IoT based Speed Control for Semi-Autonomous Electric On-Road Cargo Vehicle

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Abstract—The paper develops an investigative GSM enabled IoT based speed control scheme suitable for electric On-Road cargo vehicles. The design involves the bounding of the parameters that include the vehicle speed, motor speed, Truck payload, battery SoC (State of Charge), battery SoH (State of Health), real time navigation points using GPS, tire pressure, motor temperature and current consumption, driver fatigue detection and vehicle proximity detection which enters the system using GSM enabled wireless sensors and IoT based maps for arriving at the recommended speed. It engages a state-of-the-art Microcontroller based embedded system to govern the operation of the three-phase induction motor in accordance with the changes that the vehicle either experiences or becomes necessary for it to negotiate. It incorporates a close monitoring methodology for evolving a sequence of steps that enable the system to remain in operation over scheduled time frames. The results obtained from a simulation process carried out using embedded-c firmware code on ARM Core STM32 micro-controller exemplify the merits and illustrate the performance of the chosen vehicle in terms of its ability to be used in real world systems.

Keywords—Electric vehicle; IoT; speed control; battery SoC; battery SoH; micro-controller; embedded system; GSM; proximity sensor; payload; real time navigation; GPS

I. INTRODUCTION

The emerging development in the vehicular technology refurbishes measures to confront pollution in numerous ways with a perspective to ensemble cleaner alternatives particularly with a need for improving the performance of the cargo traffic. The advances in the communication technology bring in a need to explore autonomous vehicles (AV) as an inevitable option and as a vital business archetype.

The amalgamation of high-speed, durable, low-latency connectivity, and IoT technologies facilitate the transformation towards the fully smart Autonomous Vehicle (AV). A few of the implausible benefits of the AVs include enhancing the performance by lowering the fuel consumption, increasing the transport accessibility, reducing emission levels, and lowering congestion with the use of large-scale data/information from the connected sensors and devices [1].

The challenges involved in integrating the sensor technology with the transportation infrastructure for achieving a sustainable Intelligent Transportation System (ITS) augur efforts in enabling a fully operational and cooperative ITS environment [2].

Off late the cargo segment invites a greater attention and the related vehicle systems consider the on-road traffic on a larger framework. It demands the electric vehicles to be operated at an optimal recommended speed with a purpose to ensure the safe and secure state of the battery over a longer period [3].

There can be one or more intelligent autonomous systems in the case of unmanned, fully automatic intelligent vehicles, which continuously monitor the vehicles and control the speed of the vehicle, this paper explores the semi-automatic multi-modal speed control within the recommended limits for employing their usage in real world systems, following a structured flow with Related Works, Research Gap, Proposed Work with its methodology, simulation and unite testing with results and conclusion.

II. RELATED WORK

The new and upcoming technologies in the transportation and power sector of Electric vehicles that offer huge benefits in terms of the economic and environmental factors have been reviewed by Ayob et al. (2014). A comprehensive review and evaluation of several types of electric vehicles and its associated equipment in particular battery charger and charging station has been outlined and a comparison on the commercial and prototype electric vehicles in terms of the electric range, battery size, charger power and charging time carried out [4].

A study to shed light on future opportunities and the possible hurdles associated with autonomous vehicle (AV) technologies has been studied by Bagloee et al. (2016)[5].The evolution of the Internet of Things (IOT) relating to its use in the automotive sector has been discussed by Bajaj et al. (2018) to provide a perspective on the various areas that include the connected car services/applications, Vehicle communications, IoT in Intelligent Transportation, IoT based Supply Chain

Management in Automotive Industry and New Generation Cars, where reports reveal tangible progress [6].

The need for introducing the electric vehicles with IoT based technology to monitor the battery life of electric vehicles has been brought out by Urooj et al. (2021). The parameters in the form of the distance covered cost and capacity of battery which in turn contribute towards the smooth function of the electric vehicles have also been monitored [7].

Though a host of issues have been addressed, still there needs to be enough literature around how the firmware side of speed controller can be developed and tested at test benches before integration into real vehicle for manufacturability. The scope extends on a wide front and demands further studies to accomplish a new dimension in the field of cargo transportation.

III. PROBLEM DEFINITION

The focus accentuates to extradite a GSM enabled loT-based speed control scheme of a battery-operated on-road vehicle with different parameters in the form of the vehicle speed, engine speed, proximity, and driver fatigue detection with the battery SoC (state of charge), battery SoH (state of health), tire pressure remaining within limits to forge real time navigation needs. It attempts to involve the use of sensors and GSM enabled IoT network through an ARM based STM32 micro controller for enabling the vehicle to operate at the recommended speed. It evaluates the algorithm's adaptability using bench testing-based simulation and orients to demonstrate its real time adoption to production lines.

IV. PROPOSED WORK

The block schematic of the system seen in the Fig. 1 includes the battery-operated power source to the vehicle along with the associated auxiliary circuits. It explains the basic philosophy relating to the control of speed for the chosen vehicle across the operating range on the guidelines of the parametric considerations. Designing an Intelligent system to maintain optimum speed can help to derive the maximum efficiency of the on-road vehicles.
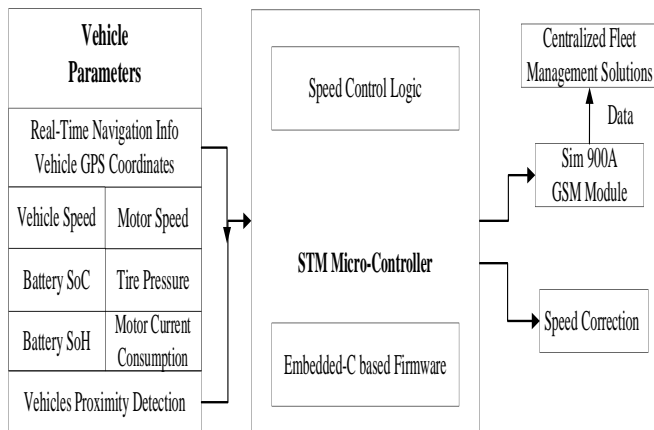

Fig. 1. Block Diagram for On-Road Electric Cargo Vehicle Speed Control.

The hardware consists of STM32 micro controller that offers advanced and flexible multi-core architecture, graphic support with power-efficient real-time control and high feature integration, ATMEGA 16 based PWM generators, DIP switches to select multiple enabling wireless technologies for IoT, powered by a standard 12 volts system, with GSM module operating at a voltage less than 4.5 volts [8].

V. PROPOSED METHODOLOGY

The optimum performance of an on-road cargo electric vehicle, measured in terms of the control of its speed may be obtained by tuning the parameters of the vehicle. The parameters that entail to be monitored include the vehicle speed, motor speed, tire Pressure, Battery SoC, Battery SoH, real time navigation points using GPS coordinates, motor current consumption, driver fatigue detection and the vehicle proximity detection.

An autonomous vehicle (AV) in general relies on the devices and components that exchange, share and construe data. Interoperability of the devices and components guarantee that they augur to shape an integrated ecosystem within the vehicle, effortlessly communicating with each other without forfeiting the performance [9].

The AVs experience inimitable capricious circumstances often and testing the on-road prototypes may be perilous and hence as an alternative, testing and validating AVs can be done using simulation for swift and cost-effective results. The guaranteed approach may be to explore the AV domain validity by means of parameterization and simulation by employing a sub-system-based test approach at the unit level in the developer bench [9].

While the AVs can reduce the burden on the driver and make the industry driverless, the march towards autonomous vehicles remains only in research for a while due to the consideration of dynamic changes in environment where the vehicle operates, bringing in many real-time unexpected factors outside its control. It may or may not require the presence of the driver, while the semi-autonomous vehicles can partially take few decisions based on the programmed intelligence at the IoT Smart Edge Nodes and enable/aid the driver with adequate recommendations [10].

The transition from manual to autonomous mode may take time to become reality, while the transition can be enabled by an interim option of the Semi-Autonomous Vehicle. It offers a realistic, pragmatic, and swift solution to necessitate mobility on-demand which refers to a vehicle operated by a human, not being self-driven. The solutions may serve to automate the driving functions under ideal conditions and can conduct the same task in a sustainable and convenient fashion.

The methodology informs the system of any circumstances that may curtail or disable the automated driving system in accordance with the demand, where in it requires the driver to perform the tasks. It involves the sensor fusion element, where the inputs from an onboard sensor that holds the semantic knowledge of the perceived environment becomes crucial for ensuing interpretation, prediction, planning and decisive action [11]. The priority on the entities considers the highest associated risk of collision with few sample entities including dynamic instances (e.g. (vulnerable) road users), static instances (e.g., road boundaries) and the obstacles on the path that surpass a specific size.

The monitoring of the electric vehicle state includes the status of the energy storage system that include the electric battery's state of Health (SoH) a figure of merit that indicates the battery level of degradation, state of Charge (SoC) providing information about the current amount of energy stored in the battery [12], the tire pressure which holds a high impact on the tire-road contact as it influences the characteristics of the tire forces [13], regulating the speed and movement of the electric vehicle by adjusting the PWM value on the DC motor thereby attaining vehicle Speed and motor speed control [14], real time navigation points using GPS coordinates that uses real time geographical data received from quite a few GPS satellites to determine the longitude, latitude, speed and route that aids in navigating the vehicle [15], motor current consumption, driver fatigue detection system that alerts the driver across multiple stages depending on the severity of the drowsiness symptoms [16] and the vehicle proximity detection which can probably reduce the fatality rate.

The monitoring of the parameters under consideration is conducted by using appropriate sensors at regular periodic intervals incessantly during the entire duration of the vehicle operation commencing from ignition ON to OFF that also includes the idle time with a periodicity of 10 ms maintained through a RTOS (real-time operating system).

The GSM for data monitoring mutually with GPS for live positioning facilitates secure and periodic monitoring of the parameters to initiate the STM32F746NG micro-controller, being the central backbone of the vehicle/system that offers reliability, performance calculating power, accessibility, real-time support, automotive bus interfaces, high speed data interfaces, digital and analog pins as well as low-power mode.

The SIM 900A, a readily available GSM/GPRS module for communication, operates with a mobile SIM card that provides internet connectivity to moving vehicles and systems. The process uses the SIM 900A to interface with the STM micro-controller by means of the serial data connection with the data

being sent from SIM 900A to the centralized server at regular intervals. The receiving interface system validates the data and upon receiving the command from the centralized server of the fleet management, when transferred to the STM controller can control the speed of the vehicle.

The highly configurable and quite versatile STM32 micro controller ensures edge processing when it conducts the computation of data directly in the smart sensor node or at the gateway, to save power consumption, guaranteeing data confidentiality, allowing analysis of the critical information at the node level, and reducing anomaly detection time [17].

The ARM interfaced to ATMEGA 16 based PWM generators simulate the vehicle speed, motor speed at the test bench. On receiving the commands, it processes the user sent instructions to operate the vehicle at its synchronized speed. However, based on the user commands, the processor simultaneously sends PWM signals for operating the motor at the desired speed to attain the desired movement.

The DIP Switch in the hardware system of the Fig. 2 facilitates to select connectivity in case of the scalable implementation across various enabling wireless technologies for IoT with the system employing two separate potentiometers for simulating the vehicle and motor speeds [19]. The hardware system as seen from the same figure receives the data from the IoT based intelligent embedded edge nodes and the sensors to allow the micro-controller for recommending the speed based on the software intelligence reflected through the Flow Chart depicted in the Fig. 3.

It operates together with the various vehicle parameters and facilitates the control implementation by means of actuators [20]. The speed correction arrives at the actuator and vehicle speed control recommendation is obtained either from the intelligence in micro-controller present within the vehicle or from the vehicle owner based on the data communicated through IoT mechanisms via SIM900A GSM Module.
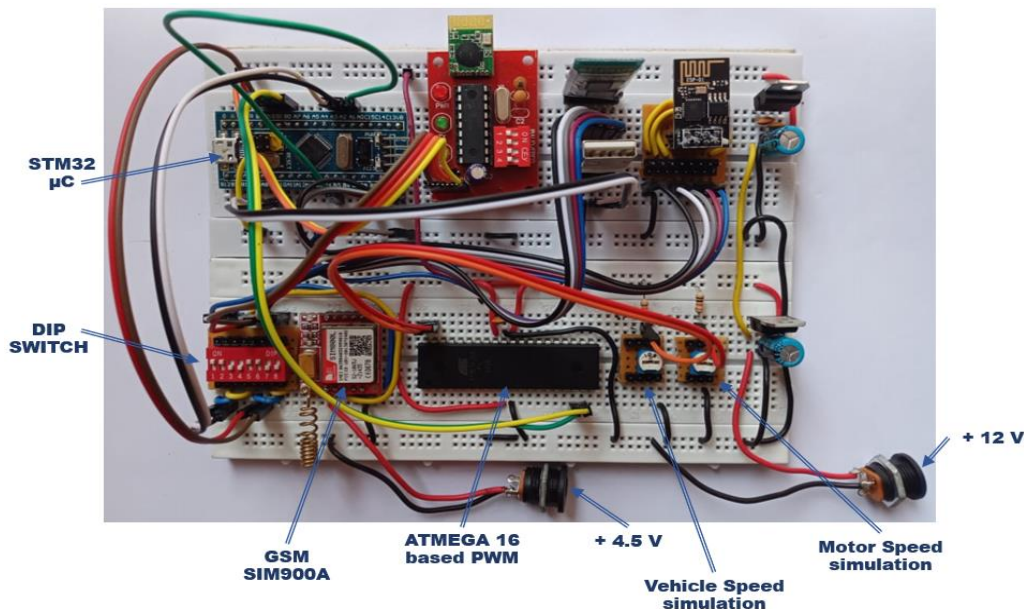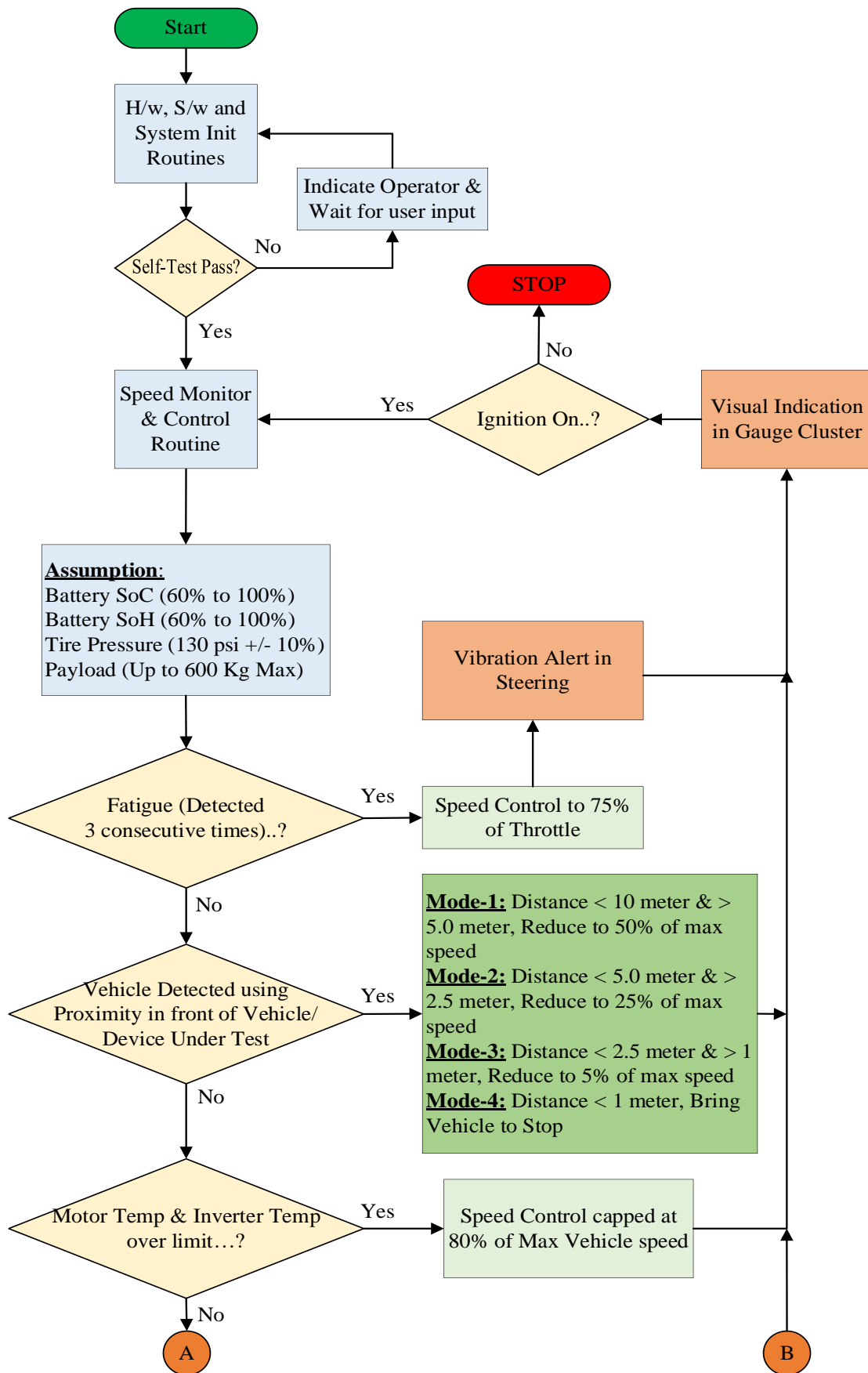

Fig. 2. Simulated Hardware Test System for On-Road Electric Cargo Vehicle Speed Control.

Start

H/w, S/w and System Init Routines

Indicate Operator & Wait for user input

Self-Test Pass? — No

Yes

STOP

Speed Monitor & Control Routine

Ignition On..? — Yes / No

Visual Indication in Gauge Cluster

Assumption:
Battery SoC (60% to 100%)
Battery SoH (60% to 100%)
Tire Pressure (130 psi +/- 10%)
Payload (Up to 600 Kg Max)

Vibration Alert in Steering

Fatigue (Detected 3 consecutive times)..? — Yes

Speed Control to 75% of Throttle

Mode-1: Distance < 10 meter & > 5.0 meter, Reduce to 50% of max speed
Mode-2: Distance < 5.0 meter & > 2.5 meter, Reduce to 25% of max speed
Mode-3: Distance < 2.5 meter & > 1 meter, Reduce to 5% of max speed
Mode-4: Distance < 1 meter, Bring Vehicle to Stop

No

Vehicle Detected using Proximity in front of Vehicle/ Device Under Test — Yes

No

Motor Temp & Inverter Temp over limit…? — Yes

Speed Control capped at 80% of Max Vehicle speed
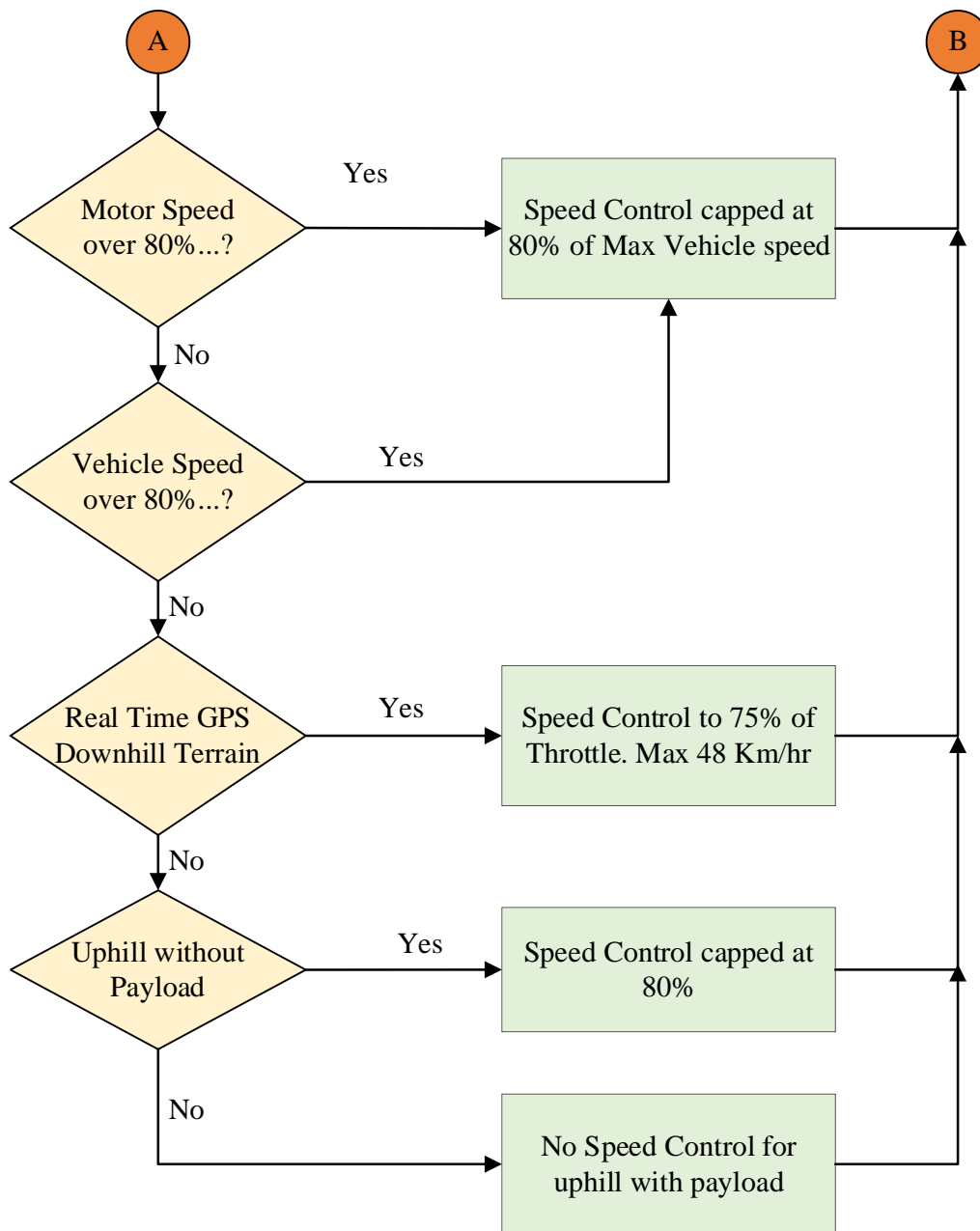
No

A

B

Fig. 3.   Algorithmic Flow Chart for On-Road Electric Cargo Vehicle Speed Control.

The IDE can be used as a development environment and the cross compiler together with the skeleton infra-structure is created with the required minimal base reset codes, initializing routines and hardware abstraction layer codes. It avails the FreeRTOS as the real time operating system functions to prioritize the task and events with embedded-C-based multi-function multi-file implementation along with the occasional assembly language instructions for accessing several registers and timing critical functions.

VI. SIMULATION AND TESTING

Understanding the accuracy offered by a simulation paves way for the means to determine its efficacy during development and validation activities. The automated/autonomous vehicles envisage the roads to be safer and operate cohesively using robust networks and powerful IoT based solutions being essential to reduce significant human errors [18].

The ᵉSupro, a stylish and spacious van launched by Mahindra & Mahindra Ltd, offers a whole new concept in cargo transportation in the sense it brings emissions down to absolute zero levels and proffers to be the first of its kind in India [18]. The benefits include being eco-friendly, direct drive transmission with a single speed gearbox and sophisticated speed management of the motor that allows to cruise through traffic effortlessly without shifting gears, home charging option that goes from 0 to 100% through a 15 amp plug point in just 8 hours 45 mins*.

The electric drive motor with an exceptional power of 25kW & 90 Nm torque gathers smooth drive with a top speed of 60kms/hr and on full charge it can run up to 110 kms. The revolutionary regenerative breaking technology helps it to literally recover the energy it dispenses. A unique instrument cluster provides valuable information in the form of the Status of Charge (Battery %), Distance to Empty (DTE), Speed, Gear Engaged, Total Running and E-gen efficiency. With a 72V lithium-ion battery, long-life, maintenance-free options are entrusted.

The boost mode provides the vehicle with additional power to manage steep inclines and the Revive® emergency feature gives an extra 7 kms range once the vehicle goes out of charge to reach the nearest charging point destination [21].

The Table I given below provides all the Technical Specifications for the chosen electric vehicle Mahindra eSupro and the Cargo Van Specifications for the same is furnished in Table II along with the input parameters and the simulation values in the Table III.

The testing adopts a simulation procedure explained using the Fig. 4 that entails generating the sensor signal using appropriate instruments to check the embedded firmware code implemented for the vehicle speed control. The process engages to simulate the engine and vehicle speed with 2 separate ATMEGA 16 based function generators and predicts the vehicle tire pressure, Battery SoC, Battery SoH, while providing information on real time navigation and payload as serial data over the bus.

The vehicle parameters on being simulated with the preconditional assumption that the vehicle continues to be fully functional with the IoT connectivity. The Intelligent Edge Node Smartness aids only in controlling while it relies on the IoT infra-structure for data monitoring and assumes that the SoC, SoH, Payload, Tire Pressure remain within the permissible limits.

TABLE I.   MAHINDRA eSUPRO TECHNICAL SPECIFICATION

Battery and Electric Motor		Warranty	
Battery Pack Rating	200Ah	Vehicle	2yrs / 40,000kms**
Electric Motor	3-ph, AC induction	Battery	3yrs / 40,000kms**
Max Power	25kW @ 3000 rpm	**Vehicle Dimensions**	
Max Torque	90Nm @ 1500 rpm	Length	3798 mm
Suspension		Width	1540 mm
Front	McPherson Strut with Coil Spring	Height	1922 mm
Rear	Leaf Spring	Wheelbase	1950 mm
Wheels & Tires		Ground Clearance	130 mm
Wheels	4.5J x 13	**Performance**	
Tire Size	155/80 R13 Radial Tubeless	Top Speed	60 km/hr
Brakes		Battery Range	115* kms (Cargo Van)
Front	Hydraulic, Disc	Charge Time (0 to 100% @ 25ºC)	8 hours 30 minutes
Rear	Hydraulic, Drum		

TABLE II.   MAHINDRA eSUPRO CARGO VAN SPECIFICATION

Specifications	Cargo Van
Seating Capacity	Driver + Co-Driver
Loading Bay (L x W x H in ft)	6 x 4 x 4
Loading Volume (litre)	2330
Payload (kg)	600
Gross Weight (kg)	1920
Kerb Weight (kg)	1320

It simulates the proximity of the other vehicles through the variable power supply (PoT), with the consideration that higher voltages relate to the objects being closer. Even though the object detection on the four directions becomes realizable, it recognizes precedence for the frontal detection.

The system, with the prioritized parameters in the Table IV attaches the highest priority to the Battery SoC & SoH and provides control over the speed only if both the parameters remain within the permissible limits, in addition to the tire pressure and payload. However, a change of the parameters together with its priority persuades the commendation of the requisite speed to be set and thus administers the accurate operational requirements to eventually achieve the desired speed control objective.

TABLE III.   INPUT PARAMETERS AND SIMULATION VALUES

| S.No.	Parameter	Max. Value Observed in Vehicle	Ideal / Optimum Value	Sensor Output		Simulation Range
				O/p Signal	Value (with unit)	
1	Motor Speed	3000 rpm	2400 rpm	PWM	Hz	0 to 150 kHz
2	Vehicle Speed	60 km/hr	48 km/hr	PWM	Hz	0 to 150 kHz
3	Truck Payload	600 kg	600 kg	Raw Data	Ton (kg)	N/A
4	Tire Pressure	130 psi	130 psi	Raw Data	Psi	N/A
5	Battery SoC	100 %	60% < SoC < 100%	Raw Data	%	N/A
6	Battery SoH	100 %	60% < SoH < 100%	Raw Data	%	N/A
7	Driver Fatigue (Eye) Detection	No	No	Boolean	Yes/No	Yes/No
8	Motor Temperature	70 deg cel	70 deg cel	ADC	Voltage	0 to 100 deg cel
9	Real Time Navigation points using GPS	20.04 deg, 20.04 deg	Non-Zero Number	Latitude, Longitude	Number	Random Values
10	Motor Current Consumption	2.1 Amp	2.1 Amp	Current Reading	Amp	0 to 10 Amp
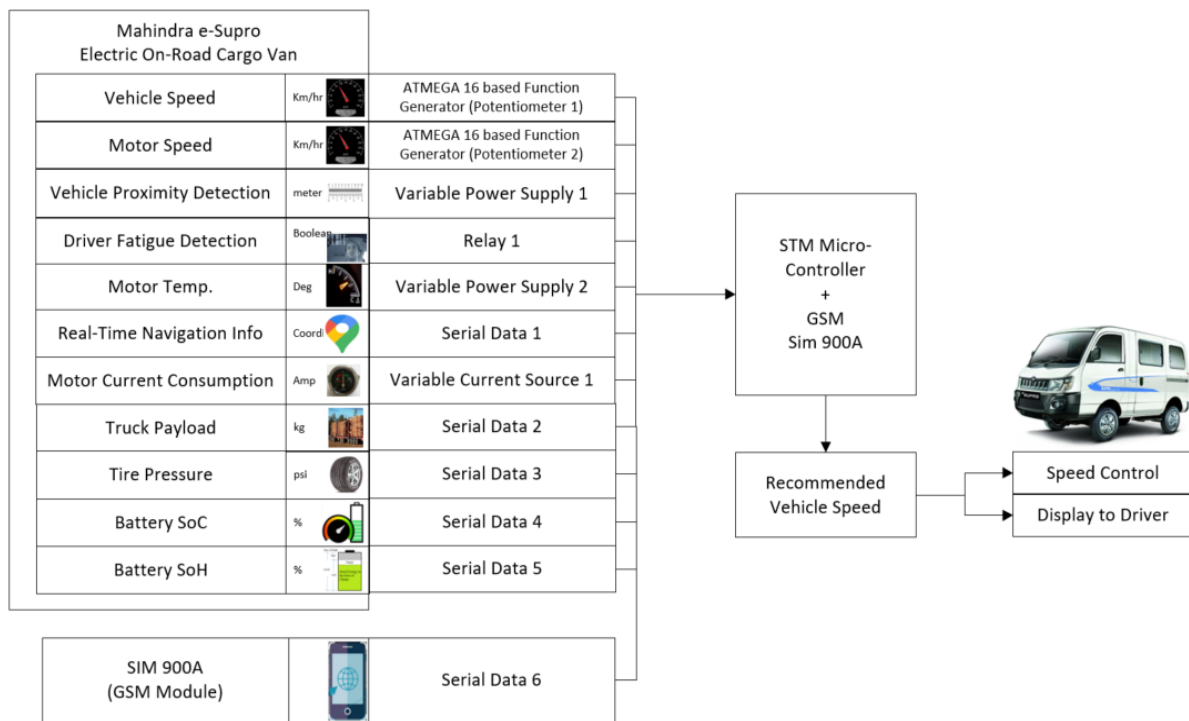
Fig. 4.   Simulation and Testing Block Diagram for On-Road Electric Cargo Vehicle Speed Control.

TABLE IV.   PRIORITIZED PARAMETERS

Parameter	Priority
Battery SoC	1
Battery SoH	2
Driver Fatigue (Eye) Detection	3
Vehicle Proximity Detection	4
Real Time Navigation points using GPS	5
Vehicle Speed	6
Motor Speed	7
Motor Current Consumption	8
Motor Temperature	9
Truck Payload	10
Tire Pressure	11

VII. RESULTS AND DISCUSSION

The target owes to examine the use of the IoT for the speed control of a battery operated on road electric vehicle across the standard operating ranges of the SoC, SoH, payload and tire pressure as detailed in the Table V. It operates on the etiquettes of the ARM microcontroller from where it controls the speed in tune with the demands over specific time frames. It monitors the other parameters with the relative sensor inputs being simulated and evaluates the vehicle for the control of the speed through the feedback mechanism from the micro controller.

The scheme rallies to vary the pulse widths to realize the change in the speed using the controller module in the ATMEGA-16 based function generator. It simulates various cases of speed ranging from 0 to 100% of the vehicle top speed, which corresponds from 0 to 60 km/hour over a span of 20 minutes rehearsing an emulation of the actual vehicle under stable operating conditions.

Fig. 5 depicts the input pulse and the output response where the vehicle when operated up to 80% of the max speed yields higher life for the battery and provides better mileage. When the vehicle crosses the expected speed, the controller reacts by reducing the speed with a deviation of ±5% which enables to extend the life- time of the battery.

The variations in the speed of the motor seen from the Fig. 6 show that the motor speed remains at an optimum of 70% to 80% of its max capacity to ensure its smooth functioning. It further explains that when the motor speed attempts to go above 80%, the micro-controller recommends the vehicle speed to be reduced.

The graph in the Fig. 7 relates to restricting the motor to operate within an ideal temperature range of around 70 deg Celsius with a view to achieve the maximum power output and a long lifespan for the battery. Since the temperature of the motor can be reduced by lowering the load on the motor, in case the temperature exceeds 70 deg Celsius, the micro-controller allows reducing the load to bring the vehicle speed within a minimal deviation of ± 5%.

TABLE V.   OPERATING RANGE OF VEHICLE PARAMETERS

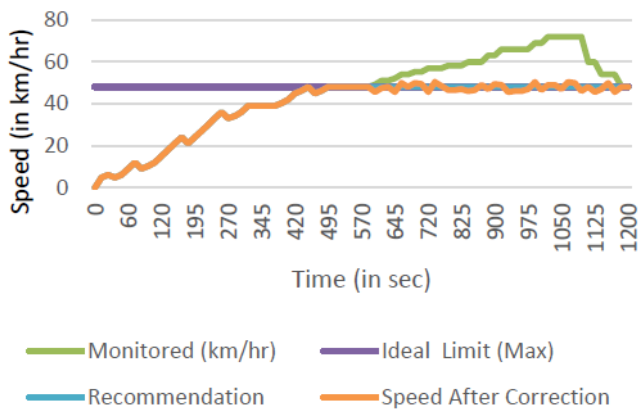| Parameter	Values
Battery SoC	60% to 100%
Battery SoH	60% to 100%
Tire Pressure	130 psi ± 10%
Payload	Up to 600 kg (max)

Fig. 5.   Speed Control based on Vehicle Speed.
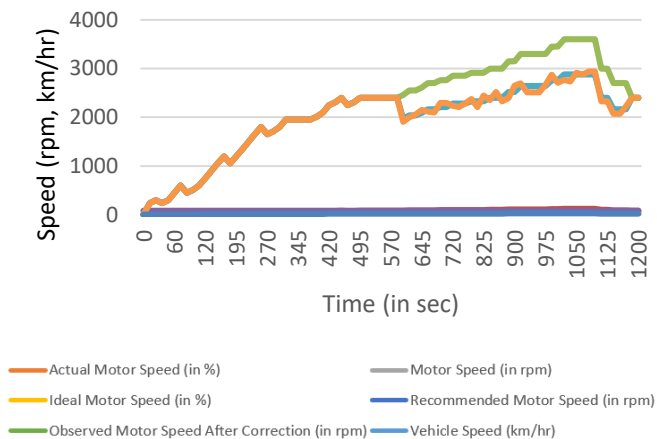

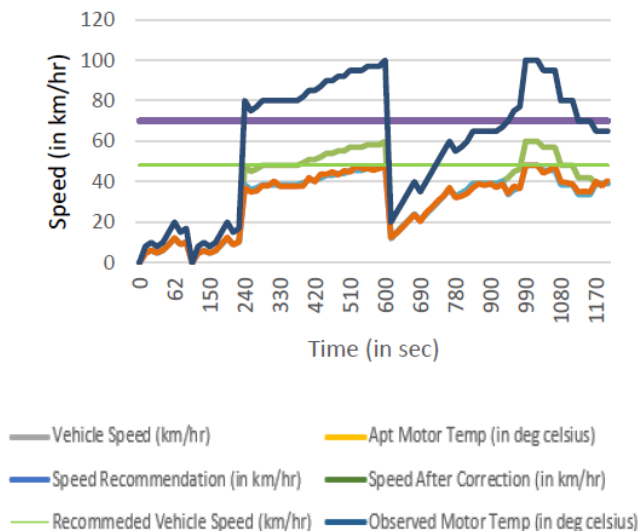Fig. 6.   Speed Control based on Motor Speed.

Fig. 7.   Speed Control based on Motor Temperature.

The driver's fatigue detection constitutes to significant criterion for manual and semi-autonomous vehicles for enabling the speed control from an increased safety

perspective. The fatigue detection as shown in Fig. 8 returns a Boolean value to indicate the safe operating conditions and in any case without the fatigue being detected, the speed of the vehicle depends only on the other parameters. Whereas in case of fatigue detection, identified by three or more consecutive repeated occurrences, considering the safety of the driver, irrespective of the vehicles speed being within or above limits, the driver receives a visual warning through the dashboard, vibrational warning through the steering system to reduce the vehicle speed to 75% of the current speed and then regulates it to be not above the recommended max of 42 km/hr.

The speed control based on Real Time GPS input coordinates underscores further study under two different cases that include the uphill and downhill terrain travel without payloads. When the vehicle travels uphill as shown in Fig. 9 or downhill as shown in Fig. 10, it does not travel a straight path with predefined fixed inclinations. However, with an empty on road electric cargo vehicle travelling upwards with no payload, the speed restrictions can be functional. With payload, limiting the speed may not provide the vehicle with required momentum, pulling power and traction to climb uphill.
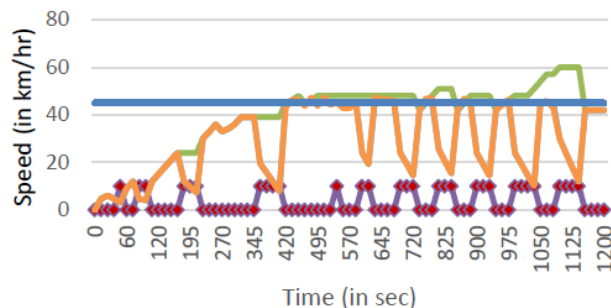

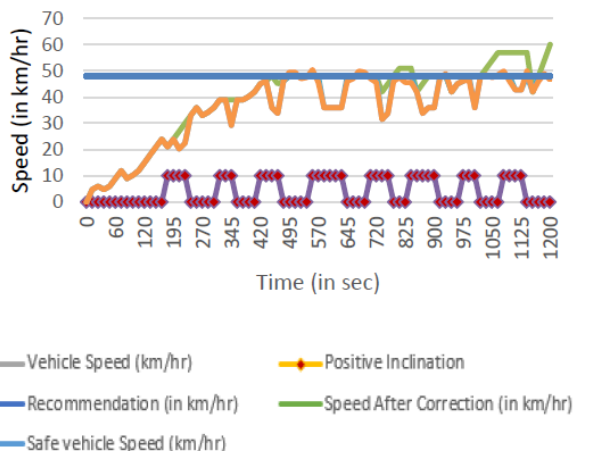Fig. 8.   Speed Control Due to Fatigue Detection.

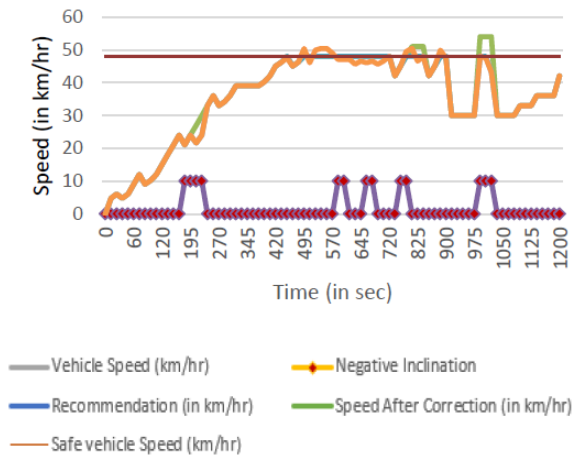Fig. 9.   Speed Control based on Uphill terrain Movement (without Payload).

Fig. 10. Speed Control based on Downhill Terrain Movement.

The speed control in the case of the vehicle travelling downhill may be very tight considering the safety of the driver, as control can be lost easily travelling downhill. The test results illustrate that the speed requires to be maintained/reduced to 80% of the driver's acceleration input, besides ensuring that it does not exceed the max speed of 48 km/hr.

It employs a proximity sensor deployed appropriately on the front grill to circumvent a crash and attempts to discern the obstructions in the frontal path of the vehicle. It orients to report the distance at which it detects the obstruction or the vehicle and follows a four-stage classification based on the distance to estimate the proximity from the frontal side of the vehicle and allow the speed reduction appropriately in the four different modes as noted in the Table VI.

It simulates the obstructions detected along with its distance from the vehicle, with the distance as the key parameter for determining on speed control. The Fig. 11 derives the resultant output enabling the speed control based on the distance reported between the vehicle and the nearest obstruction.

The intelligent microcontroller monitors the requisite parameters and elicits a decision based on more than one criterion. The results also show that the algorithm either maintains or reduces the speed of the vehicle automatically and notifies the driver that the speed reduces to the recommended level with a deviation of 5% and accuracy of 95%, as observed from the simulated results. Future research can be envisaged to validate the base parameters considered for speed control with its priorities, experiment with a different RTOS, test the same system and at integration level or system level, integrate with a real vehicle and so-on.

TABLE VI. SPEED CONTROL AS PER THE PROXIMITY RANGE

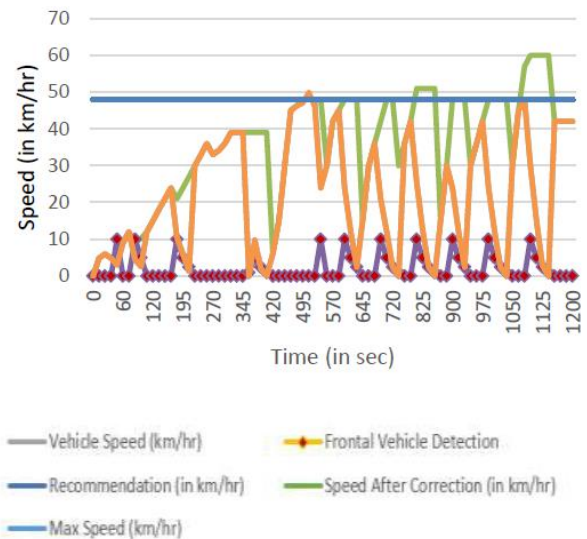|	Distance between the vehicles frontal end and Obstruction	Speed reduction (% of applied throttle)
Mode 1	> 5 to < 10 meters	50%
Mode 2	> 2.5 to < 5 meters	25%
Mode 3	> 1 to < 2.5 meter	5%
Mode 4	< 1 meter	0% (Stop)

Fig. 11. Speed Control based on Frontal Vehicle Detection.

VIII. CONCLUSION

An IoT based methodology suitable for controlling the speed of a battery operated on road eSupro cargo vehicle within the prescribed parametric range has been developed. The firmware design has been articulated using an ARM microcontroller through which it obtains the variation in the width of the PWM pulse for the converter interface that in turns controls the motor operating the vehicle. It has been formulated using the real time input from the GPS for controlling the speed based on the location services and a proximity sensor suitably deployed on the front grill. The test bench of the algorithm has been laid from a real time python-based coding to provide the varying requirements to the microcontroller through the inputs to the interface. The simulation results have been presented to foster the suitability of the scheme for use in on road cargo vehicular systems.

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