An accurate non-intrusive method for fuel estimation of a passenger vehicle using real-time acceleration data from a smartphone

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Abstract : *The conventional fuel measurement instrument needs some type of interference or contact with the fuel tank either internal or external and the accuracy of such fuel measurement is limited to various factors of the instrument such as its reliability, efficiency, repeatability, and range. In this paper we propose an algorithm to estimate the amount of fuel being consumed based on real-time acceleration data gathered in the x, y, and z directions either by a 3-axis accelerometer ADXL345 or a smartphone which can measure acceleration. Accelerometer data was collected from a used single owner Hyundai EON vehicle. Data was collected for one trip to and fro on the same route and then analyzed to find a fuel estimation constant '$\mathbf{k_{FE}}$' which is vehicle model specific and which varies with the vehicle inertia, vibrations, terrain and pattern of driving and usage. It will also depend on driver response like braking, pushing the pedal, abrupt turning, etc. Also, validation of the algorithm was done by setting a value of k_{FE} in a realistic scenario and indicating the time to refill to the driver. The algorithm will be converted into an app for a smartphone which will be available to users to input the vehicle parameters and get an estimate of fuel consumed in real-time which can aid in the decision making of buying a vehicle or help in connecting vehicles with similar fuel economy or allowing user to know which vehicle has excess fuel to supply in case of breakdown or emergency.*

***Index Terms* - fuel estimation, accelerometer, data, float, fuel tank, smartphone, app.**

I. INTRODUCTION

Not always there is a fuel indicator in a vehicle. This may be either due to cost cutting or due to lack of space for installation of the same. The existing traditional and the microcontroller based float type measurement techniques are far from exact and are on the conservative, however the microcontroller based technique is more accurate compared to the traditional technique but still lacks accuracy due to fuel sloshing in the tank unless float sensor is calibrated with respect to the size and curves of the tank. [1]

In today's scenario, the Indian consumer is very price sensitive and possesses a smartphone. The typical smartphone has an accelerometer sensor as seen in Table 1 which gives the acceleration along the 3-axis for the user. Taking this into account, the objective of this paper was to develop a fuel level measuring system that would estimate fuel consumed in real-time and provide alert to the driver to fill up the tank eliminating errors and disturbances of traditional systems.

In today's world, due to in-built sensor capability, data access and collection of data is very easily achieved. The main challenge is to clean this data and make it available in a form such that it can be processed to give a solution for engineering specific problems or improve the insight of the user thereby leading to better decision making.

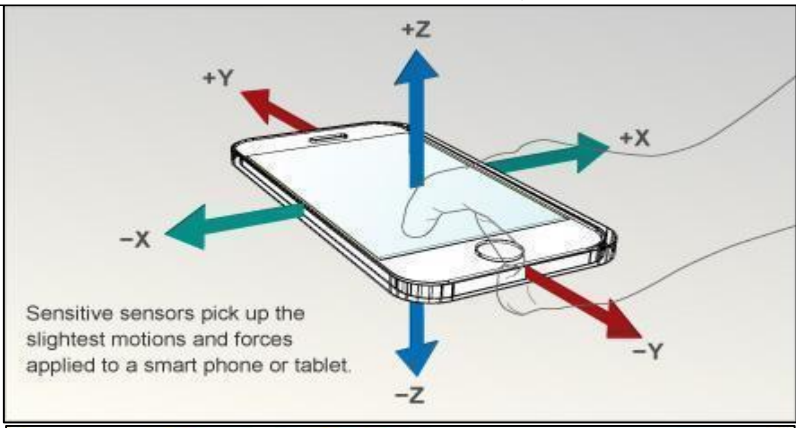
The data pertaining to acceleration in real-time can be processed to help customers know the actual fuel consumed by a vehicle with the help of an app for commercially available passenger vehicle models. This will also help the user in terms of estimating a mileage for their vehicle and allow him to make a suitable decision regarding its purchase. The data can be collected during any vehicle test drive and will give them a ball-park estimation of the mileage of the vehicle under consideration. The fuel related data collected from various smartphones will give us the overall demand of fuel at different points in time in a region (*say for example South Mumbai area*) allowing for more efficient distribution of fuel based on market consumption.

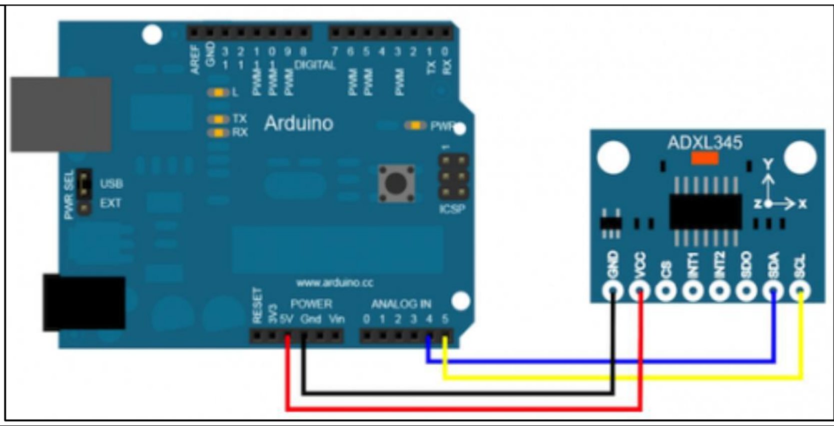
II. MOTIVATION

SAE Baja competition held every year gives students of engineering colleges a chance to participate and build an off-road all-terrain vehicle considering some constraints in the design of the vehicle components. The **INNOVATION** competition of the event consists of adding an innovation to the existing design within the given constraints.

The Team RCOE Retro of Rizvi College of Engineering, Mumbai came up with an innovation that could accurately estimate fuel consumed without contact with the fuel tank, which was used during the Endurance Rounds to alert the driver to refill the tank. The trip during endurance is on rough terrain with lots of difficult and tough driving conditions and hence a non-intrusive system needs to be installed for fuel measurement.

Table 1 - Sensors in Motorola G5 Plus and their Layout

<table>
<tr><td>Compass/ Magnetometer – Yes</td><td rowspan="7">

Reference: https://www.pinterest.com/pin/593771532107408453/</td></tr>
<tr><td>Proximity sensor - Yes</td></tr>
<tr><td>Accelerometer – Yes</td></tr>
<tr><td>Ambient light sensor – Yes</td></tr>
<tr><td>Gyroscope – No</td></tr>
<tr><td>Barometer – No</td></tr>
<tr><td>Temperature sensor – No</td></tr>
<tr><td>Setup of ADXL345 interfaced to Arduino UNO</td><td>
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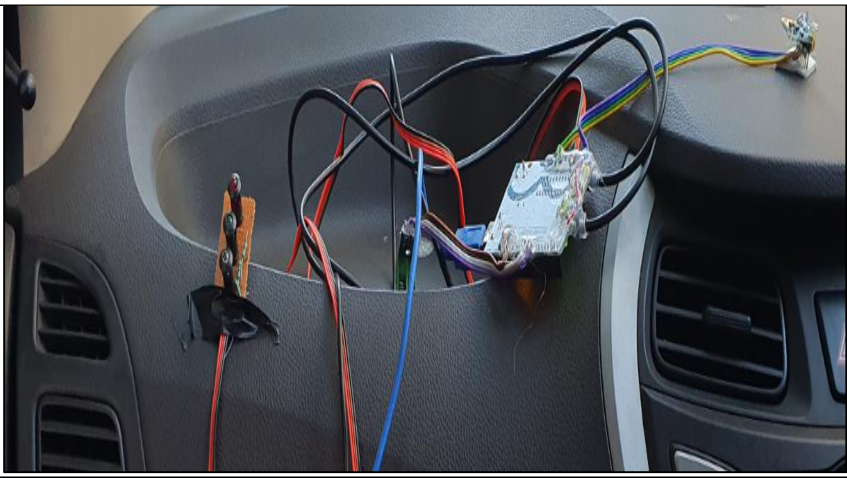
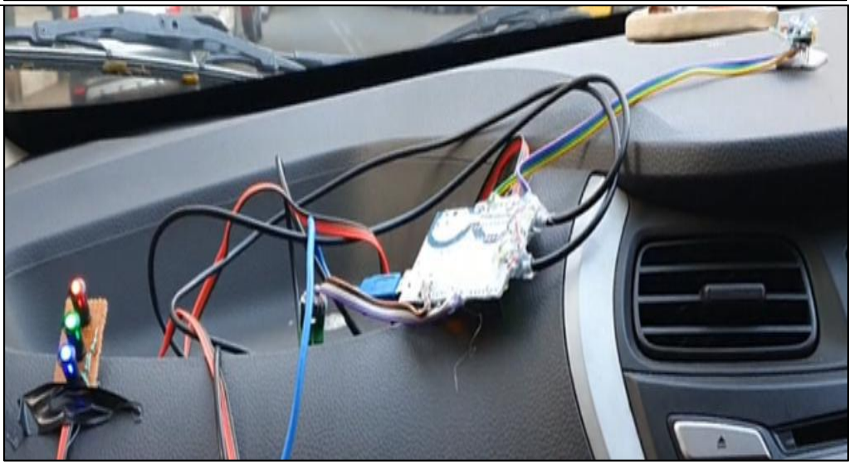
<u>Validation of algorithm based on real-time acceleration data</u> Before reaching the set threshold, the **RED** light does not blink	
<u>Validation of algorithm based on real-time acceleration data</u> After the set threshold is reached **RED** light glows	 Reference : https://www.youtube.com/watchv=tkL93lFNos0&feature=youtu.be

We proposed an accelerometer-based approach in which the ADXL345 accelerometer is attached on the chassis of the vehicle and data is collected in real-time.

The main requirement of SAE Baja to adhere to the rule book of not directly contacting the fuel tank and having a non-intrusive method of fuel measurement is also fulfilled.

<u>Sensor selection:</u> Primarily the fuel consumed is correlated with the velocity and acceleration of a vehicle. The data used in acceleration in a one axis which is the driving direction. Accelerometer is also sensitive to vibrations and road conditions and will also depend on driver response like braking, pushing the pedal, abrupt turning, etc. Hence, this sensor works ideally for estimation of fuel.

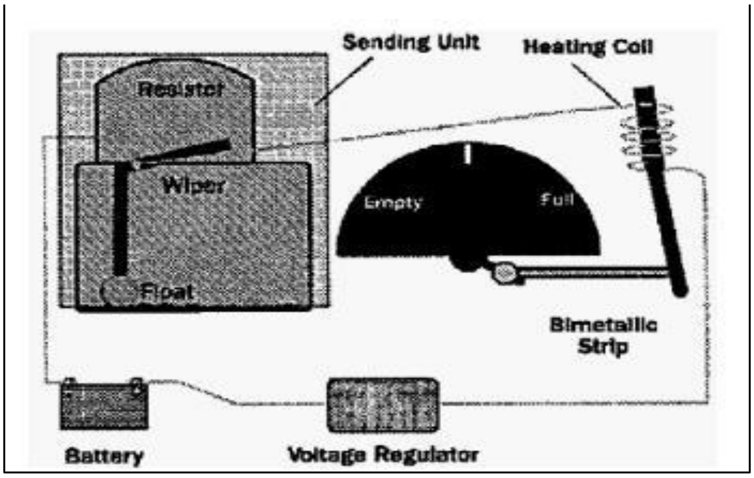
Why instantaneous?

The vehicle runs on the same path for both the routes A and B. However, still, instead of the average velocity, we consider the instantaneous sensor values for fuel consumed. This is because, the instantaneous values of acceleration and velocity are predominantly required for accurate fuel consumption while averaging effect will eliminate the driving behavior and result in loss of relevant information. The average velocity for the trip B is 3.89 m/s which gives a time period of 1900/3.89 = **488 sec** while for trip A is 4.11 m/s giving a time period of 1900/4.11 = **462 sec**, while in actual the time taken to complete the trip is about **200 seconds**. This clearly shows that the overall average is not reflecting the localized driving pattern and hence, instantaneous sensor readings are required to be considered in the estimation of fuel.

III. Existing Fuel Gauge Techniques Used In Automobiles

1. TRADITIONAL FUEL GAUGE

The traditional fuel indicator consists of two units i.e. the sending unit and the gauge. Figure 1 shows the commonly used traditional fuel measurement system. The sending unit is in the fuel tank of the car and it consists of a float, usually made of foam, connected to a thin, metal rod. The end of the metal rod is mounted on a variable resistor or potentiometer. The variable resistor consists of a strip of resistive material over it which moves across the variable resistor changing the resistance and flow of current depending on the movement of the float with respect to the level of fuel present in the fuel tank.

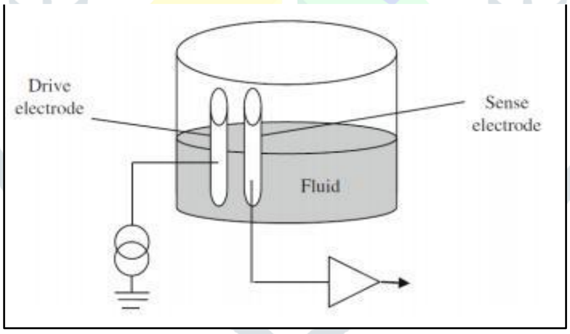


Presently the most common and traditional fuel indicator system makes use of the resistive float type sensors to measure the level of fuel in the tank and this system consists of two units i.e. 1) The sender unit responsible to measure the level of fuel in the tank, 2) The gauge unit responsible to display the measured fuel level to the driver.

Another technique is known as the Smart fuel gauge system, which is like the traditional technique but also makes use of embedded systems such as microcontrollers or microprocessors for providing better accuracy.

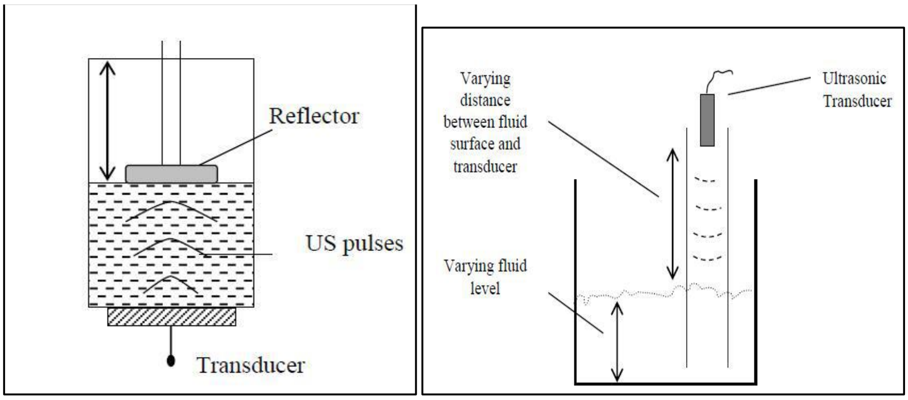
The Figure shows that the fuel in the fuel tank is almost empty and the float has moved to the bottom of the tank moving the strip on the resistor thus increasing the resistance to maximum and current flow through the resistor becomes minimum thus displaying fuel empty on the gauge [1]. The gauge consists of a bimetallic strip i.e. a strip made of different kinds of metal and whose thermal coefficient of expansion differs from each other. When resistance is decreased, current increases and thus the strip is heated during which one metal expands less than the other, so the strip curves, and this bending action is what moves the needle on the fuel gauge. As resistance increases, less current passes through the heating coil, so the bimetallic strip cools. As the strip cools, it straightens out, pulling the gauge from full to empty. The smart fuel gauge system techniques has been implemented in some newer cars in which, instead of sending the current directly to the gauge, an intermediate microprocessor is used to read the output of the resistor and then communicate with the dashboard for displaying the fuel on the gauge corresponding to the read output voltage from the sending unit and these systems actually help improve the accuracy of the gauge.

2. CAPACITIVE LEVEL SENSING



In a capacitive fuel level sensing system, the capacitive sensors have two conducting terminals electrodes and the gap between the two rods is fixed the fuel level can be found by measuring the capacitance between the two conductors immersed into the fuel as shown in Figure 2. Since the capacitance is directly proportional to the dielectric constant between the parallel rods or plates, therefore the fuel rising between the two parallel rods leads to increase or change in the net capacitance value of the measuring tank as a function of fluid height [1]. If the dielectric behaves even slightly as a conductor then this can reduce the performance of the capacitor. The dielectric material used should ideally be an insulator while chemically fuel will have other contents mixed in it increasing the conductivity of electrons to some extent, therefore a common method used to overcome this problem is placing an insulating layer on each of the rods in order to preserve the performance of the measuring system. Capacitive type fuel level measurement systems can make use of multiple capacitors or multi-plate capacitors which has an advantage of an increased capacitance value and accuracy. Multi-capacitor systems share the common dielectric constant, which is essentially the fluid itself in capacitive type fluid level measurement systems. If a capacitor is constructed with an "n" number of parallel plates, then the overall capacitance will be increased by a factor of (n-1).

3. ULTRASOUND LEVEL SENSING



Ultrasonic transducers transmit ultrasonic waves then receive those ultrasonic waves reflected from an object. The time delay between transmission and reception of the ultrasonic waves is used to detect the position of the object. This technique can be used to determine the height or vertical distance of an object from the ultrasonic sensor. Thus, ultrasonic transducers can be used to determine the height or level of fluid in a container. Based on the height of the liquid level, the amount of fuel remaining is estimated.

IV. Experiment Design For Collection Of Accelerometer Sensor Data

In order to estimate the fuel consumed, instantaneous accelerometer data was collected on two different routes as given below:

A) 2 trips of 1.9 kms from HOME-PTV to drop children to school and PTV-HOME as seen in Figure 1 used to determine k_{FE}.

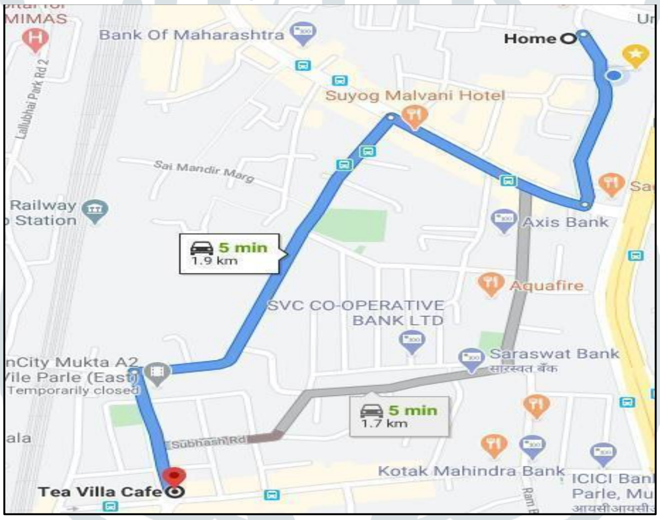


Figure 1 – Two Trips From Home To Tea Villa Café (1.9 Km One Way)

b) 4 trips around Rizvi College of Engineering (RCOE) of 450 m as seen in Figure 2.

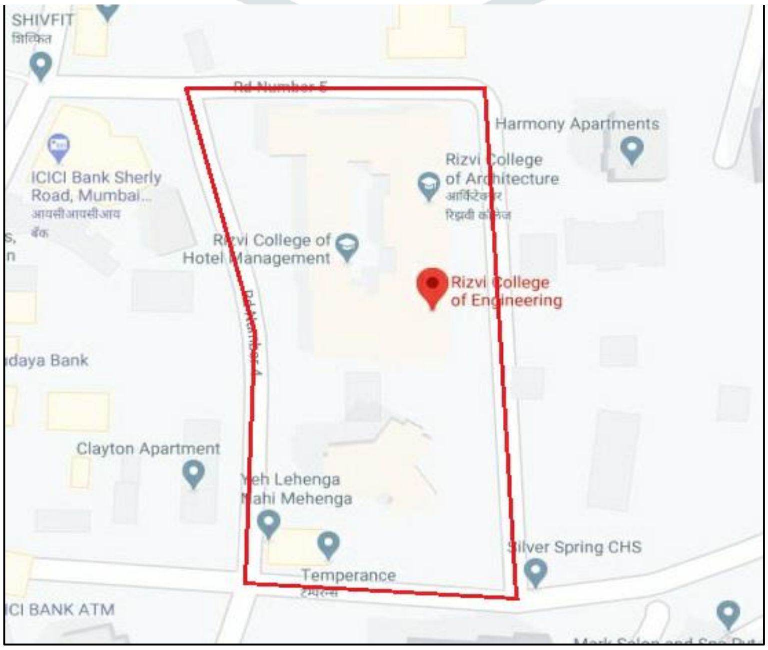


Figure 2 – Four 450 M Trials Around Rizvi College of Engineering Campus (RCOE)

Trip A – HOME-Parle Tilak Vidyalaya (PTV) – The smartphone is attached in the orientation with the Z direction aligned in the direction of travel for the first 116 seconds and then with the X direction aligned in the direction of travel for the remaining 80 seconds.

Trip B – Parle Tilak Vidyalaya (PTV) - HOME - The smartphone is attached in the orientation with the X direction aligned in the direction of travel of the vehicle.

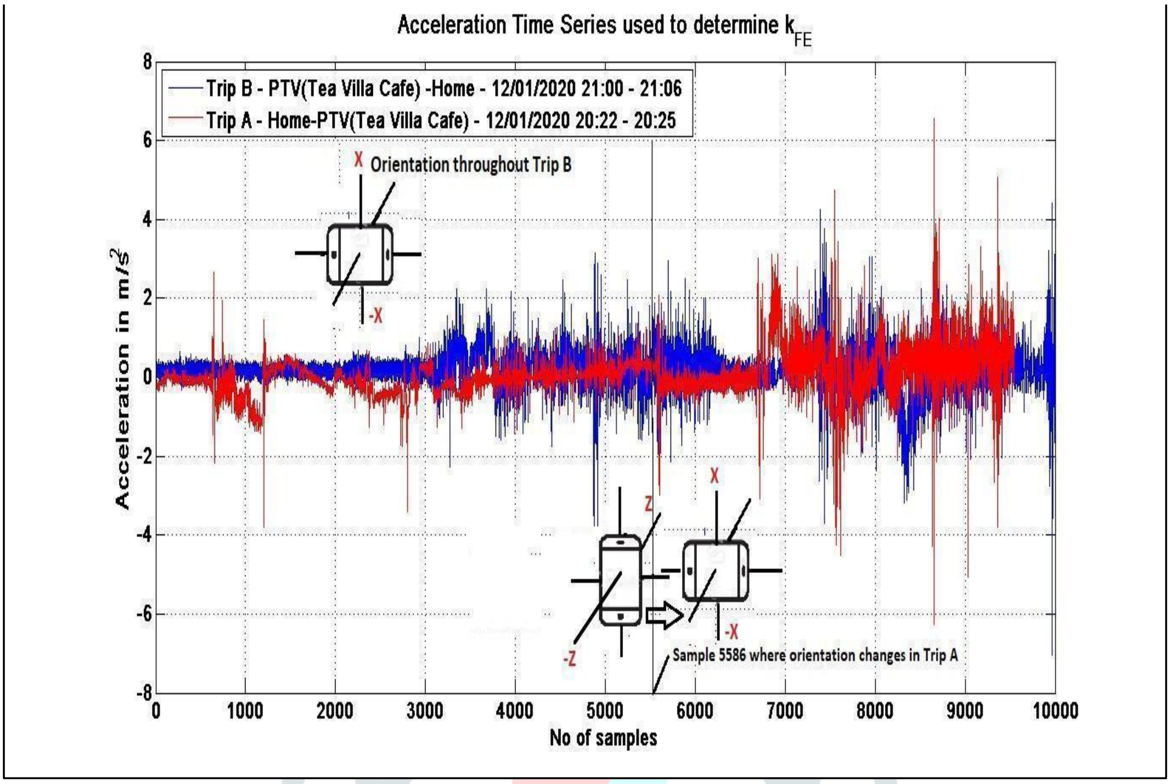


Figure 3 – Orientation of smartphone and acceleration time series data collected for two trips from HOME-PTV and back

See the Figure 3 attached with the orientations and the time series of the acceleration data collected using MOTOROLA G5-Plus on 12/01/2020. As seen, the measuring axis is along Z in Trip A and changes to X after 5586 samples (116 seconds) while orientation is along X throughout trip B.

IV. Proposed Algorithm For Fuel Estimation

The following steps are used in the algorithm:

a) Set the initial volume of fuel
b) Set the final threshold of fuel which needs to be indicated by the system for refill
c) Set sampling time using delay () function
d) Fuel consumed $\mathbf{V(t+1) = V(t) - k_{FE}*abs(A(t))}$ where k_{FE} = constant (set to $\mathbf{4.67x10^{-5}}$ for Hyundai EON) depending on vehicle specifications like power, curb weight and engine displacement [4] and A(t) is the pertinent acceleration time series in the driving direction.
e) Provide suitable indications to the driver for refill.

Acceleration data for all the 4 trips taken for analysis is with orientation in the X-direction which is the forward direction of travel of the vehicle.

Based on prior experience, it is known that the vehicle on daily usage from HOME-WORK-HOME consumes a full tank of 32 liters for a distance of 330 kms (without air conditioning) This gives a mileage for the vehicle to be **330/32 = 10.32 kmpl**.

So, for 450 m the fuel estimated is 0.45/10.32 = 0.043 liters or **approx. 43 ml is consumed in every trip of 450 m around Rizvi College of Engineering (RCOE)**.

The value of k_{FE} is decided based on the analysis of data for the 4 trips which covered the route as shown in Figure 1. During the trips, a LAPTOP connected to an Arduino UNO gathering data from ADXL345 is seen in Figure 2. The setup also includes a LED strip which initially shows **GREEN** and turns into **RED** once the threshold value of the fuel is reached. The threshold value was decided based on 4 trips and was tested in real-time during the 5th trip.

1. PROCEDURE FOR FINDING THE VALUE OF k_{FE} FOR A VEHICLE

a) Using the theoretical fuel consumption graph [3]

The fuel estimation constant (k_{FE}) is not known for a vehicle and must be determined either theoretically or experimentally. The steps for the same are listed below:

1. Get the instantaneous acceleration during vehicle run using **G-Sensor Logger** [2] app available on Play Store
2. Compute the average velocity (v) using acceleration data.
3. Select the value of fuel consumed $\Delta V(t)$ from Figure 4 [3] depending on the instantaneous acceleration and average speed.
4. Compute $k_{FE}(t) = \Delta V(t)/A(t)$
5. Finalize the average value of k_{FE} at the end of the Trip.

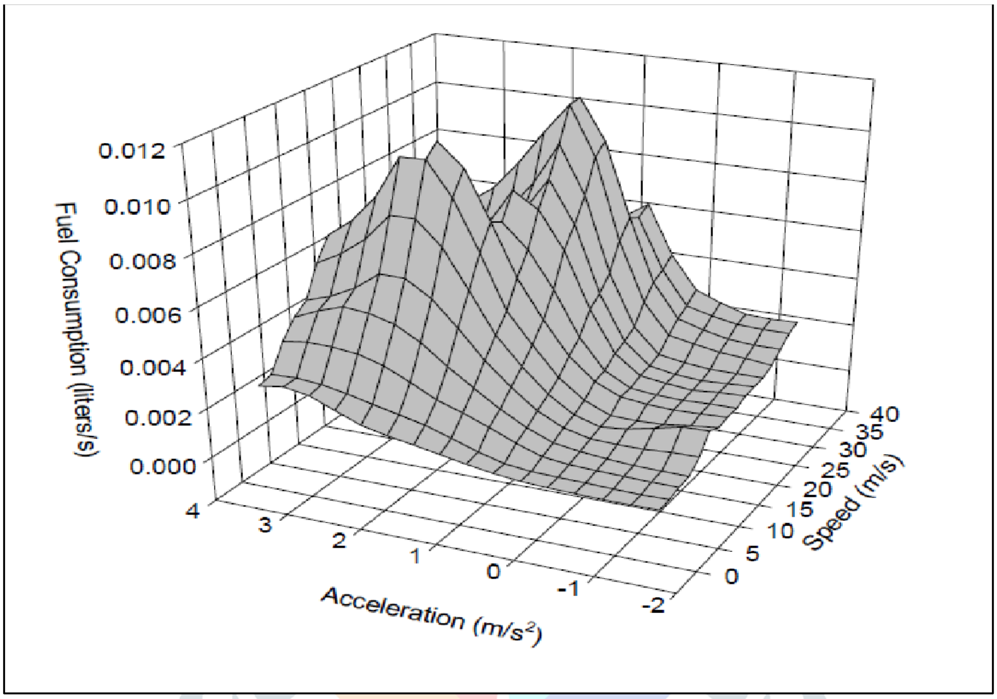


Figure 4 – Fuel consumption versus Instantaneous Acceleration A(t) and Average Speed S(t) for Mercury Villager [3] used for finding k_{FE}

b) Using the estimated mileage data for various classes of vehicles [See Table 2 below]

In order to get the k_{FE} value for the Hyundai EON, we require the mileage data for some vehicles, which resemble in dimensions, curb weight and engine displacement as close to the Hyundai EON. The table given below gives the mileage in various ranges of speed for different classes of vehicles.

The steps for estimating the k_{FE} are listed below:

1. Get the instantaneous acceleration A(t) during vehicle run using **G-Sensor Logger** [2] app available on Google Play Store and compute average speed S(t).
2. Estimate average fuel consumption $\Delta V(t)$ from Table 2 by using mileage value M(t) depending on vehicle speed S(t) and your vehicle model closest in specifications [2].
3. Compute $k_{FE}(t) = \Delta V(t)/A(t)$
4. Finalize the average value of k_{FE} at the end of the Trip.

Table 2 – Mileage of various class of vehicles with reference to average speed S(t)

Table 4.24
Steady Speed Fuel Economy for Vehicles Tested in the 1997 Study
(miles per gallon)

Closest to Hyundai EON

Speed (mph)	1988 Chevrolet Corsica	1993 Subaru Legacy	1994 Oldsmobile Olds 88	1994 Oldsmobile Cutlass	1994 Chevrolet Pickup	1994 Jeep Grand Cherokee	1994 Mercury Villager	1995 Geo Prizm	1997 Toyota Celica
5	10.0	14.5	10.5	5.1	7.9	8.2	12.3	18.1	19.1
10	16.8	24.7	14.9	7.9	16.0	11.2	19.0	23.1	34.1
15	17.7	31.9	22.2	11.4	16.3	17.5	22.4	38.9	41.7
20	21.7	34.4	26.3	12.5	19.9	24.7	25.8	39.4	46.0
25	23.9	37.4	28.3	15.6	22.7	21.8	30.8	41.7	52.6
30	28.7	39.7	29.0	19.0	26.3	21.6	30.3	40.0	50.8
35	28.6	38.0	30.9	21.2	24.3	25.0	26.1	39.1	47.6
40	29.2	37.0	33.2	23.0	26.7	25.5	29.0	38.9	36.2
45	28.8	33.7	32.4	23.0	27.3	25.4	27.8	42.3	44.1
50	31.2	33.7	34.2	27.3	26.3	24.8	30.1	39.1	44.8
55	29.1	37.7	34.6	29.1	25.1	24.0	31.7	37.7	42.5
60	28.2	35.9	32.5	28.2	22.6	23.2	27.3	36.7	48.4
65	28.7	33.4	30.0	25.0	21.8	21.3	25.3	34.1	43.5
70	26.1	31.0	26.7	22.9	20.1	20.0	23.9	31.7	39.2
75	23.7	28.8	24.0	21.6	18.1	19.1	22.4	28.3	36.8
				Fuel economy loss					
55–65 mph	1.4%	11.4%	13.3%	14.1%	13.1%	11.3%	20.2%	9.5%	-2.4%
65–75 mph	17.4%	13.8%	20.0%	13.6%	17.0%	10.3%	11.5%	17.0%	15.4%
55–75 mph	18.6%	23.6%	30.6%	25.8%	27.9%	20.4%	29.3%	24.9%	13.4%

Source:
B.H. West, R.N. McGill, J.W. Hodgson, S.S. Sluder, D.E. Smith, *Development and Verification of Light-Duty Modal Emissions and Fuel Consumption Values for Traffic Models*, Washington, DC, April 1997, and additional project data, April 1998. (Additional resources: www.fhwa-tsis.com)

2. SAMPLE CALCULATIONS

The data for Trip B is analyzed for calculation of k_{FE} and also the following parameters related to fuel economy can be evaluated

Instantaneous fuel economy = Distance travelled in time Δt/Fuel consumed in time Δt
Route economy = Total distance covered in route / Total fuel consumed in route

Instantaneous k_{FE} is plotted in Figure 5 below.

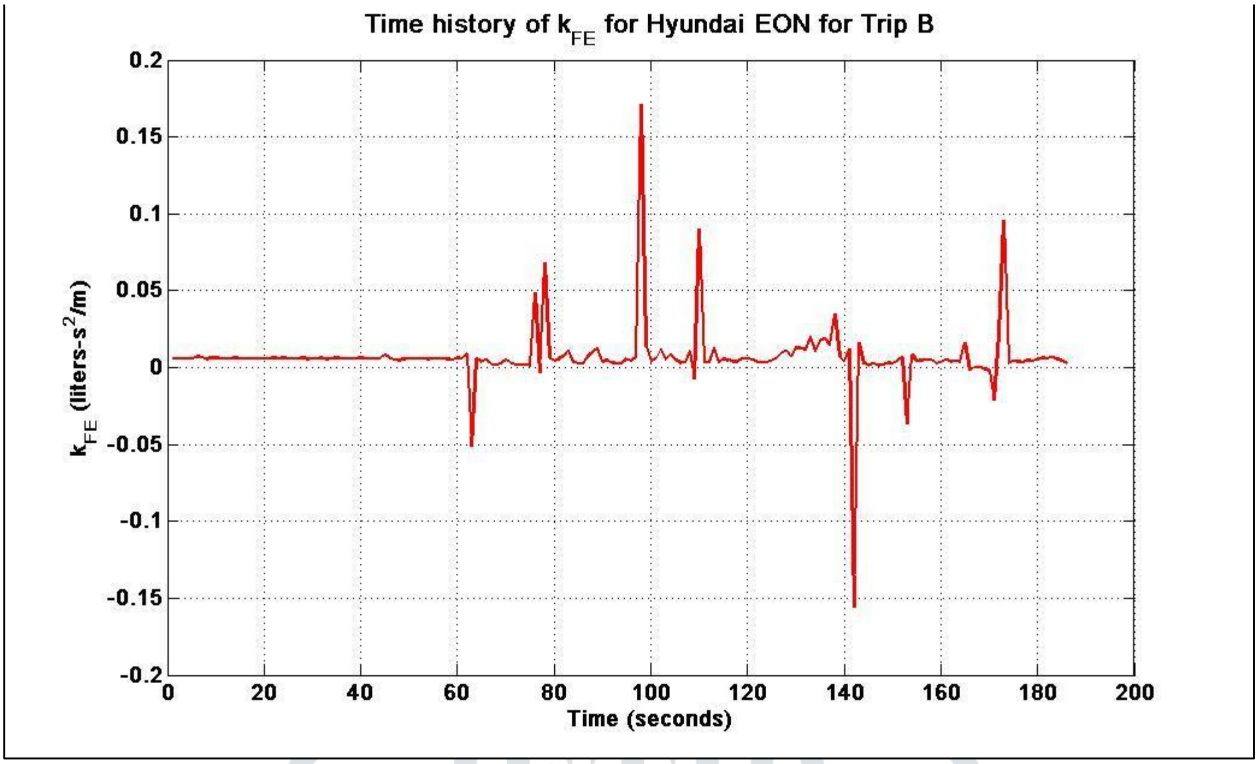


Figure 5 - Time history of k_{FE} for Hyundai EON for trip B

As seen in Figure 5, the k_{FE} is pretty constant with spikes at some points where there are sudden changes in the dynamical behavior of acceleration time series.

V. Results and Discussion

The Figure 7 below shows the results of the algorithm for fuel estimation of the two trips A and B. As seen in Figure 3, the two trips A and B follow different paths even though the route is the same. The road conditions are identical but due to different traffic conditions and different responses in driving on part of the driver, the algorithm follows a different path. The threshold for indication to refill is taken as 175 ml based on the computed theoretical TTE (**time to empty**); fuel consumed = 1.9 km/10.31kmpl = 184 ml. The time taken to consume this fuel is roughly 200 seconds.

The final time to reach the threshold of 175 ml is approximately the same in either case. Trip A reaches the TTE at 178 seconds and Trip B reaches TTE at 179 seconds. The plot also shows curves in **black** and **green** based on the estimation of fuel consumed by a) The contour plot in Figure 4 which gives fuel consumed based on instantaneous speed and acceleration; and b) The mileage table in Table 2 which gives the average mileage based on speed of the vehicle and vehicle type. As seen the estimation of fuel consumed by both these methods are conservative. This is because the contour and mileage data has been generated decades ago and depending on road conditions and traffic, the data will vary. The realistic data of today is reflected by the two trips A and B and similar data needs to be collected for validation of this algorithm and implementation for all vehicles. Also, the acceleration and velocity curves after the 60th second, show considerable dynamical behavior which is not stationary in nature and hence is not captured by the two methods. This nonlinear behavior results in deviation of the actual fuel consumption curve from the **black** and **green** curve. This is also a limitation of the two curves black and green which follow a very linear pattern even though there are statistical variations in the acceleration time series. The two trips A and B are mirror images of each other as the route is the same and traffic conditions are not too different due to proximity of time for the two trips.

Another pertinent observation is that the black curve gives a mileage of 22 kmpl which is the manufacturer specified mileage for the Hyundai EON. Since, over a period of 8 years, the vehicle has been considerably used, the mileage is expected to go down.

This is also achieved using the same value of $\mathbf{k_{FE} = 4.67x10^{-5}}$ for the Hyundai Eon. This indicates the robustness of the proposed algorithm and hence shows that the algorithm can work independent of the driving pattern. Traffic conditions within reasonable limits will not affect the TTE but bottlenecks/road blockages on the route may lead to increased time for the same threshold. As seen in Figure 6 below, the contour for the Hyundai EON has been generated based on the Speed-Acceleration-Fuel consumption contour in Figure 4.

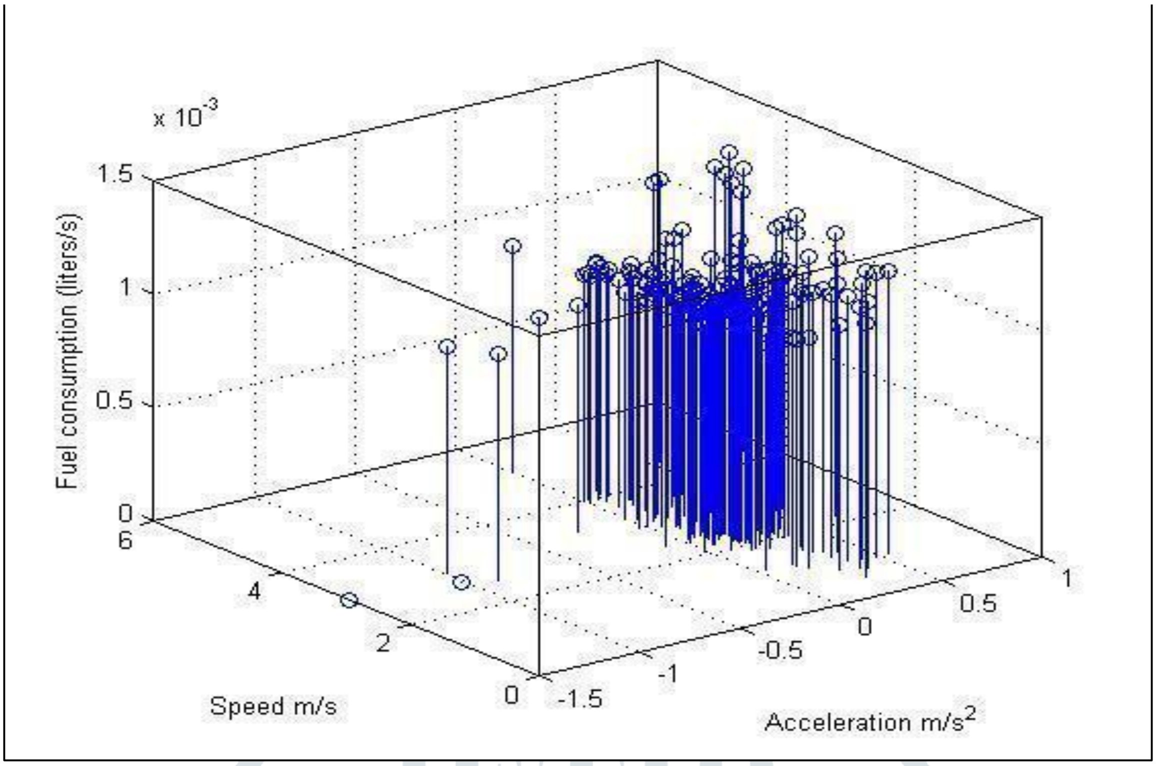


Figure 6 - Speed-Acceleration-Fuel consumption data for Trip B on the Hyundai EON

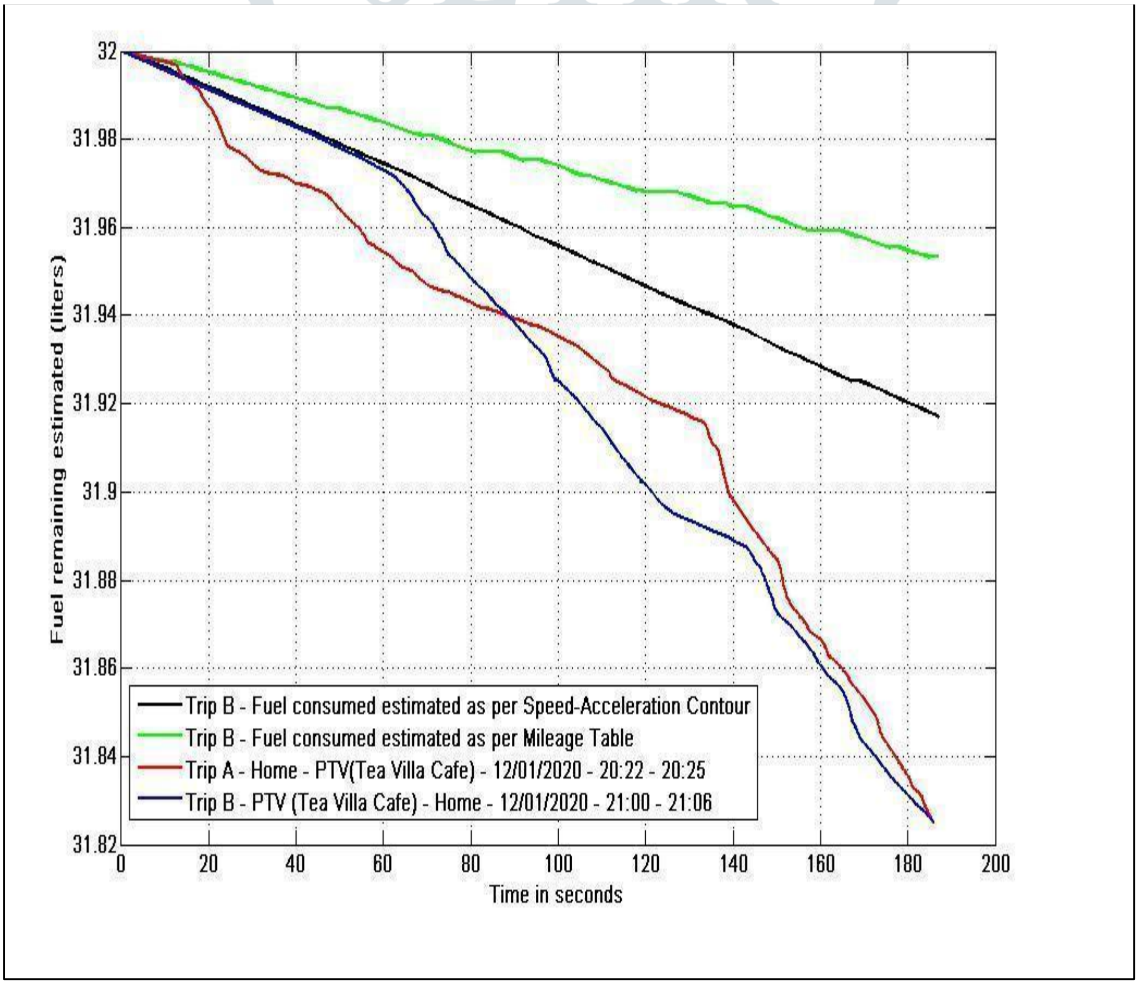


Figure 7 – Fuel consumed on the two trips A and B and time to reach threshold of 31.825 ml (32 liters – 175 ml) along with estimation by a) Speed-Acceleration-Contour as seen in Figure 4 and b) Mileage Table for various vehicles in Table 2

VI. CONCLUSIONS AND FUTURE WORK

The paper is a data driven approach to fuel estimation based on real-time acceleration gathered from a smartphone. The acceleration data is further processed to arrive at a fuel estimation constant k_{FE} for every vehicle. The simulation results show that the amount of fuel consumed for similar traffic conditions and on the same route is almost the same; however, the path shown by the algorithm is different. The fuel related data collected from these smartphones can be used to make predictive analysis of vehicles to avoid breakdown by analyzing the recorded data of similar models, as acceleration data also speaks about the condition of the vehicle which deteriorates over time. Moreover, it will also help owners in maintaining their vehicles.

We plan to make an app in which the system of connected vehicles will help the driver to get an idea of fuel consumption in specific locations which depends on road conditions, traffic, etc. The fuel related data collected over the app will also give overall demand of fuel at different points in time in a region. This will be useful information for fuel companies in setting up new stations and also managing old stations effectively.

Salient features of the algorithm

- The algorithm proposed in this research work is fairly simple to implement and fuel consumed is calculated as proportional to the instantaneous acceleration of the vehicle in the primary driving direction
- The acceleration is only considered in the primary driving direction as the thrust produced by the engine due to burning of the fuel will provide drive to the wheels. Some small amount of this power will be consumed by the component in the lateral direction due to wheel misalignment. Also, small components will be consumed in the vertical direction due to road anomalies like potholes, speed breakers and drainage tanks constructed on the roads. The above fuel consumption is neglected in this analysis
- Instantaneous acceleration being considered results in accurate estimation of fuel consumed and can very well capture the different driving behaviors or responses of the driver like braking, abrupt acceleration, clutch and brake pedal and idling conditions during traffic. During IDLING conditions, the vehicle consumes fuel which is not recorded by other data driven methods that purely rely on overall mileage or GPS. However, in our approach the algorithm will take care of this scenario as the vehicle produces acceleration even during IDLING condition.
- It has been observed on the Hyundai EON vehicle, that without AC ON, the mileage is 10.31 kmpl while with AC ON, the mileage is 7.81 kmpl. This scenario will also be incorporated in the app by gathering quite possibly some other sensor data like temperature and humidity to determine fuel consumption. This is a part of future work.

VII. DISCLAIMER AND DATA DECLARATION

The data used in generation of the results of this research work is confidential and sole proprietary of Rizvi College of Engineering (RCOE) and needs to be cited for usage by the research community. Disclosure of the data to other third parties including companies can be agreed upon by suitable authorized permission from the authors and the users may contact the corresponding author for access to the datasets for further research work. Reproducing analysis related to the datasets without proper authorization can be considered as violation of intellectual property rights.

VIII. ACKNOWLEDGMENTS

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