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# Using Ultrasonic Sensor for Fuel Measurement in Diesel Locomotives

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**Abstract:** This paper explores how ultrasonic sensors can be used to measure fuel volume in diesel locomotives. We will look at a real-world example in which we will see how the sensor can be installed. We will also see how it is calibrated to give accurate results.

**Keywords:** Ultrasonic Sensors, Diesel Locomotives, IoT, Cloud, Microcontroller

## I. INTRODUCTION

Many vehicles these days use very sophisticated fuel measurement systems. These systems provide an accurate reading of the instantaneous fuel capacity [1]. This makes it easy to calculate fuel consumption and thus narrowing down problems encountered, if any.

However, this is not the case with heavier vehicles such as trucks, diesel locomotives, marine vessels etc. These vehicles use older methods and traditional techniques. It is also worth noting that these vehicles carry a considerably large volume of fuel at any given time. Combine the aforementioned factors and we have a grave problem that requires immediate attention. Due to the inefficiencies many problems arise such as fuel theft, unexpected shortage and increased costs. We are going to be focussing on how these problems can be mitigated using ultrasonic sensors.

## II. ULTRASONIC SENSORS FOR FUEL MEASUREMENT

The ultrasonic sensors are suited for fuel measurement for the following reasons [2]:

### A. *Relatively Inexpensive*

Ultrasonic sensors are sufficiently accurate for fuel measurement at a relatively cheaper price as compared to capacitive sensors of similar specifications. Even float-type sensors are expensive.

### B. *Hassle-free Installation*

Ultrasonic sensors are easy to install. Generally, any opening above the tank, such as the vent pipe can accommodate these sensors. This means that the tank need not be modified, by drilling holes, just for a sensor installation. Modification has to be made in order to install capacitive or float-type sensors.

### C. *Contactless*

Ultrasonic sensors, unlike their capacitive or float-type counterparts, need not be in contact with the fuel being measured. This means they work efficiently even in corrosive environments.

## III. INSTALLATION ON DIESEL LOCOMOTIVES

As mentioned earlier, ultrasonic sensor installation is easier than others. We will demonstrate this by explaining how it can be installed on a locomotive tank.

All diesel locomotive tanks, especially in India, have a maximum fuel carrying capacity of 5000 litres [3]. In order to accommodate the vapours, a special opening is given at one of the edges. A vent pipe is attached to this opening. This vent pipe is fully detachable for maintenance. The idea is to install a small ultrasonic sensor, such as the HC-SR04[4], in between the vent pipe and the fuel tank opening.

The HC-SR04 is small enough to not obstruct the opening and allows the vapours to pass. The microcontroller, which is used to control this sensor, is installed separately in the grill provided near the fuel tank. In this way both these components are installed and concealed.

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## IV. CALIBRATION OF THE SENSOR

An ultrasonic sensor works by measuring the distance between itself and a plane surface or an obstacle. In our case, the plane surface is the top surface of the diesel in the tank. The HC-SR04 ultrasonic sensor is composed of a transmitter, marked T and a receiver, marked R. Whenever distance is to be measured, the microcontroller sends a trigger signal, which in turn makes the transmitter emit an ultrasonic pulse. This pulse hits the surface in question, reflects and returns back. The receiver on the sensor picks up this pulse and reports it to the microcontroller. The microcontroller keeps track of the time it takes for the above process to complete and then calculates the distance using the formula [5]:

$$Distance = \frac{Time\ \times Speed\ of\ Sound}{2}$$

Since ultrasonic sensors only give us distance, we must transform it into other parameters, such as fuel volume in our case. In order to achieve successful measurement, calibration must be performed. We will now see how to calibrate the HC-SR04 installed on the locomotive fuel tank. It is to be noted that, we have performed and documented everything on a real Indian Railways WDM2 locomotive [6]. We begin with an empty tank and take the initial reading of the sensor. We then fill the tank with the fuel, diesel here, in constant successive increments and note the readings. We chose this increment to be 50 litres as it was feasible at the time. The collected data can be seen in Table I.

Table I WDM2 Locomotive Fuel Tank Calibration Data

| Sr. No. | Distance | Volume |
|---|---|---|
| 1 | 64.11 | 1150 |
| 2 | 63.87 | 1200 |
| 3 | 62.9 | 1250 |
| 4 | 61.29 | 1300 |
| 5 | 60.49 | 1350 |
| 6 | 58.7 | 1400 |
| 7 | 57.19 | 1450 |
| 8 | 56.02 | 1500 |
| 9 | 54.67 | 1550 |
| 10 | 53.86 | 1600 |
| 11 | 53.13 | 1650 |
| 12 | 52.48 | 1700 |
| 13 | 51.36 | 1750 |
| 14 | 50.48 | 1800 |
| 15 | 49.81 | 1850 |
| 16 | 48.93 | 1900 |
| 17 | 48.11 | 1950 |
| 18 | 47.18 | 2000 |
| 19 | 46.27 | 2050 |
| 20 | 45.51 | 2100 |
| 21 | 44.78 | 2150 |
| 22 | 43.78 | 2200 |
| 23 | 43.06 | 2250 |
| 24 | 42.38 | 2300 |
| 25 | 41.62 | 2350 |
| 26 | 41.02 | 2400 |
| 27 | 40.19 | 2450 |
| 28 | 39.56 | 2500 |
| 29 | 38.96 | 2550 |
| 30 | 37.87 | 2600 |
| 31 | 36.91 | 2650 |
| 32 | 36.14 | 2700 |
| 33 | 35.48 | 2750 |
| 34 | 34.49 | 2800 |
| 35 | 33.74 | 2850 |
| 36 | 32.46 | 2900 |
| 37 | 31.99 | 2950 |
| 38 | 31.28 | 3000 |
| 39 | 30.63 | 3050 |
| 40 | 29.74 | 3100 |

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Now that we have the data, we can model it. Plotting the data in a distance v/s fuel volume graph we get Figure 1.

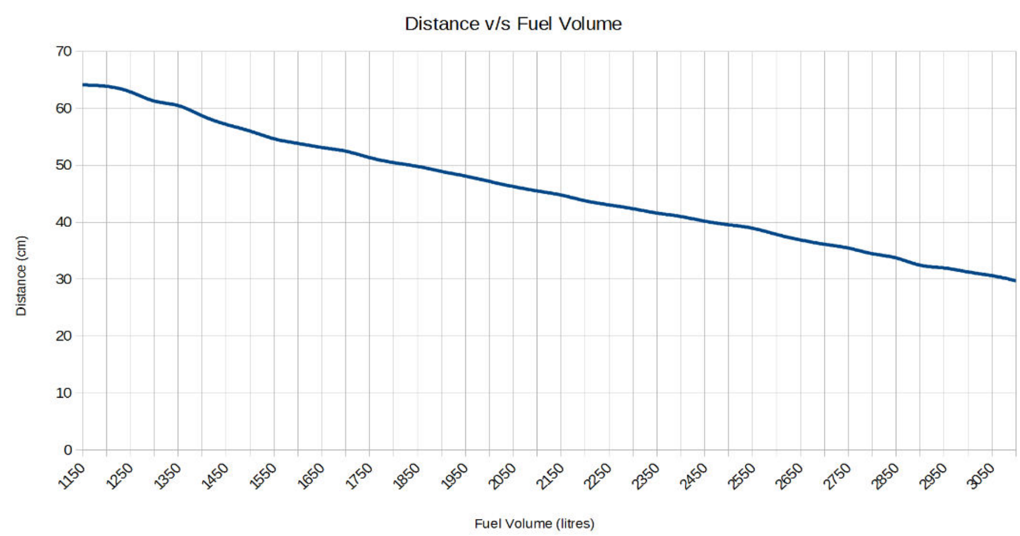


Figure 1. Distance v/s Fuel Volume graph

We can see an almost linear relationship from this graph. To create a model, we find the curve that fits our data using any spreadsheet program such as MS-Excel. First a linear model is evaluated. On plotting a linear trendline through the data, we get Figure 2.

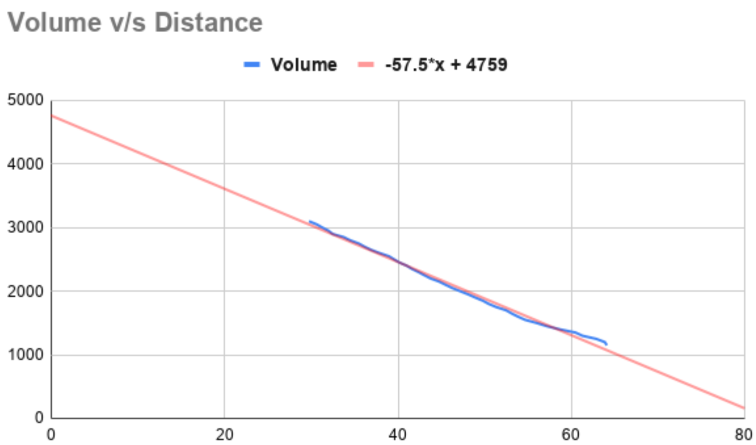


Figure 2. Linear model of the data

We can see that there are significant outliers. To further analyse, we find out what this linear model predicts for the corresponding actual measurement. This analysis can be seen in Table II.

Table II Analysis of Linear Model

| Real Values | Prediction by Linear Model | Difference (Prediction - Real) | Absolute Value |
|---|---|---|---|
| 1150 | 1072.675 | -77.32 | 77.32 |
| 1200 | 1086.475 | -113.53 | 113.53 |
| 1250 | 1142.25 | -107.75 | 107.75 |
| 1300 | 1234.825 | -65.17 | 65.17 |
| 1350 | 1280.825 | -69.18 | 69.18 |
| 1400 | 1383.75 | -16.25 | 16.25 |
| 1450 | 1470.575 | 20.58 | 20.58 |
| 1500 | 1537.85 | 37.85 | 37.85 |
| 1550 | 1615.475 | 65.48 | 65.48 |
| 1600 | 1662.05 | 62.05 | 62.05 |
| 1650 | 1704.025 | 54.02 | 54.02 |

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| | | | |
|---|---|---|---|
| 1700 | 1741.4 | 41.4 | 41.4 |
| 1750 | 1805.8 | 55.8 | 55.8 |
| 1800 | 1856.4 | 56.4 | 56.4 |
| 1850 | 1894.925 | 44.92 | 44.92 |
| 1900 | 1945.525 | 45.53 | 45.53 |
| 1950 | 1992.675 | 42.68 | 42.68 |
| 2000 | 2046.15 | 46.15 | 46.15 |
| 2050 | 2098.475 | 48.48 | 48.48 |
| 2100 | 2142.175 | 42.18 | 42.18 |
| 2150 | 2184.15 | 34.15 | 34.15 |
| 2200 | 2241.65 | 41.65 | 41.65 |
| 2250 | 2283.05 | 33.05 | 33.05 |
| 2300 | 2322.15 | 22.15 | 22.15 |
| 2350 | 2365.85 | 15.85 | 15.85 |
| 2400 | 2400.35 | 0.35 | 0.35 |
| 2450 | 2448.075 | -1.92 | 1.92 |
| 2500 | 2484.3 | -15.7 | 15.7 |
| 2550 | 2518.8 | -31.2 | 31.2 |
| 2600 | 2581.475 | -18.52 | 18.52 |
| 2650 | 2636.675 | -13.32 | 13.32 |
| 2700 | 2680.95 | -19.05 | 19.05 |
| 2750 | 2718.9 | -31.1 | 31.1 |
| 2800 | 2775.825 | -24.18 | 24.18 |
| 2850 | 2818.95 | -31.05 | 31.05 |
| 2900 | 2892.55 | -7.45 | 7.45 |
| 2950 | 2919.575 | -30.43 | 30.43 |
| 3000 | 2960.4 | -39.6 | 39.6 |
| 3050 | 2997.775 | -52.23 | 52.23 |
| 3100 | 3048.95 | -51.05 | 51.05 |

Table III Results of Analysis of Linear Model

| | Score | Percentage | Verdict |
|---|---|---|---|
| Correct Prediction within error margin | 28/40 | 70% | Unacceptable |

We can calculate the score by counting the number of readings that have absolute difference of less than 50. From the analysis we conclude that the linear model is not suitable, since it only gives correct prediction in 70 percent of the readings.

We now test out a quadratic model using a similar approach. Creating a distance v/s fuel volume graph we get Figure 3.

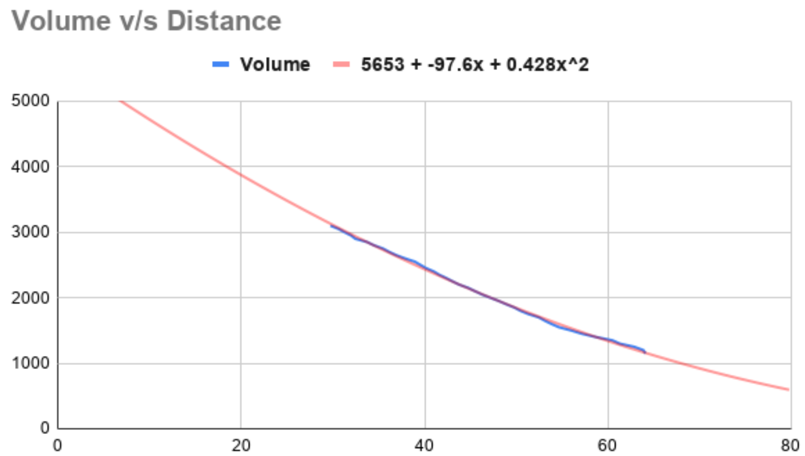


Figure 3. Quadratic model of the data

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Here we see a better relationship between the trendline and the actual values. Outliers are also significantly reduced. This is further confirmed by Table IV.

Table IV Analysis of Quadratic Model

| Real Values | Prediction by Quadratic Model | Difference (Prediction - Real) | Absolute Value |
|---|---|---|---|
| 1150 | 1154.983 | 4.98 | 4.98 |
| 1200 | 1165.261 | -34.74 | 34.74 |
| 1250 | 1207.303 | -42.7 | 42.7 |
| 1300 | 1278.863 | -21.14 | 21.14 |
| 1350 | 1315.245 | -34.76 | 34.76 |
| 1400 | 1398.635 | -1.37 | 1.37 |
| 1450 | 1471.114 | 21.11 | 21.11 |
| 1500 | 1528.615 | 28.62 | 28.62 |
| 1550 | 1596.418 | 46.42 | 46.42 |
| 1600 | 1637.849 | 37.85 | 37.85 |
| 1650 | 1675.669 | 25.67 | 25.67 |
| 1700 | 1709.728 | 9.73 | 9.73 |
| 1750 | 1769.264 | 19.26 | 19.26 |
| 1800 | 1816.795 | 16.8 | 16.8 |
| 1850 | 1853.427 | 3.43 | 3.43 |
| 1900 | 1902.126 | 2.13 | 2.13 |
| 1950 | 1948.101 | -1.9 | 1.9 |
| 2000 | 2000.94 | 0.94 | 0.94 |
| 2050 | 2053.359 | 3.36 | 3.36 |
| 2100 | 2097.681 | -2.32 | 2.32 |
| 2150 | 2140.718 | -9.28 | 9.28 |
| 2200 | 2200.415 | 0.41 | 0.41 |
| 2250 | 2243.926 | -6.07 | 6.07 |
| 2300 | 2285.428 | -14.57 | 14.57 |
| 2350 | 2332.28 | -17.72 | 17.72 |
| 2400 | 2369.618 | -30.38 | 30.38 |
| 2450 | 2421.777 | -28.22 | 28.22 |
| 2500 | 2461.761 | -38.24 | 38.24 |
| 2550 | 2500.157 | -49.84 | 49.84 |
| 2600 | 2570.699 | -29.3 | 29.3 |
| 2650 | 2633.669 | -16.33 | 16.33 |
| 2700 | 2684.747 | -15.25 | 15.25 |
| 2750 | 2728.931 | -21.07 | 21.07 |
| 2800 | 2795.908 | -4.09 | 4.09 |
| 2850 | 2847.206 | -2.79 | 2.79 |
| 2900 | 2935.867 | 35.87 | 35.87 |
| 2950 | 2968.774 | 18.77 | 18.77 |
| 3000 | 3018.844 | 18.84 | 18.84 |
| 3050 | 3065.06 | 15.06 | 15.06 |
| 3100 | 3128.928 | 28.93 | 28.93 |

Table V Results of Analysis of Quadratic Model

| | Score | Percentage | Verdict |
|---|---|---|---|
| Correct Prediction within error margin | 40/40 | 100% | Acceptable |

From the analysis we conclude that the quadratic model is suitable, since it gives correct prediction in 100 percent of the readings. Hence, we accept this model and we will use it by programming the trendline equation into the microcontroller.

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## V. READING FROM THE SENSOR

Now that the sensor is installed and calibrated, it is ready to measure fuel volume. The microcontroller may report the fuel volume readings in the following ways:

*A.* *Using an Attached Display:* An inexpensive LCD or OLED screen can be attached to the microcontroller to display the readings locally.
*B.* *Using an Attached Computer:* The microcontroller can be attached to a PC, using USB, and the readings can be read on a serial monitor using a terminal emulator such as PuTTY. [7]
*C.* *Using Internet of Things (IoT) [8]:* The microcontroller can be attached to a Wi-Fi module. This module will be connected to the Internet and will relay the fuel volume reading to the cloud. The client systems can then connect to the said cloud to access the fuel volume readings. This is by far the most suitable method.

## VI. CONCLUSION

We have seen how a relatively inexpensive ultrasonic sensor and microcontroller setup can serve as a reliable and accurate fuel volume measurement device. We also looked at an application of the concept with real-world data. This idea will also be able to accommodate many such heavy vehicles that still use traditional techniques for fuel volume measurement.

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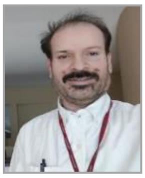
## BIOGRAPHIES

**Vipul Kushwaha** is an ME student and a developer. IoT, sensors and microcontrollers are his areas of interest. He is currently developing an IIoT project for the Indian Railways.



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