PR2 Teleoperation Implementation

Summer 2012

Blake McMillian, SUNFEST – (CSC), Hampton University
Jason Allen, SUNFEST – (E.E.), University of District of Columbia
Elizabeth Fedalei, - (M.E.), University of Pennsylvania

Advisors: Dr. CJ Taylor, Dr. Katherine J. Kuckenbecker, Rebecca Pierce

Abstract

Robotics is a field that has many facets. One pivotal aspects of robotics involves the manipulation of the robot itself. For decades the traditional joystick style controllers have hindered the scientific community. The research that I have done over the course of the summer is a bold attempt at changing that. By using the Vicon cameras along with the robot operating system (ros) I, and my fellow researchers were able to build a prototype that has the potential to dexterously control the PR2's gripper. This is done using a system that integrates Ros, the Vicon system, and a mechanical hand motor that allows the user to interact with the PR2 in an innovative way. When an individual is allowed to control a robot using the natural motion of his or her own hand, something special happens; telemanipulation spontaneously becomes unambiguous. Nearly anyone with a properly functioning hand instantly gains the ability to manipulate a previously complex system teleoperational system with ease.

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1. Introduction

Conventional telemanipulation systems are constructed around complicated controllers with arduous, cumbersome designs. In fact, the first systems were electrical, controlled by an array of on–off switches to activate various motors and move various axes [1]. Despite the fact that the original teleoperational systems were developed nearly seven decades ago very little has changed. As of yet, telemanipulation is still governed by complex controllers that require extensive training and knowledge. For instance, military bomb disposal robots are equipped with a plethora of high tech weapons and tools, yet their operators lack an intuitive ergonomic manipulator to control the device [2]. Modern telerobotics has come very far; however the way it is manipulated has not.

Dexterous, flexible functions are required for human operators to accurately manipulate robots [3]. This paper describes the creation of a prototype telemanipulation device that will be used to control the PR2 robot. The prototype will use sensors along with the Vicon system to track the movement of the teleoperational mechanism. Along with the sensors the device will use an accelerometer and haptic feedback, which will successfully model a shared controlled telerobotic architecture.

This innovative controller for the PR2 robot uses the operator's physical body to interpret movements instead of the conventional joystick controlled interface. The prototype has many practical applications that would work to disencumber a plethora of teleoperational limitations. The PR2s teleoperational manipulator has many uses. One instance could be equipping deep-sea robots with this proposed technology, which would allow for engineers to actively fix problems with great precision. This would greatly improve the reaction time in situations like the BP oil spill or the Japanese nuclear disaster.

2. Background

2.1 Teleoperation

Teleoperation is a facet of robotics that dates back to the mid 1940’s and 1950’s. A nuclear researcher named Raymond C. Goertz created a system for individuals to handle radioactive materials without having to be in direct contact with it. The first systems were electrical and controlled by a series of on and off switches. Without any feel, these manipulators were *slow and somewhat awkward to operate*, leading *Goertz* to build pairs of mechanically linked master–slave robots [1,4].

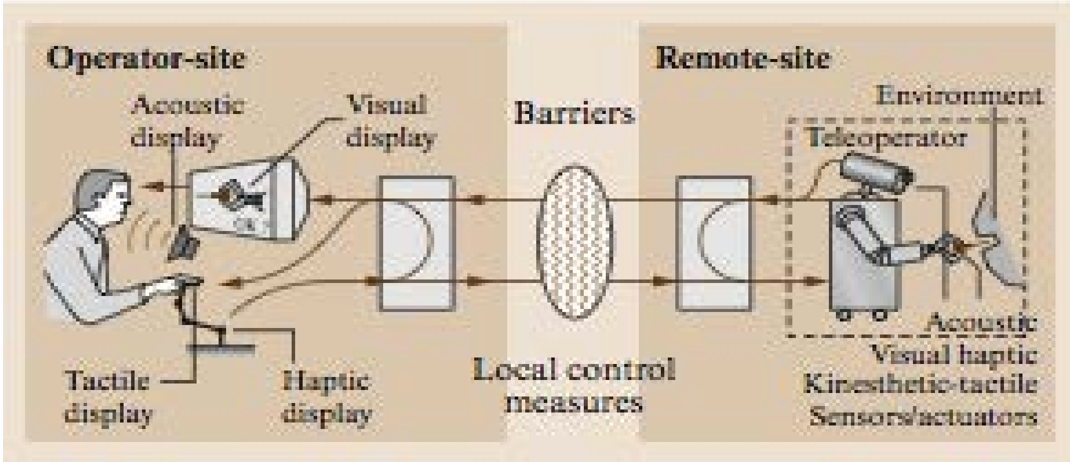
During this research a shared control master slave teleoperational system is developed for the personal robot 2 (pr2) that allows the user to effortless telemanipluate the robot. The system involves the use of a microcontroller, which is used to input, and output information from the robot operating system to the motor, an operational amplifier that is used to provide power to the motor that drives the telemanipulation device.

Teleoperation is important because it allows an operator to perform a task without physically being at the robots remote cite. This has many potential applications like disarming bombs, landmines, and many other hostile situations while not endangering the lives of the human operators.

2.2 Telerobotics

Telerobotics is subset of teleoperation and is a term used to describe a human’s remote control of a robot. There are many terms used synonymously with telerobotics like telemanipulation and teleoperation; however telerobotics is most commonly used. The differences between these various branches of robotics lie in their level of operation. Teleoperation focuses on task level operation while telemanipulation highlights object level manipulation. See fig [1] for an overview of a typical telerobotics system.

Fig 1. [5] – Overview of a telerobotics system



Telerobotics utilizes a wide array of control architectures, which includes direct, shared, and supervisory control [5]. Direct or manual control is a bilateral control scheme that gives the user all of the control. This system implies no autonomy or intelligence from the robot. Essentially, the user via a master interface dictates all of the robots functions. Shared control divides task execution between the operator site and the remote site. This system gives the robot a certain level of intelligence and autonomy.

In supervisory control the user and robot are connected with local autonomy. For example, the operator gives the robot high-level commands, which are then refined and executed. Fig [2] introduces the basic control architectures that govern telerobotics.

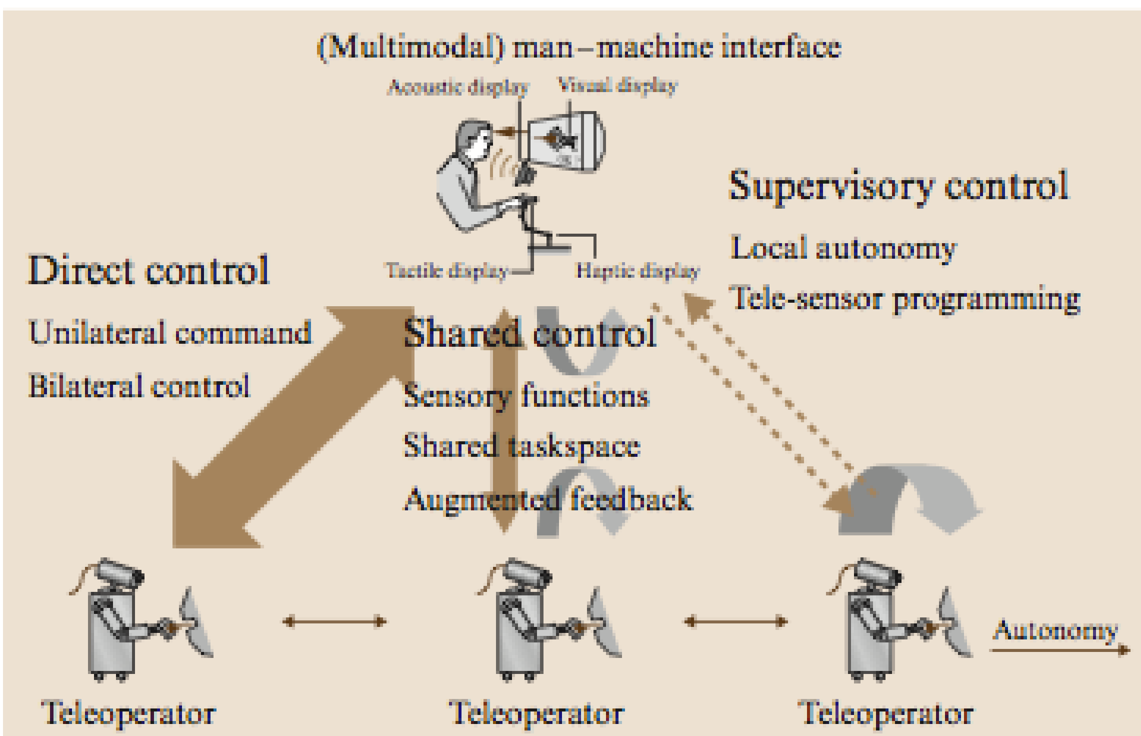


Fig 2. [6] – Displays the basic control architectures of a telerobotics

A rudimentary teleoperational system would fit the mold of a direct control architecture where the user is fully in control of the robot; however this research is different. The personal robot 2 used in the research comes equipped with sensors that give the operator a sense of telepresence that defines it as shared control architecture. By teleoperating a robot that has sensors and tactile feedback the operator is given augmented feedback from the robot.

2.3 Personal Robot 2 (PR2)

The personal robot 2, also known as the pr2 is a platform for research and development that was created by willows garage. The pr2 is a comprehensive mobile humanoid robot that has many applications. The robot's hardware consist of two quad core processors, 24 gigabytes of DDR3 memory, a 500 gigabyte hard drive, two on board severs and various other components. The pr2 has an open modular interface that lets the operator manipulate the joints, forearms, grippers, head, torso and base of the robot. The robot operating system (ros), and the personal robot 2 (pr2), worked seamlessly together to create one homogeneous robotics foundation. A graphical representation of the robot is displayed in Fig. 3.

The teleoperational system developed during the course of this research was developed for use with the pr2. During our project the Vicon system was used, coupled with a telemanipulation device was used to create a fully-fledged first generation teleoperational device for the pr2. By taking advantage of the pr2's on board sensors and implementing them into the teleoperational system a very precise teleoperational system was created. The pr2 was the perfect machine for teleoperation due to its robust hardware and wealth of sensors.

Using our telemanipulation device we were able to fully control the pr2's gripper and arm. The gripper was controlled using the telemanipulation device alone, while the arm was controlled using sensors on the surface of the device. The sensor's data was read in through the Vicon system and used to plot the position of the robots arm. The same data is then sent to the robot operating system is real-time and is used to physically control the robot under master slave control architecture scheme.

Fig. 3. – Personal Robot 2
Source - http://www.robotliving.com/humanoid-robot/pr2-and-ros-grow/

2.4 Robot Operating System (ROS)

Robot operating system, also known as ros, is a software foundation used for developing applications for robots. Ros promotes application building by providing developers with drivers, simulators, visualizers, and file package management. Ros is a completely open source-programming platform that is free to use and change.

The robot operating system is built around a network of packages and stacks that is essentially a collection of programs and code that allows the user to execute a task. In ros, a package merely contains ros nodes, libraries, and third party software. After a package is created it can be organized into ros stacks, which is a collection of packages that are arranged for sharing.

Ros supports four main programming languages that include: C++, Python, Lisp, Octave, and Java. Using these various languages programmers are able to manipulate software by utilizing the wealth of information that is held within the vast library. During this research Ros was used as a platform for communicating with the motor that drives the telemanipulation device, and as a simulator for testing and debugging code before applying it to the actual robot. The method within ros that is used for communication is known as a node, in particular a publisher and subscriber.

2.4.1 Ros Nodes

A node is a method that performs calculations. Nodes have many functions, one of which is being able to subscribe to one another and publish information as mentioned above. Nodes can also join together forming a graph that allows them to exchange information with one other using ros topics, and the server for parameters. Nodes communicate on a very precise level that is usually comprised of many other nodes connected to one another. For instance, one node can publish information pertaining to its position, while another node receives those positions and stores the information in ros.

Both publisher and subscriber nodes were used during this research to command the personal robot's gripper and arm orientation. The publisher sends the gripper position and orientation to ros while the subscriber receives this information. After the information is held within ros, it can then be sent to a simulator, or the PR2 robot where the information can be used to teleoperate the robot. Using ros nodes comes with many advantages. For example, if an error were to occur while teleoperating the PR2 ros allows the operator to view every individual node. This is very useful while troubleshooting because the developer can seamlessly identify the malfunctioning node.

2.4.2 Gazebo

Gazebo is an aspect of ros that is used to emulate the actions of the physical personal robot 2. Various tasks can be done using Gazebo including telemanipulating the pr2, and even full body control of the robot. Gazebo is organized into stacks and packages like many other facets of ros. This simulation platform is very beneficial, providing developers a safe way to test code without risking unnecessary damage on untested code. Prior to implementing the current telemanipulation system, gazebo was used as a safe way to test the effectiveness of the teleoperational device.

2.5 M2 Micro Controller

The complexity of modern microcontrollers allows designers to incorporate numerous peripheral hardware functions on a single chip [9]. In addition to the central processor unit, the microcontroller often includes modules for communication, data conversion, and timing functions. Among these modules is the microcontroller's programmable timer unit, which serves to measure and create timing waveforms [9].

In some applications, however, the micro-controller timer cannot meet the system performance requirements. For example, the timer unit might not be fast enough when monitoring a rapidly changing input signal [9]. The designer then must choose alternatives to create or measure timing waveforms and thus add circuitry to implement a specific timing function. Programmable logic devices often afford a viable choice for implementing such functions [9].

In order to successfully design and implement a tactile telemanipulation device for the PR2 robot a micro controller is required. A micro controller (as shown in figure [3]) is a miniature computer that contains a central processing unit (CPU) and memory on a single circuit. Microcontrollers are used for embedded application in various systems including: toys, household appliances, medical instruments, and various other embedded arrangements. In this teleoperational system the micro controller is used to input and output information to the hand motor from ros.

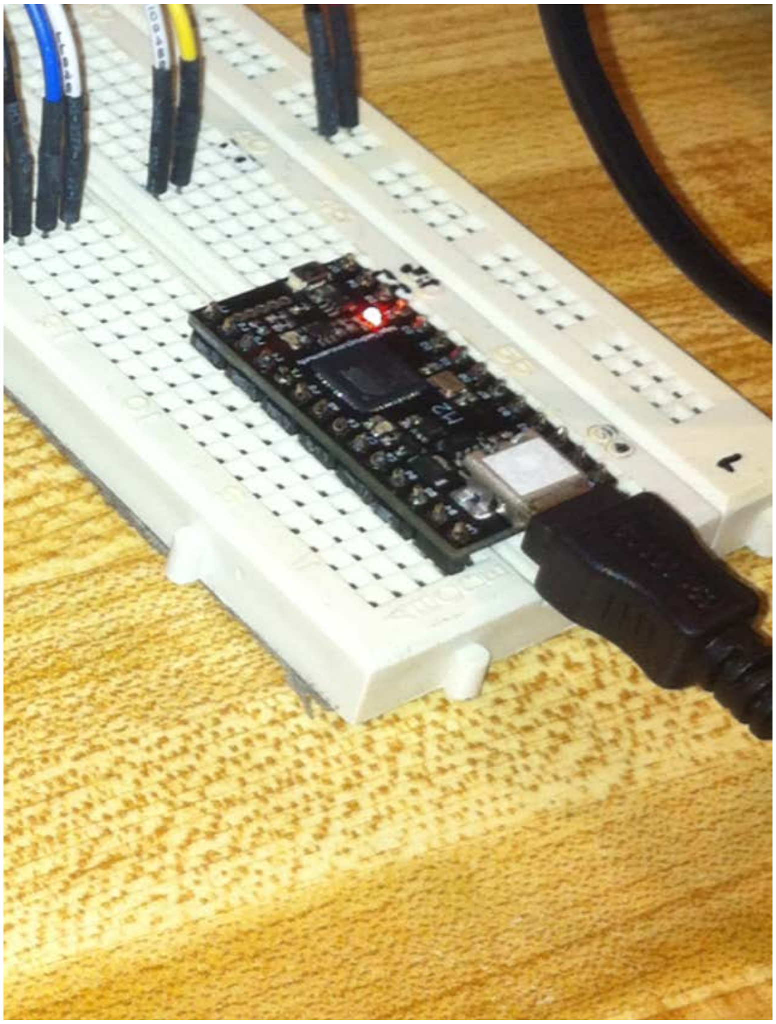


Figure 3. – M2 Microcontroller

Each microcontroller is unique and in this particular system the M2 micro controller is being used. The M2 is constructed around the ATmega32U4 processor, which is an Atmel 8-bit AVR RISC-based microcontroller. The M2 has a clock speed of 16mhz, a single button boot loader, and an expansion port with five pins.

Using the micro controller as a medium between ros and the dc motor enables the user to dictate the motor's rotational direction and speed via pulse width modulation (pwm).

Essentially a pwm is a method used to control the amount of power delivered to an electrical mechanism; in this case the dc motor used to teleoperate the PR2. A low pass filter is also required to send a stable current to the operation amplifier that powers the motor.

A low pass filter is an electrical filter that sends signals of low frequency while reducing the signal of higher frequencies also known as cutoff frequencies. The stable current provided by the low pass filter allowed operational amplifier to send effectively rotate the motor forward and backwards.

2.6 Operational Amplifier

Operation Amplifiers, also known as op-amps are high voltage, single ended output and differential input devices that are used to produce a voltage difference between its terminals. Modern operational amplifiers are designed on the base of two main topologies: voltage feedback OA (VFB OA) and current feedback OA (CFB OA) [7]. So when closed loop gain of VFB OAs is changed, it is not possible to provide constant bandwidth, while in CFB OAs it remains constant [8]. However CFB OAs have asymmetric input stage and don’t allow using of a capacitor between the output and the non-inverting input, that doesn’t allow using of them in some types of signal conditioners [9]. Figure [4] displays the operational amplifier used during the course of this research.

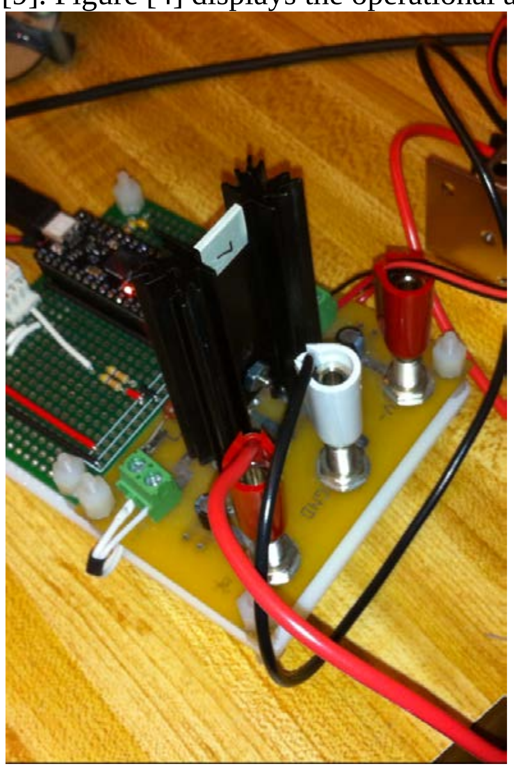


Figure 5. – Operational Amplifier

The differential input between devices consists of a V plus and a V minus. The operational amplifiers voltage output is given in the equation shown in fig [5].

$$V_{Out} = A_{OL} \left(V_+ - V_-\right)$$

2.7 Vicon System

Vicon optical motion capturing system is developed by an English company, Vicon Motion Systems (VMS). It is used in human body motion capturing. The motion capturing system is composed of the following parts: [10]

Sensor. It is the tracing equipment attached to certain positions of the moving object. It provides the Motion Capture system with information about the position of the moving object. In most cases, the number of sensors depends on the required particularity and the capturing equipment [10].

Signal Capturing Equipment. This kind of equipment's varies according the types of Motion Capturing system. Their function is to capture signals of positions. In machinery system, it is a circuit board for capturing electronic signals; in optical system, it is a high-resolution IR camera [10].

Data Transfer Equipments. Motion Capture system, especially those that provide real-time data, need to transfer large quantities of data from signal capturing equipment to computer system accurately and rapidly. Data transfer system is designed to carry out this task [10].

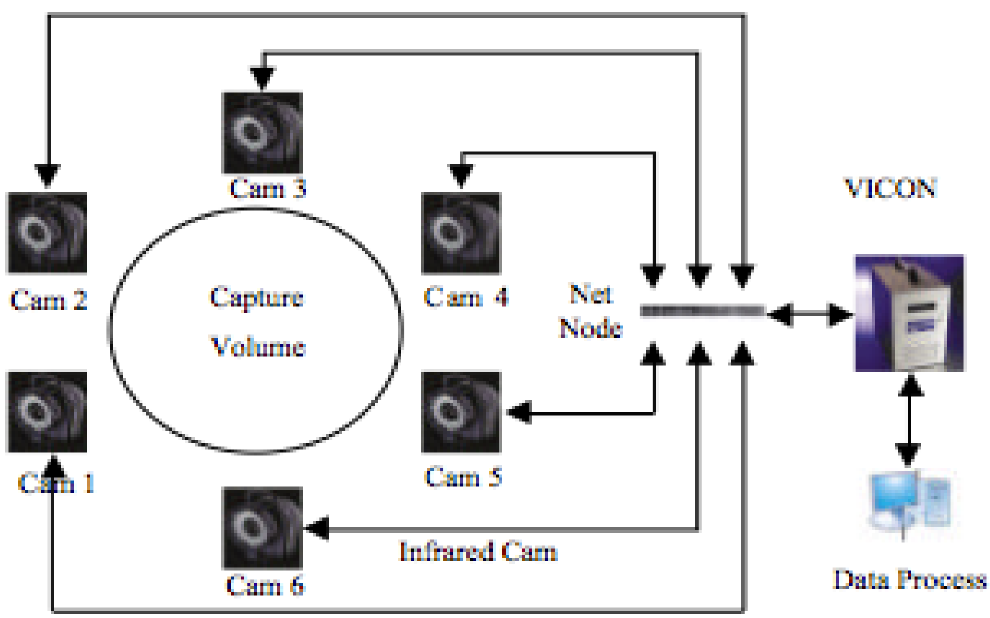


Fig. 6. [10] – The configuration of VICON motion tracing system

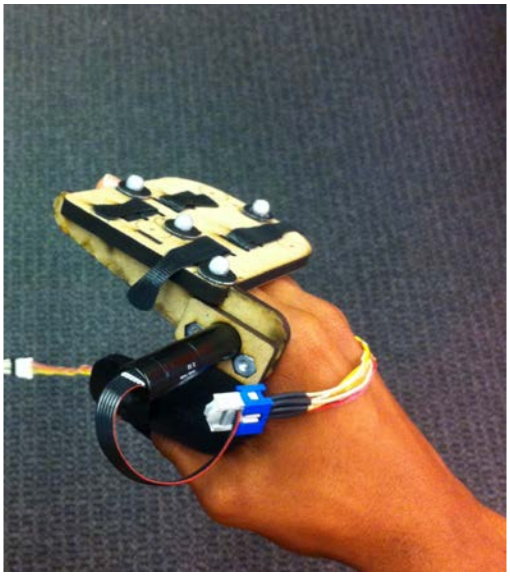


Fig. 7. – Telemanipulation Device

3. Procedures

The telemanipulation device used during this research can be seen in Fig. 7. This tool was created using a laser, and two key materials. The thumb attachment is made of abs plastic and the hand cover consists was constructed with a matted board like material. The motor that drives the telemanipulation device is mounted above the surface instrument, sitting between the finger and thumb. An OPA544 operational amplifier powers the motor. The white circular objects along the top of the instrument are reflective balls that are used for motion tracking via Vicon.

This device provides an ergonomic solution to teleoperating the pr2 robot. The device shown in Fig.7 is constructed with an adjustable thumb attachment, Velcro straps that form fit the hand, and cover made of matted board like materials to mount the reflective sensors.

The entire teleoperational system contains a telemanipulation device that is attached to the motor. The motor is provided power by the OPA544 operational amplifier through a 12V plus and 12 V minus power supply with a relative ground.
The op amp is connected to the M2 microcontroller that outputs the signal to the motor that dictates its position via pulse width modulation. All of the data is then sent through the robot operating system and into the personal robot. A full diagram of the circuit can be seen in Fig. 8.

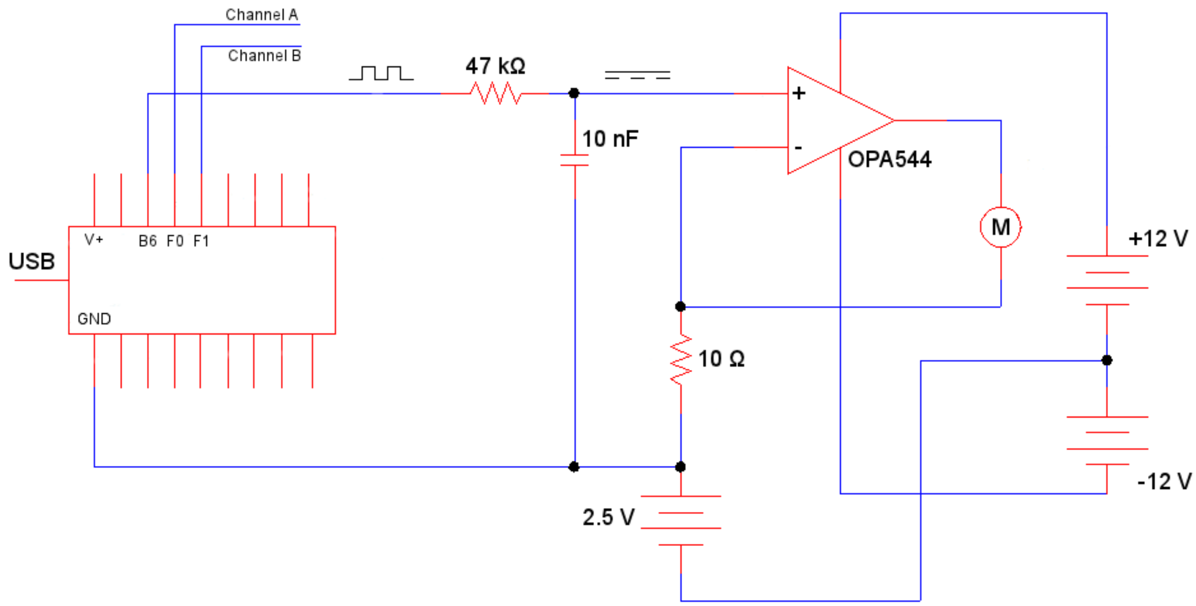


Fig. 8. - Circuit

3.1 Telemanipulation (Hardware/Software) Implementation – Moving the physical motor

The software used was complied and created on several different machines all running Ubuntu as a common platform. The robot operating system (ros) was the platform that was employed as a Segway to communicate with the robot and the telemanipulation device. Both hardware and software was required to establish a connection between the two entities. The first step toward integrating the hardware and software took place within the microcontroller. The M2 microcontroller was used as a steady medium between the motor that controls the telemanipulation device and the software that communicates the physical actions within the robot.

Creating a pulse width modulation was the first software related task pertaining to the research. The pulse width modulation takes place in the microcontroller and is the key to driving the current in the motor that causes the telemanipulation device to move. A spinning motor is significant because the motor's physical movement is necessary in order to maintain kinematic similarities, provide haptic feedback, and enabling the plotting of the gripper's relative location and replaying all of the information to both the user and robot in real time.

After successfully implementing the code for the pulse width modulation the next step required dictating the duty cycle produced by the pwm filter. The duty cycle that the pulse width modulation produces is significant because its strength controls the direction that the motor spins. A duty cycle that is greater than 50 percent spins the motor forward and a duty cycle less than 50 percent spins the motor backwards.

The pulse width modulation created by the microcontroller is sent to the motor via output pins. On this particular micro controller the output pin is B6. After the pwm leaves the pins and passes through the 47 kilohm resistor the current is refined via low pass filter. This same current is then sent into then operation amplifier. After passing through the op amp the pwm signal reaches the motor and the signal then turns into kinematic energy, which manifests itself as a spinning, motor.

3.1.1 Prototype – Hand Controllers Design and Function

Several prototypes were created during the course of this research before the current model was established. The ultimate goal when creating the device was constructing something intuitive and ergonomic. Deciding on a final design took a lot of time and effort. When deciding on the initial design our research team was forced to make a difficult decision. Creating a device that you squeeze, similar to a hand gripper, or creating a device that mimic's the natural motion of the hand similar a baseball glove. Ultimately we settled upon the later due to its intuitive nature.

Motor position is a very important part of the telemanipulation device. Initially the motor was placed in-between the operators hand. After doing several tests it was decided that the heat produced by the motor and the excess motion created by the hand would make implementing accurate haptic feedback difficult. It was also noted that while in the hand the motors position tended to be affected by the friction created when the motor was spun wither clockwise or counter clockwise. Positioning the motor in the motor above the hand eliminated the concern about how exactly the heat produced by the motor would affect the operator hand, and it would also neglect the excess motion created by the user hand when they open in close the instrument.

The extra room along the matted board that surrounds the users hand when operating the device is used for placing the reflective sensors that allows the Vicon system to track the operator's movement. This is special because it allows the device to not only telemanipluate the personal robot's gripper, but also teleoperate it's arm simultaneously.

Many telemanipulation devices that are currently in use are lacking in some way. Devices that have precise motion tracking often lack haptic feedback, and those that implement the proper feedback fail to present an intuitive design. The current telemanipulation device has potential to exceed in all area where previous devices have failed. By using the Vicon systems motion tracking capabilities in collaboration with the telemanipulation that commands the gripper this device has promise to excel where it's predecessors have failed.

4. Implementing Teleoperation

Creating a circuit that powers the motor is only half of a fully functioning teleoperational system. The communication with the robot itself is very important as well and it is essential is one wishes to create a complete system. After the circuit was complete we began working on establish reliable communication with the pr2 robot, and the best way to do that was via serial port. ROS Serial is a point-to-point version of ROS communications over serial, primarily for integrating low-cost microcontrollers (Arduino) into ROS. ROS serial consists of a general p2p protocol, libraries for use with Arduino, and nodes for the PC/Tablet side (currently in both Python and Java)[11]. Using a configuration known as ros cereal port we are able to establish a connection with the robot that allows us to publish nodes that communicate with both the telemanipulation device and the robot.

4.1. Teleoperation Testing and Application

Under the current configuration we are able to successfully telemanipluate pr2's gripper with the hand controller. Despite its successful application there are several problems that persist. For instance, when the hand controller is plugged into certain outlets it causes the device to vibrate sending unnecessary feedback to the user that is not present in the robot. Also, the teleoperational algorithm used to teleoperate the pr2's arm needs calibrating. The robots arm orientation is slightly inverted and this makes testing and practical application slightly difficult.

These shortcomings do not take away from the end result of the research. A fully function telemanipulation device was developed and successfully implemented. Although the pr2's arm tracking needs calibration, the Vicon system is able to successfully track the operators arm and accurately replicate his/her action on the physical robot.

5. Discussion & Conclusion

The aim of this research project was to develop a teleoperation system for the pr2 robot using an intuitive hand controller equipped with reflective sensors, and a mechanical motor. There were few difficulties during the course of our research, some involving the microcontroller and others pertaining to the robots operating system; however they were soon fixed. The final prototype is capable of communicating with the robot and relaying accurate feedback to the user regarding orientation and gripper positioning.

6. Recommendations

Although the current prototype is fully functional there are some improvements that can be made to the hand controller that would improve the entirety of the teleoperation system. One such improvement would be adding another hand controller allowing the operator to teleoperate both arms. An adjustable thumb piece could also be added to the device to accommodate a variety of user hand sizes.

Increasing the surface area on the front of the hand controller would allow for more reflective spheres to be placed. This would allow the Vicon system to get a better view of the controller and send more accurate feedback to the robot operating system. One final improvement would entail identifying glitch within the power supply, which causes unnecessary feedback in the hand controller. This would greatly improve the reliability and responsiveness if the entire system.

Future work could also include incorporating a teleoperation system that spanned beyond the hand and arm and extended throughout the operators entire body. This would provide the operator teleoperation system that can control the PR2 in its entirety

7. Acknowledgements

I would like to thank my Advisor, Dr. CJ Taylor for giving me an opportunity to work with him for the summer. I would also like to thank Dr. Katherine J. Kuckenbecker, Liz Fedalei, Jason Allen, and Rebecca Pierce for the assistance and guidance provided during the course of this program. Finally I would like to thank Professor Jan Van der Spiegel, the Nation Science Foundation, and the University of Pennsylvania for hosting and providing the necessary funds for making the SUNFEST program possible.

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