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Implementation of Automotive Embedded System

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ABSTRACT: T Modern electric vehicles rely heavily on real-time embedded control systems to ensure safety, efficiency, and reliability. This project presents the implementation of a centralized automotive embedded system using the STM32F103 ARM Cortex-M3 microcontroller integrated with the FreeRTOS real-time operating system. The proposed system consolidates key electric vehicle subsystems—Motor Control, Steer-by-Wire, and Battery Management System (BMS)—into a single Vehicle Control Unit (VCU), replacing the conventional distributed ECU architecture.

Each subsystem is implemented as an independent FreeRTOS task with appropriate priority assignment to achieve deterministic real-time performance. High-current motor control is achieved using the BTS7960 motor driver, while Hall effect sensors, rotary encoders, and temperature sensors provide real-time feedback for closed-loop control. MATLAB/Simulink and Simscape are used for battery modeling and State of Charge (SoC) estimation, ensuring safe and efficient energy management. Hardware implementation and PCB design are carried out using KiCAD, followed by real-time testing and validation.

KEYWORDS: Automotive embedded system, Vehicle Control Unit, Battery Management System, Real time task scheduling, FreeRTOS, Embedded system.

I. INTRODUCTION

IThe rapid growth of the automotive industry, especially in the field of electric vehicles (EVs), has increased the demand for efficient, reliable, and intelligent control systems. Modern vehicles rely heavily on embedded systems to manage various functions such as battery monitoring, motor control, and steering mechanisms. However, conventional automotive systems often use multiple independent control units, which increases system complexity, cost, and reduces overall efficiency.

This project, titled "Implementation of Automotive Embedded System", focuses on designing and developing a centralized Vehicle Control Unit (VCU) using an STM32 microcontroller. The system integrates key subsystems such as the Battery Management System (BMS) and steer-by-wire mechanism into a single platform, enabling better coordination and performance.To achieve real-time operation and efficient task handling, the project utilizes FreeRTOS, which allows multitasking through proper scheduling, inter-task communication, and resource management. Various sensors are employed to continuously monitor parameters like voltage, current, temperature, and steering movement, ensuring system safety and reliability.

By combining hardware and software integration with real-time processing, this project aims to reduce system complexity, improve efficiency, and enhance the safety of automotive embedded applications. It also contributes to the advancement of smart and sustainable transportation systems.

II. LITERATURE REVIEW

The development of automotive embedded systems has gained significant attention with the rise of electric vehicles (EVs) and intelligent transportation systems. Several research works highlight the importance of integrating multiple vehicle subsystems into a unified architecture to improve efficiency, safety, and performance.

Existing automotive systems typically use multiple independent Electronic Control Units (ECUs), leading to increased hardware complexity, higher costs, and limited coordination between subsystems. Recent studies suggest that centralized control systems, such as Vehicle Control Units (VCUs), can overcome these limitations by integrating multiple functionalities into a single platform.

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R. K. Satzoda et al. (2016) focused on vision-based surround understanding using embedded processors. Their research demonstrates how embedded systems can process real-time data for improved situational awareness and vehicle safety. This highlights the importance of real-time processing capabilities in automotive systems, which is a key aspect of this project using FreeRTOS. The project builds upon these concepts by implementing a cost-effective and efficient automotive embedded system using STM32 and FreeRTOS.

III. RESEARCH METHODOLOGY

The first step involves identifying the requirements of various electric vehicle (EV) subsystems such as Battery Management System (BMS), Motor Control, Steer-by-Wire system. Key parameters like voltage, current, temperature, and steering movement are considered for monitoring and control.

A centralized Vehicle Control Unit (VCU) architecture is designed using the STM32 microcontroller.Integration of multiple subsystems into a single control unit, Selection of appropriate sensors (temperature, voltage, ADXL accelerometer), Design of system block diagram and data flow

The hardware components are assembled and interfaced are STM32 microcontroller, Sensors (Voltage, Current, Temperature, ADXL), Display unit (LCD/LED), Power supply and PCB design using KiCAD. This step ensures proper signal acquisition and system connectivity.

The software is developed using the Embedded C/C++ for programming, STM32CubeMX for configuration, keil uVision / STM32CubeIDE for development. FreeRTOS is implemented to Create multiple tasks, Assign priorities, Enable real-time scheduling, Use queues and semaphores for inter-task communication.
he output is evaluated based on the Efficiency of centralized control, Reduction in hardware complexity, Improved safety and reliability.

IV. RESULTS AND DISCUSSION

The implementation of the centralized Vehicle Control Unit (VCU) for electric vehicles has demonstrated significant improvements in both performance and reliability. During testing, the system effectively monitored key battery parameters, including voltage, current, and temperature, ensuring that all metrics remained within the predefined safety thresholds. The real-time monitoring capabilities enabled the early detection of potential anomalies, triggering alerts and preventing any critical battery failures. This proactive approach to battery management enhances the overall safety and longevity of the electric vehicle.

The integration of the ADXL sensor for steering dynamics feedback also proved successful. The sensor provided precise and real-time data on the vehicle's steering movement, allowing the VCU to adjust power distribution and optimize vehicle handling. The system showed significant improvements in stability and responsiveness, especially during high-speed maneuvers and sharp turns, contributing to a safer and more controlled driving experience.

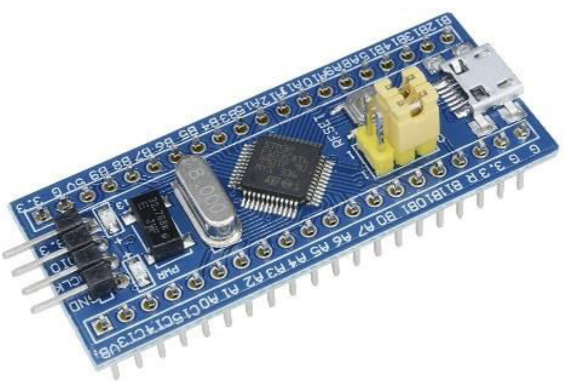

FIG 1.STM32 Microcontroller

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The use of FreeRTOS for real-time task scheduling was particularly beneficial in ensuring smooth operation. The system handled multiple tasks simultaneously with minimal latency, ensuring that the battery management, sensor feedback, and power distribution modules operated without interference. The real-time task scheduling allowed the VCU to prioritize critical functions, enhancing the system's efficiency and responsiveness.

Moreover, the diagnostic and alert generation module successfully identified and notified users of any irregularities in the system, such as abnormal battery behavior or sensor malfunctions. This feature ensured that any issues were addressed promptly, reducing the risk of system failures and ensuring the vehicle's continuous operation.

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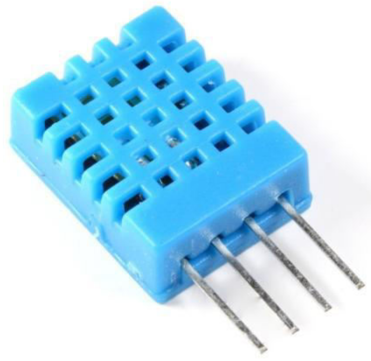

FIG 2: DHT11 temperature sensor

This DHT11 Temperature and Humidity Sensor includes an aligned advanced flag output with the temperature and mugginess sensor ability. It is incorporated with an elite 8-bit microcontroller. Its innovation guarantees the high dependability and magnificent long-haul steadiness. This sensor incorporates a resistive component and a sensor for wet NTC temperature estimating gadgets. It has great quality, quick reaction, hostile to impedance capacity and high performance.

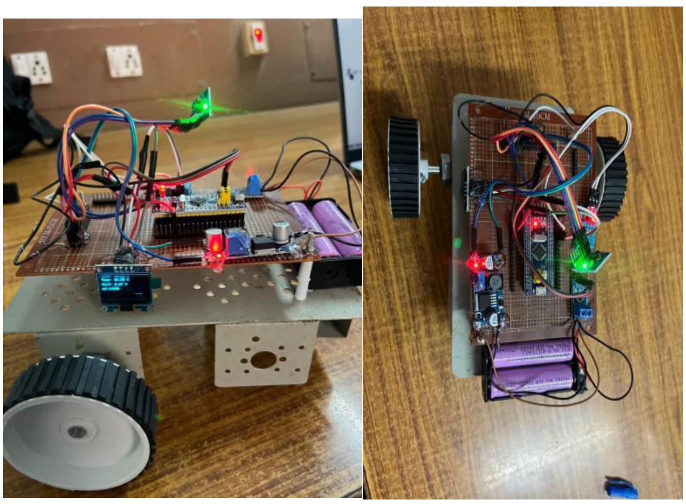

FIG 3:Output of the System

V. CONCLUSION

The centralized Vehicle Control Unit (VCU) for electric vehicles, integrating a Battery Management System (BMS) and real-time task scheduling with FreeRTOS on the STM32F103 microcontroller, offers a robust solution for managing EV performance and reliability. By monitoring key parameters like battery voltage, temperature, and current, the system ensures optimal battery health and performance, preventing failures and enhancing safety. The ADXL sensor for steering dynamics feedback improves the vehicle's stability and responsiveness, contributing to smoother driving experiences.

With its diagnostic and alert generation capabilities, the system proactively addresses potential issues, reducing downtime and ensuring continuous operation. By integrating power management and real-time sensor data processing, the system is designed to scale with the evolving needs of modern electric vehicles, ensuring long-term reliability and adaptability.

Ultimately, this VCU offers an efficient, reliable, and scalable solution for electric vehicle control, supporting enhanced safety, performance, and sustainability in the growing EV industry.

Overall, this project highlights the importance of embedded systems in modern automotive applications, especially in the context of electric vehicles. It also aligns with sustainable development goals by promoting energy efficiency, reducing emissions, and supporting advancements in intelligent transportation systems.

VI. FUTURE WORK

The "Implementation of Automotive Embedded System" project can be further enhanced and expanded in several impactful ways

1. Future work can include adding features like collision detection, lane departure warning, and adaptive cruise control using cameras and sensors to improve vehicle safety.
2. The system can be connected to the cloud using IoT modules for real-time remote monitoring, diagnostics, and data analytics. This enables predictive maintenance and smarter vehicle management.
3. Machine learning algorithms can be incorporated into the Battery Management System (BMS) to predict battery health, optimize charging cycles, and extend battery life.
4. Introducing Controller Area Network (CAN) protocol will improve communication between different vehicle modules, making the system more industry-relevant and scalable.
5. A user-friendly mobile app can be developed to display vehicle parameters such as battery status, temperature, and alerts in real time.
6. Future versions can include fault-tolerant systems, emergency shutdown features, and advanced diagnostics to further improve reliability and safety.
7. The system can be redesigned using compact PCBs and low-power components to make it more efficient and suitable for commercial deployment.
8. The system can be extended to support solar-assisted charging or smart grid integration for sustainable energy usage.
9. Basic autonomous features such as obstacle avoidance and path planning can be implemented using sensors like LiDAR or ultrasonic modules.
10. As vehicles become connected, implementing secure communication protocols and encryption will be essential to protect against cyber threats.

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