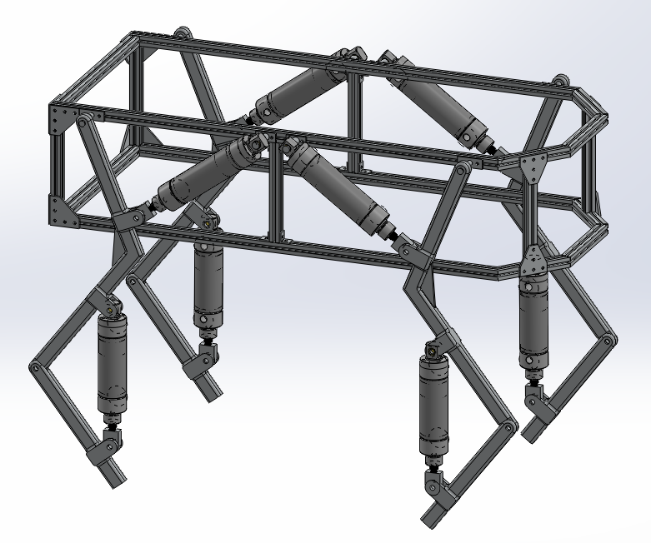
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**Implementation of an Agile Educational Robot**



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# Executive Summary

The Milwaukee School of Engineering (MSOE) participates in Science Technology Engineering and Mathematics (STEM) outreach events for prospective students. The school will benefit greatly from having a sophisticated robotic control system to build excitement about STEM as well as sparking interest in fluid power, automation, and the controls fields. An agile pneumatic robot is not only a complicated control system that can be used to get young people excited about STEM, but it will also increase the prestige of MSOE knowing that a group of seniors attending the school were able to design and build the system from the ground up. In addition it also provides an exciting opportunity for future groups to iterate on the design and integrate new and exciting features.

Implementation of the agile educational robot began. From the design quarter constraints were determined. The most important constraints are listed below:

* A maximum weight of 35 kg for portability
* Maximum size of 0.75 m x 0.75 m x 1.0 m box for portability
* Custom debug panel creation to facilitate troubleshooting
* MATLAB and Simulink model support to allow mechanical engineering students to update control algorithms without knowledge of C/C++
* Electronic fuses and shielding to protect the robot and operator during use and maintenance
* Mechanical protection to reduce the risk of pinching and self-collision damage to the robot
* An easy to access emergency stop to quickly depower the robot
* A pressure relief valve to reduce the risk of overloading and damaging pneumatic components

The design work done on this project was a continuation of the work done by Kevin Lee during the Research Experience for Undergraduates (REU) at MSOE. His work involved deriving a dynamic model for a simplified quadruped robot. Now with our team’s design work finished the implementation of this walking robot was conducted. All necessary components were ordered, tested, and assembled. Pneumatic components were mostly provided by the vendor Numatics. Numatics valves and cylinders are used in the implementation. From the previous design quarter a dog like robot was offered as the final design. The chassis of this dog-like robot was constructed out of T-slotted aluminum framing. The legs of the robot constructed out of solid aluminum. Electrical components were fabricated onto prototyping boards and tested. Software was written in Java, Windows C code, and MATLAB Simulink. The user interface was implemented in java, the controller driver was interfaced with c code dll, and the microcontroller code was written in Simulink block diagram logic.

# Electrical System

The electronics of the robot are broken up into two major subsystems, the motherboard and the debug panel. The motherboard was designed to contain the auxiliary electronics and signal conditioning components needed for the robot. The debug panel contains all necessary electronics to display battery levels and other statuses of the robot.

To power the electronics two different sets of batteries are used. A cluster of 9 volt batteries is used to power the microcontroller and the first half of the signal conditioning circuits. The DCVs run on 10 volts DC. To provide the voltage needed by the DCVs a 12 volt battery is mounted onto the robot.

The debug panel subsystem contains a physical panel with light emitting diodes (LED) and connections for banana plug cables. The LEDs are used to show battery levels and the status of the robot. The banana plug connectors are used to interface to Milwaukee School of Engineering’s test equipment in the labs. Banana plugs are used because they are standard on test equipment. A USB slot is also included on the debug panel to assist in programming the microcontroller without removing it in the robot. The following figure shows a brief layout of the debug panel components.

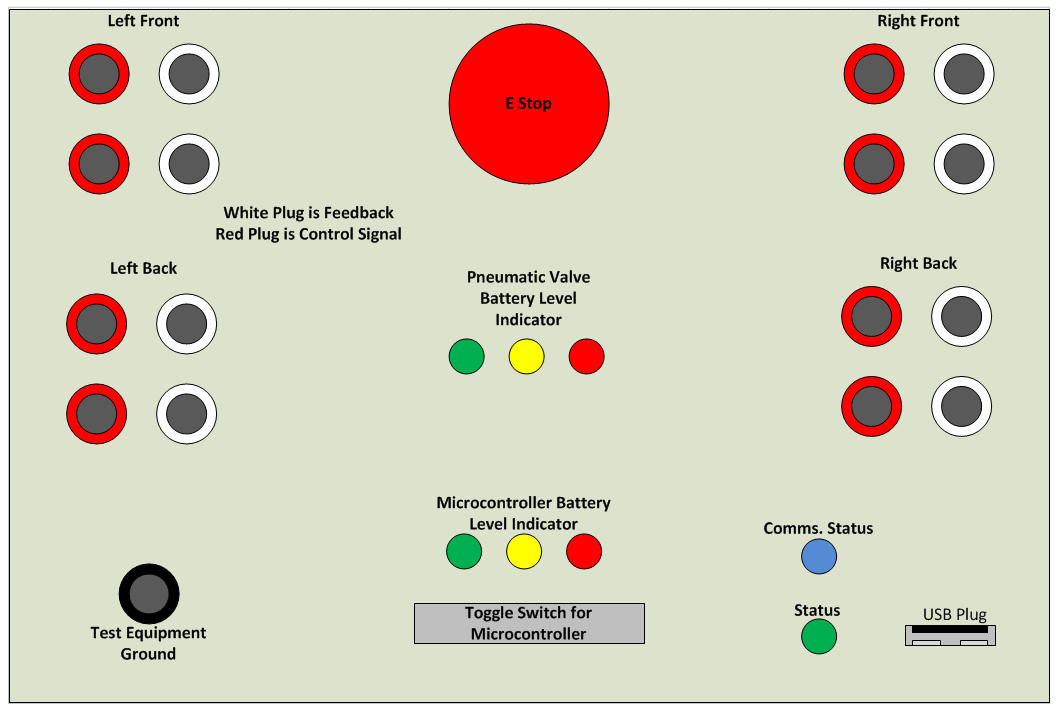


Figure 21: Debug Panel Component Layout

Two subcomponents of the debug panel are the 9 volt battery level indicator and the 12 volt battery level indicator. There were originally two options to make these indicators. The first option included using a LM 3914 chip, known as a dot/bar display driver. The LM 3914 uses 10 LEDs to create a dot graph or bar graph to display the magnitude of an input voltage. To implement the first option the battery voltage level would be connected to the LM 3914 and the 10 output LEDs used to display information to the robot operator. The second option to implement a battery level indicator uses zener diodes and LEDs. Three zener diodes with different threshold voltages are used to detect certain voltage levels of the battery. Depending on the voltage levels LEDs are turned on or off. To maintain the project timeline the simpler solution was chosen, which is using zener diodes and LEDs.

The 9 volt battery level indicator uses 3 zener diodes and LEDs. The LEDs are colored green, yellow, and red to indicate good voltage levels at green and bad voltage levels at red. To determine the voltage thresholds of the zener diodes the minimum voltage out of the battery to operate the robot was experimentally determined with an Agilent DC power supply. The microcontroller was connected to the DC power supply starting at 9 volts and slowly lowered until the microcontroller turned off. This lower voltage was measured at 4.5 volts. However, the microcontroller operates at 4.5 volts, but the 9 volt batteries have discharge curves the drop rapidly after 7 volts. To allow a long enough time for the user to change the batteries the red LED is set to turn on at 7 volts before the battery loses its electric potential. The discharge curves of an Energizer 9 volt battery is included in figure 19.

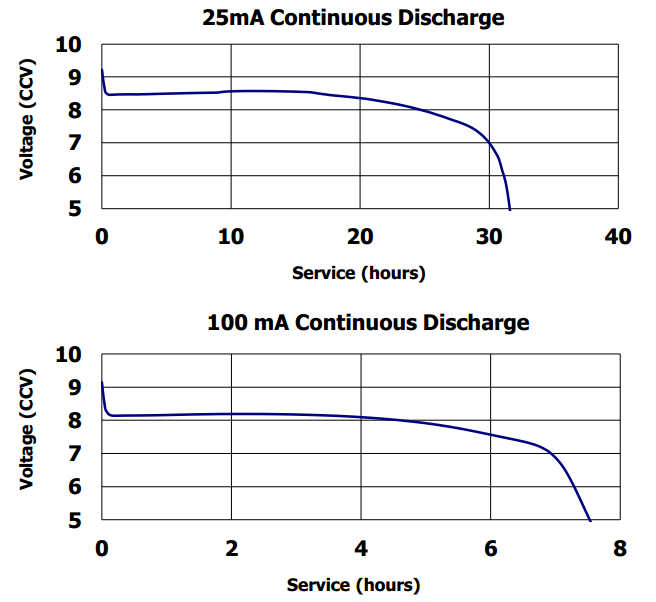


Figure 22: Energizer 9 volt battery discharge curve [15]

The Vmin is based off the 9 volt batteries and not the lower operating voltage of the microcontroller. The following equations are used to pick the required zener diode threshold voltages. Vmax is the maximum voltage of the battery. VT is the threshold voltage between each LED on voltage. The following equations are used

[26]

[27]

[28]

[29]

From the required voltages to turn on an LED the zener diode threshold voltages can be calculated.

The LEDs used are all from the same manufacturer to provide consistency in size and brightness. The LEDs are designed by Dialight and associated part numbers are 521-9210, 521-9211, and 521-9216 for green, yellow, and red respectively. The forward voltage required to turn the LEDs on is 2.1 volts. The forward current has a max rating of 30 mA for best operation. To design a path with an LED and zener diode to detect a 7 volt battery condition the following equation is used. VPath  is the voltage of the battery level being detected, VZ is the zener voltage threshold, VLED  is the LED forward bias voltage. 20mA of current is used because it is lower than the rated maximum current. The resistance of a current limiting resistor is calculated to be put in series with each path. The following three values are the zener voltage thresholds used; 5.1 volts, 4.7 volts, and 4.3 volts for green, yellow, and red LEDs respectively.

(VPath - VZ – VLED) / 20mA = R [30]

After each path was created the circuit was built in Multisim and tested for correct operation. The battery level indicator path is shown below in the following figure.

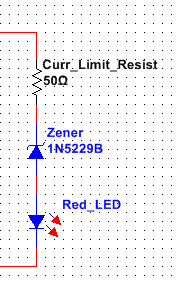


Figure 23: Battery Level Indicator Path

The motherboard contains the signal conditioning for each of the pneumatics cylinders. Each pneumatic cylinder is controlled by a signal analog direct current voltage. However, the signal driving this analog voltage is a pulse-width-modulated (PWM) output on the microcontroller. To convert a PWM into an analog signal an active low pass filter is used. After the low pass filter an opto-isolator is used to separate the microcontroller circuit from the pneumatic actuator circuit. An opto-isolator works by converting an electrical signal into an optical signal by using a diode. The optical signal is recaptures within the device and output onto another circuit as a current signal. At the output of the opto-isolator a trans-impedance amplifier is used to convert the output current signal to a voltage signal for the solenoid of the pneumatic valve. To handle the feedback signal from the pneumatic actuator another opto-isolator is used to separate the two power circuits then the signal is amplified before being read by the microcontroller’s built in analog to digital converters (ADCs). A block diagram of the motherboard signal conditioning is included in the following figures.

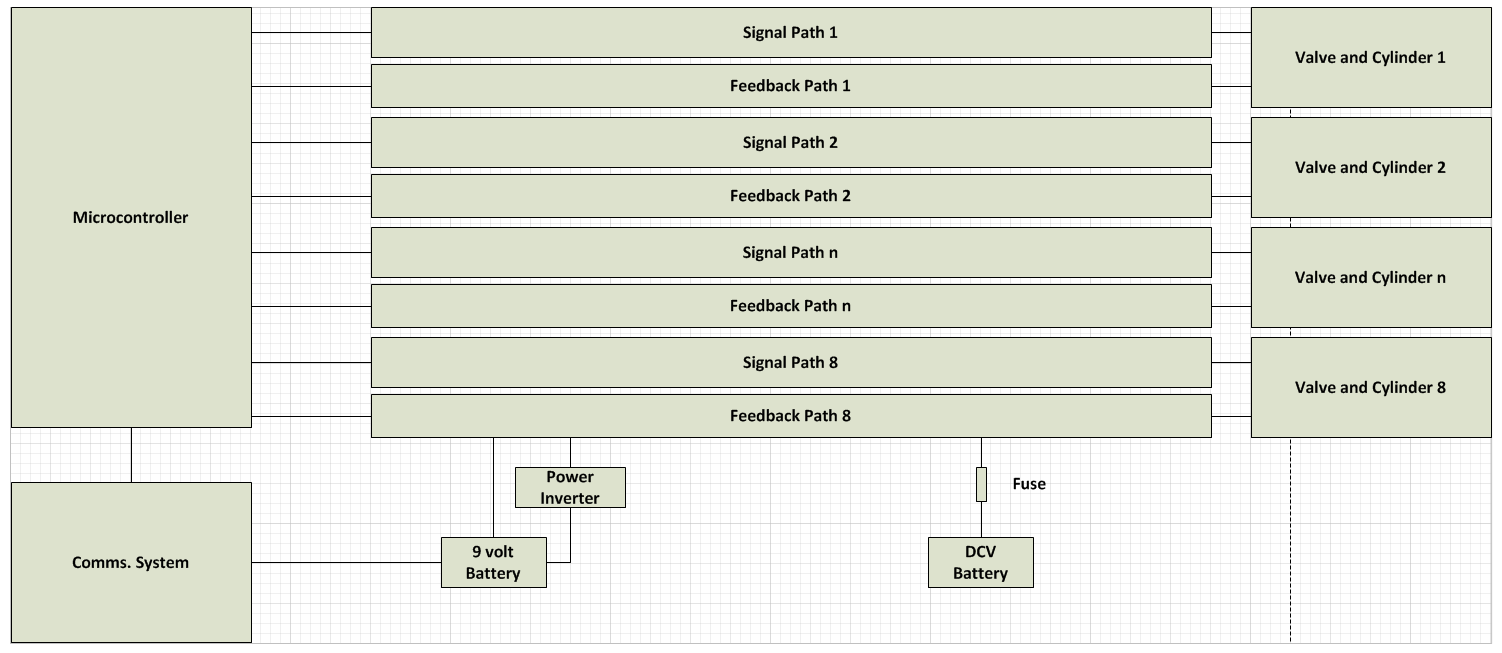


Figure 24: Motherboard Block Diagram

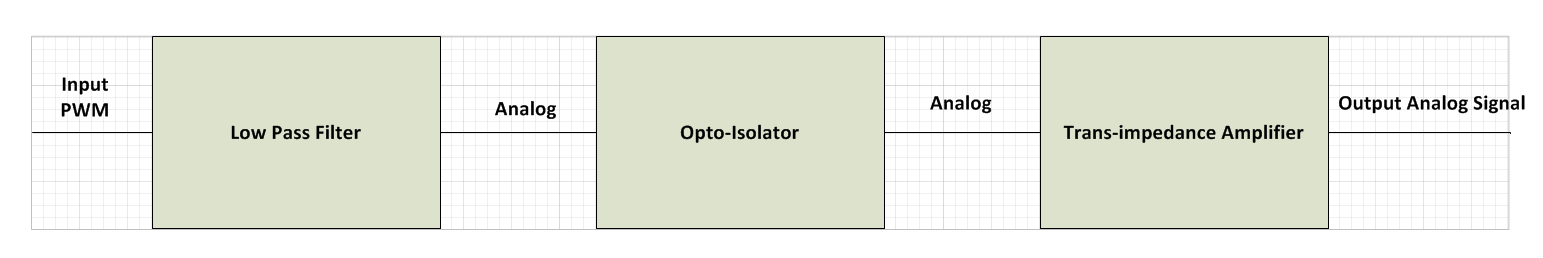


Figure 25: Signal Path Diagram

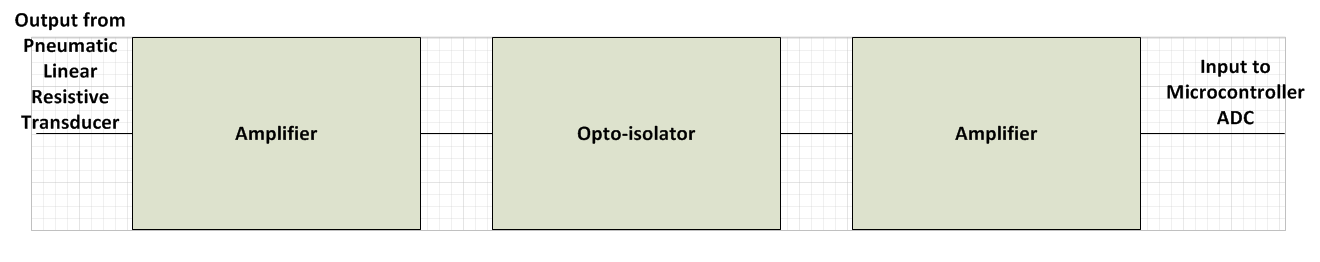


Figure 26: Feedback Path Diagram

Amplifiers are used with passive components to make an active low pass filter. The advantage of an active low pass filter is that the output impedance is near zero and the input impedance is infinity. This helps when cascading different stages of signal conditioning. The filter itself is designed to have a corner frequency of 100Hz, which is lower than the PWM frequency of 490Hz. Using 30 KΩ resistors on a third order Sallen-Key Butterworth low pass filter design tool the following capacitance values are found. The amplifiers used in the low pass filter are LM 741 standard op amps.

|  |  |  |
| --- | --- | --- |
| Stage | C1 [F] | C2 [F] |
| 1 | 5.495E-8 | 5.127E-8 |
| 2 | 7.507E-8 | 3.753E-8 |
| 3 | 2.051E-7 | 1.373E-8 |

The low pass filter circuit was built into Multisim software and tested for correct operation. The Multisim model is shown in figure 20. The possible output values of the filter are between 0 and 5 volts because of the input voltage of a 5 volt PWM.

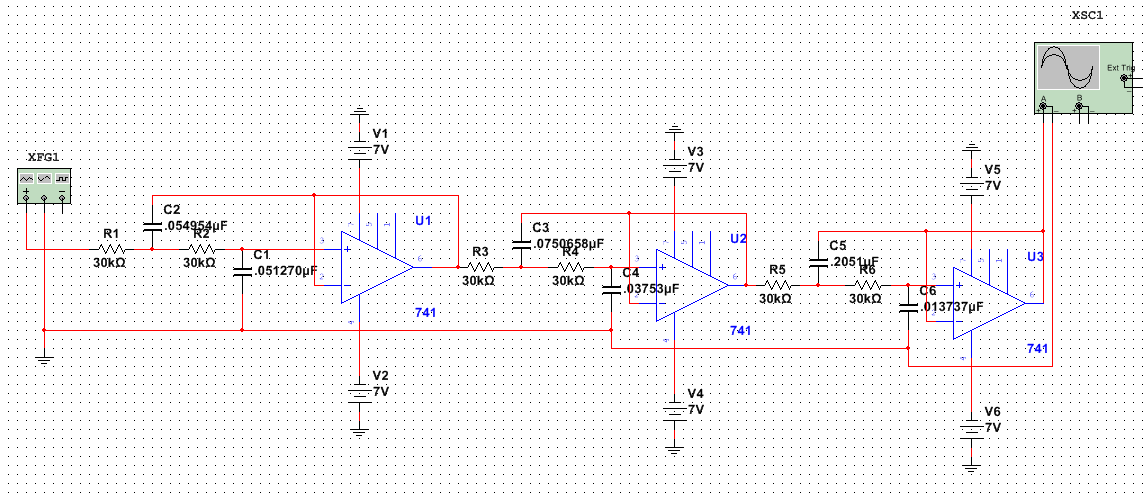


Figure 27: Low Pass Filter

The simulation is completed with the positive and negative rails of the op-amps connected to + 7 volts. This is done because 7 volts is the lower value sources by the 9 volt batteries.

The opto-isolator used in the mother board is the PS2501-4 photocoupler. This photocoupler consists of a LED and a phototransistor. The diode has a limit of 80mA forward current per channel and the transistor has a maximum collector current of 50 mA per channel. Using this device both electrical circuits will be entirely isolated from each other, but connected by an optical signal.