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DESIGN AND INTEGRATION OF AN AUTOMOTIVE TELEMATICS CONTROL MODULE

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Abstract

Telematic Control Units (TCUs) are transforming the automotive industry by providing real time communication, vehicle diagnostics, and advanced safety features. The TCU is a significant advancement in automotive technology, seamlessly integrating telecommunications and computing capabilities to transform how vehicles interact with their surroundings. At its core, the TCU acts as a link between the vehicle's internal systems and external networks, allowing for a wide range of connected services, remote monitoring, and data sharing. This work describes the design and development of a low-cost, dependable TCU prototype that uses GPS, GSM, and CAN based communication protocols. This study presents the development, integration, and simulation of an Automotive Telematics Control

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Module (TCM) built using Python. The system simulates key telematics functionalities such as real-time diagnostics, sensor monitoring, alert generation, and telemetry visualization. It dynamically produces synthetic vehicle data, which is rendered through an interactive GUI and histograms to support proactive vehicle health monitoring. This simulation-driven framework offers a cost-effective solution for prototyping and validating system behavior prior to physical hardware implementation.

Keyword: Telematic Control Units (TCUs), Intelligent Transportation Systems (ITS), Telematics Control Modules (TCMs)

1. Introduction

With the rise of Intelligent Transportation Systems (ITS) and connected vehicles, automotive telematics has become integral for vehicle diagnostics, maintenance prediction, and remote monitoring. Telematics Control Modules (TCMs) serve as the central interface bridging the gap between vehicle subsystems and remote interfaces by collecting, processing, and transmitting vehicular data to centralized platforms. This integration enables real-time visibility into vehicle health and supports data-driven decision-making for both drivers and service providers [1]. This work focuses on simulating a Python-based TCM for real-time monitoring, supporting early detection of anomalies before they lead to critical failures or breakdowns. Such systems contribute to the development of proactive, cost-effective maintenance strategies and are widely recognized in both industry and academia as enablers of next-generation connected vehicle infrastructure [2].

With the rapid evolution of Intelligent Transportation Systems (ITS) and the widespread deployment of connected vehicles, the automotive industry is undergoing a transformative shift from reactive maintenance to predictive and preventive vehicle management [3]. In this ecosystem, automotive telematics plays a pivotal role. Telematics integrates vehicular communication

technologies, sensor networks, and data analytics to enable real-time vehicle monitoring, diagnostics, and control [4-5].

At the heart of modern telematics systems lies the Telematics Control Module (TCM)—a central embedded system responsible for gathering data from various in-vehicle subsystems (e.g., engine, battery, tyres, brakes, fuel system) and transmitting it either to the driver via a Human-Machine Interface (HMI) or to cloud-based analytics systems. The TCM not only

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enables remote diagnostics and over-the-air (OTA) updates, but also supports driver behavior analysis, emergency alerting, and fleet management [6-7]. These capabilities make TCMs essential for connected vehicle ecosystems and intelligent fleet operations, allowing both individual users and service providers to access real-time health and performance data for proactive decision-making [8].

A practical illustration of the significance of Telematics Control Modules (TCMs) can be observed in modern vehicles like those manufactured by Tesla, Ford, and Toyota, where integrated telematics systems continuously track critical parameters such as engine temperature, oil pressure, battery voltage, and tyre pressure. These systems are capable of proactively alerting drivers or service centers in case of impending failures—such as overheating, low tyre pressure, or abnormal voltage—thereby reducing unplanned vehicle downtime and enhancing road safety [9-10]. In Tesla vehicles, for example, telematics data is not only used for diagnostics but also for delivering over-the-air updates and remote battery conditioning [11]. Similarly, Ford's SYNC platform and Toyota's Safety Connect offer cloud-connected diagnostics, crash notification, and predictive maintenance capabilities.

This research focuses on the simulation of a Python-based Telematics Control Module, designed to mimic real-world sensor behavior, evaluate operational thresholds, and visualize health status in real time. By using synthetic data to simulate anomalies—such as an overheated engine, underinflated tyres, or low brake fluid—the system enables developers and engineers to validate diagnostics logic and alert mechanisms in a cost-effective virtual environment. This simulation approach is especially valuable in the early phases of development when hardware integration is either infeasible or expensive.

Furthermore, integrating such simulations with a GUI and live plotting capabilities (using libraries like tkinter and matplotlib) enhances interactivity and usability, making it easier to test diverse scenarios and refine telematics algorithms before deployment in embedded automotive platforms.

In essence, this work aims to demonstrate how software-level TCM simulation can support the design, validation, and optimization of telematics functionalities, ultimately contributing to safer, smarter, and more efficient vehicular systems.

2. Lieterature Review

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Intelligent Transportation Systems (ITS) refer to the integration of advanced information and communication technologies into transportation infrastructure and vehicles to improve traffic management, road safety, and travel efficiency. The primary goal of ITS is to enhance mobility and reduce the environmental impact of transportation through real-time monitoring, data analytics, and automated decision-making [12].

ITS encompasses multiple components including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Everything (V2X) communication systems [13]. These systems enable cooperative awareness, allowing vehicles and infrastructure to share data about speed, location, traffic signals, and road conditions. This real-time exchange of information helps mitigate congestion, reduce accidents, and optimize routing[14-15].

According to Abdalla et al. (2020), ITS plays a pivotal role in the development of smart cities, where transportation networks are dynamically managed using data from sensors, GPS modules, mobile devices, and traffic cameras. The deployment of ITS technologies has also been linked with reduced travel times, improved fuel efficiency, and enhanced user experience in urban environments [16].

Modern ITS also supports autonomous driving technologies, integrating sensors such as LiDAR, radar, and onboard telematics modules to enhance situational awareness and automate decision-making. El Khatib et al. (2021) highlight that ITS is instrumental in achieving Level 3 and Level 4 autonomy, where vehicles can perform complex tasks such as adaptive cruise control, automatic lane-keeping, and emergency braking without human intervention [17].

From a policy and infrastructure standpoint, Papageorgiou et al. (2021) discuss how ITS facilitates intelligent traffic signal control, automated tolling, smart parking systems, and emergency vehicle prioritization, thereby reshaping public and private transportation services [18].

However, the deployment of ITS faces challenges including cybersecurity, interoperability, data privacy, and the high cost of infrastructure. These limitations necessitate rigorous simulation, testing, and regulatory frameworks to ensure reliable system performance [19-21].

3. Problem Statement

This research presents the design, integration, and simulation of an Automotive Telematics Control Module (TCM) developed using Python. The module emulates core telematics

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functionalities such as real-time health diagnostics, sensor monitoring, alert management, and telemetry visualization. The simulator dynamically generates synthetic vehicular data, visualizes it through a GUI and histogram, and supports proactive vehicle health management. This approach enables cost-effective prototyping and testing prior to hardware deployment.

4. System Architecture

The proposed system architecture is purposefully modular and layered to emulate real-world telematics functionality in a cost-effective, scalable, and testable software environment. Each layer plays a critical role in simulating

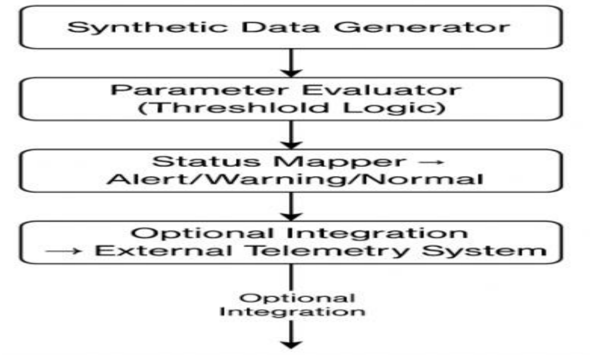

Figure 1: Modular Architecture

sensor data, evaluating vehicle health, and visualizing actionable insights, mimicking actual TCM operations found in connected vehicles.

Example Use Case: Engine Overheating Scenario

Scenario:Suppose a vehicle’s engine temperature exceeds its safe operational threshold during long-distance driving. The real-world TCM would monitor this in real-time and trigger a visual or diagnostic alert to notify the driver or fleet operator.

Here’s how the simulator handles this scenario step-by-step based on your architecture:

4.1 Architecture Diagram

The flowchart represents a **modular architecture** for a vehicle or system health monitoring simulation demonstrated in figure

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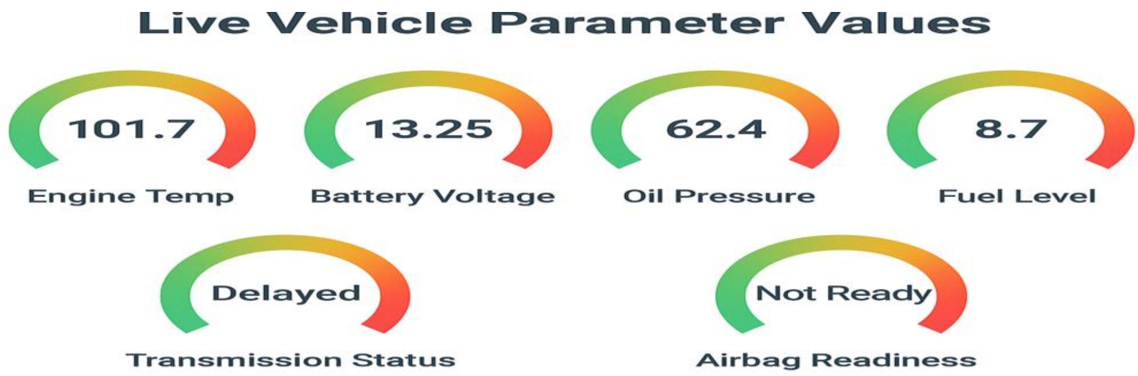

Figure 2: Vehicle Health Monitoring System

Figure 2 presents a real-time visualization of key vehicle parameters using color-coded gauge indicators for intuitive system health interpretation. Each gauge reflects the current operational value of a specific subsystem, providing immediate feedback to the user or diagnostic module.

i. Engine Temperature (101.7°C) – The value lies within the standard operational range (90–105°C), thus the gauge indicates a Normal condition.

ii. Battery Voltage (13.25 V) – Although within acceptable limits (12.6–14.7 V), the system flags it as Alert, possibly due to load imbalance or potential overcharge risk.

iii. Oil Pressure (62.4 psi) – This reading exceeds typical idle thresholds, suggesting possible abnormal pressure buildup, hence marked Alert.

iv. Fuel Level (8.7%) – Fuel is critically low; the system raises a Warning to prompt refueling before operational failure.

v. Transmission Status (Delayed) – A delay in gear shifting indicates non-optimal performance, hence classified as Alert.

vi. Airbag Readiness (Not Ready) – A critical safety component is non-functional, hence the Alert status is justified.

Overall, the diagram supports proactive diagnostics by instantly identifying potential issues in thermal regulation, fluid dynamics, electrical supply, and safety systems.

5. Result and Discussion

A Vehicle Health Monitoring Shown below Table 1, Table 2 and Table 3 with three columns: **Parameter**, **Current Value**, and **Status**. The table uses color-coded statuses to indicate the health of various vehicle systems. Here's a justification of the statuses based on the values shown:

- Engine Temperature (°C) – 101.7°C. Within typical operational range (90–105°C), so marked Normal.
- Brake Fluid Level – OK. Indicates no issues; system is working properly.
- Tyre Pressure (FL) (psi) – 33.6. Normal tyre pressure range is usually 30–35 psi.

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- GPS Signal – Active. GPS is functioning, hence status is Normal.
- Fuel Level (%) – 8.7. Fuel level is below 10%, prompting a Warning before it becomes critical.
- Battery Voltage (V) – 13.25. Though normally 12.6–14.7V is acceptable, the system might have thresholds set for specific load conditions (e.g., overcharging risk or sensor discrepancy), hence marked Alert.
- Oil Pressure (psi) – 62.4. This could indicate either abnormally high or low pressure, depending on engine state. Likely exceeds safe threshold under certain operating conditions.
- Transmission Status – Delayed. There is delay in shifting is abnormal behavior, hence alert.
- Airbag Readiness – Not Ready. Safety-critical feature is not operational. Alert is appropriate.

The system provides a quick and effective diagnostic overview. Immediate attention is required for the **airbag system, oil pressure, battery voltage, and transmission delay**, while **fuel level** should be refilled soon to avoid alerts.

Parameter	**Current value**	**Status**
Engine temp	84.9	Warning
Battery voltage	12.86	Alert
Brake Fluid Level	Low	Alert
Tyre Pressure	31.3	Warning
Oil Pressure	69.7	Alert
Fuel Level	92	Normal
Transmission status	Delayed	Alert

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Airbag Readiness	Ready	Normal
GPS signal	Low	Alert

Table 1: Vehicle health montoring

The Figure 3, Figure 4 and figure 5 - Live Vehicle Parameter Values provides a visual representation of five key vehicle parameters. Here's a justification of the values and their implications by comparing them with typical thresholds for vehicle performance and safety given below in table 4:

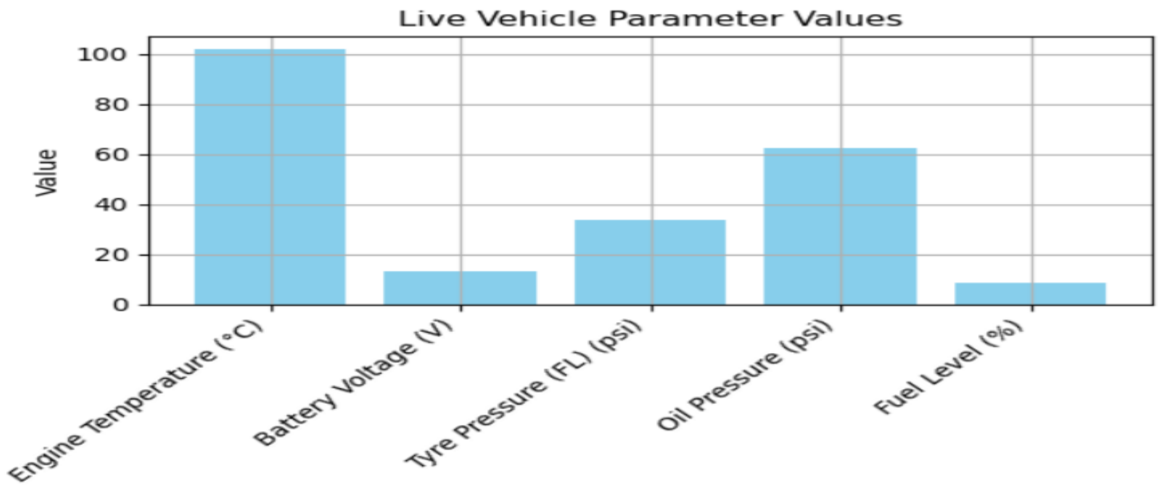

Figure 3: **Live Vehicle Parameter Values**

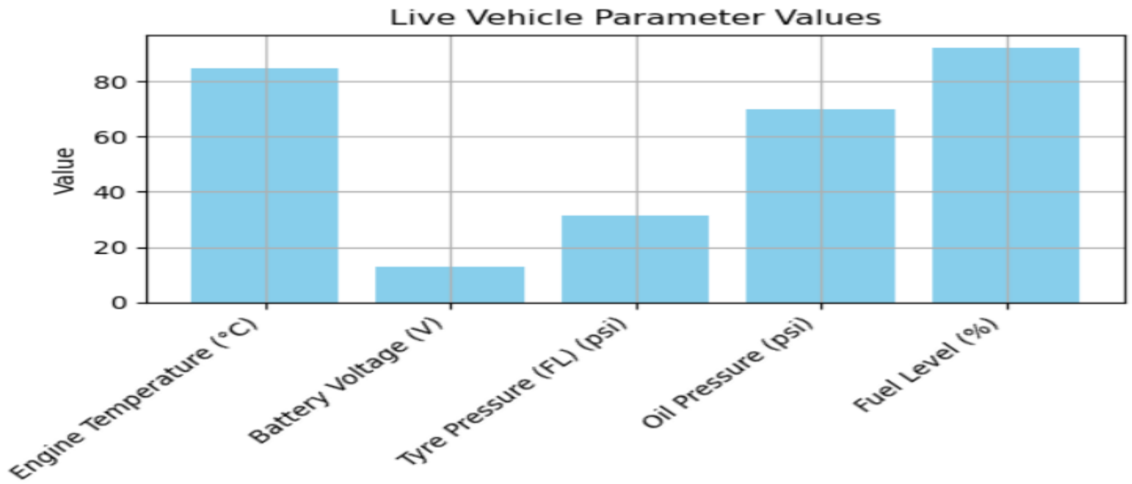

Figure 4: **Live Vehicle Parameter Values**

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Table 2: Vehicle health monitoring

Parameter	Current value	Status
Engine temp	101.7	Normal
Battery voltage	13.25	Alert
Brake Fluid Level	Ok	Normal
Tyre Pressure	33.6	Normal
Oil Pressure	62.4	Alert
Fuel Level	8.7	Warning
Transmission status	Delayed	Alert
Airbag Readiness	Not ready	Alert
GPS signal	Active	Normal

Table 3: Vehicle health monitoring

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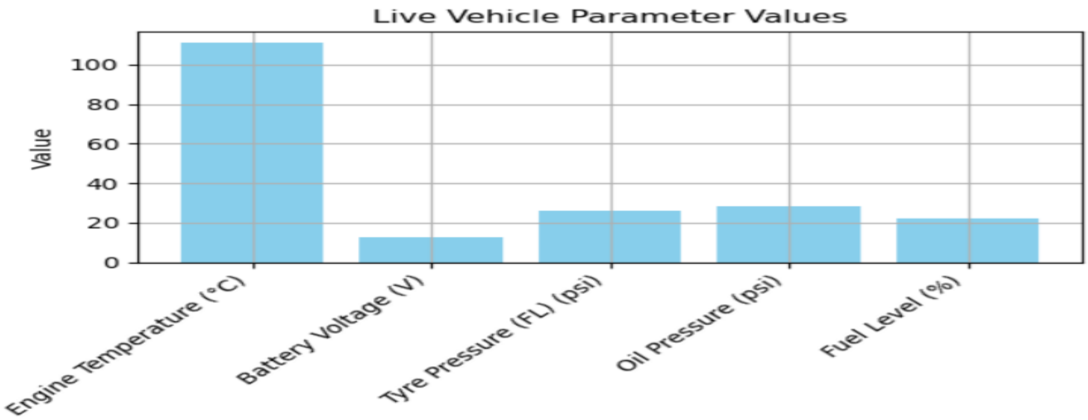

Figure 5: **Live Vehicle Parameter Values**

This simulation demonstrates that proactive diagnostics can effectively identify potentially hazardous conditions such as engine overheating, low tyre pressure, and abnormal battery levels. The alert classification algorithm ensures immediate user feedback, while the GUI supports intuitive interpretation.

6. Conclusion

The paper details the successful development and implementation of a scalable, cost-efficient Telematics Control Unit (TCU) engineered for seamless integration with diverse vehicular platforms. Leveraging key hardware components—including the ESP32 microcontroller, the EC200UCN GSM/GPS communication module, and a Controller Area Network (CAN)-based On-Board Diagnostics II (OBD-II) interface—the prototype demonstrates robust capabilities in real-time vehicular data acquisition, secure wireless communication, and remote system monitoring through a cloud-enabled dashboard. The modular architecture of the system ensures broad compatibility across a variety of vehicle types, thereby extending its applicability to both personal and commercial transportation contexts. Furthermore, the incorporation of HTTPS-based secure data transmission, along with reliable parsing of diagnostic information, contributes to improved predictive maintenance, enhanced driver safety, and more efficient fleet management operations.

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