engineering proceedings

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Proceeding Paper

IoT-Based Thermal Management System by Embedding Physical Sensors in Hybrid Vehicles †

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† Presented at The 11th International Electronic Conference on Sensors and Applications (ECSA-11), 26–28 November 2024; Available online: https://sciforum.net/event/ecsa-11.

Abstract: Hybrid Electric Vehicles (HEVs) presents unique challenges in terms of thermal management, requires a Battery Thermal Management System (BTMS). This paper presents an IoT-based thermal monitoring system for HEVs where the sensor data is uploaded to cloud and controlled by Arduino IDE-Embedded C environment. This work uses DS18B20, DHT11 and MQ-135 sensors and NODE-MCU ESP8266 receives signals from Blynk IoT for motor control. This work uses L298N, to control the speed of DC motors. Additionally, as the battery is being charged or discharged, the proposed BTMS monitors voltage, current, and temperature. The developed moule has been tested in two different scenarios for HEVs and PHEVs.

Keywords: Hybrid Electric Vehicle (HEV); Thermal Monitoring; Temperature Sensor (DS18B20 and DHT11); Gas Sensor (MQ135); Arduino IDE-Embedded C; ESP8266 module; Blynk IoT

Citation: Velu, A.; Ramamoorthy, R.; A Prasanth; Dhanaraj, R. IoT-Based Thermal Management System by Embedding Physical Sensors in Hybrid Vehicles
Citation: To be added by editorial staff during production.

Academic Editor:

Published: 26 November 2024

1. Introduction

The automotive industry's shift to more environmentally friendly modes of transportation is an emerging research area in the present world. Electric Vehicles (EVs) are those on the road that are powered by electric propulsion. Generally, EVs are of three categories Purely Electric (PEVs), Hybrid Electric (HEVs), and Fuel Cell Electric (FCEVs) [1]. The most commonly used method in EVs is drive-on electric motor approach, that typically adopt Variable-Voltage Variable Frequency (VVVF) and Field-Oriented Control (FOC). Even though PEVs produce no pollutants, there is still a bottleneck in the initial cost and management of batteries; these issues cannot be resolved anytime soon, so until there is a breakthrough in these areas, the HEV serves as a gap until PEVs are fully commercialized [2]. However, the technology of refueling system in other type of vehicles are still in early development stage HEVs are well preferred.

Hybrid vehicles are the one which combines both mechanism of electric propulsion systems with conventional mechanical engines, are gaining popularity day by day [3]. A unique set of opportunities and problems are presented by the cohabitation of these two power sources, with heat control emerging as a crucial factor affecting longevity, performance, and efficiency [4]. Batteries acts as a major part of energy storage system in hybrid vehicles, and it is essential to keep them in the ideal temperature range for maximum performance and longevity [5]. Ensuring optimal operating conditions is essential for both performance and safety in hybrid vehicles. Researchers have drawn a lot of interest to studies on HEVs since, the need to find alternative energy sources for vehicles are gaining concentration due to the limitations of fuel-based energy, global warming, and exhaust emission.

HEVs make use of electric current generated through regenerative braking, where the vehicle converts heat produced during braking into electrical energy. The heat produced by regenerative braking will be transformed into electrical energy, which is utilized as the major source by HEVs. HEVs have lower emissions and better fuel efficiency, in comparison to the conventional Internal Combustion Engine (ICE) vehicles. India has been adopting more electric vehicles; in March 2023, sales of these vehicles increased by 82% over the same month the previous year. Sales as a whole rose by 157% between 2022 and 2023. Changing from an ICE vehicle to HEV, results in substantial fuel cost reduction, little maintenance cost, and hugely reduces carbon footprint at the same time.

The remainder of the paper is structured as tails: Section II includes a thorough literature review in addition to provocation and background of the work. Section III covers brief explanation of proposed IoT-based thermal management system by embedding physical sensors in hybrid vehicles. Section IV includes outcomes and analysis of the established prototype and measured parametric factors. Finally, Section V concluded the developed system, outlining its benefits and future scope for upcoming research and development.

2. Motivation and Background

2.1. Problem Statement and Motivation

It is anticipated that by 2050, there will be 10 billion people on the planet, up from 6 billion in 2000, which results in more people likely use vehicles for transportation (Table 1). Statistic that illustrates how the number of automobiles will rise worldwide from 700 million to 2.5 billion is illustrated in Figure 1. If most vehicles activated by ICEs, fuel will run out fast and emissions will result in the greenhouse effect. Thus, environmental preservation and energy saving are becoming more and more important globally. At this point HEVs come into the role where it is operated using both internal combustion engine and the electric motor.

Table 1. Expected global population growth.

S.No	Year	Population (In Billion)
1	1800	1.26
2	1900	1.85
3	2000	4.36
4	2100	9.97
5	2200	14.52

HEVs combine ICEs with electric powertrains hence, they produce heat in multiple ways and face a special challenge in heat management issues. The management of these systems' thermal demands adds complexity, which requires the integration of several cooling techniques or the use of separate cooling systems. Variations in temperature can cause problems for batteries. For maximum efficiency, longevity, and safety, the battery pack must be kept operating within its ideal temperature range (20–40 °C). Too low of a temperature can reduce performance and range of battery, while too much heat can shorten the battery life.

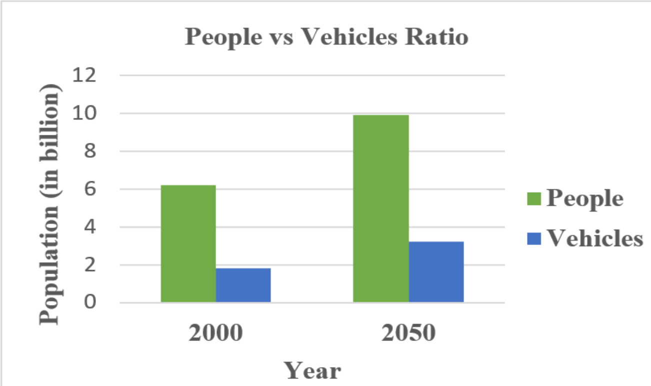


Figure 1. Vehicle vs Population statistics .

2.2. Literature Survey

Electric vehicles have completely shifted to battery technology in an effort to minimize fuel consumption and control pollution. Cooling techniques are used in EVs to monitor and control the battery [6]. The Arduino microcontroller is embedded which updates the battery condition, thus it records the temperature every time. The method for establishing a dependable electrical and thermal design of Lithium-Ion Battery (LIB) systems during the concept stage has been presented, with special attention to the needs of automotive applications [7]. The main focus is on the entire concept development process, which includes cell selection, battery system design and BTMS design, which may involve connecting the peripherals to thermal management system of vehicles.

Novel thermal management system is designed to improve the temperature-dependent elements of battery electric vehicles [8]. The system's main function is to distribute, store, and release heat in order to support the battery's warm-up process at low ambient temperatures. A review has been presented on batteries addressing related issues, problems, and solutions [9]. This examines the main battery management system technologies, such as charging, condition estimation, and battery modelling. One well-known energy management approach for HEVs is the Equivalent Consumption Minimization approach (ECMS). Fuel consumption and battery ageing components are included in the cost function of a novel optimum control problem has been presented [10].

Researchers have also concentrated on gas leakage sensing in EVs apart from heat control and battery management [11 & 12]. Few researchers use Internet of Things (IOT) to control hybrid energy distributed generation systems [13,14]. The primary requirement is the ability to seamlessly switch between the two energy sources like solar and wind through a website, that uses an ESP8266 Wi-Fi module [15]. A thorough analysis of the cooling control procedures under various thermal hazard circumstances has been analyzed proposing Fine Water Mist (FWM) powered by air flow to prevent Thermal Runaway (TR). The findings [16] indicate that effective suppression of TR can be achieved by applying FWM prior to the critical temperature, which is determined to be 252.5 ± 2.5 °C.

A bulk thermal model of LIB coupled to a simplified uneven electrochemical model has been built [17]. In order to get an accurate and reliable State of Charge (SOC) result, this coupled model implementation is used in combination with Extend Kalman-Smoothing Variable Structure Filter (EK-SVSF). A LIB electric circuit model is suggested in order to forecast the over-voltage transients that occur during charging or discharging. To investigate their effects, key elements including battery current and SOC are tested independently by researchers [18 & 19]. A novel real-time optimization-based Energy Management Systems (EMS) that can adjust to changing driving profiles and commutes with high flexibility and cheap computational costs is presented [20]. It has two layers (i) a rule-based control for frequency power sharing and (ii) Reinforcement Learning (RL) optimization to determine and adjust the optimal power sharing.

A qualitative evaluation of the literature on various BTMS for electric vehicles is established [21] to categorize BTMS that permit consideration and their principal attributes. On the other hand, temperature monitoring systems has been implemented and simulated with four different configurations; series-1, series-2, parallel and parallel/series [22]. Heat pipes and a phase-change material are used with a hybrid cooling system prototype to control abnormal heat emissions in LIB [23]. Heat pipes, a paraffin wax and an electric heater is modelled after an A4-sized laminated LIB pack were used in the construction of the system. By considering these literature works, the proposed work presents a prototype for HEVs based on IoT where the thermal management is done by developing the code on Arduino IDE-Embedded C environment. To regulate DC motor, the proposed system makes use of sensors, whose recorded values are updated to the Blynk app and cross-checked with the threshold value pre-stored in the cloud through the developed C++ code.

3. Proposed IoT-Based Thermal Management System for Hybrid Vehicles

This section deals with the architecture and functioning of projected IoT-based BTMS designed for hybrid vehicles. Figure 2 illustrates overall composition of the developed approach, consists of Gas sensor (MQ135) and Temperature sensors (DS18B20 and DTH-11) for measuring the physical parameters. DS18B20 typically has a temperature range of about −67 °F to +257 °F (−55 °C to +125 °C), whereas DHT11 sensor has temperature measurements ranging of 0 °C to 50 °C and humidity measurements from 20% to 90%. MQ-135 is used to determine a wide range of gas leaks.

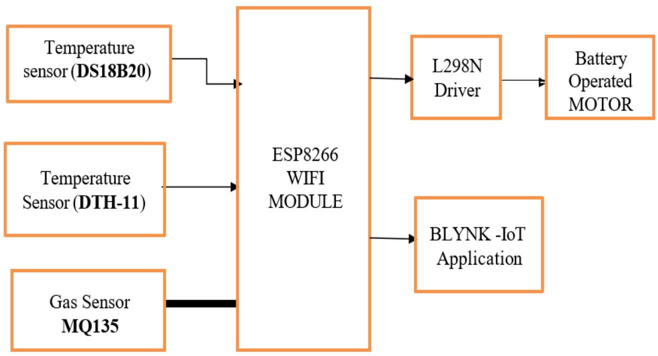


Figure 2. Block diagram of the developed IoT-based thermal management for hybrid vehicle .

L298N IC is a dual H-bridge motor driver where, two DC motors of 2A current and voltage range between 5V to 35V are simultaneously controlled for both speed and direction. The Arduino IDE environment has been used to program the ESP8266 Wi-Fi Module, a self-contained SOC with an inbuilt TCP/IP protocol. Blynk, an IoT platform is used to control Raspberry Pi, Arduino and Node MCU remotely. The developed application collects and provides the correct address on the accessible widgets to establish a Human Machine Interface (HMI).

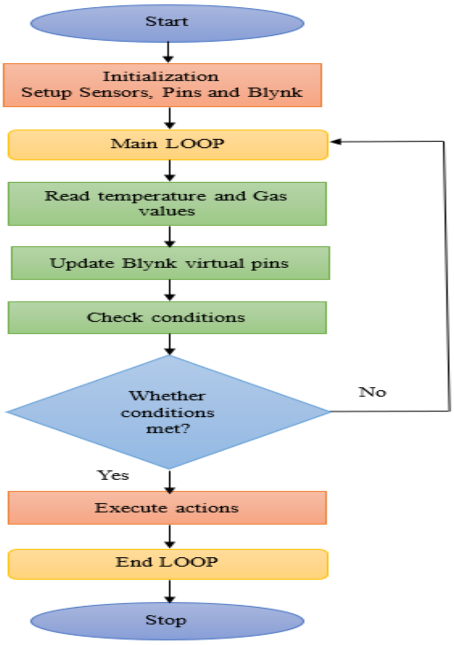


Figure 3. Work flow of the proposed system.

3.1. System Architecture

Physical parameters like temperature of battery and gas leakage will be measured by DS18B20, DTH-11 and MQ135 respectively. The recorded values are updated to Blynk virtual pins and checked with the threshold values stored previously. If the condition satisfies, L298N will control the motor to reduce the speed of vehicle (Figure 3). System architecture of the proposed system showing the connection of DS18B20, DHT-11/22 and MQ135 sensors with ESP8266 module is illustrated in Figure 4, whose controlled output is connected to L298N. The algorithm of the code written on Arduino IDE platform is represented in Table 2.

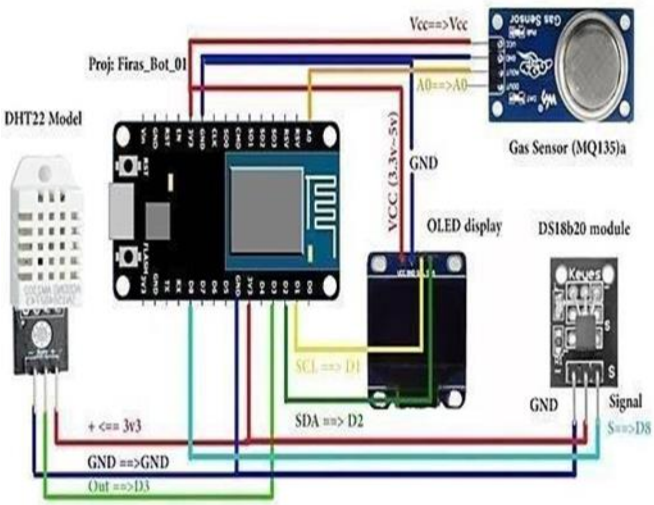


Figure 4. Systematic architecture of the developed model.

3.2. Working of the Proposed System

Working of the proposed model is initialized only when the vehicle is in running mode, where the physical parameters like Temperature (Φ_m) and Gas (φ_m) is measured by the respective sensors. The Blynk app is initialized and the measured values are updated to the app, where the threshold values of Temperature (Φ_T) i.e., 45°C and Gas (φ_T) i.e., 68 ppm are already stored in the cloud. The present value recorded by the sensor is compared with the threshold values and L298N is initiated if found to satisfy the condition. L298N IC now reduces the speed of the vehicle through integrating with H1 and H2 DC motors and stops the vehicle. The vehicle keeps on running if there is not any warning about high temperature or gas leakage, hence it is in a safe mode to drive.

Table 2. Algorithm of Arduino IDE code.

Algorithm 1. Process of thermal management

System architecture //**Initialization of Sensors, Pins and Blynk**//
Define Pins » D_2, D_3, D_5, D_6, D_7 and D_8;
  Define Sensors » DTH-11(Φ_m), DS18B20(Φ_m) and MQ135(φ_m);
    Initialize pins D_2→DHT, D_3→WireBus, D_5→m_1, D_6→m_2, D_7→m_3 and D_8→m_4;
Main Loop (L_1): Start
Read the values m_1, m_2, m_3 and m_4;
Update the values m_1→ D_5, m_2→ D_6, m_3→ D_7 and m_4→ D_8;
Case 1:
If Measured value (Φ_m) > Threshold value (Φ_T)
  Execute L298N;
  L298N→Reduce (H_1 and H_2);
  /*Reduces the speed of DC motor*/
Else;
End Case1;
Case 2:
If Measured value (φ_m) > Threshold value (φ_T)
  Execute L298N;
  L298N→Reduce (H_1 and H_2);
  /*Reduces the speed of DC motor*/
Else;
End Case2;
Back to loop (L1); /*Repeat until condition satisfies*/
End Loop (L1);

3.3. Interfacing of Hardware

The proposed system architecture has been established and executed by connecting the chosen external hardware with the ESP8266 Wi-fi module (shown in Figure 4). The chosen sensors DTH-11/22, DS18B20 and MQ135 are connected to ESP8266 module through the respective pins as illustrated in Table 3. Similarly, L298N has been interfaced with the ESP8266 module through connecting the digital pin D1 and D2 with ENA and ENB of the IC respectively. The digital pins of ESP8266 module D5 to D8 are connected to IN1 to IN4 pins of L298N respectively for motor control of the vehicle. Similarly, analog pin A0 of ESP8266 has been connected to the data pin of the sensor MQ135, whereas the data pins of DHT-11 and DS18B20 sensors are associated with digital pins D2 and D3 of ESP8266 module correspondingly.

Table 3. Interfacing of Hardware.

S.No	ESP8266 Module Pin	Interfacing Hardware
1	D1	ENA→L298N
2	D2	ENB→L298N, Data PIN→DHT-11
3	D3	Data PIN→DS18B20
4	D4	+ve→LED
5	D5	IN1→L298N

6	D6	IN2→L298N
7	D7	IN3→L298N
8	D8	IN4→L298N
9	A0	Data PIN→MQ135
10	VCC	Voltage input→(DTH-11, DS18B20, MQ135)
11	GND	-ve→LED, GND→(L298N, DHT-11 and MQ135)

3.4. Set-up Blynk Application

Blynk's top target market is found to be IoT. It includes several interesting capabilities including data storage, data visualisation, sensor data presentation, remote hardware control etc. A separate Blynk login has been created (3325VG) after identifying the hardware components and making connections as per Table 3. A new template has been created to configure the chosen device and virtual pins are selected to integrate the data. The created template has been configured to dashboard and the setup has been saved. Arduino device has been added to the setup along with ESP8266 boards and installed using board management. The Arduino IDE has been updated with the Blynk and Wi-fi libraries. After setting up the libraries Arduino IDE code has been written with respect to the Algorithm 1. Here, the threshold values of the physical parameters are included in the code which ranges with optimal functioning range of the hybrid vehicle for safest operation. Figure 5 represents the temperature range of battery in hybrid vehicles. Finally, Blynk token is added to the setup, by duplicating it to the developed application using "Device info".

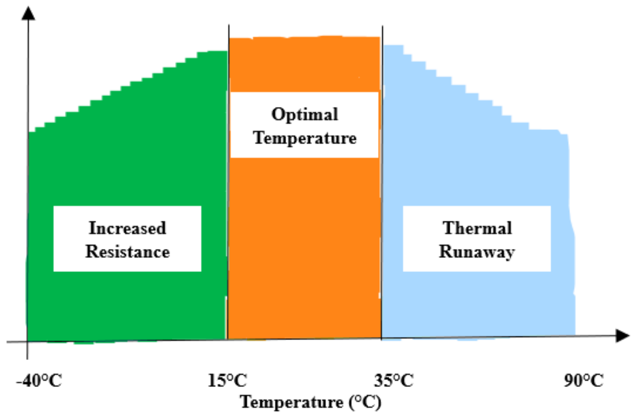


Figure 5. Temperature range of battery.

4. Results and Discussion

To assess the developed IoT-based thermal management system, a study has been conducted on a prototype designed as per the system architecture (Figure 6a). The prototype is supplied with power through the help of a lithium-ion battery with a capacity of 2000 mAh and a voltage ranging of 3.7 V which is rechargeable as illustrated in Figure 6.b. The life cycle of a Li-ion battery varies with temperature over 60 °C it causes a sharp decline in battery life (Figure 5) even at lower temperatures, the same thing occurs. Lithium-ion batteries have an extraordinary potential to explode via a chain reaction. For Li-ion and lead acid batteries, operating temperature is typically regulated to less than 60 °C.

Blynk login has been created and the device is configured to the respective virtual pins of ESP8266 Wi-fi module (Figure 7a). With respect to the proposed algorithm illustrated in Table 2, code has been developed on Arduino IDE platform (Figure 7b) to control the prototype. The digital pins of ESP8266 namely; D1 to D8 has been initialized and connected to the respective pins of external hardware L298N, DHT-11/22 and DS18B20. Similarly, the analog pin A0 has been connected to gas sensor of MQ135, along with power supply (VCC) and ground pins (GND) of the respective sensors. The prototype is set to run condition, which operates at a speed of 8 to 10 kmph, meanwhile the sensors DHT-11/22 and DS18B20 measures temperature of the battery and MQ135 checks for gas leakage in the vehicle. The recorded values are updated to the app through ESP8266 Wi-fi module, and compared with the threshold values of temperature and gas stored in cloud through dumping the developed code in Arduino IDE platform. If the recorded value is found to satisfy the condition, it controls the L298N IC to reduce the motor speed of H1 and H2 respectively, where the speed of vehicle is reduced and made to 0mph that stops the vehicle to prevent it from further damage or accident.

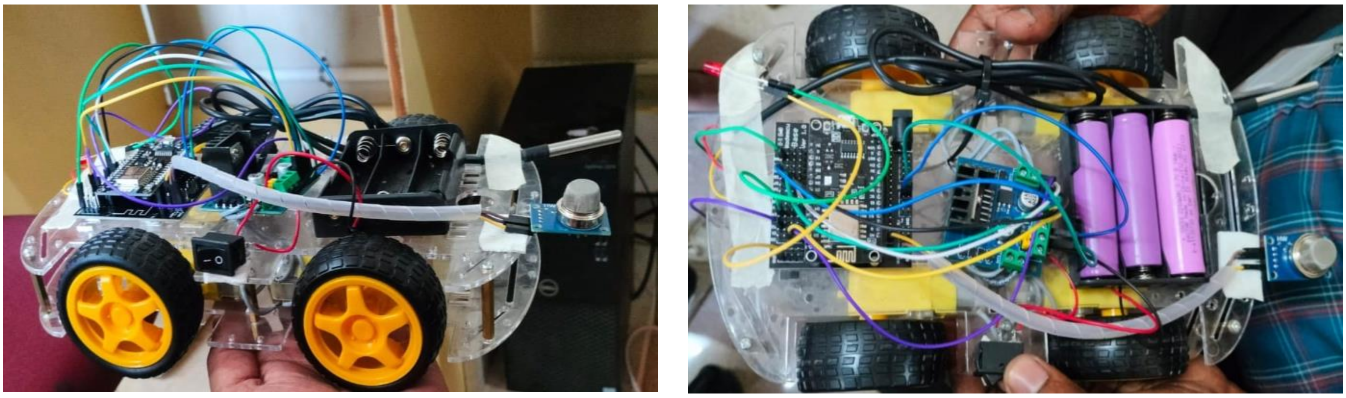
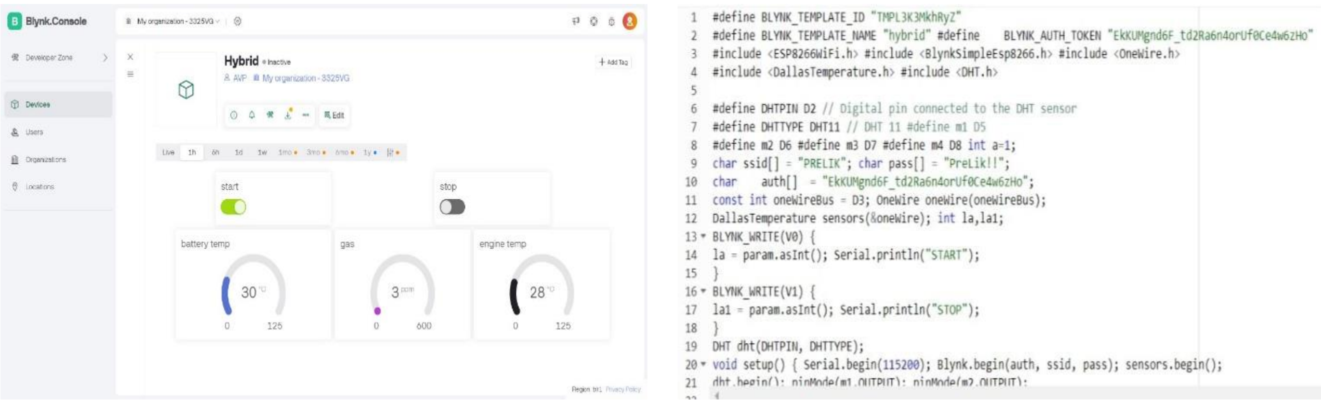


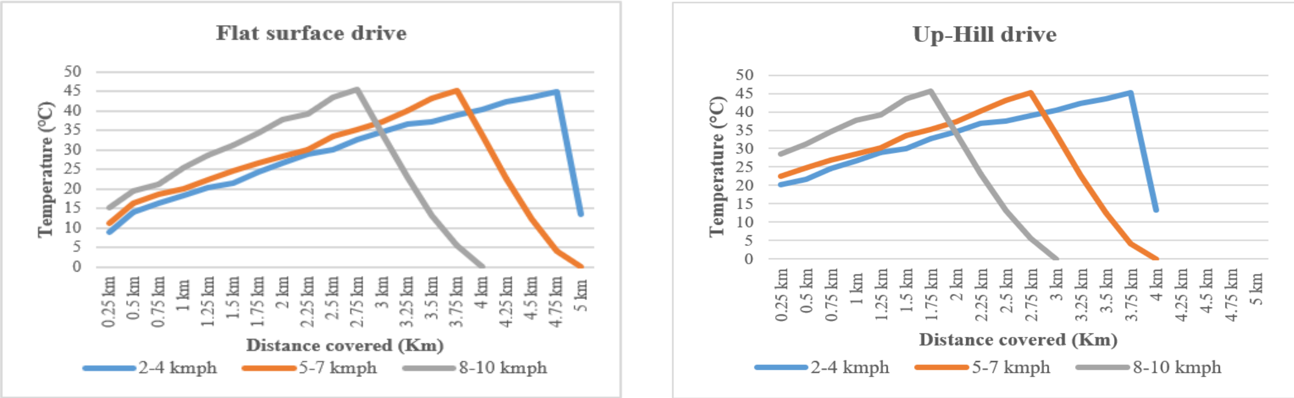
Figure 6. (**a**). Prototype of the proposed system (**b**). Prototype supplied with power through Li-ion rechargeable battery.

The device ESP8266 has been configured to Blynk app, which displays the temperature of battery (°C), temperature of engine (°C) and gas of vehicle (ppm). The prototype has been tested under two different scenarios namely; flat surface drive and up-hill drive for HEV and PHEV. Where speed of HEV ranges from 3–6 kmph and PHEV ranges from 7-10 kmph. The prototype is tested in normal surface and steep surface driving mode to achieve the speed control automatically using the proposed system. Temperature vs distance plot is calculated and plotted as shown in Figures 8 and 9.



(**a**) (**b**)

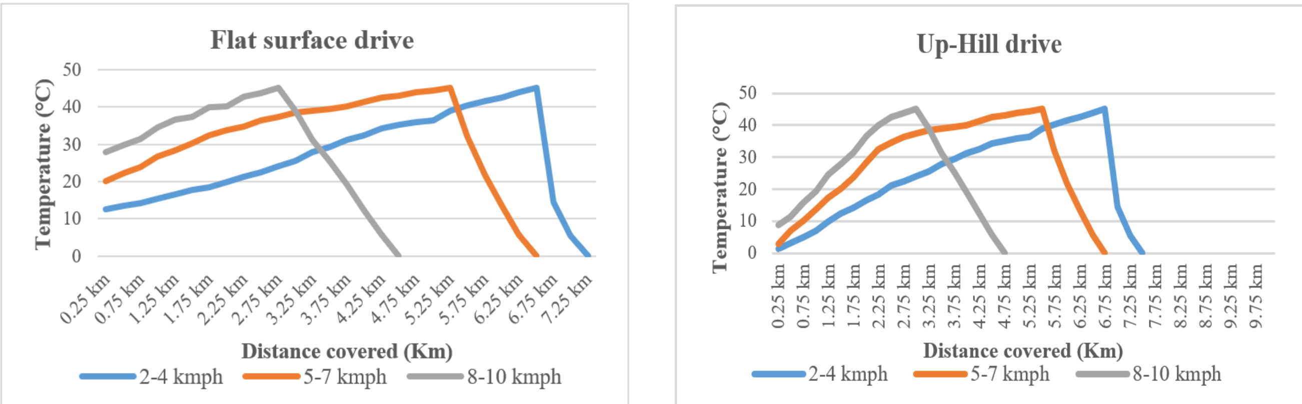
Figure 7. (**a**). Snippet of Blynk account configured with device (**b**). Snippet of Arduino IDE code written on platform.



(**a**) (**b**)

Figure 8. (**a**). Temperature vs distance plot on flat surface drive and (**b**). Up-hill drive of HEV .

By analyzing the prototype with various scenario at a speed of 2–4, 5–7 and 8–10 kmph, it is evaluated and found that during up-hill drive and higher speed the temperature raises high when compared to flat surface and low speed respectively. On an average of 3.2 km and 5.5 km temperature reaches the threshold value for HEV and PHEV respectively. Also, the performance of PHEV is found to be more efficient when compared to HEVs. At high temperature automatically the speed of the vehicle is reduced.



(**a**) (**b**)

Figure 9. (**a**). Temperature vs distance plot on flat surface drive and (**b**). Up-hill drive of HEV.

5. Conclusions

Unexpected battery fire mishaps in electric vehicles result in fatalities to human life and vehicles if not alerted in a timely manner, hence prior notice is required. IoT-based hybrid vehicle thermal observing system has been presented in this paper, where sensor data is uploaded to the cloud and controlled by developing C++ code in Arduino IDE environment. The prototype has been tested in various scenarios of flat surface and up-hill drive at different speeds of 2–4 kmph, 5–7 kmph and 8–10 kmph for HEV and PHEV. The analysis shows that during up-hill drive and higher speed the temperature raises high compared to flat surface. On an average of 3.2 km and 5.5 km distance, temperature of the prototype reaches threshold value for HEV and PHEV models respectively. It has been identified that the proposed system is effective and reasonably priced. In order to prevent more harm, the auto cut-off feature cuts the HEV's battery power. In order to precisely manage and create solid-state batteries with better thermal properties, future directions of the work plans to integrate BTMS with AI and ML algorithms. In a similar way, investigation of new cooling system or methods can be introduced. By addressing these issues, automotive sector may improve the BTMS for HEVs' effectiveness, safety, and dependability, which will eventually encourage the widespread adoption of sustainable transportation solutions.

Author Contributions: A.V. carried out all the research steps including finding the problem, analyzing the related works, implementing the proposed method as well as writing the manuscript. R.R., A.P. and R.K.D. has contributed in analyzing the results and editing the manuscript. All authors have read and approved the manuscript.

Funding:

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

Conflicts of Interest: The authors declare no conflict of interest.

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