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Original Article

IoT Based Multi-Modal Speed Controller for an Off-Road open port Electric Double Cab Vehicle

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Abstract **-** *The paper introduces an IoT platform to evolve a multimodal speed control mechanism for a double cab off-road electric vehicle operating in open port conditions. It attempts to integrate an embedded system using anARM core-based STM32 Microcontroller for monitoring the vehicle with its payload and, therefrom, provides a recommendation to control the speed in accordance with the variations in real-time. The system design involves the influence of passenger occupancy status, vehicle speed, engine speed, battery SoC (State of Charge), battery SoH (State of Health), and real-time navigation using various sensors and GPS-based IoT maps consideration. It develops a closed-loop monitoring scheme to follow a sequence of steps that allows the vehicle to remain safe in operation over a sustained duration. The results obtained from the modular test simulation process through the embedded-c firmware illustrate the advantages and establish the performance of the vehicle in relation to the efficiency of the algorithm on a wide dynamic range of varying payload and passenger combinations.*

Keywords **-** *Off-Road, Harbour Application, Open Port, Electric Vehicle, Varying Payload, IoT, Speed Control, Passenger Safety, Battery Sustenance, Micro-Controller, Embedded System, Automotive Application*

I. INTRODUCTION

With the myriad of vehicles present in the market, the vehicles can be broadly classified based on application, fuel usage, the number of wheels and axles, and payload capacity in the two categories of on and off-road for both passengers and goods (segment). The double cabs, however, invite interest due to the heavy demand and an increasing need to move people off-road to and from a place of work besides carrying the payload.

The fast-depleting fossil resources, together with the compliance of the green energy theory, enforce a new dimension to bring in electric vehicles on a wide scale in the different classes of traffic. It fosters to increase the efficiency and prolong the life of the batteries in the perspective of enabling mass adoption to create a sustainable environment for current and future generations.

Ensuring the safety of the vehicle and thriving on increased battery life forge to vehicle sustenance by operating the vehicle at optimum and controlled speeds over a longer period. Unlike a goods vehicle used only for payload, the double cabs also carry passengers, and hence the speed control recommendations require being more reliable and mostly dynamic based on real-time maps and IoT based monitoring and control strategies as Edge-based smart, intelligent embedded systems can reduce the demand on cab operator over longer shift hours.

II. RELATED WORK

With more automation and sustainability gathering importance for environmental and safety reasons, the automotive industry targets to enable the intelligence in the vehicle for it to decide by itself to plan on all actions related to safety, making it a fully automated vehicle.

A simple prototype has been built using Arduino along with the modules for communication in connected cars involving car2car car2infrastructure and analyzed as a cruise control system. A Simulink model has been used to calibrate and parametrize the system([1] – [4]).

The vehicles have been connected using more than one technology([5],[6]), whereas in vehicular Adhoc Networks(VANETs)and Mobile Ad hoc Network (MANET) (are) seen to exhibit a strong potential in improving road safety and providing travelers comfort. A good number of applications have been suggested using the VANETarchitecture and most appropriate simulation tools to simulateVANETprotocols([7]-[10]).

Off late, the passenger segment safety is gaining more traction. Vehicle safety systems research today mostly takes the on-road passenger segment into consideration. In the event of an accident, occupant protection systems are intended to keep the accelerations and forces that act on the passengers lower the consequences of the accident. Vehicle safety active safety systems help to prevent accidents and thus make a preventative contribution to road traffic safety.

One example of an active antilock braking system (ABS) with an electronic stability program(ESP) has been brought out to stabilize the vehicle even in critical braking situations that maintain steerability in the process. The passive safety airbags systems have been introduced to protect the occupants against serious or even fatal injuries after an unavoidable impact ([11]-[15]).

The connected and automated vehicles (CAVs) have been endowed with the potential to address the safety, mobility, and sustainability issues of our current transportation systems. The cooperative adaptive cruise control (CACC) has been reflected as a promising technology to allow CAVs to be driven in a cooperative manner and enjoy system-wide benefits. Different control methodologies have been used for different aspects of CACC systems and their related issues investigated from a lower level([16]-[20]).

A large share of automotive innovations has been opined to offer significant improvements in purely mechanical systems using integrated electronics together with complex information processing [21]. A host of mechatronics solutions with a concurrent design of mechanical, electrical, and information processing sub-systems have been outlined for different automotive applications([22], 23]).

Despite the ongoing developments, there still exists a huge gap in terms of being able to adapt the speed control along with passenger safety for an off-road goods vehicle, in particular upcoming niche segments like a double cab, becoming more popular.

III. PROBLEM DEFINITION

The focus orients to arrive at a multimodal speed control scheme based on the dynamic payload and passenger detection for an off-road electric vehicle primarily used in the harbor. It attempts to use a Wi-Fi Mesh enabled IoT network and realize the algorithm through an ARM code-based STM32 microcontroller. The design formulation tailors to consider the active payload along with the vehicle speed, engine speed, battery soc (state of charge), battery soh (state of health), and real-time navigation in laying down the methodology. It evaluates the algorithm's adaptability by bench testing-based simulation to demonstrate its real-time adoption to production lines.

IV. PROPOSED WORK

The Off-road double cab electric vehicles used at harbors usually face the challenge of operating safely in addition to preserving their batteries for a complete a specified duration of operation or shift when they operate, and hence it requires to preserve the batteries by operating the vehicle around (its) ideal speed. The directives relating to the ideal speed depending on the vehicle parameters may serve to model increased efficiency and optimum performance.

Fig.1 shows the architecture using a block diagram representation including the electric vehicle power source and its associated auxiliary circuits to explain the basic philosophy relating to the speed control of safety and increased performance for the chosen double cab with parametric considerations across the operating range. The approach relates to laying down a multi-modal intelligent dynamic speed control for maintaining optimum speed based on the dynamic load that may derive maximum efficiency for its application.

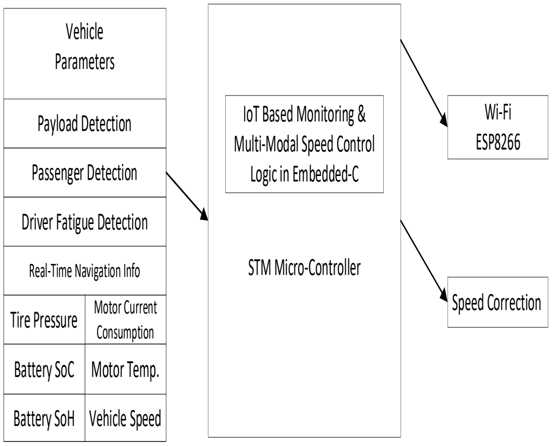

Fig.1: Block Diagram

The specifications for the off-road electric double cab understudy shown in Table.1 include seats to accommodate 4peopleinside the cab, including the driver, and reach a top speed of 44 km/hr. The vehicle can negotiate slopes up-to27% inclinations, but the vehicle augurs to operate on flat terrain in an open-port harbor.

TABLE.1: VEHICLE SPECIFICATION

S. No.	Parameters	Value
	Max Autonomy (Lead Acid 10 k WH)	64 km
	Max Autonomy (Gel 8.7 kWh)	54 km
	Wheelbase (in mm)	2890
	Approach Angel (in deg)	40
	Departure Angel (in deg)	10
	Rear Axle Distance from Ground (in mm)	130
	Maximum Loading Bed Length (in mm)	1800
	Maximum Loading Bed Width (in mm)	1500
	Maximum chassis Load Capacity (in Kg)	1150

The vehicle uses a standard Lead-Acid 10kWh battery, 8x6V configuration 48V AC, 14 kW, 113 Nm asynchronous induction electric motor including a CURTIS 48V control electronics with an estimated 1200 cycle battery life and, if operated under optimum condition, can cover a maximum of 64 km[19]. It requires a battery charging time of 9 hours and is estimated to last a full 8-hour shift cycle under ideal conditions, with the vehicle also incorporating a 12V services auxiliary battery.

The parameters to be monitored for controlling the performance include passenger detection, truck payload, tire pressure, engine speed, vehicle speed, Battery SoC, Battery SoH, Driver Fatigue (Eye) Detection, real-time navigation points using GPS, motor temperature, and motor current consumption using suitable sensors unceasingly during the complete vehicle operation at a periodic interval, including shiftless time with the RTOS maintained 10 mscyclicity. Table.2 below documents the list of parametric values, their correlation to sensors, simulation range, and its ideal values for the chosen vehicle.

TABLE.2 PARAMETRIC VALUES

SS. No.	Parameter	Max Value observed	Ideal/ optimum	Sensor Output Output	Units	Simulation Range
1	Motor speed	2000 rpm	1600 rpm	PWM	Hz	0 to 10 kHz
2	Vehicle speed	44km/hr	35.2km/hr	PWM	Hz	0 to 10 kHz
3	Truck payload	1150 kg	1150 kg	Raw Date	ton	0 to 1150 kg
4	Tire Pressure	130 psi	130 psi	Raw Date	Psi	0 to 170 psi
5	Battery SoC	100%	60%<SoC < 100%	Raw Date	%	0 to 110%
6	Battery SoH	100%	60%<SoH < 100%	Raw Date	%	0 to 110%
7	Driver Fatigue (Eye)	No	No	Boolean	Yes/No	Yes/No
8	Motor Temperatue	70 degcel	70 degcel	ADC	Voltage	0 to 100 Deg cel
9	Real-Time Navigation Points using GPS	20.04deg, 20.04deg,	Non –Zero Numer	Latitude, Longitude	Number	Random values
10	Motor current Consumption	2.1 Amp	1.68 Amp	Current Reading	Amp	0 to 3.15 Amp

V. PROPOSED METHODOLOGY

The primary design objective engages in proposing close periodic monitoring of the vehicle with a need to control the speed of the vehicle in terms of either reducing or increasing the speed to suit the requirements on the guidelines of the parametric and payload considerations relying on the sensor communication to IoT based edge intelligent micro-controller STM32F746NG.

It forms a Wi-FiMesh network using Wi-Fi routers and repeaters to communicate with the external world using an IoT mechanism through the centralized gateway within the proposed premise. Every harbor incorporates a pre-designated safe pathway for its daily operations with devoted safe passage marking for human and goods movement.

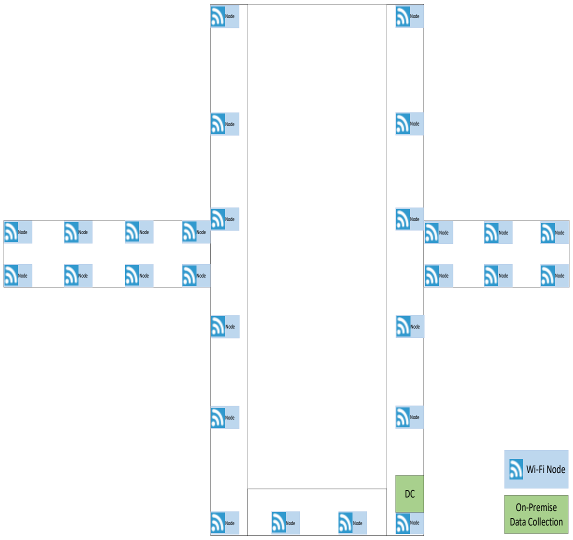

Fig 2: Port on Wi-Fi Mesh

The IoT-based smart edge device acting as an intelligent micro-controller uses the Free-RTOS over the control algorithm that periodically monitors the vehicle parameters, processes them based on the priorities, and recommends the speed to be set while receiving a feedback signal through lively mechanisms. It uses the Embedded-C-based firmware code on a scalable and modular architecture and performs unit-level testing at the developers' bench using simulated inputs.

Fig.3displays the architectural communication overview from the vehicle to the centralized unit and vice versa with Hardware, Hardware Abstraction Layer, Vehicle Application Layer, User Interface, Wi-Fi-based IoT Monitoring, and Control Interface. The Hardware abstraction processes by scaling the sensor data and transports it to the successive layer as meaningful data after validation and analysis.

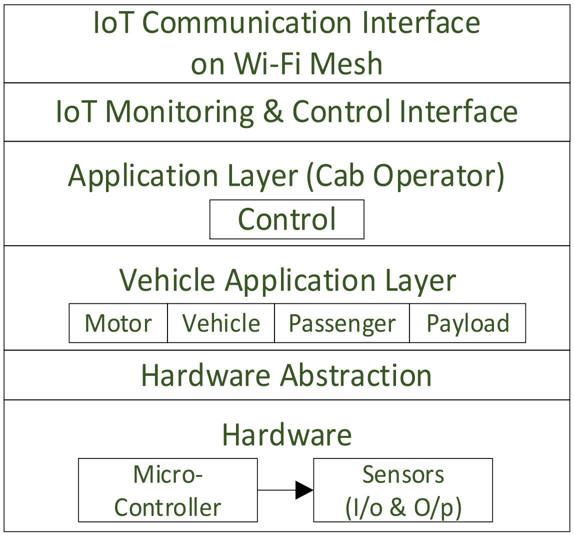

Fig.3: Software-Architecture

The IoT uses Wi-Fi for its data and communication between devices and the LAN-based internet for updating the data to the cloud for remote monitoring and control. The Wi-Fi repeaters installed across the port serve as a standard inter-operable, fully functional off-the-shelf product, using global 2.4 GHz.It involves the choice of either star, mesh, or tree chosen depending on various criteria of the application like communication range, repeatability, signal strength, application communication needs, and depth of communication.

While the Star topology finds scope in the centralized single point control short-range communication, the tree topology gathers prominence where the range needs to be extended to cover a larger area. The study, however, owes to the use of the Mesh topology as it predominantly relates to peer-to-peer communications, and data reliability becomes important as in safety-critical systems.

The ESP8266 Wi-Fi communicates with the STM32 through serial lines and sends updates through the stationary Wi-Fi modules to the centralized units. The addressing mechanism of these Wi-Fi devices can be either static or dynamic and assumes to be interoperable. It traverses the data to the centralized unit through the stationary mains power module acting as hoppers. The centralized node consolidates the data, analyses, processes, and stores in the prescribed format with a detailed view of the fleet management and the vehicle owner. The speed control can either be from the edge node or fleet management or maintenance team through the intermediate I-Finodes.

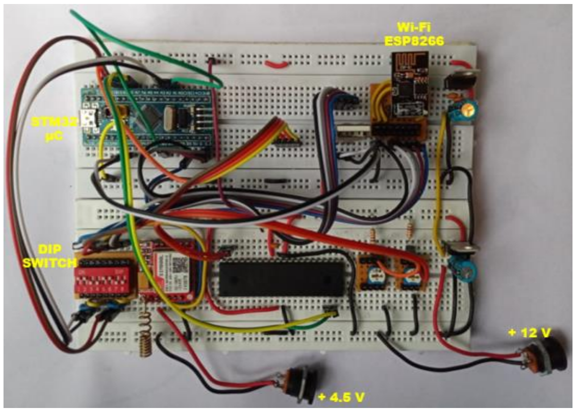

Fig.4: Hardware System

The hardware architecture seen in Fig.4 receives the vehicle data and smart microcontroller-based embedded algorithm and recommends the speed based on a multimodal dynamic payload-based approach from the observed values and its priorities as explained in the decision logic in Fig.5. The speed correction acts through the electric motor by controlling its current flow obtained either from the vehicle's IoT edge node decided either by its own intelligence or commanded by external fleet management through Wi-Fi-based communications.

Without using any additional sensors, the number of passengers in the vehicle may be sensed by detecting the seat belt usage, as wearing a seat belt becomes mandatory during travel in accordance with the existing safety norms. The vehicle needs at least a minimum of one seat belt to be activated at the cab-operators position for the vehicle to start.

The Payload remains stationary during the time of travel and maybe sensed by using a dedicated truck payload monitoring sensor which can be mounted on the suspension. The predominant inputs to the speed control algorithm are the payload and the number of passengers present, and it provides the setpoint speed taking into consideration the vehicle speed, GPS-based boundary detection, and driver fatigue detection.

The methodology uses the STM-32 IDE for cross-compilation with hardware abstraction layer code provided by IDE on the selection of controller, with reset, init routines, using FreeRTOS to prioritize on C-Language based implementation with ASM instructions to provide the necessary directives.

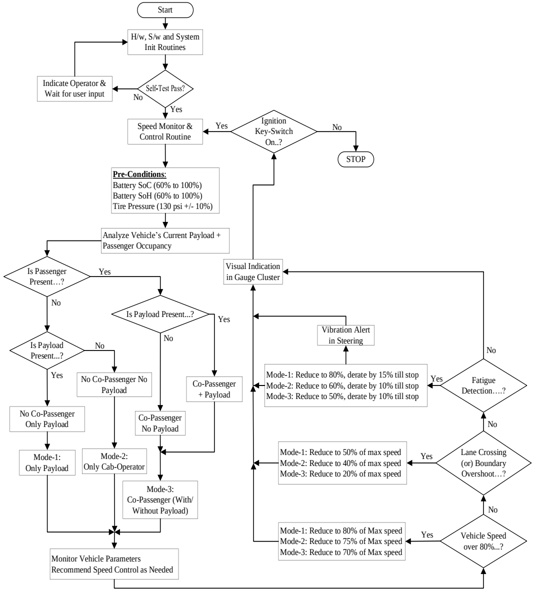

Fig.5 Algorithmic Flowchart

V. SIMULATION AND TESTING

The testing follows a simulation procedure using a module-based test approach by varying one input at a time, keeping the other parameters either as a constant or at a known operational level. It entails emulating the sensor signal using suitable instruments to validate the speed control algorithm implemented as an embedded firmware code. The process uses two different function generators to simulate the engine and vehicle speed.

It assumes the tire pressure, Battery SoC, and SoH to be under safe, functional operational ranges, while it envisages the passenger presence, payload, and Navigation Info as serial data, detects the driver fatigue through a relay contact and a variable current source for measuring the motor current.

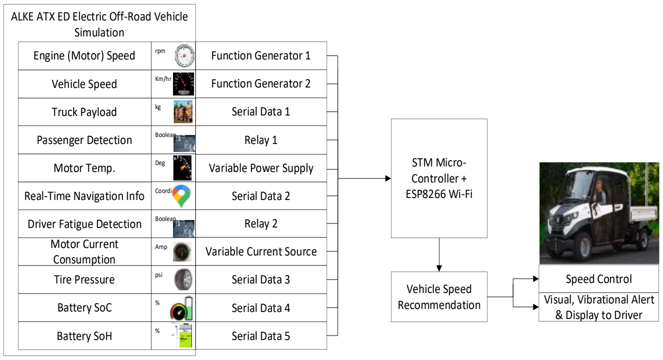

Fig.6: Simulation &Unit Test Architecture

The system, due to its multiple input criteria, demands prioritizing based on passenger's safety criticality, increased efficiency, and sustenance of the vehicle. The scheme accords the highest priority to the Battery SoC, SoH, and the tire pressure, and any change in the parameter based on its priority impacts the recommendation of the required speed to be set and thereby governs the precise operational requirements. The Payload and Passenger detection receive the next level of priority followed by the fatigue detection and others while assuming these vary within the permissible operating conditions.

TABLE.3: PRIORITIZED PARAMETERS

S.No.	Parameter	Priority
1	Engine Speed / Motor Speed	9
2	Vehicle Speed	6
3	Truck payload	3
4	Tire Pressure	10
5	Battery SoC	1
6	Battery SoH	2
7	Driver Fatigue (Eye) Detection	4
8	Motor Temperature	7
9	Real Time Navigation Points using GPS	5
10	Motor Current Consumption	8

VII. RESULTS AND DISCUSSION

The IoT-based micro-controller examines the efficiency of the algorithm and its readiness for adoption to mass production, assuming standard operating ranges for SoC, SoH, and tire pressure as depicted in Table.4.It monitors the parameters of the vehicle with the relative sensor inputs being simulated and tests the vehicle for the control of the speed through the feedback mechanism from the microcontroller.

TABLE 4: OPERATING RANGE OF VEHICLE PARAMETERS

Parameter	Values
Battery SoC	60% to 100%
Battery SoH	60% to 100%
Tire Pressure	130 psi +/-10%

The implementation scheme originates using a button-controlled Tektronix function generator with varying pulse widths to realize the speed change to controller module simulating speeds from 0 to 100% of vehicles speed, corresponding from 0 to 44.0 km/hrover a20-minute time boundary assuming stable operating conditions.

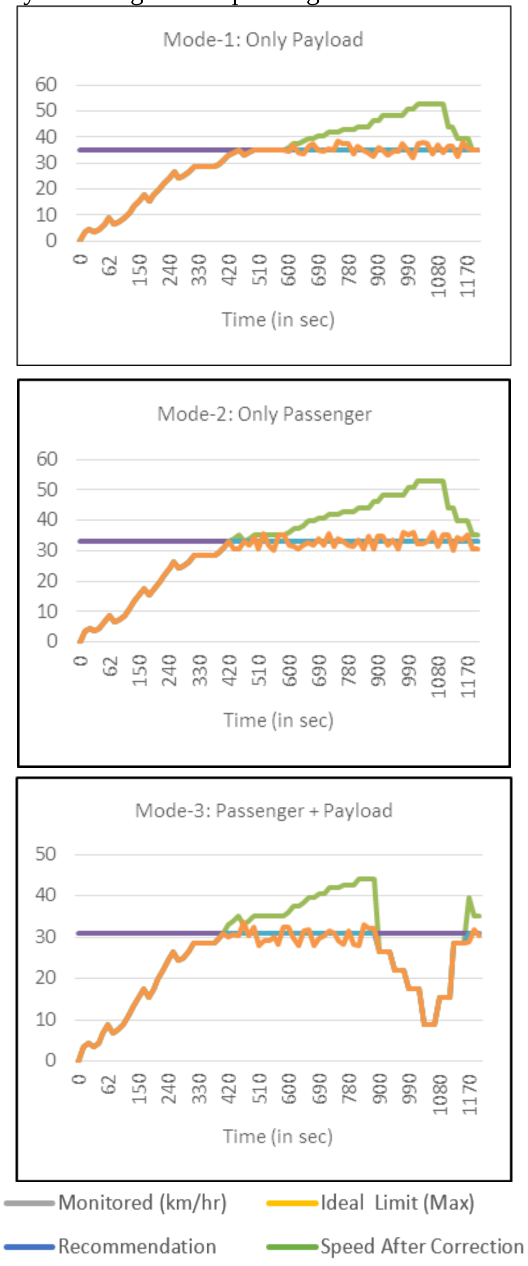

Fig.7 Speed Control at Varying Vehicle Speeds

Fig.7 illustrates the input and output response when the vehicle operates from 0% to 100% and the controlled speed up to 80% of the maximum speed harvesting a greater battery life and offers a superior mileage. The algorithm allows the maximum speed of the vehicle to be 80% for the mode of only payload, while it limits it to be 75% when the vehicle accommodates only the passenger and to70% if the vehicle operates with both the payload and passenger.

The plots explain that when the vehicle goes beyond the expected speed, the controller brings in a reduction in the speed with a deviation of (±) 9%. However, when the vehicle speed plummets lower than the expected maximum value, it does not allow the increase in speed to extend the life of the battery.

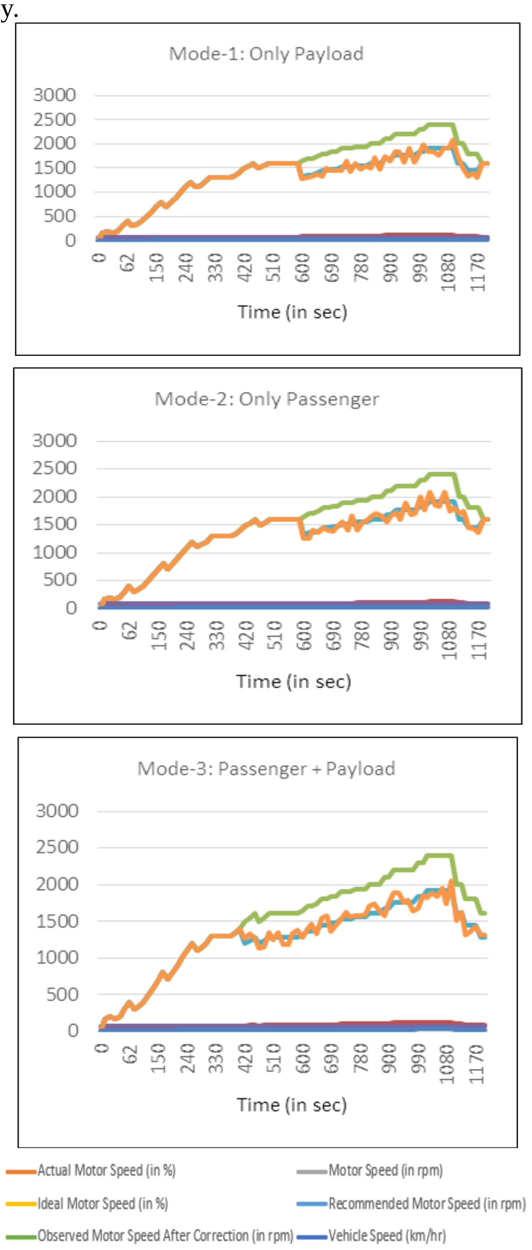

Fig.8: Speed Control based on Motor Speed (in RPM)

The motor speed variations seen in Fig.8 indicate that the motor speed remains at an optimum of 70% to 80% of its maximum value and thereby supports the multi-modal dynamic payload implementation.

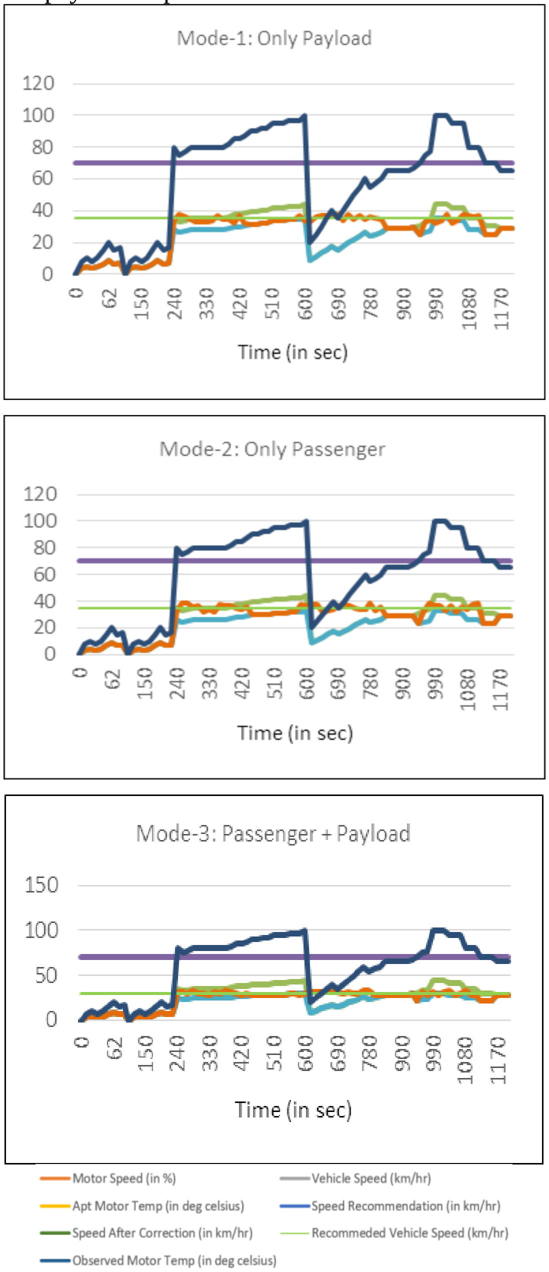

Fig.9 Speed Control Based on Motor Temperature

The graph shown in Fig.9 above correlates to reducing the vehicle speed by lowering the motor speed and enabling the motor to operate around an ideal 70 deg Celsius temperature range to achieve the maximum power output coupled with the battery's longer lifespan. When the motor temperature exceeds 70 deg Celsius, depending on the mode of operation (Mode-1, 2, or 3), the micro-controller recommends an appropriate ratio for the load to be lowered, resulting in the reduction in the vehicle speed with a deviation of (±)9%.

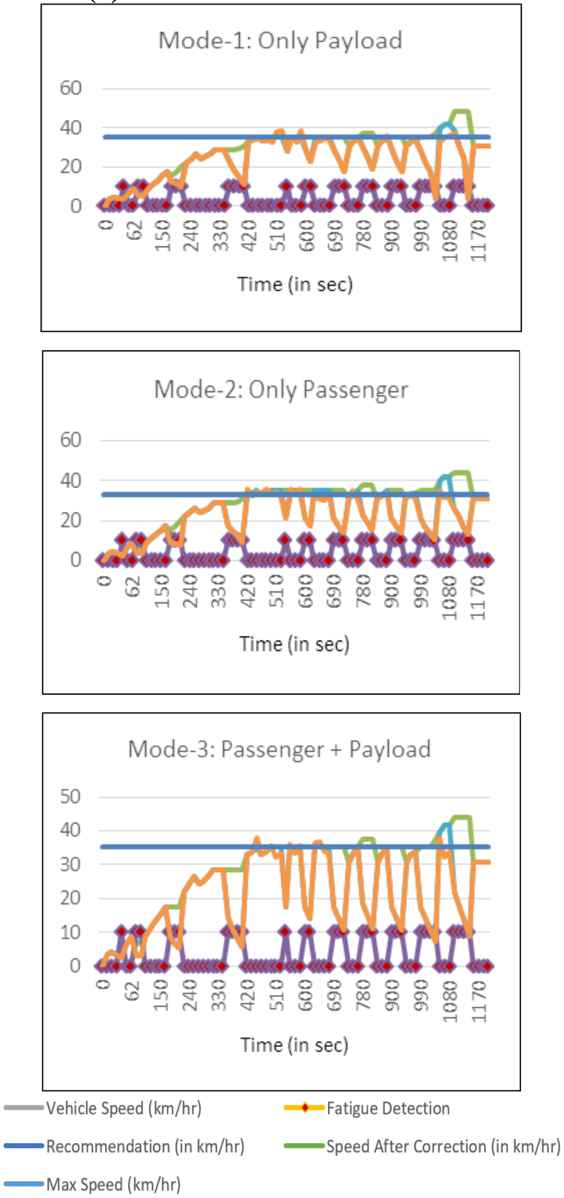

Fig.10 Speed Control due to Fatigue Detection

Figure 10 shows a fatigue detection identified by a Boolean value that necessitates the control of the speed to ensure the safety of both the passenger and the vehicle. In a case, if the fatigue remains undetected, the vehicle speed control depends on the state of other parameters in the vehicle at that point in time. On the contrary, if fatigue becomes detected, even once, the speed control algorithm reacts and decelerates the vehicle, also taking into consideration the current payload and the passenger presence.

If the vehicle operates without payload, it decelerates from 80%of its maximum value to stop at the rate of 10% for every successive fatigue detection. If the vehicle carries only passengers, considering the safety of passengers, the vehicle deploys a speed reduction starting from 60% until it stops at the same rate of 10% for successive detections.

If the vehicle includes both the passengers and payload, the vehicle deploys a speed reduction starting from 50% until the stop at the same rate of 10% for successive detections. The approach reduces the vehicle speed based on multi-modal recommendations and regulates it to not exceed a maximum of 44 km/hr.

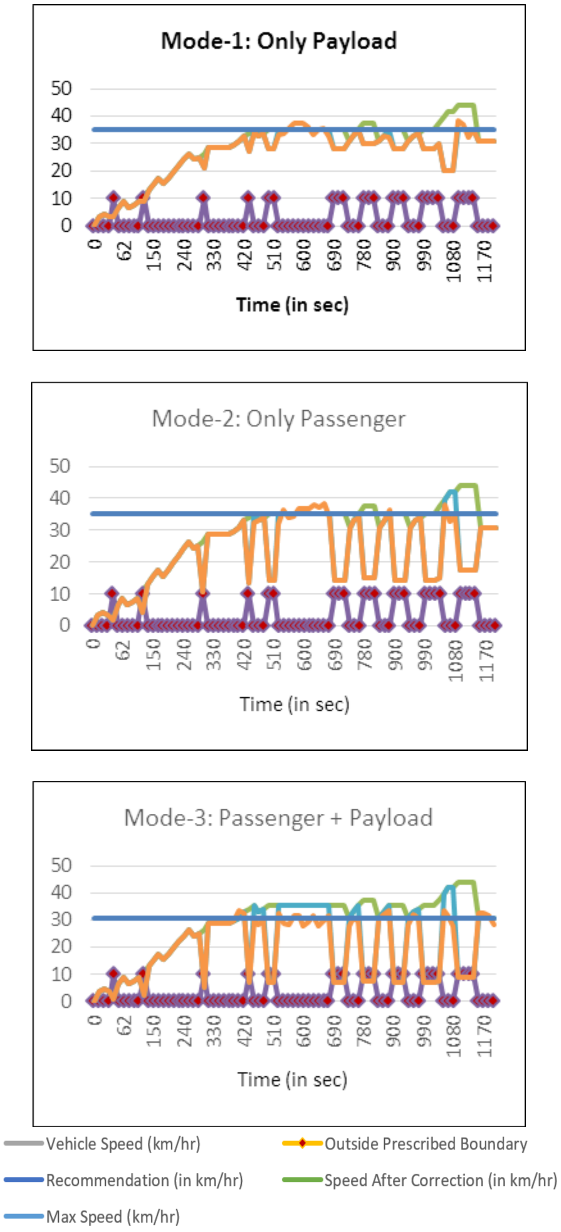

Fig.11 Speed Control based on Data from GPS Maps

The test and simulation practice investigates the speed control based on Real-Time GPS inputs under the three different modes of use. Taking the terrain of travel and safe, designated path pre-programmed into consideration, the different levels of speed restrictions may be applied to the chosen off-road electric vehicle while crossing pre-defined lanes, with safety as the only priority. The test results confirm that the vehicle speed reduces at 80% for only payload, 40% for only passenger, and 20% for the combined passenger and payload in accordance with the design considerations. The Speed Control is based on Data from GPS Maps shown a fig 11.

Table-2 register the various test cases with their observed results against the expected results, with both closely matching with each other and thus authenticating that the IoT-based smart edge device with its multi-modal intelligent speed control algorithm reduces the vehicle's speed automatically alongside driver notifications by 9% deviation and 91% accuracy.

VIII. CONCLUSION

A Multi-Modal Wi-Fi Mesh enabled IoT-based methodology has been formulated for the speed control of an off-road battery-operated electric vehicle for port applications within vehicles specified parametric range. An ARM core-based STM32 microcontroller has been used to design the framework through which it obtains a variation in the converter interface width to control the asynchronous motor driving the vehicle. The algorithm has been tested on the developer's test bench to invigorate the requirements to the microcontroller, and there of tests the implemented algorithm through rivaled vehicle inputs to meet the changing vehicle needs. The simulation results have been presented to claim the scheme's suitability with accuracy for integration in real-world vehicular systems.

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