UNIVERSITY OF SOUTHERN QUEENSLAND

Remotely Operated Telepresent Robotics

A Dissertation submitted by

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Abstract

Remotely operated robots with the ability of performing specific tasks are often used in hazardous environments in place of humans to prevent injury or death. Modern remotely operated robots suffer from limitations with accuracy which is primarily due the lack of depth perception and unintuitive hardware controls. The undertaken research project suggests an alternative method of vision and control to increase a user's operational performance of remotely controlled robotics.

The Oculus Rift Development Kit 2.0 is a low cost device originally developed for the electronic entertainment industry which allows users to experience virtual reality by the use of a head mounted display. This technology is able to be adapted to different uses and is primarily utilised to achieve real world stereoscopic 3D vision for the user.

Additionally a wearable controller was trialled with the goal of allowing a robotic arm to mimic the position of the user's arm via a master/slave setup. By incorporating the stated vision and control methods, any possible improvements in the accuracy and speed for users was investigated through experimentation and a conducted study.

Results indicated that using the Oculus Rift for stereoscopic vision improved upon the user's ability to judge distances remotely but was detrimental to the user's ability to operate the robot.

The research has been conducted under the supervision of the University of Southern Queensland (USQ) and provides useful information towards the area of remotely operated telepresent robotics.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/2 *Research Project*

Limitations of Use

Certification

I certify that the ideas, designs, and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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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Jarrad Gleeson
University of Southern Queensland
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Chapter 1

Introduction

Engineers in the field of automation and robotics have developed many devices with the aim of performing tasks on behalf of people in environments that are considered hazardous to humans. This range of robotics use extends from applications such as deep sea and space welding to bomb and land mine disposal operations. Many of these robots and machines rely on control methods such as joysticks, buttons and traditional video telemetry to be operated and interact with the real world.

The final year research project investigates stereoscopic vision and alternative control methods to determine if user interaction and operation of remotely controlled robotics can be improved. The project scope includes the design, construction and operation of such a device termed as a “remotely operated telepresent robot”. The robot itself includes a platform with a robotic arm and two cameras mounted on a gimbal to achieve a sense of depth perception for the user when operated remotely.

A study to investigate whether there are any benefits to incorporating these features into current tele-operated robotics has been conducted following the construction of the robot. It compares the factors of accuracy, speed and ease of use of the telepresent features against more traditional telepresence methods.

1.1 Objectives

The objectives in order that the project aimed to achieve through research and implementation were:

1. An increase in accuracy for remotely controlled robotic limbs through improved vision for the user by implementing depth perception and directed camera movement. The device used to investigate this was the Oculus Rift Development Kit 2.0.

2. The development of a wearable control apparatus worn on the user's arm to control a robotic arm which can mimic the position of the users arm. This focuses on reducing the learning curve for a user by providing a more natural control method.

3. Compare the proposed research project vision and control methods against traditional methods in terms of speed, accuracy and usability for multiple users to determine if user operation can be improved through the implementation of newly developed technologies.

4. Construct or utilise a mobile platform for the robotic arm to increase the functionality and reach of the robot affecting the type of tasks it may perform

1.2 Expected Outcomes

The project has been designed to utilise newly developed technologies (Oculus Rift DK2.0) in the field of robotics as well as the design and construction of a wearable form of controller to mimic that of human movement. As limited research has been conducted into this area, this study will provide useful information in regards to speed, accuracy and usability for multiple users to determine if there can be an improvement in regards to user operation.

The expected outcomes at the conclusion of the project include:

- The development of a new remotely controlled telepresent robot
- Detailed information on whether the Oculus Rift can provide an advantage over normal camera-monitor combination for users
- Detailed information on whether a wearable control apparatus can provide an advantage over joystick and button for users
- How easily this technology is can be adapted into robotics

As a whole, the information above should provide a technical benefit to any future research, development or implementation in regards to remotely controlled telepresent robotics.

Chapter 2

Literature Review

This section contains the relevant information in regards to remotely controlled tele-present robotics. More specifically the topics of literature reviewed include:

- The general types, features and uses of remotely operated robotics
- Current robotic control and vision methods
- The Oculus Rift Development Kit 2.0
- OVRVision Pro Stereo Camera
- Testing/ Experimentation
- The Human Depth Perception

2.1 General Types and Uses of Tele-operated Robotics and Remotely Operate Vehicles

The field of Tele-operated robotics has been a heavily focused area in the fields of Mechanical, Mechatronic and Electrical Engineering for decades, improving the performance capabilities of remotely controlled robotics in particular. The main objective for advancement has been to develop methods which eliminate the need for an individual to be directly present to perform a task for either safety or just general convenience. Today's most common application of tele-operated robots or remotely operated vehicles (ROVs) perform tasks involving patient care, explosive ordnance disposal (EOD) and hazardous environment operations (Wojtara et al., 2005),(Launius & McCurdy, 2007), (van Osch, Bera, van Hee, Koks, & Zeegers, 2014).

There is a great need for devices which can perform the task of safe EOD either autonomously or by user operation. The removal of landmines has become a global emergency with over 100 million landmines still actively placed in the ground worldwide. As a result, the loss of over 20 thousand lives occurs every year with the vast majority being civilians. (Portugal, Cabrita, Gouveia, Santos, & Prado, 2015)**,** (Wojtara et al., 2005),(Albert, Mason, Kiing, Ee, & Chan, 2014)

The research and development of robotic solutions has had the ultimate goal of safeguarding lives by keeping humans away from the threat while increasing the clearance speed in a cost-effective manner (Portugal, Cabrita, Gouveia, Santos, & Prado, 2015). These robotic solutions include features of intuitive human-machine interfaces with real-time interaction and the possibility to remotely control the robot within safe distances while maintaining portability (Portugal, Cabrita, Gouveia, Santos, & Prado, 2015). **Figures 2** and **3** depict commonly used EOD robots which are operational in the field today.

Figure 1: *The FSR Husky demining robot*

Figure 2: *Northrop Grunman HD-1*

Source: (Portugal, Cabrita, Gouveia, Santos, & Prado, 2015)

Exploring under water environments is dangerous and impractical for humans and even more so when a task requires precision or extended periods of time to complete. ROVs (remotely operated vehicles) are an area of particular interest in regards to underwater hazardous environments (Azis, Aras, Rashid, Othman, & Abdullah, 2012). A sub-surface ROV can be more generally described as a tethered unmanned underwater robot which and are used extensively in deep-water applications such as oil and gas exploration, telecommunications and geotechnical investigations and mineral exploration. They commonly feature several dextrous manipulators, TV's, video cameras and tools (Azis, Aras, Rashid, Othman, & Abdullah, 2012). An operational underwater ROV can be seen in **Figure 4** below.

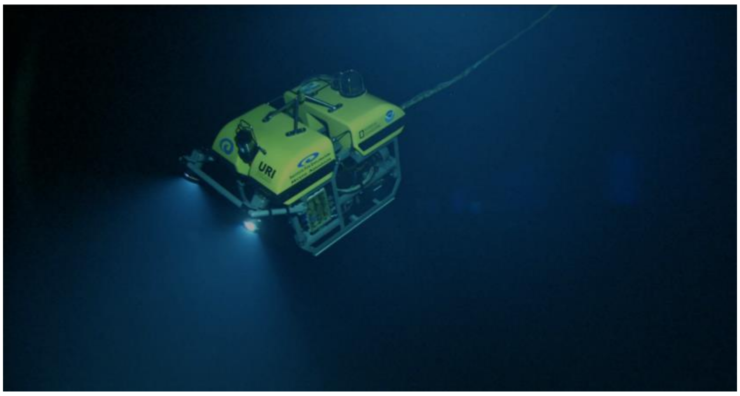


Figure 3: *Little Hercules*
(Source: Ocean Explorer, 2015)

Not all tele-operated robots are designed with the specific intent of operating in environments which would be considered dangerous to humans. Healthcare and Medical applications are another key driving force behind research into the advancements in user operated robotics. Currently automated robotics can only deal with very specific tasks in very specific situations. Researchers such as van Osch, Bera, van Hee, Koks, & Zeegers, 2014 believe that for robots to be made applicable in domestic environments in the near future, human operators must stay in the loop. This belief is due to technology still not able to prevent a robot from being cornered or stuck. A manual form of control is required to help the robot continue on its way. Robots such as those created by van Osch, Bera, van Hee, Koks, & Zeegers, 2014 are utilised to assist the elderly and disabled. This class of robots has been termed as Tele-operated Service Robots (TSRs) and are described as robots which are controlled by a human being from a distance which perform tasks that are typically in an uncontrolled environment.

The robot ROSE has been developed (van Osch, Bera, van Hee, Koks, & Zeegers, 2014) to combat the increase in the population of the elderly and the reduction in the working population. Today there are not enough people who are available to take care of the elderly. The Elderly and the physically disabled mostly want to stay at home and maintain their independence for as long as possible. (van Osch, Bera, van Hee, Koks, & Zeegers, 2014)

Robots such as ROSE find their application in the simplest tasks which care givers must do frequently and are often deemed as the most cumbersome. These tasks for instance include opening curtains, preparing food, doing dishes and posting letters. To achieve this, robots may either operate autonomously or be controlled manually. Manual control involves the use of a joystick to control both the arm and the main platform (van Osch, Bera, van Hee, Koks, & Zeegers, 2014). **Figures 5** and **6** depict a TSR and their function.

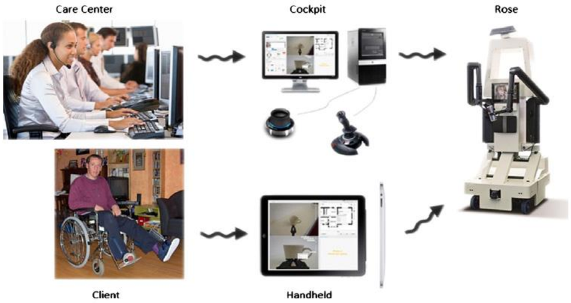


Figure 4: *Rose Setup*

(Source: van Osch, Bera, van Hee, Koks, & Zeegers, 2014)

Figure 5: *Health Care Robots*

2.2 Control Methods

2.2.1 Traditional Robotic Controls

A common control interface for machinery and robotics is the joystick. It was originally created by Robert Esnault-Pelterie for aviation purposes (Naughton, R, 2002). Modern day joysticks operate by the use of 2 potentiometers, one measuring the x-position and the other measuring the y-position (a two-dimensional joystick) (Jain, 2012). These positions of the potentiometers are read as voltages by analogue to digital converters (ADC) often embedded in microprocessors (More Process, 2012). These digital values may be used by a microprocessor to perform a number of functions such as controlling the speed of a motor, the steering of a vehicle or a control input for video games.

2.2.2 Experimental Controls

The use of human mimicking controls has been experimented with in the hopes of allowing humans to control robots more accurately or allow robots greater motor control in general. A great deal of research has been conducted in this area with most utilising electric motors to control the finger joints while others such as the five-finger shadow hand have been developed to operate by pneumatic means (Wojtara et al., 2005). The controls operate as a system which is known as a master/slave setup. The master refers to the operator's control device that typically involves a wearable glove, which as the operator moves their hand; the glove itself measures the position data and sends it to the slave device (robotic hand). The slave device then uses the position data to orientate itself to mimic the hand’s position. Wojtara et al., 2005, claim that using the human hand as a master gives the operator an intuitive and easy to learn way to control the slave hand.

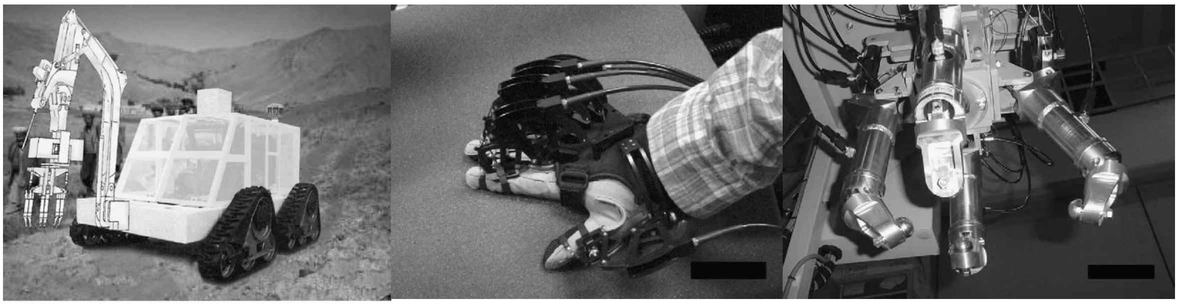


Figure 6: *A Master-Slave Configuration* (Source: Wojtara et al., 2005)

2.3 Virtual Reality (Oculus Rift Development Kit 2.0)

The Oculus Rift Development Kit 2.0 (DK2) is a low cost product developed by Oculus which was released in July 2014 (Baldominos, Saez, & Pozo, 2015) . It is a head mounted display (HMD) for virtual reality (VR). It utilises state of the art display technology to simulate a 3-dimensional world for the user. The Oculus Rift DK2 features head tracking allowing the user's head position to be logged and used by the device for tasks such as looking around in a virtual environment or controlling an external hardware device. Currently the DK2 is intended for development and research purposes which a consumer model to be released in Q1 2016 (Oculus, 2015). Originally intended for gaming, the Oculus Rift has been widely adapted for uses outside of the entertainment industry (Beattie, Horan, & McKenzie, 2015), (Fominykh, Prasolova-Førland, Morozov, Smorkalov, & Molka-Danielsen, 2014).

In the past there have been attempts to create functional virtual and augmented reality devices. Until recently, the technology and concepts have not been greatly successful. With the recent breakthroughs in Virtual Reality HMD technology, applications involving VR hardware have shown promising results. Due to previous iterations of VR hardware being unsuccessful, many of its applications in the real world are currently untested or unknown with researchers only now investigating its potential in other applications. Oyekan et al., 2015, present work on how current systems are improved through the Oculus Rift by the realism offered by the immersive virtual reality technology. They state that traditional 2D and 3D visual representations of environments lack a full sense of presence when designing factory layouts and may lead to layout error. Through use of VR technology such as the Oculus Rift DK2 it is now possible to provide a sense of presence and enable designers to visualize the factory layouts before actual construction begins.

The technology is also being adapted for use in practical areas such as physiotherapy, environment modelling, assembly guidance and biomechanics studies (Oyekan et al., 2015) , (Xu, Chen, Lin, & Radwin, 2015), (Syberfeldt, Danielsson, Holm, & Wang, 2015) , (Baldominos, Saez, & Pozo, 2015).

Figure 7: *Oculus Rift Development Kit 2.0 HMD*
(Source: Oculus, 2015)

2.3.1 Oculus Rift Iterations

The Oculus Rift has undergone hardware iterations since its original release in 2014. The original release known as the Oculus Rift Development Kit (DK1) was the first to be made commercially available.

The hardware featured in the most recent iteration, the DK2, includes:

- A Head Mounted Display (HMD)
- An infrared USB camera for tracking head position
- A positional tracker sync cable
- Two separate pairs of lenses, referred to as A and B set.
- A DVI-HDMI adapter
- A 5V DC power adapter

(Oculus, 2015)

2.3.2 The Head Mounted Display

The Oculus rift HMD (**Figure 7**) houses the internal components in casing formed by black moulded plastic. The headset is able to be adjusted to allow the display to be positioned closer to or farther from the face of the user by the use of the adjustment wheels on the both the left and right side of the headset. Foam padding is located on the relevant surfaces of the headset between the device and the user’s skin to provide comfort. The foam also gives the benefit of blocking out light to give extra immersion. (Davis, Bryla & Benton , 2015)

The HMD requires to be firmly adjusted by the user with limited movement of the device when worn and is done so by the use of the provided elastic straps which allow adjustments to suit the individual similar to traditional goggles. An extra strap which spans from the back of the user’s head to the top of the HMD provides extra support for the device which is front heavy due the size, weight and location of the device (Oculus, 2015), (Davis, Bryla & Benton, 2015).

The HMD features little to no physical controls with only a single power button located on the top front surface. Next to the power button is a LED which indicates whether the device is powered on and has video signal. The LED glows blue when the HMD is powered on and receiving video signal and orange when powered on but no video signal is detected. (Davis, Bryla & Benton , 2015)

Key features which are incorporated into the headset are:

- A single 1920 x 1080 LCD display
- An inertial measurement unit (IMU) which can record angular and linear acceleration while also recording magnetic field strength and direction
- A tracking camera to provide user position data by detection of several infrared lights
- A built in latency tester

(Oculus, 2015)

2.3.3 The DK2 Lenses

Two separate pairs of lenses are included in the Oculus Rift DK2 which are officially referred to as set A and B. Set A is initially installed in the HMD by default and is intended for those with 20/20 vision. The B pair of lenses is for individuals who are very near sighted.

Figure 8: *Rift lenses (Set B)*
(Source: Oculus, 2015)

The key differences between the lenses are not how they transmit light but how they are physically positioned and their dimensions. These aspects of the lenses effect how close they are from for the LCD display. In combination with the distance adjustment, users are able to control the distance between the lenses and the user’s eyes. These adjustments allow for what is termed as “eye relief” which requires the user to position the lenses in an arrangement which is comfortable for use. This adjustment feature allows for a wide variety of different facial characteristics and prescription glasses to be worn underneath of the HMD. (Oculus, 2015)

2.3.4 The Positional Camera

The DK2 takes advantage of its positional camera to track the user’s head movements by detecting the infrared lights which can be found inside of the device itself. The lens of the camera has a mirrored finish as it is only required to track infrared light. The camera must be interfaced with a computer to function correctly. A recommended horizontal distance of 5 feet between the positional camera and the Oculus Rift is stated by Oculus for the head tracking to function optimally. Any objects located between the path of the Oculus Rift and the positional camera can have detrimental effects in the head tracking performance. (Davis, Bryla & Benton , 2015)

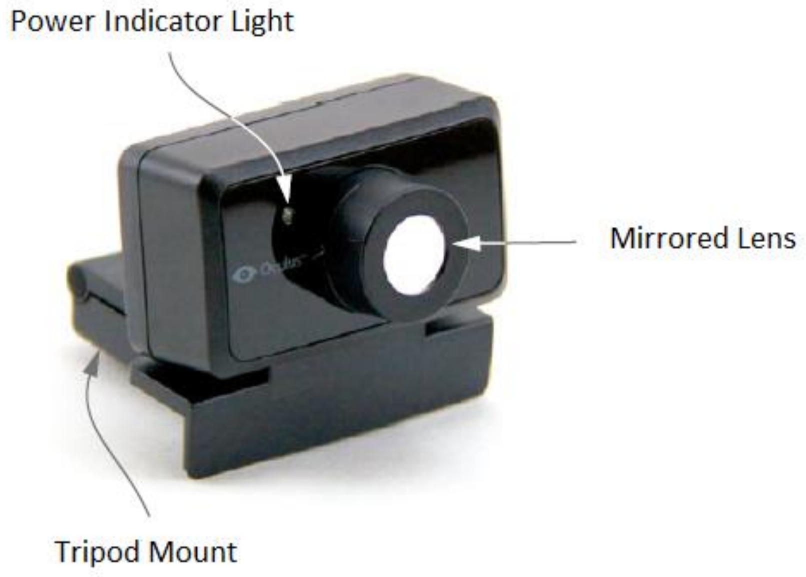


Figure 9: *The Positional Camera*
(Source: Oculus, 2016)

2.3.5 The Rift’s Field of View

An advantage the Oculus Rift has over a standard display or monitor is the much larger field of view that the HMD offers. Davis, Bryla & Benton , 2015 states that even a 30 inch monitor will typically occupy about 50 degrees of the human field of view when viewing at a suitable distance from the display. This is much less than the 100+ degrees which is offered by the Oculus Rift. The field of view experienced by the user of the Oculus Rift may still be greater than 100 degrees depending on the psychical characteristics of the wearer and the hardware configuration.

The high field of view that the Oculus Rift is capable of is due to the placement of the display and its unique sets of lenses. The LCD display sits at an approximate distance of 40mm from the eyes of the wearer. Due to the LCD display being located so close to the eyes it occupies a large portion of the field of view but being so close it presents the challenge of not being easily focused. (Davis, Bryla & Benton , 2015)

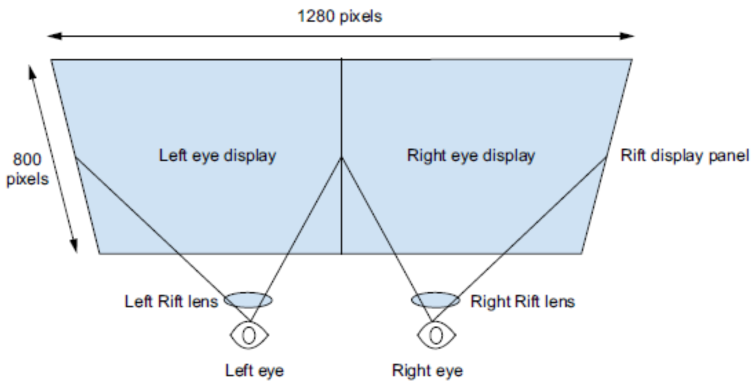


Figure 10: *Field of View for the Oculus Rift*

(Source: Davis, Bryla & Benton , 2015)

2.3.6 Rendering to the Rift

All images must be correctly rendered for the Oculus Rift to function correctly. The lenses which are used by the rift are prone to distortion known as the fisheye lens effect as is the case with most lenses. Due to the lens distortion, the images shown on the LCD display must be altered to account for the distortion by inverting the distortion beforehand. When the image is rendered correctly the lens distortion is cancelled out resulting in a clear and crisp image.

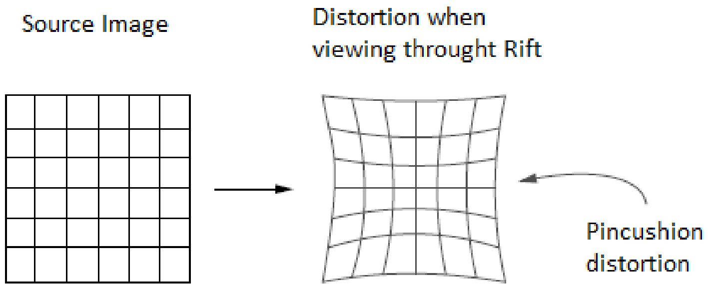


Figure 11: *Pincushion Distortion*

(Source: Davis, Bryla & Benton , 2015)

Figure 11 above indicates the inward distorted image caused by the lenses of the Oculus Rift. This distorted image is termed as “pincushion” distortion. This effect needs to be countered by software to counter the pincushion effect. The distortion applied to counter the pincushion distortion is termed as “barrel” distortion and is applied to the source image before it is sent to the rift. (Davis, Bryla & Benton, 2015)

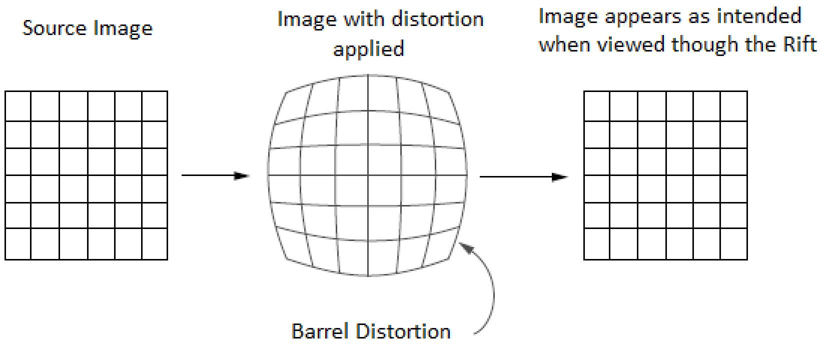


Figure 12: *Barrel Distortion*
(Source: Davis, Bryla & Benton , 2015)

2.3.7 Cyber-sickness

Though substantial progress has been made in the area of virtual reality, the operation of the device has commonly caused motion sickness in users and in some cases injury. Nalivaiko, Davis, Blackmore, Vakulin, & Nesbitt, 2015, use the term cyber-sickness to describe effects such as motion sickness, dizziness, nausea, cold sweating, disorientation and eye strain which are all possible side effects from the use of virtual reality HMDs. Through a detailed study, Nalivaiko, Davis, Blackmore, Vakulin, & Nesbitt, 2015**,** found that exposure to virtual reality provoked nausea, prolongation of simple reaction time, changes in heart rate, and changes in skin temperature.

Cyber (motion) sickness is generally a result of conflicting sensory signals going to the brain, specifically a mismatch between the visual appearance of velocity and the inner ear's sensation of motion. The level of immersion provided by the Oculus Rift often causes motion sickness in individuals even to those who are not generally prone to it. Because of this there are several strategies recommended by Davis, Bryla & Benton to cope with the sickness which can coincide with use of VR headsets.

If a user is nauseous or suffering from other motion sickness symptoms and resting has not alleviated the symptoms, a few suggested remedies to try include:

- Eating ginger- a long used motion sickness remedy
- Try acupressure bands- or other stimulation on specific points of the body to treat ailments
- Talk to your doctor- as there are many prescription and non-prescription medicines to prevent and treat motion sickness

(Davis, Bryla & Benton , 2015)

2.4 OVRVision Pro USB3.0 Stereo Camera

The OVRVision Pro is a high performance stereo camera intended to work in conjunction with the Oculus Rift DK2.0. Its primary function is to obtain video feeds by its two digital cameras and send them to be viewed through each respective lens on the Oculus Rift. This in turns creates what the user experiences as stereoscopic vision.

The OVRVision Pro camera module is commonly used to develop augmented reality and hand tracking applications through the use of its dedicated SDK (Software Development Kit). It is set apart from most other digital cameras by its high fps (60 frames per second), high resolution, wide viewing angle, eye synchronisation and a low delay of 50ms. (Wizapply, 2016)

The contents of the OVRVision Pro consist of:

- OVRVision Pro x1
- OVRVision Pro Cover x1
- OVRVision Pro Mount x1
- Screws x2
- Phillips Screw Driver (#0) x1
- USB 3.0 Cable 2.0m x1
- Hand Tracking Finger Coat x2
- Warranty Card x1 (Wizapply,2016)

Figure 13: *OVRVision Pro*

(Source: Wizapply, 2016)

2.5 Testing/Experimentation

Proper scientific testing is essential in order to extract useful and reliable information from an experiment or project. Rene J. Dubos. (Beveridge, 1963) stated that ‘the experiment serves two purposes, often independent one from another. It allows the observation of new facts, either unsuspected, or not yet well defined; and it determines whether a working hypothesis fits the world of observable facts.

It is widely believed that the essence of science is its method (Bauer, 1992). The act of experimentation and interpreting the results is commonly referred to as ‘Empirical research’. Empirical research involves experimenting where an event is made to occur under known conditions where as many extraneous influences as possible are eliminated from the experiment, so that more accurate observation of the test can be carried out to produce more reliable results (Beveridge,1963). Empirical research is noted by Kicinger & Wiegard, 2013, to be limited in its use. It is implied that empirical research cannot answer a question either outside the scope of a project or a question which is poorly posed but however it achieves the goal of producing useful results of a clearly posed question, scenario or comparison. (Kicinger & Wiegard, 2013)

Kicinger & Wiegard, detail the steps for testing/experimentation as:

1. Methodology
2. Design Experiments
3. Conducting Experiments
4. Presenting Experiments

The methodology is described as a clear organized scientific approach to scientific experimentation with a plan containing a source, goal and a path to achieve satisfactory results. Kicinger & Wiegard, 2013, also states the relevance of finding the story within the results.

A singular driving point emphasizing focus on one clear question/goal is recommended to obtain accurate data and to reach concise conclusions. All tests or experiments should not necessarily be included but what is only germane to the point in order to avoid presenting the experiments in a way others may find confusing. Experiments which weaken the conclusion of a hypothesised outcome should not be omitted and enough detailed information should be provided so that the experiment may be accurately replicated again under the same conditions. (Kicinger & Wiegard, 2013)

2.6 The Human Depth Perception

As humans we experience sight with the ability of depth perception coming naturally. Garin, 2012, describes the term depth vision as the ability to determine distances between objects and to perceive surroundings in three dimensions. This phenomenon occurs with binocular stereoscopic vision.

The human body is able to experience this due to the eyes being positioned horizontally apart from one another producing two separate images which are slightly separate with the difference proportional to the relative depth. The brain interprets these images producing what we know as stereoscopic vision. At this stage the brain handles the processing from the visual images. Two separate areas of the brain known as V1 and V2 extract rudimentary features from the visual images such as the direction of motion, colour and edges. (Vilayanur, Rogers-Ramachandran, 2009, Garin, 2012)

Garin, 2012, states that our eyes use three methods to determine the distance at which we perceive objects within the surrounding environment. These include the known size of an object on your retina, moving parallax and stereoscopic vision.

Experience aids the brain in calculating the distance based on the size of an object on the retina. The moving parallax effect is experienced by the brain and aids in the calculation of distance. Garin, 2012 gives an example of this event as the effect which ‘happens when you stand face to face with someone and move your head sided to side. The person in front of you moves quickly across your retina, while the objects that are farther away do not move very much at all. This helps your brain calculate how far an object is from you’. Vilayanur, Rogers-Ramachandran, 2009, Garin, 2012 and UCI, 2004 all state this method of how the brain can interpret visual images to calculate distance, with this method not being so effective for objects further away.

The brain also uses a number of different tools for depth perception otherwise known as depth cues (Garin, 2012, UCI, 2004). These cues fall into categories classified as binocular (both eyes), monocular (singular eye) and inferred (a combination if the monocular and binocular cues).

Binocular cues include:

- **Retinal disparity**: each eye receiving a different image due to the different displacement of the eyes viewing its surroundings at a slightly altered angle
- **Fusion**: the event of the brain using the retinal images generated by the two eyes to form a singular image

Monocular cues give the ability to judge the size and distance of objects when using just a single eye. These monocular cues consist of:

- **Interposition**: this cue arises when there is an overlapping of an object
- **Linear perspective**: as objects which begin at a known distance appear to grow smaller, this cue is deduced by the brain that the objects are indeed moving further away
- **Aerial perspective**: the contrast and colour of the viewed objects give information to the object's displacement. Specifically the outline of the object is affected by scattering light blurring the object and giving the perception of distance
- **Light and shade**: Shadows and highlights give clues to the dimension and depth of the viewed object
- **Monucular movement parallax**: Head movement from side to side, gives the information to the brain that objects at different distances are moving at different velocities with respect to the viewer. Additionally, objects which are positioned close to the viewer appear to move in the opposite direction of the head movement while farther objects appear to move with the viewer's head.

(Garin, 2012**,** UCI, 2004)

However UCI, 2004, states another cue category being Oculomotor Cues which discusses convergence and accommodation whereas Garin, 2012, seems to indicate these cues are binocular.

2.7 Review of Information

From performing the literature review, there are numerous knowledge gaps for research to be done and it is often suggested so by the authors of the respective literature. Due to the technology of the master-slave control configurations and the Oculus Rift head mounted display (HMD) still being very new and under further development, there is a limited amount of technical and credible information that has been published. Much of the literature investigates how the technology is being applied or how it could be applied. This further demonstrates the significant gaps in the knowledge of utilising VR HMDs for real world practical applications.

Chapter 3

Methodology

This section contains all of the considerations which have gone into the execution of the research project. These considerations involve the project methodology, risk assessment, project timeline and the project content licensing. Any future implications which are a direct result of this dissertation will also be considered.

3.1 Project Methodology

To achieve the outlined objectives of the proposed research project the method of approach followed the following 6 phases:

- Utilising a literature review, research and experimentation to incorporate learned information and results into the construction of the remotely operated telepresent robot

- Incorporating new virtual reality headset technology (still unreleased to the consumer market but available in development kits) in tandem with video cameras to achieve a depth perception effect for the user. This feature is aimed to impress upon the wearer the sense of being present in a 3-dimentional environment, allowing for increased accuracy

- Construction of a wearable device which allows an operator the sense of direct control of a robotic device by the robot mimicking the movements of the human body via a wearable device by the use of potentiometers, haptic feedback motors and a microcontroller.

- Construction of a mobile platform to house the robotic limb (arm) and cameras

- Amalgamation of all aspects of research and constructed components to experimentally test results against traditional remote control methods for various users

- Write-up Phase involving the preparation of the project dissertation

Further details and information of the methodology involving individual task descriptions can be found in **Table A.1** of **Appendix A**.

3.2 Testing Methodology

A proper structured approach will be required to successfully achieve the desired goals, outcomes, and obtain usable data. The project requires repetitive experimentation with changing hardware and multiple participants involved with the testing.

The current testing methodology is as follows:

1. Setting the task for the experiment. This involves specifying the task which the robot is to perform under the control of the operator and ensure the repeatability of the task.

2. Setting the environment for the experiment. The environment where the experiment is to take place must be free from any external interference which can have influencing effects on the results.

3. Select a range of individuals to participate in the experimentation. People with varying experience when using remotely operated vehicles and equipment need to be included within the sample population.

4. Perform multiple tests with different hardware configurations (i.e. with the Oculus Rift, without the Oculus Rift, with the wearable control apparatus, without the wearable control apparatus, etc.)

5. Record the results of the following aspects:

    1) Time to complete task
    2) Accuracy of completed task

6. Repeat steps 4 and 5 to investigate any changes in the results when using different vision methods. The experiments will be conducted until a satisfactory amount of data is obtained.

7. Compare the data and draw conclusions from the results

3.3 Risk Assessment

This section will consider the risks which have a possibility of threats occurring for the duration of the project and will detail the preventative steps to reduce the level of risk and the possibility of occurrence.

3.3.1 Identification of Hazards

The most significant risk of a hazard occurring during the project is injury from power tool use (drill, soldering iron, etc.) when creating the hardware for the project. Other identified risks included receiving an electric shock from incorrect handling and construction of the electronic circuits. Due to the electric components having a maximum of 12V the electrical work is classed as extra low voltage and does pose a significant threat even in the case of electric shock. Additional risks include contact between the user and robotic arm or remote controlled vehicle and tripping hazards within experiment workspace. For a full description of identified tasks that may pose a risk please see **Appendix C**.

3.3.2 Evaluation of Risk Level

Creating physical devices which require the use of power tools, testing robotics and other equipment which is run by code that is still in development carries a risk which is always susceptible to human error. It is essential that every task is evaluated to assess the severity of the threat that is associated with relevant task. Injury from power tool use was identified as posing the most significant hazard and has been evaluated as a low level risk (NVET, 2014). For evaluation of all the risk levels please see **Appendix C.**

3.3.3 Risk Reduction

The hazards involved with conducting this research project were identified and their level of risk evaluated. The steps which have been determined and which are to be taken to reduce to level of risk are also listed in **Appendix C**.

3.3.4 Project Consequential Effects

Upon completion of the research project, the hardware configurations and created programs may either be used or replicated to further investigate or improved upon. It is essential to ensure that I am personally not liable for any damage or injury as a result of any future research in regards to this research project.

Thorough documentation is to be provided to assist any user or researcher in the attempt of mitigating any unintentional misuse the information regarding this research project. By providing the proper information within the dissertation, the project will have been conducted in an ethical matter whilst minimizing the likelihood of any detrimental consequential effects.

3.4 Project Intellectual Property

The work produced within this project, the code that has been created, the designed electronic circuitry and the hardware component list will form a solid foundation for any person who is aiming to progress deeper into robotics and tele-presence. Tasks which require the use of the Oculus Rift to a render video stream to produce real time stereoscopic vision will be greatly benefited.

Any students seeking support in regards to research within the related field will only require a request for attribution in the use of or modification of the work which is presented within this dissertation. Simply put, only appropriate recognition is required to build up the research presented within this dissertation.

Chapter 4

Telepresent Robot Hardware, Operation & Integration

This section of the research project details the hardware of the created remotely operated telepresent robot. Specifically what are the components used and how each of them are interfaced together. The programs and code utilised for the Oculus Rift DK2.0 and any relevant microcontrollers have also been included in their relating sections.

4.1 Original Oculus Vision Hardware Components

In order to achieve stereoscopic vision, two separate video images are required to be sent to each eye of the Oculus Rift HMD. The necessary video images can be captured by two separate digital cameras. This video source is then sent wirelessly from the transmitter to its respective AV receiver. The video signal is an Analogue Video feed and must be converted to digital in order to for the dedicated computer to receive and then initialise and upload to the Oculus Rift HMD.

Below is the original list of the components which may be used to achieve stereoscopic vision with the Oculus Rift:

- Oculus Rift Development Kit 2.0 (DK2)
- 2x CMOS Camera Module SEN-11745

- 2x 5.8 GHz Skyzone 600 mW Wireless AV Transmitter & Receiver
- 2x Hauppage USB-LIVE 2
- 12V Battery
- Dedicated Computer

Although many of the components listed above are no longer utilised in achieving stereoscopic vision with the Oculus Rift, they have repurposed in the creation of the tele-operated telepresent robot. **Figures 14** and **15** below depict an early arrangement of the components for the original concept of using the Oculus Rift HMD to generate stereoscopic vision.

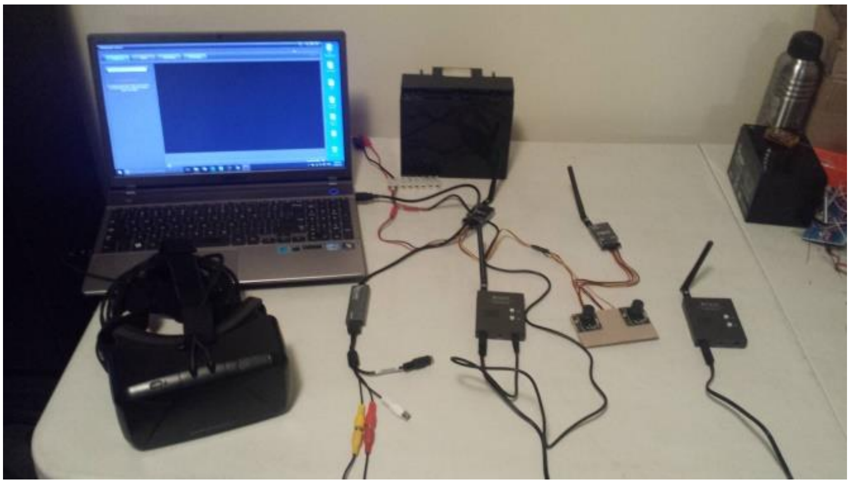


Figure 14: *The Early Stereoscopic Concept*

4.1.1 CMOS Camera Module

The camera used for video capture is the CMOS Camera Module SEN-11745. It features:

- A resolution of 728x488
- 5V to 20V input
- 50mA (at 12V)
- NTSC & PAL supported (Sparkfun, 2016)

4.1.2 5.8GHz Skyzone Wireless AV Video Transmitter & Receiver

A 5.8GHz TS832 transmitter and receiver has been utilised to send the video feed form the camera wirelessly to the dedicated receiver. The specifications of the receiver are as follow:

Transmitter TS832 specifications:

- 7.4V to 16V power input
- 600mW of transmitting power
- Working current of 220mA at 12V
- Video bandwidth of 8 MHz
- Weight: 21g
- Dimension: 54 x 32 x 10mm (without antenna)

Receiver RX RC832 specification:

- 12V power input
- 200 mA of working current
- NTSC & Pal video formats supported
- Dimension 80 x 65 15mm
- Weight: 85g (Hobby King, 2016)

The components and how they were intended to interface together in the original design can found below in **Figure 15**.

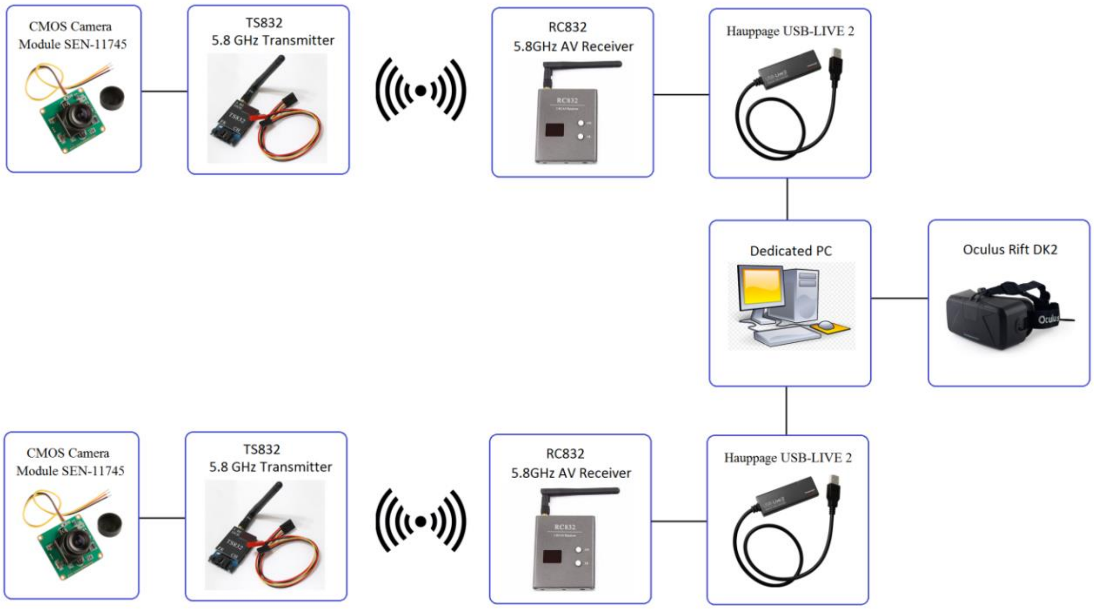


Figure 15: *Original Oculus Hardware Interfacing Diagram*

4.1.3 Discussion of Original Design

The original design of the circuitry to achieve stereoscopic vision with the Oculus Rift was insufficient and has been included in the research project in order to document the disadvantages associated with using the previously mentioned hardware. For the final design used for testing the remotely operated tele-present robot refer to **Section 4.3**.

Numerous key factors resulted in the flawed design of the original configuration. These factors were:

- Low camera frame rate- of the CMOS Camera Module SEN-11745 module was detrimental to the operation of the project. The CMOS camera module produced a frame rate much lower than the Oculus Rift’s native refresh rate of 75Hz. Preliminary testing of the equipment on a 60Hz monitor proved to be a jarring experience as viewing motion also proved to be difficult to follow without a smooth and fluid video feed.

- Low camera resolution - of 728x488 was sufficient enough to gain a clear image, but the HMD of Oculus Rift DK2 is capable of displaying resolutions up to 960x 1080 per eye. This resolution of the camera was considered acceptable when selecting components which would give satisfactory performance whilst still being relatively inexpensive. The camera module of the final design features digital camera with resolutions much closer the native resolution of the Oculus Rift DK2 and is detailed in **Section 4.2**.

- Low camera field of view - had a negative effect as this resulted in the camera having to constantly to be repositioned to either be close enough to see the object with enough detail and far enough to have a proper awareness of the surroundings.

- Large latency – was a result of the Hauppage USB capture device. The analogue video sent to the device via the receiver was required to be converted into a live digital video feed which could be altered and sent to the Oculus Rift by the use of additional software. However, the product did successfully generate a digital video feed but produced a large latency of approximately 3 seconds. This resulted in the task of controlling the robot being extremely difficult and making adjustments to the robotic arm meant having to wait to receive video feedback on the robots new position.

- Interfacing difficulty- with the DK2 proved a challenging experience in regards to successfully retrieving images from the two cameras. The original design utilised OpenCV and Microsoft Visual Studio 2013 to receive the digital video feed and apply the correct distortion so the user is provided with clean and crisp footage. With the constant upgrading of the drivers, SDK, Oculus runtime and the APIs, troubleshooting for errors was a persistent challenge in regards to creating a fully functioning program within Microsoft Visual Studio 2013. These issues were overcome with the use of a dedicated SDK for the final camera module discussed in **Section 4.2**.

4.2 OVRVision Pro Camera

The OVRVision Pro VR stereo camera is a dedicated camera module for interfacing with the Oculus Rift DK2. The dual camera setup is intended to be mounted to the front of the HMD but is easily removed and relocated. The inclusion of the OVRVision Pro allowed the use the OVRVision SDK. It provided a great reference point for any work with the Oculus Rift DK2 as the standard drivers, DirectX 11 and the Oculus Runtime version 0.8 is all that is required to correctly interface. It is important to note that running the OVRVision Pro camera module with the Oculus Rift on Windows 10 was unsuccessful on multiple computers although stated as officially supported. A new installation of Windows 7 was created in order to successfully run the hardware.

4.2.1 Specification and Features of the OVRVision Pro

Important features of the OVRVision Pro which made the use of the camera module ideal for the project are:

- Various output resolutions
- Lenses which produce 115° of horizontal angle and 105° of vertical angle
- Dimensions: 100mm x 75mm x 45mm
- Weight 65g (Wizapply ,2016)

The various output resolution of the OVRVision Pro provided the choice of the output resolution but resulted in a lower frame rate the higher the chosen resolution. The options available between resolution and frame rate are:

OUTPUT RESOLITION	FRAMES PER SECOND
2560 x 1920	15fps
1920 x 1080	30fps
1280 x 960	45fps
1280 x 800	60fps
960 x 950	60fps
640 x 480	90fps
320 x 240	120fps

The balance of output resolution and frame rate chosen was constant throughout the experimental testing. A resolution of 1280 x 960 at 45 fps was chosen. Preliminary testing with these settings determined that this resolution produces a sufficiently detailed image at a frame rate which is still relatively smooth to follow when viewing through the Oculus Rift HMD.

Figure 16: *OVRVision Pro mounted on the DK2.0*

4.3 Single Camera/Monitor Interfacing

The components the telepresent robot utilised for sending a video feed from a single digital camera to a dedicated monitor can be seen below in **Figure 17**. The camera captures the footage of the robot performing the task which is then transmitted to the receiver which in turn is then displayed on the monitor.

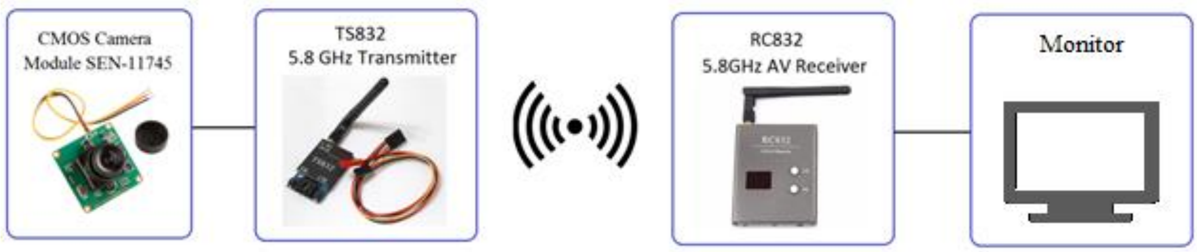


Figure 17: *Interfacing Diagram for a Single Camera and Monitor Configuration*

4.4 Six Axis Robot & Controls

Multiple hardware components were required to create a robot which would serve as the main platform for the testing of any advantages or disadvantages to the addition of stereoscopic vision. The major components that were implemented or created include:

- Six Axis Robotic Arm
- Gripper
- Mobile Platform
- Operators Control Panel

Figure 18: *The Created Robot*

4.4.1 The Six-Axis Robotic Arm

The inclusion of a robotic arm was necessary as it acts as the core mechanism for interacting with the environment.

The main features of the robotic arm which made it ideal for the research project include:

- Six-Axis (six degrees of freedom)
- Constructed from sturdy stainless steel plate
- Fully waterproof servo motors for axis J1 to J4
- Is controllable by Arduino or similar microcontrollers
- Horizontal reach of 300mm
- Vertical reach of 270mm

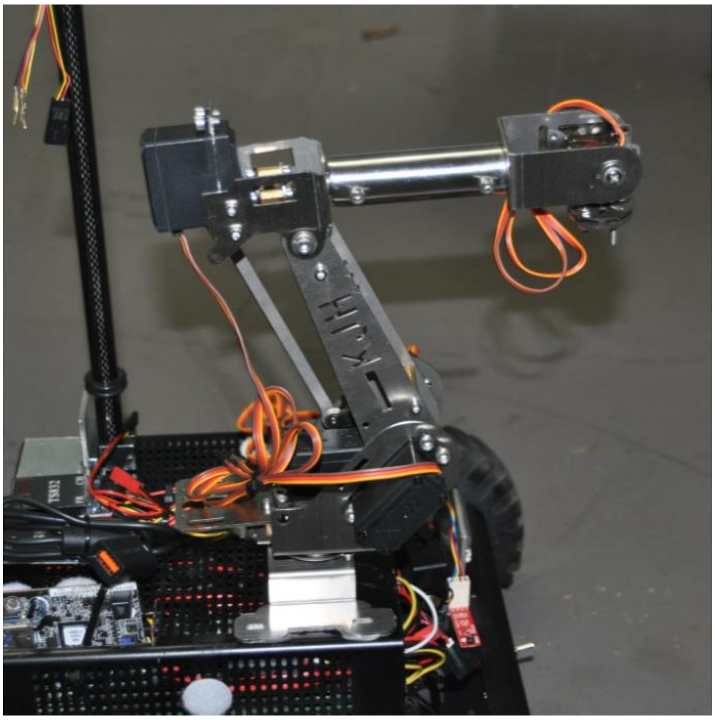


Figure 19: *KJH Six-Axis Robotic Arm*

4.3.2 Robotic Gripper

The six-axis robot requires a tool in order to interact with objects. A gripper was designed and created for this purpose and performs the tasks specified in **Chapter 6**. The gripper is made from ABS (Acrylonitrile-Butadiene-Styrene) by using a 3D printer and is able to be remotely opened and closed by the operator. The three parts of the gripper include:

- Left Pincer
- Right Pincer
- Servo Housing
- SG90 Micro Servo

Figure 20: *Gripper for the Robotic Arm*

The servo box is designed to hold a single SG90 micro servo and allows both the left and right pincer to be attached to the servo box. Each pincer has a gear located at their respective base. The right pincer is controlled form the servo motor between an angle of 0 and 90 degrees. The left pincer moves in synchronisation with right due the meshing of the gears on the bases of the pincer. The open and closed position of the gripper can be seen in **Figure 21** and **Figure 22**.

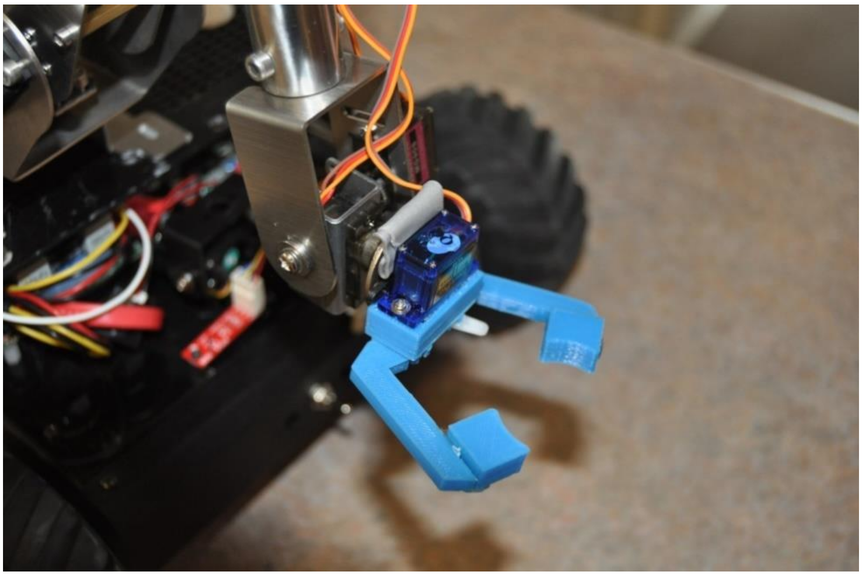


Figure 21: *Gripper Open Position*

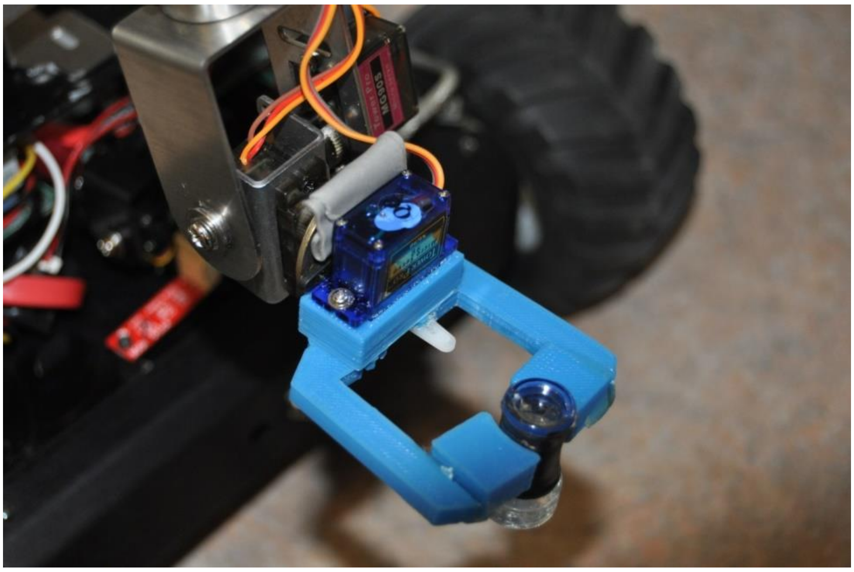


Figure 22: *Gripper Closed Position*

4.4 Control Panel

A control panel was created to house the electronic components required to operate the six-axis robotic arm. An image of how the electronic components interface with one and other can be found below in **Figure 23**. The electronic components which have been used to create the control panel are:

- 2x Arduino Leonardo
- 1x Arduino Duemilenove
- 2x Adafruit Motor Shield
- 7x 10k potentiometers
- Miscellaneous components (wire, veroboard, perspex, etc.)

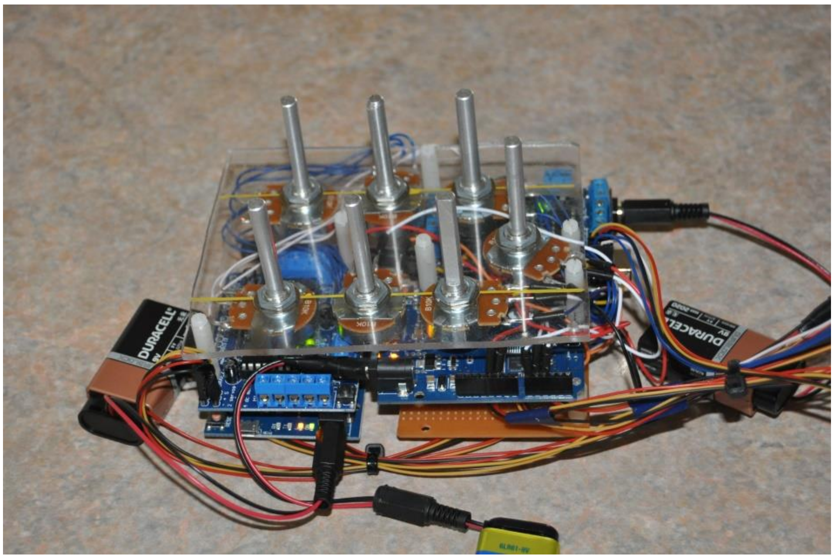


Figure 23: *Control Panel*

The two Arduino Leonardo and single Duemilenove microcontrollers have been incorporated into the control panel with the exclusive task of controlling the six servo motors located on the robotic arm and one servo motor used to control the gripper. The two Adafruit motor shields were used in conjunction with the two Leonardo microcontrollers to correctly operate the KS-3518 servo motors which require more power than each board can provide alone. The single Duemilenove controls the smaller servo motors of the robot including two MG90S servo motors located on axis J5 & J6 and the gripper's SG90 servo motor.

The seven 10 kilo-ohm potentiometers act as the physical control for the user to adjust the position of the servo motors. The potentiometers scale a 5V source which is to be converted into a digital value by the microcontroller (0 to 1024). This value is normalised to a value between 0 and 180 which relate to the operating range of 0 to 180 degrees of the servo motor respectively. The value is then written to the servo motor by the microcontroller. Using this method the microcontroller is able to accurately control the position of the servo motor.

The potentiometers were used over buttons and joystick, as preliminary testing with the potentiometers revealed that this control method proved to offer ease in making both small incremental and large quick adjustments to the robotic arm's position.

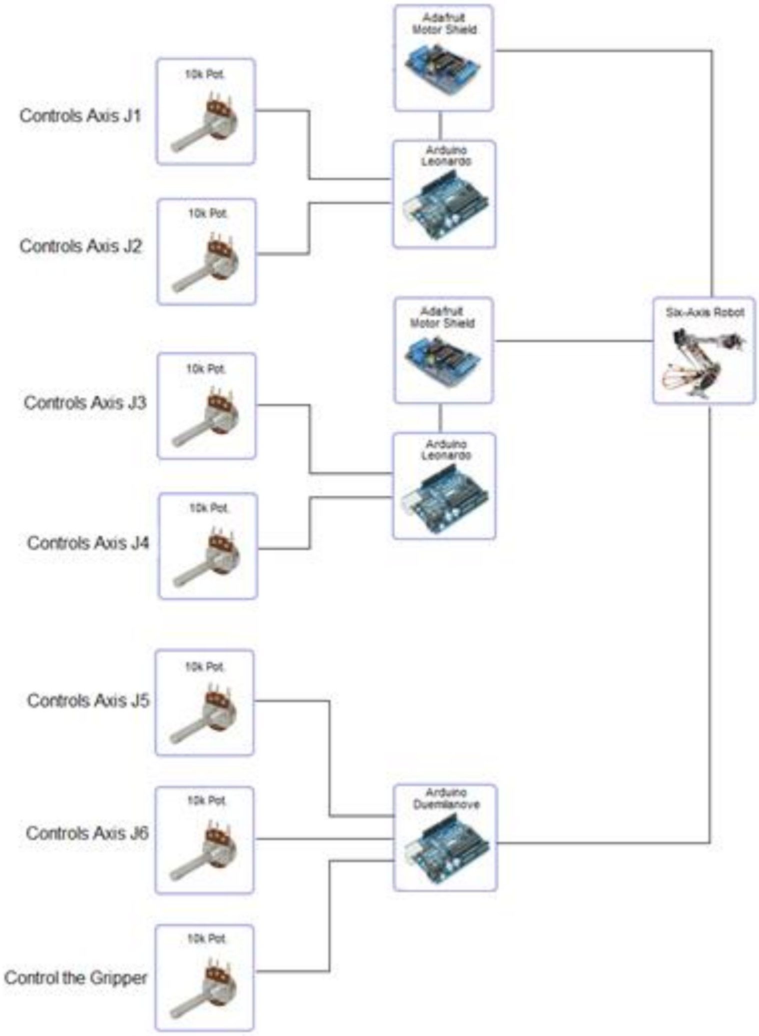


Figure 24: *Control Panel Component Interfacing Diagram*

4.4.1 Control Panel Arduino Code

Below is the Arduino program to operate the Six-Axis Robot by the use of potentiometers. The program controls up to three potentiometers and per microcontroller. Three microcontrollers were used due to the limitation of controlling two KS-3518 servos per motor shield.

```
/*
 Controlling the position of 3 servo motors using potentiometers
Author: Jarrad Gleeson
Last Modified: September,2016
*/

#include <Servo.h>
Servo myservo;             // create servo object to control a servo
Servo myservo1;            // create servo object to control a servo
Servo myservo2;            // create servo object to control z servo (claw)

int potpin = 0;            // analogue pin used to connect the potentiometer (axis 6)
int val;                   // variable to read the value from the analogue pin
int potpin1 = 1;           // analogue pin used to connect the potentiometer (axis 5)
int val_1;                  // variable to read the value from the analogue pin
int potpin2 = 2;            //analogue pin used to connect the potentiometer (claw)
int val_2;                  //variable to read the values from the analogue pin

void setup() {
  myservo.attach(9);                  // attaches the servo on pin 9 to the servo object
  myservo1.attach(10);                // attaches the servo on pin 10 to the servo object J
  myservo2.attach(11);               //attaches the servo on pin 11 to the servo object
}

void loop() {
  val = analogRead(potpin);          // reads the value of the potentiometer (value between 0 and 1023)
  val = map(val, 0, 1023, 0, 180);  // scale it to use it with the servo (value between 0 and 180)
  myservo.write(val);               // sets the servo position according to the scaled value

  val_1 = analogRead(potpin1)    // reads the value of the potentiometer (value between 0 and 1023)
  val_1 = map(val_1, 0, 1023, 0, 180);   // scale it to use it with the servo (value between 0 and 180)
  myservo1.write(val_1);                    // sets the servo position according to the scaled value

  val_2 = analogRead(potpin2) // reads the value of the potentiometer (value between 0 and 1023)
  val_2 = map(val_1, 0, 1023, 0, 90);   // scale it to use it with the servo (value between 0 and 180)
  myservo1.write(val_2);                  // sets the servo position according to the scaled value

  delay(15);                                // waits for the to reach its position
}
```

4.5 Arm Controller

In relation to objective 2, a wearable arm controller was attempted. The intent of the arm controller was to investigate whether the telepresence effect could be improved by providing a more intuitive control method and experience. The main function of the arm controller was to mimic the movement of the user wearing the apparatus and then have the robotic arm produce the same or similar position. By providing a controller method which is able to be controlled more naturally, any evidence of improving the robot control experience was to be investigated by testing with the control along with the traditional control methods.

The constructed segment of the arm controller functioned by the use potentiometers positioned on the pivot points to send a signal to the microcontroller which could then be used to control the angle of the servo motor on the robotic arm. The joints intended to be controlled were from joint J1 to J5 on the robotic arm. This relates to the joints on the human body from the shoulder to the wrist. Joint J6 was not included in the axis to control as humans are unable to rotate the wrist separately to the forearm, whereas the robotic arm is able to rotate axis J4 and J6 separately. The segments of the arm controller that were trialled early on was constructed from aluminium bar and was able to be fixed to the user’s arm by Velcro straps.

4.5.1 Interfacing Diagram

For the arm controller to correctly function, it requires the use of additional microcontrollers which in turn operate the robotic arm. The same microcontroller and potentiometers for the joint were used in both the created segments of the arm controller and the control panel. How the components of the arm controller interface with each other can be seen below in **Figure 25**.

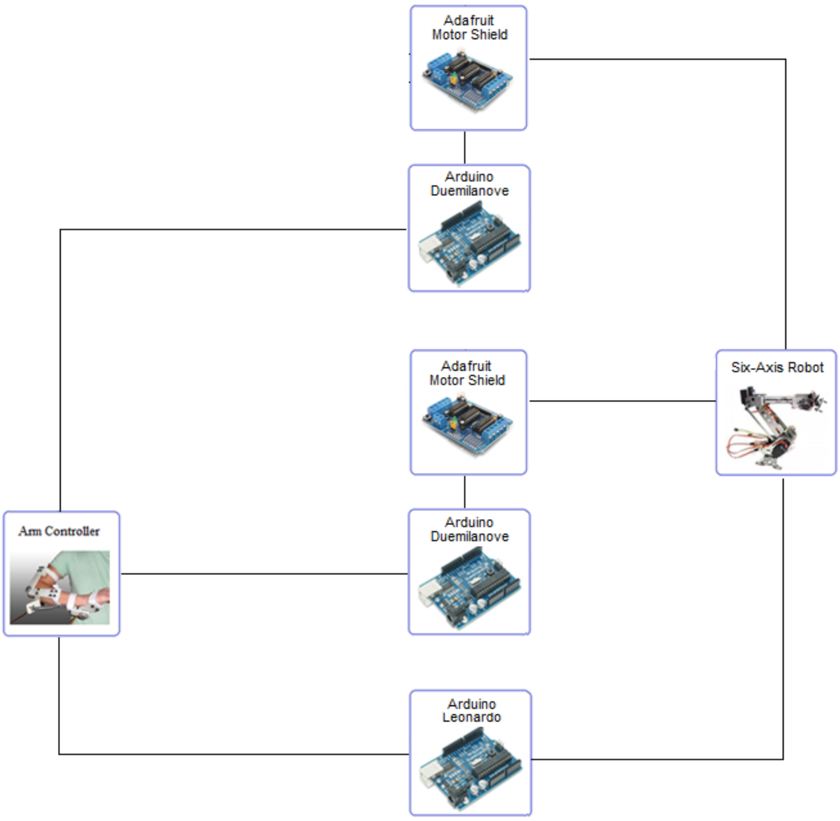


Figure 25: *Arm Controller Interfacing Diagram*

4.4.4 Preliminary Testing

The arm controller was partially constructed in segments and it was decided not to proceed further into its development due to the disadvantages presented in testing its basic functionality. The joints which were tested required the operator to continue to hold their arm at an uncomfortable position for relatively long durations of time without moving. The concept of a robot mimicking a human’s movement is practical in theory but the reality leaves an apparatus with causes discomfort and introduces human error into the robots operation.

Chapter 5

Depth Perception Testing

This chapter covers the experimental testing and investigates the effects of using stereoscopic vision for judging distances. The test has been created to determine if using a VR headset can provide a benefit similar to the natural human depth perception and compare it against a traditional telepresence method of a single camera and monitor arrangement.

5.1 Stereoscopic Depth Perception Test

The stereoscopic vision is a key element of the research and before it can be determined if stereoscopic vision can improve telepresence/ tele-operated robotics, it must first be compared to our own natural vision of the human eye.

The OVRVision camera is used in conjunction with the Oculus Rift DK2 for this section of testing. The user is to wear the Oculus Rift HMD with the OVRVision Pro camera module mounted on the front of the HMD. The focus of the Stereoscopic Depth Perception Test is to give an informative comparison of just how accurately an individual can judge an object at a distance normally and then compare it against using the Oculus Rift DK2 and the single camera and monitor arrangement. No robot or additional controls are included within the Stereoscopic Depth Perception Test.

5.1.1 The Created Test

The primarily objective of testing the user's depth perception with the Oculus HMD and the user's depth perception without the Oculus HMD is to determine whether the human depth perception is the same as when using the HMD as compared to not.

The users/participants have been tasked with judging a object at varying distances. This includes judging small incremental distances up to 2 metres, moderate incremental distances up to 5 metres and large increments in distances up to 10 metres. The same object is to be consistently used for testing with the object placed at the various distances in no specific order.

The distances to be judged are as follows:

- Small Increments up to 2m:
    - 0.5m
    - 1m
    - 1.5m
    - 2m

- Moderate Increments up to 5m:
    - 1m
    - 2m
    - 3m
    - 4m
    - 5m

- Large Increments up to 10m:
    - 2m
    - 4m
    - 6m
    - 8m
    - 10m

The test has been performed by group of 11 people of various age and ability.

Figure 26 and **27** below show an example of an object (styrofoam head arbitrarily chosen) positioned 5 m away from the user. It near impossible to acquire a sense of the immersion Oculus Rift provides without trying the hardware in person.

Figure 26: *Viewing and object 5m away using the Oculus Rift DK2*

Figure 27: *An object viewed normally 5m away*

5.1.3 Recording the Results

Due to the large sample population of people performing the test, a reliable and detailed recording plan was created in the form of a test sheet to easily record and track the results from each individual participant. Each participant was provided their own test sheet prior to testing.

A questionnaire was also included on the test sheet to gather information of the user's experience with all three methods. Information on preference and opinions of the testing has been reviewed to determine any trends from within the sample population of the individuals who participated in the testing.

5.1.4 Informed Consent Form

A consent form which all participants in the experimentation have signed a copy of can be found in **Appendix E**. It states how the results form the experimentation will be used and what limited personal information will be disclosed. It applies to both of the tests performed.

5.1.5 Stereoscopic Depth Perception Test Preparation

With a significant amount of people involved in the testing of equipment which is unfamiliar to them, it is important that each individual have a clear understanding of the task's requirements. Hardware such as the Oculus Rift DK2 and stereoscopic camera are not common knowledge amongst people who do not possess up to date knowledge of technology. As such it is necessary to give a brief overview the device by describing what is, how it works and what it is used for as part of the stereoscopic test preparation.

Before Testing:

1) Familiarise the participant with the Oculus Rift
2) Familiarise the participant with the OVRVision Pro camera module
3) Introduce the 3 different vision methods to the individual
4) Clearly explain the task to the user
5) Provide a copy of the experiment test sheet to each individual which also contains a descriptive explanation on the task
6) Explain how to correctly fill in the test sheet including the questionnaire provided

After Testing:

1) Examine the participant's test sheet to ensure it has been completed and assist with any section if the participant does not find the description clear
2) Ask the participant to sign the declaration form giving permission to use the results as a part of the research project

5.1.6 Stereoscopic Depth Perception Test Overview

To successfully test how well participants were able to judge distance, the steps of the Stereoscopic Depth Perception Test were put in place to ensure that the accuracy in the results from the participants was consistent throughout the entire testing phase. All of the steps were designed with a difficulty to allow participants to produce contributable results.

The steps of the test are:

1) Take position at the designated mark
2) Estimate and record the distance of the object for 14 positions
3) Answer the questionnaire provided regarding the testing experience
4) Repeat the test until all 3 vision methods have been tested

The above test is to be repeated using the following vision methods:

Natural Vision	(Judging distance normally by eye)
Stereoscopic Vision	(Using the Oculus Rift)
Single Monitor	(Using a traditional camera & monitor arrangement)

5.1.6 Aspects for Investigation

The stereoscopic vision test has been designed to specifically aim at investigating the following:

- Depth perception judgement – How accurate are participants able to judge the distances using the three vision methods (natural eye, Oculus Rift, single camera)?

- Cyber Sickness- Is cyber sickness affects many participants and the gain insight of the duration of using the headset before it is noticeable?

- User Friendliness- Are particular types of vision method easier or worse the others? Does using a particular one give a specific advantage or disadvantage?

- Preference- Which is the order of preference that users preferred of the three vision methods?

5.1.7 Hypothesised Results

Prior to performing the Stereoscopic Depth Perception Test, there were some predicted outcomes of the testing, mostly which have been determined from the literature review and experience with the hardware. The hypothesised results of the test were as follows:

- An increase in depth perception when using the Oculus Rift DK2 in conjunction with the OVRVision camera module when compared to the single camera and monitor configuration
- A decrease in depth perception when using the Oculus Rift DK2.0 in conjunction with the OVRVision camera module when compared to judging the distance by eye naturally without the HMD
- A limited time a user/participant can comfortably wear the Oculus Rift HMD before experiencing cyber sickness
- A preference to the three methods in the order of Natural eye, Oculus Rift, Single Camera

5.2 Statistical Analysis of Stereoscopic Depth Perception

Of the varying distances tested using the three separate vision methods, the results indicated that there were clear differences in the ability to judge objects at a specific distance. However some methods were better than other within a particular range while others seemed to indicate very little difference at all within those ranges.

5.2.1 Evaluating the Accuracy of the Natural Eye

Using the natural human eye as the only tool to judge the distance of an object is not a difficult task. It is a skill almost every person learns from infancy and is used through the entirety of that person's lifetime. As such it provides an excellent basis to compare against in regards to how well a user can judge distances through telepresence.

The data obtained from testing various participants in the experiment can be seen presented below in **Table 1** and the solutions for the test presented in **Appendix E**.

Judging Depth Perception by the Natural Eye Results

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Between 0-2m				Between 0-5m					Between 0-10m				
J. Gleeson	1.5	1	2	0.5	3	4	1	2	5	4	8	6	10	2
J. Winter	1.5	1.5	2	0.5	3	4	1	2	6	4	8	6	10	2
B. Gleeson	1.5	1	2	0.5	3	4	1	2	5	4	8	6	10	2
G. Collins	1.5	1	2	0.5	3	4	1	2	5	4	8	6	9	2
B. Winter	1.5	1	2	0.5	3	4	1	2	5	4	8	6	10	2
D. Winter	2	1	2.5	0.5	3	4	1	2	5	4	10	8	10	2
A. Shephard	2	1.5	2	0.5	3	4	1	2	5	6	8	8	10	2
F. Border	1.5	1	2	0.5	3	4	1.5	2	5	4	10	8	10	2
S. Shephard	1.5	1	2	0.5	3	4	1	2	5	6	10	8	10	2
K. Collins	1	1	2	0.5	3	4	1	2	5	4	8	6	9	2
D. Phillips	1.5	1	2	0.5	3	4	1	2	4	4	8	6	10	2

Table 1: *Results from Judging Distance by Eye*

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Solution (m)	1.5	1	2	0.5	3	4	1	2	5	4	8	6	10	2

Table 2: *Solution to the Natural Eye Phase*

Judging the distance an object is located from an individual proved to be an uncompleted process. The majority of participants of the Stereoscopic Depth Perception Test were consistently able to judge the distance correctly. The test featured reasonable increments to cater for the participants whom are not commonly required to judge a specific distance accurately. In doing this, it is possible that this phase of the test may have been too simple to perform well. However it provides a useful indication how well and simply humans are able to judge distances with natural eye sight and provides a target for the monitor and stereoscopic phase of the test.

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Between 0-2m				Between 0-5m				
Correct (%)	72.73	81.82	90.91	100	100	100	90.91	100	81.82
Range (%)	86.37				94.55				
Mean (m)	1.55	1.09	2.05	0.5	3	4	1.05	2	5
Solution (m)	1.5	1	2	0.5	3	4	1	2	5

Table 3: *General Statistics from Natural Eye Phase*

Location	**10**	**11**	**12**	**13**	**14**
	Between 0-10m				
Correct (%)	81.82	72.73	63.64	81.82	100
Range (%)	80				
Mean (m)	4.36	8.55	6.73	9.82	2
Solution (m)	4	8	6	10	2

Table 4: *General Statistics from Natural Eye Phase Continued*

Table 4 above contains the statistics of the percentage of the participant population which correctly estimated the distance of the object's position across the 14 locations trialled. It also contains the mean estimated distance as well how successful the population was overall at estimating between the three range categories (0 to 2m, 0 to5m & 0 to 10m).

5.2.2 Evaluating the Accuracy of the Camera & Monitor

Judging the distance at which an object is located away from a camera by viewing of a traditional monitor proved to be significantly more challenging than simply viewing it in person by eye. A lot of additional information the brain uses to determine what is directly in front of an individual is lost by this method and confirms a significant disadvantage with telepresence. **Table 5** below contains the results of the testing during the camera and monitor phase.

Judging Depth Perception by Camera & Monitor Results

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Between 0-2m				Between 0-5m					Between 0-10m				
J. Gleeson	0.5	2	1	1.5	4	2	1	3	2	2	8	6	8	4
J. Winter	0.5	2	1	1.5	5	2	1	4	3	2	8	6	8	4
B. Gleeson	1	2	1	1.5	4	2	1	5	4	2	10	6	8	4
G. Collins	0.5	2	1	1.5	5	3	1	4	3	2	10	6	8	6
B. Winter	0.5	2	1	1.5	5	2	1	4	3	2	10	6	8	4
D. Winter	0.5	2	1	1.5	5	2	1	4	3	2	10	8	10	4
A. Shephard	0.5	2	1	1.5	5	2	1	4	3	2	10	6	8	4
F. Border	2	0.5	1.5	1	3	3	2	1	4	2	10	8	6	2
S. Shephard	0.5	2	1	1.5	4	2	1	5	3	2	8	6	8	4
K. Collins	0.5	2	1.5	2	5	2	1	4	3	2	10	8	10	4
D. Phillips	1	2	1	1.5	5	2	1	5	3	2	8	6	8	4

Table 5: *Results from Judging by Camera & Monitor*

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Solution (m)	0.5	2	1	1.5	5	2	1	4	3	2	10	6	8	4

Table 6: *Solution to the Camera & Monitor Phase*

Out of the three phases, judging distances via a single camera and monitor setup is the least accurate out of the three methods. This provides further evidence of the disadvantage of typical telepresence.

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Between 0-2m				Between 0-5m				
Correct (%)	72.73	90.9	81.82	81.82	63.64	81.82	90.9	54.55	72.73
Range (%)	81.84				72.73				
Mean (m)	0.73	1.86	1.09	1.5	4.55	2.18	1.09	3.91	3.91
Solution (m)	0.5	2	1	1.5	5	2	1	4	3

Table 7: *General Statistics from Camera & Monitor Phase*

Location	**10**	**11**	**12**	**13**	**14**
	Between 0-10m				
Correct (%)	100	72.73	72.73	72.73	81.82
Range (%)	80				
Mean (m)	2	9.27	6.55	8.18	4
Solution (m)	2	10	6	8	4

Table 8: *General Statistics from Camera & Monitor Phase Continued*

Table 8 above contains the statistics of the percentage of the participant population which correctly estimated the distance of the object's position across the 14 locations trialled. It also contains the mean estimated distance as well how successful the population was overall at estimating between the three range categories (0 to 2m, 0 to5m & 0 to 10m).

5.2.3 Evaluating the Accuracy using Stereoscopic Vision

Judging Depth Perception by Stereoscopic Vision Results														
Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	Between 0-2m				Between 0-5m					Between 0-10m				
J. Gleeson	2	0.5	1.5	1	4	3	3	1	5	8	4	8	6	2
J. Winter	2	0.5	1.5	1	4	3	2	1	5	8	4	10	6	2
B. Gleeson	2.5	0.5	1.5	0.5	5	4	3	1	5	8	4	10	6	2
G. Collins	2	0.5	1.5	1	4	3	2	1	5	8	4	8	6	2
B. Winter	2	0.5	1.5	1	4	3	2	1	5	8	4	10	6	2
D. Winter	2	0.5	1.5	1	5	2	4	1	6	10	6	10	8	2
A. Shephard	2	0.5	1.5	1	4	3	2	1	5	8	6	10	8	2
F. Border	2	0.5	1.5	1	3	3	2	1	5	8	4	10	6	2
S. Shephard	2	0.5	1.5	1	5	4	3	1	5	10	6	10	8	2
K. Collins	1.5	0.5	1.5	1	4	3	2	1	5	8	4	8	6	2
D. Phillips	2	0.5	1.5	1	4	3	2	1	5	8	4	10	6	2

Table 9: *Results from Judging by using the Oculus Rift for Stereoscopic Vision*

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Solution (m)	2	0.5	1.5	1	4	3	2	1	5	8	4	10	6	2

Table 10: *Solution to the Stereoscopic Vision Phase*

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Between 0-2m				Between 0-5m				
Correct (%)	81.82	100	100	90.91	63.64	72.73	63.64	100	90.91
Range (%)	93.18				78.18				
Mean (m)	2	0.5	1.5	0.95	4.18	3.09	2.45	1	5.09
Solution (m)	2	0.5	1.5	1	4	3	2	1	5

Table 11: *General Statistics from the Stereoscopic Test Phase*

Location	**10**	**11**	**12**	**13**	**14**
	Between 0-10m				
Correct (%)	81.82	72.73	72.73	72.73	100
Range (%)	80				
Mean (m)	8.36	4.54	9.45	6.54	2
Solution (m)	8	4	10	6	2

Table 12: *General Statistics from the Stereoscopic Test Phase Continued*

5.3 Vision Method Accuracy Comparison

The group accuracy is able to be compared to identify which vision method worked most effectively within certain ranges.

Location	**1**	**2**	**3**	**4**
	Between 0-2m			
Eye	86.37			
Camera & monitor	81.84			
Stereoscopic Vision	93.18			

Table 13: *Group Accuracy between 0 & 2m*

Location	**5**	**6**	**7**	**8**	**9**
	Between 0-5m				
Eye	94.55				
Camera & monitor	72.73				
Stereoscopic Vision	78.18				

Table 14: *Group Accuracy between 0 &5m*

Location	**10**	**11**	**12**	**13**	**14**
	Between 0-10m				
Eye	80				
Camera & monitor	80				
Stereoscopic Vision	80				

Table 15: *Group Accuracy between 0 & 10m*

For judging distances between 0 & 2m, it was found that the stereoscopic vision using the Oculus rift allowed the participants in this experiment to have an overall accuracy of 93.18% within the group.

When the object was placed at a distance 0 to 5m away from the individual, naturally judging the distance by eye yielded a group accuracy of 94.55% which was significantly better than both the stereoscopic vision and the camera and monitor arrangement.

At distances approaching 10m, the data indicates that neither vision method was advantageous nor disadvantageous compared to one another. All 3 methods totalled 80% in the group accuracy.

5.4 Analysing Questions from the Stereoscopic Depth Perception Test

The questionnaire included in the test sheet was answered in depth by most participants. The questions in order which were asked to be completed at the end of the test are:

1) Which, if any was your preferred and least preferred vision method and why?
2) Which do you believe was the most accurate and least accurate method?
3) Did the Oculus Rift make you feel unwell at any time?
4) Do you believe the Oculus Rift provided and experience similar to the natural human eye?
5) Are you confident in your depth perception ability?
6) Do you commonly use remotely operated vehicles or play video games?

From these questions, valuable information was able to be extracted from the replies. This included:

- The preference out of the 3 vision methods
- Which was believed to be most accurate
- Whether cyber-sickness had an impact on the participants and is a significant disadvantage to incorporating stereoscopic vision into telepresence
- How effective is the Oculus Rift DK2 at creating the telepresence effect
- Whether the gain in accuracy is consistent with those who typical use remotely operated vehicles or are used to video games which require similar hand eye co-coordination and judgement skills

5.4.1 Most Accurate

The questionnaire attached to the stereoscopic vision test was conclusive in which vision method the participants found most accurate. In 100% precent of cases the participants believed that the method they believed as most accurate followed as:

1) Natural eye
2) Stereoscopic vision via the Oculus Rift HMD & OVRVision Pro
3) Single camera & monitor combination

5.4.2 Participant’s Preference on Vision Methods

Unsurprisingly, the method the participants preferred to use was also the same as that which was found most accurate to use. In all 11 tested cases the order of preference from highest preference to lowest was:

1) Natural eye
2) Stereoscopic vision via the Oculus Rift HMD & OVRVision Pro
3) Single camera & monitor combination

5.4.3 Impact of Cyber Sickness

The impact of cyber-sickness was a hypothesised result with expectations of occurrence within at least a few of the participants. During the stereoscopic vision test, not a single user commented on feeling uneasy or sick when asked. This bodes well for future use with VR headsets in the future as cyber-sickness/ motion sickness is typically one of the significant disadvantages. Although it is a great outcome, it is likely a non-occurrence due to the mostly static nature and low intensity of the test. It was mentioned that sudden abrupt movements did have a jarring effect on the user.

5.4.4 Oculus Rift DK2 Immersion

Participants answered that the Oculus Rift DK2.0 provided an experience quite similar to the human eye. It was stated that although not on the same level of quality of vision method the DK2 provided a level of immersion which was much greater than expected. This was the general opinion with only very few who seemed to disagree.

5.5 Conclusion

The results drawn from the data of the distance judging test and the questionnaire provide evidence of the advantages when using the Oculus Rift DK2 to achieve stereovision. An improvement of judging distances up to 11.34% and 5.45% more accurately with stereoscopic vision at distances of 0 to 2m and 0 to 5m respectively then against the traditional telepresence method of using a camera and monitor. As expected there is a definitive drop in accuracy when using any of the two telepresence methods compared to a human judging the distance by eye. At distances approaching 10m, no vision method provided any benefits during the experiment which indicates that telepresence is more viable at shorter ranges.

Chapter 6

Stereoscopic Vision & Robotics Testing

This chapter covers the experimental testing of the created remotely operated telepresent robot. The test has been created to determine if using a VR headset can provide a benefit similar to the natural human depth perception and compare it against a traditional telepresence method of a single camera and monitor.

6.1 Stereoscopic Telepresent Robot Test

The following section describes the test which the tele-operated robot is to perform. The following described test has been created to obtain information to determine if utilising virtual reality technology such as the Oculus Rift DK2 can provide an advantage in the form of telepresence. The Stereoscopic Vision Robotic Test is to be completed by the same participants following the Stereoscopic Depth Perception Test.

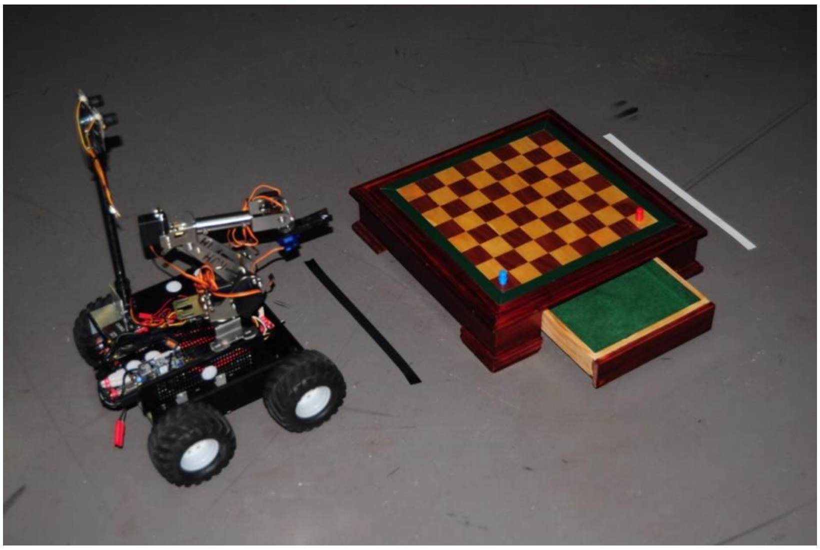


Figure 28: *The Created Telepresent Robot Test*

6.2 Robotic Test Preparation

With the population size of 11, the participants involved in the testing of the tele-operated/telepresent robot were required to be clearly aware of what the task required them to do. Participants of the experimental testing have had various experience operating remotely controlled vehicles so it was important the each participant feel they have been made aware of how to correctly operate the robot. Before any testing had been performed by each participant, the following were put in place to provide a fluid and positive experience for the participant. The steps listed below have been put in action for reasons previously listed.

Before Testing:

1) Familiarise the user with robot
2) Familiarise the user with the robots control panel
3) Introduce the 3 different vision methods to the individual
4) Clearly explain the task to the user
5) Provide a copy of the test task sheet to each individual which also contains a descriptive explanation on the task
6) Explain how to correctly fill in the results sheet

After Testing:

7) Examine the participant’s result sheet to ensure it has been completed and assist with any section if the participant does not find the description clear
8) Ask the participant to sign the declaration form giving permission to use the results as a part of the research project

6.3 Robotic Testing Overview

To ensure the repeatability of the created test, six basic steps are detailed below which must be performed in a specific order each time the test is performed. These steps have been intended to require a low amount of skill to complete to allow every participant to complete and contribute useful data to be further analysed.

The steps of the test in order are:

1) Using the control panel, navigate the robotic arm to a position near the chess piece
2) Orientate the robotic gripper into a position which the participant will believe will grip the chess piece when the gripper closes
3) Grip the chess piece
4) Move the piece onto the opposite corner of the chess board
5) Wait for instructor to measure the error in terms of x and y displacement and record the time taken to complete the task

The above test is to be repeated with the following three vision methods:

• Natural Vision	(Judging distance normally by eye)
• Stereoscopic Vision	(Using the Oculus Rift)
• Single Monitor	(Using a traditional camera & monitor arrangement)

6.4 Test Walkthrough

This section elaborates on each step of the Stereoscopic Telepresent Robot Test

Step 1: *Navigate robotic arm near the chess piece*

Step 1 involves the operator navigating the robotic arm via the control panel into a position which is considered to be near the chess piece. The purpose of this step is not gathering information but to allow the user to set up and concentrate on the finer movements required for step 2.

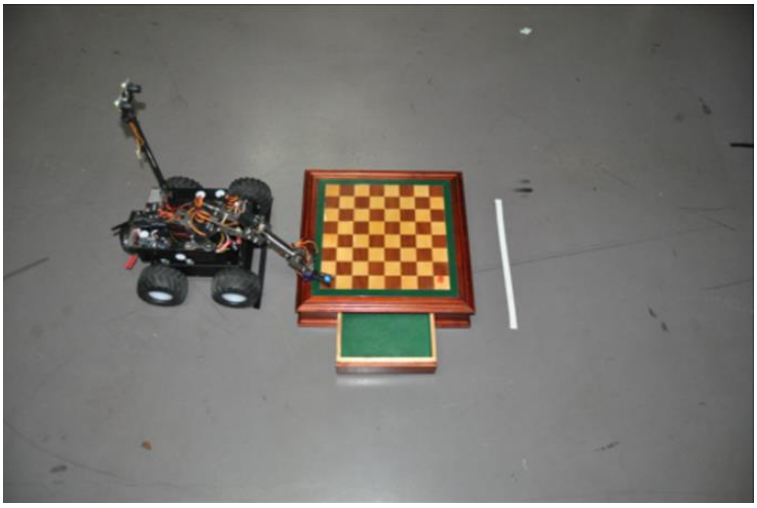


Figure 29: *Navigating the Robotic Arm*

Step 2: *Position the Gripper*

In this step the user is to operate the arm to position the gripper into a position the user will believe they will grip the chess piece if the gripper closes. The location of the gripper is important and the user/participant must believe they are as certain with the final positioning of the gripper.

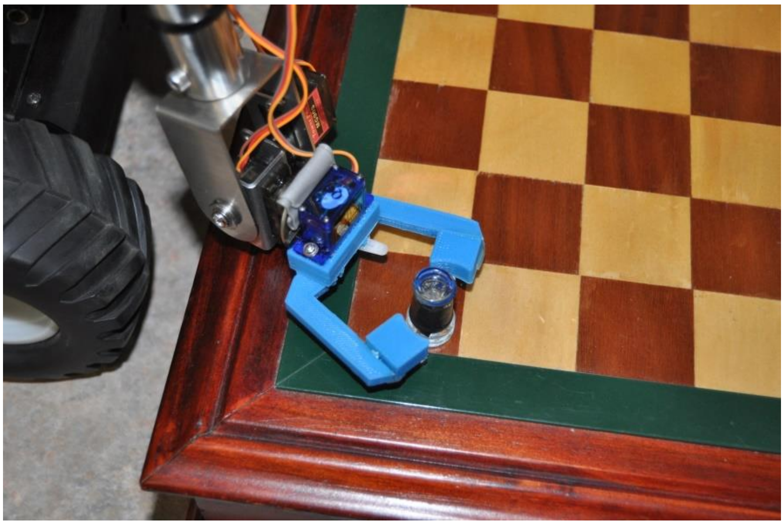


Figure 30: *Positioning the Gripper*

Step 3: *Grip the Chess Piece*

For this step, the user is to grip the chess piece successfully. The object must be gripped successfully inside the gripper sufficiently so it may be moved without falling or being dropped. If the chess piece's location is altered too much by the attempts of the user to a situation where it can no longer be picked up, the chess piece is then to be reset back to the original position so that the test may continue.

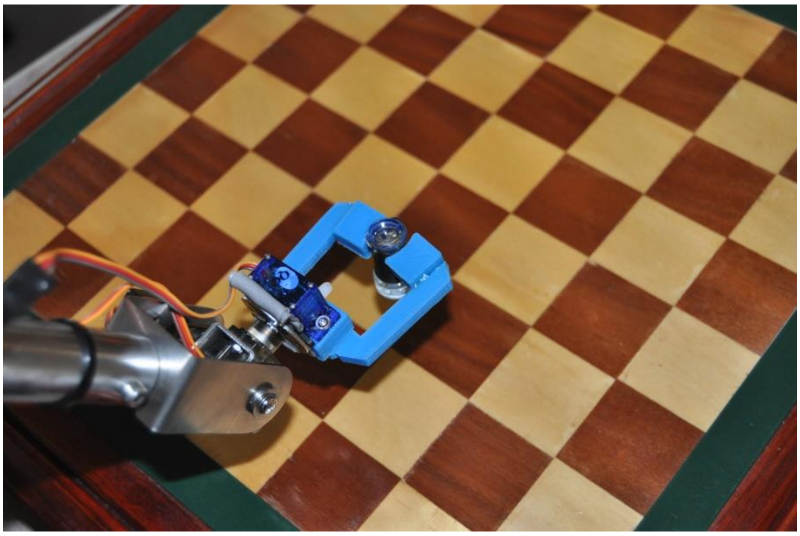


Figure 31: *Gripping the Chess Piece*

Step 4: *Relocate the Chess Piece*

Once the chess piece is successfully obtained by the gripper, it is then required to be moved to the target square of the chess board by the robotic arm. It is required to be positioned as accurately as possible with the centre of the target square of the chessboard. The initial and target square of the chess board is any two adjacent corners of the board. If the piece is dropped or placed in way which caused the piece to topple, the step is to be repeated.

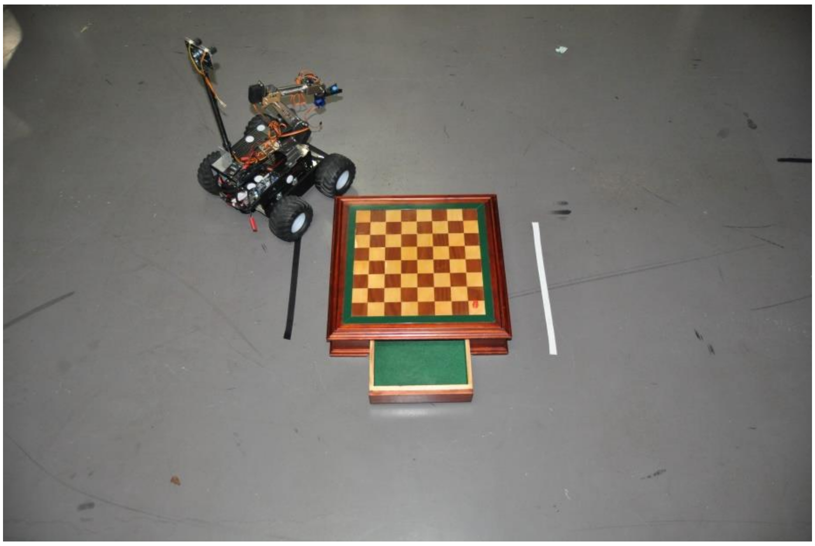


Figure 32: *Relocating the Chess Piece (1)*

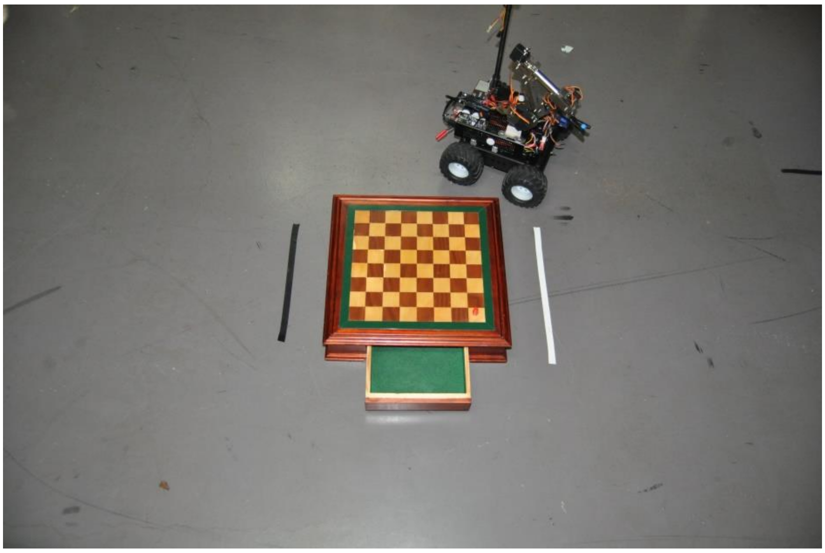


Figure 33: *Relocating the Chess Piece (2)*

Figure 34: *Step 5 Relocating the Chess Piece (3)*

Step 5: *Measuring the Chess Piece Offset Distance*

The offset distance which the chess piece is located from the centre of the target square in Step 5 is measured and recorded on the participant's test sheet along with the total time taken to complete the 5 steps. The offset is easily determined as each square is 40mm and the diameter of the base of the chess piece is 16mm.

Figure 35: *Step 6 Measuring the Chess Piece Offset Distance*

6.5 Aspects for Investigation

The experimental test has been designed to specifically aim at investigating the following:

- Depth perception- How well the user can interaction with an object which is positioned directly in front of them. Is a significant change when going from method to method?

- Accuracy- How well are the object interacted with? Does alternating between the three vision methods have an impact on how well we can interact with the real world?

- Speed- How the test varies in terms of time taken to complete the task of the experiment. Does the vision method make a difference in the time taken?

- User Friendliness- Are particular types of vision method easier or worse the others? Does using a particular one give a specific advantage or disadvantage?

- Preference- Which is the order of preference that users preferred of the three vision methods (natural eye, Oculus Rift, single camera)?

6.6 Hypothesised Results

Prior to commencing testing and reviewing the results, the expected outcomes are as follows:

- An increase in judging distances due to the addition of stereoscopic vision
- A decreased time to perform the test using the Oculus Rift DK2

- A preference of using the Oculus Rift compared to using a single method and camera
- A limited time of use before cyber-sickness sets in

6.7 Statistical Analysis of Stereoscopic Telepresent Robot Test

Utilising the three different vision methods, the robotic test was performed by the participants and the results recorded.

Test Duration			
	Stereovision	Monitor	Eye
J. Gleeson	1 min 17 sec	1min 10 sec	0 min 45 sec
J. Winter	2 min 40 sec	3 min 12 sec	1 min 19 sec
B. Gleeson	0 min 58 sec	0 min 41 sec	0 min 42 sec
G. Collins	3 min 17 sec	1 min 01 sec	1 min 03 sec
B. Winter	1 min 27 sec	1 min 34 sec	0 min 54 sec
D. Winter	3 min 04 sec	3 min 42 sec	2 min 11 sec
A. Shephard	2 min 12 sec	2 min 36 sec	1 min 29 sec
F. Border	1min 30 sec	2 min 45 sec	1 min 15 sec
S. Shephard	2 min 05 sec	1 min 42sec	1 min 22 sec
K. Collins	1 min 53 sec	1 min 14 sec	1 min 08 sec
D. Phillips	1 min 27 sec	1 min 34 sec	0 min 58 sec

Table 16: *Duration of the Stereoscopic Telepresent Robotic Test*

Target Location Accuracy						
	Stereovision		Monitor		Eye	
	Displacement (mm)		Displacement (mm)		Displacement (mm)	
	x	y	x	y	x	y
J. Gleeson	6	5	8	4	3	1
J. Winter	7	3	2	9	4	6
B. Gleeson	3	7	9	15	2	1
G. Collins	5	6	5	4	12	9
B. Winter	2	5	5	5	2	1
D. Winter	16	7	9	8	1	5
A. Shephard	9	13	11	4	5	3
F. Border	12	9	10	13	0	1
S. Shephard	7	11	6	9	2	2
K. Collins	16	5	2	7	1	20
D. Phillips	7	4	9	3	3	2

Table 17: *Accuracy of the Stereoscopic Telepresent Robotic Test*

Magnitude of Error in Displacement (mm)			
	Stereovision	Monitor	Eye
J. Gleeson	7.810	9.434	8.944
J. Winter	7.616	3.606	9.220
B. Gleeson	7.616	11.402	17.493
G. Collins	7.810	7.810	6.403
B. Winter	5.385	7.071	7.071
D. Winter	17.464	11.402	12.042
A. Shephard	15.811	17.029	11.705
F. Border	15.000	13.454	16.401
S. Shephard	13.038	12.530	10.817
K. Collins	16.763	5.385	7.280
D. Phillips	8.062	9.849	9.487

Table 18: *Error Magnitude in the Stereoscopic Telepresent Robotic Test*

From the tables of information recorded form the test results, **Table 19**, is able to be created detailing mean time and the magnitude the 3 different vision methods produced.

Mean Test Duration			
	Stereovision	Monitor	Eye
Mean Time	1 min 59 sec	1 min 56 sec	1 min 11 sec
Magnitude (mm)	11.125	9.906	10.624

Table 19: *Averages of the Stereoscopic Telepresent Robotic Test*

6.8 Survey of Stereoscopic Vision Robotic Test

The questionnaire included in the Stereoscopic Vision was answered in depth by most participants. The questions which were asked to be completed at the end of the test are identical the stereoscopic vision test. To reiterate questions asked are:

1) Which, if any was your preferred and least preferred vision method and why?
2) Which do you believe was the most accurate and least accurate method?
3) Did the Oculus Rift make you feel unwell at any time?
4) Was the robotic arm’s gripper easier to operate with stereoscopic vision?
5) What was the most challenging aspect of the test?

The information which was extracted from these questions was:

- The preference out of the 3 vision methods
- Which was believed to be most accurate
- Whether cyber-sickness had an impact on the participants and is a significant disadvantage to incorporating stereoscopic vision into telepresence
- How effective is the Oculus Rift DK2 at creating the telepresence effect

6.8.1 Most Accurate

Amongst the participants of the experiment, judging by eye was an preferred expected result but a strong agreement of using the monitor over Oculus Rift HMD was surprisingly the greater preference between the two telepresence methods.

6.8.2 Participant's Preference on Vision Methods

Using the Oculus Rift HMD to operate the robot was thought to be the least accurate as well as the least preferred. The most commonly stated reason for this is due to the nature of HMD not allowing the user to view the control and hand position. The ability to quickly glance at the controls while using a monitor proved to be a much more user friendly experience.

6.8.3 Impact of Cyber Sickness

Any form of cyber-sickness was a non-occurrence during the experiment. The fixed position of the OVRVision Pro camera module was the difference in is the setup between the distance judging experiment the robot control experiment. As a result of the no signs of momentary uneasiness, jarring or sickness were experienced. Comparing the responses form the two separate tests, it is evident that momentary uneasiness and sickness is a direct result of quick abrupt movement from the OVRVision Pro stereo camera and not to prolonged exposure to the Oculus Rift HMD.

6.8.4 Oculus Rift DK2 Immersion

The level of immersion was significantly lower for this test by having the OVRVision camera module in a mostly fixed position. The immersion offered by the depth perception was thought to be more immersive than the single camera and monitor configuration but the disadvantages with viewing the controls outweighed all the advantages offered by the moderate gain in depth perception.

6.8.5 Gripper Operation

It was hypothesised that by using stereoscopic vision the accuracy and ease of use of the robotic arm's gripper would increase due the having depth perception to gauging distances. For the operation of gripping the chess piece, this was correct, however as stated in **Section 6.62**, getting the gripper to the object was difficult whilst wearing the headset for participants. Often the gripper was positioned incorrectly by the user due to in experience thus blocking view of the object and rendering the depth perception effect redundant.

6.9 Conclusion

From **Table 19** above, it is evident and expected that using the human eye to operate a vehicle when able to is by far the superior option with an average time of 1 minute and 11 seconds to complete the task. Both of the telepresence methods (stereoscopic vision using the Oculus Rift and the camera and monitor setup) were very similar in time to complete the task and both were far inferior to judging in person by eye. The average time for completion for an operator using the Oculus Rift was 1minute and 59 seconds and 1 minute and 56 seconds for the camera and monitor configuration.

The magnitude of the error of the final target position that the chess piece was placed was fairly consistent across all three of the vision methods of the test. The vision method which resulted in the greatest positioning error of the chess piece was the stereoscopic vision method. Using the Oculus Rift thus resulted in an average error of 11.125mm from the target location. The monitor and camera method proved to be the most accurate with an error of 9.906mm and 10.624mm for judging the robot in person by eye.

After evaluating the data, the results from the robotic test are significantly less indicative of any advantages or disadvantages than the Stereoscopic Depth Perception Test. Contributing factors to this are:

- The robotic arm, although generally easy to control has limited minimum amount of movement when slight adjustments are attempted to be made to its position. Moving the chess piece 2 or 3mm is feasible, but small increments of less than 1mm is not within the ability of the KS-3518 servo motors. Upgrading to a higher quality arm or servo motors would likely overcome this problem of overshoot but is an expensive modification to the robot.

- The operator’s skill level and confidence also had a negative impact on the experiment. Being unfamiliar with the control system of the robotic arm and how the robot axes were able to move often unwilling forced the user into positions which were awkward

- The fixed position of the OVRVision Pro & the CMOS camera modules made it so that the user only had one persistent angle to operate from. The outcome of this meant the user was not able to obtain sufficient information on the location of the chess piece and that of the robotic arm.

Chapter 7

Results and Discussion

The final summaries and findings of the project will be presented in this chapter, along with suggestion for future work relating to the field of remotely operated telepresent robotics.

7.1 Project Outcome

By evaluating the data collected from the performing two separate tests. It is evident that using a Virtual Reality headset to achieve stereoscopic vision does provide advantages over a traditional camera and monitor setup in terms of a user's ability to judge objects at a distance. Many participants reported that using the Oculus Rift VR headset in tandem with OVRVision camera presented a similar feeling of immersion as if they were present.

The arm controller was partially constructed and deemed to only provide disadvantages in terms of the robots operation. The joints which were tested required the operator to continue to hold their arm at an uncomfortable position for relatively long durations of time without moving. The concept of a robot mimicking a user's movement is practical in theory but the reality leaves an apparatus with causes discomfort and introduces human error into the robots operation.

The Remotely Operated Telepresent Robot was constructed successfully albeit was not able to provide conclusive evidence to the advantages of stereoscopic vision due to the very fine incremental movements required for comparable accuracy. The testing of the robot however did provide strong evidence of the disadvantages which hindered the user's ability to locate and operate the robot's controls when their peripheral vision had been removed.

7.2 Recommendations for Future Work

Although an investigation into determining whether stereoscopic vision can provide an advantage to remotely operated telepresent robotics has been completed, many other interesting areas of research have arisen which lay outside the scope of this research project. The purpose of detailing these areas of interest is to provide information to those who wish to proceed with further research in relation to tele-operated or telepresent robotics.

7.2.1 Augmented Reality

Within the last decade, augmented reality, the technology of overlaying digital information with that of the real world, has seen significant developments in both the technology and its application. OVRVision, the camera module used to generate the 3D stereoscopic effect is one of the few devices currently being utilised for the development of augmented reality applications with virtual reality technology. The merging of the two technologies has primarily been utilised for gaming (similar to the Oculus Rift) and information on the benefits of using the two in real world applications is very limited.

Applications of how this could be incorporated include; overlaying digital information into the augmented reality such as distance to an object, an example of the task to be performed, instructions & training information and unobtrusive HUD overlays.

7.2.2 Haptic Feedback

Haptic feedback is currently being applied to various robotic applications for telepresence. However there is little information available on how well it performs as most designs are still early concepts or mainly utilised for medical purposes. An investigation into the advantages haptic feedback can contribute to the field of telepresence is interesting and open to investigation, especially if utilised in tandem with the Oculus Rift for stereoscopic vision.

7.2.3 Reducing the Occurrence Cyber Sickness

The occurrence of cyber-sickness (motion sickness) is one of the most limiting factors to a user of the Oculus Rift and other similar VR HMDs. How users are affected by cyber-sickness varies for each individual and the tasks being performed. Investigation into the reduction of cyber-sickness could yield valuable information to making the technology more viable and user friendly.

Possible areas open to investigation include; determining which tasks are the most likely to cause cyber-sickness, determining the typical time a particular task takes to cause cyber-sickness, determining a recommended time limit for particular tasks and figuring out solutions to quickly recover or to increase a user's tolerance.

7.3 Final Conclusion

Overall, the objectives of this project were successful in determining how accurate current telepresence methods are in regards to tele-operated robots and whether or not they can be improved upon by the use of modern virtual reality technology. It is evident that the implementation of stereoscopic vision generates an increase in a user’s ability to remotely judge distances improving environmental awareness. It is also evident that using a head mounted display to generate the stereoscopic vision is detrimental to the user’s ability to correctly operate or interact with anything outside of what is displayed to the operator.

References

Albert, F. Y. C., Mason, C. H. S., Kiing, C. K. J., Ee, K. S., & Chan, K. W., 2014, *Remotely Operated Solar-powered Mobile Metal Detector Robot*,Procedia Computer Science, 42, 232-239, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.procs.2014.11.057>

Azis, F. A., Aras, M. S. M., Rashid, M. Z. A., Othman, M. N., & Abdullah, S. S.,2012, *Problem Identification for Underwater Remotely Operated Vehicle (ROV): A Case Study*, Procedia Engineering, 41, 554-560, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.proeng.2012.07.211>

Baldominos, A., Saez, Y., & Pozo, C. G. d 2015, *An Approach to Physical Rehabilitation Using State-of-the-art Virtual Reality and Motion Tracking Technologies*. Procedia Computer Science, 64, 10-16, viewed 20 October 2015, < doi:http://dx.doi.org/10.1016/j.procs.2015.08.457>

Bauer, H. 1992, *Scientific Literacy and the Myth of the Scientific Method*, viewed 10 May 2016, < http://macaulay.cuny.edu/eportfolios/branco2014/files/2014/08/Bauer_1992.pdf>

Beattie, N., Horan, B., & McKenzie, S., 2015 ,*Taking the LEAP with the Oculus HMD and CAD - Plucking at thin Air?* Procedia Technology*, 20*, 149-154, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.protcy.2015.07.025>

Davis, B., Bryla, K., Benton , P., 2015, *Oculus Rift in Action*, Manning Publications Co., Shelter Island, New York

Beveridge, W. 1963, *The Art of Scientific Investigation*, University of Cambridge, view 10 May 2016, < http://pauladaunt.com/books/artofscientificinvestigation60beve.pdf>

Fominykh, M., Prasolova-Førland, E., Morozov, M., Smorkalov, A., & Molka-Danielsen, J, 2014, *Increasing Immersiveness into a 3D Virtual World: Motion-tracking and Natural Navigation in vAcademia*, IERI Procedia*, 7*, 35-41, viewed 20 October 2015 <doi:http://dx.doi.org/10.1016/j.ieri.2014.08.007>

Hobby King, 2016, Hobby King Australia, viewed 9 October 2016, <http://www.hobbyking.com/hobbyking/store/__15295__SkyZone_5_8Ghz_200mw_FPV_Wireless_AV_Tx_Rx_Set.html>

Jain, P. 2012, Engineers Garage: Joysticks, viewed 17 August 2015, <http://www.engineersgarage.com/articles/what-is-a-joystick>

Kicinger, R., Wiegand, R., 2013, *Experimental Design and Methodology,* Basic lessons in empiricism, George Mason University, view 18 May 2016, < https://cs.gmu.edu/~eclab/papers/lecture-pres/expdes.pdf>

Launius, R. D., & McCurdy, H. E. (2007). Robots and humans in space flight: Technology, evolution, and interplanetary travel. *Technology in Society, 29*(3), 271-282, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.techsoc.2007.04.007>

M, Garin., 2012, *Understanding Your Depth Perception*, *Eye Health Web, viewed* 15 May 2016, <http://www.eyehealthweb.com/depth-perception/>

More Process 2012, *How does a joystick work?*, viewed 17 August 2015, <http://www.moreprocess.com/devices/how-does-a-joystick-work>

Nalivaiko, E., Davis, S. L., Blackmore, K. L., Vakulin, A., & Nesbitt, K. V., 2015, *Cybersickness provoked by head-mounted display affects cutaneous vascular tone, heart rate and reaction time*, Physiology & Behavior*, 151*, 583-590, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.physbeh.2015.08.043>

National Vocational Education and Training Content NVETC 2014, *Introduction to hazards and risks*, viewed 20 October 2015, <https://nationalvetcontent.edu.au>

Naughton, R. (ed) 2002, *Hargrave the Pioneers: Robert Esnault-Pelterie (1881-1957)*, viewed 17 August 2015, http://www.ctie.monash.edu/hargrave/rep.html

Ocean Explorer, 2015, Ocean Explorer, viewed 20 October 2015, <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/info/info.htm>

Oculus, 2015, Oculus USA, Irvine, California, viewed 20 October 2015, < https://www.oculus.com/en-us/rift/>

Oyekan, J., Hutabarat, W., Turner, C., Tiwari, A., Prajapat, N., Ince, N., . . . Waller, T, 2015, A 3D *Immersive Discrete Event Simulator for Enabling Prototyping of Factory Layouts*, Procedia CIRP, *38*, 63-67, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.procir.2015.08.043>

Portugal, D., Cabrita, G., Gouveia, B. D., Santos, D. C., & Prado, J. A., 2015, *An autonomous all terrain robotic system for field demining missions*, *vloume 70*, 126-144, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.robot.2015.02.013>

R, Vilayanur., Rogers-Ramachandran, D., 2009,*Two Eyes, Two Views: Your Brain and Depth Perception*, Scientific American Mind, viewed 12 May 2016, <http://www.scientificamerican.com/article/two-eyes-two-views/>

Sparkfun , 2016, SparkFun Electronics, Colorado, viewed 12 May 2016, <https://www.sparkfun.com/products/11745>

Syberfeldt, A., Danielsson, O., Holm, M., & Wang, L., 2015, *Visual Assembling Guidance Using Augmented Reality, Procedia Manufacturing, 1*, 98-109, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.promfg.2015.09.068>

UCI, 2004, *Perceiving Depth and Size,* UCI Donald Bren School of Information and Computer Sciences, viewed 15 May 2016, <http://www.ics.uci.edu/~majumder/vispercep/chap8notes.pdf>

van Osch, M., Bera, D., van Hee, K., Koks, Y., & Zeegers, H., 2014, *Tele-operated service robots: ROSE*,Automation in Construction*, 39*, 152-160, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.autcon.2013.06.009>

Wizapply, 2016, Wizapply Office, Osaka, viewed 13 September 2016, <www.ovrvision.com/about-en/>

Wojtara, T., Nonami, K., Shao, H., Yuasa, R., Amano, S., Waterman, D., & Nobumoto, Y.,2005, *Hydraulic master–slave land mine clearance robot hand controlled by pulse modulation*, Mechatronics, 15(5), 589-609, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.mechatronics.2004.09.007>

Xu, X., Chen, K. B., Lin, J.-H., & Radwin, R. G., 2015, *The accuracy of the Oculus Rift virtual reality head-mounted display during cervical spine mobility measurement*, Journal of Biomechanics*, 48*(4), 721-724, viewed 20 October 2015, <doi:http://dx.doi.org/10.1016/j.jbiomech.2015.01.005>

Appendix A

ENG 4111/4112 Research Project

Project Specification

For:	Jarrad Gleeson
Title:	Remotely Operated Telepresent Robotics
Major:	Mechatronic Engineering
Supervisors:	Tobias Low
Sponsorship:	N/A
Enrolment:	ENG4111-ONC S1, 2016 ENG4112-ONC S2, 2016
Project Aim:	To research and utilise depth perception vision, alternative control and force feedback methods to determine if user interaction and operation of remotely controlled robotics can be improved.

Programme: **Issue A, 16th March 2016**

1. Achieve an increase in accuracy for remotely controlled robotic limbs through improved vision for the user by implementing depth perception and directed camera movement which utilises head tracking technology. The device used to achieve this will be the Oculus Rift Development Kit 2.0.

2. The development of a wearable control apparatus worn on the user's arm to control a robotic arm which would mimic the position to that of the users arm.

3. Compare the proposed research project vision and control methods against traditional controls (joystick and buttons) in terms of speed, accuracy, usability and learning curve for multiple users to determine if user operation can be improved through the implementation of newly developed technologies.

If time and resources permit:

4. Construct or utilise a mobile platform for the robotic arm to increase the functionality and reach of the robot affecting the type of tasks it may perform.

5. Achieve a force feedback control method when interacting with objects to emulate the sensation of a user physically interacting with an object themselves in an attempt for greater accuracy.

Project Planning

Phase 1	**Initial Phase**
1A	Resource gathering - gathering essential hardware (i.e. electronic components, microcontroller, Oculus Rift Development Kit 2.0, robotic arm, digital video cameras, etc.). For the current full hardware list see Table 3.2
1B	Literature review - covering all of the aspects of the project in depth relevant to the current stage of the project
1C	Commence construction – of the main robot (platform, arm, receiver, camera support, robotic arm and gimbal etc.)
Phase 2	**Depth Perception and Camera/Headtracking Phase**
2A	Oculus Rift integration – by adapting the headset to be used in junction with two video cameras positioned side by side on a specifically designed mount. The two cameras will serve as the video inputs into each lens of the VR headset to achieve depth perception
2B	Construction of the gimbal – to allow for the two cameras to rotate about the x, y and z axis of the camera mount with respect to the user's head position taken from the Oculus Rift's head tracking log.
2C	Testing/debugging of the hardware - ensuring hardware interfaces and operates correctly
Phase 3	**Robotic Mimicking Phase**
3A	Construction of the wearable control device - from potentiometers, a microcontroller and haptic feedback motors which are to read the position of the users limb and send this information to the robot via a 2.4 GHz transmitter
3B	Construction of the embedded system – to receive the information from the wearable apparatus and then use the information to control the robotic arm and platform
3C	Program creation – written in C++ to be uploaded to the microcontroller for control all of the interfaced hardware
Phase 4	**Mobile Platform Construction Phase**
4A	Construction of the mobile platform – to allow for more vigorous non stationary testing (only to be done if previous stages are completed and sufficient time remains for this phase)
Phase 5	**Testing Phase**
5A	Amalgamation and testing- of all the aspects of hardware and software to ensure the complete robot functions as intended
5B	Testing the effectiveness – by conducting a study were a sample population of users will control the robot and perform the same task using traditional control methods (Joystick buttons, camera and monitor) and then again with the research project's control methods (limb mimicking, depth perception and head tracking via the VR headset. The study is looking to determine if there is: • Improvements in speed • Improvements in accuracy • A reduction in the learning curve • Greater ease in usability The task will involve interacting with the real world by having the robotic arm grab an

	object and relocating it to a specified location which will require accuracy to position it correctly.
Phase 6	**Write-up Phase**
6A	Draft dissertation – complete and submit draft to Supervisor for review and feedback
6B	Finalise dissertation – make alterations based on feedback and submit final draft

Table A.1: *Phase Task Plan*

Appendix B

Resource Requirements

The estimated required resources for the research project regarding the necessary equipment is listed in **Table B.1**. The status on which items have been obtained since the beginning of the project has also been included in the table below.

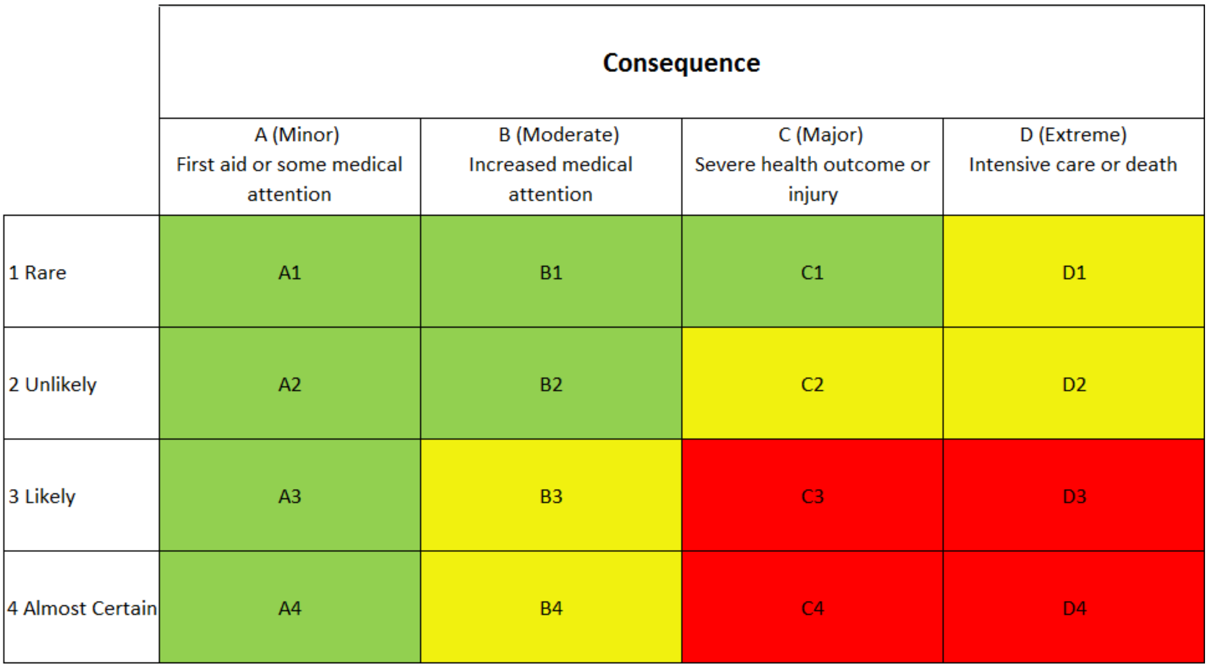
Task	Item	Amount	Source	Cost	Status
1C	Platform	1	USQ	Nil	No
1C	Camera support	1	3D printed	$10	Have
3A-B	Electronic components	20+	Jaycar	$50	Have
3B	Microcontroller	1	Student	Nil	Have
2A	Oculus Rift Development Kit 2.0	1	Student	$450	Have
1C	Lynxmotion AL5B Robotic arm	1	Robot Shop	$135	Do not Have
2A	Sony CCD Video Camera	2	HobbyKing	$101	Have
2B-4A	Motors (brush, servo and haptic)	8	Jaycar	$150	Have
2B	Gimbal	1	3D printed	$10	Have
2A	Video Tx/Rx	1	HobbyKing	$240	Have
2A	LCD monitor	1	Student	Nil	Have
4A	Remote transmitter	1	Student	Nil	Have
Unknown	Miscellaneous 3D printed parts	Unknown	Student	$60	Have
5B-6B	WORD software	1	Student	Nil	Have
5B	EXCEL spreadsheet	1	Student	Nil	Have

Table B.1: Initial Estimation of Project Resources

Appendix C

Risk Assessment

Before commencing work on the research project it is important that time be taken to perform a risk assessment on the work to be carried out for each task of the project. The safety matrix below in **Table C.1** provides a useful way to measure the likelihood and consequence of an undertaken task (NVETC, 2014). Risks levels in the matrix consider low, medium and high risks and are applied the colours green, yellow and red respectively. Any task that falls into the high risk category should not be attempted and requires further risk reduction to bring the task to a safe risk level. **Table C.2** considers each task that presents a risk to the student, details the risk level and considers an appropriate method of risk reduction. In addition to risks that affect the health and safety of the individual, the risks that may have a detrimental effect on the project are also considered and can be found in **Table C.3**.



	Consequence			
	A (Minor) First aid or some medical attention	B (Moderate) Increased medical attention	C (Major) Severe health outcome or injury	D (Extreme) Intensive care or death
1 Rare	A1	B1	C1	D1
2 Unlikely	A2	B2	C2	D2
3 Likely	A3	B3	C3	D3
4 Almost Certain	A4	B4	C4	D4

Table C.1: *Risk Assessment Matrix*

Task	Hazard	Risk Level	Risk reduction
1C	Injury from tool use(drill, hacksaw, etc.)	B2	1) Wear eye protection 2) Clear adequate workspace
2A	Light electrical shock, tripping hazard	A1	1) No food or drink in work space 2)Clear adequate workspace
2B	Injury from tool use(drill, hack saw, etc.)	A1	1) Wear eye protection 2) Clear adequate work space
2C	Light electrical shock, tripping hazard	A1	1) No food or drink in work space 2) Clear adequate workspace
3A	Light electrical shock, light abbrassions from wearing device	B2	1) No food or drink in work space 2) long sleeve protective clothing
3B	light electrical shock	A1	1) No food or drink in work space
4A	Injury from tool use(drill, hack saw, etc.), light electrical shock	B1	1) Wear eye protection 2) No food or drink in work space
5B	Risk of unintentional robot/ human contact	A1	1) Operators and onlookers to be positioned at a sufficiently safe distance from the robot

Table C.2: *Personal Risk Assessment*

Task	Hazard	Risk Level	Risk Reduction
2A	Unable to source the Oculus Rift hardware	Medium Risk	1) Develop a contingency plan that may result in the use of a different vision method adjust project scope to account for this altered factor
N/A	Insufficient personal funds	Low Risks	1) Set aside more than a sufficient amount of funds to cover any unforeseen costs

Table C.3: *Project Risk Assessment*

Appendix D

Project Schedule

The project will follow the planned schedule shown in Figure 1. It aims for the student to meet the predetermined dates for each listed requirement. Each week of the project has been allowed approximately of 10 hours of effort. The schedule aims to ensure the student follows:

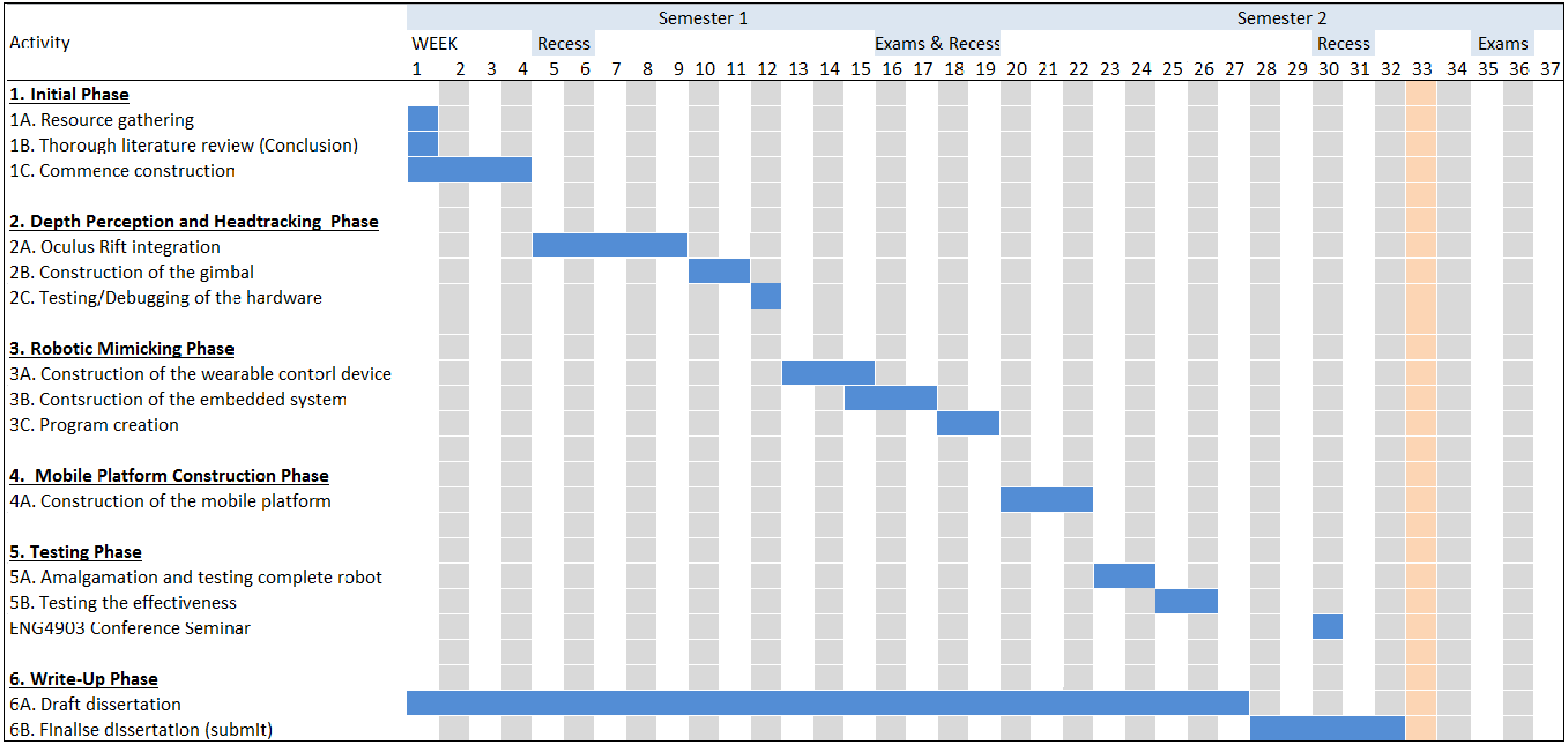
- The project preparation work which commenced on 4th January (gathering hardware resources and additional literature review)

- The official project start date of Week 1 Semester 1 and official end date of October 13th 2016

- Meetings and progress reports on a set date and time

- ENG4903 conference and seminar activities which will occur in the semester 2 holidays at residential school

- A timely analysis of the study data and sufficient progress with the dissertation write-up which is to be undergone simultaneous with other phases of the project as progress permits



Activity	Semester 1																			Semester 2																	
	WEEK				Recess											Exams & Recess														Recess					Exams		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1. Initial Phase																																					
1A. Resource gathering	■																																				
1B. Thorough literature review (Conclusion)	■																																				
1C. Commence construction	■	■	■	■																																	
2. Depth Perception and Headtracking Phase																																					
2A. Oculus Rift integration					■	■	■	■	■																												
2B. Construction of the gimbal										■	■																										
2C. Testing/Debugging of the hardware												■																									
3. Robotic Mimicking Phase																																					
3A. Construction of the wearable contorl device													■	■	■																						
3B. Contsruction of the embedded system															■	■	■																				
3C. Program creation																		■	■																		
4. Mobile Platform Construction Phase																																					
4A. Construction of the mobile platform																				■	■	■															
5. Testing Phase																																					
5A. Amalgamation and testing complete robot																							■	■													
5B. Testing the effectiveness																									■	■											
ENG4903 Conference Seminar																														■							
6. Write-Up Phase																																					
6A. Draft dissertation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
6B. Finalise dissertation (submit)																												■	■	■	■	■					

Figure D.1: Project Schedule

Appendix E

INFORMED CONSENT PROFORMA

Please complete this form after you have read the Information Sheet and listened to an explanation about the research.

Project Title: Remotely Operated Telepresent Robotics

Researcher: Jarrad Gleeson

Thank you for your interest in taking part in this research. Before you agree to take part, please await further explanation.

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join. If you would like to be given a copy of this Consent Form to keep, please ask the researcher prior to the commencement of the experiment.

Participant's Statement

I agree that:

- I have read the notes written above and the Information Sheet, and understand what the study involves
- I understand that the information I will submit will be published as a result within a dissertation where my surname and initials may be used for reference purposes only
- I understand that if at any time that I no longer wish to take part in this project, I can notify the researcher involved and withdraw immediately
- I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998

Signature: Date:

Experimental Testing

Name:

Date: / /2016

Test: Depth Perception Test

Instructions:

The following test involves performing the same simple task with 3 varying vision methods. The participant is to judge the distance of an object which will vary multiple times.

Health & Safety:

Users of the Oculus Rift are very prone to experience sickness similar to motion sickness, if you feel unwell during any part of the testing, please notify the instructor.

	Test			
	Step	Eye	Monitor	Stereovision
0 to2m 0.5m increments	1			
	2			
	3			
	4			
0 to 5m 1m increments	5			
	6			
	7			
	8			
	9			
0 to 10m 2m increments	10			
	11			
	12			
	13			
	14			

1) Which, if any was your preferred and least preferred vision method and why?

____

____

____

____

2) Which do you believe was the most accurate and least accurate method?

3) Did using the Oculus Rift make you feel unwell/ uneasy at any time?

4) Do you believe using the Oculus Rift provided an experience similar to the natural human eye?

5) Are you confident in your depth perception ability?

6) Do you commonly use remotely operated vehicles/devices or play video games?

Solutions to Stereoscopic Vision Test

The solutions to the experiment can be seen below in **Table x**. They have been predetermined to allow a certain degree of consistency when judging depth perception. This allows for easy repeatability and efficiency for running the test. It also ensures that the object is measured at the same distances for the next user to be able to compare results easily and determine if the participant had difficulty judging at any specific region.

	Test			
Step	**Range**	**Solutions**		
1	Small up to 2m:	1.5	0.5	2
2		1	2	0.5
3		2	1	1.5
4		0.5	1.5	1
5	Moderate up to 5m:	3	5	4
6		4	2	3
7		1	1	2
8		2	4	1
9		5	3	5
10	Large up to 10m:	4	2	8
11		8	10	4
12		6	6	10
13		10	8	6
14		2	4	2

Experimental Testing

Name:

Date: / /2016

Test: Stereoscopic Telepresent Robot Test

Instructions:

1) Using the control panel, navigate the robotic arm to a position near the chess piece
2) Orientate the robotic gripper into a position you believe will grip the chess piece when the gripper closes
3) Grip the chess piece
4) Move the piece onto the opposite corner of the chess board. Aim for the middle of the square to accurately as possible
5) Wait for instructor to perform a measurement

Health & Safety:

Users of the Oculus Rift are very prone to experience sickness similar to motion sickness, if you feel unwell during any part of the testing, please notify the instructor.

	Test		
	Stereovision	Monitor	Eye
Time to Complete			
x-Displacement Error			
y-Displacement Error			

1) Which, if any was your preferred and least preferred vision method and why?

____

____

____

____

2) Did you feel the task was difficult or easy?

____

____

____

____

3) Did using the Oculus Rift make you feel unwell/ uneasy at any time?

____

____

____

____

4) Do you believe using the Oculus Rift provided an experience similar to the natural human eye?

____

____

____

____

5) Did you feel more co-ordinated using the Oculus Rift compared to the monitor?

____

____

____

____

Additional Comments:

____

____

____