2015

Smart Fuel Tank Sensor

EE491 SENIOR DESIGN – PROJECT PLAN – GROUP 1627

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Introduction

Nowadays, most of cars are still consuming gas, which off course need fuel tanks on them. In order to know how much fuel left in the tank, we put a fuel gauge, like a sensor somehow inside of the tank. However, these causing some problems. For example, the sensor need electric to power it so it may cause sparks and make explosions. Also, it's very difficult to fix the sensor because it's inside of the tank.

Due to the above situations and problems, we made a great thought to design a new sensor or a new way to measure the fuel level inside of the tank.

Project requirement

For this project, finally, we want to actually implement how to measure the fuel level outside the tank. The error need to within 5% and the budget is under 10 dollars, which means we are designing a commercial product. First all of our designs are basing on water.

Proposed Solutions

There are a lot of ways to determine the fuel level in the world, but basically can be divided into two category:

Electrical: Hydrostatic, ultrasonic, capacitance, radar and load cell

Mechanical: magnetic level gauges

Considering our requirements, we have researched following methods and have some basic conclusions:

Methods	Advantages	Disadvantages	Conclusion
Hydrostatic: Usually just mount the sensor at the tank side bottom	Cheap, accurate, easy to install	Causing leak and the sensor is inside the tank	Not satisfy our project requirement, so we may have to give up this method
Ultrasonic: Put at the top of the tank	Outside of the tank, accurate, easy to install	Too expensive and cost too much for maintenance	Still keep looking this method

Capacitance: Put two plates outside of the tank and connect to source voltage to make it work as a capacitor	Outside of the tank, accurate, easy to install, cheap	No major disadvantages until now but also depends on our further researches	One method that we are considering that might be our final design technology
Radar: Put the radar at the top of the tank	Outside of the tank and accurate	Expensive and cost too much for maintenance	Not satisfy our requirement so we may give up this method
Load cell:	Outside of the tank and accurate	No major disadvantages but how to mount the load cell may vary from different shape of tanks	One method that we are going to actually prototype
Magnetic: Put a magnetic float inside of the tank, and track the float somehow outside of the tank	Outside of the tank and accurate	Hard to track the magnetic float and take too much space	Not satisfy our requirement so we may have to give up this method

Table 1: Proposed solutions

Therefore, we conclude to two major methods to achieve this problem:

Method 1: Thumping the tank

Description: The sound go through liquid and air is different, so we are thinking that have a little mechanic thumb to hit the tank regularly and have a receiving equipment to receive the sound or vibrate frequency. Then send the data to computer and calculate. Find out the relationship between the receiving sound or frequency and the water level. Finally get the gas level inside.

Method 2: Capacitance

Description: The level of liquid in a tank can be found by measuring the capacitance of the tank. There are number of ways that capacitance can be measured, however, one of the most promising ways we have found has been implemented by Texas Instruments. The FDC2x1x chip finds capacitance indirectly by measuring changes in resonant frequency. Using an LC resonator the chip measures the oscillation frequency which is output as a proportional digital value. This value can then be displayed as the liquid level given a few baseline measurements.

Method 3: Load cell

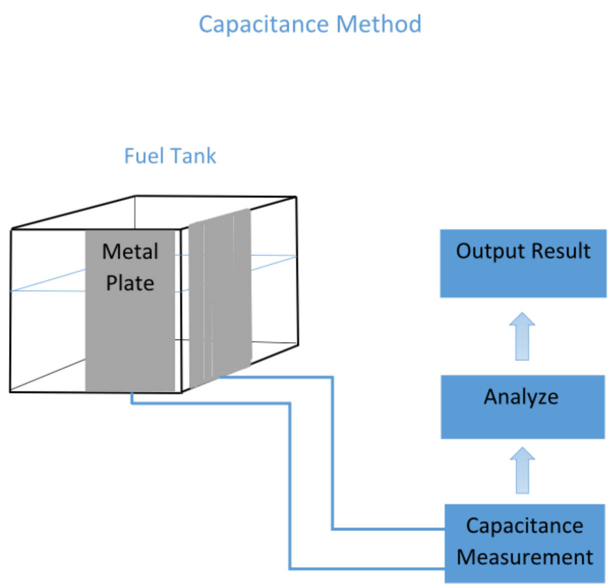
Description: Load cell sensors are very popular in measuring tank weight. By reading the measured weight, we can know the difference of liquid in the tank because the weight of the tank is proportional to the liquid level inside of the tank. This method also matches our requirement to put all sensors outside of the tank. The advantage why we chose this method a load cells are inexpensive, easy to implement but also very stable and accurate.

Design Specifications

Capacitance Method:

The capacitance method is relatively simple to prototype. We can put two plates on either side of a tank and knowing the dimensions of the tank as well as the dielectric constant of the tank, gasoline, and air/fumes we can accurately get the liquid level inside of the tank.

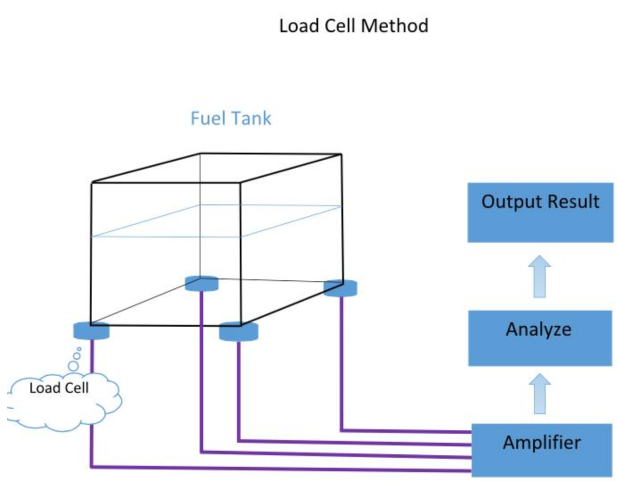
One way to accomplish this would be by connecting our capacitors to a microcontroller and performing a capacitance to digital conversion. We can then calculate the liquid level based on the capacitance value and perhaps output the value to an LCD screen. This would be a relatively simple way to create a working prototype / proof of concept that would be very similar to what we be implemented in reality and very accurate.



Load Cell Method:

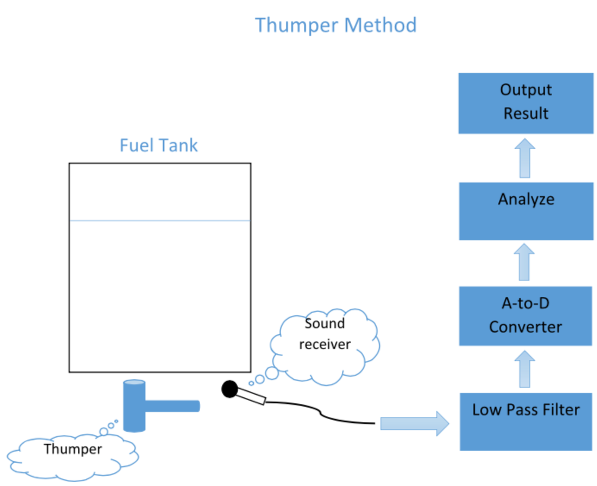
The load cell method should be the easiest way to prototype. Basically, just install three or four load cells under the triangle structure or rectangle structure. Then connect all load cells to the microcontroller. Some microcontroller has the LCD screen. We first need to do experiment to find out the relationship between the output voltage signal and the height of liquid level. Then we can code the microcontroller to directly show the liquid level.

After a very large number of experiments, we believe the relationship should be consistent so the measurement should be accurate and reliable.



Thumper Method:

When prototyping the thumper method, we also need several components: a microphone, a low pass filter, an analog-to-digital (A-to-D) converter, and a computer. Firstly, we need a hammer, which is for knocking on the surface of the tank and generating the frequency of vibration. Then we will use a microphone to record the signal. After that, we process the signal by a low pass filter, and convert the signal to digital format by using A-to-D converter. Then we can use Matlab to get the spectrum using fast Fourier Transform. Lastly, we can determine the relationship between the dominant frequency and the fuel level inside the tank. That is how we measure fuel level by analyzing the spectrum.



<u>Test Plan</u>

Capacitance test plan:

For the purpose of modeling our capacitance method we'll assume we're trying to find the liquid level of the one-gallon gas tank as seen in Figure 1.

Figure 1: One gallon gas tank 11.5"x6.5"x4.5"

Case 1:

This is the most trivial case. Assume that we have two parallel plates with heights of 4.5 inches and widths of 10 inches each (area of .0058 meters squared) and these plates are separated by 6.5 inches (the width of the tank).

We will also assume that there is only water between these plates, which has a dielectric constant of $70C^2N^{-1}m^{-2}$. Finally, we will be neglecting fringe capacitance in this case.

Using the following equation then we can find the capacitance between the two plates

$$C = \frac{k\varepsilon_0 A}{d}$$

In this case then the capacitance is the following

$$C = \frac{70N^{-1}m^{-2} * 8.854x10^{-12} * (.029m^2)}{.165m} = .109pF$$

Case 2:

This case is the same as Case 1 except we will assume that the space between the plates is empty. So the only thing that we will change for this example is the dielectric constant which will now be that of air ($1N^{-1}m^{-2}$).

$$C = \frac{1N^{-1}m^{-2} * 8.854x10^{-12} * (.029m^2)}{.165m} = .0015pF$$

Case 3:

This is a case closer to our real life example. We now have a combination of both gasoline and air in tank (with the height of the gasoline of θ making the height of the air 1- θ).

$$C = \frac{k_{gasoline}\varepsilon_0 w(\theta)}{d} + \frac{k_{air}\varepsilon_0 w(1 - \theta)}{d}$$

We can solve this equation then to find the height of gasoline, θ:

$$\theta = \frac{\frac{Cd}{\varepsilon_0} - k_{air}}{k_{gasoline} - k_{air}}$$

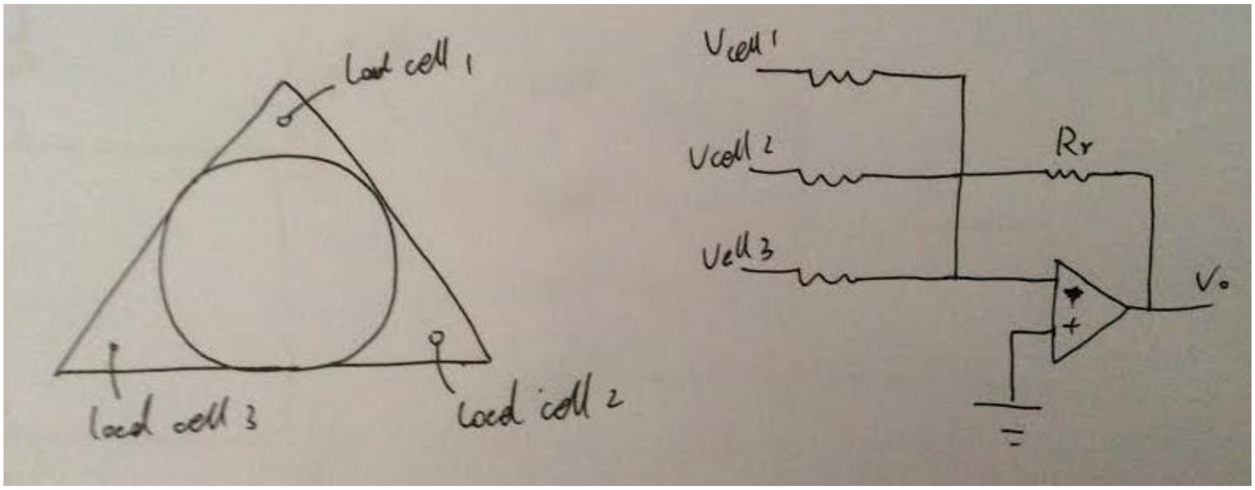
Knowing the height of the gasoline and the height of the tank it is trivial to find how full the tank is as a percentage. The above examples are a simplification as we are not accounting for fringe capacitances or the capacitance of the polyethylene gas tank, but it shows how this method can be applied to determine liquid level with high accuracy.

Load cell test plan

To model this method, it's pretty dependent on the geometry of the tank. Right now, we just considering experimental purpose, so the commonly used tanks are cylinder or rectangular.

Case 1: Cylinder tank:

Because the bottom of the cylinder is round, it is hard to find the stable points on a complete round. Therefore, we need a triangle structure at the bottom of the cylinder, and put one load cell at each angle of the triangle structure, which means totally three load cells. The ideal design is just below:



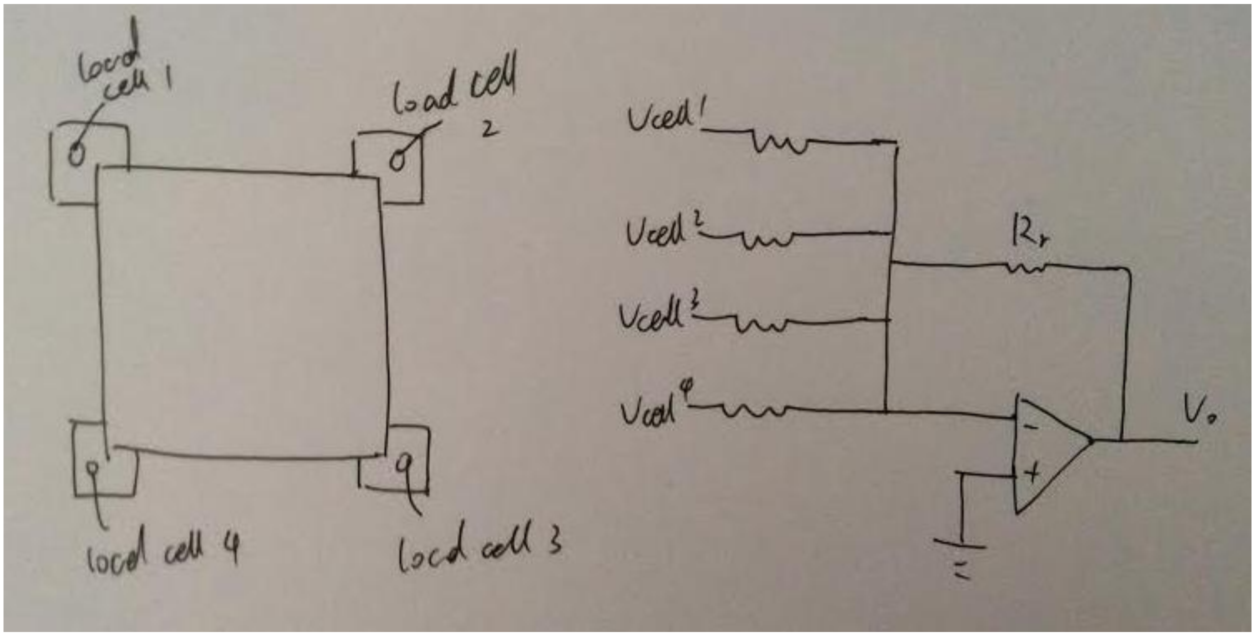
On the right side of the design figure is the circuit model for three load cells. Vout is the total output voltage from load cells and that's all signals we have from measurement. The rest part need to be done by the microcontroller of computer.

$$V_{out} = R_r \times (I_{cell1} + I_{cell2} + I_{cell3})$$

After we can detect the output voltage, we can do some experiments to find out the relationship between voltage and the liquid level.

Case 2: Rectangular tank

Due to the rectangular shape, we just make the four corners as the support points because they are stable and easy to find. Totally use four load cells. The ideal design is as below:



It’s pretty much the same as the three load cells design, but just add one more load cell. The equation:

$$V_{out} = R_r \times (I_{cell1} + I_{cell2} + I_{cell3} + I_{cell4})$$

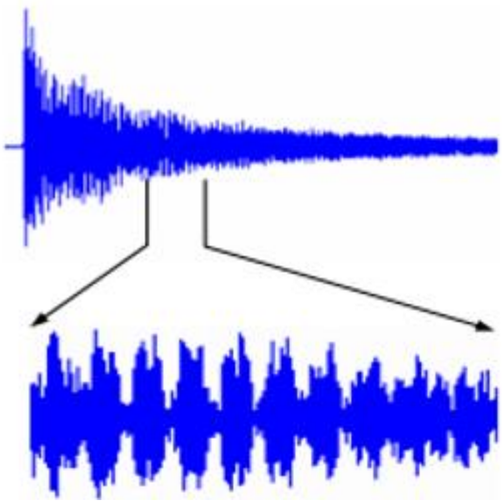
After we can detect the output voltage, we can do some experiments to find out the relationship between voltage and the liquid level.

Thumper test plan:

In this method, we will plot the digitized signal with the help of a microphone, a low pass filter, an analog-to-digital (A-to-D) converter. We then will do numerous experiments before finding the relationship between (the frequency where the largest magnitude occurs in the spectrum) and the fuel

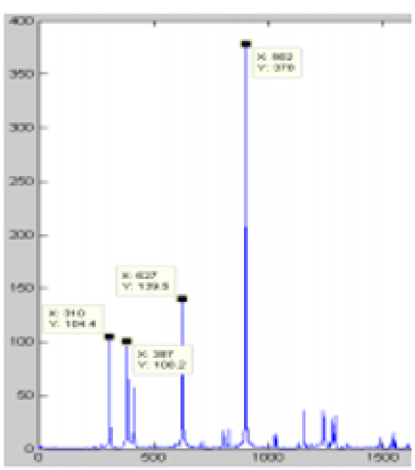
level inside the tank. Every time the fuel level changes, we will create a corresponding spectrum and find the dominant frequency in the spectrum.

One example of the digitalized signal plotted by Matlab is shown below:



Case 1:

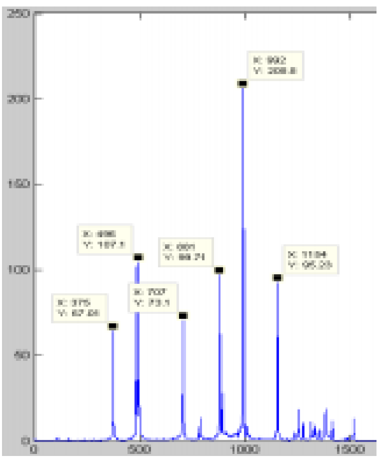
When the gasoline is almost full inside the tank, we can get the spectrum:



According to the spectrum, we can determine the dominant frequency is about 900 Hz.

Case 2:

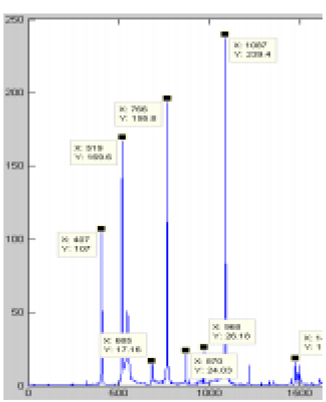
When the gasoline is half-full inside the tank, we can get the spectrum:



Based on the spectrum, we can determine the dominant frequency is about 1000 Hz.

Case 3:

When the gasoline is almost empty inside tank, we can get the spectrum:



Based on the spectrum, we can determine the dominant frequency is about 1100 Hz.

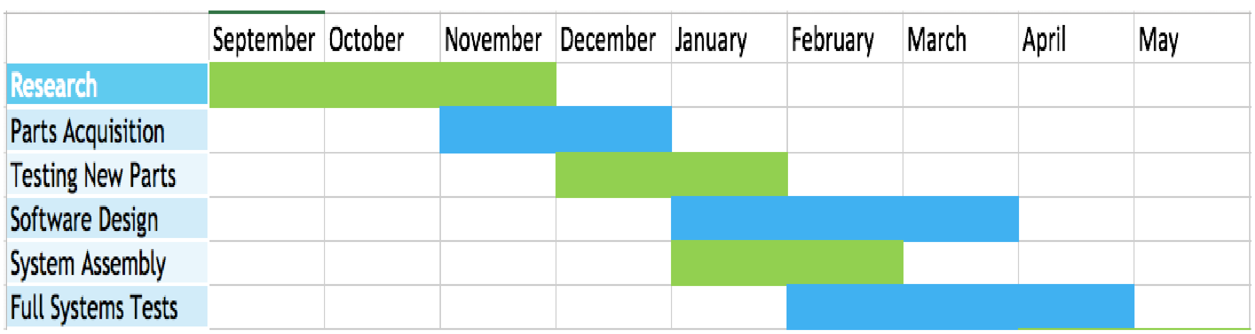
We have found an initiatory relationship between the level and dominant frequency. That is the more gasoline remaining in the tank, the lower dominant frequency will be. We still need more experiments in order to make our sensor more accurate in the future.

Risks/Feasibility

There are numerous ways to do liquid level detection that have been implemented and are used every day in industry and that is essentially what we are trying to do with a few constraints. Because gasoline and fumes can be highly combustible our main goal with the project is to move electrical components outside of the gas tank. Although the likelihood that existing methods would actually cause a fire is low, it still exists and there is a need to eliminate this risk.

As is clear from table 1 there are a number of viable option that can meet the goals for this project. Through further research, prototyping, and proof of concept projects we will need to narrow down our viable options and elect for one method that fits with the inherent cost constraints.

Project Schedule



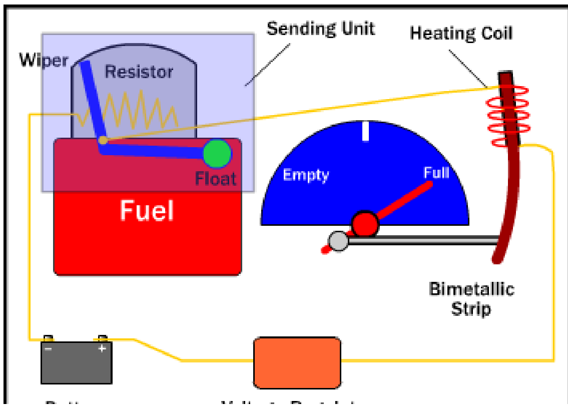
Cost Considerations

Cost Estimate: $500.00

The majority of the costs for this project will go toward prototyping. Because this project based on research more so than other projects there is a greater need to prototype. While we will be doing a great deal of research as well and modeling, prototyping is a necessity for all viable options. This will mean we will need to purchase various sensors, one or more micro controllers, an LCD screen, and other electrical components.

Market/Literature Survey

Illustration



There are a number of solutions for liquid level detection. There is, however, only one method that is used gas tanks and the is the “float” method. This method relies on a float that falls as the level of gasoline in the tank decreases. When the float falls then the wiper on the variable resistor moves and the current sent decreases.

There are two problems with this method:

1. This method is very inaccurate. For example, after a tank is filled the gauge will stay on full for a very long time. This happens because there is a very small difference in the current sent from the sending unit when the tank is completely full versus when the tank is 90% full.

2. There is a safety issue with this method because it is introducing electrical components inside a hostile environment. The possibility of fire or explosion exists, when there are better methods exist.

There are a number of methods that exist for liquid level detection that can be, but have not been applied to gasoline tanks (see Proposed Solutions). Research will continue to be conducted on capacitance sensors, thumping, weigh scales, radar, sonar, hydrostatic and other methods.

Conclusion

The goal of this product will be to create an inexpensive (under $10) and accurate (within 10%, likely much better) fuel tank sensor that measures the fuel level from outside of the tank. There exists a large market for a safer, more accurate fuel tank sensor. Target markets not only include the automotive industry but also on lawn mowers, industrial machinery, and essentially anything that uses a gas tank. Along with there being a need for a better method there exist many possible solutions for a safer, more accurate fuel tank sensor. Given the need and the market for this product we will move forward with testing and prototyping.

Works Cited

How Fuel Gauges Work. Digital image. *How Fuel Gauges Work*. N.p., 2001. Web. 1 Oct. 2015.