EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(2), 113–121
https://doi.org/10.12912/27197050/145584
ISSN 2719-7050, License CC-BY 4.0

Received: 2021.12.21
Accepted: 2022.01.13
Published: 2022.02.01

Internet of Things based Speed Control for an Industrial Electric Vehicle using ARM Core

P.L. Arunkumar[1*], M. Ramaswamy[1], C. Sharmeela[2]

[1] Department of Electrical Engineering, Annamalai University, Chidambaram, Tamil Nadu, India
[2] Department of Electrical and Electronics Engineering, Anna University, Chennai, Tamil Nadu, India
* Corresponding author's email: plarunkumar@gmail.com

ABSTRACT
Increasing greenhouse gases impose severe concern over the environment resulting in rising dangerous calamities of climate change in the form of floods, etc. Major disadvantages like intermittency of electric vehicles need to be charged after traveling fixed distance. The paper develops an algorithm for a selected industrial electric vehicle to be controlled at different speeds that envisages working on real time Internet of Things (IoT) based Global Positioning System (GPS) signals. It engages the ARM core based STM micro-controller in conjunction with mesh networked Bluetooth Low Energy (BLE) to govern the operations besides enabling it to be dynamically monitored. The system design considers the vehicle parameters that include the speed of vehicle and the engine, State of Charge (SoC) and State of Health (SoH) of battery together with real time GPS based navigation system using IoT bundled GPS based maps interface. The methodology involves a closed loop monitoring with specified sequence of steps that augur the system to operate at defined speed over designated work shifts and schedules. The procedure introduces an embedded C environment with a process of unit-testing based simulation to capture the merits of schema in terms of an improved vehicle performance under varying parametric conditions.

Keywords: off-road, electric vehicle, industrial application, IoT, speed control, micro-controller, ARM core, automotive, speed control of BLDC motor

INTRODUCTION

The industrial vehicles continue to gather momentum owing to the extensive automation prevalent in both on and off-road goods category. However, in view of the rapidly depleting conventional resources, there is a strong need to explore the use of electric powered vehicles and comply with the clean energy initiatives. In addition there is the urge for the vehicles to be smarter, safe, and energy efficient for sustaining a longer operational period with lower maintenance and running cost, being amply supported by increased vehicle efficiency with smaller downtime.

The transportation sector appears to experience a greater push to become electric and support goods vehicle due to increased traffic movement. It mandates the vehicles to operate at optimum capacities for sustaining maximum efficiency alongside operating the vehicles within its speed limit without affecting the mileage by consuming less fuel for the same distance covered.

The industrial electric vehicles necessitate the vehicles to operate at a recommended speed to ensure the sustenance of the life of the battery for longer tenure. The intelligent autonomous mode can be aided by one or more systems that monitor the vehicle continuously and control its speed within the prescribed limits. However, with the manual mode the speed control depends on the driver which may be strenuous, considering the quantum of workload.

The vehicle segment encompasses a significant space in view of the exhaustive automation in almost every class of both on and off-road passenger and goods traffic. The introduction of the embedded segment brings in an impetus enabling wireless vehicle-to-vehicle communications system.

The driverless vehicles have been a part of the Intelligent Transportation Systems (ITS) with the release of several intelligent vehicles to the roads which in turn necessitated the coordination among the vehicles and the associated infrastructure (Turcian and Dolga 2020).

The architecture for using three different categories of Vehicle to Everything (V2E) communications schemes in off-road environments over multiple autonomous vehicles has been proposed. Numerous experiments have been performed for each communication scheme and the results prove the stability of the schemes in addition to establishing their high performance over 4G connection in terms of efficiency, in comparison to Wi-Fi connection (Al-Sultan et al., 2014; Schweppe et al., 2011).

The autonomous industrial off-road vehicles that include baggage tractors, drone-based surveillance systems, and vehicles in mines or construction sites have been operated and proved the ease of design with a higher degree of control (Fabian et al., 2014; Reif et al., 2014; Wang et al., 2018). However, the communication abilities of the vehicles, irrespective of their off- or on-road nature have been demanding a higher thrust(Schöner2004; Lajunen et al., 2016; Vellucci et al., 2012; Porsche Engineering, 2011; Al-Othman et al., 2016; Club Technical, 2020).

It has been projected that the autonomous vehicles avoid many accidents simply by following the traffic rules and attract the development of new services (Iora and Tribioli 2019; Indira Gandhi National Open University; Mohammad et al., 2016; Lajunen et al., 2012; Liukkonen et al., 2013; Jo et al., 2011). The industrial electric vehicle has been experiencing huge challenges for making fossil fuel-based vehicles autonomous and intelligent. Considerable efforts have been the order of the day in the growth of the off-road industrial electric vehicle segment and address the challenges that arise for various reasons (Paraszczak et al., 2014; Molet al., 2010; https://amperevehicles.com/industrial-vehicles/; Praphul et al., 2018; Lajunen et al., 2016).

The emphasis relates to evolving an algorithm for controlling the speed of an industrial electric vehicle mostly operated manually over longer duration to ensure better payload movement efficiency. It attempts to use mesh BLE network to operate the vehicle from an IoT platform using real time GPS tracking. The design orients to encompass the vehicle parameters that include the speed of the vehicle and the engine, SoC and SoH of battery for arriving at the predefined speed over varying parametric uncertainties. It incites to follow a unit testing approach on embedded C environment for demonstrating the claim to be used in practice.

PROPOSED WORK

The off-road electric vehicle faces its own challenge depending on the usage and its area of application. The industrial electric vehicles often operate over the recommended speed to move more goods within a stipulated shift timing, reducing the life of the vehicle and the battery. Operating the vehicle at the optimum speed can provide the much-needed life for the vehicle and safety to the people who move around the vehicle with in a predefined closed industrial premises.

Figure 1 explains the high-level design including the battery-operated electric power to the vehicle and its dependent circuits articulating the basic approach to control the speed across

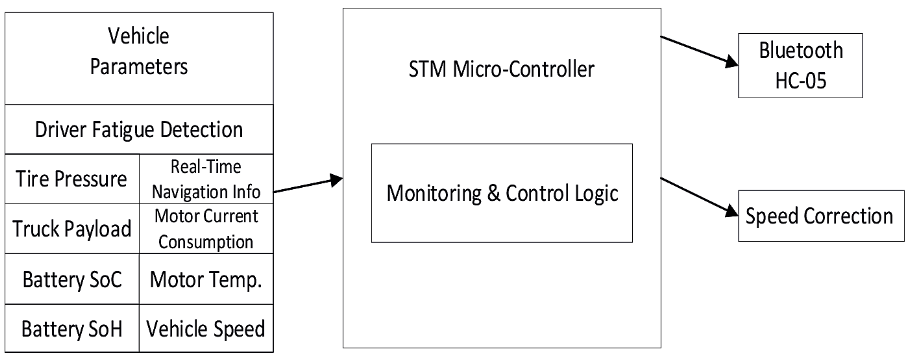

Fig. 1. Block diagram

vehicles parametric considerations. Designing a controllable track able Intelligent vehicle to maintain speed can help fleet owners to extract maximum efficiency.

The industrial vehicle under study with technical specifications in Table 1 may reach a top speed of 25 km/hr and can be expected to be operated on a flat surface within an industrial complex operated using a sealed Lead Acid Battery.

The parameters to be monitored include the Battery SoC, Battery SoH, Driver Fatigue (Eye) Detection, Real Time Navigation points using GPS, Vehicle Speed, Motor Temperature, Motor Current Consumption, Tire Pressure and Truck Payload. The efforts to control the speed require monitoring the parameters closely at a constant periodic interval across the complete vehicle, including idle time at millisecond accuracy maintained by a RTOS. Table 2 records a sample of the parametric values for the chosen vehicle.

METHODOLOGY

The primary exercise endeavours to form a BLE Mesh network around the area within which the vehicle envisages to move or designated to traverse with safe warnings including audio and visual with flashing lights. The network interconnects the mesh within the traffic space and further to the centralized on-premises data collection centre for monitoring and control with the vehicle with a BLE device in it. It operates on the real-time data from the different sensors interfaced to the STM32F746NG micro-controller.

The main objective revolves around close vehicle monitoring on constant periodic intervals to trigger the control logic in the controller to decide the specified speed depending on the parameters under consideration, in addition to the pay load in the vehicle.

It brings in a closed loop control system approach with the monitoring parameters forming the input, the micro-controller edge device

Table 1. Vehicle specifications

No.	Parameters	Value	No.	Parameters	Value
1	Charging time	10–12 hours	9	Charger rating	60 V – 12/15 A
2	Range per charge	70 km	10	Kerb weight in kg	430
3	Speed	25 kmph	11	Length (mm)	3506
4	Payload	400 kg	12	Width (mm)	1093
5	Battery capacity	6 V / 150 Ah	13	Height (mm)	1499
6	Motor capacity	1280 W	14	Wheelbase (mm)	2175
7	Motor type	BLDC	15	Battery life (No. of cycles)	300
8	Battery type	Sealed lead acid	16	Reverse option	Yes

Table 2. Parametric values

No.	Parameter	Max value observed in vehicle	Ideal / optimum	Sensor output	Units	Simulation Range
1	Motor speed	455 rpm	1600 rpm	PWM	Hz	0 to 10 kHz
2	Vehicle speed	25 km/h	20 km/h	PWM	Hz	0 to 10 kHz
3	Truck payload	400 kg	400 kg	Raw date	kg	0 to 400 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 100%
6	Battery SoH	100%	60%< SoH<100%	Raw date	%	0 to 100%
7	Driver fatigue (eye)detection	No	No	Boolean	Yes/No	Yes/No
8	Motor temperature	70 deg cel	70 deg cel	ADC	V	0 to 100 V
9	Real time navigation points using GPS	20.04 deg	Non – zero number	Latitude, longitude	Number	Random values
10	Motor current consumption	9 A	2.1 A	Current reading	A	0 to 5 A

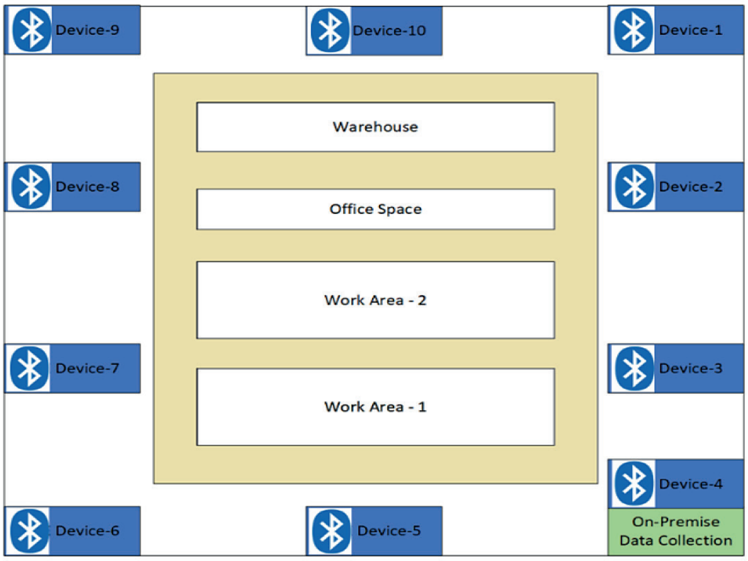

Fig. 2. Industrial IoT on BLE mesh

smartness acting as the process block and the speed control acting as the output, with the vehicle speed also acting as a feedback signal together with appropriate signal conditioning circuits. The firmware code in the embedded-c framework with RTOS allows the formulation in the unit testing at bench.

Figure 2 reflects a modular approach to control the speed of the chosen industrial electric goods vehicles with Hardware, Hardware Abstraction Layer, Basic Vehicle Application Layer, Cab Operator Application Layer, IoT Monitoring and Control Interface. The Hardware abstracts the sensor data, validates, analyses, processes by scaling and provides it to the vehicle layer. The software-architecture is shown in Figure 3.

STM32F746NG communicates with all sensors in the vehicle and collects the data. The IoT monitoring and control interface layer incorporates the BLE protocol to communicate between the other BLE nodes installed across the premises. The stationary BLE nodes act as repeaters and extenders, carry the vehicle data from the vehicle to the centralized data collection master and there from returns the control information back to the vehicle. The smart edge device powered by STM-32F746NG inherits inbuilt intelligence to control the speed of the vehicle based on the dynamic behaviour of the vehicle and its parameters.

The process enables the interface of the Bluetooth Module HC-05 with the STM on SPI (Serial Peripheral Interface) and includes BLE 4.0 stack in it with additional application layer

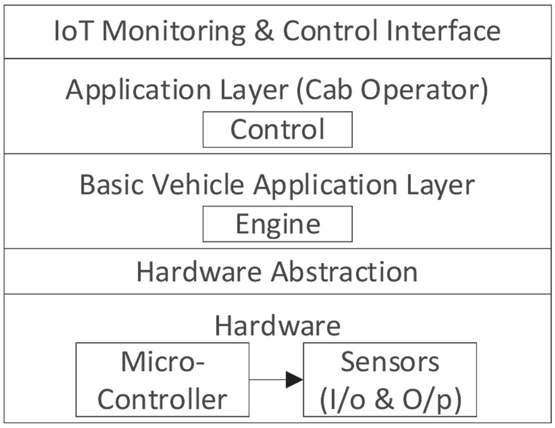

Fig. 3. Software architecture

implementation. The stationary BLE nodes installed in the industry can be an off-the-shelf certified inter-operable customizable repeater to facilitate communication with the centralized on-premises data collection unit.

It identifies the centralized on-premises unit by a static addressing mechanism to transmit the data from the vehicle to the central node through the intermediate mains powered by the stationary BLE nodes. The centralized unit consolidates the data analyses, processes, and stores in a prescribed format, providing a detailed view to the industry maintenance team and to the fleet management team. Either of fleet management or industry maintenance team can suggest a recommendation in speed control to the vehicle through the intermediate BLE nodes from the centralized server.

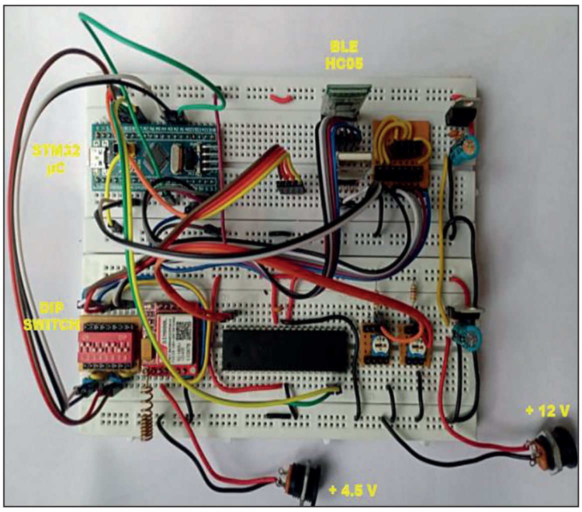

Fig. 4. Hardware system

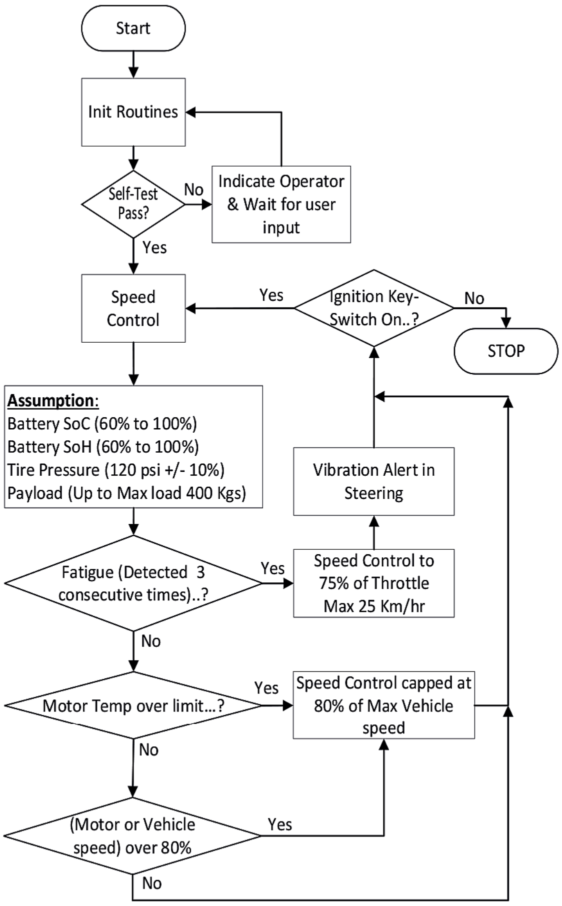

Fig. 5. Algorithmic flow chart

The hardware system depicted in Figure 4 receives the data from the sensors to the micro-controller and intelligent embedded algorithm on the IoT edge device to recommend the speed based on the observed values and its priorities as explained in the Flow Chart in Figure 5.

The speed correction acts through the actuators based on recommendation obtained either from vehicle internal intelligent micro-controller or from the external party through BLE dependent interfaced IoT mechanisms.

It involves the STM-32 IDE (Integrated Development Environment) for the development and cross compilation with minimal architectural wrapper provided by IDE on processor selection with reset, init routines and abstraction layer codes, using Free RTOS (Real Time Operating System) to prioritize on an embedded-C-based implementation with occasional ASM instructions.

SIMULATION AND TESTING

The testing follows a split sub-system architecture type unit test strategy, assuming off-the-shelf connections remain stable and interoperable. It uses appropriate signal generators to simulate the sensors output for evaluating the efficiency of the firmware with a view to control speed engaging a PWM Out signal, read back as the vehicle speed through feedback. It monitors the vehicles Payload, tire, SoC, SoH and Navigation Info as serial data, uses a 2-stage relay for fatigue detection, signal generators for speed, potentiometer for temperatures, and current source for the motor current consumed. The simulation and testing block diagram are shown in Figure 6.

RTOS prioritizes the parameters in the sense it offers the highest priority to battery related parameters, SoC & SoH, and triggers speed control only if battery exists in the operating condition within limits and the lowest priorities to the truck payload and tire pressure assuming

Table. 3. Prioritized parameters

Parameter	Priority
Battery SoC	1
Battery SoH	2
Driver fatigue (eye)detection	3
Real time navigation points using GPS	4
Vehicle speed	5
Motor temperature	6
Motor current consumption	7
Tire pressure	8
Truck payload	9
Motor speed	10

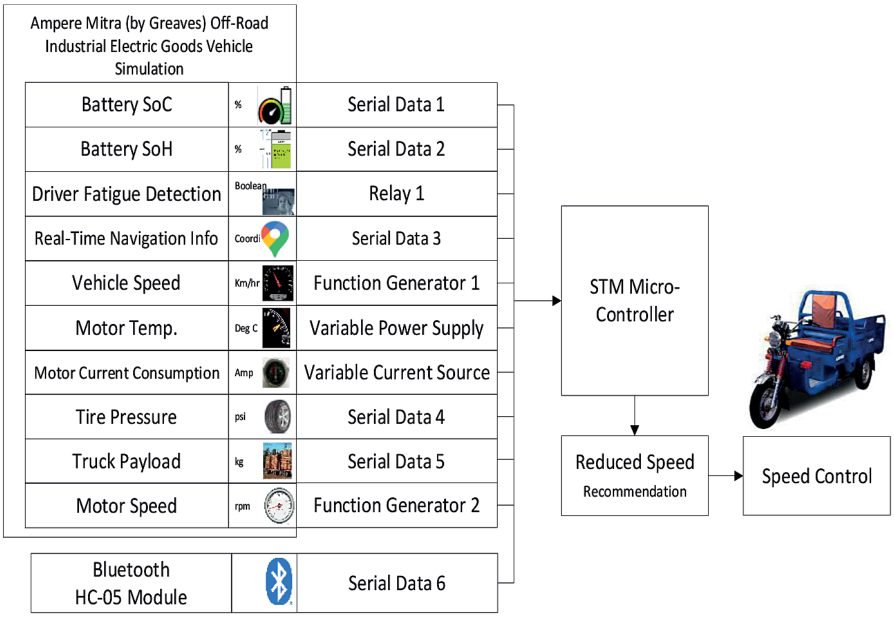

Fig. 6. Simulation and testing block diagram

Table 4. Operating range of vehicle parameters

Parameter	Values
Battery SoC	60% to 100%
Battery SoH	60% to 100%
Tire pressure	120 psi +/- 10%
Truck payload	Up to Max 400 kg

those remain within the limits. The procedure creates a change of vehicles parameters based on the priority for directing the reduced speed to be set as the operating value. Table 3 shows the prioritized parameters.

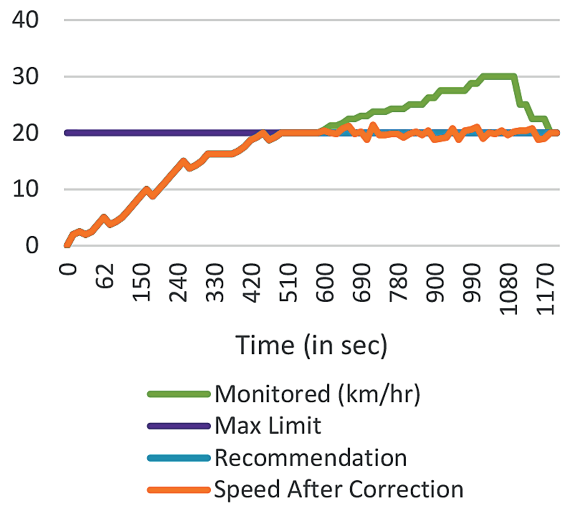

Fig. 7. Speed control based on vehicle speed

RESULTS AND DISCUSSION

The process examines the efficiency of the speed control algorithm for the battery operated off-road industrial electric vehicle against the permissible operating ranges of SoC, SoH, payload and tire pressure listed in Table 4. It operation on an ARM-Core based STM32 microcontroller from where the speed control enters against the dynamic behaviour of the vehicle over a time bound simulation. It involves testing around varying pulse widths for simulating the real-world vehicle speed to the controller using x cluma PWM Pulse Frequency Duty Cycle Adjustable Module capable of generating Square Wave and Rectangular Waves.

It monitors the vehicle parameters in relation to the simulated sensor inputs and tests the vehicle against the recommended speed control through appropriate feedback mechanism. Figure 7 represents the relationship between the input PWM and its output response capturing the vehicle higher battery life and better mileage of the vehicle when operated up to 80% of its maximum speed.

The speed variations of motor in Figure 8 record that the motor speed remains around an optimum of 70% to 80% of its maximum value and bring in a speed reduction when the motor speed attempts to go above 80%. The graph shown in Figure 9 explains restricting

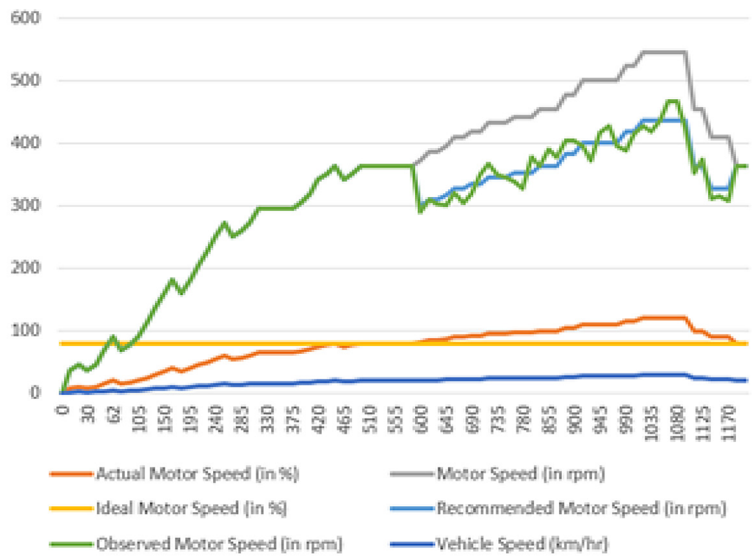

Fig. 8. Speed Control based on motor speed (in rpm)

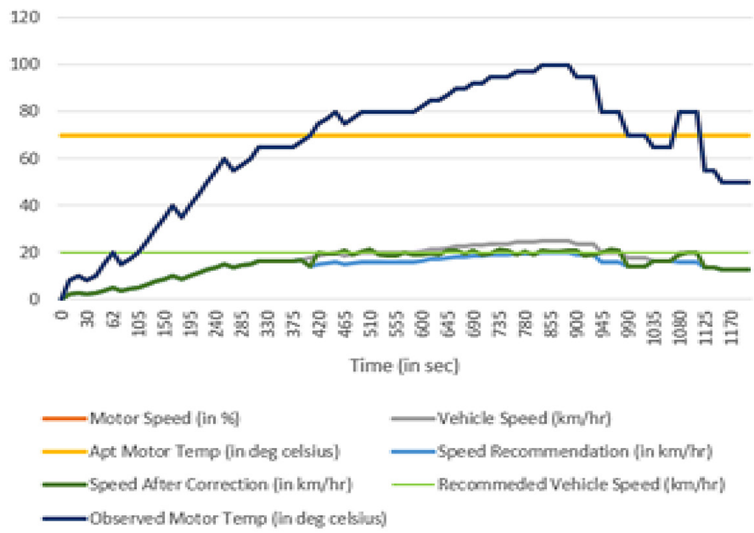

Fig. 9. Speed control based on motor temp

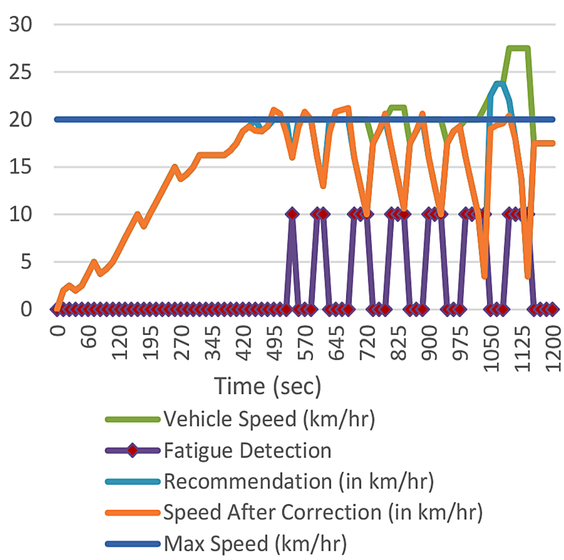

Fig. 10. Speed control due to fatigue detection

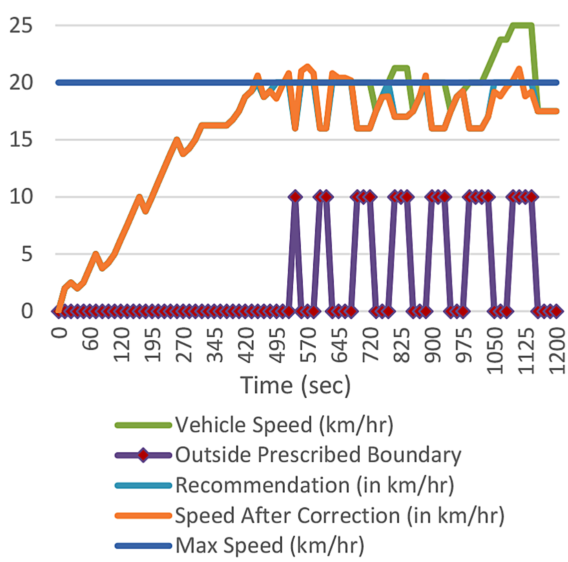

Fig. 11. Speed control tracking vehicle using GPS

the motor to operate around an ideal temperature range of 70 °C for sustaining the longer battery lifespan with maximum power output. The algorithm recommends lowering the load to reduce the vehicle speed within a minimal deviation of (±) 7% and results in reducing the motor temperature when it exceeds 70 °C.

Figure 10 represents the occurrence of fatigue as a Boolean value to indicate the safe operating conditions and the approach entails detecting fatigue only if it arises three or more consecutive times, considering the safety of the workers within the industry, irrespective of the vehicles speed in which the operator receives a steering system vibrational warning to reduce the vehicle speed to 15% of current speed. On successive fatigue detection, it enables the reduction in speed by additional 15% every time and the vehicle can be bought to zero acceleration gradually. With ignition on, the cycle becomes reset and the speed reduction due to fatigue detection starts over again, assuming the operator enjoys sufficient time to refresh and return to the normal operating condition.

The exercise further investigates the speed control based on the real time GPS inputs monitoring if the vehicle operates within its prescribed predefined boundaries. On any instance of the vehicle crossing over the prescribed boundary, it reduces the speed of the vehicle to 80% of the maximum speed. Besides for every instance of the vehicle crossing the boundary, it lowers the speed immediately reduced by an additional 10%. Figure 11 shows the Speed control tracking vehicle using GPS.

The IoT based intelligent microcontroller monitors the vehicle parameters and takes a combinatorial decision driven by priorities. The results detail the various test cases and facilitate the fact that the algorithm reduces the vehicle speed automatically to the recommended level with 7% deviation and 93% accuracy ensuring safe vehicle operation and guaranteeing longevity to the life of the battery.

CONCLUSIONS

A BLE Mesh network based IoT speed control mechanism was designed for a battery operated industrial off- road electric vehicle suitable for a confined predefined boundary. The architecture was designed on an ARM core based STM32 microcontroller through which it recommends a pulse width variation to switch the converter interface for controlling the BLDC motor responsible for driving the vehicle. The methodology was implemented with the real time input from GPS location services to decide on the set points for controlling the speed. The coding was automated to operate the test bench in accordance with the design of the algorithm and thereby emulate the changing dynamic time bound behaviour of the vehicle. The simulation results were presented to claim the suitability of the scheme for adoption by industries to be integrated into live production lines.

REFERENCES

1. Al-Othman A.K., Nabil A.A., Al Sharidah M.E., El-Naggar K.M. and Bader A.N. 2016. Speed Control of Electric Vehicle. In: International Conference on Mechatronics, Control and Automation Engineering, MCAE'2016, 32–33.
2. Al-Sultan S., Al-Doori M.M., Al-Bayatti A.H. and Zedan H. 2014. A comprehensive survey on vehicular Ad Hoc network. Journal of Network and Computer Applications, 37, 380–392. doi: 10.1016/j.jnca.2013.02.036
3. Ampere Industrial Vehicle – Mitul, by Greaves Cotton, https://amperevehicles.com/industrial-vehicles/, (accessed on 2021-Sep-06)
4. ClubTechnical, 2020. Automobile. Definition, Types, Parts. [Fully explained with images], ClubTechnical Mechanical Engineering Blog, 1–14.
5. Fabian J., Hirz M., and Krischan K. 2014. State of the art and future trends of electric drives and power electronics for automotive engineering. SAE International Journal of Passenger Cars-Electronic and Electrical Systems, 7(2014-01-1888), 293-303.
6. Indira Gandhi National Open University, Automobile Engineering Textbook, UNIT 1 Introduction to Automobile Engineering, 2016, 1–10.
7. Iora P. and Tribioli L. 2019. Effect of ambient temperature on electric vehicles' energy consumption and range: Model definition and sensitivity analysis based on nissan leaf data. World Electric Vehicle Journal, 10(2), 1–15; doi:10.3390/wevj10010002
8. Jo D.-Y., Kwak S., and Kim N. 2011. Development of fuel-efficient construction equipment. In: 8th International Conference on Power Electronics - ECCE Asia. doi: 10.1109/icpe.2011.5944374
9. Lajunen A. and Suomela J. 2012. Evaluation of energy storage system requirements for hybrid mining loader. IEEE Transactions on Vehicular Technology, 61(8), 3387–3393.

10. Lajunen A., Suomela J., Pippuri J., Tammi K., Lehmuspelto T. and Sainio P. 2016. Electric and hybrid electric non-road mobile machinery – present situation and future trends. World Electric Vehicle Journal, 8(1), 172–183. doi: 10.3390/wevj8010172
11. Liukkonen M., Lajunen A. and Suomela J. 2013. Feasibility study of fuel cell-hybrid power trains in non-road mobile machineries. Automation in Construction, 35, 296–305.
12. Praphul M.N., Divya M., Maity B., Bindhu V. and Nivedita C.S.R. 2018. Exact rate control of electric vehicle using ARM with battery saving mode. In: International Conference on Design Innovations for 3Cs Compute Communicate Control (ICDI3C'2018), 88-91. doi: 10.1109/icdi3c.2018.00027
13. Mohammad A., Abedin M.A. and Khan M.Z.R. 2016. Microcontroller based control system for electric vehicle". In: 5th International Conference on Informatics, Electronics and Vision (ICIEV'2016), 693-696. doi: 10.1109/iciev.2016.7760090
14. Mol C., O'Keefe M., Brouwer A. and Suomela J. 2010. Trends and insight in heavy-duty vehicle electrification. World Electric Vehicle Journal, 4(2), 307-318.
15. Paraszczak J., Svedlund E., Fytas K. and Laflamme M. 2014. Electrification of loaders and trucks – a step towards more sustainable underground mining. In: International Conference on Renewable Energies and Power Quality (ICREPQ'2014), Spain, 8-10.
16. Porsche Engineering, 2011. Thermal management in vehicles with electric drive system. Porsche Engineering Magazine, 1, 1-3.
17. Reif K. 2014. Brakes, brake control and driver assistance systems. Automotive mechatronics. Control Engineering Practice, 12(11), 1343–1351. doi: 10.1016/j.conengprac.2003.10.004
18. Schweppe H., Roudier Y., Weyl B., Apvrille L. and Scheuermann D. 2011. Car2x communication: securing the last meter-a cost-effective approach for ensuring trust in car2x applications using in-vehicle symmetric cryptography. In: IEEE Vehicular Technology Conference (VTC'2011), 1-5.
19. Turcian D. and Dolga V. 2020. Intelligent speed control system for electric vehicle. In: IOP Conf. Series: Materials Science and Engineering, 012064 IOP Publishing, 1–12, doi: 10.1088/1757-899X/997/1/012064,
20. Vellucci F., Pede G., Ceraolo M. and Huria T. 2012. Electrification of off-road vehicles: examining the feasibility for the Italian market. World Electric Vehicle Journal, 5(1), 101-117. doi: 10.3390/wevj5010101
21. Wang Z., Wu G. and Barth M.J. 2018. A review on cooperative adaptive cruise control (CACC) systems: Architectures, controls, and applications. In: 21st International Conference on Intelligent Transportation Systems (ITSC'2018) 2884-2891. doi:10.1109/itsc.2018.8569947