

Dual Liquid Electrical Sensing System for Railroad Lubricant Tank

Norfolk Southern Corporation

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ECE480 Design Team 8

Proposal

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Abstract

The Wayside Top of Rail (TOR) system distributes lubricant material from its 100 gallon storage tank via a mechanical pump. The internal pump is self-lubricated with the same lubricant material and fails when the level falls below the pump connection, requiring maintenance or replacement. A high variance of use makes regularly scheduled tank refilling problematic. Norfolk Southern Corporation has requested a solution that can be retrofitted to current systems. ECE 480 Design Team 8 proposes a robust dual local sensor design to monitor the lubricant material level with fail-safe implementation to shut down the pump and signaling when the level becomes low. The level of liquid will be monitored from data received through an ultrasound transducer and cavity resonance in the audible range. The dual ultrasound-audio sensing system will provide the tank status locally with the option to expand the accessibility through remote communication.

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Introduction

Norfolk Southern Corporation has implemented 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. An external solar panel is positioned in the area to charge the battery for a minimum of four hours per day. The pump currently runs for a quarter of a second for every 12 axles, resulting in 0.13 gallons per 1000 axles. The locations where these systems are installed have an average of 8000 axles per day but a high standard deviation makes a standard refilling schedule hard to implement. The lubricant inside the tank must not sink below the pump connection because air inside the pump will cause failure and the pump will need to be replaced.

The Dual Liquid Electrical Sensing System proposed by ECE 480 Design Team 8 will monitor the level of lubricant and shut off the pump when it sinks below the tolerance level. The new system must not modify the tank but should be placed in the electronics cabinet, which currently houses the battery and pump. The lubricant has the consistency of latex paint and will solidify if exposed to air for a period of time. The status of the amount of lubricant will therefore be displayed inside the electronics cabinet so the contents will not be exposed. The addition of an external wireless communication system is an extra feature that would give convenience of remote monitoring of multiple systems from railway inspection.

Background

Background research by ECE480 Design Team 8 revealed that the problem of determining liquid levels in a sealed tank is a significant issue for many companies. These companies would therefore want information on any working prototype developed by ECE480 Design Team 8 that would accomplish this task. As there are other organizations trying to accomplish the same goal, ECE480 Design Team 8 reviewed current state-of-the-art solutions. Liquid levels in a sealed tank are most frequently analyzed using ultrasound techniques. Issues that have occurred in documented incidents involving ultrasound use are as followed:

- The ultrasound having too high reflection off of the metal, causing the liquid reflection to be difficult to extract
- Incorrect data that displays the amount of air instead of liquid in the system from the unknown liquid having similar ultrasonic properties to air
- The walls of the dense metal container greatly reducing the ability for ultrasound to penetrate to and bounce back from the liquid
- The ultrasound generating too much heat from friction between the waves and molecules
- The transducer being too delicate from weather or heavy use conditions, making the remote location maintenance costly

ECE480 Design Team 8 proposes a novel dual-sensor strategy to overcome the limits of ultrasound when used alone. It is proposed to also utilize the natural cavity resonances of the partially-filled container tank through interrogation of the tank by a mechanical arm coupled with an audio resonance frequency pick-up sensor. After looking at the design and implementation issues and discussing them, it has been decided upon that the audio resonance frequency sensing of the natural resonances of a partially filled

cavity is a feasible approach. The resonances of a partially filled cavity are well known. Modern acoustic sensors have achieved substantial refinement of signal-to-noise, mainly through their development for use in health-related fields. The proposed unique integration of the two sensing techniques is expected to create a combined system with greatly increased robustness to failure. Therefore, an audio resonance frequency pick-up system will be integrated with the ultrasound system to achieve correct liquid lubricant level readings.

Objectives and Design Specification

The customer, Norfolk Southern Corporation, has presented an objective along with design constraints in order to produce an effective product. The objective of this design is to design and integrate a device, which will measure the lubricant level inside a sealed wayside TOR (Top of Rail) 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. Within the lubricant lie mechanical components that are susceptible to air and can rust. As an added feature, the customer will also desire intermittent levels of the lubricant, which will be transmitted by some form of communication. This design will include the following features:

- Status indicator of lubricant level
- Communication to user of intermittent lubricant levels
- Ultrasonic transducer
- Audio pick-up device
- Embedded system, which turns off system when lubricant level is at a minimum
- Solar panel (already in place)
- Battery (already in place)

FAST Diagram

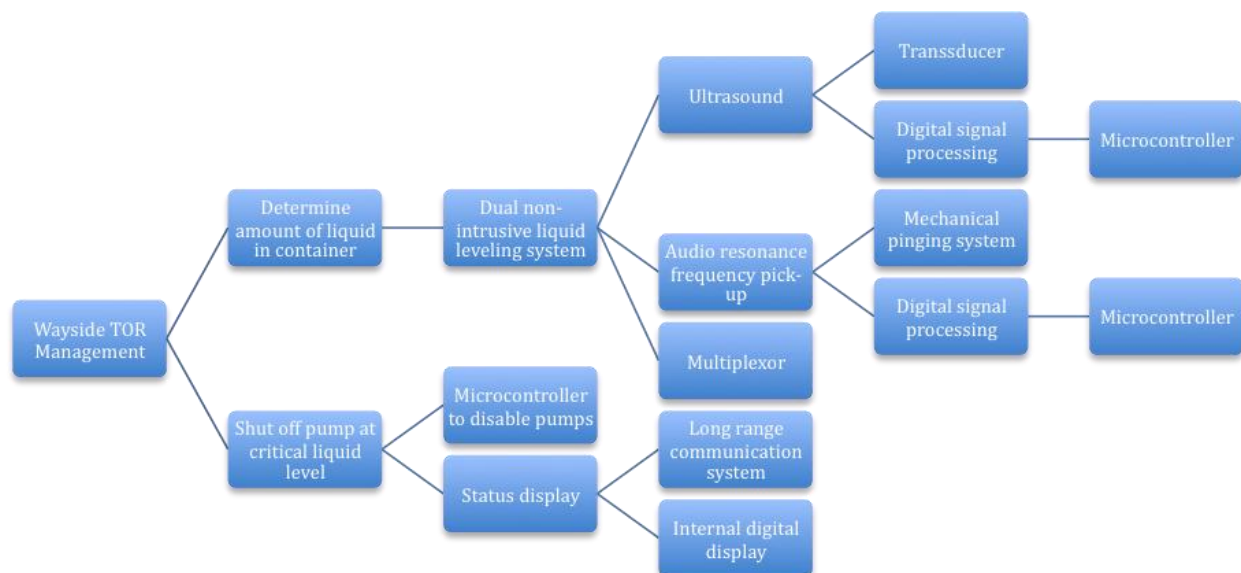


Figure 1: FAST Diagram for Dual Liquid Electrical Sensing System

Conceptual Design Descriptions

Ultrasound

The location of the transducer:

Based on the data to be analyzed, the transducer can be placed in one of three locations. The three location that best suit the data at hand are as followed:

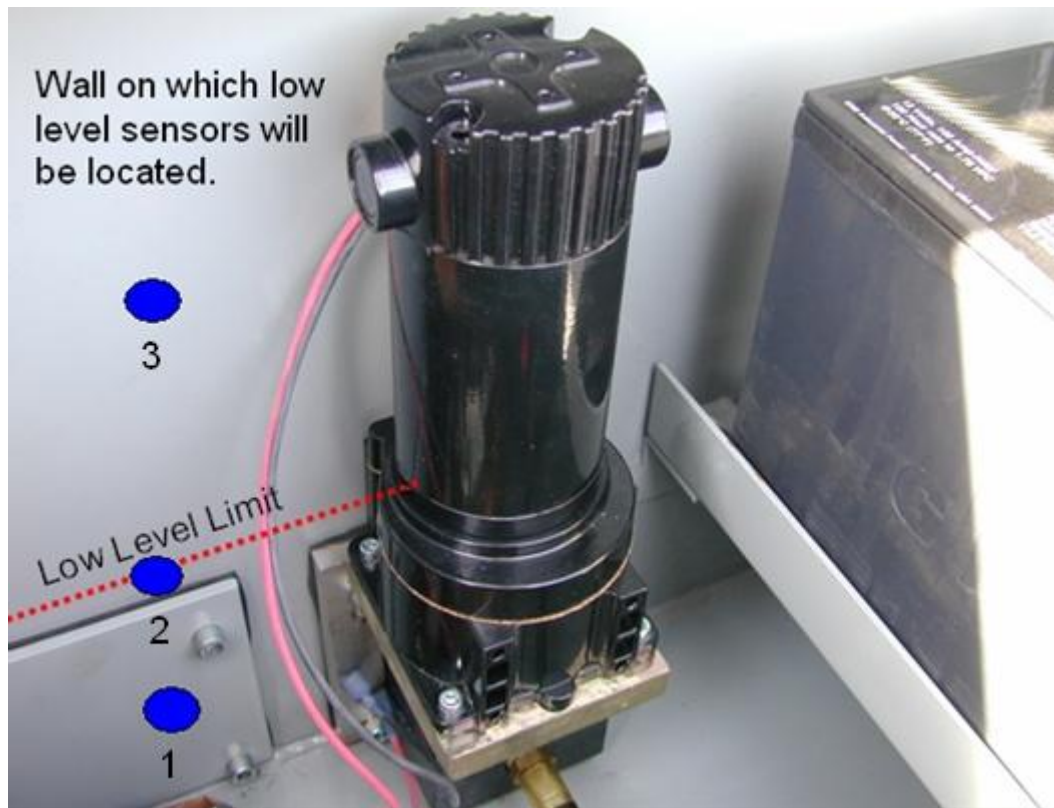


Figure II: Ultrasound Transducer Locations inside Electronics Cabinet

1. Below the minimum level line: The purpose of placing it at this location is so the ultrasound will always be transmitting into the liquid. 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 always be transmitting in to the air. This will allow the system to determine the amount of air in the tank.

Attachment of the transducer:

One issue with ultrasound is that the transducer needs to have no air between the steel wall of the tank and itself [1]. Any amount of air can cause issues in the system and data received. This turns out to be a huge issue because if the installation is not simple enough, it could ruin the whole setup.

Reading and Calculating the Data:

Once the transducer is in place, a microcontroller will be programmed to interpret the data sent to it. The microcontroller we are going to be using to do the processing of this system is the Programmable Interface Controller (PIC). One of the main reasons we will be using the PIC microcontroller is the relative availability of this controller and the previous knowledge that we acquired to program this PIC.

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

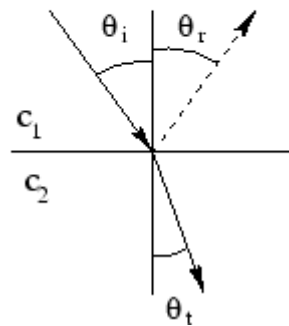


Figure III: The geometry of reflection and refraction at a boundary between media with different sound speeds [2]

Audio Resonance Frequency

The audio resonance frequency pick-up system will be used to analyze the resonance in the tank. Given that the tank is rectangular, rectangular cavity modes can be used to calibrate the system to ensure higher accuracy of the calculations. In order for this to be obtained, the propagation of the sound waves will need to be captured. To do this, a mechanical device will be installed on the outside of the tank, which will “ping” the side of the tank. The mechanical component that will be attached to the side of the tank will be configured to a timer, which will activate it at specified time intervals. The audio pick up device will be able to capture the resonant frequency due the free space in the tank.

These sound waves will then be analyzed and by methods of propagations of sound waves, the level of the liquid will be determined. Given that the external noise will be coherent and the audio resonance frequency pick-up will be a sensitive device, filters will need to be in place to ensure accuracy and quality of the signals captured for analysis. Figure I shows the equation to an enclosed rectangular cavity to uncover the presence of resonance frequencies with dimensions a , b , c such that $a < b < c$.

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

ϵ = permittivity

μ = permeability

λ = freespace wavelength

$$\mu_0 = 4\pi \times 10^{-7}$$

$$\mu_{r,water} = 1.257 \times 10^{-6}$$

$$\mu_{r,steel} = 875 \times 10^{-6}$$

$$\mu = \mu_r \cdot \mu_0$$

Figure IV: Resonance Frequency Equation [3]

Ranking of Conceptual Designs

In order to focus on the proper direction, a feasibility matrix is used with weighted design criteria, seen below, for guidance. After careful consideration and researched solutions, the outcome shows that ultrasound is of the most important aspect of the design. The ultrasound design concept will be the first focus. The audio sensor and the integration of the two sensors are only slightly less important. These will follow as the second and third foci of the ECE 480 Design Team 8 project effort.

Design Criteria	Importance	Ultrasound	Audio Pick up	Communication
Cost	3	4	3	1
Power	4	4	2	3
Accuracy	5	5	5	2
Size	2	2	2	3
Durability	2	3	3	4
Interference	3	5	5	5
	Totals	23	20	18

Figure V: Feasibility Matrix

Proposed Design Solution

The capability to recognize the level of the tank at its minimum level and turning off the pumps when the minimum level is reached is the most important task of the project. Through the integration of two sensing systems, robust accurate readings of the level of the tank should be achievable.

The audio resonance frequency pick-up system will consist of a motor connected to a mechanical arm, which will interrogate the tank. The motor will be controlled by a microcontroller. The microcontroller will also process the frequency received from inside the tank by means of a precision microphone.

The ultrasound system will consist of a transducer attached to the side of the tank. The ultrasound will be operated by the microcontroller which will process the signal from the ultrasound as well.

The microcontroller incorporates an analog to digital convertor which will convert the signal and then send the digital signals off to the Digital Signal Processor (DSP). The DSP in conjunction with the controller will cross-reference the signals to determine the level of the tank.

The microcontroller will control all aspects of the system and will process the input from the DSP and determine if the tank needs to be turned off. The microcontroller will control all necessary signals and activation of all processing systems.

This system will be built from the ground up, starting with the sensors. The sensors will be tested on the tank with different liquid levels to gather the necessary data and determine strengths and weaknesses of both sensors. The circuitry for control will need to be built in conjunction and be tested through random input signals. The signal processing circuitry will be completed after the tank level is calibrated. This will be tested by imputing data and recording resulting outputs.

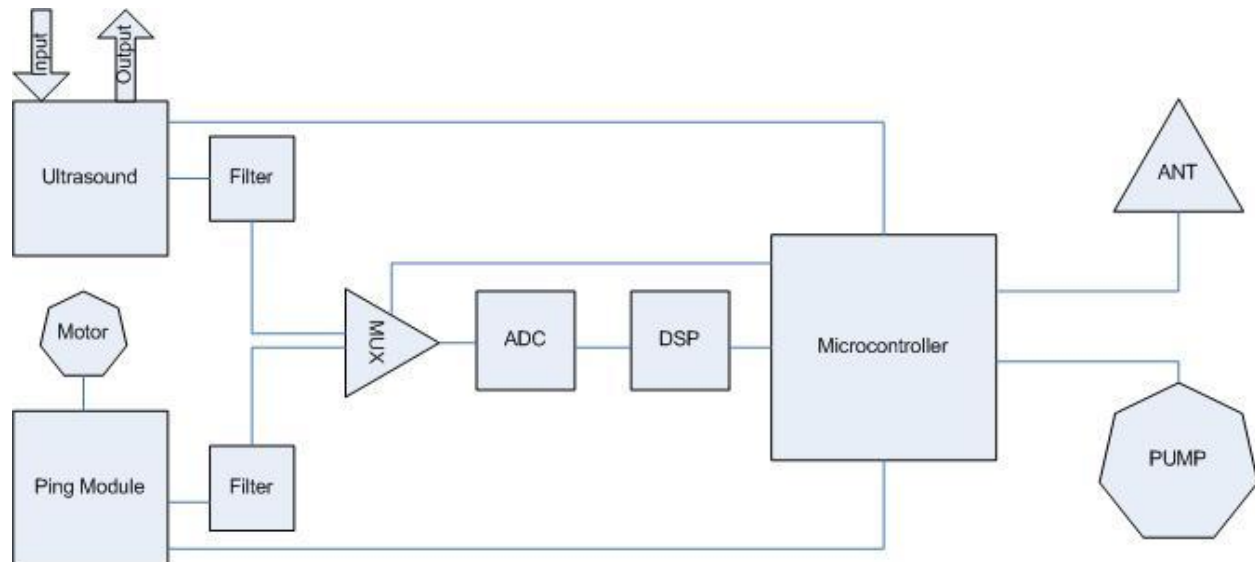


Figure VI: Dual Liquid Electrical Sensing System Block Diagram

Risk Analysis

Successful integration with the components along with the existing electronics within the electronics cabinet is the primary concern. With any design, one must keep in mind the compatibility and ensure that all devices can harmoniously work together as an integrated system.

Another concern is the accuracy with the audio device and the ultrasound transducer. Developing noise filters to block out external noises will ensure the quality of readings. With the ultrasound transducer, there will be significant reflection of signals due to the fact the lubricant is stored in a steel tank.

Finally, safety is always a concern. There will be a car battery that is charged by a solar panel, which only around 80mA will be able to be drawn. This can be a dangerous amount. With this being said, there will be proper precautions taken to prevent accidental discharges.

Project Management Plan

Each member is in charge of a Non-Technical Role, as well as a Technical Role. The following roles put each person in control of certain aspects of the design, but in no way makes them solely responsible for it. They are responsible for the efforts of that aspect of the design. They must oversee that it is completed correctly and on time in an efficient manner through the efforts of themselves and the rest of the team.

Craig Zofchak

Non-Technical Role: Project Manager

The Project Manager is responsible for keeping track of the team budget, and making sure the project is on schedule by maintaining the team's Gantt chart. He is also responsible for keeping good communication between the team, the facilitator and the team sponsor. Finally, he will schedule meetings and ensure they are organized and productive.

Technical Role: System Controls

Mr. Zofchak will be responsible for the design of the overall system control circuitry. This circuitry will command and allow operation of every sensor, pump, and sub circuit. He will also be in charge of designing and implementing the mechanical pinging device. Furthermore, he will be assisting in the designing of the circuitry for the external reporting along with the testing these components and ensuring all subsequent components integrate properly.

Michael Dow

Non-Technical Role: Webmaster

The Webmaster is responsible for maintaining the team web site. He is in charge of uploading necessary documents and photos, as well as keeping the calendar up to date. He also assumes the responsibility for keeping the UNIX directory maintained.

Technical Role: Ultrasound Sensor System

Mr. Dow will be responsible for the ultrasound experimental setup, signal analysis, and power consumption design. He will ensure that the signal is measurable and filtered properly to omit any unwanted interference along with power management of the entire system. He also assumes the responsibility of designing a circuit to control the power input and output of the circuit as well as the power save mode. Finally, he will be responsible for testing these components and ensuring their proper operation.

George Ballios

Non-Technical Role: Presentation Preparation and Laboratory Coordinator

The Presentation Preparation Coordinator is responsible for ensuring all presentations are put together professionally. He is in charge of coordinating the preparation of all team members in their presentations and reports. He also will be in charge of coordinating the presentation of the final design poster. The Laboratory Coordinator is responsible for maintaining the cleanliness and functionality of the lab workstation, as well as ordering all parts for the team.

Technical Role: Audio Resonance Sensor System

Mr. Ballios will be responsible for the construction and implementation of the audio resonance system. In addition, he is assuming the role for designing the hardware for the audio resonance system. He will also be responsible for filtering out any excessive noise and finding the desired signal, along with designing the antenna for external communications. Finally, he will test all of these components and ensure their proper functionality.

Nicholas Vogtmann

Non-Technical Role: Document Preparer

The Document Preparer is responsible for all written reports and ensuring that they are professional. He is responsible for delegating writing assignments and putting subsequent documents together in a proficient manner. Finally, he is in charge of maintaining the documentation portfolio.

Technical Role: Dual Sensing System Integration

Mr. Vogtmann will be responsible for integration and programming of all systems to ensure that the ultrasound, audio resonance frequency pick-up system, and communication devices work together. He will assist on the processing and filtering of the audio resonance frequency pick-up system and ultrasound signals. In addition, he will be designing a circuit that will correlate both signals and then communicate with the control circuit. This role will also require designing the software for communicating the device status to external sources. Finally, he will be responsible for testing of all components and ensuring their proper operation.

Proposed Schedule

Week	Important Tasks
Week 4	Pre-proposal due, Conference call with sponsor
Week 5	Receive tank, Begin testing ideas on tank, Prepare and practice presentation
Week 6	Rework design based on testing outcomes, Give oral presentation, Final proposal due
Week 7	Order parts, Begin building prototypes, Design day program pages due
Week 8	Final build of prototypes after parts received
Week 9	Testing prototypes, Progress report 1 due, Demo 1 due, Project notebooks due
Week 10	Rework design based on testing of prototype
Week 11	Test reworked design, Individual application notes due
Week 12	Build final design, Progress report 2 due, Demo 2 due
Week 13	Build final design, Design issues paper due
Week 14	Test final design, Poster design
Week 15	Buffer week, Team evaluation forms due, Final reports due, Final website revisions, Notebooks due, Final oral presentation, Design day

Figure VII: Proposed Schedule

Budget

Item	Cost
Ultrasound Transducer	\$250.00
PCB	\$100.00
Windshield Wiper Motor	\$50.00
Precision Microphone	\$50.00
Mallet/Hammer	\$15.00
Wiring	\$10.00
Components	\$25.00
Total	\$500.00

Figure VIII: Proposed Budget

References

- [1] University of Virginia Physics Department, "Fetal Ultrasound." [Online Document] [2008 Oct 3], Available at HTTP: <http://galileo.phys.virginia.edu/outreach/8thGradeSOL/UltrasoundFrm.htm>
- [2] 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>
- [3] Dixon, Paul, "Cavity-Resonance Dampening." [Online Document] June 2005 [2008 Oct 3], Available at HTTP: <http://www.eccosorb.com/file/586/appnote-proof.pdf>

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