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A Power Line Inspector Device

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A POWER LINE INSPECTION DEVICE

by

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Abstract:

The goal of this project is to create a functional power line inspection device which could replace the old inspection method of using helicopters. This microchip based robotic device is able to ride along a conductor and send video feed, encoder readouts, and temperature measurements to the user. The user operating system consists of an LCD screen, two potentiometers for motor control, and a screen to display video feed. Achieved specifications include a battery lifetime of 1 hour and 45 minutes, distance measurements within 1 inch, and temperature accuracy within 2 °C. This thesis includes a brief discussion on previous methods and robots, theory of operation, design summaries, and a compilation of the final results.

Dedication:

To my parents and wonderful family that have supported me throughout my life.

Acknowledgements:

I would like to thank Jesse Sawin for all his help partnering with me in this project, Scott Dunning and Mohsen Shahinpoor for advising me, Alec Johnston for parts and troubleshooting help, and Kurt Strauch for assistance in the development of PCBs. I would also like to thank the many faculty members and students who helped Jesse and I along the way.

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I. Introduction

As power lines are relied on more and more to power schools, hospitals, and places of business, catching the problem areas before failure becomes much more important. One way to find these problem areas is by conducting a thorough inspection of a given transmission line. A big driving factor of power line inspection is government policy. After the blackout in the Northeast United States in 2003, The Energy Policy Act of 2005 led the Federal Energy Regulatory Commission to designate the North American Electric Reliability Corporation (NERC) as the electric reliability organization for the US. NERC standards set prior to this were only followed on a voluntary basis, but they are now mandatory in the US and increase the need for reliability and therefore for inspection. (31, North American Electric Reliability Corporation, 2007) This inspection not only includes the physical conductor but also the vegetation growing nearby. The utilities are expected to provide a more reliable distribution of power, in an attempt to prevent another blackout from occurring. This reliability is created through redundancies and inspecting crucial lines.

This project came about from an article read in the IEEE Spectrum Automation Blog on Hydro Quebec's robotic device called the LineScout. (13, Guizzo, 2011) Their robot was a project started after the '98 ice storm, originally an ice breaking robot, that lead to an inspection and maintenance robot. This article sparked the idea of creating an inexpensive inspection robot to ride on the conductors which my senior project partner, Jesse Sawin, and I began to develop. Several designs and papers were found on the subject including other companies that have worked on similar devices to the LineScout, detailed in section Bii. The advantages and disadvantages of each design were reviewed.

A simple device was created that can ride on a power line and keep track of distance and temperature measurements with a battery lifetime of about an hour and three quarters. This document details research on inspection and maintenance of conductors and the various devices and methods followed by the design, construction, and operation of the robot that was developed by Jesse and myself.

II. Background Information

A. Inspection and Maintenance

Inspection and preemptive maintenance of power lines can prevent unnecessary losses of revenue due to breaks of the power line. These breaks are caused by natural forces such as wind and ice, and manmade forces such as automobile crashes and various chemical contaminations. There are many different techniques that are used to look for discrepancies in the conductor, splices, and other components on the line. This section will detail the problems faced, inspection techniques, and a brief overview of maintenance methods that are used.

i. The Source of the Damages

There are several forces that act on a power line. Mark Burns detailed these forces in his 2003 Conference Paper, *Distribution Line Hazards that Affect Reliability and Conductor Repairs and Solutions to Avoid Future Damage*. (6) In this paper he suggests that there are two major forces on the line, natural and manmade. The natural forces are composed mostly of wind, ice, snow, and the combination of the three. These natural forces create conductor motions defined as Aeolian Vibration, Galloping, and Wind Sway.

Aeolian Vibration is a high frequency, low amplitude vibration of the conductor at 30-150 Hz. It is caused by smooth parallel winds that create vertical motion of the conductor though vortex shedding. The result of this movement is a bending stress at restraints causing abrasion and fatigue over time.

Galloping is a low frequency high amplitude sinusoidal vibration at 1-3 Hz. Galloping amplitudes are measured in feet as opposed to Aeolian Vibration being measured in inches. It is caused by steady 15-40 mph winds on lines that have buildup of ice or snow. The result is immediate damage to support hardware and also tensile failure over time due to abrasion and fatigue.

Wind Sway is a term referring to general swaying of the conductors caused by gusts of wind. This causes abrasions at supports and restraints. The abrasion caused is related to the looseness of the connections at supports; as they get looser, the damage accelerates.

These forces cause abrasion, fatigue breakages at supports, and tensile breakages. The primary focus is on abrasion, and also corrosion, which can be caused by chemical plants nearby, salting of the roads, or coastal power lines that are contaminated by the salty ocean mists and breezes. Full on breakages require maintenance and don't need to be inspected. There are some mechanical solutions to minimize the types of line movements mentioned above. Proper design and maintenance is important in addressing the issues that come about from the motion of the conductor. In the paper mentioned above Burns detailed a few techniques used to lessen the effects of Aeolian Vibration, Galloping, and Wind Sway.

Aeolian Vibration solutions incorporate reducing line tension and installing dampers; mechanical devices which dampen vibrations of the line. These devices generally consist of two opposing masses which minimize vibrations.

Figure 1: Vortex Damper
(35, Preformed Line Products, 2010)

Galloping Solutions include increasing line tension to reduce amplitude and installing Air Flow Spoilers, Detuning Pendulums, or Dampers. Air Flow Spoilers are helically formed rods wrapped several times around the conductor to disturb the aerodynamic lift of the conductor. Detuning Pendulums consist of a single mass secured to a conductor.

Figure 2: Air Flow Spoiler
(35, Preformed Line Products, 2010)

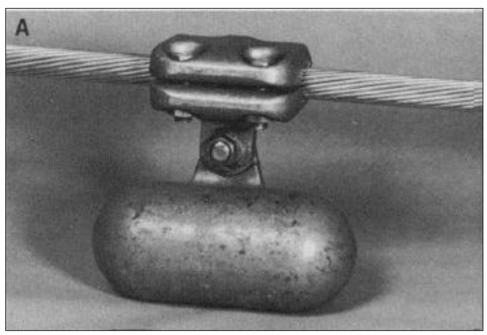

Figure 3: Detuning Pendulum
(14, Havard, 1984) © 1984 IEEE

Wind Sway solutions try to reduce motion at the insulator, which can be done by using formed wire ties on a pin insulator to create a solid connection at the pole.

As you may notice intuitively, the tensioning and reduction of tension of the lines have opposite effects on Aeolian Vibration and Galloping. Tensioning a galloping line too tight may cause Aeolian Vibration and vice versa. Dampers are a good method to reduce vibrations. One must keep in mind that, like any other component connected to the line, dampers can be a problem area when not installed correctly. Locations of repairs and maintenance of power lines are also important to look at because they can be weak points on the line.

ii. Connections

Splices, Dampers, and various connections to the line are likely weak spots on the line and most affected by the abrasion and corrosion. In another of Mark Burn's papers, *Reliability of the Conductor System in Today's Environment and the Importance of Maintaining Its Integrity* (7), he details issues caused by improper installation splices, corrosion, and damages due to environmental exposure. Burns states that many failures are caused by splices becoming more resistive and creating "hot spots" due to bad installations, corrosion, faults, or other damage.

When fixing breaks in lines or tying two lines together there are several types of connectors that can be used. These connectors include compression splices, automatic wedge splices, formed wire connections, and bolted components.

Compression splices consist of a pressed fit metal sleeve that is filled with an oxide inhibitor to prevent corrosion. A press and die is used to install the splice.

Figure 4: Compression Splice
(http://www.cnyauctions.com/nationalgrid/inventory/59-68-606.JPG)

Automatic wedge splices are comprised of a metallic sleeve that collapses wedges onto the conductor as you slide it on.

Figure 5: Automatic Wedge Splice
(http://classicconnectors.com/2012/05/17/inner-workings-of-an-automatic-splice-and-using-clampstar-as-a-safety-tool/)

Formed wire splices are helically formed rods that are glued together to create splices or dead ends.

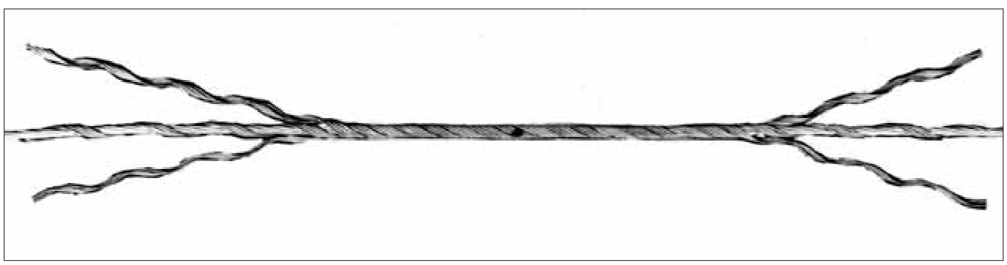

Figure 6: Formed Wire Splice
(36, Preformed Line Products, 2011)

Conductors can also be bolted to the power line with a bracket. These connections are good for low tensions, but are more likely to cause conductor damage by clamping down on the line.

These connection points can be bad spots for contamination, corrosion, and general high resistivity in the line due to loose connections. These things can be caused by improper installation, swaying of the line, or otherwise. These points should be examined thoroughly during inspection as they are known to be trouble spots.

iii. Inspection Methods

There are many techniques that can be used to inspect the conductor and components on the power line. EPRI's paper, *Future of Overhead Transmission Lines* (10), details the many types of sensing technologies available, current uses of these sensors, and possible future uses as they are developed further. Initial detection techniques usually involve some sort of visual inspection. The visual inspection often includes either infrared image sensing to find "hot spots" or ultraviolet image sensing to analyze corona discharges alongside traditional photography or videography.

> Visual inspection of the lines is important. Many problems are found by linemen or other power company workers simply noticing something wrong while going from place to place. It is good to keep an eye out for any fraying in the line abrasion, or other damaging of connections or components so they can be replaced or analyzed further. EPRI suggests the possibility of using image analysis comparisons by storing images in a database and placing cameras at key locations. These cameras may be fixed cameras, pan/tilt cameras, movable cameras on a line robot, mounted on a UAV, or even satellite imaging systems. This type of imaging is good for finding fraying, damaged insulators, encroachment of right of ways, and any other visible problems, but is less effective at finding potential failure points such as high resistive areas that cannot be seen with the bare eye. As higher resolution cameras become available, satellite imaging becomes much more viable for right of way inspection for bushes, trees, avian nests, and other obstructions. There are several satellite imaging companies that provide these services, including Digital Globe with their

Geo Eye satellites and Astrium with their SPOT satellites. For preventative inspection of problem areas that are not visual to the naked eye, other methodologies are needed.

Infrared photography is a widely used technique both for initial inspection of a power line and closer up inspection to confirm a suspected faulty connection. Infrared photography allows visual inspection of the heat being dissipated by the power line using microbolometer arrays which are designed to detect a certain range of infrared wavelengths. A bolometer is a device that measures heat input from its surrounds. It consists of an element that absorbs the infrared or other radiation with a weak link to a thermal reservoir. A thermistor is used to measure the temperature of the absorbing element and determine heat levels based on the change in temperature from the initial temperature. (40, Wilson) The most well-known manufacturer of infrared cameras is FLIR systems. Their cameras are widely used in helicopter inspection of power lines. Using infrared photography, utilities can observe areas of high resistivity, corrosion, faulty splices, insulator leakage currents, and bad connections which cause heat. EPRI estimates the cost of these cameras to be 7-50 thousand dollars. A cost-effective alternative to this is an infrared thermometer, which can be purchased at the IC level for about 10 dollars.

Another methodology of inspecting lines is to use a corona analyzer. A corona analyzer is simply a camera designed to identify ultraviolet light. It picks up electromagnetic discharges from the power line and attempts to differentiate these discharges from other noise and normal discharges by honing in on certain frequencies. CCD imaging arrays are used to do this by filtering light to only look at a small band of the UV spectrum of about 250-280 nm creating a solar-blind for daylight detection. (10, EPRI, 2008) These devices often include sensitivity controls and software to count photon events. The major manufacturers of these devices are Ofil Systems, the makers of DayCore, and UViRCO Technologies, the makers of COROCAM. These devices are often used to perform infrared, corona, and visual helicopter inspections.

Another method that is used with helicopter inspection is LIDAR. LIDAR stands for Light Detection and Ranging. It works similar to RADAR; light is transmitted, reflected off the surroundings, and received back. The time between transmission and reception determines the distance to the object. Large systems scan back and forth with an array of light, using GPS to record locations of violations. One product that is commercially available is Leica GeoSystem's ALS-40. This device has a range of 20,000 feet at 40 kHz with a 75 degree field of view. A simple example of LIDAR is a rangefinder. These have been used for finding the distance to a golf ball, locations of targets for warfare, or even to focus a camera on a particular location. They locate the distance of an object by sending and receiving pulses using a single beam of light. A rangefinder mounted to a cable climbing robot could take ground clearance measurements very easily with minimal cost. The larger systems like the ALS-40 are used to check for right of way encroachment along the conductor while mounted to a helicopter but are expensive.

Phase metering can also be an effective and inexpensive way to determine where a bad connection may be in a power line. As utilities already keep track of system loading and try to keep relatively equal phase loading, reviewing phase loading over time can show any abnormal values that may be caused by faulty joints. Once suspected, the line section can be inspected more thoroughly using other methods.

Another method of detection is the placement of sensors directly on the line and connecting to them remotely. Some sensors that may be used include power, vibration, acoustic, strain, tilt, magnetostrictive, and ultrasonic sensors. Similar to looking at phase metering, by measuring currents and voltages on particular places on the line and looking at the changes, problem areas can be identified. Vibration and acoustic sensors can be used to identify any outside tampering and birds nesting on towers. Strain and tilt sensors can identify problems with the structural integrity of towers. Magnetostrictive and ultrasonic sensors can detect the structural integrity of materials by sending sound waves through a material, receiving the corresponding signal, and comparing the results to the reception from a new solid material. Although Magnetostrictive and ultrasonic sensors can detect corrosion and physical damage in a conductor or structure, they must be attached to the material and are limited in distance. They may work well as wireless sensors but aren't very practical on a cable climbing robot or helicopter.

Once a joint is suspected to be faulty there are many techniques of confirming the failure which include infrared photography, measuring the resistivity of connection, using

EMAT imaging on the suspected failure, and taking X-ray images of the joint. (3, Avidar, 1993)

Infrared photography, as mentioned above, is a good method for finding “hot spots”. These inspections may be performed from a bucket truck or by other means.

Measuring resistivity of a connection also shows problem areas based on joint connectivity. This could be integrated into a cable climbing robot to test cable splices and other components and is used with Hydro Quebec’s LineScout, but requires two physical connection points.

EMAT’s, or Electromagnetic Acoustic Transducers, are good sensors for inspecting suspected faulty connections. They operate similarly to ultrasonic sensors but eliminate the need for a physical connection. By injecting signals into the material and reading the waves that bounce back, flaws, inconsistencies, corrosion, and broken strands inside connectors can be determined. This is done using the principles of magnetics by placing a wire near a conducting material and driving current through that wire to produce eddy currents in the nearby material. A static magnetic field, created by a magnetic configuration on the sensor, combined with these eddy currents will create Lorentz forces which can be measured by the receiving unit. (10, EPRI, 2008) The big advantage of EMAT is its contactless operation and the ability to create guided waves at various frequencies. These sensors can be used for inspecting towers, broken strands in transmission lines, and other components. As these sensors and the equipment required to operate them become smaller and cheaper the possibility of mounting them on a cable climbing robot will become more viable.

Another product that could be integrated into a cable climbing robot is a Radio Frequency Interference “Sniffer”. This “Sniffer” picks up on partial discharges from power components. The discharges are sensed as radio frequency interference in the MHz range. Handheld “Sniffers” and locators are available from Radar Engineers in Portland, Oregon. These devices utilize antennas and signal processors to find the source of the interference, operating in similar to metal detectors.

X-ray imaging was used for direct inspection early on. By taking x-ray films, breaks and incongruities can be determined. Use has diminished greatly since the 1980’s due to health risks of exposure to radiation and the high cost of operation. New developments allow robotic inspection from devices riding along the line, or UAV’s flying near the line to find faulty connections. These devices can utilize the various sensing technologies mentioned above among others. Once a faulty connection is found, maintenance must be performed to prevent breakage of the line.

iv. Repairs

There are two basic ways to repair a faulty connection. The first is to install a new splice. The other option is to install a shunt over the faulty connection.

A splice connection requires a physical disconnect of the line or failed spice. A failed splice will likely require two new splices with a line section in between them.

Installing a shunt is often a good option when turning off the line section is a problem, as it can be done on a live line with hot sticks. It bypasses the bad line section, providing the path of least resistance, while maintaining and sometimes enhancing the structural integrity of the connection.

As repairs are something that follows inspection, no further detail is included.

B. Previous Works and Robots

i. Helicopter Inspection

Helicopter inspection is a very costly task that can be replaced by robotic methods. In order to have an understanding of the task that was to be accomplished by the inspection device, it was necessary to first have an understanding of helicopter inspection. As previously mentioned, infrared inspection of power lines is often done using helicopters with a camera system mounted to the aircraft. They record video and inspect the line while riding above it in a helicopter. They look for high resistance or "hot spots" and examine them more closely when observed. Mike Marshall, an ABB engineer, wrote a paper called *Aerial Infrared Line Inspection* (20) in 1999 which details the helicopter inspection process. In this paper Marshall details how often inspection is necessary, loading impacts, and costs of inspection.

The time between inspections varies greatly and depends on how thorough an inspection you are willing to make. Marshall suggests the inspections should be done every 3-4 years at light load conditions, as is generally accepted. At light load conditions only critical and severe problems will show up, which cuts down on inspection time. The interval of time between inspections depends on the type and reliability of the power line, and also the opportunity cost versus doing nothing. The NERC reliability requirements also play into the decisions which must be made by the local utility.

The loading of the line impacts how hot the problem spots get and how visible they are to the inspection equipment. At full load all problems spots are visible, while at light loading only the critical and severe problems show up. Severe problems can be identified on a line section with very minimal current loading as the high resistance causes a large emission of heat by the line. Lines with more loading also tend to have more problems than under-loaded lines. Some lines will require more frequent inspections than others that may require very rare inspections or not be found cost effective to inspect.

The cost of helicopter inspections is dependent on the type of line, loading, location, weather, and many other factors. To make good documentation of hot spots with videos and photos inspection can take an extended period of time. Turns in lines also cause inspections to be more costly due to time spent maneuvering the helicopter. For this reason, distribution and sub-transmission lines are much more costly to inspect than transmission lines. Due to costs, only lines of high importance are inspected, generally transmission lines. The costs of inspection include a helicopter, pilot, camera man, and camera and other equipment involved. In 1999, Mike Marshall estimated costs to be as shown in Table 1 below. The payback is found to be every 3-5 years. These costs are what have motivated the move to create robots and other devices to inspect the lines which take much less fuel and effort.

Table 1: Helicopter Inspection Costs

Line Type	$ per mile	#miles per day
Transmission	17.33	300
Rural Subtransmission	26.00	200
Urban Subtransmission	34.67	150
Rural Distribution	29.71	175

Eliminating the costs of a helicopter and pilot can reduce the cost of this effort greatly. A more recent cost estimate received by Avant Media Group is 1000 dollars per hour moving along at 40 knots (46 mph). This would put the cost at about 22 dollars per mile which is comparable to Marshall's price for transmission lines plus an increase for the rise in fuel prices. This estimate did not include a camera man or a spotter which would be provided by the utility company. While inspecting, spotters will look for other problems that can be noted such as mechanical problems and tree conditions. These are also important for an inspection robot to be looking for. The next section will explore the different robots and designs that have been developed.

ii. Inspection Devices

Due to the high costs of helicopter inspection, many have thought about solutions that can replace the task. These solutions include various types of cable-climbing robots and UAV's. UAV's provide reduced costs and closer up imaging, but have their limitations. They have a limited payload depending on the size of the UAV and are also limited by the weather as are helicopters. They are often manned from the ground and provide a good solution for reduced costs. It was decided to build a robot that rides on the cables, so this section is focused on cable robots. A joint paper out of the University of Canterbury called *Cable-Climbing Robots for Power Transmission Lines Inspection* (29, Nayerloo, 2009) gives a great overview of problems faced, symptoms and detection methods, and various mechanisms designed over the last 20 years.

Inspection devices are generally looking for cracks in insulators and corrosion or fretting in conductors. There are various methodologies to detect these, most commonly infrared inspection, corona analysis, and visual inspection. The cable climbing robots not only have to inspect the power line, but they also have many obstacles in their way. They must make it past insulators, dampers, splices, spacers, and even the occasional aircraft warning sphere. The robots also need a means of communication and control, whether manually controlled or autonomous. Detection of these obstacles can also be important, although it can be as simple as having camera feedback when manually controlled. The following is a synopsis of various devices and their attempts to overcome these obstacles that they are faced with.

a. LineScout

The first robot to discuss is the one that started this project, Hydro Quebec's LineScout. The LineScout is a large robot capable of surpassing large obstacles, running for about 5 hours at a time, and allows user control from distances of up to 5 km. It was created after extensive research and an in-depth design.

Figure 7: Hydro Quebec's LineScout
(33, Pouliot, 2012) © 2011 Wiley Periodicals, Inc.

The LineScout performs visual inspections of the power line and also is capable of measuring resistance across splices. It can also loosen and tighten bolts and make temporary repairs to broken conductor strands. To perform inspection and maintenance, there are three cameras mounted on the robot. Two small cameras are mounted on the gripper arms and a third is mounted between the wheels of the robot with an adjustable pan and tilt.

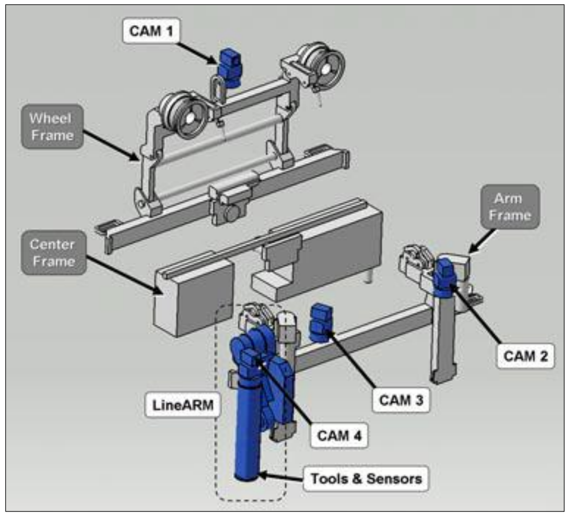

Figure 8: LineScout Breakdown
(33, Pouliot, 2012) © 2011 Wiley Periodicals, Inc.

The LineScout's obstacle avoidance scheme requires it to be a rather large robot, but is very functional for various types of obstacles. The avoidance scheme seen below involves a slide, clamps, and actuators to remove the drive pulleys from the conductor. By sliding the clamps over and grabbing the line, the robot is able to release its pulleys and slide over to the other side of the obstacle, seen below.

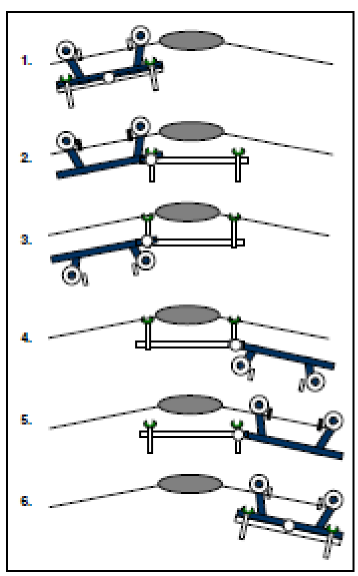

Figure 9: LineScout Obstacle Avoidance
(24, Montambault, 2006) © 2006 IEEE

The LineScout also has a good telecommunications design with a 5 km wireless control range. It uses two radio-frequency transceivers to accomplish this range, leaving only the antenna outside of the circuitry's electromagnetic interference shielding. Electronic protection was also incorporated in the antenna circuit. Video feed, controls, and sensor data is communicated over the radio connection. The electronics include optical encoder feedback for speed based motors, and potentiometer readouts for motors that require more precise movements. The LineScout has shielded fans to maintain temperature of the circuitry using thermal switches. The LineScout also uses an infrared thermometer to monitor conductor temperature and GPS locating for mapping of problem areas. The control station receives the information from its transceiver, displays the video feed, and provides information and controls using a PC with a LabVIEW Digital Interface. It also has two joysticks for control of various motors. Their software is designed such that you can switch between modes to control different motors. Generally one joystick would control the upper camera and the other the speed of the drive motors.

The LineScout has undergone intensive testing for electromagnetic discharge, run time, and various other functionalities. Its lithium ion batteries allow 5 hours of run time, and it is constructed for conductor diameters of 12-60 mm and power lines up to 735 kV and 1000 A. The weight and size of the robot are a couple possible disadvantages of this robot with a length of 1.37 m and weight of 100 kg. Overall it is a very well designed inspection and maintenance robot for transmission lines. (24, Montambault, 2006)

b. LineROVer

Hydro Quebec also made a robot called the LineROVer. This device is more similar to the simple lightweight device that is detailed in this thesis. The LineROVer's main purpose was as a de-icing robot, a need which became more apparent to us here in the northeast section of North America after the ice storm of '98.

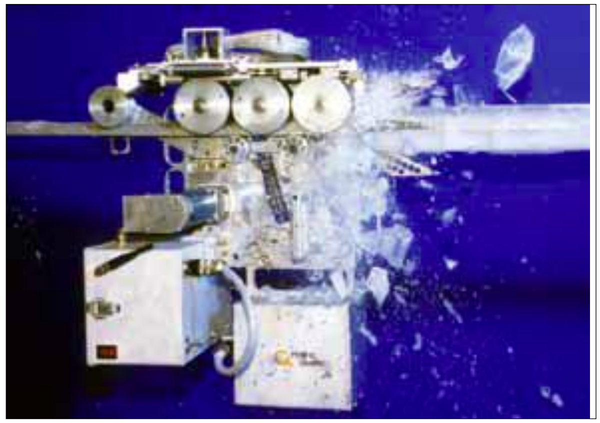

Figure 10: Hydro Quebec's LineROVer
(26, Montambault, 2010)

Ice on wires can cause faults due to conductors getting too close to each other, hardware failure, and support failure. Using three drive wheels, fixed steel blades, and a pressure stabilizing back wheel, the LineROVer is very effective at removing ice from the lines. The LineROVer also has both a pan and tilt camera and an infrared camera. An Ohmstik sensor was also added to the LineROVer to take measurements across splices. It is not designed for obstacle avoidance, but has good remote control range of 1 km. It is designed to pass over conductor splices and is adaptable to most conductor sizes. The LineROVer is very robust with batteries designed to last for 45 minutes of deicing and recharge in 1 hour from a small generator. They are looking at using the device for cleaning conductors as well. The LineROVer is a great de-icing ROV and is fairly lightweight for its purpose at about 50 lbs. (23, Montambault, 2003)

c. TI

TI is an inspection robot that is under development from EPRI, the Electric Power Research Institute. Its purpose slightly differs from that of Hydro Quebec's robots. Instead of inspecting existing lines or acting as an ice breaker, TI is being designed to be an autonomous part of a new smart grid in helping to relay data from sensors and looking for high risk vegetation and right of way encroachment along with the inspection of the conductor and line components. To do this TI, seen below, is equipped with an HD camera, LIDAR sensor, and is also to have an electromagnetic interference antenna that will detect corona discharges from failing components or conductors. It has GPS to keep track of its position and speed and sensors to monitor the weather.

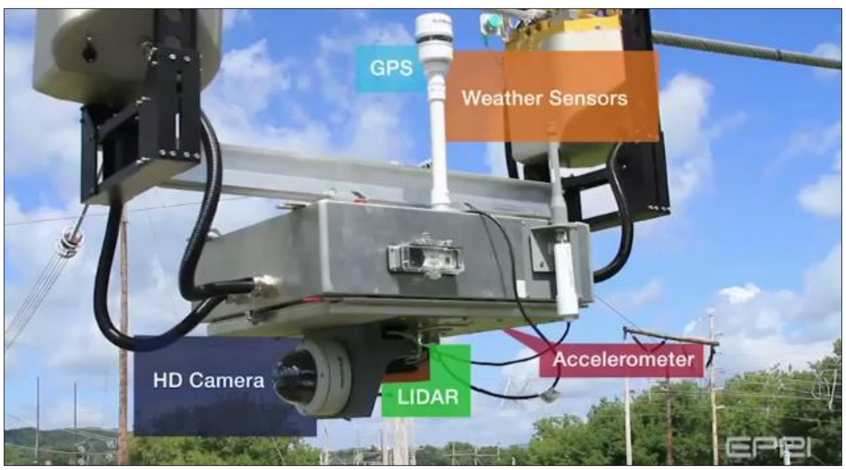

Figure 11: EPRI's TI
(http://www.youtube.com/watch?v=nWOfQeiWylM&feature=watch-vrec)

EPRI took a different approach to obstacle avoidance by using diverter cables and proximity sensors to detect the diverter and release the wheel locking mechanism seen below. The locking system with pulleys on either side makes for a very stable connection to the conductor, and as long as all the sensors are functioning properly this design works quite well.

Figure 12: TI's Obstacle Avoidance
(http://www.youtube.com/watch?v=nWOfQeiWylM&feature=watch-vrec)

As a part of a new smart grid that is to be developed, the diverter cables would be installed along with new sensors. EPRI's design integrates a RF sensor reader antenna and data collection module to the robot along with a communications to the data collection center. The idea is that sensors would be installed in areas that were known for problems, and the robot would be one means of collecting the data alongside satellites, cell towers, ground patrols, and any other means possible. For example, vibration sensors would be installed in the windy areas, lighting sensors where lightning frequently strikes, and leakage current sensors where there is salt contamination or other chemical contamination to the lines. The sensor data could all be relayed back to the data collection center, and maintenance groups would be alerted as needed.

As an autonomous robot, TI is designed to incorporate energy harvesting. EPRI's initial idea of running the robot completely off of solar has been modified to include charging off the power line by making contact with the shield wire. This is a very interesting concept that would allow robots to be completely autonomous if implemented correctly. EPRI is working with AEP, American Electric Power, to test TI and the rest of their system on a new 138 kV transmission line after extensive testing on their test loop in Lenox, Massachusetts. The robot is designed to withstand 765 kV lines. (11, Electric Power Research Institute, 2012)

d. EXPLINER

EXPLINER, seen below, is a robot developed by HiBot Corporation in Tokyo, Japan. It performs visual inspections of conductors, spacers, and other components on the power line with on board cameras. The focus of HiBot's design was to create a robot that could surpass certain obstacles which include spacers and suspension clamps.

Figure 13: HIBOT's EXPLINER
(15, HIBOT)

The design of the EXPLINER was created in an attempt to limit weight and make a stable mobile platform. Using a counterweight connected to mobile linkages, the robot's center of mass can be easily shifted in any direction. By shifting the counterweight all the way to one side or the other, the majority of the robot's weight can be transferred to one motion unit or the other which allows the other motion unit to be removed from the power line.

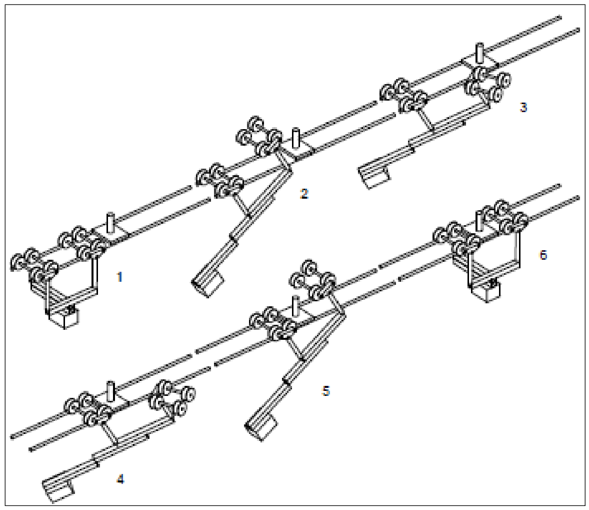

Figure 14: EXPLINER's Obstacle Avoidance
(9, Debenest, 2008) © 2008 IEEE

A semi-automatic control system was designed for the EXPLINER. This system automates obstacle avoidance and transfers to and from access cables but allows for direct control of speed and cameras. The control unit consists of a tablet, switches, joysticks, a wireless module complete with antenna, and batteries in a weather proof case. The control unit communicates to the robot using TCP/IP protocol over wireless LAN to allow control of the robot, display video feed, and display current robot configurations using the encoder data.

Although the EXPLINER lacks the various sensors of TI, its obstacle avoidance design is very capable on 2 and 4 conductor bundles. The battery life of the robot is approximately 6 hours with a wireless range of 200 m. It is a very capable design with the ability to climb up to a 30 degree incline. (9, Debenest, 2008)

e. Other Notable Robots

1. MoboLab

MoboLab is a robot that was designed out of Semnan University in Semnan, Iran. This robotic design played a part in the initial design of the robot, so it's worth noting. The design of MoboLab was an attempt to create a robot that can quickly travel on a conductor and traverse obstacles while having simplicity in control and low energy consumption which resulted in the model seen below. This robot performs visual inspection with a camera controlled by the user.

Figure 15: Semnan University's MoboLab
(30, Nayyerloo, 2007) © 2007 InTech

MoboLab uses power screw systems to move its 3 arms and 3 grippers about the slide and avoid obstacles. Using its three arms, Mobolab can easily release one arm without compromising the stability of the robot. By moving one arm down out of the way at a time, advancing, and reattaching the arm many obstacles can be traversed relatively quickly. Testing of a scaled model resulted in a 35 second time required to traverse an obstacle and a 30 cm/sec speed on the line.

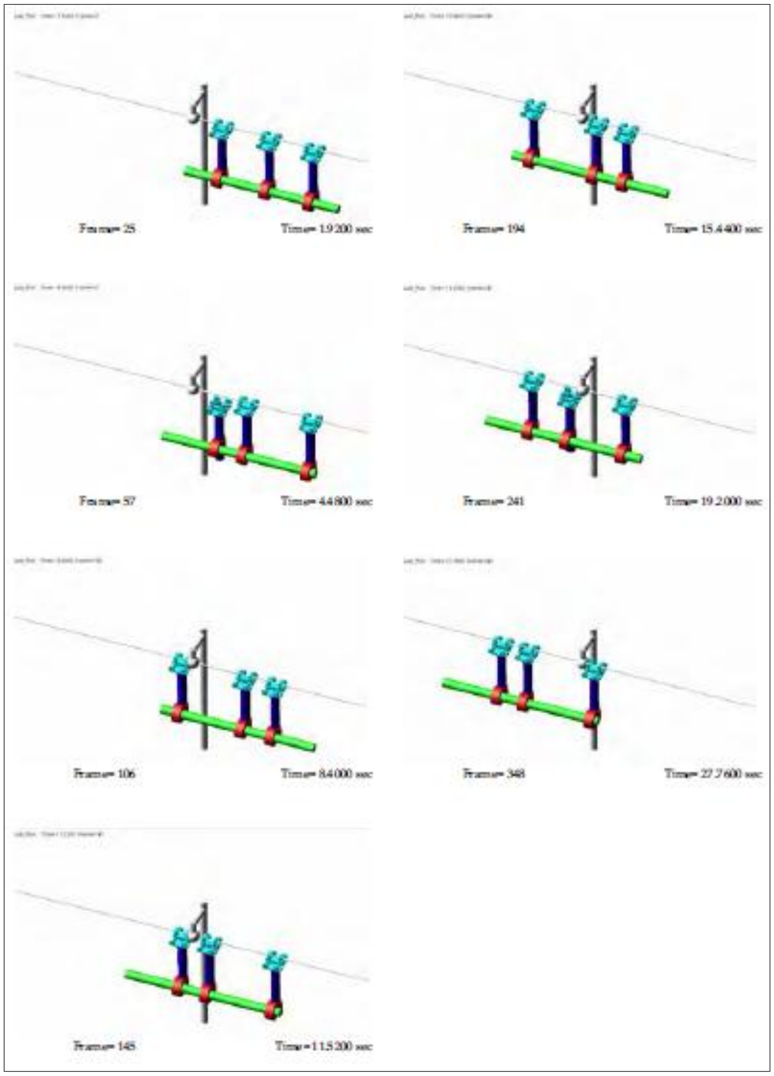

Figure 16: MoboLab's Obstacle Avoidance
(30, Nayyerloo, 2007) © 2007 InTech

The MoboLab model is very capable with the ability to climb an 18% grade and carry a 1 kg payload. The model weighed 14 kg and was about 3 feet long. The control system used an AVR microcontroller to communicate via RS232 with a computer. Using a GUI a user can easily control each motor, watch video feed, or take images of the conductor. Controls are sent from the AVR to a relay board which operates the motors. (30, Nayyerloo, 2007)

2. ROBTET

ROBTET is a maintenance robot that was designed out of the Universidad Politéchnica de Madrid in collaboration with Iberdrolla and Cobra and was in use in 2002. The ROBTET system consisted of an autonomous truck, a 10 kW electric generator, hydraulic pump unit, and robotic arms from Kraft TeleRobotics. Kraft is a company out of Kansas which has been involved in many similar ventures, including maintenance robots with EPRI and Hydro Quebec. This was one of the early attempts to integrate robotics into the utility industry using robotic arms mounted to an insulated boom truck. ROBTET is rated for power lines up to 69 kV, and rather unique as a completely tele-operated unit. The control system utilizes a vision system and haptic joysticks which allow the operator to receive force feedback from the robotic arms.

Figure 17: Universidad Politéchnica de Madrid's ROBTET (2, Aracil, 2007)

III. Project Objectives and Scope

The goal of this is project was to create a working prototype of a power line inspection robot. It would inspect the line by recording temperature, distance, and sending back video feed to visually inspect for flaws in the conductor, insulators and other components along the line. Design parameters were set to measure distance within 15% accuracy and temperature within 10 °C for at least 15 minutes. A camera was to be implemented for visual inspection and an encoder would be used to measure the length of conductor between the fixed poles.

Advanced goals for this project would be to further refine the initial design parameters and allow control of the robot wirelessly from the ground at a distance of 40 feet, or the height of a pole. These specifications included distance measurement within 5% accuracy, temperature measurement within 2 °C, and 30 minutes of continuous runtime. The details of these specifications can be found in the project specification in Appendix B section A.

IV. Project Execution

A. General Discussion of Project Design History

As previously mentioned, this project came about from an article read in the IEEE Spectrum Automation Blog on Hydro Quebec's robotic device called the LineScout. This article sparked the idea of creating an inexpensive inspection robot to ride on the conductors. A block diagram of the electrical system was drawn up as seen in Appendix A section Aiii and initial project specifications were agreed upon. After reviewing several of the designs detailed in the previous section, initial sketches were drawn in attempts to create a simple robot capable of obstacle avoidance.

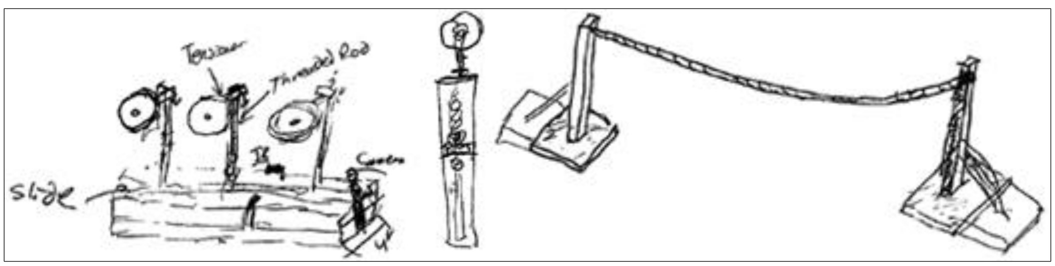

Figure 18: Initial Sketches

The design was refined as manufacturing possibilities were assessed. The conceptual design below was created as a platform that could be modified for obstacle avoidance capabilities later on. The rack and pinion for mobility of the arms was kept through these modifications although it was later found to be of little use.

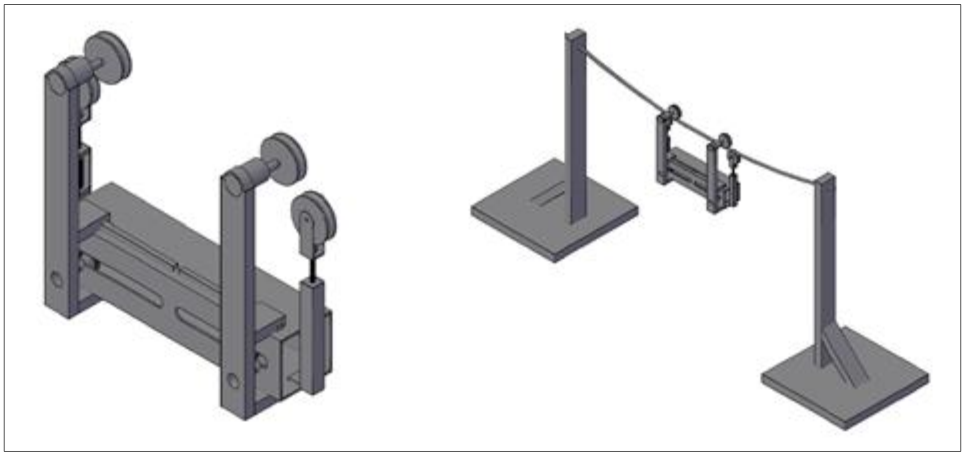

Figure 19: Conceptual Design

Throughout this design process parts were specified for the mechanical construction along with the motors to run the drive pulleys. These parts can be seen in a labeled view in Appendix A Section Aii. Construction of the mechanics began and the electrical circuits were discussed. From the initial block diagram the electrical circuitry was expanded upon in creating a communications diagram as seen in Appendix A Section Aiv. Using this diagram, the major electrical components were selected beginning with the PIC microcontroller. The initial selection was a PIC 32 microcontroller but connection difficulties, detailed later on, brought about the use of a PIC 18. An infrared thermometer was selected for temperature measurement as it was a cheap non-contact sensor that met the required accuracies. Batteries were selected and ordered based on the power requirements of each component. Next, the motor control design began. PID control was accessed but needs only required speed control; PWM control with H-Bridges to reverse direction was the selected method. Next, the power requirements of each component were accessed and buck converters were selected to efficiently provide four different voltage levels to the circuit. Communication difficulties with the infrared thermometer lead to the use of a thermistor in contact with the conductor, and testing of encoder inputs, thermistor operation, and batteries was performed. A working prototype of the robot was completed.

Despite a successful project, several problems were encountered during the design process that altered the direction of the project. Early on, wireless communication and infrared thermometers were researched extensively. A PIC 32 was selected for its Ethernet capabilities and TCP/IP library. This chip was only available in a surface mount style and required a break-out board. Due to soldering problems, a more familiar PIC 18 was used, temporarily sacrificing the wireless features. Another problem was the operation of the h-bridges for motor control using a PWM input signal from the PIC 18. The motors did not operate correctly and required extra circuitry. Serial communication with the IR thermometer was more challenging than originally thought and a thermistor was used as a temporary replacement due to time constraints. A few problems occurred during the testing stages of the project. The first run on the line showed that the drive motors were drawing more current than intended causing the buck converter chip to overheat; a replacement was found and a heat sink was mounted. Lastly, the battery holders purchased for this project had connection problems and required soldering to ensure solid connections.

B. Technical Discussion of Project

In the electrical design of the power line inspection device the overall goals included the selection of a microcontroller, motor control, distance measurements taken from an encoder, temperature measurements, battery selection, voltage regulation, and communication to a display. The selection of the components and some of the theory behind how they work are included in the following section followed by the solutions to problems faced and the testing and verification of specifications.

i. Theory of Operation

a. Microcontroller

The PIC microcontroller is the brains of both the robot and the control board of this device. Why might one use a microcontroller? The answer is often cost, size, or low power consumption among many things. These three reasons fit along with the familiarity with PIC chips from microcontroller class. Although a small CPU may greatly simplify communication and processing, a microcontroller takes up much less space than a CPU and doesn't require external ROM, RAM, or I/O ports that would be required with a microprocessor. Another advantage is the ability to easily configure external connections. In the selection of PIC microcontrollers, the availability of many I/O pins was stressed along with available analog pins and an onboard analog to digital converter. The PIC 18 and PIC 32 microcontrollers from Microchip fit the requirements.

b. H-Bridge

The H-Bridge chips are the basis of the robot's motor control system. They allow control of dc gear motors using a 5V signal voltage and the ability to run them in both forward and reverse. H-Bridge operation is a fairly basic concept. By creating an H with switches and placing a motor or other load along the center line, the polarity of the power to the device can easily be reversed. The operation is comparable to a DPDT Switch wired as below. Consider position A on the DPDT switch being the same as S1 and S4 being closed and position B being the same as S2 and S4 being closed. The two positions allow a reversal of polarities of the motor power supply, allowing the rotor to be turned in either forward or reverse depending on the switch operation. The H-Bridge also allows the motor to be brought to a complete stop, bringing each side of the motor to the same potential by closing both S1 and S3 or S2 and S4. One thing to notice is the ability to short the power supply with the H-Bridge. S1 and S2 or S3 and S4 should not be closed simultaneously.

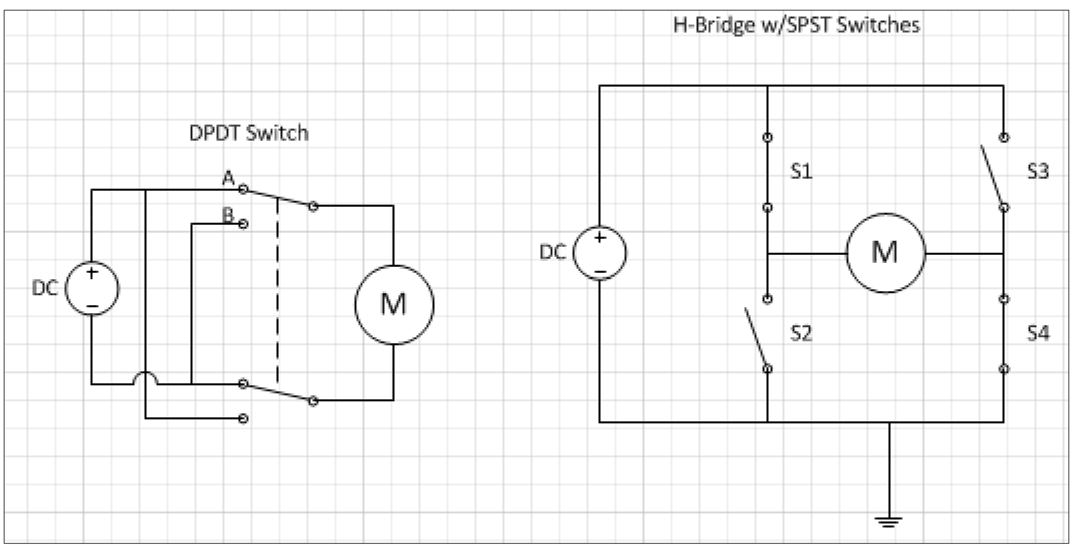

Figure 20: H-Bridge Operation

Perhaps the most important part of the H-Bridge operation is the ability to control the switches. The actual circuitry uses transistors to switch the voltage on and off to the motor. Older style NJM2670 dual h-bridge IC’s from New Japan Radio were used. These integrated circuits use Bipolar Junction Transistors along with some logic circuitry to replace switches 1-4 as seen below. The logic circuitry, represented by empty boxes, allows an enable pin to act as a safety and safe operation of the transistors so they do not short the battery.

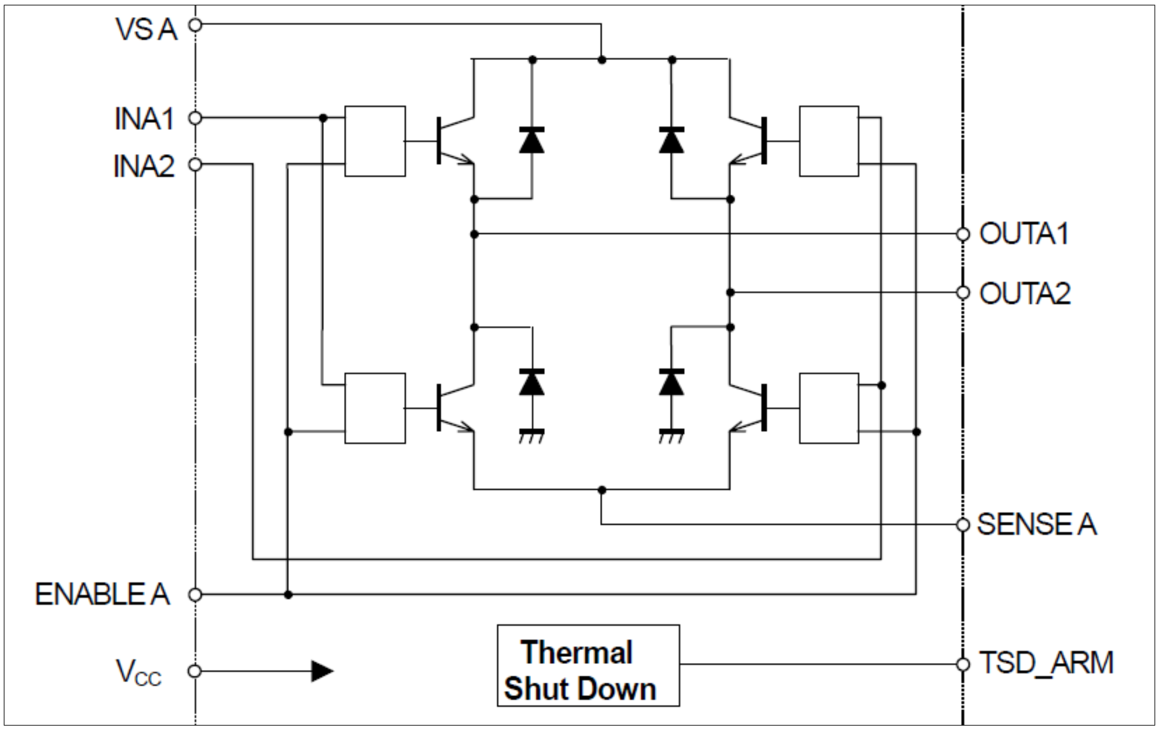

Figure 21: NJM2670 Schematic

One problem with this design, which has since been corrected using MOSFETs, is that the output current through a BJT is dependent on the input current into the base. This problem was found in the initial attempts of motor control and the solution is detailed in the following section.

Motor controller code was designed to control the speed of the motors in both forward and reverse using potentiometer inputs. The potentiometer inputs were wired through the flat wire to the robot PIC chip which reads the voltage through the onboard ADC and outputs a PWM signal to the H-Bridge chip. Code was designed to cycle through a while loop, reading the potentiometer voltage and outputting the corresponding PWM outputs to turn the motor in forward or reverse based on that voltage. PWM, or Pulse Width Modulation, allows us to vary the speed of the motor using the voltage input of the potentiometer to change a Duty Ratio. The Duty Ratio represents the time the signal is high during the period of the square wave; DR = Ton/Period. By varying the time the motor is on using the Duty Ratio with a small period, the motor is turned on and off smoothly. In the code, a Cycle_Time variable which represents the period of the square wave is set to 255 cycles. The potentiometer input from the onboard ADC sets a T_On variable (0-255). As the code cycles, a count is incremented and compared to the T_On variable to determine the output, whether the motor should be turned on or off. When the count reaches 255 the counter is reset. Within this loop the T_On variable is continuously updated from the ADC to change the Duty Ratio. The fully commented code for the Robot PIC microcontroller can be seen in Appendix A Section B.

c. Encoder

The magnetic encoder that was ordered with the motors consists of a magnetized rotor and a two channel Hall Effect sensor. The Hall Effect sensor, seen on the left side of the figure below, recognizes the magnetic changes in polarity in the rotor and outputs a signal.

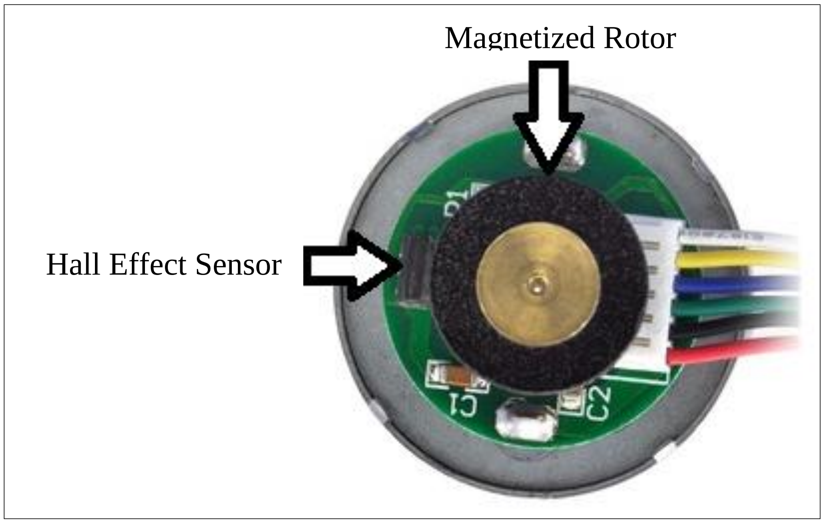

Figure 22: Magnetic Encoder

For example, each magnetic South Pole would give a positive signal, and each North Pole would give a negative signal or zero. This results in a pulse signal which can be used to determine distance, speed, and acceleration given the number of changes of poles in one rotation of the motor. By using two overlapping sensors and comparing rising and fall edges the direction of rotation can be determined based on which sensor receives a pulse first.

This pulse signal was read from the microcontroller. Original code attempted to read the encoder counts in the same while loop that operated motor control, but the cycle wasn't fast enough, so Timer3 was used as a counter and a calibration was performed. More details are included in section iv.

d. Thermistor

A thermistor is a resistor that is sensitive to temperature. There are two classifications of thermistors, PTC and NTC. A PTC type thermistor increases resistance at a particular temperature to act as a switch, while an NTC thermistor changes resistance across a broad range of temperatures decreasing in resistance as temperature increases. The NTC thermistor resistance decreases at a decreasing rate as temperature increases until it reaches its limit. As it gets colder, resistance increases at an increasing rate until it reaches its limit. (38, Vishay, 2002) The thermistor used is an NTC thermistor, as steady change in resistance was required to calibrate the voltage measurements with the actual temperatures. To measure the change in resistance the thermistor was placed in a voltage divider, in the following diagram. The voltage divider was used to minimize power losses when the thermistor was at a low resistance. The PIC chip read the voltages and calculated the temperature.

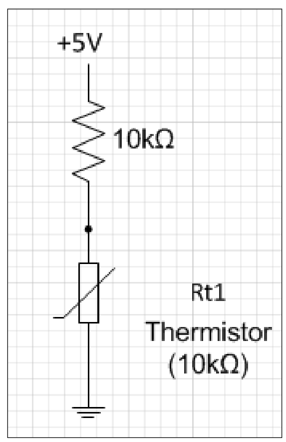

Figure 23: Thermistor Voltage Divider

The code written to read the thermistor was fairly simple. The voltage was measured using the built in function for the analog to digital converter. The control PIC received a signal through the flat wire and read the value converting 0-5V to 0-255 bits in its high register. The lower 2 bits of the 10 bit ADC were ignored and the value was converted to a temperature based on the linear fit of the calibration curve. More details on calibration are included in section iv.

e. Battery

To select batteries it was decided that weight and longevity were most important, along with the ability to recharge, and a low cost. All major components were considered, and power losses were added up. This resulted in an approximate 2.75Ah, 12V power rating. To make up for wire losses, losses across resistors, and other passive component losses, the calculated power loss was doubled and a set of batteries with a lifetime of about an hour or so with a voltage above 12V researched. Ultrafire 18650 batteries satisfied all the criteria. These Lithium batteries were rechargeable, measured 3.7V each and had a 4900 mA hour rating. Using four batteries in series gave the robot a 14.8V supply to be stepped down for the various components of the circuit.

f. Switch Mode DC-DC Converter (Buck)

DC-DC converters allow an efficient conversion from one DC voltage to another, 88% efficient with the TL2575, as opposed to other much less efficient methods such as voltage dividers. When the circuitry was designed, it was decided to use a battery voltage higher than the electronics and motors required. To power the loads of various voltages, several step-down converters or buck converters were needed.

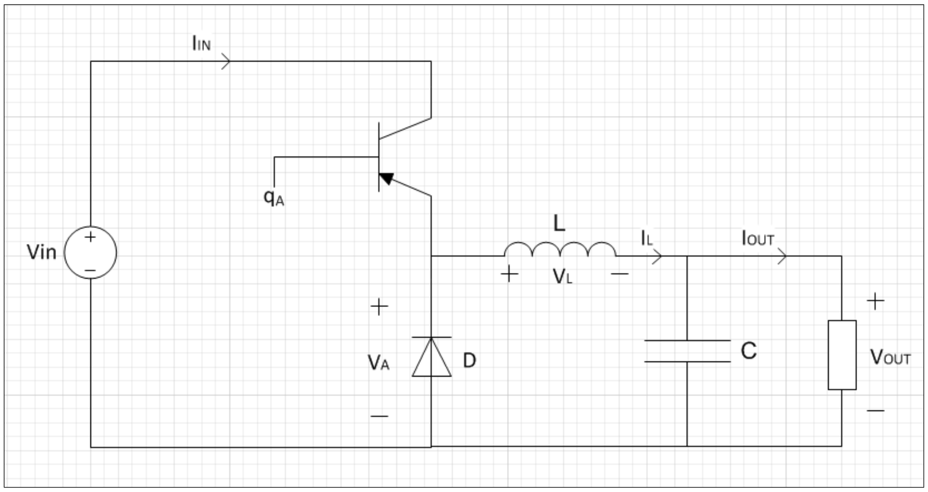

Figure 24: Buck Converter Schematic

A buck converter operates based on Pulse Width Modulation control of a transistor applied to q_A in the above diagram. Like the PWM control of the motor, the buck converter varies voltage based on changing the Duty Ratio (D) of a square wave input. With a buck converter, however, the output voltage needs to be relatively stable; with minimal oscillation. To maintain a stable voltage, an inductor and capacitor are used to store energy and a diode blocks current to ground when voltage is applied and allows current flow from the inductor when the transistor is off. An output voltage is attained; . The analysis of the buck converter circuit and relationships between the voltages and currents can be seen below.

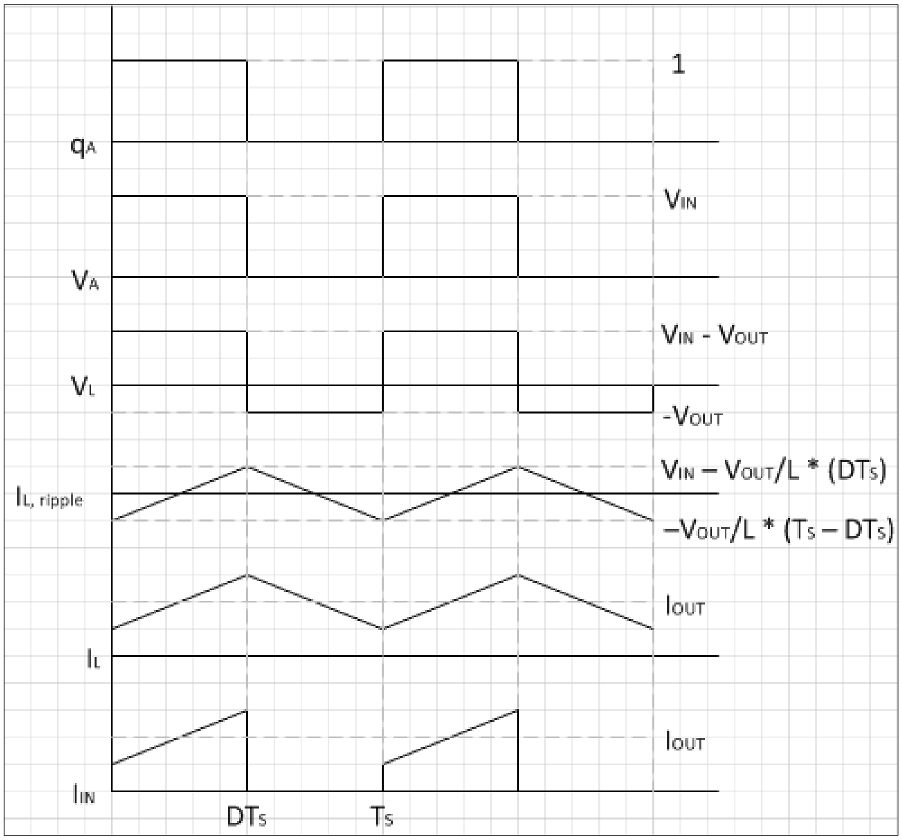

Figure 25: Buck Converter Curves

Voltage and Current Equations:

To establish the q_A signal in the above diagrams, Texas Instruments TL2575 IC's were used. The TL2575 converter chips are designed as closed loop control chips to maintain a voltage set point of 3.3V, 5V, 12V, or an adjustable voltage based on two resistors connected in a voltage divider configuration. The recommended inductors, capacitors, and diodes were used as seen below.

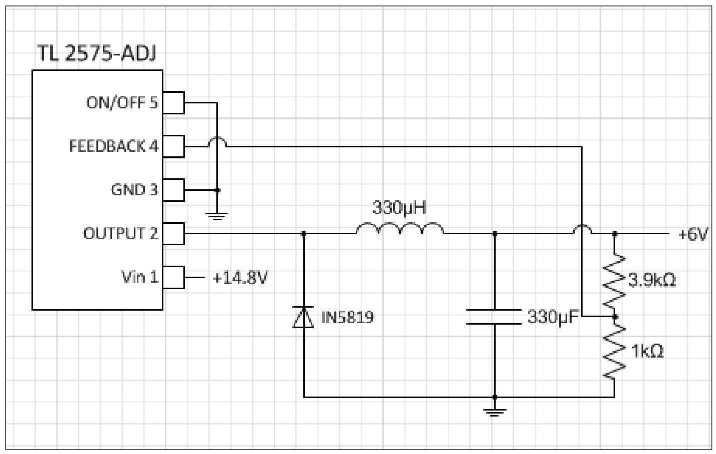

Figure 26: Step Down Converter Circuit

g. LCD Screen

The LCD screen that was used operates using simple commands from a serial interface. It has 8 pins to send and receive data, an enable pin to send commands, register select pin, and read/write pin. Using the instruction set from the datasheet, seen in Appendix A Section G, display of distance and temperature data was achieved. The code that was written to display the data consists of LCD commands and text displays that are stored in ROM, two functions that execute commands and display data, and various "FOR" loops to send characters to the screen one by one. The code for display is cycled through in a while loop that runs continuously after startup. Outside of the while loop, the display variables are written to the screen;

distance, inches, temperature, degC. Inside the “WHILE” loop the screen is commanded to scroll to the display points where the numbers are display and write the updated distance and temperature measurements. The control PIC code can be seen in Appendix A Section B.

Figure 27: LCD Screen

ii. Problem resolutions

a. Microcontroller (PIC 32)

The first electrical problem encountered was connecting to the PIC 32 microcontroller; which happened to be the only Ethernet compatible PIC chip available. This chip was only available as a surface mount, so it required a breakout board in order to be placed on a breadboard.   Initial attempts to solder a TQFP package chip to a breakout board using a soldering iron resulted in damaged traces and no connection. The proper way to solder this chip would have been with solder paste and an oven. Due to this problem, a PIC 18 was used as a replacement because of its mounting style, familiarity, and availability. It was intended to use the PIC 32 later on to incorporate the wireless feature, and a pre-made breakout board with the mounted chip was ordered.

b. Motor Control (MOSFET, Pull-up, and Pull-down)

In initial attempts to create a functional motor control circuit with the H-Bridge receiving a PWM input from the PIC18, the motor was not operating correctly. Instead of smoothly increasing and decreasing speed, the motor went from off to a chattering and then right to full speed. This problem was likely caused by a lack of current to the H-Bridge BJT's. The current through a BJT is approximately equal to its gain value β multiplied by the input current to the base. If the base current is not large enough, the output current is limited. To fix this a MOSFET was added with a pull-down resistor on the gate and a pull-up resistor on the drain, seen below.

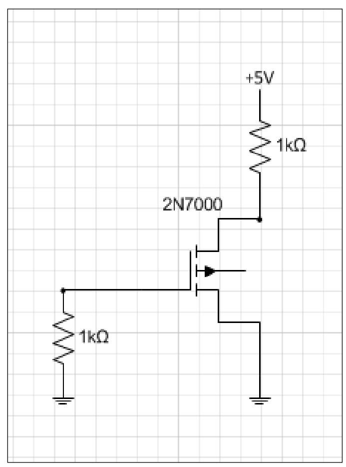

Figure 28: MOSFET, Pull-up, and Pull-down

MOSFETs' require very little current to switch on and off as the bias is created by a voltage across the gate and the source. The pull-up resistor allows current to be pulled directly from the power supply to switch the BJT's in the H-Bridge chip on and off with enough current to turn the motors. The pull-up and pull-down resistors make it very easy to operate the MOSFET by pulling the input low and the output high when there is no signal. When a pulse is sent out by the PIC, the gate to source voltage is brought up to 5V biasing the transistor and pulling the drain to ground.

Although theoretically all that would be necessary is a pull-up resistor to allow more current and help the microcontroller bring the voltage high, when a pull-up was used in the circuit it didn't function. The added isolation and easy switching from the MOSFET which was suggested by a classmate, Alec Johnston, functioned properly.

c. Buck Converter Driver Overheating

Initial Buck Converter selection involved the use of several TL2575 control chips. These chips were designed to achieve a desired voltage output out of a buck converter by acting as both the transistor switch and the control of that switch in the buck converter. The current limit of 1A was too small for the two drive motors. This current wasn't exceeded but approached the chip's limit. This became apparent in initial battery testing as the buck converter heated up excessively. As the current was still below an amp, an attempt was made to solve the problem by mounting a heat-sink on the chip. Further battery testing showed that after significant run time the chip was still heating up and failing to operate correctly so a 3A converter was ordered. The 3A converter was tested with the robot and ran smoothly with a heat sink.

d. Encoder Code

As mentioned previously, an attempt was made to read the encoders in the same loop as the motor control code by incrementing a counter each time a pulse was received. The issue with this was that the cycle time of the loop was too slow and wouldn't count all of the encoder counts. To solve this, the Timer 3 register was used.

e. Thermometer

The original device that was to be used for temperature measurements was a Melexis IR thermometer. Since the robot was intended to be moving at all times, a temperature probe with zero contact was the most desirable. An issue arose from the communication with this thermometer. To read the temperature, serial communication was required between the PIC 18 and the sensor. This communication was in the form of a SMBus configuration. In this configuration there are two shared data wires (SCL and SDA), a master device, and a number of slave devices. The SCL wire is a clock signal that the devices use to synchronize timing with each other. The SDA wire is a data wire on which all information is passed back and forth between the master and slave devices. In order to do this, the master first pulls the SDA wire to ground. Next it sends the address of the slave device it is trying to get information from along with a read/write bit. If there is a slave device that has this address, it is then supposed to pull the data wire low to acknowledge that it is there. After this acknowledge, the master would send the internal register location to read or write to, or wait to read data from the slave. Following this the master would send data to the slave device and send a stop sequence which is represented by an extended high signal. This type of serial communication is called I^2C. The PIC 18 microcontroller had little documentation on the I^2C communication in C, so this was a challenging programming problem. Much time was spent on this, but due to time constraints and the lack of information available on the topic, the IR thermometer was replaced with a 10 kΩ thermistor. The PIC 32 has a built in I^2C module which will allow easy communication with the

IR thermometer if used later on. The thermistor had a very simple operation, as detailed in the previous section, and was easily read as an analog voltage input to the PIC 18. Another problem that was faced was that the thermistor responded slowly to change in temperature; an alternative was sought out. An attempt was made to use a spare temperature probe from a multi-meter. Using this probe would have drawn too much current and thusly reduced the battery lifetime, so the slower acting thermistor became a temporary solution for the project until a faster acting thermistor was ordered.

f. Battery Packs

In initial testing of the batteries, the connections of the battery packs were found to be faulty. To solve this, the springs and connection wired to the rivets were soldered. Loose connections continue to be a problem due to poor quality springs, but are much simpler to fix. New, higher quality battery packs will be investigated.

g. Motor Couplings

Initial testing showed the motor couplings were failing. The original couplings were ¼" nylon spacers with set screws to join the motor shaft and the threaded rod shaft of the pulley assembly. When on the line, these couplings began to bend under the load. The nylon couplings were replaced with steel threaded rod couplings, which were bored and fitted with a set screw to attach the motor shafts. This allowed for a secure motor coupling.

<u>iii. Testing</u>

The testing portion of this project came down to the required specifications; distance measurements within 5% accuracy, temperature readings within 2 degrees

Celsius, and 30 minutes of battery lifetime. To achieve these specifications and prove the robot's functionality, calibrations of the encoder and thermistor were performed and the batteries were tested for a full discharge cycle.

a. Encoder Calibration

The encoders that were ordered with the motors had two hall sensor outputs which combined provide 64 counts per encoder revolution (48 CPR on slide motors). As only one hall sensor output was used, initial attempts to calculate a distance based on a 64 CPR encoder signal failed. If both sensor outputs were used together, the conversion to distance could be calculated as follows.

Instead of using this calculation a calibration was performed by testing various distances, measuring with a tape measure, and recording their corresponding number of counts. The data was plotted and a linear fit was performed in excel; see Appendix A Section Dii. The calibrated display was tested with several distances to prove its accuracy.

b. Thermistor Calibration

The calibration of the thermistor was similar to that of the encoder. Since no curves were available documenting the operation of the thermistor that was donated to us by Alec Johnston, a calibration was performed. The thermistor was placed in water baths of varying temperatures and connected in a voltage divider. Voltage measurements and temperature measurements were recorded using a multimeter, and a linear fit was performed; see Appendix A Section Diii. Although an exponential fit would be more accurate, this fit performed within the range of error that was specified; 2 degrees Celsius. The calibrated display was tested with various temperatures to assure accuracy.

c. Battery Testing

Battery discharge testing was performed to find the battery lifetime of the device. The inspection robot was steered back and forth on a 10 ft length of conductor that was mounted on a test stand until the motors no longer turned. Battery voltages were recorded each minute through the control board using a multimeter and a discharge curve was generated. Although there were slight disruptions in the curve as batteries were temporarily disconnected due to loose connections, the discharge curve fits a standard curve for a lithium ion battery. There were also disruptions caused by coupling failure. The robot ran for 1 hour and 45 minutes as seen in Appendix A Section Ciii.

C. Cost and Schedule Performance

Compared to a typical EET capstone project the power line inspection device was on the expensive side, however, compared to inspection robots currently in industry this project was relatively inexpensive. For approximately $840.00, the project demonstrated that a working prototype of a power line inspection robot could be created with a small budget and be built using mostly parts from hardware stores. This price included tools and equipment needed to execute portions of the project, as well as spare components. An official budget was not created for this project, but care was taken in ordering parts and components at the lowest price, while still obtaining all the requirements needed. If this project were to be rebuilt on a new budget, the price could be reduced greatly by only ordering necessary components.

Scheduling initially was set with large goals. Creating a detailed timeline for the project was a fairly difficult thing to do as this project was a first and many items had not been previously attempted. By planning extra time for most scheduled items, the project followed the timeline fairly closely. A few items, such as the infrared thermometer and some of the mechanics took longer than intended, pushing back the project schedule slightly. Overall, the project's goals were met by the time of presentation at the end of the fall semester.

V. Design Results

The completion of this project showed the robot's ability to meet three out of four of the scope's advanced specifications, and subsequently all of the basic specifications. The robot, seen below, was able to record distance to the nearest inch, temperature within 2 °C, and run for 1 hour and 45 minutes.

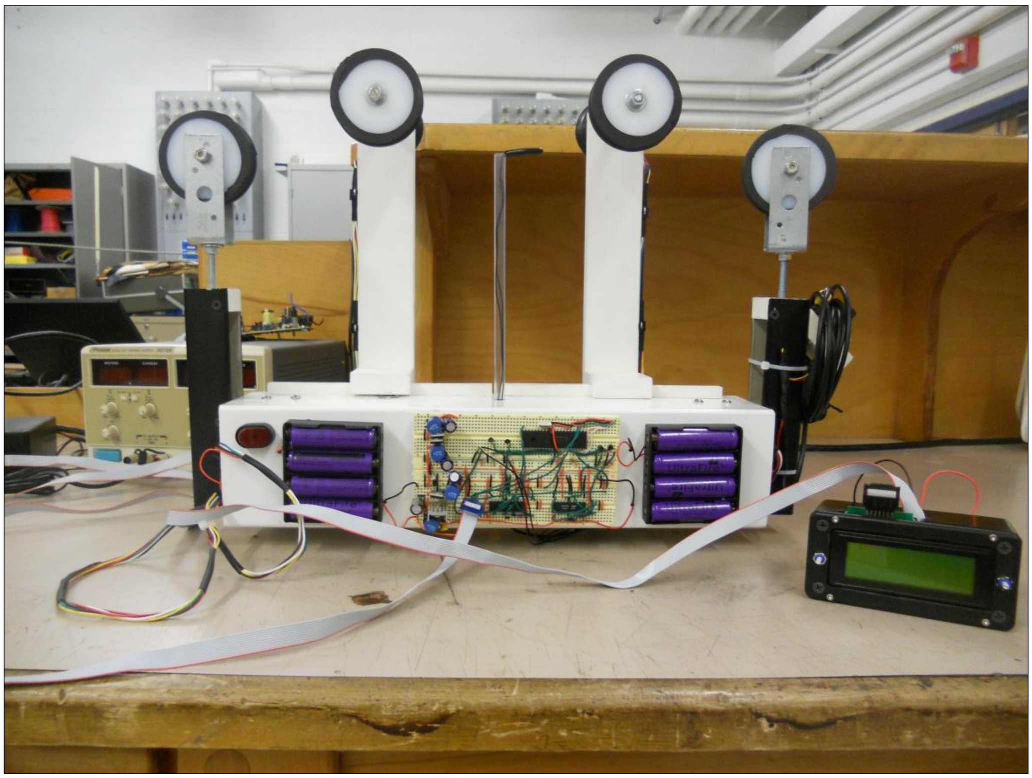

Figure 29: Completed Prototype

The only advanced item that was not accomplished was wireless control; instead a tethered control box was used for robot operation. Early on in the project, attempts to incorporate wireless control into the prototype using the PIC 32 were pushed back, and became too difficult to achieve within time constraints. Wireless communication remains as one of the future improvements to this project. Final touches done on the project include the manufacturing of printed circuit boards for the robot and control circuitry along with the removal of the slide and replacement of the thermistor, seen in the above figure, with a faster acting thermistor. Manufacturing procedures can be seen in Appendix A Section E.

There are several improvements that could be done to the device. Wireless control of the prototype would include the PIC 32, an Ethernet data layer chip, and a router. A laptop would send and receive data to and from the PIC 32. The second improvement on the list is obstacle avoidance. This would allow the robot continuous travel past insulators, splices and other line components that impede on straight line travel. Plans to accomplish this include replacing existing tensioners with linear actuators and adding in two motors to remove the pulleys from the line. A drawing of obstacle avoidance operation can be seen in Appendix A Section Aviii. Another future improvement is an infrared thermometer to allow non-contact temperature readings. The original plans with the project were to include this device, but due to complications in communication, a thermistor was used in its place. Another feature to be added is pan and tilt control of the camera. By having this additional control, the user could view the other conductors and more of the conductor. The magnetic encoders that were used should be replaced by optical encoders to eliminate the possibility of magnetic interference from the power line. Additional features that could be added include a range finder, wireless current sensor, and an inductive charging coil along with upgrades of existing equipment.

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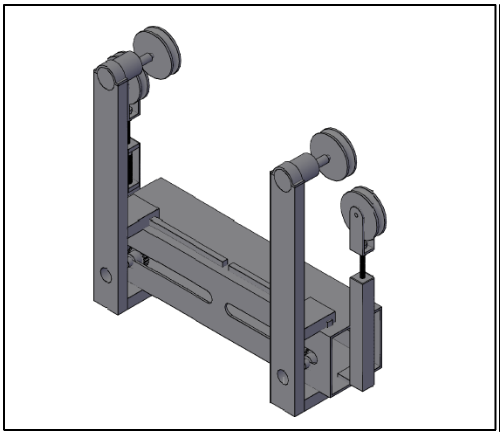
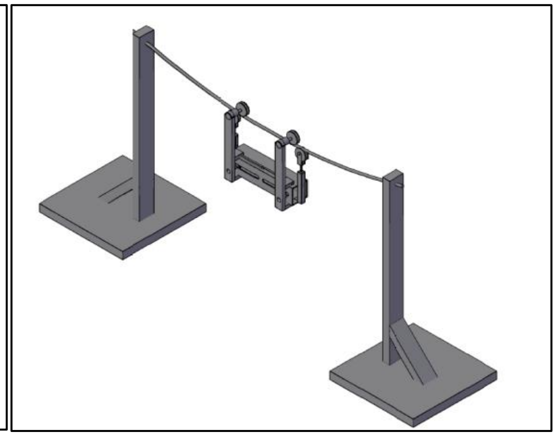
VII. Appendix A

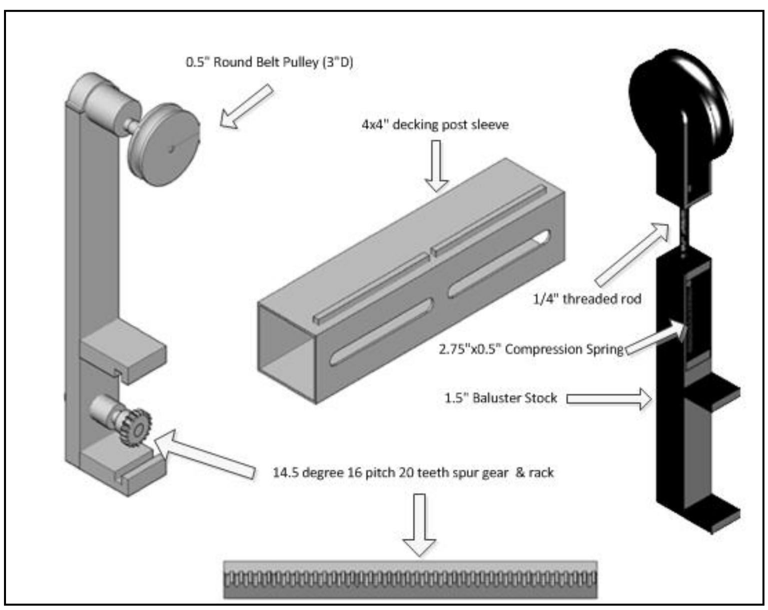
A. Drawings

i. Conceptual Design

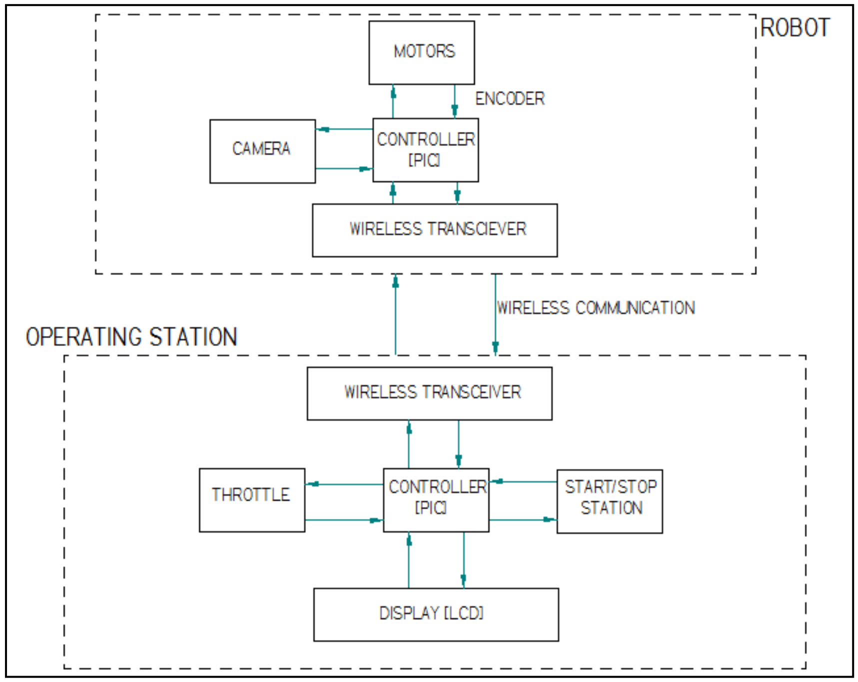




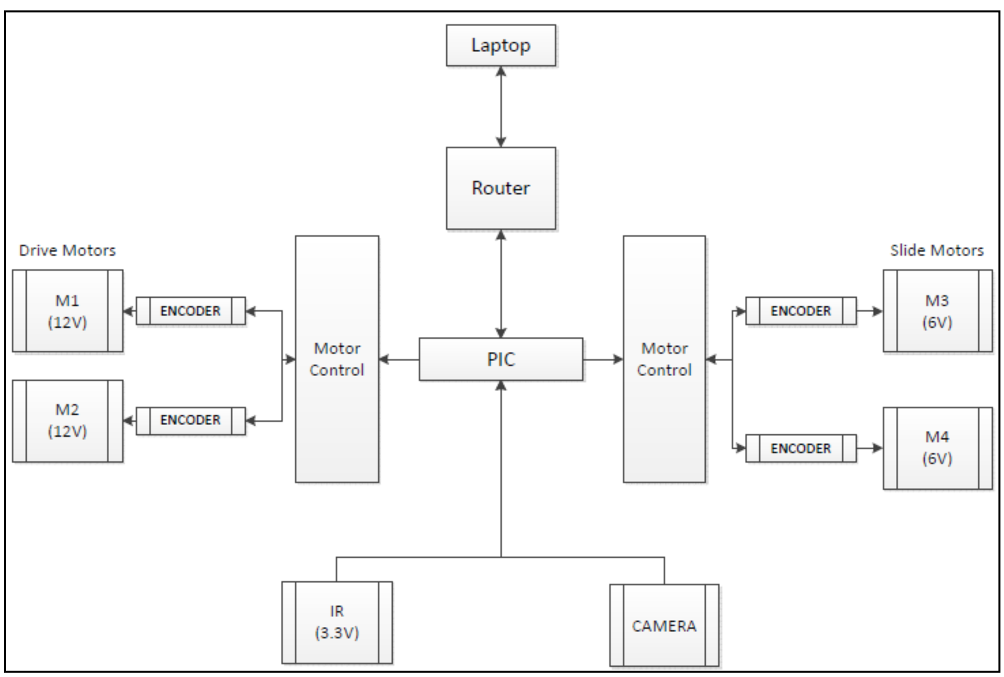
ii. Mechanical Detail



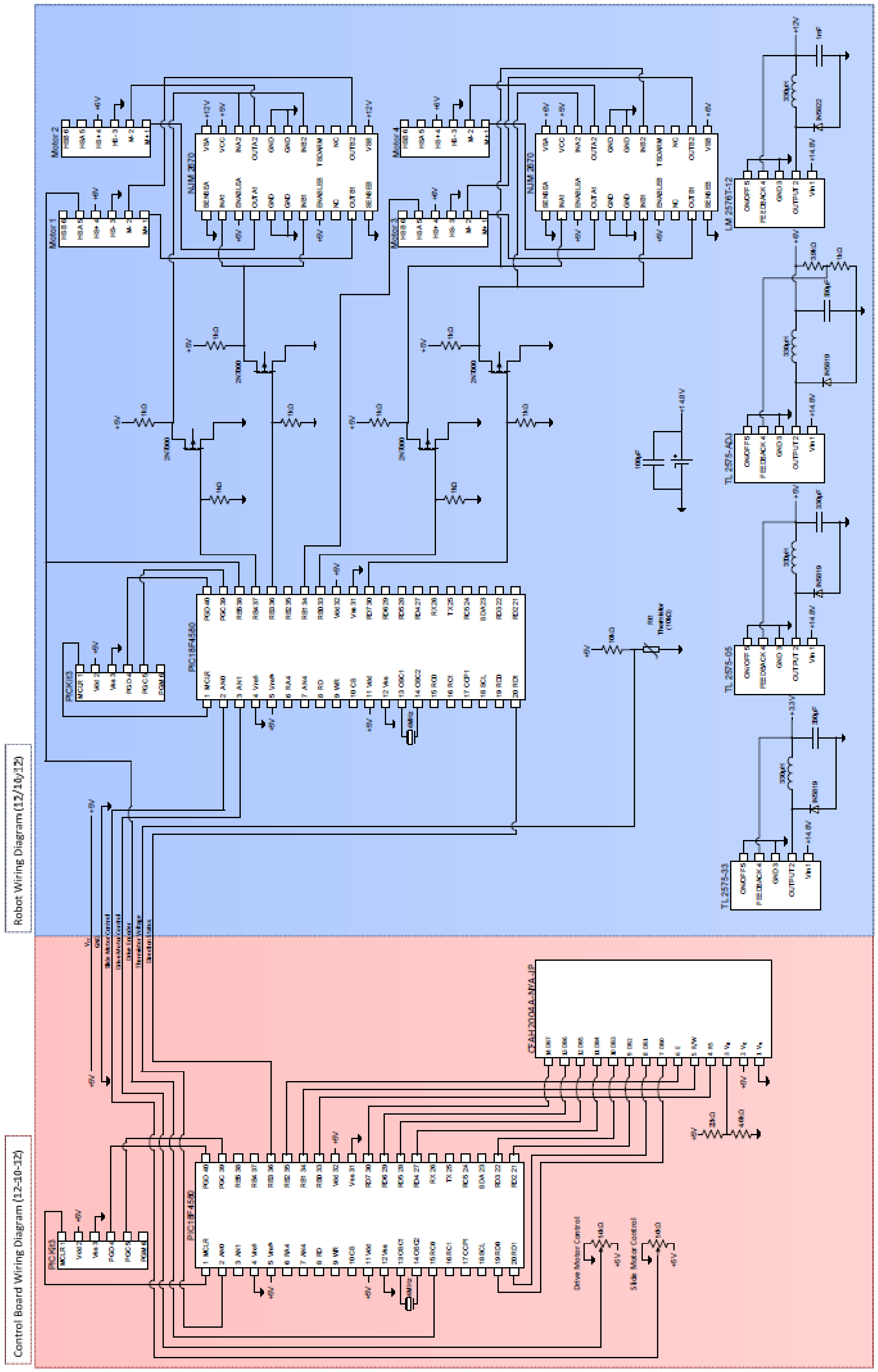
iii. Block Diagram



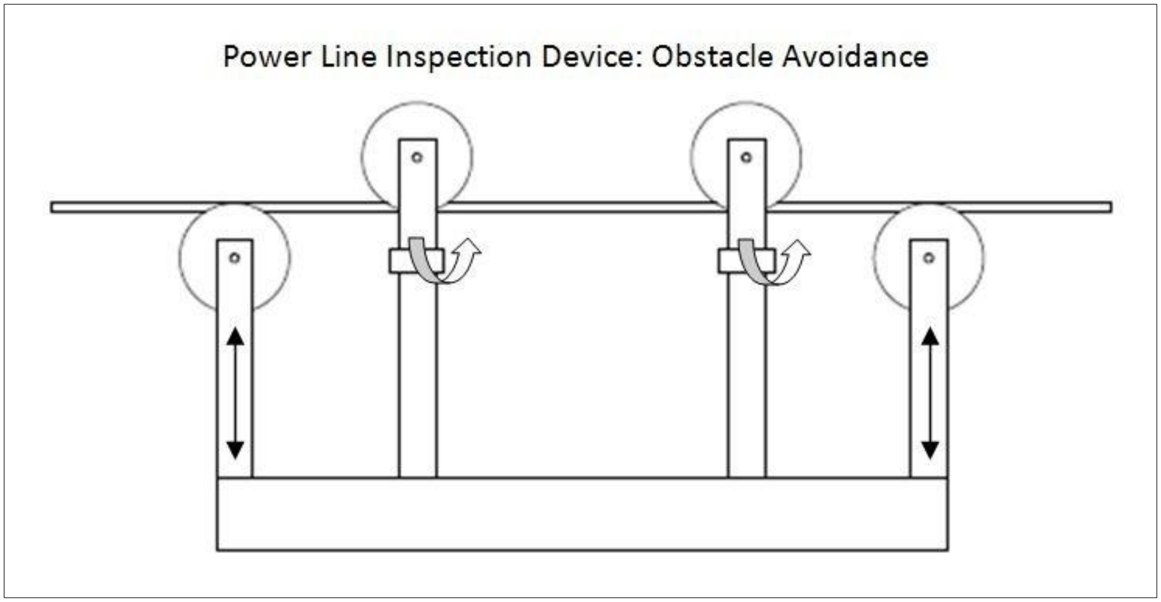
iv. Communications Block Diagram



vii. Wiring Diagram



viii. Obstacle Avoidance Diagram



B. Source Code

```
/*
 * File:   Robot_PIC.c
 * Author: Brendan
 *
 * Created on November 12, 2012, 7:23 PM
 */

/*COMMENTED LINES WERE FOR FORWARD/REVERSE ENCODER COUNTS AND WEREN'T FOR
DEMO*/

#include <stdio.h>
#include <stdlib.h>
#include <p18f4580.h>
#include <adc.h>
#include <string.h>
#include <i2c.h>
#include <timers.h>
#include <math.h>
#pragma config MCLRE=OFF, WDT=OFF, OSC=XT, LVP=OFF, PBADEN=OFF

#define MD_Encoder PORTBbits.RB5
#define MD_IN1     PORTBbits.RB3
#define MD_IN2     PORTBbits.RB4
#define MS_Encoder PORTBbits.RB1
#define MS_IN1     PORTBbits.RB0
#define MS_IN2     PORTDbits.RD7
#define DirectionD PORTDbits.RD1

/*  KEY
    (D) - Drive Motors
    (S) - Slide Motors  */

void main(void)
    {   unsigned int AnCon0 = 0;            // Control Variable 0 (D)
        unsigned int AnCon1 = 0;            // Control Variable 1 (S)
        unsigned int T_On0 = 0;             // On Time(D)
        unsigned int T_On1 = 0;             // On Time(S)
        unsigned int Cycle_Time = 0xFF;     // Cycle Time
        unsigned int Count =0;              // Counter
      //char DirectionD = 'S';              // Direction (Drive:F,R,S)
        char DirectionS = 'S';              // Direction (Slide:F,R,S)
```

```
int Encoder_Status1 = 0;            // Encoder Status (D)
int Encoder_Count1 = 0;             // Encoder Count (D)
int Encoder_Status2 = 0;            // Encoder Status (S)
int Encoder_Count2 = 0;             // Encoder Count (S)
int R = 0;                          // Reverse Direction
int F = 1;                          // Forward Direction

TRISAbits.TRISA1 = 1;               // Analog Control Input on PortA1
TRISAbits.TRISA4 = 0;               // Analog Control Output on PortA4
TRISBbits.TRISB5 = 1;               // Encoder Input on Port B5
TRISBbits.TRISB4 = 0;               // Drive Motor Outputs on PortB3-4
TRISBbits.TRISB3 = 0;
TRISBbits.TRISB0 = 0;               // Slide Outputs on PortB0,D7
TRISDbits.TRISD7 = 0;
TRISDbits.TRISD1 = 0;               // Direction Status Bit as Output

// ADC Settings
ADCON0 = 0b00000000;                // AN0 as analog in, ADC off
ADCON1 = 0b00001010;                // AN2=AVss,AN3=AVdd,AN0-4=Analogs
ADCON2 = 0b00000000;                // Left Justified, Fosc/2 Clock

while(1)
{   // Drive Motor Control
    ADCON0bits.CHS0 = 0;                    // Select PortA0
    ADCON0bits.ADON = 1;                    // Turn ADC on
    ADCON0bits.GO = 1;                      // Start Converting
    while(ADCON0bits.GO == 1);              // Wait Until Converted
    AnCon0 = ADRESH;                        // Store Control Value

    if (AnCon0 <= 120)                      // Reverse control(0-120)
    {   DirectionD = R;                     // Set direction reverse
        T_On0 = ((~AnCon0 & 0x00FF)-128)*2; // Convert Time_On Scale
        if(Count <= T_On0)                  // Count less than T_On:
        {   MD_IN1 = 1;                     // turn motor in reverse
            MD_IN2 = 0;  }
        else                                // Otherwise, turn it off
        {   MD_IN1 = 1;
            MD_IN2 = 1;  }
    }
    else if (AnCon0 >= 135)                 // Forward (135-255)
    {   DirectionD = F;                     // Set direction forward
```

```
    T_On0 = (AnCon0-128)*2;              // Convert Time_On Scale
    if(Count <= T_On0)                   // Count less than T_On:
    {   MD_IN1 = 0;                      // turn motor forward
        MD_IN2 = 1;   }
    else                                 // Otherwise, turn it off
    {   MD_IN1 = 1;
        MD_IN2 = 1;   }
}
else                                     // Stoped(120-135)
{ //DirectionD = 'S';                    // Set direction stopped
    T_On0 = 0;                           // Stop Drive Motors
    MD_IN1 = 1;
    MD_IN2 = 1;      }

// Slide Motor Control
ADCON0bits.CHS0 = 1;                     // Select PortA1
ADCON0bits.ADON = 1;                     // Turn ADC on
ADCON0bits.GO = 1;                       // Start Converting
while(ADCON0bits.GO == 1);               // Wait Until Converted
AnCon1 = ADRESH;                         // Store Control Value

if (AnCon1 <= 120)                       // Reverse control(0-120)
{   DirectionS = 'R';                    // Set direction reverse
    T_On1 = ((~AnCon1 & 0x00FF)-128)*2; // Convert Time_On Scale
    if(Count <= T_On1)                   // Count less than T_On:
    {   MS_IN1 = 1;                      // turn motor in reverse
        MS_IN2 = 0;   }
    else                                 // Otherwise, turn it off
    {   MS_IN1 = 1;
        MS_IN2 = 1;   }
}
else if (AnCon1 >= 135)                  // Forward(0-135)
{   DirectionS = 'F';                    // Set direction forward
    T_On1 = (AnCon1-128)*2;              // Convert Time_On Scale
    if(Count <= T_On1)                   // Count less than T_On:
    {   MS_IN1 = 0;                      // turn motor forward
        MS_IN2 = 1;   }
    else                                 // Otherwise, turn it off
    {   MS_IN1 = 1;
        MS_IN2 = 1;   }
}
```

```
        else                                            // Stopped(120-135)
        {   DirectionS = 'S';                           // Set direction stopped
            T_On1 = 0;                                  // Stop Drive Motors
            MS_IN1 = 1;
            MS_IN2 = 1;      }

        if(Count > Cycle_Time)                          // Count exceeds cycle:
            {Count = 0;}                                // reset the count
        Count ++;                                       // Increment the counter

        // Encoder Count
        //if (DirectionS == 'F')                          // Forward: add count
        //{   if (MS_Encoder == 1 & Encoder_Status2 == 0)
        //    {   Encoder_Status2 = 1;
        //        Encoder_Count2++;   }
        //      else if (MS_Encoder == 0 & Encoder_Status2 == 1)
        //    {   Encoder_Status2 = 0;    }
        //}
        //else if (DirectionS == 'R')                     // Reverse: sub. count
        //{   if (MS_Encoder == 1 & Encoder_Status2 == 0)
        //    {   Encoder_Status2 = 1;
        //        Encoder_Count2--;   }
        //    else if (MS_Encoder == 0 & Encoder_Status2 == 1)
        //    {   Encoder_Status2 = 0;    }
        //}
    }
}
```

```
/*
 * File:   Control_PIC.c
 * Author: Brendan
 *
 * Created on November 28, 2012, 12:29 PM
 */
/* NOTE: COMMENTED LINES WERE USED POSITION FROM START AND EXCLUDED FOR DEMO*/

#include <stdio.h>
#include <stdlib.h>
#include <p18f4580.h>
#pragma config MCLRE=OFF, WDT=OFF, OSC=IRCIO67, LVP=OFF, PBADEN=OFF

#define ldata PORTD                  // PORTD = LCD data pins
#define rs PORTBbits.RB0             // rs = PORTB.0
#define rw PORTBbits.RB1             // rw = PORTB.1
#define en PORTBbits.RB2             // en = PORTB.2
#define DirectionD PORTBbits.RB3     // Robot Direction Status (0 = R, 1 = F)

far rom const char mycom[] = {0x0E, 0x01, 0x06, 0x84};  // LCD Commands
far rom const char Distance[] = "Distance:";            // Display Variables
far rom const char Inches[] = "inches";
far rom const char Temperature[] = "Temperature:";
far rom const char Degrees_C[] = "degC";
far unsigned long Encoder_Count1_L = 0x00;          // Encoder Count Low
far unsigned long Encoder_Count1_H = 0x00;          // Encoder Count High
far unsigned long Encoder_Count1_I = 0x00;          // Encoder Count Interrupt
far unsigned long Encoder_Count1 = 0x00;            // Complete Encoder Count
far unsigned int Sensor_Temp = 0x00;                // Temperature

void lcdcmd(unsigned char value);       // LCD Command Call
void lcddata(unsigned char value);      // LCD Data Display
void MSDelay(unsigned int itime);       // Milisecond Delay
void chk_isr(void);                     // Interrupt Check
void TMR3_ISR(void);                    // Timer 3 Interrupt

#pragma code My_HiPrio_Int = 0x0008     // High priority Interrupt Location
void My_HiPrio_Int(void)                // On Interrupt, Check It
{   _asm
    GOTO chk_isr
    _endasm    }
```

```
#pragma interrupt chk_isr
void chk_isr (void)                     // Check for Timer 3 Interrupt
{   if(PIR2bits.TMR3IF == 1)            // If Timer 3 Caused Interrupt
        TMR3_ISR();           }         // Execute TMR3_ISR


void main(void)
    {   unsigned char d1, d2, d3, d4, d5;       // BCD variables
        unsigned char z = 0;
        unsigned long x;
        unsigned long Distance_Traveled = 0x0;  // Distance Traveled
      //unsigned long Count_Last = 0x0;         // Distance Count Placeholder
      //unsigned long Count_Difference = 0x0;   // Difference Placeholder
      //unsigned long Distance_Count = 0x0;     // Distance From Start Point
        unsigned int Encoder_Count1L;           // Low Byte - Encoder Readout
        unsigned int Encoder_Count1H;           // High Byte - Encoder Readout

        TRISD = 0;                      // Ports B and D as Outputs
        TRISB = 0;
        TRISAbits.TRISA1 = 1;           // Encoder Input
        TRISBbits.TRISB3 = 1;           // PortB3 as Direction Status Input
        TRISCbits.TRISC0 = 1;           // T3CLK Pin as Input (Encoder)

        // ADC Settings
        ADCON0 = 0b00000000;            // AN0 as analog in, ADC off
        ADCON1 = 0b00001010;            // AN2=AVss, AN3=AVdd, AN0-4=Analog Inputs
        ADCON2 = 0b00000000;            // Left Justified, Fosc/2 Clock

        INTCON2bits.RBPU = 1;           // Enable PortB pullup resistors
        T3CON = 0x42;                   // Set Timer3 for capture, 1:1 prescaler

        for(z=0;z<4;z++)                // Initialize display
        {   lcdcmd(mycom[z]);   }
            MSDelay(15);
        for(z=0;z<4;z++)                // Scroll backward 4 spaces
        {   lcdcmd(0x10);   }
            MSDelay(15);
        for(z=0;z<9;z++)                // Display distance
        {   lcddata(Distance[z]);
            MSDelay(15);    }
```

```
for(z=0;z<5;z++)              // Scroll forward 5 spaces
{   lcdcmd(0x14);   }
    MSDelay(15);
for(z=0;z<6;z++)              // Display inches
{   lcddata(Inches[z]);
    MSDelay(15);    }
for(z=0;z<12;z++)             // Display temperature
{   lcddata(Temperature[z]);
    MSDelay(15);    }
for(z=0;z<4;z++)              // Scroll forward 4 spaces
{   lcdcmd(0x14);   }
    MSDelay(15);
for(z=0;z<4;z++)              // Display degrees C
{   lcddata(Degrees_C[z]);
    MSDelay(15);    }
for(z=0;z<31;z++)             // Scroll backward 31 spaces
{   lcdcmd(0x10);   }
    MSDelay(15);

// Encoder Capture Setup
TMR3H = 0;                    // Initialize timer count variables to 0
TMR3L = 0;
PIR2bits.TMR3IF = 0;          // Clear interrupt flag
PIE2bits.TMR3IE = 1;          // Enable Timer 3 interrupt
INTCONbits.PEIE = 1;          // Enable periferal interupts
INTCONbits.GIE = 1;           // Enable interrupts globally
T3CONbits.TMR3ON = 1;         // Turn on timer

while (1)                     // Main Loop
{   // Combine count variables for total
    Encoder_Count1L = TMR3L;
    Encoder_Count1H = TMR3H;
    Encoder_Count1H = Encoder_Count1H << 8;
    Encoder_Count1_L = Encoder_Count1L|Encoder_Count1H;
    Encoder_Count1_H = Encoder_Count1_I << 16;
    Encoder_Count1 = Encoder_Count1_L|Encoder_Count1_H;
```

```
        // Add or subtract count based on direction
        //Count_Difference = Encoder_Count1 - Count_Last;
        //Count_Last = Encoder_Count1;
        //if (DirectionD == 1)
        //    Distance_Count = Distance_Count + Count_Difference;
        //if (DirectionD == 0)
        //    Distance_Count = Distance_Count - Count_Difference;

          // Convert to inches using calibration curve (y = 0.0039x-0.4332)
          Distance_Traveled = Encoder_Count1*0.0039 - 0.4332;

          // Binary to Decimal Conversion of Distance Traveled
          x = Distance_Traveled;
          d1 = x%10;                            // Least Significant Digit
          d2 = (x/10)%10;                       // Middle Digits
          d3 = (x/100)%10;
          d4 = (x/1000)%10;
          d5 = (x/10000)%10;                    // Most-Significant Digit

          lcddata(d5+48);                       // Display Number (0-65535 in)
          lcddata(d4+48);
          lcddata(d3+48);
          lcddata(d2+48);
          lcddata(d1+48);

          for(z=0;z<18;z++)                     // Scroll forward 18 spaces
          {   lcdcmd(0x14);    }
              MSDelay(15);

          // Read PortA0 for voltage across Thermister
          ADCON0bits.ADON = 1;                  // Turn ADC on
          ADCON0bits.GO = 1;                    // Start Converting
          while(ADCON0bits.GO == 1);            // Wait Until Converted

          // Convert to degC using calibration curve (y = -0.4355x-81.681)
          Sensor_Temp = -0.4355*(ADRESH) +  81.681;

          // Binary to Decimal Conversion of Control 1 (8 bit number)
          x = Sensor_Temp;
          d1 = x%10;                            // Least Significant Digit
          d2 = (x/10)%10;                       // Middle Digits
```

```
            d3 = (x/100)%10;                            // Most-Significant Digit
            d4 = 0;

            lcddata(d4+48);                             // Display Number (0-255 degC)
            lcddata(d3+48);
            lcddata(d2+48);
            lcddata(d1+48);

            for(z=0;z<27;z++)                           // Scroll backward 27 spaces
            {    lcdcmd(0x10);    }
                MSDelay(15);
        }
    }
void TMR3_ISR(void)
{   T3CONbits.TMR3ON = 0;                               // Turn off timer
    Encoder_Count1_I++;                                 // Increment Count
    PIR2bits.TMR3IF = 0;                                // Clear interrupt flag
    T3CONbits.TMR3ON = 1;                               // Turn on timer
}
void lcdcmd(unsigned char value)
    {   ldata = value;                                  // Put the value on the pins
        rs = 0;
        rw = 0;
        en = 1;                                         // Strobe the enable pin
        MSDelay(1);
        en = 0;         }
void lcddata(unsigned char value)
    {   ldata = value;                                  // Put the value on the pins
        rs = 1;
        rw = 0;
        en = 1;                                         // Strobe the enable pin
        MSDelay(1);
        en = 0;         }
void MSDelay(unsigned int itime)
    {   unsigned int i, j;                              // Cycle processor for 1 ms
        for(i=0;i<itime;i++)
            for(j=0;j<135;j++);    }
```

C. Test Data

i. Distance Measurement

Table 2: Distance Measurement Testing 2-25-13

Tape Measure Measurement (Inches)	Distance Readout (Inches)	Accuracy
4	3	75.00%
5	5	100.00%
9	9	100.00%
13	12	92.31%
15.5	16	96.77%
20.5	21	97.56%
30.5	30	98.36%
45	45	100.00%
66	66	100.00%
96	96	100.00%
	Average Accuracy:	**96.00%**

ii. Temperature Measurement

Table 3: Temperature Measurement Testing 2-26-13

Multimeter Probe Measurement (°C)	Temperature Measurement(°C)	Accuracy
6	7	83.33%
15	15	100.00%
18	18	100.00%
32	33	96.88%
23	23	100.00%
37	39	94.59%
42	44	95.24%
47	49	95.74%
52	52	100.00%
64	62	96.88%
65	67	96.92%
	Average Accuracy:	**97.63%**

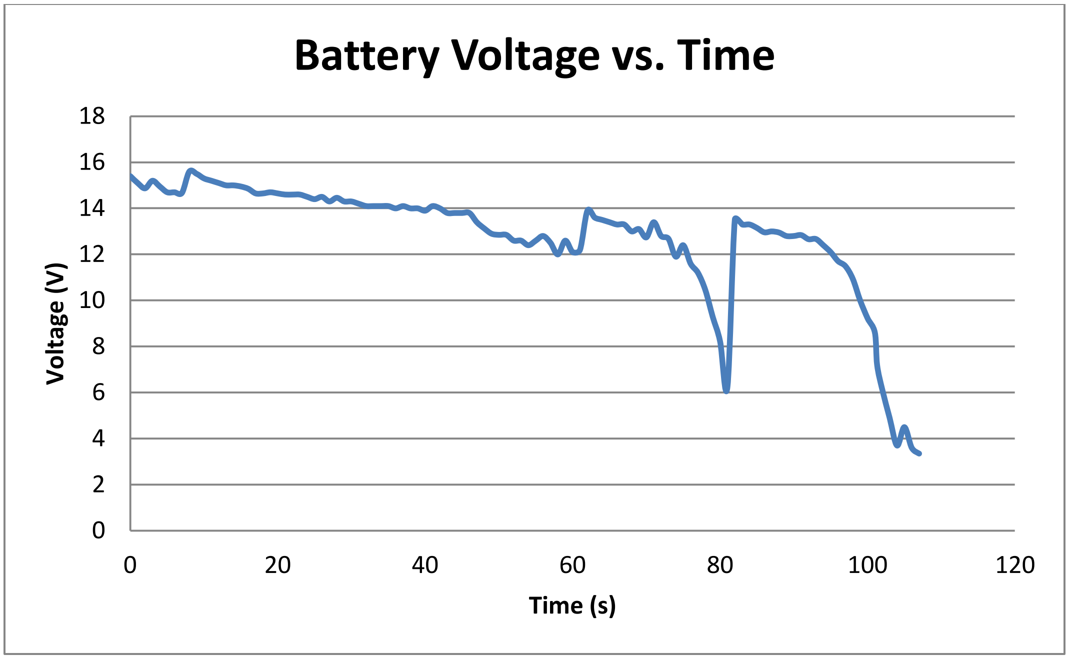
iii. Battery Discharge

Table 4: Battery Discharge Measurements

Time(min)	Voltage(V)	Comments
0	15.4	
1	15.1	
2	14.87	Turned off due to
3	15.2	mechanical failure
4	14.95	
5	14.7	
6	14.7	
7	14.67	Turned off due to
8	15.6	mechanical failure
9	15.5	
10	15.3	
11	15.2	
12	15.1	
13	15	
14	15	
15	14.95	
16	14.85	
17	14.65	
18	14.65	
19	14.7	
20	14.65	
21	14.6	
22	14.6	
23	14.6	Some small stops due to tensioner rubber
24	14.5	12V Buck Converter beginning to heat up
25	14.4	
26	14.5	
27	14.3	
28	14.46	
29	14.3	
30	14.3	
31	14.2	
32	14.1	
33	14.1	
34	14.1	
35	14.1	
36	14	

37	14.1	
38	14	
39	14	
40	13.9	
41	14.1	
42	14	
43	13.8	
44	13.8	
45	13.8	
46	13.8	
47	13.4	
48	13.13	
49	12.9	
50	12.85	
51	12.85	Stopped Briefly, turned batteries and restarted
52	12.6	
53	12.6	
54	12.4	
55	12.6	
56	12.8	
57	12.5	
58	12	
59	12.6	
60	12.1	
61	12.2	
62	13.9	
63	13.6	
64	13.5	
65	13.4	
66	13.3	
67	13.3	
68	13	
69	13.1	
70	12.74	
71	13.4	
72	12.8	
73	12.68	
74	11.9	
75	12.4	
76	11.6	
77	11.2	

78	10.45	
79	9.29	
80	8.22	
81	6.25	No Movement
82	13.52	Stopped Briefly, turned batteries and restarted
83	13.3	
84	13.3	
85	13.15	
86	12.96	
87	13	
88	12.95	
89	12.8	
90	12.8	
91	12.84	
92	12.66	
93	12.67	
94	12.4	
95	12.1	
96	11.71	
97	11.49	
98	10.94	
99	10	
100	9.23	
101	8.6	
101.3	7.2	No Movement, Voltage Declining
102	6.13	
103	4.9	LCD Dimming
104	3.7	LCD Gone
105	4.5	Turned batteries to test connection
106	3.6	
107	3.35	Stopped robot due to component and battery heating


Battery Voltage vs. Time
Voltage (V)
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
Time (s)

D. Calculations and Analysis

i. Motor Calculations

Table 5: Drive Motor Speed

Speed(mph)	Pulley Diameter(in)	Circumference(in)	Motor Speed(rpm)
0.1	3	18.84	5.605095541
0.2	3	18.84	11.21019108
0.3	3	18.84	16.81528662
0.4	3	18.84	22.42038217
0.5	3	18.84	28.02547771
0.6	3	18.84	33.63057325
0.7	3	18.84	39.23566879
0.8	3	18.84	44.84076433
0.9	3	18.84	50.44585987
1	3	18.84	56.05095541
1.1	3	18.84	61.65605096
1.2	3	18.84	67.2611465
1.3	3	18.84	72.86624204
1.4	3	18.84	78.47133758
1.5	3	18.84	84.07643312
1.6	3	18.84	89.68152866
1.7	3	18.84	95.2866242
1.8	3	18.84	100.8917197
1.9	3	18.84	106.4968153
2	3	18.84	112.1019108

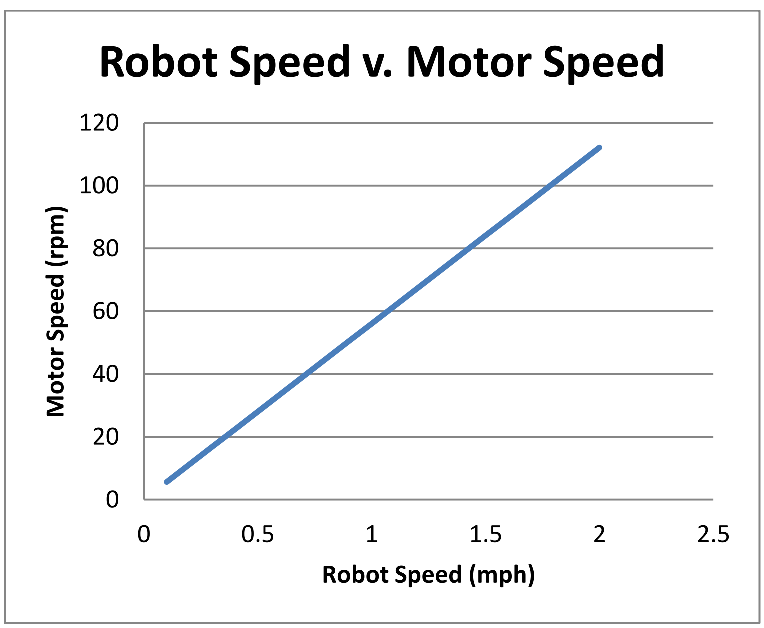
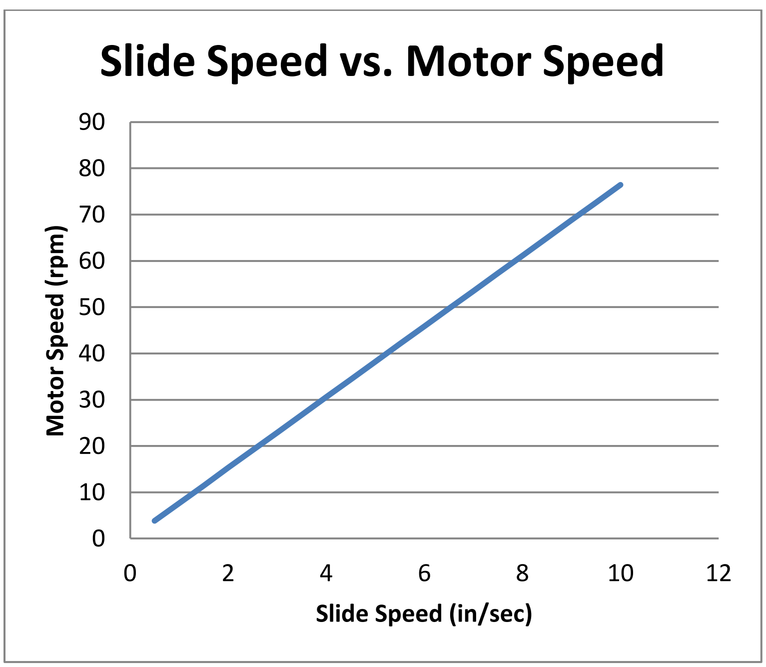


Table 6: Slide Motor Speed

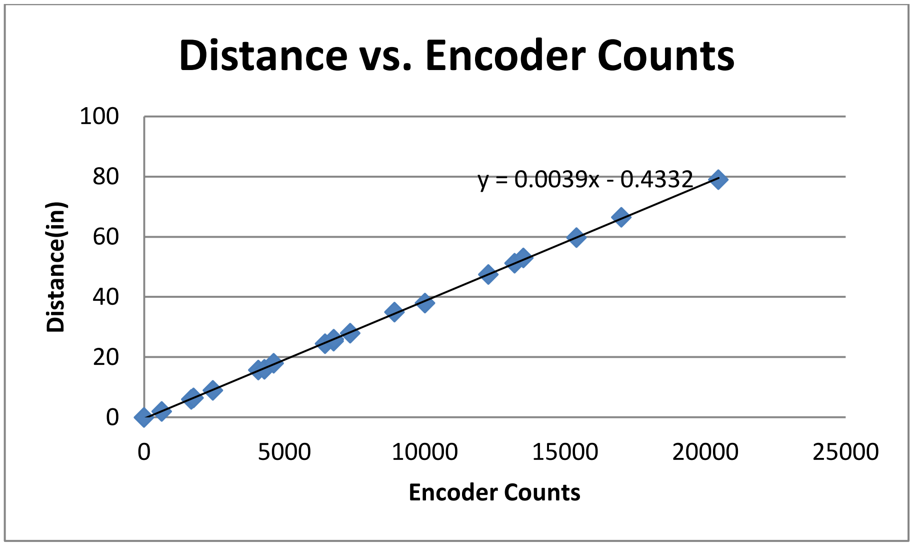
Speed(in/sec)	Gear Diameter(in)	Circumference(in)	Motor Speed(rpm)
0.5	1.25	7.85	3.821656051
1	1.25	7.85	7.643312102
1.5	1.25	7.85	11.46496815
2	1.25	7.85	15.2866242
2.5	1.25	7.85	19.10828025
3	1.25	7.85	22.92993631
3.5	1.25	7.85	26.75159236
4	1.25	7.85	30.57324841
4.5	1.25	7.85	34.39490446
5	1.25	7.85	38.21656051
5.5	1.25	7.85	42.03821656
6	1.25	7.85	45.85987261
6.5	1.25	7.85	49.68152866
7	1.25	7.85	53.50318471
7.5	1.25	7.85	57.32484076
8	1.25	7.85	61.14649682
8.5	1.25	7.85	64.96815287
9	1.25	7.85	68.78980892
9.5	1.25	7.85	72.61146497
10	1.25	7.85	76.43312102



ii. Encoder Calibration

Table 7: Encoder Calibration Readings

Counts	Distance(in)
0	0
632	2
1686	6
1766	6.5
2455	9
4074	15.75
4293	16
4622	18
6453	24.5
6759	25.35
6763	26
7350	28
8928	35
10015	38
12274	47.5
13209	51.25
13522	53
15415	59.75
17014	66.5
20471	79

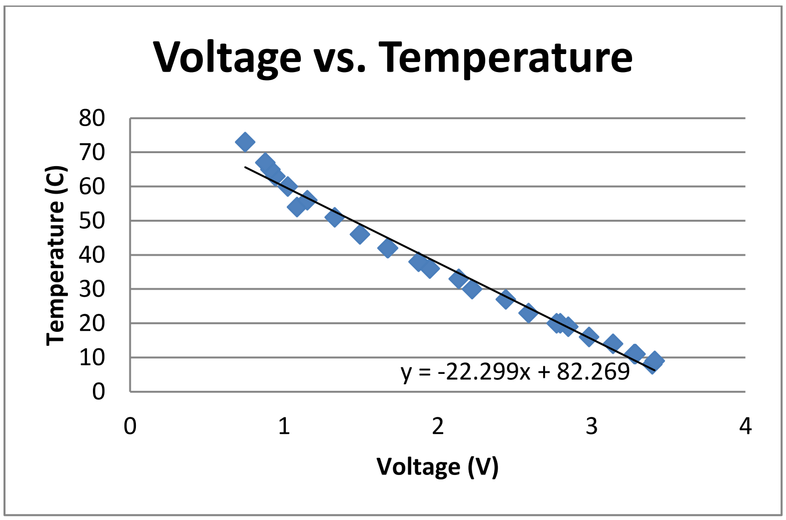


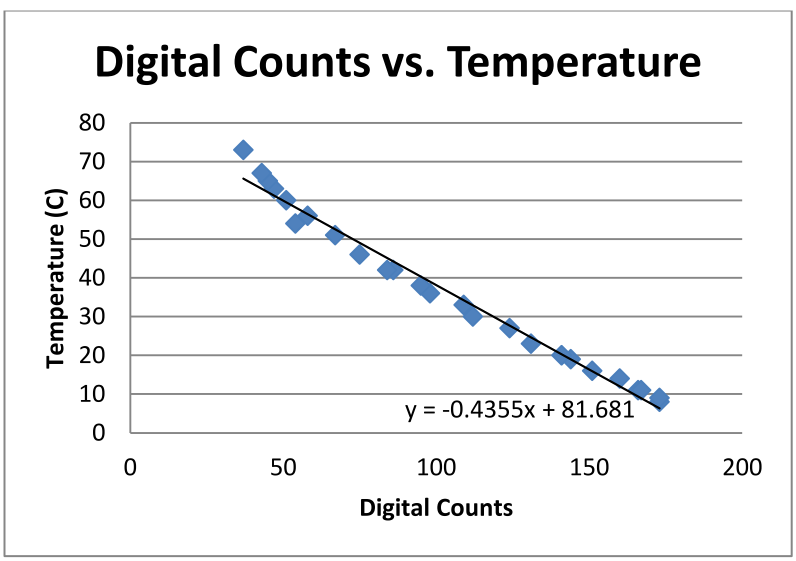
iii. Thermistor Calibration

Table 8: Thermistor Calibration Readings

Voltage(V)	Digital Counts	Temperature(C)
3.394	173	8
3.41	173	9
3.277	166	11
3.285	167	11
3.139	160	14
2.983	151	16
2.848	144	19
2.796	141	20
2.772	141	20
2.59	131	23
2.442	124	27
2.223	112	30

2.136	109	33
1.948	98	36
1.875	95	38
1.677	86	42
1.673	84	42
1.494	75	46
1.33	67	51
1.085	54	54
1.152	58	56
1.025	51	60
0.9443	47	63
0.912	45	65
0.879	43	67
0.748	37	73





iv. Battery Loading

Table 9: Battery Loading Requirements

	(These are estimations based on datasheets)				
Component	**Voltage(V)**	**Current(mA)**	**Power/Load(W)**	**Quantity**	**Total Load(W)**
Drive Motors	12	1000	12	2	24
Camera(USB)	12	50	0.6	1	0.6
Slide Motors	6	500	3	2	6
Thermistor	5	0.5	0.0025	1	0.0025
PIC Chip	5	250	1.25	2	2.5
H-Bridge	5	40	0.2	1	0.2
FET's	5	200	1	2	2
LCD Screen	5	1.6	0.008	1	0.008
Potentiometer	5	0.5	0.0025	1	0.0025
Converter	**Efficiency (%)**	**Load(W)**	**Losses(W)**	**Total Load(W)**	
12V Buck	88	24.6	2.952	27.552	
5V Buck	77	6	1.38	7.38	
6V Buck	77	4.713	1.08399	5.79699	
Overall Selection Specifications					
Total Load (W)	**Time(hr)**	**Voltage(V)**	**Total Load (Ahr)**		
40.72899	1	14.8	2.751958784		
Battery Selection:	14.8V	4.9Ahr			

E. Printed Circuit Board Design & Construction Procedures

i. PCB Design Procedure (Altium Designer)

1. Create new project with schematic, PCB, schematic library and PCB library

2. Create footprints for each component in the PCB library using Component Wizard

3. Create schematics for each component in the schematic library and link the schematic with its corresponding footprint.

4. Place schematics in the schematic document and connect the pins.
   (Use Vcc and GND labels to simplify voltage connections)

5. Update PCB document with component footprints.

6. Draw a Keep Out layer to represent the physical circuit board dimensions and place the components inside it.

7. Set up the trace, pad, via and through-hole rules and select auto-route.

8. Select design rule check and fix any bad connections or unconnected components

9. Export Gerber Files (Top Layer, Bottom Layer, Keep Out Layer)

10. Export NC Drill Files and save the export files seen in the project outputs folder

ii. PCB Manufacturing Procedure (LPFK S63)

1. Create project in CircuitPro software and select material & ProConduct plating

2. Import Gerber & NC Drill files and label (Top Layer, Bottom Layer, Board Outline, Plated Holes, Unplated Holes)

3. Place fiducials on each corner (be careful not to place too close to the board outline)

4. Calculate necessary drill bits (select double pads, contour routing, and check contour routing bit size)

5. Place drill bits and confirm locations on the software

6. Start production wizard and place board

7. After the bottom layer is milled, flip the board and manually locate fiducials if necessary

8. After the top layer is milled remove the board, place protective material on both sides of the board but not covering the fiducial holes

9. Apply ProConduct paste until all holes are filled

10. Place the board on the table with felt and porous board underneath and vacuum the ProConduct Paste through

11. Repeat steps 9 and 10 for the opposite side

12. Cure the paste in the oven for 30 minutes at 375 degrees F

<u>iii. Conformal Coating Procedure (LPFK ProMask)</u>

1. Import top and bottom layers to Circuit CAM and remove all traces, pours, and holes that are to be coated

2. Print out on clear plastic sheeting

3. Mix paint and curing agent (ProMask Comp A and Comp B) and use paint roller to apply coating

4. Dry coating in oven at 176 degrees F for 10 minutes or until it is completely dry

5. Place printout over circuit board and expose to UV Light for 30 Seconds

6. Repeat step 5 for the other side of the board

7. Mix Developer packet with 1000mL of 104-122 deg. F water in bath and take the epoxy off the PCB pads with a brush or scrubbing pad

8. Mix Conditioner solution with Developer solution and 5000mL of water for disposal

9. Clean thoroughly, inspect, and remove excess copper with a razor blade

<u>iii. Tips</u>

1. Double check trace size requirements for the required voltage and current.

2. Don’t use through holes to make connections between layers; place a separate via to avoid bad connections

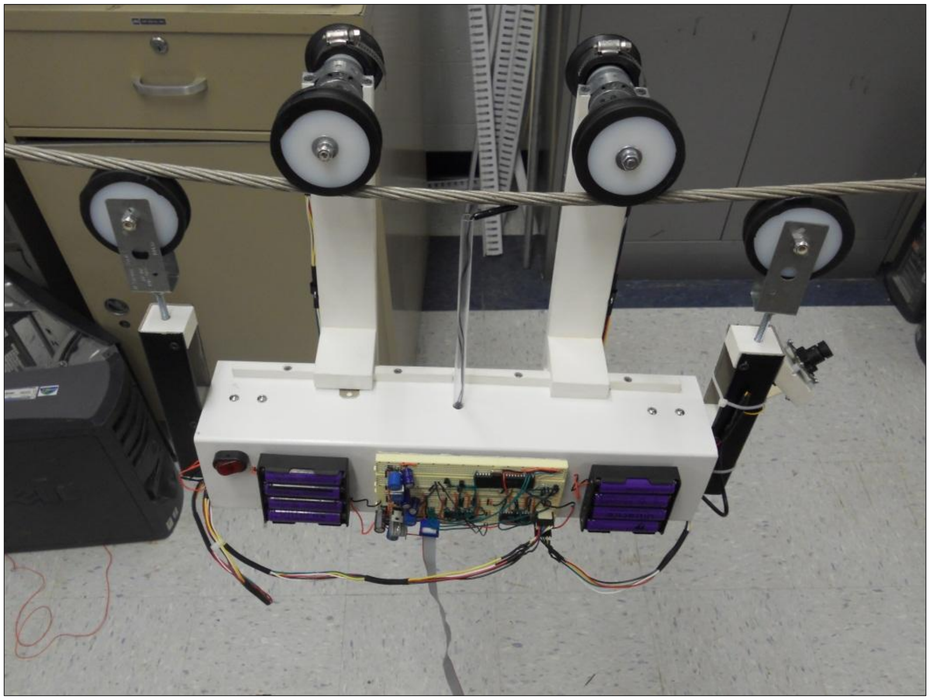
2. Ensure the coating is completely dry before exposing to UV light to avoid patches of copper

3. Be careful to make sure holes are larger than leads and the machine has the correct bits to drill the holes

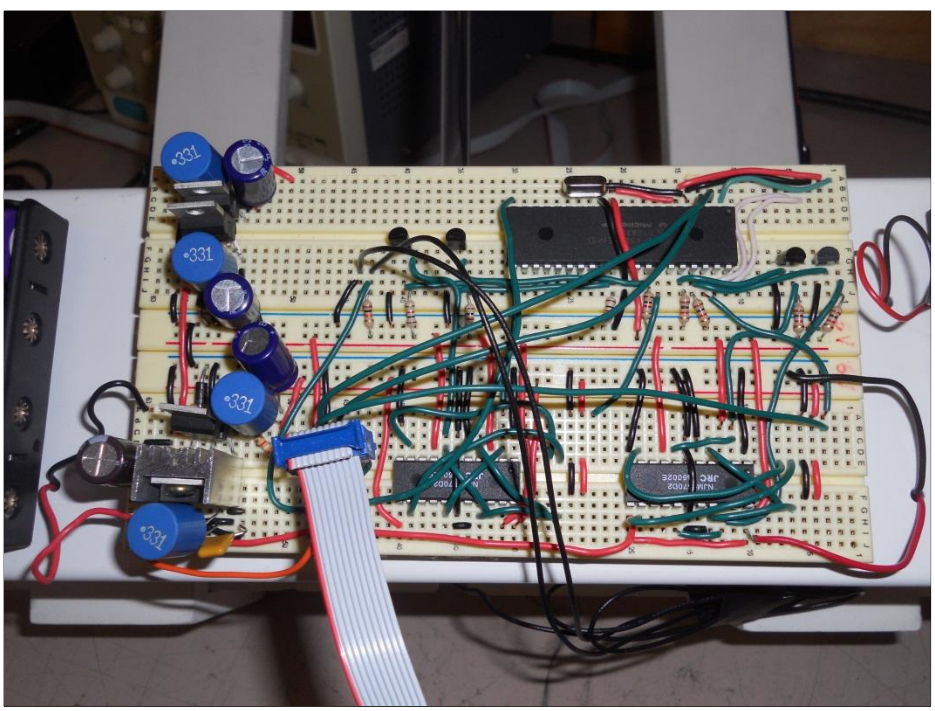
4. Clean off the air permeable pad between millings of each side of the board

F. Photographs

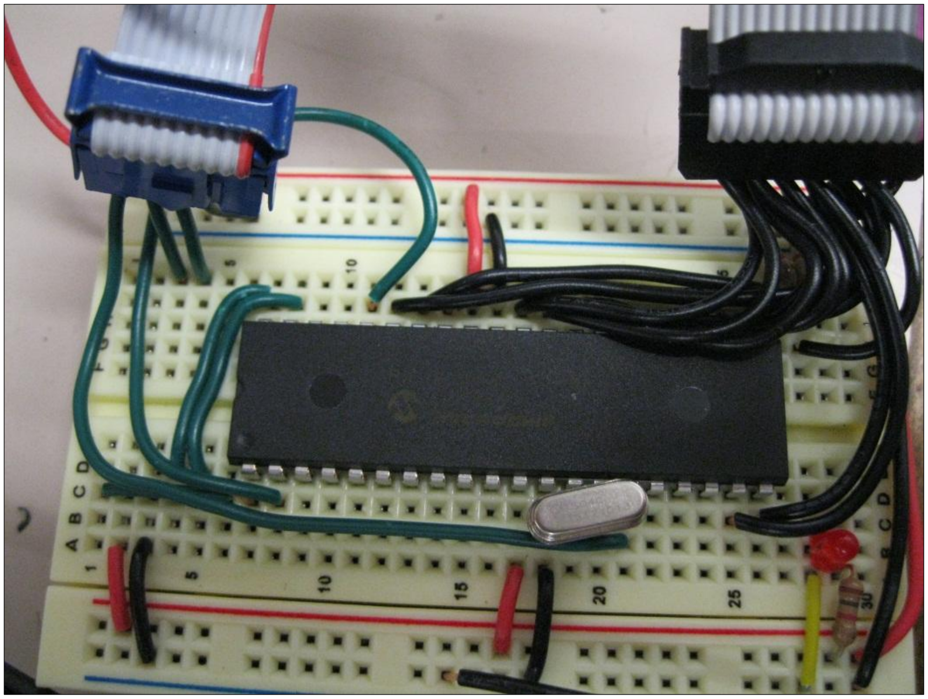
i. Fall Semester Prototype



ii. Robot Board

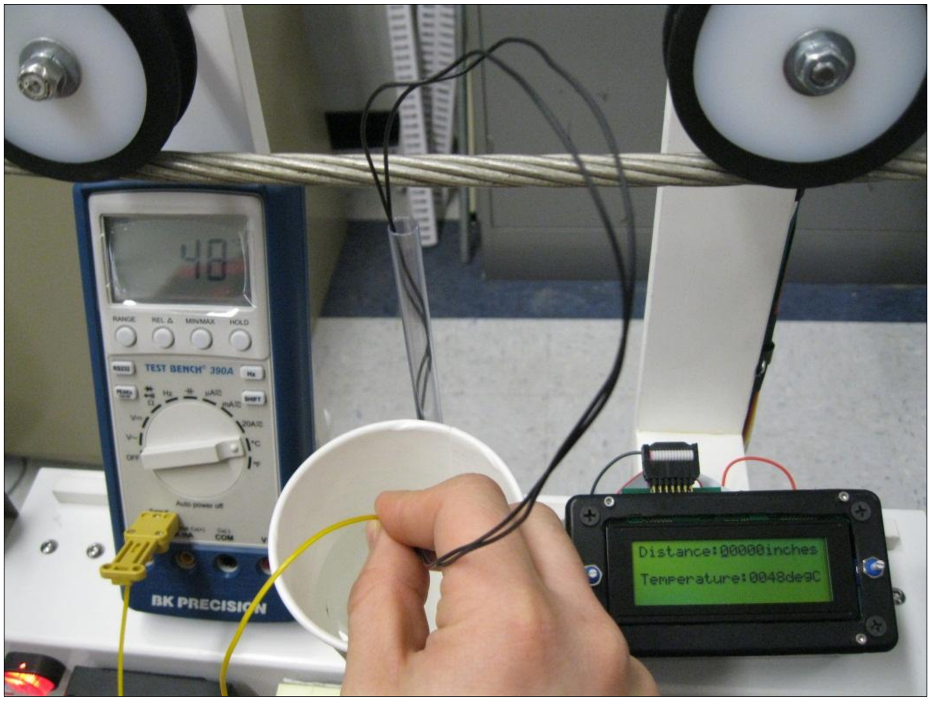


iii. Control Board

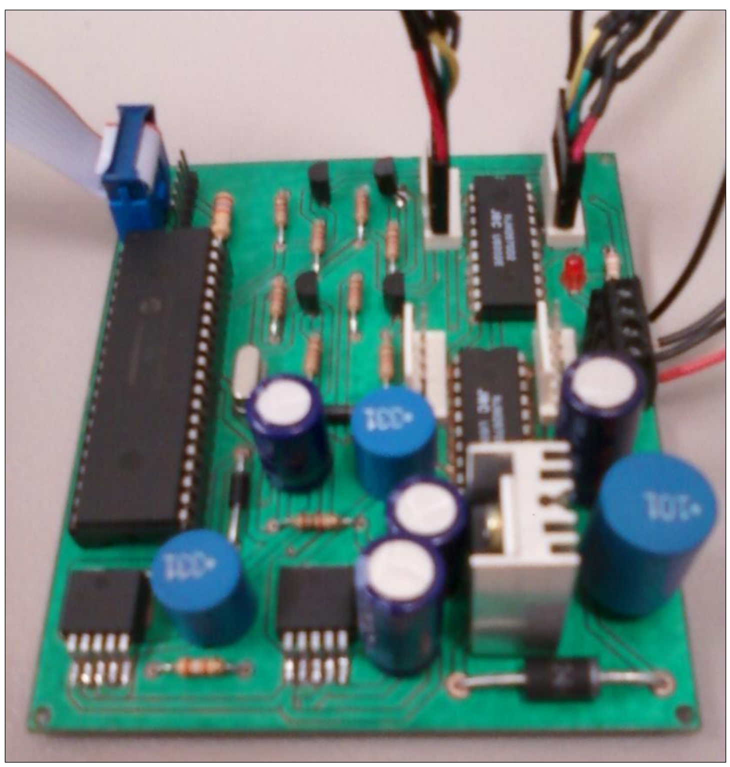


iv. Distance Measurement

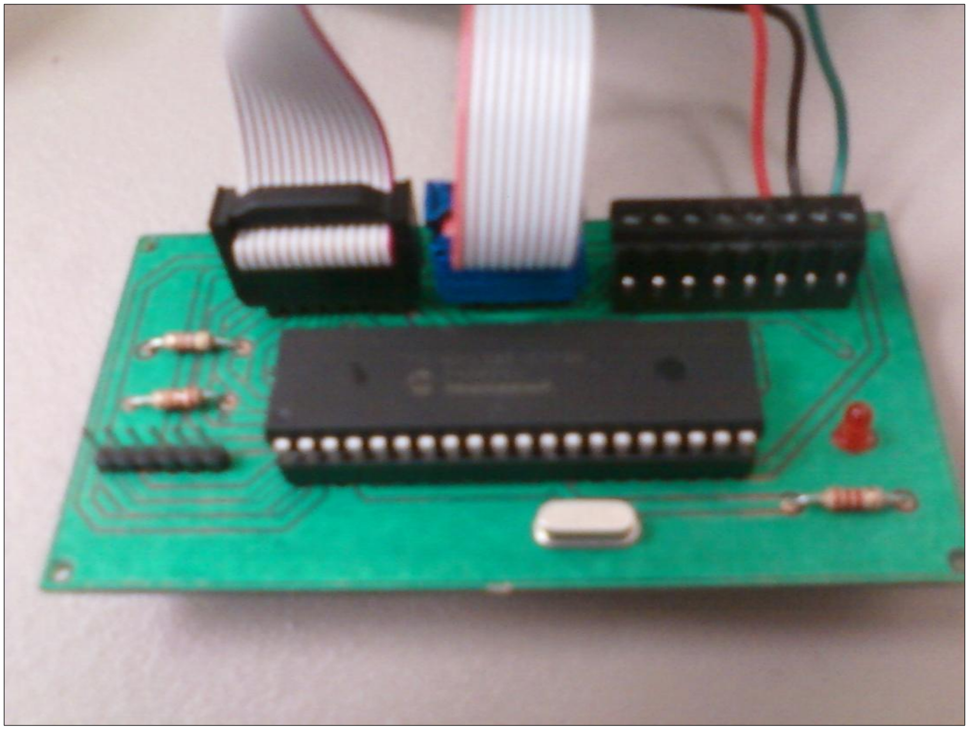
v. Temperature Measurement



v. Robot PCB



v. Control PCB



G. Equipment Manuals and Data Sheets

1. Drive Motors - http://www.pololu.com/catalog/product/1447
2. Slide Motors - http://www.pololu.com/catalog/product/2288
3. PIC 18F4580 - http://ww1.microchip.com/downloads/en/devicedoc/39637c.pdf
4. PIC 32MX795F512H - http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en545655#2
5. IR Thermometer(MLX90614)- http://www.sparkfun.com/datasheets/Sensors/Temperature/MLX90614_rev001.pdf
6. Camera(CM-26N/P)- http://www.sparkfun.com/datasheets/Sensors/Imaging/CM-26N.pdf
7. Thermistor(USP10982)- http://media.digikey.com/pdf/Data%20Sheets/U.S.Sensors/USP10982.pdf
8. Dual H-Bridge IC(NJM2670)- http://www.datasheetcatalog.org/datasheet/newjapanradio/be10021.pdf
9. 3A Buck Converter IC(lm2576)- http://www.ti.com/lit/ds/symlink/lm2576.pdf
10. 1A Buck Converter IC(tl2575)- http://www.ti.com/lit/ds/symlink/tl2575-05.pdf
11. 2N7000 MOSFET - http://www.fairchildsemi.com/ds/2N/2N7000.pdf
12. 1N5819 Diode - http://www.diodes.com/datasheets/ds23001.pdf
13. 1N5822 Diode - http://www.datasheetcatalog.org/datasheet/vishay/1n5820.pdf
14. 100 µH Inductor - http://docs-europe.electrocomponents.com/webdocs/082f/0900766b8082f8e2.pdf
15. 330 µH Inductor - http://www.smae.de/uploads/tsl1112.pdf
16. LCD Screen(CFAH2004A-NYA-JP)- https://engineering.purdue.edu/ece477/Webs/F04-Grp11/index_files/Documents/20x4LCD.pdf

1. Drive Motors

131:1 Metal Gearmotor 37Dx57L mm with 64 CPR Encoder

Pololu item #: 1447

Price break	Unit price (US$)
1	39.95
10	35.96

Quantity: 1
backorders allowed

This 2.71" × 1.45" × 1.45" gearmotor is a powerful 12V brushed DC motor with a **131.25:1** metal gearbox and an integrated quadrature encoder that provides a resolution of 64 counts per revolution of the motor shaft, which corresponds to **8400 counts per revolution** of the gearbox's output shaft. These units have a 0.61"-long, 6 mm-diameter D-shaped output shaft. This gearmotor is also available without an encoder.

Key specs at **12 V**: 80 RPM and 300 mA free-run, 250 oz-in (18 kg-cm) and 5 A stall.

2. Slide Motors

172:1 Metal Gearmotor 25Dx56L mm with 48 CPR Encoder

Pololu item #: 2288

Price break	Unit price (US$)
1	34.95
10	31.46

Quantity: 1
backorders allowed

This cylindrical, 2.69″ × 0.98″ × 0.98″ brushed DC gearmotor with a 171.79:1 metal gearbox is a lower-current alternative to our 25D mm HP gearmotors. It has an integrated 48 CPR quadrature encoder on the motor shaft, which corresponds to **8246 counts per revolution** of the gearbox's output shaft. These units have a 0.315"-long, 4 mm-diameter D-shaped output shaft. This gearmotor is also available without an encoder.

Key specs at 6 V: 33 RPM and 80 mA free-run, 170 oz-in (12.2 kg-cm) and 2.2 A stall.

3. PIC18F4580

PIC18F2480/2580/4480/4580

28/40/44-Pin Enhanced Flash Microcontrollers with ECAN™ Technology, 10-Bit A/D and nanoWatt Technology

Power-Managed Modes:

- Run: CPU on, Peripherals on
- Idle: CPU off, Peripherals on
- Sleep: CPU off, Peripherals off
- Idle mode Currents Down to 6.1 μA Typical
- Sleep mode Current Down to 0.2 μA Typical
- Timer1 Oscillator: 1 μA, 32 kHz, 2V
- Watchdog Timer: 1.7 μA
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, up to 40 MHz
- 4x Phase Lock Loop (PLL) – Available for Crystal and Internal Oscillators)
- Two External RC modes, up to 4 MHz
- Two External Clock modes, up to 40 MHz
- Internal Oscillator Block:
  - Fast wake from Sleep and Idle, 1 μs typical
  - 8 user-selectable frequencies, from 31 kHz to 8 MHz
  - Provides a complete range of clock speeds, from 31 kHz to 32 MHz when used with PLL
  - User-tunable to compensate for frequency drift
- Secondary Oscillator using Timer1 @ 32 kHz
- Fail-Safe Clock Monitor
  - Allows for safe shutdown if peripheral clock stops

Special Microcontroller Features:

- C Compiler Optimized Architecture with Optional Extended Instruction Set
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory Typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory Typical
- Flash/Data EEPROM Retention: > 40 Years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 41 ms to 131s
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via Two Pins
- In-Circuit Debug (ICD) via Two Pins
- Wide Operating Voltage Range: 2.0V to 5.5V

Peripheral Highlights:

- High-Current Sink/Source 25 mA/25 mA
- Three External Interrupts
- One Capture/Compare/PWM (CCP) module
- Enhanced Capture/Compare/PWM (ECCP) module (40/44-pin devices only):
  - One, two or four PWM outputs
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Master Synchronous Serial Port (MSSP) module Supporting 3-Wire SPI (all 4 modes) and I²C™ Master and Slave modes
- Enhanced Addressable USART module
  - Supports RS-485, RS-232 and LIN/J2602
  - RS-232 operation using internal oscillator block
  - Auto-wake-up on Start bit
  - Auto-Baud Detect
- 10-Bit, up to 11-Channel Analog-to-Digital Converter (A/D) module, up to 100 ksps
  - Auto-acquisition capability
  - Conversion available during Sleep
- Dual Analog Comparators with Input Multiplexing

ECAN Technology Module Features:

- Message Bit Rates up to 1 Mbps
- Conforms to CAN 2.0B Active Specification
- Fully Backward Compatible with PIC18XXX8 CAN modules
- Three Modes of Operation:
  - Legacy, Enhanced Legacy, FIFO
- Three Dedicated Transmit Buffers with Prioritization
- Two Dedicated Receive Buffers
- Six Programmable Receive/Transmit Buffers
- Three Full 29-Bit Acceptance Masks
- 16 Full 29-Bit Acceptance Filters w/Dynamic Association
- DeviceNet™ Data Byte Filter Support
- Automatic Remote Frame Handling
- Advanced Error Management Features

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ ECCP (PWM)	MSSP		EUSART	Comp.	Timers 8/16-bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)				SPI	Master I²C™			
PIC18F2480	16K	8192	768	256	25	8	1/0	Y	Y	1	0	1/3
PIC18F2580	32K	16384	1536	256	25	8	1/0	Y	Y	1	0	1/3
PIC18F4480	16K	8192	768	256	36	11	1/1	Y	Y	1	2	1/3
PIC18F4580	32K	16384	1536	256	36	11	1/1	Y	Y	1	2	1/3

4. PIC 32MX795F512H

MICROCHIP

PIC32MX5XX/6XX/7XX

High-Performance, USB, CAN and Ethernet 32-bit Flash Microcontrollers

High-Performance 32-bit RISC CPU:

- MIPS32® M4K® 32-bit core with 5-stage pipeline
- 80 MHz maximum frequency
- 1.56 DMIPS/MHz (Dhrystone 2.1) performance at zero Wait state Flash access
- Single-cycle multiply and high-performance divide unit
- MIPS16e® mode for up to 40% smaller code size
- Two sets of 32 core register files (32-bit) to reduce interrupt latency
- Prefetch Cache module to speed execution from Flash

Microcontroller Features:

- Operating voltage range of 2.3V to 3.6V
- 64K to 512K Flash memory (plus an additional 12 KB of Boot Flash)
- 16K to 128K SRAM memory
- Pin-compatible with most PIC24/dsPIC® DSC devices
- Multiple power management modes
- Multiple interrupt vectors with individually programmable priority
- Fail-Safe Clock Monitor mode
- Configurable Watchdog Timer with on-chip Low-Power RC oscillator for reliable operation

Peripheral Features:

- Atomic SET, CLEAR and INVERT operation on select peripheral registers
- Up to 8-channels of hardware DMA with automatic data size detection
- USB 2.0-compliant full-speed device and On-The-Go (OTG) controller:
  - Dedicated DMA channels
- 10/100 Mbps Ethernet MAC with MII and RMII interface:
  - Dedicated DMA channels
- CAN module:
  - 2.0B Active with DeviceNet™ addressing support
  - Dedicated DMA channels
- 3 MHz to 25 MHz crystal oscillator

Peripheral Features (Continued):

- Internal 8 MHz and 32 kHz oscillators
- Six UART modules with:
  - RS-232, RS-485 and LIN support
  - IrDA® with on-chip hardware encoder and decoder
- Up to four SPI modules
- Up to five I²C™ modules
- Separate PLLs for CPU and USB clocks
- Parallel Master and Slave Port (PMP/PSP) with 8-bit and 16-bit data, and up to 16 address lines
- Hardware Real-Time Clock and Calendar (RTCC)
- Five 16-bit Timers/Counters (two 16-bit pairs combine to create two 32-bit timers)
- Five Capture inputs
- Five Compare/PWM outputs
- Five external interrupt pins
- High-speed I/O pins capable of toggling at up to 80 MHz
- High-current sink/source (18 mA/18 mA) on all I/O pins
- Configurable open-drain output on digital I/O pins

Debug Features:

- Two programming and debugging interfaces:
  - 2-wire interface with unintrusive access and real-time data exchange with application
  - 4-wire MIPS® standard enhanced Joint Test Action Group (JTAG) interface
- Unintrusive hardware-based instruction trace
- IEEE Standard 1149.2 compatible (JTAG) boundary scan

Analog Features:

- Up to 16-channel, 10-bit Analog-to-Digital Converter:
  - 1 Msps conversion rate
  - Conversion available during Sleep and Idle
- Two Analog Comparators

 DS61156G-page 3

5. IR Thermometer(MLX90614)

Melexis
Microelectronic Integrated Systems

MLX90614 family

Single and Dual Zone
Infra Red Thermometer in TO-39

Features and Benefits

- ❑ Small size, low cost
- ❑ Easy to integrate
- ❑ Factory calibrated in wide temperature range:
  - -40…+125 °C for sensor temperature and
  - -70…+380 °C for object temperature.
- ❑ High accuracy of 0.5°C over wide temperature range (0..+50°C for both Ta and To)
- ❑ High (medical) accuracy calibration
- ❑ Measurement resolution of 0.02°C
- ❑ Single and dual zone versions
- ❑ SMBus compatible digital interface
- ❑ Customizable PWM output for continuous reading
- ❑ Available in 3V and 5V versions
- ❑ Simple adaptation for 8…16V applications
- ❑ Power saving mode
- ❑ Different package options for applications and measurements versatility
- ❑ Automotive grade

Applications Examples

- ❑ High precision non-contact temperature measurements;
- ❑ Thermal Comfort sensor for Mobile Air Conditioning control system;
- ❑ Temperature sensing element for residential, commercial and industrial building air conditioning;
- ❑ Windshield defogging;
- ❑ Automotive blind angle detection;
- ❑ Industrial temperature control of moving parts;
- ❑ Temperature control in printers and copiers;
- ❑ Home appliances with temperature control;
- ❑ Healthcare;
- ❑ Livestock monitoring;
- ❑ Movement detection;
- ❑ Multiple zone temperature control – up to 100 sensors can be read via common 2 wires
- ❑ Thermal relay / alert
- ❑ Body temperature measurement

Ordering Information

Part No.	Temperature Code	Package Code	- Option Code
MLX90614	E (-40°C to 85°C)	SF (TO-39)	- X X X
	K (-40°C to 125°C)		(1) (2) (3)

(1) Supply Voltage/ Accuracy
- A - 5V
- B - 3V
- C - Reserved
- D - 3V medical accuracy

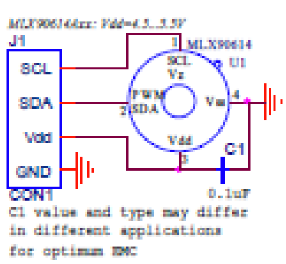
(2) Number of thermopiles:
- A – single zone
- B – dual zone
- C – gradient compensated*

(3) Package options:
- A – Standard package
- B – Reserved
- C – 35° FOV
- F – 10° FOV

Example:
MLX90614ESF-BAA

*** : See page 2**

1 Functional diagram



MLX90614 connection to SMBus

Figure 1 Typical application schematics

2 General Description

The MLX90614 is an Infra Red thermometer for non contact temperature measurements. Both the IR sensitive thermopile detector chip and the signal conditioning ASSP are integrated in the same TO-39 can.

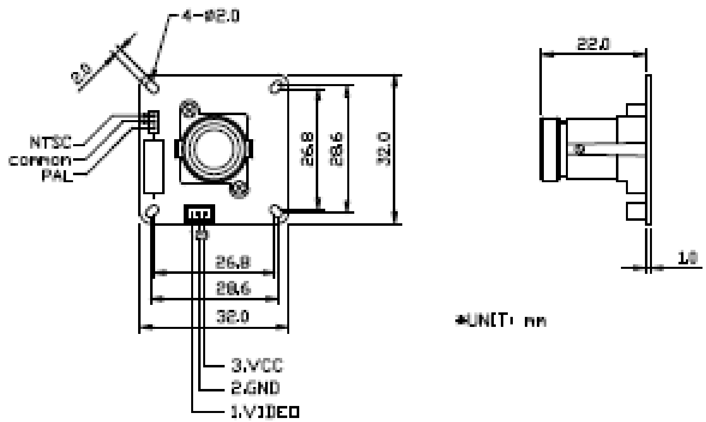
Thanks to its low noise amplifier, 17-bit ADC and powerful DSP unit, a high accuracy and resolution of the thermometer is achieved.

The thermometer comes factory calibrated with a digital PWM and SMBus (System Management Bus) output.

As a standard, the 10-bit PWM is configured to continuously transmit the measured temperature in range of -20…120 °C, with an output resolution of 0.14 °C and the POR default is SMBus.

6. Camera(CM-26N/P)

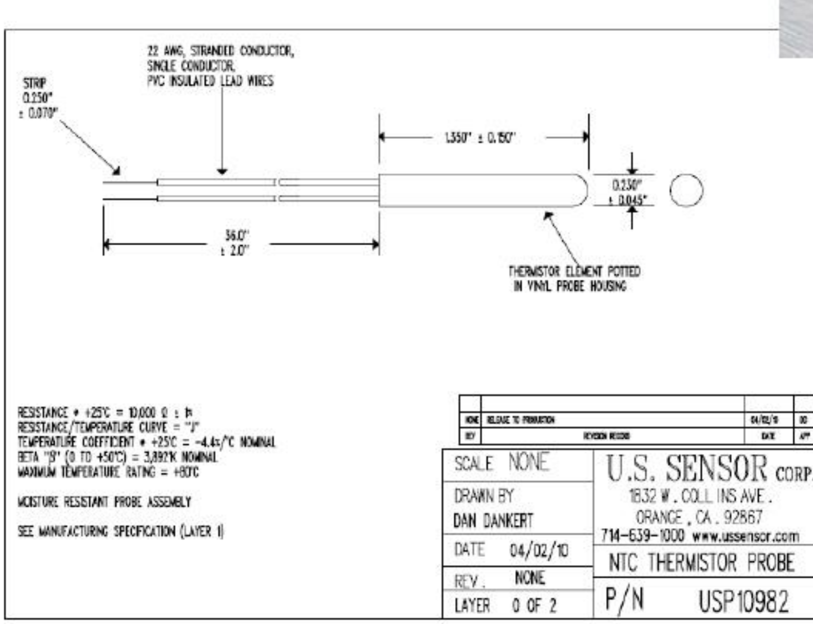
" CM-26N/P C-MOS COLOR CAMERA MODULE "



Model no / Description	SPEC	
	CM-26N	CM-26P
IMAGE SENSOR	1/4 Inch 668(H) x 496(V) MICRON C-MOS IMAGE SENSOR	
Effective pixel	640(H) x 480(V)	
Unit Pixel Size	5.6 ㎛ X 5.6 ㎛	
Scanning system	525 Line 2:1 INTERLACE	625 Line 2:1 INTERLACE
SYNC system	Internal	
Scanning frequency	Horizontal : 15.734 KHz ± 1% Vertical : 59.94Hz ± 1%	Horizontal : 15.625 KHz ± 1% Vertical : 50Hz ± 1%
Horizontal resolution	420 TV LINES above (center)	
Video output	1.0 ±0.2Vp-p / 75Ω (Video signal : 0.7Vp-p, Sync. signal : 0.3Vp-p)	
S/N RATIO	More than 45dB (AGC off)	
Dynamic Range	60dB	
Min. Illumination	0.1 lx / F1.6(50% of Video Level, AGC ON)	
Shutter Type	Electronic rolling shutter(ERS)	
Lens angle	70°(Default) or Option	
A G C CONTROL	AUTO	
BLC	Built-In	
Dimensions	32(W) x 32(H) x 22(D) ±0.3mm	
Operation Temper.	-20℃ ~ 60℃	
Power consumption	DC 12V(Tolerance 5V~15V)	
	MAX 50mA (12V)	

7. Thermistor(USP10982)

U.S. SENSOR Corp.



- **± 1% Tolerance**
- **80°C Max Temp**
- **PVC Insulated Lead Wire**
- **0.230" Diameter Vinyl Housing**

www.ussensor.com

8. Dual H-Bridge IC (NJM2670)

JRC **NJM2670**

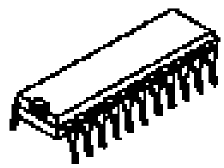
DUAL H BRIDGE DRIVER

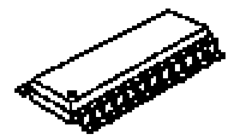
■ GENERAL DESCRIPTION

The NJM2670 is a general-purpose 60V dual H-bridge drive IC. It consists of a pair of H-bridges, a thermal shut down circuit and its alarm output. The alarm output can detect application problems and the system reliability will be significantly improved if monitored by Micro Processor.

Therefore, it is suitable for two-phase stepper motor application driven by microprocessor.

■ PACKAGE OUTLINE

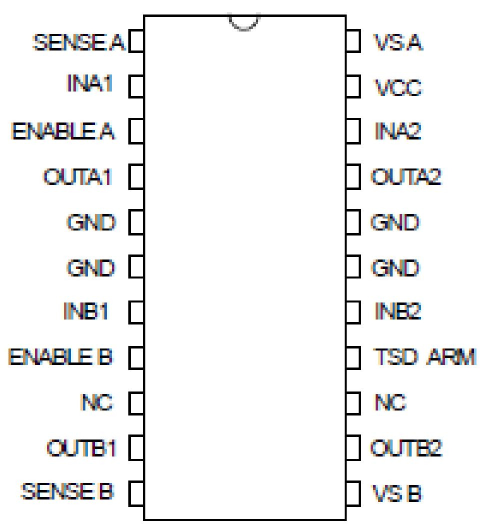

NJM2670D2


NJM2670E3

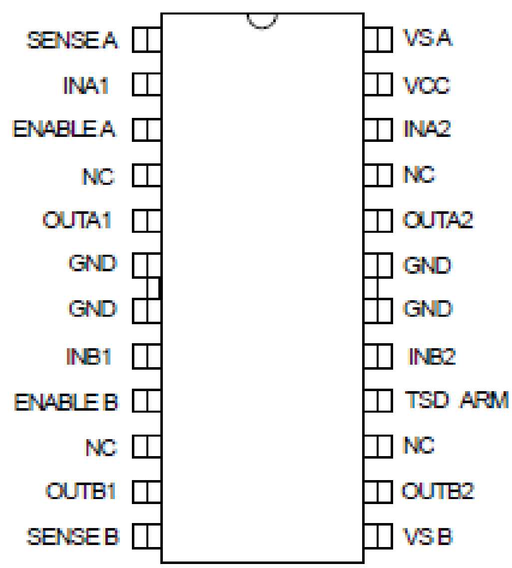
■ FEATURES

- Wide Voltage Range (4V to 60V)
- Wide Range of Current Control (5 to 1500mA)
- Thermal overload Protection
- Dead Band Protector
- Package Outline (DIP-22, EMP-24)

■ PIN CONNECTION



DIP-22



EMP-24

9. 3A Buck Converter IC(lm2576)

LM2576/LM2576HV Series SIMPLE SWITCHER® 3A Step-Down Voltage Regulator

Check for Samples: LM2576, LM2576HV

FEATURES

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range,
  - 1.23V to 37V (57V for HV version) ±4% max over
  - line and load conditions
- Guaranteed 3A output current
- Wide input voltage range, 40V up to 60V for
  - HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

APPLICATIONS

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

DESCRIPTION

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

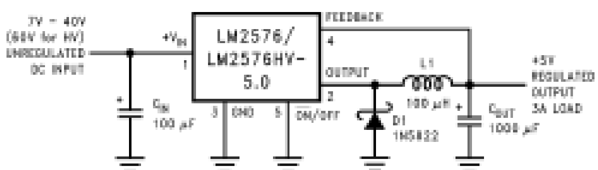
The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

Typical Application

(Fixed Output Voltage Versions)



10. 1A Buck Converter IC (tl2575)

TEXAS INSTRUMENTS
www.ti.com

TL2575, TL2575HV
1-A SIMPLE STEP-DOWN SWITCHING VOLTAGE REGULATORS

SLVS638B–MAY 2006–REVISED JANUARY 2007

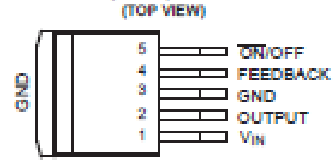
FEATURES

- Fixed 3.3-V, 5-V, 12-V, and 15-V Options With ±5% Regulation (Max) Over Line, Load, and Temperature Conditions
- Adjustable Option With a Range of 1.23 V to 37 V (57 V for HV Version) and ±4% Regulation (Max) Over Line, Load, and Temperature Conditions
- Specified 1-A Output Current
- Wide Input Voltage Range…4.75 V to 40 V (60 V for HV Version)
- Require Only Four External Components (Fixed Versions) and Use Readily Available Standard Inductors
- 52-kHz (Typ) Fixed-Frequency Internal Oscillator
- TTL Shutdown Capability With 50-µA (Typ) Standby Current
- High Efficiency…as High as 88% (Typ)
- Thermal Shutdown and Current-Limit Protection With Cycle-by-Cycle Current Limiting

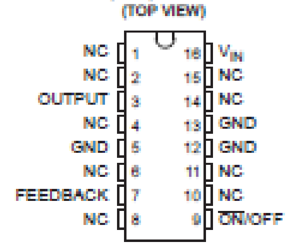
APPLICATIONS

- Simple High-Efficiency Step-Down (Buck) Regulators
- Pre-Regulators for Linear Regulators
- On-Card Switching Regulators
- Positive-to-Negative Converters (Buck-Boost)

KTT (TO-263) PACKAGE
(TOP VIEW)

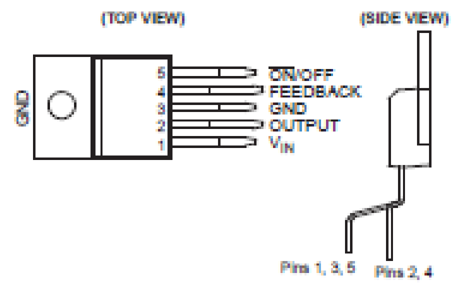


N (PDIP) PACKAGE
(TOP VIEW)



NC – No internal connection

KV (TO-220 STAGGERED LEADS) PACKAGE



DESCRIPTION/ORDERING INFORMATION

The TL2575 and TL2575HV greatly simplify the design of switching power supplies by conveniently providing all the active functions needed for a step-down (buck) switching regulator in an integrated circuit. Accepting a wide input voltage range of up to 60 V (HV version) and available in fixed output voltages of 3.3 V, 5 V, 12 V, 15 V, or an adjustable-output version, the TL2575 and TL2575HV have an integrated switch capable of delivering 1 A of load current, with excellent line and load regulation. The device also offers internal frequency compensation, a fixed-frequency oscillator, cycle-by-cycle current limiting, and thermal shutdown. In addition, a manual shutdown is available via an external ON/OFF pin.

The TL2575 and TL2575HV represent superior alternatives to popular three-terminal linear regulators. Due to their high efficiency, the devices significantly reduce the size of the heatsink and, in many cases, no heatsink is required. Optimized for use with standard series of inductors available from several different manufacturers, the TL2575 and TL2575HV greatly simplify the design of switch-mode power supplies by requiring a minimal addition of only four to six external components for operation.

The TL2575 and TL2575HV are characterized for operation over the virtual junction temperature range of –40°C to 125°C.

11. 2N7000 MOSFET

FAIRCHILD
SEMICONDUCTOR ™

November 1995

2N7000 / 2N7002 / NDS7002A
N-Channel Enhancement Mode Field Effect Transistor

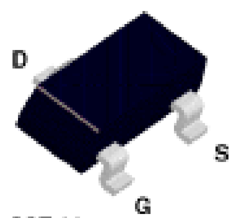
General Description

These N-Channel enhancement mode field effect transistors are produced using Fairchild's proprietary, high cell density, DMOS technology. These products have been designed to minimize on-state resistance while provide rugged, reliable, and fast switching performance. They can be used in most applications requiring up to 400mA DC and can deliver pulsed currents up to 2A. These products are particularly suited for low voltage, low current applications such as small servo motor control, power MOSFET gate drivers, and other switching applications.

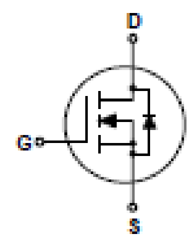
Features

- High density cell design for low $R_{DS(ON)}$.
- Voltage controlled small signal switch.
- Rugged and reliable.
- High saturation current capability.

TO-92
2N7000



SOT-23
(TO-236AB)
2N7002/NDS7002A

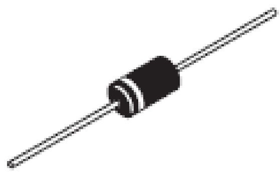


Absolute Maximum Ratings T_A = 25°C unless otherwise noted

Symbol	Parameter	2N7000	2N7002	NDS7002A	Units
V_{DSS}	Drain-Source Voltage	60			V
V_{DGR}	Drain-Gate Voltage (R_{GS} ≤ 1 MΩ)	60			V
V_{GSS}	Gate-Source Voltage - Continuous	±20			V
	- Non Repetitive (tp < 50μs)	±40			
I_D	Maximum Drain Current - Continuous	200	115	280	mA
	- Pulsed	500	800	1500	
P_D	Maximum Power Dissipation	400	200	300	mW
	Derated above 25°C	3.2	1.6	2.4	mW/°C
T_J,T_{STG}	Operating and Storage Temperature Range	-55 to 150		-65 to 150	°C
T_L	Maximum Lead Temperature for Soldering Purposes, 1/16" from Case for 10 Seconds	300			°C
THERMAL CHARACTERISTICS					
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient	312.5	625	417	°C/W

12. 1N5819 Diode

Schottky Rectifier, 1.0 A



DO-204AL

PRODUCT SUMMARY	
Package	DO-204AL (DO-41)
$I_{F(AV)}$	1 A
V_R	40 V
V_F at I_F	0.55 V
I_{RM} max.	12 mA at 125 °C
T_J max.	150 °C
Diode variation	Single die
E_{AS}	See Electrical table

FEATURES

- Low profile, axial leaded outline
- High frequency operation
- Very low forward voltage drop
- High purity, high temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Guard ring for enhanced ruggedness and long term reliability
- Compliant to RoHS Directive 2002/95/EC
- Designed and qualified for commercial level
- Halogen-free according to IEC 61249-2-21 definition (-M3 only)

DESCRIPTION

The VS-1N5819... axial leaded Schottky rectifier has been optimized for very low forward voltage drop, with moderate leakage. Typical applications are in switching power supplies, converters, freewheeling diodes, and reverse battery protection.

MAJOR RATINGS AND CHARACTERISTICS			
SYMBOL	CHARACTERISTICS	VALUES	UNITS
$I_{F(AV)}$	Rectangular waveform	1.0	A
V_{RRM}		40	V
I_{FSM}	t_p = 5 µs sine	225	A
V_F	1 Apk, T_J = 25 °C	0.55	V
T_J	Range	- 40 to 150	°C

VOLTAGE RATINGS				
PARAMETER	SYMBOL	VS-1N5819	VSS-1N5819-M3	UNITS
Maximum DC reverse voltage	V_R	40	40	V
Maximum working peak reverse voltage	V_{RWM}			

ABSOLUTE MAXIMUM RATINGS					
PARAMETER	SYMBOL	TEST CONDITIONS		VALUES	UNITS
Maximum average forward current See fig. 4	$I_{F(AV)}$	50 % duty cycle at T_L = 90 °C, rectangular waveform		1.0	A
Maximum peak one cycle non-repetitive surge current See fig. 6	I_{FSM}	5 µs sine or 3 µs rect. pulse	Following any rated load condition and with rated V_{RRM} applied	225	
		10 ms sine or 6 ms rect. pulse		35	

13. IN5822 Diode

VISHAY.

1N5820 thru 1N5822

Vishay General Semiconductor

Schottky Barrier Rectifier

DO-201AD

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	3.0 A
V_{RRM}	20 V, 30 V, 40 V
I_{FSM}	80 A
V_F	0.475 V, 0.500 V, 0.525 V
T_J max.	125 °C

FEATURES

- Guardring for overvoltage protection
- Very small conduction losses
- Extremely fast switching
- Low forward voltage drop
- High forward surge capability
- High frequency operation
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

RoHS COMPLIANT

TYPICAL APPLICATIONS

For use in low voltage high frequency inverters, freewheeling, dc-to-dc converters, and polarity protection applications.

MECHANICAL DATA

Case: DO-201AD
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes the cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER	SYMBOL	1N5820	1N5821	1N5822	UNIT
Maximum repetitive peak reverse voltage	V_{RRM}	20	30	40	V
Maximum RMS voltage	V_{RMS}	14	21	28	V
Maximum DC blocking voltage	V_{DC}	20	30	40	V
Non-repetitive peak reverse voltage	V_{RSM}	24	36	48	V
Maximum average forward rectified current at 0.375" (9.5 mm) lead length at T_L = 95 °C	$I_{F(AV)}$		3.0		A
Peak forward surge current, 8.3 ms single half sine-wave superimposed on rated load	I_{FSM}		80		A
Operating junction and storage temperature range	T_J, T_{STG}		- 65 to + 125		°C

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)

PARAMETER	TEST CONDITIONS	SYMBOL	1N5820	1N5821	1N5822	UNIT
Maximum instantaneous forward voltage	3.0	V_F [1]	0.475	0.500	0.525	V
Maximum instantaneous forward voltage	9.4	V_F [1]	0.850	0.900	0.950	V
Maximum average reverse current at rated DC blocking voltage	T_A = 25 °C	I_R [1]		2.0		mA
	T_A = 100 °C			20		

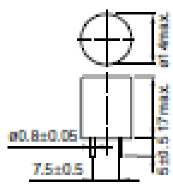
Note
[1] Pulse test: 300 μs pulse width, 1 % duty cycle

14. 100 µH Inductor

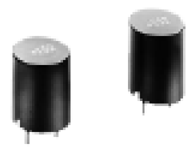
Inductors
For Power Line
Radial

TSL Series TSL1315 Type

SHAPES AND DIMENSIONS



Weight: 7.5g
Dimensions in mm

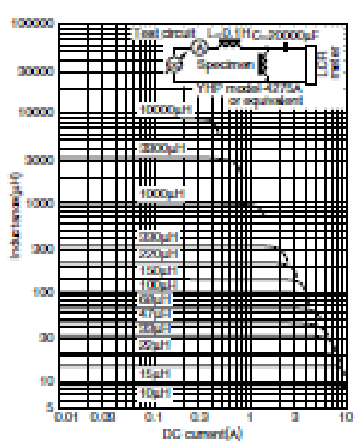


ELECTRICAL CHARACTERISTICS

Inductance (µH)	Inductance tolerance	Q min.	Test frequency L/Q (Hz)	Self-resonant frequency (MHz)min.	DC resistance (Ω)max.	Rated current (A)*1 max. Based on inductance change	Based on temperature rise	Part No.
10	±10%	90	1k/2.52M	19	0.023	12	5.1	TSL1315□*2-100K5R1-PF
15	±10%	90	1k/2.52M	12	0.028	9.5	4.5	TSL1315□-150K4R5-PF
22	±10%	80	1k/2.52M	7.6	0.036	8.2	4.2	TSL1315□-220K4R2-PF
33	±10%	70	1k/2.52M	6.9	0.043	6.8	3.7	TSL1315□-330K3R7-PF
47	±10%	50	1k/2.52M	5.6	0.052	5.7	3.4	TSL1315□-470K3R4-PF
68	±10%	40	1k/2.52M	4.4	0.068	4.8	3	TSL1315□-680K3R0-PF
100	±10%	50	1k/796k	3.3	0.097	3.9	2.5	TSL1315□-101K2R5-PF
150	±10%	50	1k/796k	2.6	0.14	3.2	2.1	TSL1315□-151K2R1-PF
220	±10%	40	1k/796k	2.2	0.2	2.7	1.7	TSL1315□-221K1R7-PF
330	±10%	30	1k/796k	1.8	0.3	2.1	1.4	TSL1315□-331K1R4-PF
470	±10%	30	1k/796k	1.5	0.43	1.8	1.1	TSL1315□-471K1R1-PF
680	±10%	30	1k/796k	1.2	0.61	1.5	0.99	TSL1315□-681KR99-PF
1000	±5%	30	1k/252k	1	1	1.2	0.78	TSL1315□-102JR78-PF
1500	±5%	40	1k/252k	0.83	1.3	1	0.68	TSL1315□-152JR68-PF
2200	±5%	40	1k/252k	0.7	2	0.83	0.55	TSL1315□-222JR55-PF
3300	±5%	40	1k/252k	0.6	3.1	0.69	0.44	TSL1315□-332JR44-PF
4700	±5%	40	1k/252k	0.43	4.4	0.58	0.37	TSL1315□-472JR37-PF
6800	±5%	30	1k/252k	0.38	6.5	0.46	0.3	TSL1315□-682JR30-PF
10000	±5%	70	1k/79.6k	0.3	10	0.4	0.24	TSL1315□-103JR24-PF

*1 Rated current: Value obtained when current flows and the temperature has risen to 25°C or when DC current flows and the initial value of inductance has fallen by 10%, whichever is smaller.
*2 □: Please specify packaging style, S(Bulk) or RA(Taping).

TYPICAL ELECTRICAL CHARACTERISTICS
INDUCTANCE CHANGE vs. DC SUPERPOSITION CHARACTERISTICS



• All specifications are subject to change without notice.

TDK

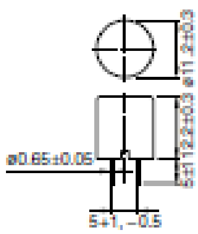
15. 330 µH Inductor

Inductors

For Power Line
Radial

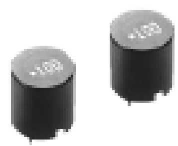
TSL Series TSL1112 Type

SHAPES AND DIMENSIONS



Weight: 3.3g

Dimensions in mm



ELECTRICAL CHARACTERISTICS

Inductance (µH)	Inductance tolerance	Q min.	Test frequency L/Q (Hz)	Self-resonant frequency (MHz)min.	DC resistance (Ω)max.	Rated current (A)*1max. Based on inductance change	Rated current (A)*1max. Based on temperature rise	Part No.
1.0	±20%	15	1k/7.96M	144	0.068	14	7.7	TSL1112□*2-1R0M7R7-PF
2.2	±20%	15	1k/7.96M	70	0.073	10	6.7	TSL1112□-2R2M6R7-PF
3.3	±20%	10	1k/7.96M	36	0.01	8.8	5.9	TSL1112□-3R3M5R9-PF
4.7	±20%	10	1k/7.96M	28	0.015	7.2	4.8	TSL1112□-4R7M4R8-PF
6.8	±20%	10	1k/7.96M	18	0.016	6.1	4.6	TSL1112□-6R8M4R6-PF
10	±20%	20	1k/2.52M	16	0.025	5	3.7	TSL1112□-100M3R7-PF
15	±20%	20	1k/2.52M	12	0.029	4.2	3.4	TSL1112□-150M3R4-PF
22	±10%	20	1k/2.52M	9.5	0.04	3.4	2.9	TSL1112□-220K2R9-PF
33	±10%	30	1k/2.52M	7	0.062	2.8	2.3	TSL1112□-330K2R3-PF
47	±10%	30	1k/2.52M	5.8	0.075	2.3	2.1	TSL1112□-470K2R1-PF
68	±10%	20	1k/2.52M	4.7	0.13	1.9	1.6	TSL1112□-680K1R6-PF
100	±10%	20	1k/796k	3.8	0.16	1.6	1.4	TSL1112□-101K1R4-PF
150	±10%	20	1k/796k	3.1	0.26	1.3	1.1	TSL1112□-151K1R1-PF
220	±10%	20	1k/796k	2.5	0.33	1.1	1	TSL1112□-221K1R0-PF
330	±10%	20	1k/796k	2	0.52	0.88	0.82	TSL1112□-331KR82-PF
470	±10%	10	1k/796k	1.6	0.66	0.75	0.72	TSL1112□-471KR72-PF
680	±10%	10	1k/796k	1.3	1.1	0.61	0.56	TSL1112□-681KR56-PF
1000	±5%	20	1k/252k	1.1	1.4	0.51	0.5	TSL1112□-102JR50-PF
1500	±5%	30	1k/252k	0.82	2.4	0.43	0.38	TSL1112□-152JR38-PF
2200	±5%	20	1k/252k	0.76	3.2	0.35	0.33	TSL1112□-222JR33-PF
3300	±5%	30	1k/252k	0.64	4.9	0.28	0.26	TSL1112□-332JR26-PF
4700	±5%	30	1k/252k	0.54	7.6	0.24	0.21	TSL1112□-472JR21-PF
6800	±5%	30	1k/252k	0.45	9.8	0.2	0.18	TSL1112□-682JR18-PF
10000	±5%	30	1k/79.6k	0.38	18	0.17	0.14	TSL1112□-103JR14-PF
15000	±5%	50	1k/79.6k	0.29	24	0.13	0.12	TSL1112□-153JR12-PF

*1 Rated current: Value obtained when current flows and the temperature has risen to 25°C or when DC current flows and the initial value of inductance has fallen by 10%, whichever is smaller.

*2 □: Please specify packaging style, S(Bulk) or RA(Taping).

16. LCD Screen(CFAH2004A-NYA-JP)

Crystalfontz America, Inc.
15611 East Washington Road
Valleyford, WA 99036
Phone: (509) 291-3514
Fax: (509) 291-3345
http://www.crystalfontz.com
email: sales@crystalfontz.com

4.Absolute Maximum Ratings

Item	Symbol	Min	Typ	Max	Unit
Operating Temperature	T_{OP}	0	—	+50	℃
Storage Temperature	T_{ST}	-10	—	+60	℃
Input Voltage	V_I	V_{SS}	—	V_{DD}	V
Supply Voltage For Logic	V_{DD}-V_{SS}	-0.3	—	7	V
Supply Voltage For LCD	V_{DD}-V_0	-0.3	—	5.5	V

5.Electrical Characteristics

Item	Symbol	Condition	Min	Typ	Max	Unit
Supply Voltage For Logic	V_{DD}-V_{SS}	—	4.5	—	5.5	V
Supply Voltage For LCD	V_{DD}-V_0	Ta=0℃	—	—	4.8	V
		Ta=25℃	—	4.5	—	V
		Ta=50℃	4.2	—	—	V
Input High Volt.	V_{IH}	—	2.2	—	V_{DD}	V
Input Low Volt.	V_{IL}	—	—	—	0.6	V
Output High Volt.	V_{OH}	—	2.4	—	—	V
Output Low Volt.	V_{OL}	—	—	—	0.4	V
Supply Current	I_{DD}	V_{DD}=5V	—	1.6	—	mA

11.Instruction Table

Instruction	Instruction Code										Description	Execution time (fosc=270Khz)
	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0		
Clear Display	0	0	0	0	0	0	0	0	0	1	Write "00H" to DDRAM and set DDRAM address to "00H" from AC	1.53ms
Return Home	0	0	0	0	0	0	0	0	1	—	Set DDRAM address to "00H" from AC and return cursor to its original position if shifted. The contents of DDRAM are not changed.	1.53ms
Entry Mode Set	0	0	0	0	0	0	0	1	I/D	SH	Assign cursor moving direction and enable the shift of entire display.	39 μs
Display ON/OFF Control	0	0	0	0	0	0	1	D	C	B	Set display (D), cursor (C), and blinking of cursor (B) on/off control bit.	39 μs
Cursor or Display Shift	0	0	0	0	0	1	S/C	R/L	—	—	Set cursor moving and display shift control bit, and the direction, without changing of DDRAM data.	39 μs
Function Set	0	0	0	0	1	DL	N	F	—	—	Set interface data length (DL:8-bit/4-bit), numbers of display line (N:2-line/1-line)and, display font type (F:5×11 dots/5×8 dots)	39 μs
Set CGRAM Address	0	0	0	1	AC5	AC4	AC3	AC2	AC1	AC0	Set CGRAM address in address counter.	39 μs
Set DDRAM Address	0	0	1	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Set DDRAM address in address counter.	39 μs
Read Busy Flag and Address	0	1	BF	AC6	AC5	AC4	AC3	AC2	AC1	AC0	Whether during internal operation or not can be known by reading BF. The contents of address counter can also be read.	0 μs
Write Data to RAM	1	0	D7	D6	D5	D4	D3	D2	D1	D0	Write data into internal RAM (DDRAM/CGRAM).	43 μs
Read Data from RAM	1	1	D7	D6	D5	D4	D3	D2	D1	D0	Read data from internal RAM (DDRAM/CGRAM).	43 μs

* "—" : don't care

VIII. Appendix B

A. Original Project Specification

Power Line Inspection Device

Our project is a device that will inspect conductors, insulators and other components on the power line. This robot will ride along the line and visually inspect these components using a camera while monitoring temperature and distance traveled on the line. We will use encoders to measure the line distance between the fixed poles. We will control our robot wirelessly from the ground. Our final design "should" also be able to locate hot spots on the line by measuring temperature. The operating system will display the video feed, distance measurement, temperature measurement and will allow user control.

Robot Circuitry:

- Motor Control Circuit
- Robot Controller (PIC)
- Camera Interface
- Wireless Transceiver/Router

On-ground Controller/Laptop:

- Wireless Transceiver
- PIC/Computer
- Visual Display
- Controls Interface (Throttle, Start/Stop, Video Feed, etc.)

Measureable Specifications:

Category	*Basic*	*Advanced*
Battery Lifetime:	15 Minutes	30 Minutes
Temperature Accuracy:	±10°C	±2°C
Distance Measurement:	15%	5%
Communication:	Wired	Wireless within 40 ft.

Team:

- Brendan Gates
- Jesse Sawin

Senior Project Advisor:

- Scott Dunning

B. Schedule

Task Name	Duration	Start	Finish	Resource Names	Notes
Senior Project Schedule	241 days	Fri 6/1/12	Fri 5/3/13	Brendan/ Jesse	
I. First Summer meeting	1 day	Sat 6/9/12	Sat 6/9/12	Brendan/Jesse	
A. Part Specifications	1 wk	Sat 6/9/12	Thu 6/14/12	Brendan/Jesse	
i. Motors	1 wk	Sat 6/9/12	Thu 6/14/12	Brendan	
ii. Pulleys	1 wk	Sat 6/9/12	Thu 6/14/12	Jesse	
iii. Gearing	1 wk	Sat 6/9/12	Thu 6/14/12	Jesse	
iv. Stock	1 wk	Sat 6/9/12	Thu 6/14/12	Jesse	
B. Preliminary Conceptual Design	33 days	Sat 6/9/12	Tue 7/24/12	Brendan/Jesse	
i. Motor/Component Research	33 days	Sat 6/9/12	Tue 7/24/12	Brendan	
ii. Project CAD Drawing	33 days	Sat 6/9/12	Tue 7/24/12	Brendan/Jesse	
iii. Gearing Research	33 days	Sat 6/9/12	Tue 7/24/12	Jesse	
II. Second Summer Meeting	1 day	Tue 7/24/12	Tue 7/24/12	Brendan/Jesse	
A. Part Ordering	2 wks	Tue 7/24/12	Mon 8/6/12	Brendan/Jesse	
i. Pulleys	1 day	Wed 7/25/12	Wed 7/25/12	Jesse	
ii. Gearing	1 day	Wed 7/25/12	Wed 7/25/12	Jesse	
iii. Members	1 day	Sat 7/28/12	Sat 7/28/12	Jesse	
iv. Main Assembly Stock	1 day	Sat 8/11/12	Sat 8/11/12	Jesse	
v. Infrared Thermometer	6 days	Tue 8/21/12	Tue 8/28/12	Brendan	
vi. Motors	6 days	Tue 8/21/12	Tue 8/28/12	Brendan	
B. Secondary Design	29 days	Tue 7/24/12	Sat 9/1/12		
i. Final Conceptual Design	1 day	Tue 7/24/12	Tue 7/24/12	Brendan/Jesse	

ii. Preliminary Mechanical Construction	24 days	Wed 8/1/12	Sat 9/1/12	Jesse	
III. Fall Semester	75 days	Sat 9/1/12	Fri 12/14/12	Brendan/ Jesse	
A. Part Ordering	71 days	Sat 9/1/12	Fri 12/7/12	Brendan/ Jesse	
i. Threaded Rod	1 day	Sat 9/8/12	Sat 9/8/12	Jesse	
ii. Motor Caps	7 days	Sat 9/8/12	Sun 9/16/12	Jesse	
iii. Break-Out Board	4 days	Tue 9/11/12	Fri 9/14/12	Brendan	
iv. Spring	1 day	Tue 9/11/12	Tue 9/11/12	Jesse	
v. Miscellaneous Tensioner Components	1.2 wks	Thu 9/13/12	Thu 9/20/12	Jesse	
vi. Motor Control Components	6 days	Tue 10/2/12	Tue 10/9/12	TBD	
vii. Wireless Components	3 days	Tue 10/2/12	Thu 10/4/12	TBD	TBD 2nd Semester
B. Electrical Design	70 days	Sat 9/1/12	Thu 12/6/12	Brendan/Jesse	
i. Motor Control Circuit Design	23 days	Tue 9/18/12	Thu 10/18/12	Brendan/ Jesse	
ii. Voltage Regulation	11 days	Tue 10/23/12	Tue 11/6/12	Brendan/ Jesse	
iii. Wireless Specifications & Setup	31 days	Thu 10/11/12	Thu 11/22/12	Brendan/ Jesse	TBD 2nd Semester
iv. Programming	46 days	Tue 10/2/12	Tue 12/4/12	Brendan	
v. Motor Control	11 days	Tue 10/2/12	Tue 10/16/12	Brendan	
vi. Encoder and IR Thermometer Input	29 days	Thu 10/18/12	Tue 11/27/12	Brendan	Used Thermistor
vii. Camera Input	16 days	Thu 11/1/12	Thu 11/22/12	Brendan	
viii. Data Communication	19 days	Tue 11/6/12	Fri 11/30/12	Brendan	
ix. Testing & Tweaking	26 days	Sat 11/10/12	Fri 12/14/12	Brendan/ Jesse	
C. Mechanical Work	76 days	Sat 9/1/12	Fri 12/14/12		
i. Secondary Mechanical Construction	66 days	Sat 9/1/12	Fri 11/30/12	Jesse	
D. CAD Drawings	70 days	Sat 9/1/12	Thu 12/6/12		

i. Conceptual CAD Drawing Completion	4 days	Sat 9/1/12	Wed 9/5/12	Brendan	
ii. As Built Mechanical Drawing (3D)	37 days	Tue 10/2/12	Wed 11/21/12	Brendan	TBD
IV. Spring Semester	68 days	Mon 1/14/13	Wed 4/17/13	Brendan/Jesse	
A. PCB	33 days	Mon 1/14/13	Wed 2/27/13	Brendan/Jesse	
B. Layout/Design	20 days	Mon 1/14/13	Fri 2/8/13	Brendan/Jesse	
C. Populating and Soldering	19 days	Mon 2/25/13	Thu 3/21/13	Brendan/Jesse	
D. Paper	33 days	Mon 1/14/13	Wed 2/27/13	Brendan/Jesse	
E. Presentation Slide Show	29 days	Fri 3/1/13	Wed 4/10/13	Brendan/Jesse	
F. Robot Upgrades	34 days	Fri 3/1/13	Wed 4/17/13	Brendan/Jesse	
G. Wireless Communication				Brendan	
H. Obstacle Avoidance				Jesse	
I. Drawings	68 days	Mon 1/14/13	Wed 4/17/13	Brendan/Jesse	

C. Correspondence: Advisor Meeting Log

Date	Things Discussed
9/13/12	Overview of Summer Progress (presentation of CAD design) Discussed items to be edited on contract - Temperature tolerance within 2 degrees - Sag calculation changed to distance measurement Discussed wireless issues: received referral to Bruce Segee - Bruce suggested a wireless router Possible December Break Trip to Hydro Quebec's Research Center
9/27/12	On the week of the 17th Jesse and I completed our Expanded Senior Project Contract (Attached) with edits as suggested. We also stopped by to see Bruce Segee about what the most effective wireless device might be to send video and temperature data back to a control station. He recommended using a router and controlling the robot from a laptop on a webpage. On this recommendation, we began wireless router research, but have decided to postpone this until our PIC chip is up and running. We made some final decisions on the mechanical construction (mounting) and plan to complete it over fall break. This week we created a Communications Schematic (Attached) as an overview of how devices will interact. We also tested out motors, encoder, and IR Thermometer. The motors and encoders functioned properly, but the IR thermometer was faulty, and we have contacted Sparkfun for a replacement. We decided to use Pulse Width Modulation to control our motors, using an H-Bridge IC to reverse directions. We also began a Battery Study to figure out how large of a battery or battery pack we will need. Using preliminary conservative estimates, we have decided to look for a 4-5Ah, 12V battery or battery pack. We have begun, researching batteries, and are looking into a pack of AA size rechargeable lithium batteries.
10/12/12	Before October break, we began exploring battery options. Based on our battery calculations, we need a 4-5Ah battery pack that would supply 12V, and have decided to use 4 Ultrafire 18650 (3.7V, 4900mAh) AA size batteries. We also soldered our PIC chip onto its break-out board. Due to complications with connecting, we are currently exploring using a preassembled PIC 32 on a DIP board. We are hoping this will

	make utilizing and troubleshooting much easier. On the 5th, we sent a message to Serge Montambault of Hydro Quebec to try and set up a time to meet and discuss power line inspection devices, but haven't heard back yet. Over break, we made some more progress on mechanical construction. The tensioners have been built, motor mounts assembled, and couplings fitted. Mechanical construction should be complete by next week. We are jumping into the programming now using a PIC 18 while we wait for the PIC 32 board.
10/27/12	On the 16th of October, we ordered the batteries we had specified [8 Ultrafire 18650 (3.7V, 4200mAh)]. We are hoping that these will arrive within the next few weeks. We have made some progress on mechanical construction. The only remaining components are fabricating the drive motor mounts and re-cutting threaded rod for the drive motor assemblies. We have also made progress on our motor control design. We have wired the PIC and the h-bridge chips and have completed some PWM testing. Due to our complications in soldering the PIC 32 onto a break-out board. We decided to order a preassembled PIC 32 on a DIP board and an Ethernet physical layer break-out board. This should make troubleshooting easier and will hopefully provide an easier way to utilize wireless communication. (To be delivered in 2 weeks or so) This week, we have completed our camera research and have ordered a CMOS Camera Module – with a 640x480 resolution from sparkfun.com. We have also completed some research on our voltage regulation circuit and have ordered some buck converter IC samples from Texas Instruments. This chips include all the logic to buck our voltage to the 4 levels we need; 3.3V, 5V, 6V, and 12V. We began testing our infrared thermometers but are still having issues with the replacement. We plan to get John Allen's assistance next week and attempt to figure out the problem.
11/20/12	On the 30th we finished Mechanical construction by mounting the

	drive motors. We also designed buck converter circuits to obtain our four voltage levels (3.3V, 5V, 6V and 12V) and ordered parts. We decided this would allow us to achieve our voltage levels with the most efficiency. We began router research and programming PWM control on the PIC chip. November 1st, we tested the IR thermometer once again and had no success. Since then we have contacted both the manufacturer and the distributer. Both sources provided some guidance in communication with the thermometer, but we ordered an evaluation board from sparkfun.com just in case. On the 5th, we received an e-mail from Hydro-Quebec telling us that they cannot schedule a meeting of the type we wanted. We have not pursued this any further. We built our buck converter circuits and confirmed their operation to output 3.3V, 5V, 6V, and 12V We received our batteries and chargers and confirmed their operation. Their size was misleading; they were much larger than the AA package we had intended so we ordered new battery packs to fit the larger size. Temporarily we connected four of the batteries and shrink wrapped them to achieve the 14.8 volts we needed for our buck converter inputs. We also mounted the drive motors on the robot. On the 7th, we finished assembly of our test stand by spanning the conductor between ends. We realized that ballast would be required on either end to ensure the robot doesn't fall so we purchased several cement blocks to hold the ends down. On the 9th, we rewired the breadboard to take off the outer rails so it would fit inside the robot. We followed up with Melexis about the IR Thermometers and later heard back that they needed to be wired and programmed in a SMBus configuration. On the 13th, we began to wire and write code for our potentiometer control circuit. This is how we want to control the both the slide and drive motors of the robot. We also began drawing a schematic of our breadboard for aid in troubleshooting. On the 14th, we were having trouble with the potentiometer control. Internally the PIC was not switching fast enough so we supplemented this control circuit with external transistors using pull-up and pull-down resistors to correct the problem. This past weekend, we soldered the motor leads on all four motors

	to allow enough length to connect to our breadboard that will be mounted internally on the robot. We used heat shrink tubing to wrap all the conductors together. We tested out the CMOS camera we will use for visual inspection using an AV cable which we plan on hooking the camera up to a small TV to display the video feed this semester. We also wired up an LCD screen and wrote some code to display data. We are using this screen to display the position data from our drive motor encoders as well as from our thermometer. We completed our wiring diagram for the robot breadboard as well. I am going to attempt to program the PIC chips to communicate over SMBus protocol over Thanksgiving break and see if we can communicate with the IR thermometer as well. If this doesn't work out, we should receive the evaluation board we ordered by the end of break so we can complete all the measurable spec's we need to fulfill our contract.
12/12/12	Over Thanksgiving break, we finished some of the remaining mechanical work by constructing a camera mount, mounting cables, and making tensioner/slide adjustments. We also completed the LCD screen programming to display our encoder and temperature readings. Immediately following break we received our IR Thermometer evaluation board and after more contact with the Sparkfun, we were still unsuccessful in getting the thermometer to work. Later on, we received a thermistor (a donation from Alec) and we were able to get this to accurately read temperature. Also following break, we began routing our flat wire communication from the robot to the control box. On the 1st of December, we worked on and tested encoder readouts followed by some troubleshooting of the interrupts. We also did the first test of the robot on the line and discovered that our 12V, 1A regulator was reaching close to its maximum load at 900mA. We ordered a 3A regulator to account allow more current draw from the drive motors. On the 4th we received the thermistor mentioned above and confirmed its operation with a power supply. We also completed the encoder readout programming in the forward direction, with the intent to later add the reverse direction encoder readout as well. Lastly we mounted the LCD screen to the control enclosure and began prepping the enclosure for cable and potentiometer cutouts. By the 6th, we completed the encoder readout programming for the reverse direction and received our size A battery packs. We then began calibrating our thermistor and completed this using water baths at various temperatures. We generated a curve with these data points and used a linear fit to use in code. Our sensor can now typically sense within 1-2°C.

	We also purchased a half-sized breadboard to place in our control box and got all off the components swapped onto it and finished construction of the control box by mounting the potentiometers. On the 7th, we decided to try one of our multimeter test probe thermistors to use instead of the bulkier thermistor we received. The problem we had with the larger thermistor was that the high resistance of it made it very slow in reaching its set point and displaying temperature. Since our test probe was very fast acting we decided to try another test probe. We discovered that the test probes only change about an ohm, so our output voltage would need to be amplified. After a discussion with John, we decided that amplifying would draw too much current so we stuck with the original thermistor. So we mounted the thermistor we had on the center of the robot using some thin-wall aquarium tubing donated by Travis and Eric. Over the weekend of the 8th and 9th, we began prepping the entire project for a presentation on Monday (12/10). We replaced our 12V regulator with the 3A version we ordered, the chip still seemed to heat up significantly so we mounted it to heat sink. We re-calibrated our thermistor to ensure an accurate reading and to include more data points on our curve. We also calibrated our distance measurement once again and got accuracy within one inch. Our last minute mechanical work consisted of mounting a power switch and some more cable routing. On Saturday we tested the battery lifetime of one battery pack on the motors, we barely cleared our 15 minute C spec by lasting 22 seconds over that mark. Sunday, we decided to hook up both of our battery packs in parallel to increase battery life. The battery packs were prone to connection failure, but we were able to confirm a battery lifetime of 1 hour and 47 minutes, and generate a decent battery curve. We encountered a few mechanical issues and had to adjust the batteries once or twice to ensure contact during the test. Before our presentation on the 10th, we re-taped our motor pulleys with 3 strips to ensure better traction with the line and made sure our batteries were operable prior to the presentation. At noon we gave our demonstration to John and Jude and were able to meet our A specs for: battery lifetime, temperature accuracy, and distance accuracy. We did not meet A spec on wireless communication as we had not planned to complete this until next semester. On the 11th and 12th, we began cleaning up or documentation and prepping our project binder. We also took pictures and videos to give some visual aspects to our documentation.

D. Summary of Expenses

Item No.	Part	Description	Part No.	Quantity	Supplier	Ordered	Rec'd	Unit Price	Total Price
1	*Conductor*	Aluminum Conductor	-	1	VEC Donation	7/5/2012	7/5/2012	$0.00	$0.00
2	*PIC Chip*	32 Bit Microprocessor	32MX795F512H	3	Microchip	7/19/2012	7/23/2012	$0.00	$0.00
3	*Pulleys*	UHMW Plain-Bore Round-Belt Pulley 1/2" Belt Dia, 3" OD, 3" Pitch Dia, 3/4" Width	6284K81	4	McMaster-Carr	7/26/2012	7/31/2012	$13.31	$53.24
4	*Racks*	Molded Nylon 14-1/2 Deg Angle Spur Gear Rack , 16 Pitch, 5/16" Face Width, 5/15" H O'all, 1' L	57655K64	3	McMaster-Carr	7/26/2012	7/31/2012	$7.26	$21.78
5	*Pinion Gears*	Molded Nylon 14-1/2 Deg Angle Spur Gear 16 Pitch, 20 Teeth, 1.25" Dia, 1/2" Bore	57655K56	2	McMaster-Carr	7/26/2012	7/31/2012	$5.21	$10.42
6	*Plastic Stock*	Member Stock - 8' Exterior Plastic Boarding .75" X 4.5"	-	1	Scrap	7/28/2012	7/28/2012	$0.00	$0.00
7	*Body Stock*	48" 4"X4" White Decking Post Sleeve	160835	1	Lowe's	8/11/2012	8/11/2012	$24.10	$24.10
8	*Stand Members*	2" X 4" X 8'	-	6	Home Depot	8/11/2012	8/11/2012	$2.25	$13.50
9	*Stand Platform*	15/32" - 2' X 2' Plywood	-	2	Home Depot	8/11/2012	8/11/2012	$5.00	$10.00
10	*Hardware*	Miscellaneous Hardware	-	1	Lowe's	8/18/2012	8/18/2012	$21.20	$21.20
11	*Dowel*	1/2"D X 3' Oak Dowel	-	1	Lowe's	8/18/2012	8/18/2012	$2.32	$2.32
12	*Motors*	131:1 Metal Gearmotor 37Dx57L mm with 64 CPR Encoder	1447	2	Pololu	8/21/2012	8/28/2012	$39.95	$89.37
13	*Slide Motors*	172:1 Metal Gearmotor 25Dx56L mm with 48 CPR Encoder	2288	2	Pololu	8/21/2012	8/28/2012	$34.95	$79.37
14	*IR Thermometer*	Melexis 3V Infrared Thermometer	MLX90614	1	Sparkfun	8/21/2012	8/28/2012	$19.95	$23.59
15	*Threaded Rod*	Zinc Thread Rod 1/4" X 24"	30699171606	1	Home Depot	9/8/2012	9/8/2012	$1.47	$1.47
16	*Motor Cap*	3/4" PVC Slip Cap	012871628306	2	Home Depot	9/8/2012	9/8/2012	$0.37	$0.74
17	*Motor Hole Saw*	1" Carbon Hole Saw w/ Mandrel	045325183168	1	Home Depot	9/8/2012	9/8/2012	$5.69	$5.69
18	*6-Pin Connectors*	6-Pin Board Connectors (Pkg. of 2)	-	3	ICC North	9/11/2012	9/11/2012	$1.19	$3.57
19	*Breakout Board*	QFN / QFP / TQFP / LQFP (16-80 pins) to DIP Breakout Board	IM120718009	1	Imall	9/11/2012	9/11/2012	$8.40	$8.40
20	*Tensioner Hardware*	1/4" Nuts, Washers and Lock Washers	30699005178	1	Home Depot	9/14/2012	9/14/2012	$2.36	$2.36
21	*Motor Coupling*	1/4" Rod Coupling 3 pk	30699191161	1	Home Depot	9/14/2012	9/14/2012	$1.24	$1.24
22	*Motor Strapping*	EMT 2-hole 1-1/4" Strap	51411261641	1	Home Depot	9/14/2012	9/14/2012	$1.56	$1.56
23	*Set Screws*	Miscellaneous Hardware	-	2	Home Depot	9/14/2012	9/14/2012	$0.84	$1.68
24	*Pulley Mount*	LSTA9 9" 20GA Strap Tie	44315667909	2	Home Depot	9/21/2012	9/21/2012	$0.93	$1.86
25	*Tensioner Stock*	Black Baluster Stock	813101	1	Home Depot	9/21/2012	9/21/2012	$20.97	$20.97
26	*PICKIT3*	Pic Programmer for PIC 32 Chips	-	1	Microchip	9/26/2012	9/28/2012	$40.49	$40.49
27	*Motor Hole Saw*	PC Hole Saw 1-1/2"	300703	1	Lowe's	10/8/2012	10/8/2012	$6.97	$6.97
28	*Miscellaneous Tensioner Hardware*	Miscellaneous Hardware	-	1	Home Depot	10/7/2012	10/7/2012	$25.19	$25.19
29	*IR Thermometer*	Melexis 3V Infrared Thermometer	MLX90614	1	Sparkfun	10/13/2012	10/20/2012	$19.95	$23.59
30	*DIP Microcontroller Board*	PIC 32 DIP Board	PIC32DIPC	1	eflightworks	10/18/2012	11/16/2012	$36.00	$40.25
31	*DIP Proto PHY Board*	Proto PHY (TCP/IP Ethernet physical layer)	PROTOPHYC	1	eflightworks	10/18/2012	11/16/2012	$36.00	$40.25
32	*Battery Holder*	4 AA Battery Holder	2700391	2	Radio Shack	10/20/2012	10/20/2012	$2.16	$4.32
33	*Bread Board*	Universal Breadboard U202	2760002	1	Radio Shack	10/20/2012	10/20/2012	$16.49	$16.49
34	*Batteries*	4 x Ultrafire 18650 3.7V Rechargable Li-Ion Battery 4900mAh	-	2	BuyInCoins	10/14/2012	11/6/2012	$7.04	$14.08
35	*Chargers*	Battery Charger for 18650 Rechargeable Li-Ion 3.6V 3.7V Battery	-	2	BuyInCoins	10/14/2012	11/6/2012	$3.16	$6.32
36	*Miscellaneous Hardware*	Miscellaneous Hardware	-	1	Lowe's	10/20/2012	10/20/2012	$3.60	$3.60
37	*Camera*	CMOS Camera Module - 640X480	SEN-08739	1	Sparkfun	10/23/2012	11/1/2012	$35.59	$35.59
38	*Buck Converter Regulators*	3.3V, 5V, 12 V and Adj.	-	12	Texas Instruments	10/23/2012	10/27/2012	$0.00	$0.00
39	*Buck Converter Capacitors*	Cap Alum 330µF 16V 20% Radial	P1169-ND	10	DigiKey	10/30/2012	11/5/2012	$0.74	$7.40
40	*Buck Converter Inductors*	Inductor 330µH .83A Radial	445-3775-1-ND	10	DigiKey	10/30/2012	11/5/2012	$0.80	$8.00
41	*Buck Converter Diodes*	Diode Schottky 40V 1A DO-41	1N5819IR-ND	10	DigiKey	10/30/2012	11/5/2012	$0.38	$3.80
42	*Test Stand Ballast*	16"x8"x8" Hollow Cinder Blocks	-	4	Home Depot	11/7/2012	11/7/2012	$1.37	$5.48

43	*Drive Motor Strapping*	3/4"X10' Galv Hanger Strap 28 GA	739236203083.00	1	Home Depot	11/4/2012	11/4/2012	$2.97	$2.97
44	*Miscellaneous Hardware*	Miscellaneous Hardware	30699712885	1	Home Depot	11/4/2012	11/4/2012	$3.12	$3.12
45	*Parts Locker Lock*	1-7/8" Combo Lock	-	1	Home Depot	11/7/2012	11/7/2012	$3.98	$3.98
46	*Stranded Wire*	22 gauge stranded (red, black, white, green, yelllow)	-	5	ICC North	11/16/2012	11/16/2012	$4.00	$20.00
47	*Solder*	Thin lead solder	-	1	ICC North	11/16/2012	11/16/2012	$3.00	$3.00
48	*AV Cable*	12' RS AV cable	1500224	1	Radio Shack	11/16/2012	11/16/2012	$21.99	$21.99
49	*Motor Caps*	1-1/4" PVC Caps	-	2	Home Depot	11/16/2012	11/16/2012	$1.60	$3.20
50	*Evaluation Board*	Evaluation board for MLX90614 IR Thermometer	SEN-10740	1	Sparkfun	11/14/2012	?	$53.59	$53.59
51	*Pulley Grip*	Rubber Linerless Tape	78453	1	Lowe's	11/23/2012	11/23/2012	$2.50	$2.50
52	*Loom Clamps*	Plastic loom clamps 1/4"	48409	1	Lowe's	11/23/2012	11/23/2012	$1.86	$1.86
53	*Ballast*	8"X8"x16" concrete block	938076	4	Home Depot	11/25/2012	11/25/2012	$1.37	$5.48
54	*Micellaneous Hardware*	Miscellaneous Hardware	-	1	Home Depot	11/25/2012	11/25/2012	$3.58	$3.58
55	*Motor Caps*	1-1/2" Cap for PVC	18578000483	2	Home Depot	11/25/2012	11/25/2012	$2.92	$5.84
56	*Loctite*	Loctite 242 blue threadlocker	79340242005	1	Home Depot	11/25/2012	11/25/2012	$6.47	$6.47
57	*Potentiometers &Transistors*	2 - 50k pots & 10 - 2n7000 mosfets	-	1	Digikey	11/15/2012	11/22/2012	$13.52	$13.52
58	*Potentiometers & Inductor*	2- 50k pots & 1 00 microH Inductor	-	1	Digikey	12/6/2012	12/10/2012	$8.05	$8.05
59	*Buck Converter*	3A Drive Motor Buck Converter	LM2576T	3	Texas Instruments	12/4/2012	12/7/2012	$0.00	$0.00
60	*Headers and Buck Components*	2-dual row 14 pos, 2-dual row 10 pos, 10-6 pos, 10-8MHz Osc., 2-1N5822, 2-100uH, 2-1mF	-	1	Digikey	1/24/2013	1/26/2013	$13.51	$13.51
	Totals			134					$839.40