

Electric Liquid Sensing System for Railroad Lubricant Tank



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Executive Summary

The Electric Liquid Level Sensing System provides a collaboration of monitoring sensors, which will shut off the pump motor at a specified critical level for a Top of Rail lubricant disbursement system. The lubricant inside the tank is susceptible to air and if the level falls too low, it can cause significant damage to the pump. The overall system is very robust because all three sensors, temperature, audio, and magnetic reed are integrated together to check each other and determine if the lubricant is at a sufficient level. This monitoring system ensures that the pumps will have a longer life and prevent frequent replacement. Also, technicians will not need to travel to the remote locations where these tanks are, and they will not need to monitor them as closely.

Acknowledgements

Throughout the design process assistance was received from multiple individuals. Recognition goes to the ECE shop for all their help with parts, printed circuit board milling, and most importantly help with design ideas. Our facilitator Dr. Virginia Ayres gave much direction, technical knowledge and presentation guidance. Finally we would like to give a special thank you to our sponsor Kevin Conn of Norfolk Southern, for sending the physical Top of Rail tank system. This ultimately made it possible for the testing that needed to be performed possible.

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Chapter I – Introduction and Background

Norfolk Southern Corporation has many Wayside Top of Rail (TOR) systems that dispense lubricant onto train tracks in high friction locations, such as tight curves. The system consists of a 100 gallon tank, a pump, and a battery to power the system. An external solar panel is positioned near the TOR to charge the battery for a minimum of four hours per day. The pumps are lubricated by the lubricant in the tank and must always be submerged. To prevent damage to the pump(s) the lubricant inside the tank must not sink below the pump connection. Any air inside the pump will eventually cause failure of the pump and a replacement will be needed. The objective of this design is to integrate a device, which will measure the lubricant level inside a sealed wayside TOR tank. When the level is at a specified minimum, the system will turn off the lubricant release valves and indicate the current status on a display. The lubricant will solidify when exposed to air, so minimal internal tank components must be implemented to prevent sensor failure and clogging of the pump(s). To prevent the lubricant from solidification, the tank should not be opened for checking the level and should only be opened when being filled. Due to this the tank should be assumed sealed and the level thus monitored externally. This entire system should be easily retrofitted onto the TOR while it is operational at its installed location, no matter how remote it may be.

Currently there is no existing technology to accomplish this task. External monitoring of tanks has been pursued through many different techniques and has only yield rough estimates that are difficult to verify. A promising technology that is currently being pursued is Ultrasonic Monitoring. Ultrasonic waves will be sent through transducers through the tank wall into the liquid. The wave will then penetrate the liquid and reflect off the opposite wall, or top of the liquid, and then return back through the liquid and wall to the transducer. The system will use the time delay to determine the liquid level or material present on the opposite side of the tank's wall. This technique is only being used as a rough estimate and has been known to deliver very inaccurate results. This technology could be pursued, with means to increase the accuracy, although the current inaccuracies, as well as the tremendous cost of the transducers, have ruled out the most promising technology existing today.

Our system has taken a multiple sensor approach to increase the accuracy of our unique, and cost effective, detection sensors. We have devised three different sensors to shut off the pump(s) before they become exposed to air, and to estimate the liquid level on the system. Our first sensor uses audio cavity modes to detect the differences of the audio emitted based on different lubricant levels when the tank is resonated externally. The second sensor uses multiple temperature sensors placed vertically on the external tank wall. The system will detect the differences in the tank wall temperature based on the internal wall's exposure to lubricant or air. The third sensor will be a fail safe, and partially internal, system that uses a float in a guided track inside the lubricant reservoir. The float contains a high powered magnet which, when in close proximity, will close a reed switch located at the lowest possible point in the liquid reservoir. The first two sensors both have their limitations, but when combined together to check against one another, and in conjunction with the fail-safe reed switch, will yield accurate results and successful shut off of the pump(s) before damage will be aloud to occur. The combination of these sensors will produce a robust system, which will successfully

accomplish the designs objectives of shutting off the system before damage, and giving an estimate of the lubricant level.

This system will have to be successful to ensure the existing TOR systems will not need extensive maintenance or replacement of parts. The TOR systems are located all over Norfolk Southern's track network and many are in remote locations that do not allow easy maintenance. If this system is not successful Wayside TOR's will need maintenance that will be very difficult. Due to the location of these systems, the cost could be very expensive if replacement is required. The cost of refilling these systems can also be very pricey due to the location. Sending someone to refill the tank when it is not needed will cost a lot of money to send a technician to the TOR's location. This system has to be successful or it will cost the Sponsor a lot of money in replacement and servicing.

Chapter II – Exploring the solution space and selecting a specific approach

During the proposal and preliminary stage, the two methods of liquid level sensing that were being explored were the use of an ultrasound transducer and an audio resonance frequency detector. Both of these approaches are non-invasive because all sensors are placed on the outside of the tank in the attached electronics compartment. After further investigation, ultrasound was found to be impractical to implement because of the high cost any volume deployment. This realization provided a spark of multiple new ideas, which some of them have been included in the final product. These other methods include a Radio Frequency Identification (RFID) sensor, magnetic reed switch and temperature sensor.

Ultrasound

Ultrasound is a classification of pressure waves that have a frequency above the highest audible pitch of the human ear. Like the acoustic sound range, ultrasonic waves can penetrate mediums that cannot be seen visually with traditional light and optical sensors. This is a major advantage in its most well known application, medical imaging, where a doctor can examine a patient without performing any operation. Ultrasonic waves are safe for longer exposure than other imaging techniques, such as X-rays, because of the lower frequency. Using ultrasound in liquid level measurement, a transducer could be attached to the tank in several places, shown below and in Figure I.

1. Below the minimum level line: The purpose of placing it at this location is so the ultrasound will be transmitting from the liquid up to the beginning of the air. This will allow the system to determine the amount of liquid in the tank.
2. On or slightly above the minimum level line: This location is a respectable spot because the ultrasound will be transmitting into the liquid until it gets too low. Also at this point, there should be a drastic change in the received information.
3. On the top inside wall: The purpose of placing it at this location is so the ultrasound will be transmitting from the air up to the surface of the liquid. This will allow the system to determine the amount of air in the tank.

The calculations would have been able to be interpreted by an imbedded system, such as a microcontroller. The ultrasound reflection coefficient can be calculated with the formula, shown in Figure II. The result of the reflection coefficient for the boundary between steel and water is $R_{(\text{steel, water})} = 0.385$. Using this information, a microcontroller could be programmed to detect when the liquid reaches the critical level. The voltage of the sinusoid is proportional to the amount of liquid of the tank if the transducer is placed in position one or three. If the transducer is placed in the second position, there would be a drastic change in the signal when the ultrasound medium changes from liquid to air.

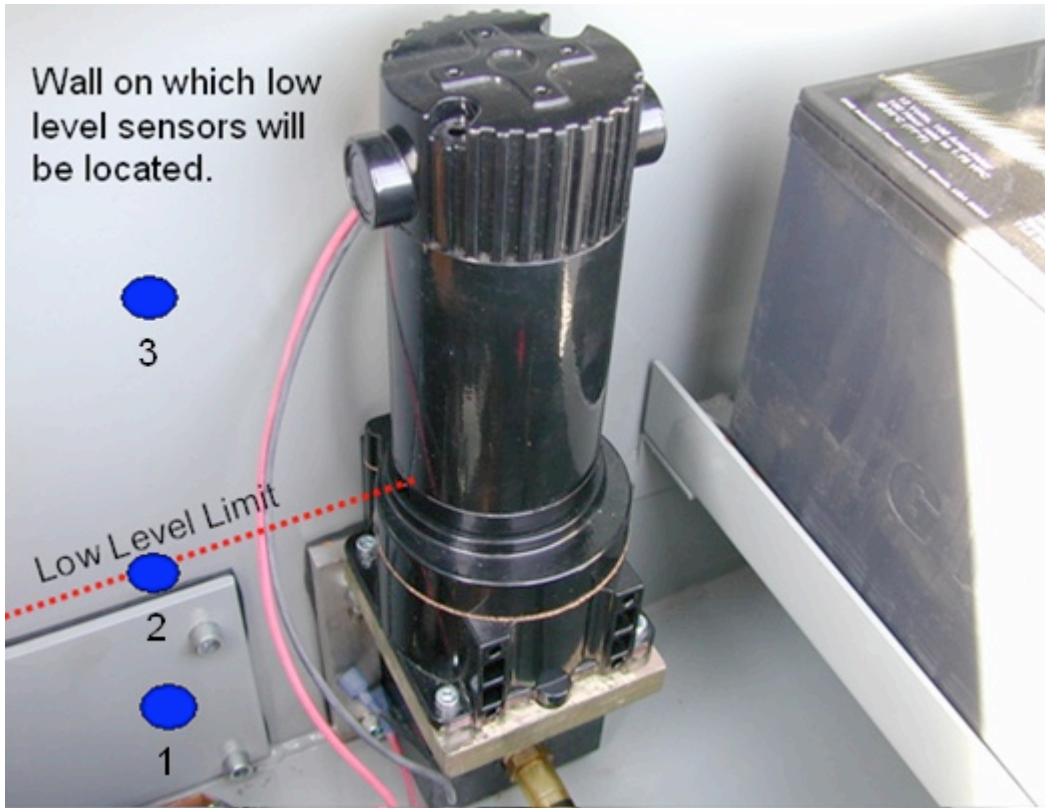


Figure I: Ultrasound Transducer Locations inside Electronics Cabinet

$$R = \frac{(Z_2 / \cos \theta_t) - (Z_1 / \cos \theta_i)}{(Z_2 / \cos \theta_t) + (Z_1 / \cos \theta_i)} \quad \text{where} \quad \frac{\sin \theta_i}{\sin \theta_t} = \frac{\lambda_1}{\lambda_2} = \frac{c_1}{c_2}$$

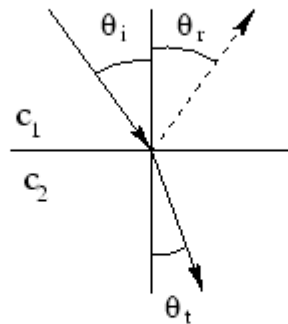


Figure II: The geometry of reflection and refraction at a boundary between media with different sound speeds

Ultrasound transducers have been previously implemented to measure liquid levels in metal tanks, but nothing has been done on remote tanks such as this project. Also they have been done for unique applications and not for a high volume product. Implementing an ultrasound

transducer for the project with the budget provided has proven to be ineffective. The cost for a transducer for penetrating steel would put the project over the budget. Implementing a high cost product on many installations would not be cost effective for Norfolk Southern and an alternative method should be used.

Audio Resonance Frequency Detector

Audio resonance frequency detection is the other method of liquid level detection that was proposed at the beginning of the project. The concept of audio detection can be explained by water in a drinking glass. When an object strikes the glass, it will produce a resonate sound that can be heard. When the amount of water changes within the glass, the pitch will also change. Since the tank is an enclosed box, it should also produce a resonant sound that can be interpreted. To replicate this method with the steel tank, a solenoid will replace of the striker and a microphone will replace a human ear.

The audio resonance frequency pick-up system would analyze the resonance in the tank. Given the shape of the tank, rectangular cavity modes would be used to understand the result of different conditions. Figure III shows the equation to an enclosed rectangular cavity to uncover the presence of resonance frequencies with dimensions a, b, c such that $a < b < c$. To produce the data to be interpreted, the solenoid would strike the side of the tank and audio would be captured and processed. Ambient noise would need to be filtered out to correctly determine the level of the tank. Like the ultrasound, there are the three same positions where the microphone and solenoid can be placed, shown below.

$$(f)_{mnp} = \frac{1}{2\sqrt{\epsilon\mu}} * \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2} \geq \frac{1}{2}\lambda$$

$\epsilon = \text{permittivity}$
 $\mu = \text{permiability}$
 $\lambda = \text{f respacewavelength}$
 $\mu_0 = 4\pi \times 10^{-7}$
 $\mu_{r,\text{water}} = 1.257 \times 10^{-6}$
 $\mu_{r,\text{steel}} = 875 \times 10^{-6}$
 $\mu = \mu_r \cdot \mu_0$

Figure III: Resonance Frequency Equation

1. Below the minimum level line: The purpose of placing the solenoid and microphone at this location is so the audio resonance frequency will only travel through the liquid and the liquid produces a resonance based on the volume of the liquid.
2. On or slightly above the minimum level line: This location is a respectable spot because audio resonance frequency will travel through the liquid until the liquid gets

too low. Also at this point, there should be a drastic change in the received sound wave.

3. On the top inside wall: The purpose of placing the solenoid and microphone at this location is so the audio resonance frequency will only travel through the air and the liquid produces a resonance based on the volume of the air.

Since the tank is a solid steel box, the resonance frequency should be consistent to be able to produce an accurate algorithm. This method has not been implemented but evidence from applications but signal processing should detect variations between liquid level audio samples. The components cost considerably less than an ultrasound transducer so is inexpensively implementable.

Radio Frequency Identification

Radio Frequency Identification (RFID) is a developed technology that is used for receiving stored data with remote communication. Its popularity has increased its application use every year. Systems include a host and a transponder, also called an RFID tag. This method communicates through the air at short distances with an antenna on each side for data transfer. There are three main modes for RFID: Active, Passive, and beacon modes. The passive mode for RFID is the most applicable for a non evasive system. The only device present in the tank is a passive RFID tag incased by a floating ball that follows the level of liquid in the tank. This ball follows is confined inside a cage so that the ball will stay close to the wall. A passive tag has an advantage because the internal tag does not need to be connected to a power source because it receives its power from the signal it receives.

The data on the RFID tag is not important for this project, but the signal and feedback from the tag is the only information needed. When the tag is in range of the transmitter, the pump will be signaled to shut off. A 13 MHz RFID system does not pass the requirement to penetrate steel with the thickness of the tank but a 125 kHz RFID system has been experimentally tested to work. The cost of the lower frequency RFID system is above budget and has the same disadvantages that ultrasound has.

Magnetic Reed Switch

A Magnetic Reed Switch is an electrical device that is controlled by the presence of a magnetic field. There are three different connections to the device as shown in Figure IV. Under no magnetic field, there is a short circuit between Common and Normally Closed and an open circuit between Common and Normally Open. When there is a presence of a magnetic field, the circuit is reversed so that there is a short circuit between Common and Normally Open and an open circuit between Common and Normally Closed.

The Magnetic Reed Switch uses the same float concept as RFID because a magnet is placed within the float and the reed switch is fixed to the outside of the tank. With the tank provided by Norfolk Southern, the tank is made out of steel so the ferrous properties do not allow the magnetic field to pass all the way through. Stainless steel is being used for all of the new tanks being manufactured so the absence of the ferrous properties allows the magnetic field to

penetrate across the medium. To circumvent this problem, putting a sealed reed switch attached to the cage that confines the floating ball.

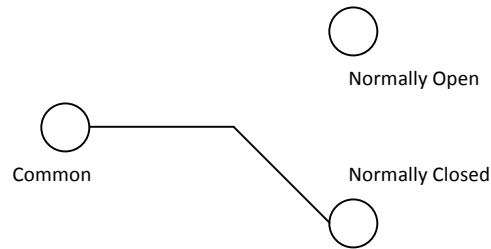


Figure IV: Magnetic Reed Switch Diagram

Temperature Sensor

Different substances, such as water and air dissipate and absorb heat at different rates. The absorption and dissipation rate of water is slower, therefore giving a measurable temperature difference. This can be seen with a large body of water and the air directly above it. Integrated circuits have been developed to be able to determine the temperature by outputting a DC voltage. Placing multiple temperature sensors on the side of the tank should be able to locate the liquid level. Because the temperature sensors would be placed on the steel and not on directly touching the tank's air and liquid, there is a time delay for the differences to be captured.

FAST Diagram

The fast diagram figures below show the flow of our design process. As you can see our design methods have changed. Our initial approach changed due to limited budget and unforeseen obstacles. These obstacles were accounted for and calculations were performed, although they were not as successful as anticipated. Our revised fast diagram shows our new approach to monitor the lubricant level within the tank using multiple sensors. Each of these sensors all are interfaced to a PIC microcontroller for analysis of the different methods of detection. Finally the house of quality diagram shows the new focus of our project. The diagram indicates the most important tasks throughout the design process along with where heavy emphasis was needed. The House of Quality, previous FAST diagram and current FAST diagram are shown in Figure V, Figure VI, and Figure VII, respectively.

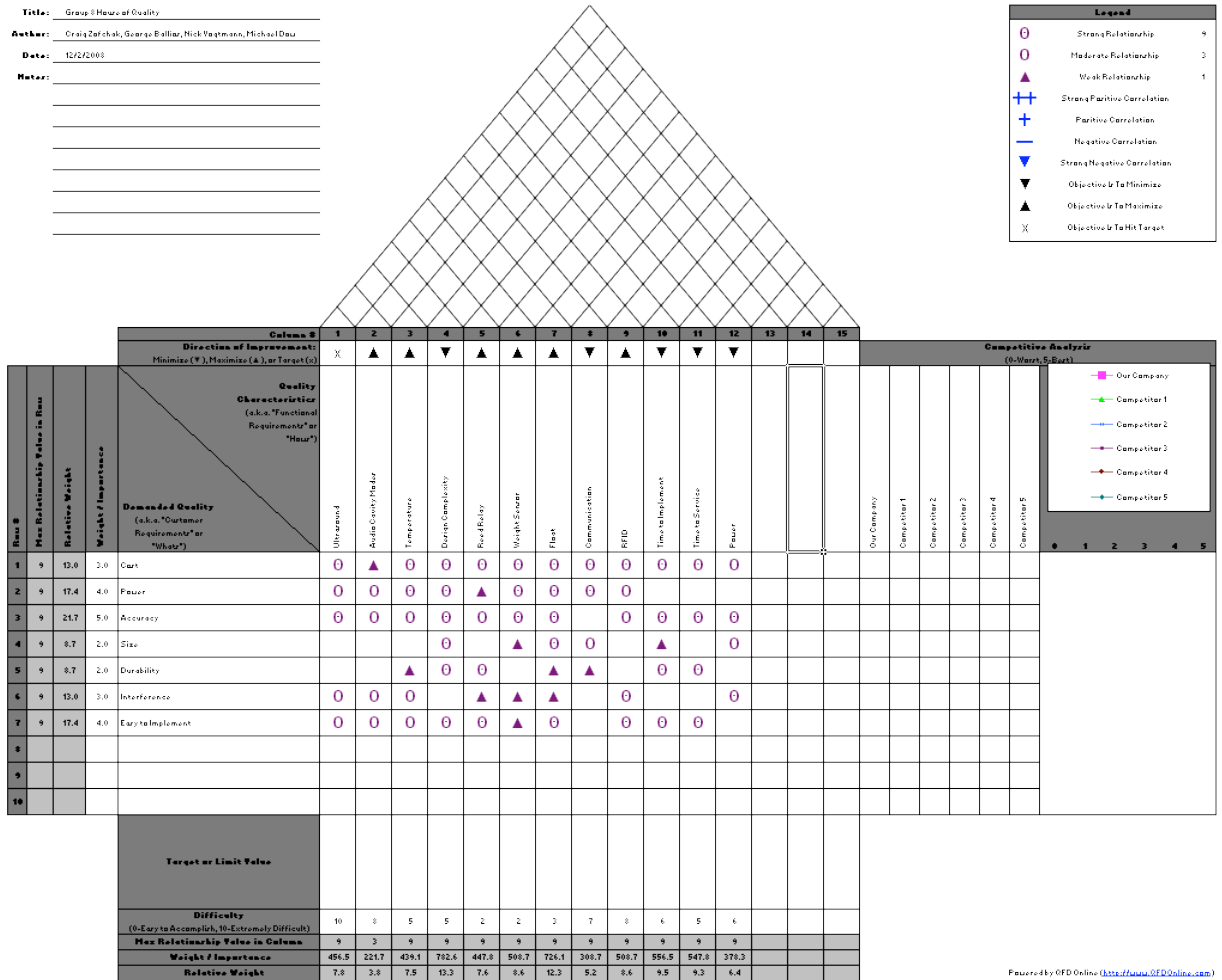


Figure V: House of Quality

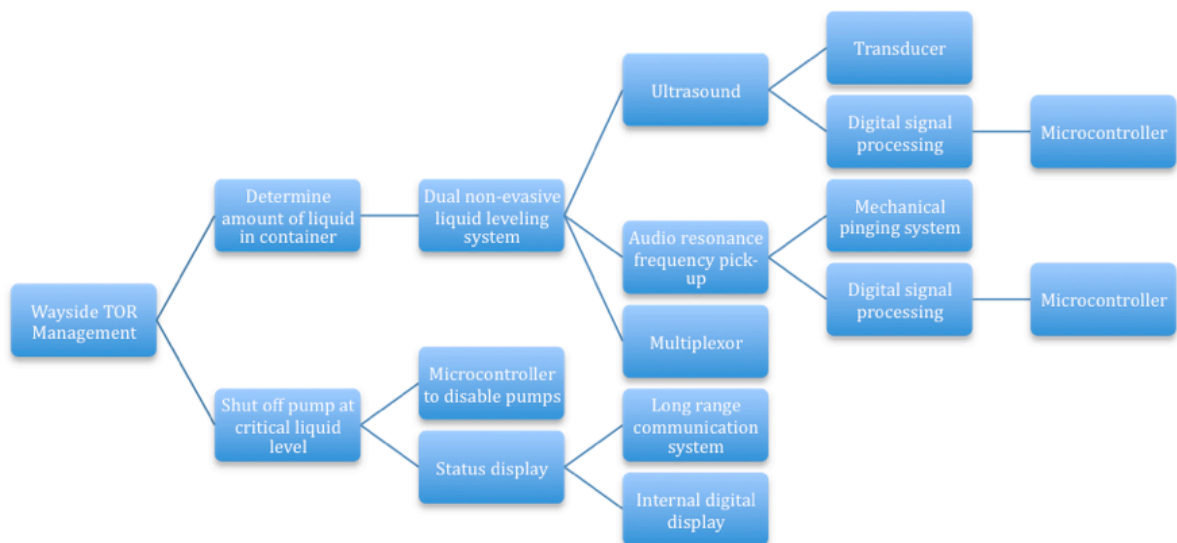


Figure VI: Previous FAST Diagram

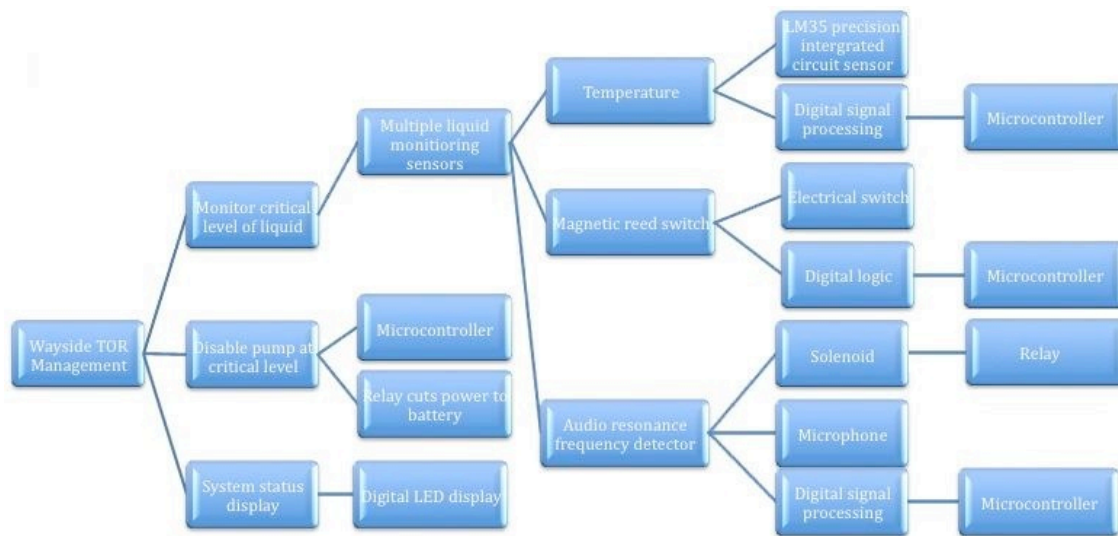


Figure VII: Current FAST Diagram

Budget

Shown below in Figure IX is the project's Budget.

Estimated Cost per Unit			
Qty	Part	Unit Price	Total
1	Digital Signal Controller	\$4.26	\$4.26
1	Printed Circuit Board	\$50.00	\$50.00
1	Suction Cup Microphone	\$11.99	\$11.99
1	Magnetic Reed Switch	\$14.32	\$14.32
1	Neodymium Iron-Boron Magnet Pack	\$29.99	\$29.99
6	Precision Temperature Sensor	\$2.89	\$17.34
1	Plastic Enclosures	\$6.82	\$6.82
1	Miscellaneous Parts / Hardware	\$20.00	\$20.00
		Grand Total	\$154.72

Figure VIII: Project Budget

Chapter III – Technical description of work performed

With any design multiple ideas will arise in the thought process. As research progresses many of these ideas will filter out. In the design for the Electric Liquid Level system many ideas began to surface, which include the following:

- Audio Resonant Frequency Detector
- Magnetic Reed Switch
- Temperature Sensor
- PCB

Audio Resonance Frequency Detector

- Pinging Device

To develop a device to resonate the tank, a component is required to be able to replicate consistent vibrations to capture for testing. The device that was put in place to accomplish this task is a solenoid. A solenoid is similar to an electric plunger, seen in pinball machines. When current is transmitted to the iron core an electromagnetic field is created and the inner metal piece is propelled forward. The solenoid implemented in the system can only force the inner metal piece in one direction. Unfortunately it is not bi-directional which can be an issue since the interior metal piece cannot be reset if it is all the way extended. To solve this issue the solenoid was attached to a system that has an angel so gravity will force the interior metal piece back to its original positions. The next issue is that there is no stopper that prevents the inner metal piece from falling out. To resolve this, a bracket was placed behind the solenoid to prevent this from happening. Once this system was set-up, magnets were then attached to the front bracket harness to make an effortless attachment and removal of the resonating device.



Figure IX: Solenoid

- Audio Pick-up

Since this system relies mostly on audio, a device must be implemented on the tank to pick-up the audio. A standard microphone cannot be easily attached to the side of the tank. The type of microphone that was implemented into the system was a suction cup microphone. This type of microphone was developed to record conversations while on the phone by suctioning the microphone to the receiver. However this system requires something that has a better pick-up. The microphone used is designed to record audio from a guitar. This microphone is more sensitive, which is why it was used.



Figure X: Suction Cup Microphone

This microphone is then attached to the side of the tank using the basic suction principle. The microphone can be sealed to the tank for a more permanent hold; however, that was not necessary at this point



Figure XI: Microphone Placement

The microphone is then hooked to the microcontroller through the PCB

- Signal Processing

The resonate vibrations needed to be captured for processing. The analog signal from microphone captures these audio files. The audio files were then imported using MATLAB using a function called wavread, which returns the sample rate (Fs) in hertz and the number of bits used to encode the data in the file. The data that is collected is in the time domain. Next, the Fast Fourier Transform (FFT) is performed on the data.

```
[x, Fs, N]=wavread('Audio.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
```

This will then give us a main peak. That main peak is the data that is used to tell if the tank needs to be shut off or not. Once the peak shifts to the left a certain amount the pump needs to be shut off.

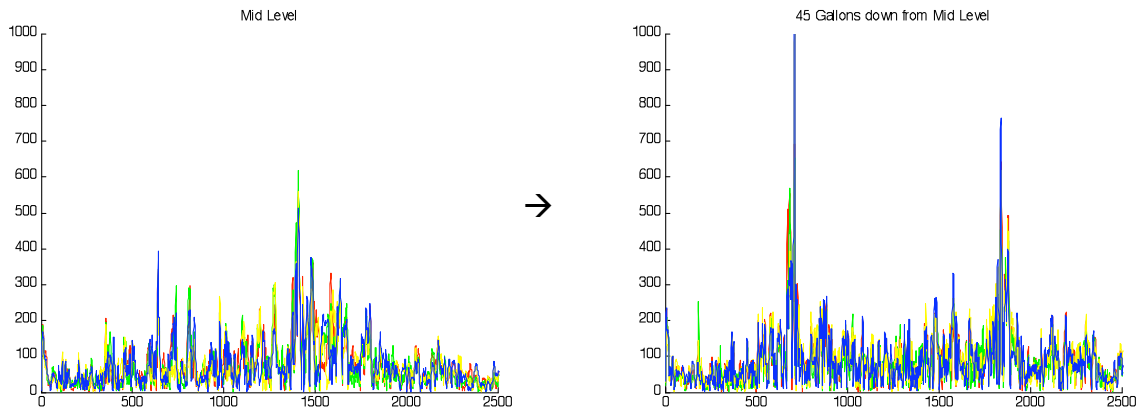


Figure XII: Algorithm Raw Data

The microcontroller uses a slightly different format when calculating the FFT of an audio signal.

```
fractcomplex sigCmpx[<Num of Samples>] __attribute__ ((section (".ydata, data, ymemory"), aligned
(<Num of Samples> * 2 * 2))) =
{
0xSample01.Real, 0xSample04.Real, 0xSample03.Real, 0xSample04.Real,
0xSample05.Real, 0xSample06.Real, 0xSample07.Real, 0xSample08.Real,
0xSample09.Real, 0xSample10.Real, 0xSample11.Real, 0xSample12.Real,
0xSample13.Real, 0xSample14.Real, 0xSample15.Real, 0xSample16.Real,
0xSample01.Imag, 0xSample04.Imag, 0xSample03.Imag, 0xSample04.Imag,
0xSample05.Imag, 0xSample06.Imag, 0xSample07.Imag, 0xSample08.Imag,
0xSample09.Imag, 0xSample10.Imag, 0xSample11. Imag,0xSample12.Imag,
0xSample13.Imag, 0xSample14.Imag, 0xSample15. Imag,0xSample16.Imag
};

FFTComplexIP (<Num of Butterfly Stages>, &sigCmpx[0], &twiddleFactors[0], COEFFS_IN_DATA);
BitReverseComplex (<Num of Butterfly Stages>, &sigCmpx[0]);
SquareMagnitudeCplx(<Num of Samples>, &sigCmpx[0], &sigCmpx[0].real);
VectorMax(<Num of Samples>/2, &sigCmpx[0].real, &peakFrequencyBin);
peakFrequency = peakFrequencyBin*(<Sampling Rate>/<Num of Samples>);
```

Once the Microcontroller sees this shift in the audio signal, it sends a signal to a relay that shuts off the pump.

Magnetic Reed Switch

- Float

The device that was used to develop a float sensor was a ping-pong ball. The ping-pong ball was tested to make sure it was able to float in the Keltrack substance. Once it was verified that the ping-pong ball floats in the substance, a magnet needs to be implemented inside. To insert the magnet into the ping-pong ball, a slice, cut with a razor, needs to be scored into it. The slice needs to be big enough to insert a magnet. Once the magnet is inserted into the ping-pong ball, the slice was sealed with tape and then hot glue was added to hold the seal in place. To further the strength of the seal, strips of duct tape were wrapped tightly around the ping-pong ball, in an overlapping manner. After the final layer was implemented, the float was tested in the substance to make sure there were no leaks and the device still floats properly.



Figure XIII: Float Sensor

- Float Enclosure

While developing the float sensor system, a device must be put into operation to make sure the float does not go all over the place and will come close enough in contact with the reed switch. The system that was developed was a cage-based enclosure. To build this system, two corner brackets were tack welded together to create a covered square.

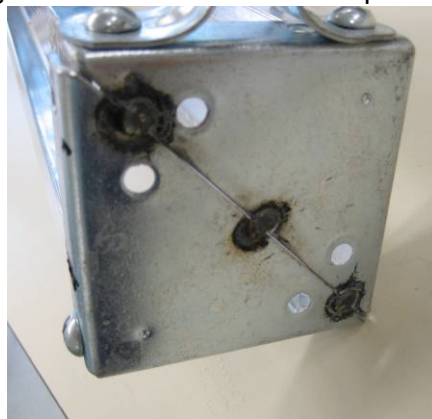


Figure XIV: Tack Weld of Square Bracket

Next the sides of the system need to be put in place. Four non-ferrous metal corner pieces were cut to size and a hole was drilled in the ends to attach to the two corner brackets. The metal corner pieces were then bolted to the corner brackets to create a cage enclosure.

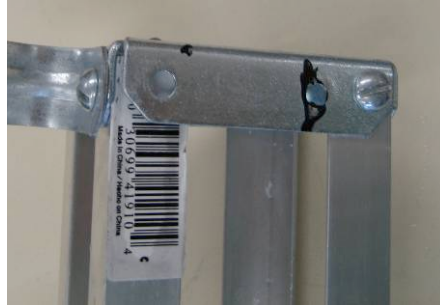


Figure XV: Bolted Bracket

Since the magnet float will stick to the side of the tank, a spacer had to be put in place to move the enclosure away from the wall. Two half PVC brackets were bent to a proper shape and then attached to the top and bottom square corner brackets. The spacers were able to make sure the magnet stayed 2" away from the wall at all times.



Figure XVI: Added Spacer

To easily attach the system to the tank, magnets were attached to the spaced brackets and attached using duct tape. Also, on the bottom of the enclosure five smaller magnets were attached to create a stronger hold on the tank.

- Magnetic Reed Switch

Since the magnet reed switch cannot sense the magnet through the steel, the reed switch needs to be fully submerged in the lubricant. The first step it is make sure the reed switch is fully water proof. This task was completed by using a substance called liquid electrical tape. The liquid electrical tape was painted on the cracks of the reed switch to further waterproof the system.



Figure XVII: Waterproofing Reed Relay

Next, extension needed to be attached to the wires on the reed switch since they were not long enough to reach the microcontroller and PCB. The wires were then soldered to the ends of the reed switch and covered in electrical tape to prevent any shorts. Then, shrink tube was placed over the electrical tape and then sealed with the liquid electrical tape. This was done to make sure if any liquid were splashed on the wire, nothing would happen to the system.



Figure XVIII: Waterproofing Reed Relay (Cont)

The reed switch now needed to be put in place at the level when the pump needs to be turned off. To set the level a PVC pipe was cut to the height of the pump shut off level. Holes were then drilled in to the PVC to make easy attachment of the sensor. It was then inserted in the metal enclosure and zip tied to the bottom. The reed switch was then place flat on top of the PVC, which is at the pump shut off level, and zip tied to the PVC pipe.

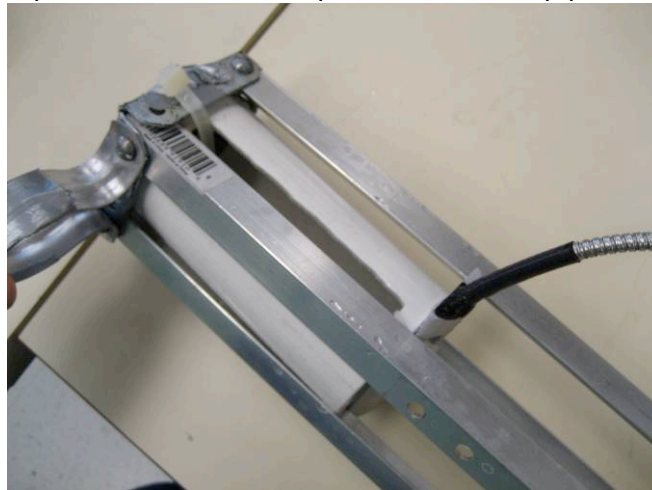


Figure XIX: Installed Reed Switch

- Implementation

The reed switch is then attached to the microcontroller input on the PCB. The Microcontroller then reads if a signal is sent to it and based on that a different operation will happen. When the magnet gets close enough to the reed switch the microcontroller recognizes it and uses a relay shut off the pump.



Figure XX: Inside of tank with installed Reed Switch

Temperature Sensor

The temperature sensor system design consists of multiple LM35 precision integrated-circuit temperature sensors. The hardware for this design is a TO-220 plastic package. This package has three pins, V_s , GND, and V_{out} as shown in figure below. The input voltage ranges between 4V and 20V, V_{out} ranges from 0 mV $+10.0\text{mV}/^{\circ}\text{C}$ for monitoring. This IC has a temperature range of $+2^{\circ}\text{C}$ to $+150^{\circ}\text{C}$. These three pins are connected to serial cable, which will be connected to the PBC for data interpretation. This IC was selected in that it has a low error of $(\pm) .5^{\circ}\text{C}$ compared to other packages which were not as accurate and accuracy is essential.

These series of sensors are aligned from the top of the electronics cabinet to, where the critical level would be in the tank but inside the electronics cabinet, spaced at equal distances in which to measure the temperature differences.

The difference in temperature will be interfaced with the PIC microcontroller. The temperature effects, the voltage of the IC, every 10mV represents 1°C .

IC's in general are sensitive to high heat from a soldering iron, these IC's especially. When performing some tests on this system, it was noticed that one of the temperature sensors data did not make any sense. After measuring the resistance between each pin, it was determined that it was fried. Fortunately there were extra IC's so it could be replaced. Extra care was taken into account with the rest. Also there is some degree of variance of $.5^{\circ}\text{C}$, which can vary our results given certain temperatures. To correct this we accounted for this in our code to correct any inconsistencies.

- Hardware Component

The Hardware was laid out in a precise matter to allow the components to have the best possible functionality and ease of trace placement. The Voltage regulator was placed right next to the power input to give the lowest possible distance, which would allow for thicker wires between the two components. The reed switches to turn off the pump and turn on the solenoid are located next to one another due to their isolated, and high, voltages and current flow compared to the rest of the circuit. The LED's were placed near the edge of the board all next to each other to allow a free flowing display that is not scattered. The Button is also near the edge of the board to allow ease of pressing without requiring extensive wiring to flow inside the board. For the two largest components, the DB-25 and the PIC microcontroller, placement was extremely careful. This is because each component runs to one another and has 25 and 28 pins each. The layout of this was extremely careful and required a lot of precision and attempts to get a reasonable layout with minimal amount of VIA's. Below is the Board layout in Figure XXIII.

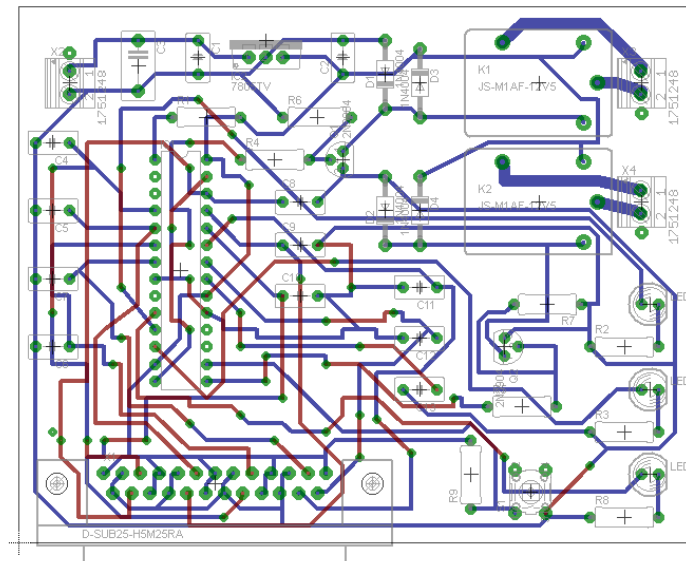


Figure XXIII: Project Board Layout & Pin Selection

μC Pin	Sensor
4	RTD0
5	RTD1
6	RTD2
7	RTD3
26	RTD4
25	RTD5
24	Microphone
23	Reed Switch
18	Reset

Figure XXIV: Pin Selection

Chapter IV –Test data with proof of functional design

In the process of developing a system to determine the level of lubricant in the tank, one must realize that there is many ways of accomplishing this task, if one aspect was different. The biggest roadblock is that the tank has ¼" thick steel walls. These steel walls make many measurements extremely difficult to calculate. Our original idea for calculating the level in the tank was to use a form of ultrasound. The ultrasound would send a signal and based on the level it would reflect a different value. This was great in theory, except the power required to penetrate the steel is much higher then what was allotted. After many calculations, there was an ultrasound transducer that would acquire the results needed. The only issue turned out to be cost. The method had great potential to work, but costing 20 times our budget had us move to our next idea.

Another system created was an audio frequency sensing system. The device would hit the side of the tank and based on the lubricant level a certain frequency would arise. After dealing with calculations on this, in MATLAB, what was concluded was the steel walls cause there to not be enough variance for us to determine the difference in frequency. After this, the system was then moved to calculate data at different locations. The solenoid, the pinging device, was place at a height so it would hit an inch above the critical level. The purpose of this is to have the microphone pick up either the frequency when the water is above the solenoid and when the water is below the solenoid. This set up displays a bigger change in frequency. When the water level is above the solenoid, the max peak location tends to stay in one generalized location. Once the water level falls below the solenoid, the max peak location tends to shift to another location. This change in peak location can show when the level reaches the critical point and the pump needs to be shut off.

Ore next design consisted of RFID. What was intended was to have a RFID sensor on the wall of the internal cabinet and a floating device that contained a RFID tag. This system had great possibilities of working if the tank was not made of steel. The steel walls reflect too much of the directional RF leaving none to penetrate and not picking up the RFID tag. After testing this system on a stainless steel wall and it functions, as it is suppose to. Norfolk Southern said the tanks would soon be replaced with stainless steel models, which means this system could be ideal.

The next method tried was using a magnet reed sensor to pick up a signal through the tank. The magnet reed sensor had a 2" operating gap. After the system was hooked up, it turned out that the sensor is not strong enough to sense the magnet through steel. This system was then implemented to be an internal level sensor. A floater with an internal magnet was put in a cage that aloud the float to move freely without going all over the tank with no sense of direction. This cage was then set up to easily attached to the side of the tank using high-powered magnets and a space system to keep the cage off the wall. The reed switch was then placed at the bottom of the cage, which is at the critical level where the pump needs to be turned off. The reed switch is implemented in a way so that the magnet float will stop on top of it giving it a more accurate reading. The system is the most accurate out of all the systems in place. The only downfall is it has some internal parts.

The temperature sensing system consists of five sensors along the outside of the tank. This method is consistent when determining the level of the system. There are a few downfalls. The temperature system takes a long time for it to stabilize and get accurate readings. Also the sensors have a .5mV variance and the data between the sensors can sometimes vary by only that much and it can cause a false result.

Chapter V – Final cost, schedule, summary and conclusions

This project has given rise to a lot of realizations about external measurement techniques. Team eight has found a couple of things that will, and a whole lot more that will not, work for this particular application. The first thing team eight has recognized is that the most promising technology for this application, ultrasound, is a very expensive technique that could easily be more costly than the TOR system it is being implemented for. This had ruled out our entire focus from the early part of the semester due to funding constraints. We moved on to focus our full effort towards our secondary sensor using audio cavity modes. We implemented this sensor with mixed success. This system consisted of a solenoid to ping the tank and a precision suction cup microphone attached to the lubricant reservoirs wall. This system would have to take the audio signal and do calculations to determine the differences in them based on the different lubricant levels. This system has been very difficult to perform calculations on. Due to the extremely small differences in the audio feedback received, in conjunction with the solenoids built in low, but present, percentage error between separate pings, calculations have been off. The range of the audio signal's difference between the full and empty tank is smaller than our percentage error range. This has thus yielded occasional erroneous results which would not be acceptable as a stand alone sensor. To improve this, multiple pinging sensors could be implemented vertically on the tank wall and measure the difference's against one another. A new technique to ping the tank could also be devised with greater accuracy to reduce the solenoids differences between pings.

The next technique attempted was an RFID reader in the electronics cabinet with a passive sensor inside the tank. The sensor was in a float inside an encased tube with liquid vents on the side that are not big enough for the float to escape. This tube would ensure that the float did not roam free inside the tank, would pass directly in front of the RFID reader, and also did not interfere with the pumps. When the passive RFID tag would pass in front of the RFID reader, placed at the lowest allowable liquid level, on the other side of the tank, it would detect the sensor and then shut off the pump. This technique did not work due to the metal shell of the tank. Despite a three inch operating gap that penetrates almost all materials, the radio waves do not penetrate metal and thus did not work on our tank. To improve this, a lower radio frequency could work to penetrate steel. The only downside is that lower frequency RFID systems do not exist and would require a new antenna and tag to be build by the design team. The lower frequency would also greatly increase the wavelength which could affect the operating gap when reading the signal. A solution proposed to modify this setup was to use a magnetic reed switch as the trigger instead of the RFID. This system proved to have the same operating gap as the RFID only would rely on magnetism as the trigger. This system failed however because the steel tank once again blocked the switch trigger by not allowing the magnetism to penetrate. Unlike the RFID which had trouble penetrating metals, magnetism would penetrate metals. The only problem was magnetism would not penetrate ferrous metals which attract magnets. The Magnetism would penetrate aluminum, and stainless steel, which new tanks have been proposed to be switched to due to its rust free properties. This system would unfortunately only work for new tanks that are proposed but not the current systems. This system was modified to become internal, while meeting requirements of the sponsor. The

only difference is the reed switch was moved to inside the reservoir instead of the electronics cabinet. This system has shown to be 100% effective and will work as long as the system remains powered. This system has been implemented very cost effectively and simply.

The final system that has been attempted has been the temperature sensor array. This system has proven to be surprisingly accurate. The sensors are affixed to the wall in the electronics cabinet that is flush with the lubricant reservoir. The temperature sensors will have a slight difference in temperature since heat rises, although in retrospect, this is minimal. The sensors that are affixed to the tank wall that is below the waterline will all be within a few tenths of a degree Celsius. The sensors that are affixed to the tank that is exposed to open container on the other side will also all have a temperature difference within a few tenths a degree Celsius. This temperature is different, higher or lower, based on the outside temperature by about one degree Celsius. This system can thus tell the liquid level within a few inches. This system is quite accurate but will take up to ten minutes or more to adjust with vastly changing temperatures and when new liquid is added or taken away abruptly. This is due to the law of thermodynamics where temperature has to penetrate into the tank and change its temperature before it can be detected by the sensors. Since the temperature in nature doesn't fluctuate abruptly, and the pump drains the tank slowly over the course of weeks to months, this is not an issue. The only issue is when the tank is refilled. The system can mistakenly take the tank for full if all of the temperature sensors are above the liquid level and then the tank is filled so all of the sensors are below the lubricant level. This has been taken care of by a full tank reset button which will let the system know that it is a completely full tank and not a completely empty tank. This will prevent the system from believing that it is empty and not utilizing the new lubricant. To improve this system more temperature sensors could be implemented to increase the level detection accuracy, as well as temperature sensors that are able to detect temperatures below freezing. The current system can detect that temperatures are around or below freezing but not the true temperature, so the readings are not taken as accurate in these ranges.

All three implemented systems are used in conjunction with one another to reduce the error percentage of the overall system. The reed switch is also there to backup the level sensors for shutting down the pumps should their levels be inaccurate. Since the most expensive system has been ruled out, our cost has remained relatively low. The current cost is broken down below with estimated costs of failed systems, if improved to work, shown in red.

Estimated Cost per Unit			
Qty	Part	Unit Price	Total
1	Digital Signal Controller	\$4.26	\$4.26
1	Printed Circuit Board	\$50.00	\$50.00
1	Suction Cup Microphone	\$11.99	\$11.99
1	Magnetic Reed Switch	\$14.32	\$14.32
1	Neodymium Iron-Boron Magnet Pack	\$29.99	\$29.99
6	Precision Temperature Sensor	\$2.89	\$17.34
1	Plastic Enclosures	\$6.82	\$6.82
1	Miscellaneous Parts / Hardware	\$20.00	\$20.00
1	RFID Reader	(\$100.00)	(100.00)
1	RFID Sensor	(\$ 0.05)	(\$ 0.05)
1	Ultrasonic Transducer	(\$7000.00)	(\$7000.00)
	Grand Total		\$154.72

Figure XXV: Revised Budget

The timetable of when the systems were implemented is below in the schedule.

Week	Tasks
4	1. Research Ideas
5	1. Research Ultrasound
	2. Research Audio Cavity Modes
6	1. Research Ultrasound
	2. Research Audio Cavity Modes
7	1. Tank Arrives
	2. Testing of Audio Cavity Modes Feasibility
	3. Attempt to Acquire Ultrasonic Transducer
8	1. Build Audio Prototype
	2. Request Additional Funding/Donations for Ultrasound
	3. Build Audio Pinging Solenoid
	4. Test Audio Prototype
9	1. Analyze Audio Data in MATLAB
	2. Program PIC Microcontroller

10	1. Analyze Audio Data in MATLAB
	2. Program PIC Microcontroller
	3. Research alternate solutions
11	1. Analyze Audio Data in MATLAB
	2. Program PIC microcontroller
	3. Program RFID Reader
	4. Build Internal Float Sensor
12	1. Analyze Audio Data in MATLAB
	2. Program PIC Microcontroller
	3. Test RFID System
13	1. Program PIC Microcontroller
	2. Test Solenoid System
	3. Research alternate solutions
14	1. Program PIC Microcontroller
	2. Build Temperature Prototype
	3. Design PCB
15	1. Test Temperature Prototype
	2. Rework and Implement Temperature System
	3. Implement Reed Float Sensor
	4. Program PIC Microcontroller
	5. Collaborate different Systems
	6. Build PCB
	7. Package Design
	8. Final Test of Design

Figure XXVI: Team Schedule

Appendix I – Technical roles, responsibilities, and work accomplished

George Ballios



Throughout the development of the Electric Liquid Sensing System I participated in a number of roles, however concentrated on three main components. Initially I had come up with the electronic transducer proposal, which lead to the audio resonance frequency detector design. Initially I began to record the resonance using an analog microphone. I was trying to determine where the best location was to place it in order for it to receive feedback accurately. Once I had recorded this I knew the information was going to have to be processed. Working side by side with Mike, I imported all of the initial audio results from different levels into MATLAB. Using the wavread function it allowed me to import my .wav and returns the sample rate (Fs) in Hertz, and the number of bits used to encode the file. All of this information was in the time domain and when graphed was not useful, the Fast Fourier Transform (FFT) function was used to convert these files to the frequency domain.

After working with the audio, I moved on to a magnetic reed switch sensor. I knew with this idea it was not going to be easy to detect a magnetic field through the steel tank in that it is composed of ferrous material and absorbs any such field. I then began to calculate skin depths

for the steel in order to determine if a different type of signal could work $\delta = \sqrt{\frac{2\rho}{\omega\mu}}$ (resistivity

(ρ), frequency (ω), and permeability (μ) are needed in order to determine the correct skin depth value (δ). My research led me to a RFID sensing system. The RFID would work well in that the transmitting antenna is directional and when the receiving antenna critical level it comes in contact with the signal it would disable the pump. When testing the RFID kit that was purchased it seemed as if the wavelength of the 13.56 MHz signal was too short and that a much lower frequency of 125 kHz, which has a longer wavelength, would be ideal. Also the properties of steel reflect waves making it very difficult for a low power signal to penetrate.

Finally my efforts went into the design of a temperature monitoring system. This system consisted of multiple LM35 precision centigrade integrated circuit temperature sensors. After much research of datasheets online I determined with my team that the LM35 would be the best choice in that it has a low error, and the largest surface area for receiving temperature

readings. With the collaboration of my team members it was decided to align the sensors in the middle, from top to the critical level inside the electronics cabinet. Each of these IC's has three pins, GND, Vs, and Vout. I soldered each of these sensors to a different set of three wires which all fed into a serial cable that would be mounted later on our PCB. For the testing of these sensors I plugged the Vout pins into a protoboard and was able to see the voltages using a digital multimeter. I recorded successful readings from different levels and also different temperature water for my testing. Overall this design is important in that it will provide a check for the other monitoring systems.

Michael Dow

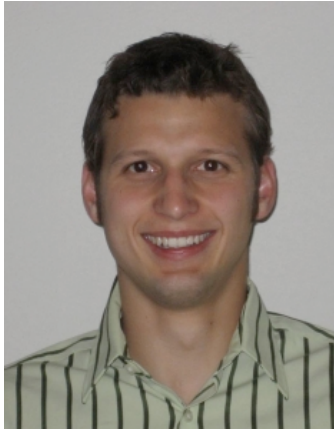


When developing our level sensing system, I decided to start by developing the initial MATLAB code. The MATLAB code, that I was developing, was to determine the resonance frequency of the tank when the solenoid pinged the tank. The signal inputted was an audio file and I made it in to a vector. Then I took that vector and did the FFT of it to determine the resonance frequency. This data was taken at many different levels and over 60 audio samples were taken. I took all the data that was implemented and wrote a basic formula to determine if the pump needed to be turned off or not. When writing this code I also put in extra steps to make sure there was a little error as possible.

After developing the code for the audio system, I went on to developing an internal level sensor. The best idea we could come up with was a float sensor. We decided to make the sensor using a magnet reed switch. While developing this system I decided that we needed to come up with a way of keeping the float on a track system. We decided to use PVC piping, but we soon realized that the Keltrack was to think to travel smoothly through the openings. I came up with an idea to develop a cage type track that has big slits that go the whole way down the enclosure. Then I attached the magnet reed sensor to the enclosure at the critical level.

One issue with having a magnet float is that if it gets too close to the steel wall it will stick to it and not float. I decided to add two brackets to the enclosure, so when it attaches to the wall it is 2" away. The enclosure is then attached to the wall by high-powered magnets so the system can be easily removed and attached.

Nicholas Vogtmann



During the design of the Electric Liquid Level Sensing System, I had three main components of the project where I focused my work. The first was data collection for testing algorithms for the Audio Resonance Frequency Detector. I setup the experiment, captured the audio samples on a computer and cropped them to the desired length for input into MATLAB. This needed to be done in an organized and repeatable fashion so that the results from the Fast Fourier Transform would be accurate and not skewed because of inconsistent samples. I also worked on different conditions for the audio sample to be captured to see what the best result. This task proved to be very important because the audio algorithm took time to complete.

The second task that I completed is selecting and programming the Digital Signal Controller. The audio resonance frequency detector, magnetic reed relay, and temperature sensor array were programmed to all work on the same microcontroller. The major components that were used were the Analog to Digital Converter, the Digital Signal Processing unit, and standard logic operations. With the Digital Signal Processing Unit, I programmed a Fast Fourier Transform. The Analog to Digital Converter is initialized for two different operations, depending on the sensing method being performed. For the audio resonance frequency detector and one AC signal is captured and for the temperature sensors, six DC voltages are captured.

The final task that I performed was the design of the schematic and PCB. I selected microcontroller pins for sensor inputs and data outputs as well as designed the relay driving circuits. Given the fact that certain pins can perform unique operations, such as the Analog to Digital conversions, the layout of the PCB was a challenge. Using Eagle Layout Editor, I placed the traces so that the schematic would fit on a two layer board.

Craig Zofchak



While our Electric Liquid Level Sensing System was in the development stage, I worked on a few main things. The first thing I did was work heavily on collecting and retrieving data. I started by assisting with the data collection of audio samples and improvement of the audio pinging device. With this I helped set up the experiment and enticed the shifting of the test data from scaled down model mockups of the tank, to the actual tank to avoid unforeseen differences. I assisted with pinging of the data and filling and draining the tank. I soon continued to try to keep the team's momentum moving forward by shifting focus away from underperforming ideas such as the audio cavity modes sensor, and the sonar donation request efforts. Despite these great ideas, the outlook was looking bleak, and the progress was in gridlock even with continued exertion. I increasingly pushed our efforts away until the team decided to focus our efforts on other design ideas.

I came up with the design idea for the internal float sensor with RFID detection and pushed to shift to it as our first task in our reworked design attempts. I went on to develop the internal float sensor concept of the ping pong ball with a RFID tag inside the ball placed inside a PVC pipe with many slots drilled in it. This concept proved to be a working prototype for the gap but would not penetrate through metal. With this concept the team easily was able to divert to a new idea with the reed switch sensor. I assisted in implementing this reed switch and making a working prototype. When this concept had the same problem as the RFID, I assisted in moving the concept to a fully internal sensor as a backup check against the other two sensors.

Once the concept of the Temperature sensors was presented I quickly assisted in optimizing them to yield the greatest results and accuracies. I went ahead and put the sensors together in a fully integrated unit using a serial cable. I helped out taking lots of data measurements and proving the idea as a viable design. I then assisted with making the temperature sensor algorithm which would be able to recognize different levels on the tank. I then went ahead and made the PCB board to tie everything together. I laid out the board using Eagle design software. Once the board was milled in the ece shop I went ahead and assembled the board and tested all of its components to ensure the team had a robust and working board for the final design. When the board was completed, I assisted in putting the board together in the final enclosure to create a professional looking package that could be presented on design day.

Appendix II – Literature and website references

Anderson, Martin E, “A brief introduction to ultrasound.” [Online Document] Feb 2006 [2008 Oct 3], Available at HTTP: <http://dukemil.egr.duke.edu/Ultrasound/k-space/node2.html>

Dixon, Paul, “Cavity-Resonance Dampening.” [Online Document] June 2005 [2008 Oct 3], Available at HTTP: <http://www.eccosorb.com/file/586/appnote-proof.pdf>

National Semiconductor, Precision Centigrade Temperature Sensors, [Online Document] November 2000, [2008 Nov 20], Available at HTTP: <http://cache.national.com/ds/LM/LM35.pdf>

Appendix III – Detailed technical attachments

Latest MATLAB Code and Data

```
clc;
close all;
clear all;
figure;
[x, Fs, N]=wavread('MidLevel1.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
hold on
title 'Mid Level'
plot(abs(fx1),'r')
axis([0 2500 0 1000])
mm(1) = find(fx1==max((fx1)));
ml(1) = max(abs(fx1));
mml = mm(1);

[x, Fs, N]=wavread('MidLevel2.wav');
fx = fft(x,Fs);
fx2 = fx(1:length(fx)/2);
hold on
plot(abs(fx2),'g')
mm(2) = find(fx2==max((fx2)));
ml(2) = max(abs(fx2));
if (ml(2) >= max(ml))
    mml = mm(2);
end

[x, Fs, N]=wavread('MidLevel3.wav');
fx = fft(x,Fs);
fx3 = fx(1:length(fx)/2);
hold on
plot(abs(fx3),'y')
mm(3) = find(fx3==max((fx3)));
ml(3) = max(abs(fx3));
if (ml(3) >= max(ml))
    mml = mm(3);
end

[x, Fs, N]=wavread('MidLevel4.wav');
fx = fft(x,Fs);
fx4 = fx(1:length(fx)/2);
hold on
plot(abs(fx4))
mm(4) = find(fx4==max((fx4)));
ml(4) = max(abs(fx4));
if (ml(4) >= max(ml))
    mml = mm(4);
end

if(abs(fx1(mml))>400 & abs(fx2(mml))>400 & abs(fx3(mml))>400 & abs(fx4(mml))>400);
    MidLevel_Max_Peak = mml
```

```

else
    MidLevel_mean_Max_Peak = mean(mm)
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure;
clear all;
[x, Fs, N]=wavread('MidLevel-15G1.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
hold on
title '15 Gallons down from Mid Level'
plot(abs(fx1),'r')
axis([0 2500 0 1000])
mm(1) = find(fx1==max((fx1)));
ml(1) = max(abs(fx1));
mml = mm(1);

[x, Fs, N]=wavread('MidLevel-15G2.wav');
fx = fft(x,Fs);
fx2 = fx(1:length(fx)/2);
hold on
plot(abs(fx2),'g')
mm(2) = find(fx2==max((fx2)));
ml(2) = max(abs(fx2));
if (ml(2) >= max(ml))
    mml = mm(2);
end

[x, Fs, N]=wavread('MidLevel-15G3.wav');
fx = fft(x,Fs);
fx3 = fx(1:length(fx)/2);
hold on
plot(abs(fx3),'y')
mm(3) = find(fx3==max((fx3)));
ml(3) = max(abs(fx3));
if (ml(3) >= max(ml))
    mml = mm(3);
end

[x, Fs, N]=wavread('MidLevel-15G4.wav');
fx = fft(x,Fs);
fx4 = fx(1:length(fx)/2);
hold on
plot(abs(fx4))
mm(4) = find(fx4==max((fx4)));
ml(4) = max(abs(fx4));
if (ml(4) >= max(ml))
    mml = mm(4);
end

if(abs(fx1(mml))>400 & abs(fx2(mml))>400 & abs(fx3(mml))>400 & abs(fx4(mml))>400);
    MidLevel_15GD_Max_Peak = mml

```

```

else
    MidLevel_15GD_mean_Max_Peak = mean(mm)
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure;
clear all;
[x, Fs, N]=wavread('MidLevel-30G1.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
hold on
title '30 Gallons down from Mid Level'
plot(abs(fx1),'r')
AXIS([0 2500 0 1000])
mm(1) = find(fx1==max((fx1)));
ml(1) = max(abs(fx1));
mml = mm(1);

[x, Fs, N]=wavread('MidLevel-30G2.wav');
fx = fft(x,Fs);
fx2 = fx(1:length(fx)/2);
hold on
plot(abs(fx2),'g')
mm(2) = find(fx2==max((fx2)));
ml(2) = max(abs(fx2));
if (ml(2) >= max(ml))
    mml = mm(2);
end

[x, Fs, N]=wavread('MidLevel-30G3.wav');
fx = fft(x,Fs);
fx3 = fx(1:length(fx)/2);
hold on
plot(abs(fx3),'y')
mm(3) = find(fx3==max((fx3)));
ml(3) = max(abs(fx3));
if (ml(3) >= max(ml))
    mml = mm(3);
end

[x, Fs, N]=wavread('MidLevel-30G4.wav');
fx = fft(x,Fs);
fx4 = fx(1:length(fx)/2);
hold on
plot(abs(fx4))
mm(4) = find(fx4==max((fx4)));
ml(4) = max(abs(fx4));
if (ml(4) >= max(ml))
    mml = mm(4);
end

if(abs(fx1(mml))>400 & abs(fx2(mml))>400 & abs(fx3(mml))>400 & abs(fx4(mml))>400);
    MidLevel_30GD_Max_Peak = mml
else

```

```

MidLevel_30GD_Max_Peak = mean(mm)
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure;
clear all;
[x, Fs, N]=wavread('MidLevel-45G1.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
hold on
title '45 Gallons down from Mid Level'
plot(abs(fx1),'r')
AXIS([0 2500 0 1000])
mm(1) = find(fx1==max((fx1)));
ml(1) = max(abs(fx1));
mml = mm(1);

[x, Fs, N]=wavread('MidLevel-45G2.wav');
fx = fft(x,Fs);
fx2 = fx(1:length(fx)/2);
hold on
plot(abs(fx2),'g')
mm(2) = find(fx2==max((fx2)));
ml(2) = max(abs(fx2));
if (ml(2) >= max(ml))
    mml = mm(2);
end

[x, Fs, N]=wavread('MidLevel-45G3.wav');
fx = fft(x,Fs);
fx3 = fx(1:length(fx)/2);
hold on
plot(abs(fx3),'y')
mm(3) = find(fx3==max((fx3)));
ml(3) = max(abs(fx3));
if (ml(3) >= max(ml))
    mml = mm(3);
end

[x, Fs, N]=wavread('MidLevel-45G4.wav');
fx = fft(x,Fs);
fx4 = fx(1:length(fx)/2);
hold on
plot(abs(fx4))
mm(4) = find(fx4==max((fx4)));
ml(4) = max(abs(fx4));
if (ml(4) >= max(ml))
    mml = mm(4);
end

if(abs(fx1(mml))>400 & abs(fx2(mml))>400 & abs(fx3(mml))>400 & abs(fx4(mml))>400);
    MidLevel_45GD_Max_Peak = mml
else
    MidLevel_45GD_Max_Peak = mean(mm)
end

```

end

%%

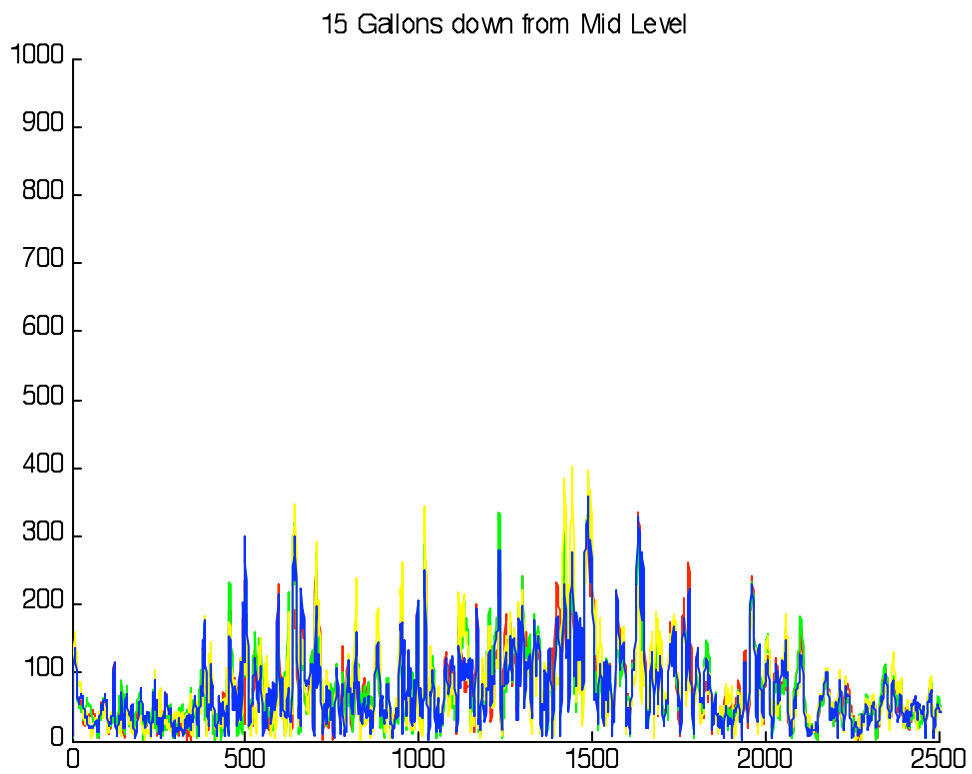
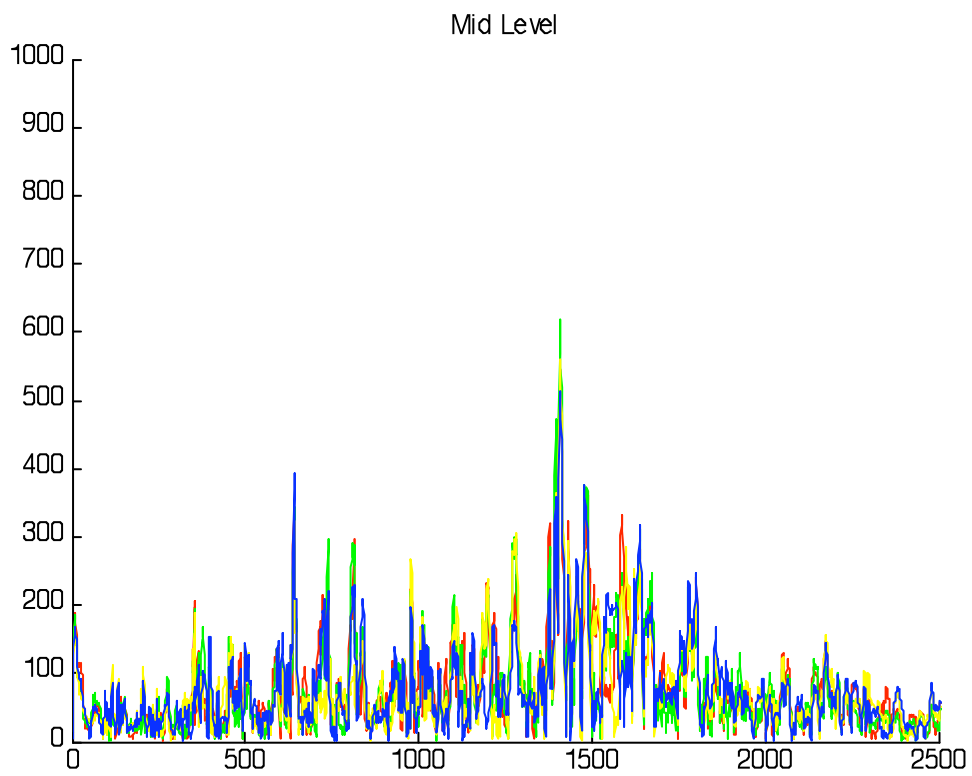
```
figure;
clear all;
[x, Fs, N]=wavread('CriticalLevel1.wav');
fx = fft(x,Fs);
fx1 = fx(1:length(fx)/2);
hold on
title 'Critical Level'
plot(abs(fx1),'r')
AXIS([0 2500 0 1000])
mm(1) = find(fx1==max((fx1)));
ml(1) = max(abs(fx1));
mml = mm(1);

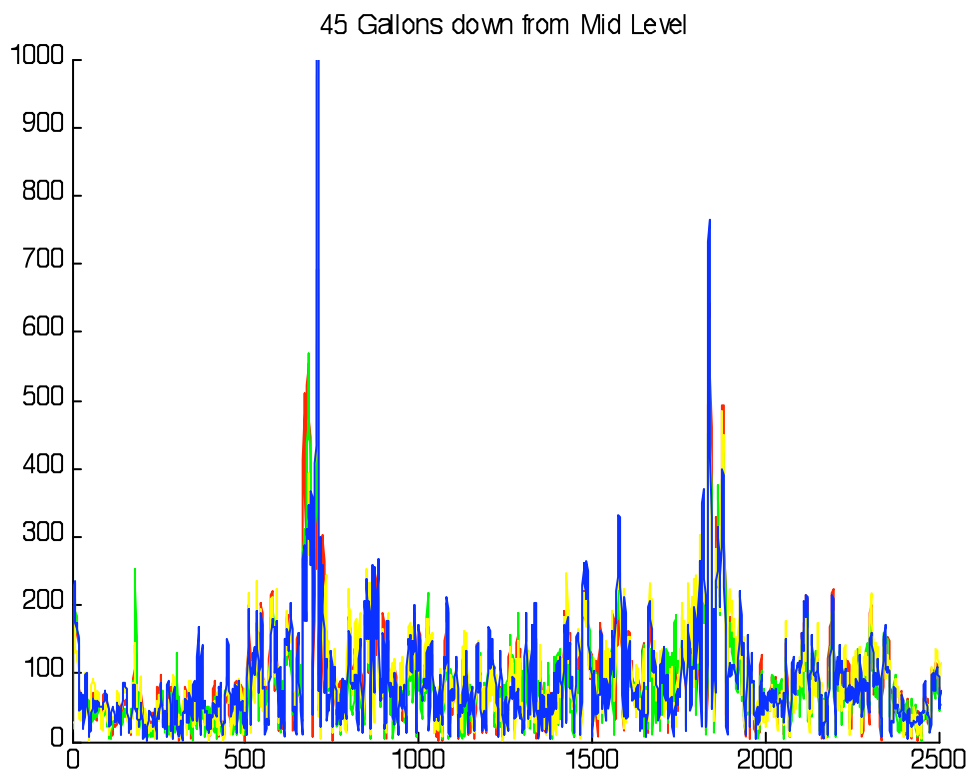
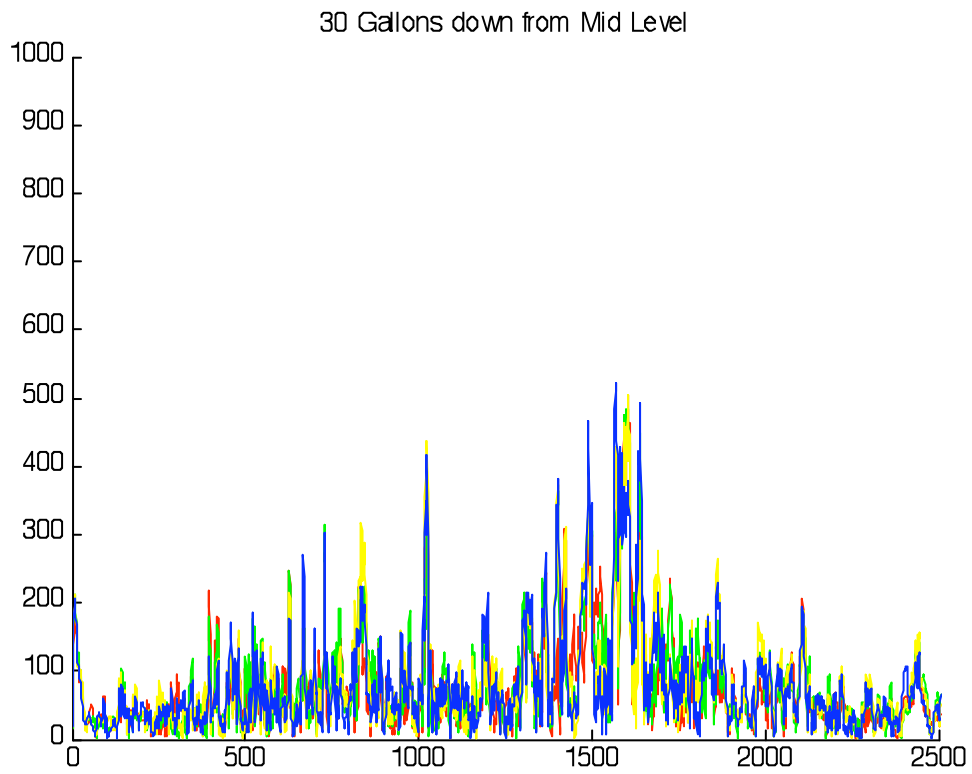
[x, Fs, N]=wavread('CriticalLevel2.wav');
fx = fft(x,Fs);
fx2 = fx(1:length(fx)/2);
hold on
plot(abs(fx2),'g')
mm(2) = find(fx2==max((fx2)));
ml(2) = max(abs(fx2));
if (ml(2) >= max(ml))
    mml = mm(2);
end

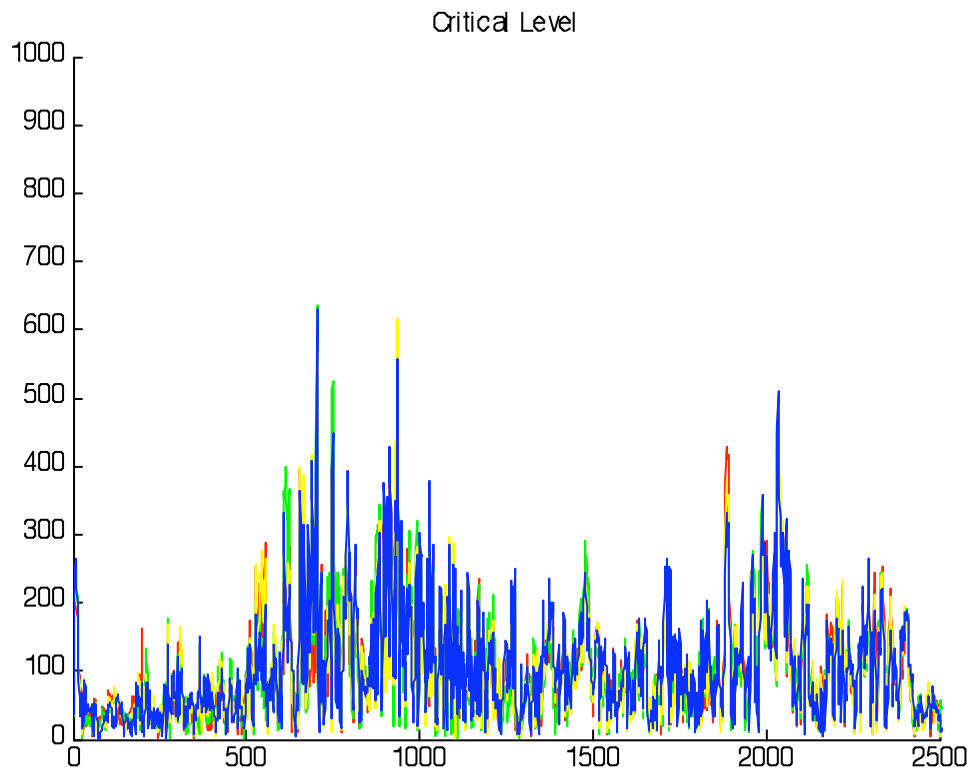
[x, Fs, N]=wavread('CriticalLevel3.wav');
fx = fft(x,Fs);
fx3 = fx(1:length(fx)/2);
hold on
plot(abs(fx3),'y')
mm(3) = find(fx3==max((fx3)));
ml(3) = max(abs(fx3));
if (ml(3) >= max(ml))
    mml = mm(3);
end

[x, Fs, N]=wavread('CriticalLevel4.wav');
fx = fft(x,Fs);
fx4 = fx(1:length(fx)/2);
hold on
plot(abs(fx4))
mm(4) = find(fx4==max((fx4)));
ml(4) = max(abs(fx4));
if (ml(4) >= max(ml))
    mml = mm(4);
end

if(abs(fx1(mml))>400 & abs(fx2(mml))>400 & abs(fx3(mml))>400 & abs(fx4(mml))>400);
    Cricital_Level_Max_Peak = mml
else
    Cricital_Level_Max_Peak = mean(mm)
end
```







Original Idea for Audio Code

```
clc;
close all;
clear all;
% read wave file
[Critical, fs1, bits1]=wavread('CriticalLevel1.wav');
[n1, nChan1]=size(Critical);
if nChan1 > 1
    error('this example requires a mono audio file');
end

freqbase1=fs1*(mod(((0:n1-1)+floor(n1/2)), n1)-floor(n1/2))/n1;

spectrum1=fft(Critical.* hamming(n1));

spectrum1=spectrum1.* conj(spectrum1);

Cbin1=min(find(freqbase1 > 16));
Cbin2=min(find(freqbase1 > 16000)-1);
spectrum1=spectrum1(Cbin1:Cbin2);
freqbase1=freqbase1(Cbin1:Cbin2);

subplot(3,1,1);
plot(freqbase1, 10*log10(spectrum1+1e-15)); xlabel('f/Hz'); ylabel('p/dB');
title 'Critical Low1'

peakbin1=find(spectrum1==max(spectrum1));

Critical_fPeak=freqbase1(peakbin1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Switch, fs2, bits2]=wavread('MidLevel-15G3.wav');
[n2, nChan2]=size(Switch);
if nChan2 > 1
    error('this example requires a mono audio file');
end

freqbase2=fs2*(mod(((0:n2-1)+floor(n2/2)), n2)-floor(n2/2))/n2;

spectrum2=fft(Switch.* hamming(n2));

spectrum2=spectrum2.* conj(spectrum2);

Sbin1=min(find(freqbase2 > 16));
Sbin2=min(find(freqbase2 > 16000)-1);
spectrum2=spectrum2(Sbin1:Sbin2);
freqbase2=freqbase2(Sbin1:Sbin2);

subplot(3,1,2);
plot(freqbase2, 10*log10(spectrum2+1e-15)); xlabel('f/Hz'); ylabel('p/dB');
title 'Switch Low1'
```

```

peakbin2=find(spectrum2==max(spectrum2));

Switch_fPeak=freqbase2(peakbin2)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Full, fs3, bits3]=wavread('MidLevel1.wav');
[n3, nChan3]=size(Full);
if nChan3 > 1
    error('this example requires a mono audio file');
end

freqbase3=fs3*(mod(((0:n3-1)+floor(n3/2)), n3)-floor(n3/2))/n3;

spectrum3=fft(Full.* hamming(n3));

spectrum3=spectrum3.* conj(spectrum3);

Fbin1=min(find(freqbase3 > 16));
Fbin2=min(find(freqbase3 > 16000)-1);
spectrum3=spectrum3(Fbin1:Fbin2);
freqbase3=freqbase3(Fbin1:Fbin2);

subplot(3,1,3);
plot(freqbase3, 10*log10(spectrum3+1e-15)); xlabel('f/Hz'); ylabel('p/dB');
title 'Full Low1'

peakbin3=find(spectrum3==max(spectrum3));

Full_fPeak=freqbase3(peakbin3)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Level, fs, bits]=wavread('Stop');
[n, nChan]=size(Level);
if nChan > 1
    error('this example requires a mono audio file');
end

freqbase=fs*(mod(((0:n-1)+floor(n/2)), n)-floor(n/2))/n;

spectrum=fft(Level.* hamming(n));

spectrum=spectrum.* conj(spectrum);

bin1=min(find(freqbase > 16));
bin2=min(find(freqbase > 16000)-1);
spectrum=spectrum(bin1:bin2);
freqbase=freqbase(bin1:bin2);

peakbin=find(spectrum==max(spectrum));

Level_fPeak=freqbase(peakbin)

if (Level_fPeak >= Critical_fPeak)

```

```

display 'STOP PUMP!!!';
elseif (Level_fPeak < Critical_fPeak && Level_fPeak > Full_fPeak)
    display 'Tank is Getting Low';
elseif (Level_fPeak <= Full_fPeak)
    display 'Tank is Full';
end

```

