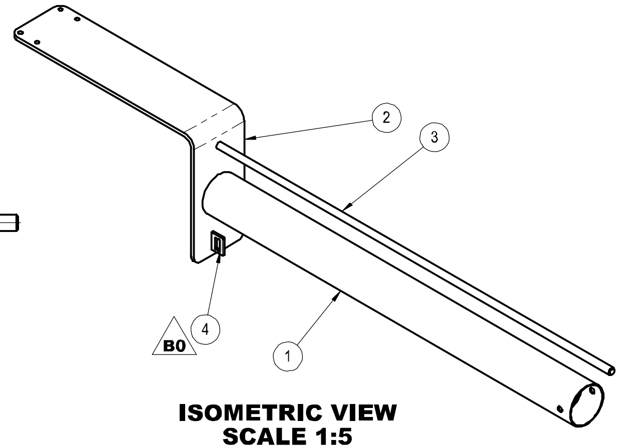
NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PIPE - 50mm OD x 3mm ALUMINIUM	555
2	1	PLATE - 5mm ALUMINIUM	-
3	1	THREADED ROD - M10 STEEL	588
4	1	PLATE - 3mm ALUMINIUM	23 x 17

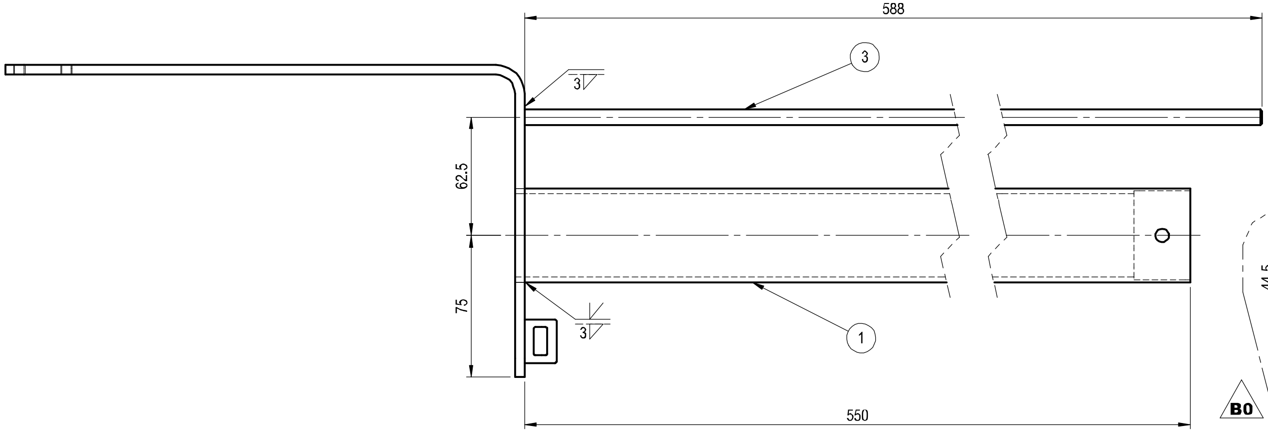
B0



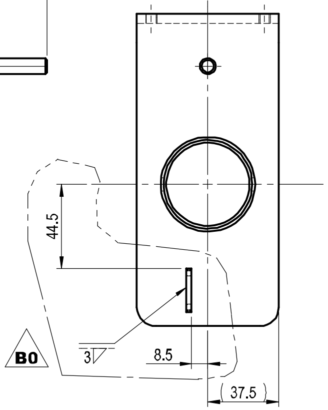
TOP VIEW



ISOMETRIC VIEW
SCALE 1:5



FRONT VIEW



SIDE VIEW

ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED ITEM 4	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 3.3kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:2.5 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

Horizontal Shaft

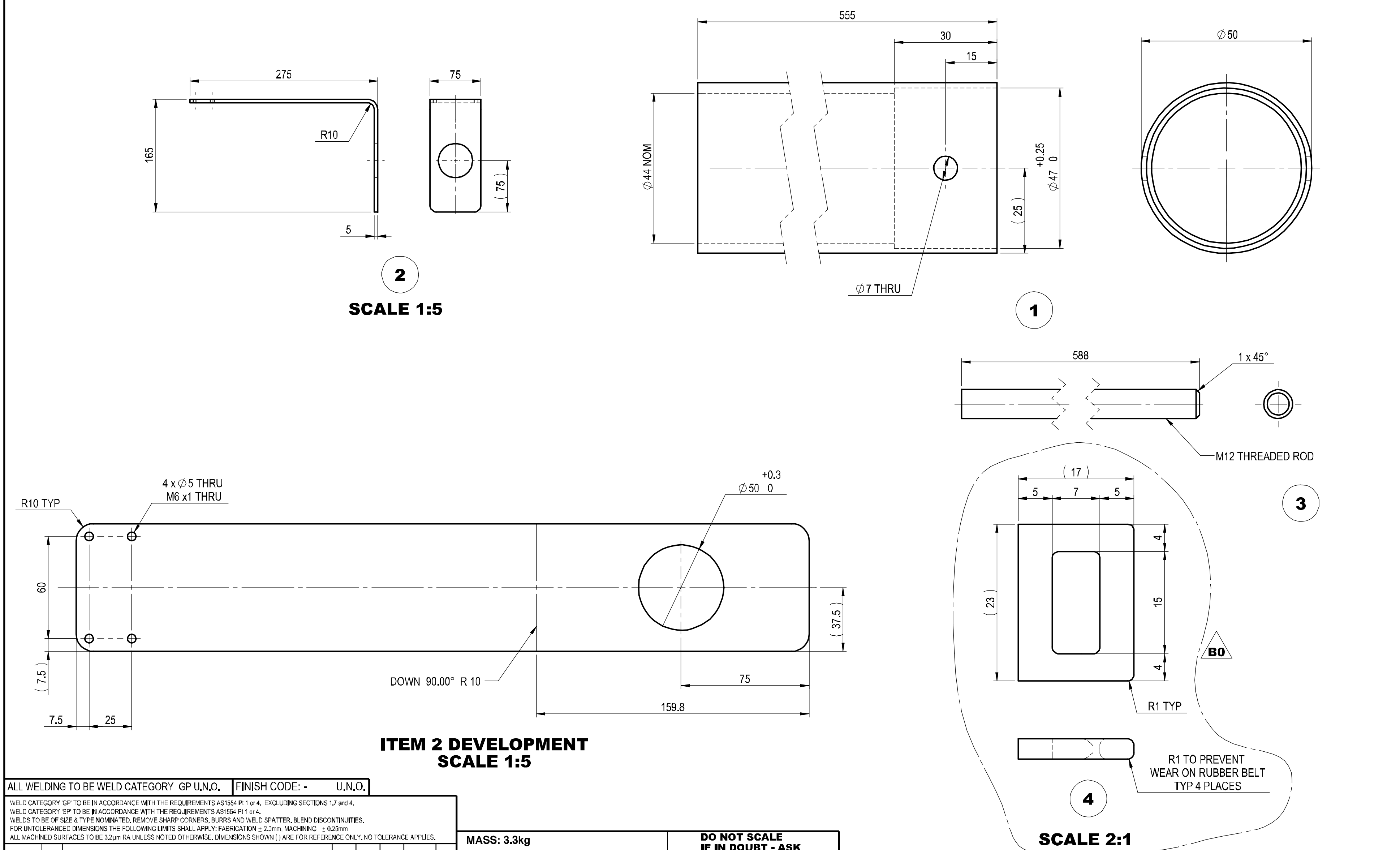
SHEET 1 of 2

3rd ANGLE PROJECTION U.N.O. | A3

DRAWING STATUS
PRELIMINARY

Drawing Number | REV
Horizontal Shaft | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK



ALL WELDING TO BE WELD CATEGORY GP U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED, REMOVE SHARP CORNERS, BURRS AND WELD SPATTER, BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2,0mm, MACHINING ± 0,25mm
ALL MACHINED SURFACES TO BE 3,2µm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY, NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED ITEM 4	JMS	-	-	27/08/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 3.3kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	09/06/10
DRAWN	JMS	09/06/10
CHECK	-	-
APP'D	-	-

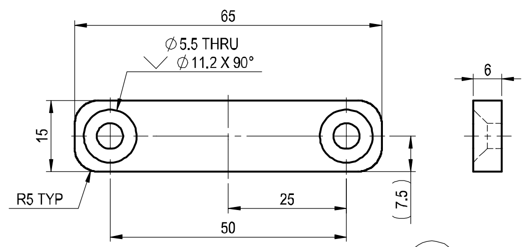
Horizontal Shaft

SHEET 2 of 2

3rd ANGLE PROJECTION U.N.O. | A3
DRAWING STATUS
PRELIMINARY
Drawing Number | REV
Horizontal Shaft | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 6mm ALUMINIUM	65 x 15
2	1	PLATE - 6mm ALUMINIUM	48 x 30



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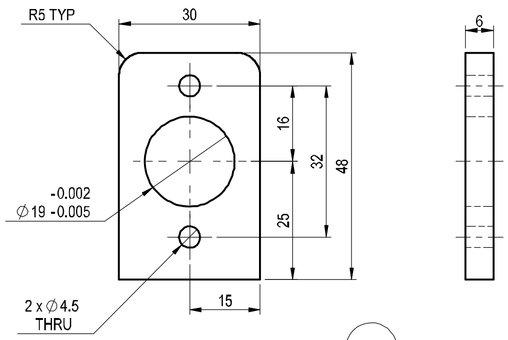
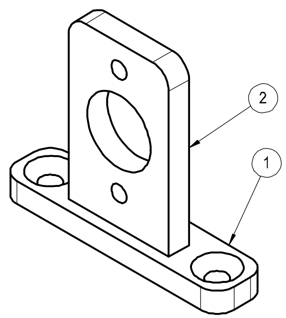
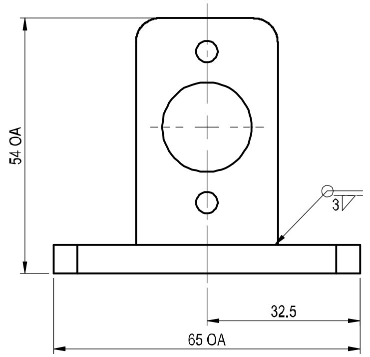


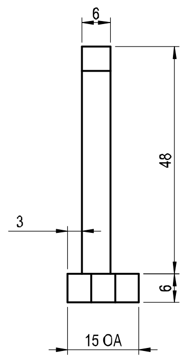
2



ISOMETRIC VIEW



FRONT VIEW



SIDE VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
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ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.1kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

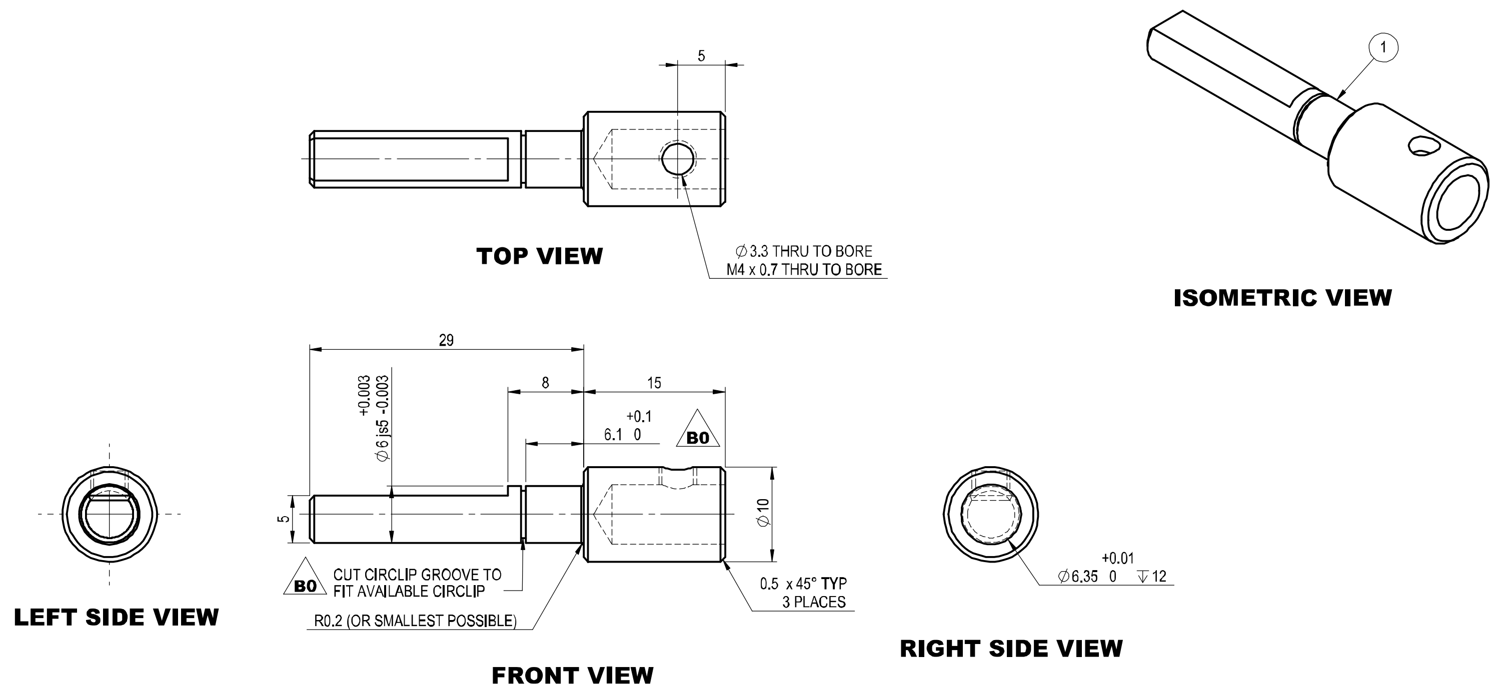
Vertical Pulley Holder

SHEET 1 of 1

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Vertical Pulley Holder

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	BAR - RND Ø10 STAINLESS STEEL	44



ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED CIRCLIP GROOVE	JMS	-	-	06/09/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.0kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	2:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

Potentiometer Pulley Shaft

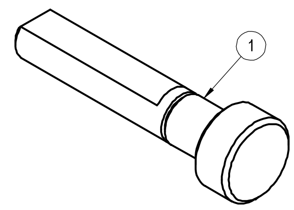
SHEET 1 of 1

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV

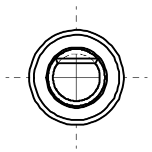
Potentiometer Pulley Shaft

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

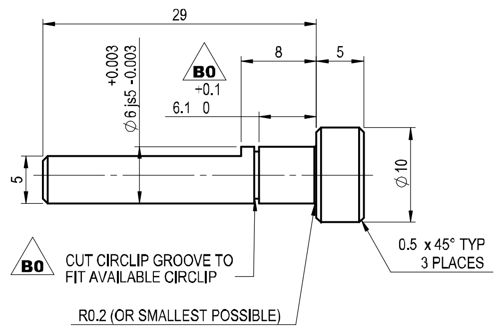
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	BAR - RND Ø10 STAINLESS STEEL	34



ISOMETRIC VIEW



SIDE VIEW



FRONT VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	B0	ADDED CIRCLIP GROOVE	JMS	-	-	06/09/10	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.0kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	2:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

Pulley Shaft

SHEET 1 of 1

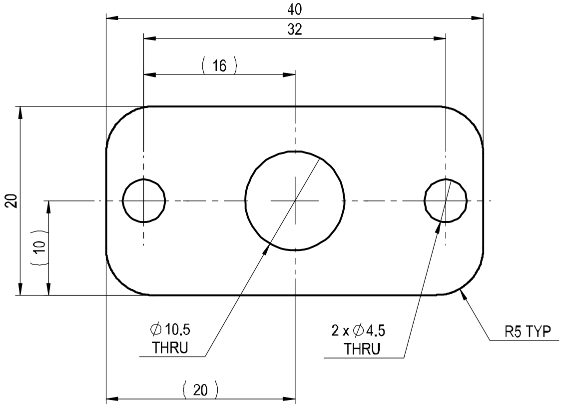
3rd ANGLE PROJECTION U.N.O. | A3

DRAWING STATUS
PRELIMINARY

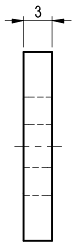
Drawing Number | REV
Pulley Shaft | P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

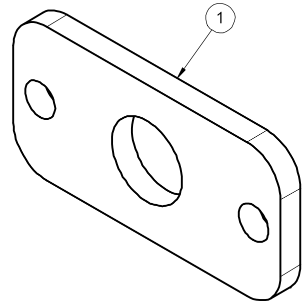
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 3 ALUMINIUM	40 x 20



FRONT VIEW



SIDE VIEW



ISOMETRIC VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.0kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	2:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

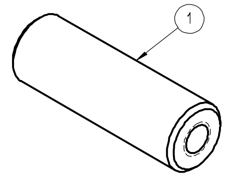
Potentiometer Mounting Plate

SHEET 1 of 1

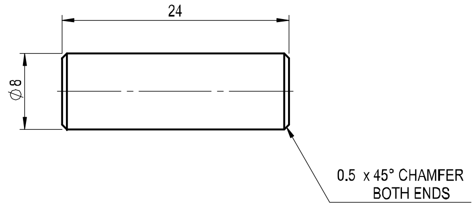
3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Potentiometer Mounting Plate

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

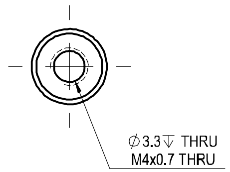
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	BAR - Ø8 RND STAINLESS STEEL	-



ISOMETRIC VIEW



FRONT VIEW



SIDE VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.0kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	2:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

Spacer Bar

SHEET 1 of 1

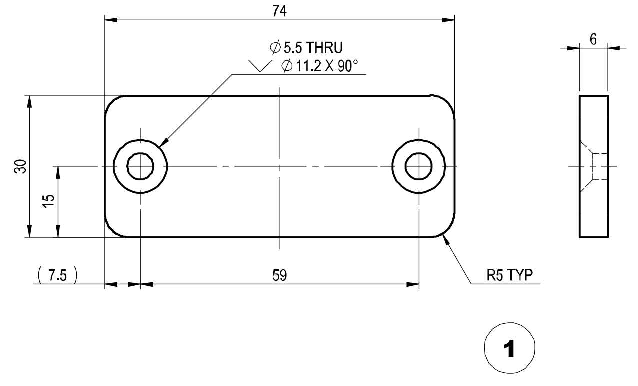
3rd ANGLE PROJECTION U.N.O. | A3

DRAWING STATUS
PRELIMINARY

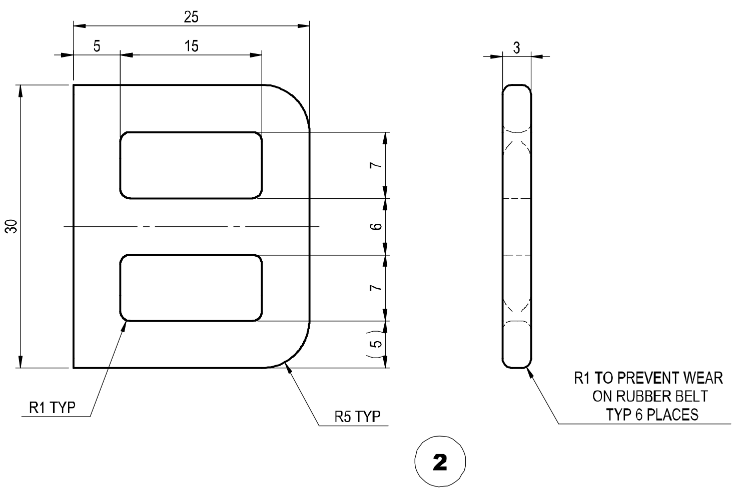
Drawing Number	REV
Spacer Bar	P9

NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

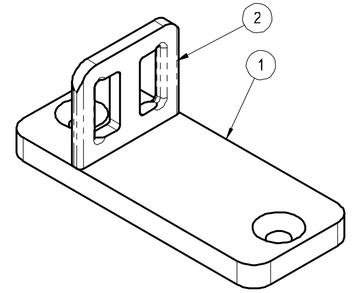
ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 6mm ALUMINIUM	74 x 30
2	1	PLATE - 3mm ALUMINIUM	30 x 25



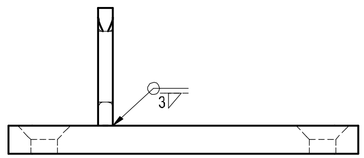
1



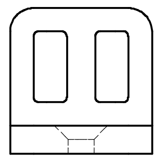
2



ISOMETRIC VIEW



FRONT VIEW



SIDE VIEW

ALL WELDING TO BE WELD CATEGORY - U.N.O. | FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
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E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.1kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

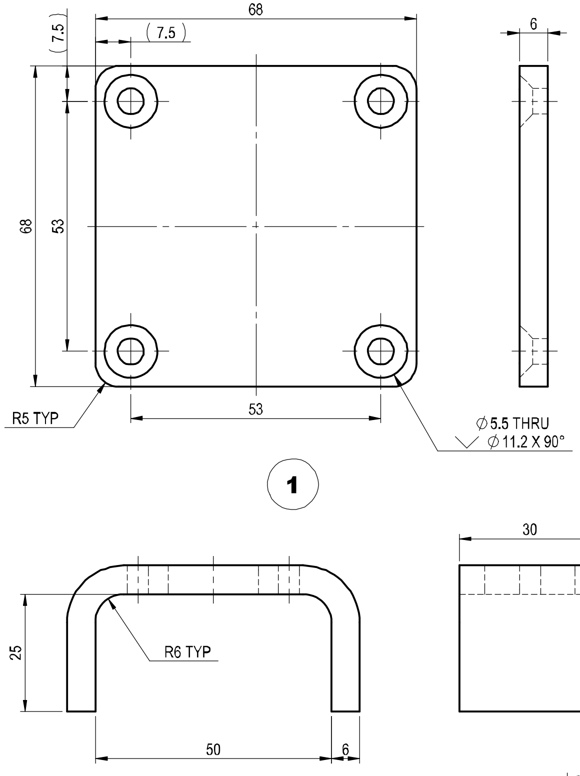
Vertical Belt Holder

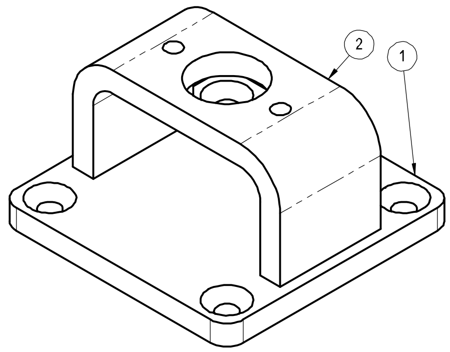
SHEET 1 of 1

3rd ANGLE PROJECTION U.N.O. | A3
DRAWING STATUS
PRELIMINARY
Drawing Number | REV
Vertical Belt Holder | P9

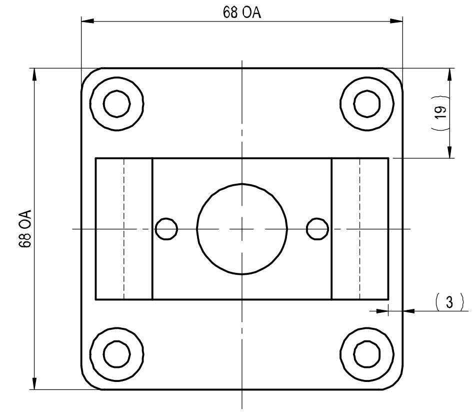
NOTE: WHERE ITEM LIST AND DRAWING CONFLICT, DRAWING SHALL BE TAKEN AS CORRECT.
FABRICATORS USING ITEM LIST AS CUTTING LIST WITHOUT REFERRING TO DRAWING DO SO AT THEIR OWN RISK

ITEM NO.	QTY.	DESCRIPTION	SIZE
1	1	PLATE - 6mm ALUMINIUM	68 x 68
2	1	PLATE - 6mm ALUMINIUM	104 x 30

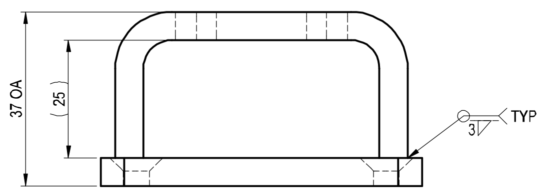




ISOMETRIC VIEW

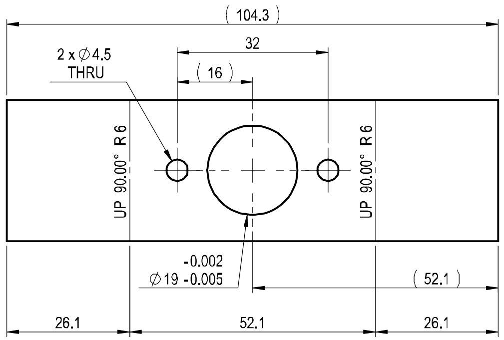


TOP VIEW



FRONT VIEW

2



ITEM 2 DEVELOPMENT

ALL WELDING TO BE WELD CATEGORY - U.N.O.	FINISH CODE: - U.N.O.

WELD CATEGORY 'GP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4. EXCLUDING SECTIONS 1.7 and 4.
WELD CATEGORY 'SP' TO BE IN ACCORDANCE WITH THE REQUIREMENTS AS1554 Pt 1 or 4.
WELDS TO BE OF SIZE & TYPE NOMINATED. REMOVE SHARP CORNERS, BURRS AND WELD SPATTER. BLEND DISCONTINUITIES.
FOR UNTOLERANCED DIMENSIONS THE FOLLOWING LIMITS SHALL APPLY: FABRICATION ± 2.0mm, MACHINING ± 0.25mm
ALL MACHINED SURFACES TO BE 3.2μm RA UNLESS NOTED OTHERWISE. DIMENSIONS SHOWN ( ) ARE FOR REFERENCE ONLY. NO TOLERANCE APPLIES.

E.C.N. No.	No.	Description	DWN	CHK	APPD	DATE	Rev. Code
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	A0	APPROVED FOR CONSTRUCTION	As per Approvals				

MASS: 0.3kg

DO NOT SCALE
IF IN DOUBT - ASK

Jake Salomon

USQ Toowoomba Campus

SCALE	1:1 UNO	
DESIGN	JMS	27/08/10
DRAWN	JMS	27/08/10
CHECK	-	-
APP'D	-	-

Horizontal Pulley Holder

SHEET 1 of 1

3rd ANGLE PROJECTION U.N.O. A3
DRAWING STATUS
PRELIMINARY
Drawing Number REV
Horizontal Pulley Holder