# STATE OF ART OF SMART VEHICLE MANAGEMENT SYSTEM BASED ON PIC MICROCONTROLLER WITH ACCELEROMETER

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***Abstract:** This research article introduces a single vehicle tracking and monitoring device for automotive applications, which apart from providing conventional vehicle tracking in real-time, can also communicate with vehicle electronics and acquire parameters essential for assessing vehicle health using a PIC series microcontroller. The presented device also includes an accelerometer which can provide critical information related to shocks experienced by the vehicle, acceleration and deceleration of vehicle. Cloud connectivity of the presented design adds another dimension for optimal utilization of vehicle information. Advanced software analytics in cloud can provide information helpful for predicting preventive maintenance of the vehicle and the driving behaviour of driver. Information generated can be used in a multitude of ways by insurance agencies, road infrastructure management, vehicle manufacturers and vehicle owners.*

***Keywords**: Vehicle tracking; GPS; GPRS/GSM; accelerometer; cloud analytics; On-Board Diagnostics (OBD-II), PIC microcontroller*

## 1. Introduction

Now-a-days, a number of vehicle tracking systems are available in the market which can track the location of the vehicle and also provide some basic information like ignition state of vehicle, speed, time and so on. These systems are being successfully utilized in number of ways to locate and display the position of a vehicle. Cloud connectivity enables this information to be viewed from PC or mobile applications, enhancing the utilization of data. Another category of devices, which exist in the market utilizes OBD-II communication and transfers data to cloud platform [1-4].

In this paper author is presenting a single , compact ,low-power, flexible in-vehicle embedded device, named 'Smart Vehicle Management System(VMS)', which can also extend the scope of application by integrating essential information captured from accelerometer and from vehicle On Board Diagnostics (OBD-II) port. Advanced cloud data analytics has also been added for the information processing. The discussed 'Smart VMS' can acquire all essential vehicle parameters from the integrated accelerometer chip and OBD- II port of the vehicle. The data once processed by cloud software can be help of immense help for users.

Smart VMS can acquire latitude and longitude information of the vehicle with help of an integrated Global Positioning System (GPS) receiver. Further, it is communicated to cloud via General Packet Radio Service (GPRS) and SMS service. The hardware of Smart VMS is designed around a PIC24 series 16-bit microcontroller which is responsible for data acquisition, communication, data processing and managing the cloud connectivity. Microcontroller communicates with a base band processor to enable cloud connectivity via GPRS and also reads the information sent by cloud through SMS service. Accelerometer data is acquired over SPI bus and the OBD- II port communication with vehicle is achieved using a Controller Area Network (CAN) controller and CAN physical layer interface [5-6].

As mentioned above, Smart VMS functionality is controlled by a 16-bit PIC24 series microcontroller which operates using an external crystal of 11.0592MHz.

This microcontroller features multiple communication channels, good amount of SRAM and flash memory along with low power consumption. In VMS hardware, capabilities of PIC24FJ256GA106 microcontroller are utilized to communicate with device peripherals like GPS, accelerometer, CAN Controller, Serial EEPROM and GSM Modem. 16-bit timers of the PIC controller are used by system to execute different states of firmware at certain time interval. Along with these features, integrated 16 channel, 10 bit ADC and availability of +5V tolerant digital input pins of PIC24FJ256GA106 makes it a suitable choice for this application [7]. Firmware implemented in PIC microcontroller apart from acquiring and analyzing data, pushes the information to the cloud server.

Cloud server operates with a unique domain name and a listener port where multiple devices can connect concurrently. Cloud backend is TCP/IP socket connection and data analytics are applied by the 'Smart VMS' application. In this paper author is providing system level details of the 'Smart VMS' and information flow process. One case study is also included with real time results which demonstrates that data provided by the device can not only be conveniently utilized for carrying out various types of on-line or off-line evaluations but can help to assess the driving behavior of the driver.

## 2. Architecture of Smart VMS

The block level architecture of smart VMS is given in Fig.1.It shows the basic architecture of VMS. It can be seen, the device has been designed in a modular fashion with three layers viz hardware layer, microcontroller firmware layer and cloud software. The various functions of the VMS are handled collectively by the three layers. Product revisions in industrial control applications usually include migration of the complete product to a different hardware and software platform. Thus, the firmware has been developed in form of a cross-platform software which can be in turn abstract the hardware and can be easily ported and reused on different microcontroller architectures. The developed software is scalable, expandable and portable across various microcontroller architectures.
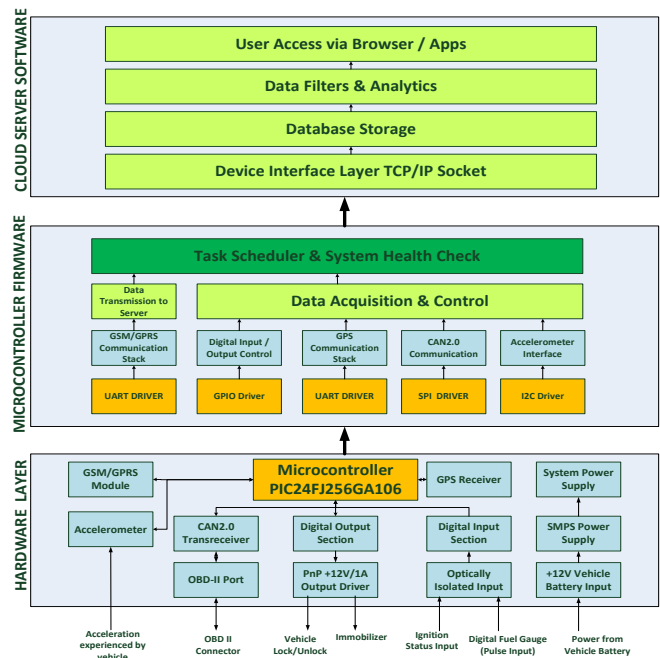


Fig.1. Architecture of the Smart VMS

## 3. Design of PIC microcontroller based VMS Hardware

The hardware layer of VMS is designed around PIC microcontroller. Latitude-Longitude information of the vehicle is collected from GPS receiver. GPRS provides a link for pushing acquired data to cloud server. Data related to vehicle health is acquired from OBD- II Port of the vehicle, details of which are listed in the sections below. Acceleration/deceleration data is captured through accelerometer. Provision for optically isolated digital inputs and optically isolated digital outputs have also been provided for different functions. This section is obtaining its power supply of 12V from the vehicle battery, provided vehicle battery is in healthy state. VMS is enabled with its own battery back-up incase vehicle battery is discharged .Such abnormal conditions are intimated by VMS to an emergency contact number through SMS service. Various hardware modules are discussed below:

### 3.1. GPS Module
GPS Module SIM39EA is used in this design for acquiring the co-ordinates of the vehicle. In addition to this, GPS receiver also helps microcontroller to adjust its clock by providing accurate timing in GMT format. Output of GPS module is NEMA formatted ASCII

string transmitted over UART. SIM39EA used in this design is a GPS receiver with Integrated Patch Antenna with signal sensitivity as low as -165dBm. Different low power modes of this module make it an excellent choice for battery backed applications [8]. Fig.2 shows the block level details of GPS module. Authors have provided a coin cell 3.0V lithium ion battery exclusively for GPS module. In case of system power failure, GPS module can retain its synchronization information using this battery power.
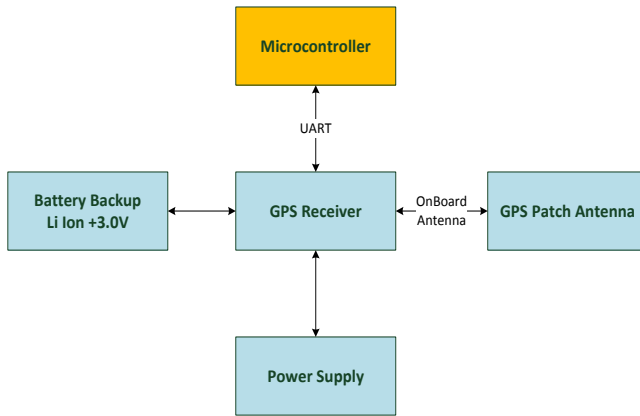


Fig.2. Block Level Details of GPS Module

## 3.2. GSM/GPRS Module

The GSM/GPRS module SIM800H has been utilized in the system for GSM/GPRS connectivity. This module communicates with the microcontroller through UART with AT Command set as data link layer of communication. Extensive details regarding the usage of AT commands is provided in the manufacturer's documentation. Fig. 3 highlights the block level details of GSM/GPRS module.

SIM800H has capability to handle data, voice and SMS communication over GSM network. Various low power modes are utilized in the application to achieve maximum throughput with a limited power supply requirements. Fig.3 also shows the basic interconnection details and a section software flow of microcontroller which interacts with SIM800H module [9].
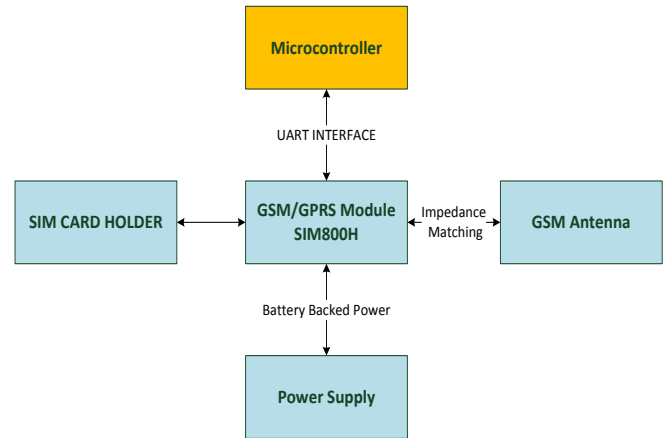


Fig.3. Block Level Details of GSM/GPRS Module

## 3.3. Controller Area Network (CAN) Bus module

All modern vehicles are equipped with second generation On-Board-Diagnostics port, used to read vehicle health parameters. Presently OBD- II is the supported protocol standard which has a mandatory CAN2.0 physical layer and a data link layer interface [10-11].

The capability of CAN bus module to fetch vehicle parameters in real-time, its flexibility and reliability has provided the feature of smartness to VMS [12]. Fig.4 shows the CAN bus module implemented in the device.
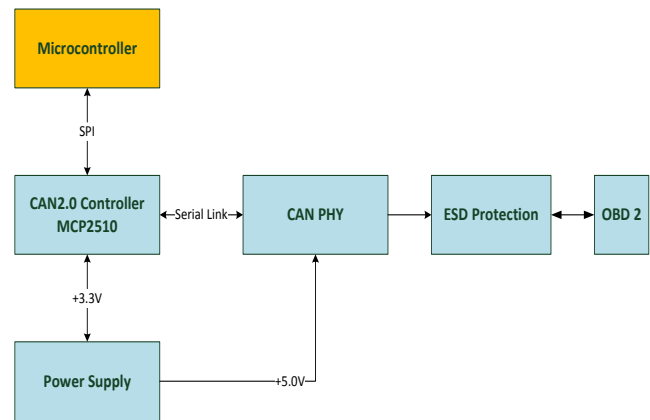


Fig.4. Block Level Details of CAN Module

### 3.4. Accelerometer

Accelerometer chip BMA250 is integrated in VMS device and is capable of SPI communication with host microcontroller and also provides two interrupt output pins. Interrupts can be configured for detection of certain level of acceleration/deceleration in the direction of pre-configured axis [13-14].Fig.5 reveals the major blocks of accelerometer section.
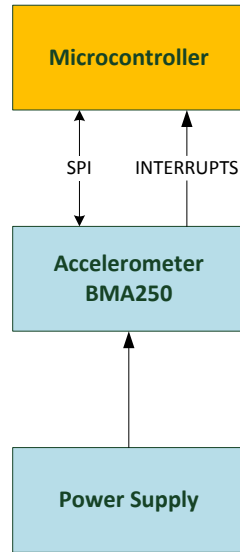


Fig.5. Block Level Details of Accelerometer section

### 4. Brief about firmware and cloud software

VMS firmware is designed in a modular fashion and represented in Fig.6 with a state diagram. Finite State Machine which manages the different operational states of VMS is the heart of the embedded firmware. It handles all the events, associated functionalities and even switching between different states.

List of various events which modify the state of the device operation includes vehicle ignition turn on, vehicle ignition turn off, vehicle battery discharge, excessive acceleration, excessive deceleration, GPS fix detection, system power failure, system health check time scheduler interrupt, GSM/GPRS disconnection or low signal strength and reading incoming SMS.

State diagram in Fig.6 also shows the interrelation of different events and states. Bubble boxes show the operational state of device firmware and arrows highlight the associated event trigger.
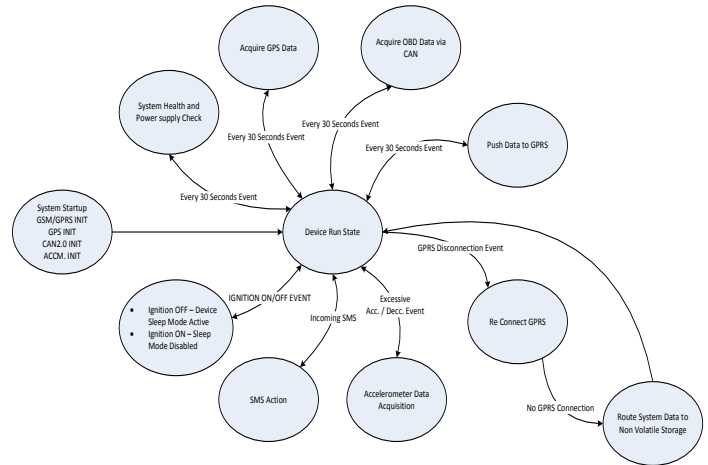


Fig.6. State Diagram of Firmware

The Smart VMS software is capable of cloud computing capability which helps to handle massive data being send to it by Smart VMS. Multiple VMS can be connected to a single cloud. Cloud software has been written in PHP language and handles various tasks like TCP socket listening, negotiating socket connection with device, acquiring data from VMS device and pushing data to MySQL database server. Information stored in database can be viewed by multiple clients via web browser. Client side JavaScript/HTML provides various visualizations and filters to access stored information as per user requirements [15-16].

### 5. Designed and developed VMS Hardware

The discussed VMS was fabricated with two sided, four layer very compact PCB, so that it occupies very less space in the vehicle. The complete hardware of the VMS has been shown in Fig.7 and Fig.8.



Fig.7. Top view of the Smart VMS

Fig.8. Bottom view of the
Smart VMS

## 6. Implementation of Smart VMS in a vehicle

Fig.9 shows the implementation scenario of smart VMS. The smart VMS needs to be configured for parameters like network operator, cloud ID, cloud port number and emergency contact number before being embedded in the vehicle. The smart VMS needs to be configured for various parameters before commissioning for various field test viz mobile operator (which can be selected among various service providers), Cloud ID (which needs to be one and unique), Cloud Port number (which would be specific and unique for each VMS) and emergency contact number (to which device will automatically send a SMS during unlikely events).
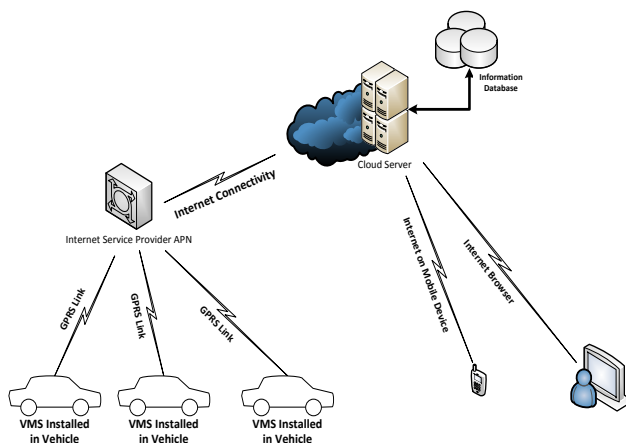

Fig.9. Implementation Block Diagram of VMS

Author has provided sample representation of the data collected from VMS and has provided various assessment based on the same. Table 1 depicts the data transmitted by the device to cloud server, it provides information related to latitude-longitude co-ordinates, time, north/south, east/west indicator, acceleration/deceleration, vehicle speed, mass air flow, engine temperature, data validity etc. A checksum is included at the end of GPRMC string to verify the integrity of data .Data is sent as JASON formatted information which can be parsed easily by server software and stored directly in the database. Author has utilized SQL database to manage the information.

## 7. Usability of Work and Data Analytics

Author has tested the device by installing it in different vehicles and analysing the data collected over period of time, in and around city of Bangalore, Karnataka, India. Suggested improvements are discussed and scope of gathering additional information is presented.

For the first analysis, Smart VMS was installed in few vehicles of a leading car rental company in Bangalore and random data collected from different vehicles over a span of two weeks was analyzed by creating data sets based on common parameters. This analysis has been utilized to discuss the various artefacts of the road infrastructure and identification of certain aspects of city traffic.

In another case study, author has implemented the device in a fleet of school buses to keep track of the vehicle and also to assess the driving behaviour of driver. Author has thus focused on analysing the behaviour of two drivers of school buses over the same route by running the vehicle from HSR Layout Bangalore, India to HBR Layout Bangalore, India.

Using simple yet significant cloud analytics capability to the conventional tracking, useful results have been extracted from the devices.Suggestions for improvement in personal safety, fuel economy, accident prone stretches, road infrastructure quality and vehicle maintenance are highlighted to show the advantages of Smart VMS in realistic and engineering works[17-21].

Table 1. Raw sample data provided by smart VMS

Data of trip:
{"VI":"ZmBTCheck","GPS":["$GPRMC,133523.000,A,1254.2029,N,07738.6374,E,0.00,62.73,
120416,,,A*5D","$GPRMC,133533.000,A,1254.2029,N,07738.6374,E,0.00,62.73,120416,,,A*5C",
"$GPRMC,133543.000,A,1254.2056,N,07738.6296,E,0.99,272.89,120416,,,A*68","$GPRMC,133553.
000,A,1254.2072,N,07738.6246,E,1.34,287.97,120416,,,A*61","$GPRMC,133603.000,A,1254.2094,N,
07738.6215,E,1.38,301.05,120416,,,A*61","$GPRMC,133613.000,A,1254.2110,N,07738.6251,E,0.00,
338.66,120416,,,A*68"],"STS":"01","OBD":["3C","00","00","0083","000000A0","00","5A","8","00000064"
,"07D0","03E8"]\}

{"VI":"ZmBTCheck","GPS":["$GPRMC,133623.000,A,1254.2110,N,07738.6256,E,0.00,343.13,120416,,,A*62"
,"$GPRMC,133633.000,A,1254.2102,N,07738.6335,E,1.04,87.00,120416,,,A*58","$GPRMC,133643.000,A,
1254.2084,N,07738.6387,E,1.14,107.18,120416,,,A*68","$GPRMC,133653.000,A,1254.2071,N,07738.6379,E,
0.00,124.09,120416,,,A*67","$GPRMC,133703.000,A,1254.2071,N,07738.6379,E,0.00,124.09,120416,,,A*63"
,"$GPRMC,133713.000,A,1254.2071,N,07738.6379,E,0.00,124.09,120416,,,A*62"],"STS":"01","OBD":["3C",
"00","00","008D","000000AA","00","5A","8","00000064","07D0","03E8"]\}

{"VI":"ZmBTCheck","GPS":["$GPRMC,133723.000,A,1254.2071,N,07738.6379,E,0.00,124.09,120416,,,A*61",
"$GPRMC,133733.000,A,1254.2071,N,07738.6379,E,0.00,124.09,120416,,,A*60","$GPRMC,133743.000,A,1254.
2071,N,07738.6379,E,0.00,124.09,120416,,,A*67","$GPRMC,133753.000,A,1254.2071,N,07738.6379,E,0.00,
124.09,120416,,,A*66","$GPRMC,133803.000,A,1254.2071,N,07738.6379,E,0.00,124.09,120416,,,A*6C",
"$GPRMC,133813.000,A,1254.2166,N,07738.6381,E,1.67,323.08,120416,,,A*69"],"STS":"01","OBD":
["3C","00","00","0097","000000B4","00","5A","8","00000064","07D0","03E8"]\}

{"VI":"ZmBTCheck","GPS":["$GPRMC,133823.000,A,1254.2188,N,07738.6367,E,1.22,314.13,120416,,,A*6D"
,"$GPRMC,133833.000,A,1254.2167,N,07738.6398,E,0.00,312.41,120416,,,A*6D","$GPRMC,133843.000,A,
1254.2167,N,07738.6398,E,0.00,312.41,120416,,,A*6A","$GPRMC,133853.000,A,1254.2167,N,07738.6398,
E,0.00,312.41,120416,,,A*6B","$GPRMC,133903.000,A,1254.2167,N,07738.6398,E,0.00,312.41,120416,,,A*
6F","$GPRMC,133913.000,A,1254.2167,N,07738.6398,E,0.00,312.41,120416,,,A*6E"],"STS":"01","OBD":
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{"VI":"ZmBTCheck","GPS":["$GPRMC,133923.000,A,1254.2222,N,07738.6403,E,0.00,325.51,120416,,,A*6F",
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.2223,N,07738.6404,E,0.00,327.10,120416,,,A*68","$GPRMC,133953.000,A,1254.2229,N,07738.6475,E,0.97,
70.22,120416,,,A*5BB","$GPRMC,134003.000,A,1254.2214,N,07738.6521,E,0.85,79.02,120416,,,A*56F",
"$GPRMC,134013.000,A,1254.2217,N,07738.6522,E,0.00,69.78,120416,,,A*56E"],"STS":"01","OBD":["3C
","00","00","00AB","000000C8","00","5A","8","00000064","07D0","03E8"]\}

{"VI":"ZmBTCheck","GPS":["$GPRMC,134023.000,A,1254.2217,N,07738.6522,E,0.00,69.78,120416,,,A*55F"
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1254.2217,N,07738.6522,E,0.00,69.78,120416,,,A*538","$GPRMC,134053.000,A,1254.2217,N,07738.6522,E,
0.00,69.78,120416,,,A*52B","$GPRMC,134103.000,A,1254.2268,N,07738.6483,E,0.80,290.18,120416,,,A*6E"
,"$GPRMC,134113.000,A,1254.2277,N,07738.6465,E,0.00,302.97,120416,,,A*6C"],"STS":"01","OBD":["3C",
"00","00","00B5","000000D2","00","5A","8","00000064","07D0","03E8"]\}

## 7.1. Data Analytics related to road infrastructure and traffic management

The latitude-longitude plot in Fig.10. has been shown to provide the location of vehicles running at speeds above 80 Km/h. Plotted markers in Fig.10 indicates outer periphery roads of the Bangalore city. It can be therefore inferred that in outer periphery of the city road infrastructure is of good quality, also six lane highways and controlled traffic may be considered as

few reasons for the speeds above of 80 Km/h. The presented data also highlights the risk of road accidents at an elevated level. The vehicles were also seen to show low fuel efficiency when fuel consumption was co related with speed, through scatter diagram. High speeds on this outer periphery roads also implies that traffic congestions may be observed at the city entry points where speed of vehicles is much slower and couldn't cope with the incoming traffic. Dynamic speed limit imposition using internet connected glow signs or display boards on the outer periphery roads can surely help to improve the above mentioned conditions.
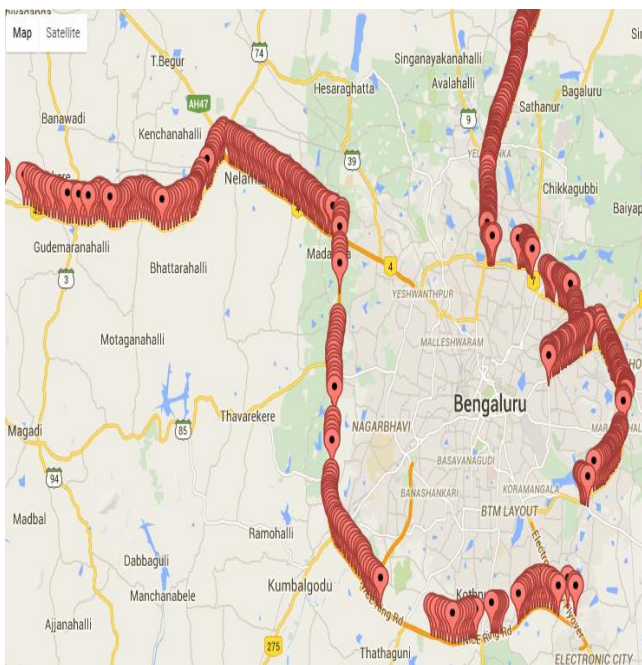


Fig.10. Routes on which vehicles are observed to be running at speed higher than 80 km/h

## 7.2. Data Analytics related to acceleration, deceleration and vehicle break down zones

In Fig.11, data points with deceleration of vehicles greater than 6 m/s$^2$ have been plotted. This has been a common observation that different vehicles have exhibited at almost same locations and hence an analysis of that stretch of road was done. It may be observed that mostly traffic congestions at certain curves are due to the fact that, road conditions or merging traffic at some points tend to break the speed of vehicles. If strict speed limits are enforced over the complete stretch, vehicles reaching the congestion point per minute will reduce and will allow the traffic to slowly but continuously pass without log jam. Few sudden deceleration points shown in Fig.11 were observed on the road stretches which are having poorly visible speed breakers and thus causing sudden drop in speed and potential danger of an accident.
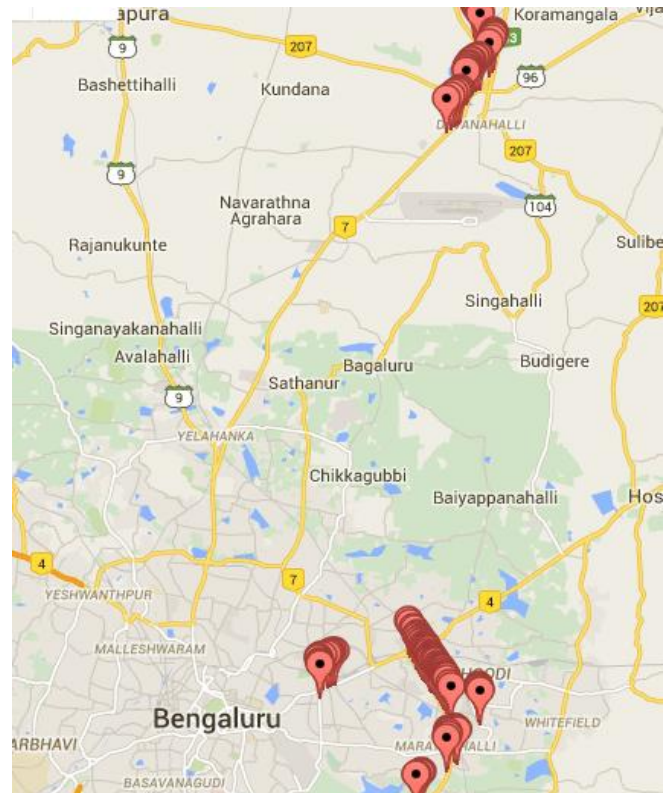


Fig.11. Road Stretches showing sudden decelerations of the vehicles

Similarly Fig.12. has been shown for some routes where sudden acceleration of vehicles were observed. These events are mostly observed on the wide road stretches after pedestrian crossings or after a congested stretch of road. These road stretches thus may have possibility of accidents and vehicle break downs. Acceleration and shock information correlated from accelerometer data confirms that most of the above highlighted locations have good road conditions, and hence indicate places of high pedestrian activity leading to deceleration first and then sudden acceleration. Recommendations for pedestrian over

bridges or underpasses may be considered by road infrastructure management agencies.
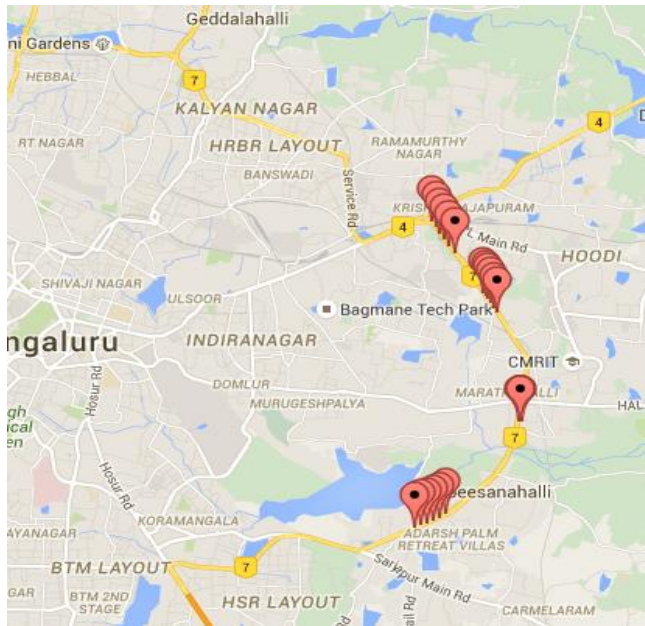


Fig.12. Road Stretches showing sudden accelerations of the vehicles

## 7.3 Data Analytics for Accelerometer Data

Fig.13. shows the raw data captured from the Accelerometer mounted On-board VMS device. The first plot shows the X, Y and Z direction data captured every 100ms from the device plotted with respect to time. It gives the crucial information about the instantaneous shocks experienced by the vehicle.

In the second plot, data for X and Y axis is plotted with respect to each other. A sudden high value of g-forces on all axis indicate an accidental condition which can be easily identified by software algorithms in scatter diagrams. Similarly irregularities in road, driving behavior and other information useful accessing health of mechanical structure of vehicle can be derived from accelerometer g-force data.
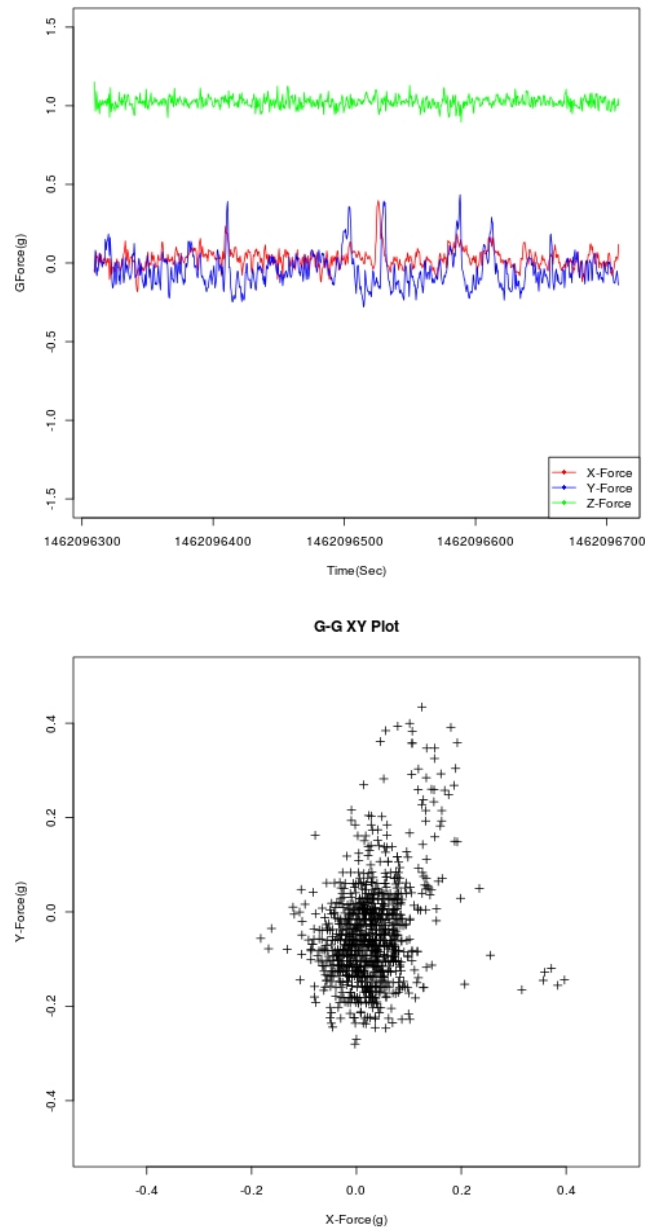


Fig.13. Accelerometer data plots

## 7.4. Data Analytics related to driving behavior of the drivers

Fig.14, Fig.15 and Fig.16 further depicts the data analyzed for fuel consumption, excessive acceleration/decelerations and time taken to complete the same journey by two drivers of the school buses.

Fuel Efficiency of the vehicle is calculated utilizing 'mass air flow' information provided by VMS as

sample values shown in Table 1. The fuel efficiency comparison is done by the cloud software and provided in Fig.14.
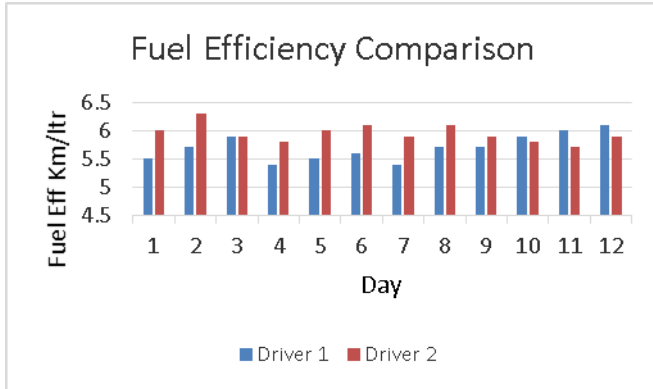


Fig.14. Fuel Efficiency Analysis

It can be observed from Table 1, that sudden acceleration and deceleration events incurred by a vehicle are also reported every 100ms by Smart VMS as a hex number. It can be decoded by the cloud software to indicate the exact $m/S^2$ acceleration or deceleration. This data is being collected from the accelerometer chip communicating with the device and information is stored in the database.

Fig.15. shows the total number of sudden acceleration events summed up for the both drivers running between the same trip coordinates and plotted by the cloud software.
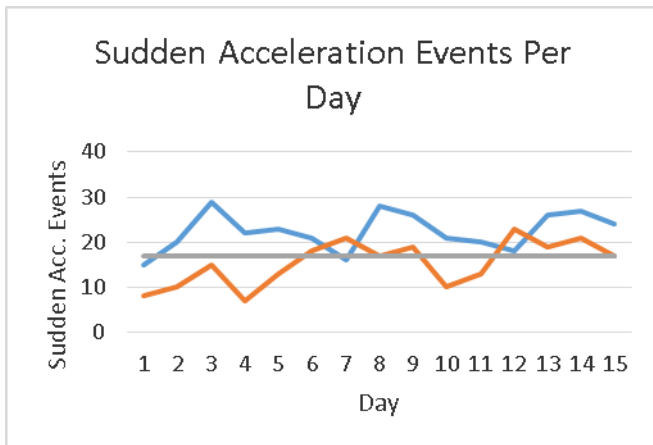


Fig.15. Acceleration/deceleration Analysis

Trip time is calculated between latitude/longitude pairs as difference of time reported by GPS information. GPS reports the timing information in GMT format and can be converted to required time zone by cloud software as shown in Fig.16.
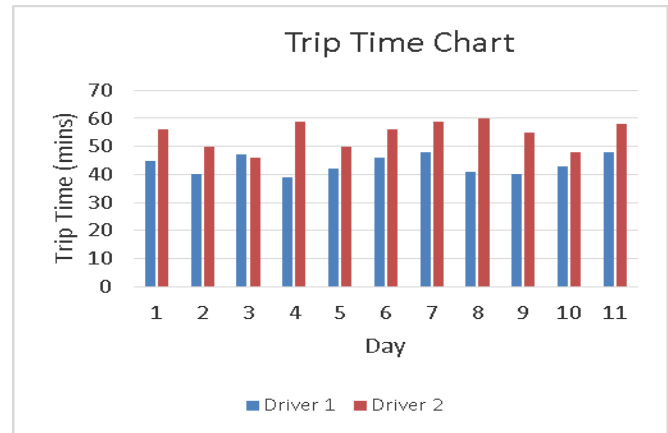


Fig.16. Trip time Analysis

In the second test case, both the drivers were deployed on same route at around same time of the day in same model vehicles. Rash driving is evident from the driver 1 data analytics and driver 2 has shown much better fuel efficiency and his driving pattern can be deduced to be more suitable for children school bus driving.

**Scope and Conclusion**

This research paper provides details about design of a cloud connected VMS capable of communication with vehicle electronics and also presents a case study to highlight the usefulness of the smart VMS. Similar applications of the designed and presented VMS can be for insurance agencies who can introduce dynamic insurance pricing based on driving patterns of driver and usage of vehicle. The discussed VMS can be of immense use for OEMs to improve their automotive design based on the obtained wear and tear information of the vehicle. Traffic and road infrastructure management agencies can get an idea of vehicle driving patterns and also vehicle health parameters which can help them to assess the condition of certain stretch of the road.

Though author has tested the designed device for a very limited set of conditions and derived some basic

information from data analyitics,whereas, this device has enomourous capabilities when information is analysed based on a bigger and wider datasets. This device can be used to feed information to LED Road Sign Boards for safety information , track shipments in containers and shocks experienced by the goods, derive detailed vehicle information from OBD parameters, and predict failures or preventive maintenance etc.

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