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Accurate Thermal Sensing for Electric Vehicles in Automotive

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ABSTRACT:

This research paper presents the design and implementation of a coolant control system that leverages the capabilities of STM32 microcontrollers, a stepper motor, temperature sensor, and Analog-to-Digital Converter (ADC) with Direct Memory Access (DMA). The system's primary objective is to regulate the temperature of a specific environment by controlling the flow of coolant. This is achieved through a closed-loop control system that continuously monitors the temperature and adjusts the coolant flow rate in real-time to maintain the desired temperature setpoint. The system architecture consists of two STM32 microcontrollers, interconnected via a Controller Area Network (CAN) [4] bus, providing a modular and scalable approach to temperature control. The first microcontroller is responsible for temperature sensing using a precision temperature sensor, while the second microcontroller controls the stepper motor, which modulates the coolant flow. The ADC and DMA peripherals ensure efficient data acquisition and processing. The research includes a detailed description of the hardware and software components, emphasizing the utilization of the STM32 microcontrollers'[8] capabilities for real-time control. The software is designed to receive temperature setpoint commands through the CAN bus and execute precise coolant flow adjustments based on the feedback from the temperature sensor.

Experimental results demonstrate the system's effectiveness in maintaining temperature stability within defined tolerances. The paper also discusses the advantages of using STM32 microcontrollers, such as their real-time processing capabilities and robust communication via CAN. The implementation's scalability and adaptability for various cooling applications are highlighted.

This research contributes to the field of embedded systems and automation by showcasing a practical application of microcontroller-based temperature control. The findings offer insights for engineers and researchers interested in similar control systems for industrial or laboratory settings.

Keywords: STM32 Microcontrollers, Stepper Motor, Temperature Sensor, Analog-to-Digital Converter (ADC), Direct Memory Access (DMA), Coolant Control System, Controller Area Network (CAN) bus

I. INTRODUCTION

In today's rapidly evolving technological landscape, the demand for efficient and precise temperature control systems has grown significantly, finding applications in various industries, from manufacturing to research and development. Maintaining temperature stability within defined parameters is often critical for the performance and longevity of equipment, as well as the quality of processes and products. To address this need, our research project focuses on the development of a "Coolant Control System" using advanced embedded technologies.

This project aims to design and implement a coolant control system that leverages the capabilities of STM32 microcontrollers, a stepper motor, and a temperature sensor, all interconnected through a Controller Area Network (CAN) bus. The system's primary objective is to maintain a specific environment's temperature by regulating the flow of coolant. Achieving this control requires continuous monitoring of the temperature and real-time adjustment of the coolant flow rate to keep it within the desired temperature setpoint.

The significance of this research is underscored by the ever-increasing demand for precision temperature control across various industries. Whether it is in semiconductor manufacturing, biotechnology research, or automotive engineering, precise temperature control is essential for the optimization of processes, safety, and overall operational efficiency. Traditional methods of temperature control often fall short in terms of accuracy and real-time adaptability, making microcontroller-based systems a compelling solution.

Our project embraces the concept of modular and scalable temperature control. It employs two STM32 microcontrollers, each with a specific role within the system. The first microcontroller is dedicated to temperature sensing, employing a high-precision temperature sensor to continuously monitor the environment. The second microcontroller is responsible for controlling the stepper motor, which modulates the coolant flow. Analog-to-Digital Converter (ADC) and Direct Memory Access (DMA) peripherals are incorporated to ensure efficient data acquisition and processing.

By using STM32 microcontrollers [8] and a CAN bus for communication, this research project exploits the real-time processing capabilities and robust data exchange to create an adaptive and responsive temperature control system. The software component is designed to receive temperature setpoint commands through the CAN [4] bus and execute precise adjustments based on the feedback from the temperature sensor.

The results of our research are anticipated to not only demonstrate the efficacy of this embedded system but also shed light on its potential applications in various industries. The system's scalability and adaptability render it a valuable solution for a wide range of cooling applications, providing a cost-effective, reliable, and precise means of temperature regulation.

II. LITERATURE REVIEW

Previous research on thermal management in EVs [1] has focused on various aspects, including passive cooling methods, active cooling strategies, and thermal modelling techniques. Passive cooling methods, such as heat sinks and natural convection, have been used to dissipate heat from EV components. Active cooling strategies, such as fans and pumps, have been employed to enhance heat dissipation. Thermal modelling techniques, such as finite element analysis and computational fluid dynamics, have been used to simulate and optimize the thermal behaviour of EV components.

While these studies have provided valuable insights into thermal management in EVs [2], there is a need for more precise and adaptive thermal control systems. Existing systems often lack the ability to respond dynamically to changing thermal conditions, leading to inefficient cooling and potential overheating of critical components. The proposed research aims to address these limitations by developing a coolant control system that can adaptively regulate coolant flow based on real-time temperature feedback.

Hardware Analysis

The hardware analysis for the proposed coolant control system in EVs encompasses a detailed examination of the system's components and their functions. The system is built around several key hardware components, each playing a crucial role in ensuring accurate and efficient thermal management. At the core of the system is the stepper motor [7], which is responsible for regulating the flow of coolant through the EV's thermal management system. The stepper motor offers precise control over coolant flow, allowing for adjustments to be made based on real-time temperature feedback from sensors. This level of control is essential for maintaining optimal thermal conditions within the vehicle.

Temperature sensors are strategically placed throughout the EV's thermal management system [1] to provide real-time temperature data to the microcontroller. These sensors are critical for ensuring that the coolant control system can accurately monitor and respond to changes in temperature, helping to prevent overheating and damage to critical components. The STM32 microcontroller serves as the brain of the coolant control system, processing temperature data from the sensors and sending control commands to the stepper motor. The microcontroller also interfaces with the CAN bus, allowing for communication with other vehicle systems and enabling coordinated operation.

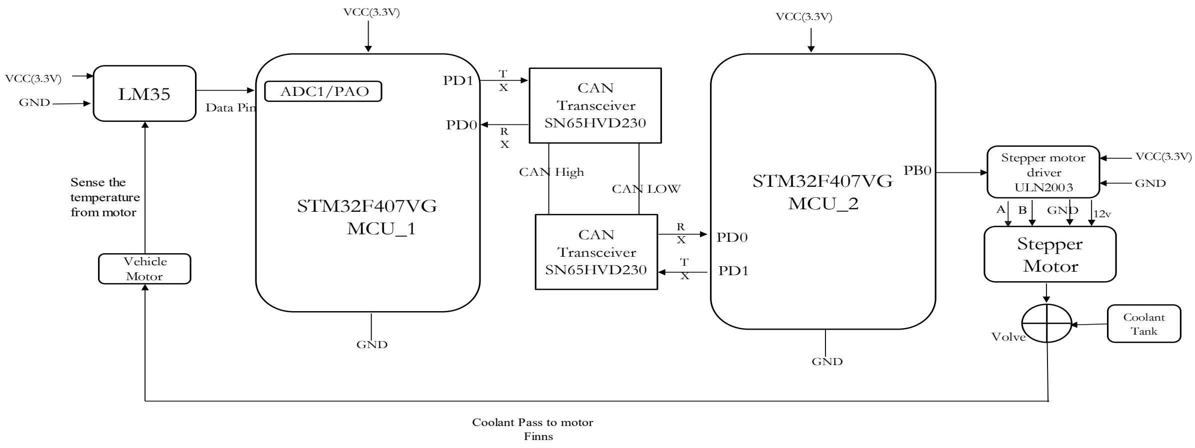
The CAN bus [4] interface plays a crucial role in the system, enabling seamless communication between the coolant control system and other vehicle systems. This allows the coolant control system to receive commands and data from other systems, ensuring that coolant flow is adjusted in response to the vehicle's overall operating conditions. Additionally, a stable and reliable power supply is essential for the operation of the coolant control system. The power supply must be capable of providing sufficient power to all components while maintaining stable voltage levels, ensuring that the system operates reliably under all conditions.

Software System Analysis

The software system analysis for the proposed coolant control system in EVs involves the utilization of the STM32CubeIDE, an integrated development environment specifically designed for STM32 microcontrollers. This IDE offers a range of tools and features tailored to the development process, including code editing, debugging, and project management capabilities. One of the key aspects of the software architecture is the use of STM32CubeMX for configuring the microcontroller's peripherals. This tool allows developers to easily set up the required peripherals, such as timers, GPIOs, and UARTs, and generate initialization code, thereby simplifying the development process and ensuring compatibility with the STM32 microcontroller. The software development process in STM32CubeIDE involves writing code in the C programming language, which is then compiled and flashed onto the microcontroller. The software implements a control algorithm that regulates coolant flow based on real-time temperature feedback from sensors. The algorithm continuously reads temperature data from the sensors, processes it, and sends control commands to the stepper motor to adjust coolant flow accordingly.

Additionally, the software includes functionality for communicating over the CAN [4] bus, a robust and widely used communication protocol in automotive applications. This allows the coolant control system to exchange data and commands with other vehicle systems, enabling coordinated operation. The software system is designed to be modular and scalable, allowing for easy expansion and modification as the project progresses. It is also designed with efficiency and reliability in mind, ensuring that the coolant control system can operate effectively in the demanding automotive environment.

III. BLOCK DIAGRAM



IV. SELECTION CRITERIA

Microcontroller

Processing Power: The STM32 microcontroller [8] should have sufficient processing power to handle the complex control algorithms required for the coolant control system. This can be measured in terms of the microcontroller's clock speed, number of cores, and processing capabilities.

Peripheral Support : The microcontroller should have built-in support for the peripherals required by the coolant control system, such as timers for controlling the stepper motor and CAN bus interfaces for communication with other vehicle systems.

Memory Size: Sufficient memory size is essential for storing the control algorithms, sensor data, and communication protocols. The microcontroller should have enough Flash memory for program storage and RAM for data storage.

Low Power Consumption: Since EVs operate on battery power, the microcontroller should have low power consumption to minimize energy usage and extend battery life.

Temperature Sensor

LM 35 Temperature Sensor

Temperature Range	-55°C to + 150°C
Output Voltage	10 mV per °C
Supply Voltage	4V to 30V.
Accuracy	±0.5°C
Low Self-Heating	The LM35 has low self-heating, which makes it suitable for precise temperature measurements
Calibrated Output	Output voltage is directly calibrated in Celsius.
Low Power Consumption	It suitable for battery-powered applications.

CAN Protocol

The selection of the CAN [4] protocol for the coolant control system is based on several key measurement points, including:

The CAN protocol is known for its high reliability, making it suitable for critical automotive applications such as coolant control. The research paper should highlight the protocol's reliability in ensuring that control commands are transmitted accurately and efficiently. CAN [4] offers real-time communication capabilities, which are essential for the coolant control system to respond quickly to temperature changes and adjust coolant flow accordingly. The paper should discuss how the CAN protocol enables real-time communication in the system.

CAN is a scalable protocol, allowing for easy integration with other vehicle systems and future expansion. The paper should mention how the protocol's scalability benefits the coolant control system in terms of flexibility and adaptability.

CAN is widely used in the automotive industry, ensuring interoperability with other CAN-enabled devices and systems. The paper should emphasize how this interoperability simplifies integration with the EV's existing control systems. CAN includes built-in error handling mechanisms, ensuring that data is transmitted accurately even in noisy environments.

CAN [4] is a low-bandwidth protocol, which is sufficient for transmitting control commands and sensor data in the coolant control system. The paper should discuss how the protocol's bandwidth efficiency meets the system's communication requirements without excessive data overhead.

Stepper Motor

The 28BYJ-48 stepper [7] motor offers a step angle of 5.625 degrees, providing fine resolution for precise control over coolant flow rates. This level of precision is crucial for maintaining optimal thermal conditions in the EV. The motor's torque output is sufficient to drive the coolant control mechanism, ensuring reliable operation under varying load conditions. This torque output is essential for maintaining consistent coolant flow rates, especially in demanding operating conditions.

The motor operates at a voltage of 5V, which is compatible with the power supply requirements of the EV. This compatibility ensures seamless integration into the vehicle's electrical system.

The 28BYJ-48 stepper motor's [7] compact size and lightweight design make it suitable for integration into the limited space available in the EV's thermal management system. This compact design allows for flexible mounting options and simplifies installation.

Stepper Motor Driver

The ULN2003 stepper motor [6] driver is compatible with the 28BYJ-48 stepper motor, ensuring seamless integration into the coolant control system. This compatibility simplifies the design and implementation of the system.

The ULN2003 stepper motor driver has a high current handling capacity, making it suitable for driving the 28BYJ-48 stepper motor. This high current capacity ensures reliable operation of the coolant control system under varying load conditions. The ULN2003 stepper motor driver [6] is easy to use and requires minimal external components, reducing the complexity of the coolant control system. This ease of use simplifies the design and implementation process, making it more efficient The ULN2003 stepper motor driver [6] is known for its reliability and durability, ensuring long-term performance of the coolant control system. This reliability is crucial for maintaining the efficiency and effectiveness of the system over time.

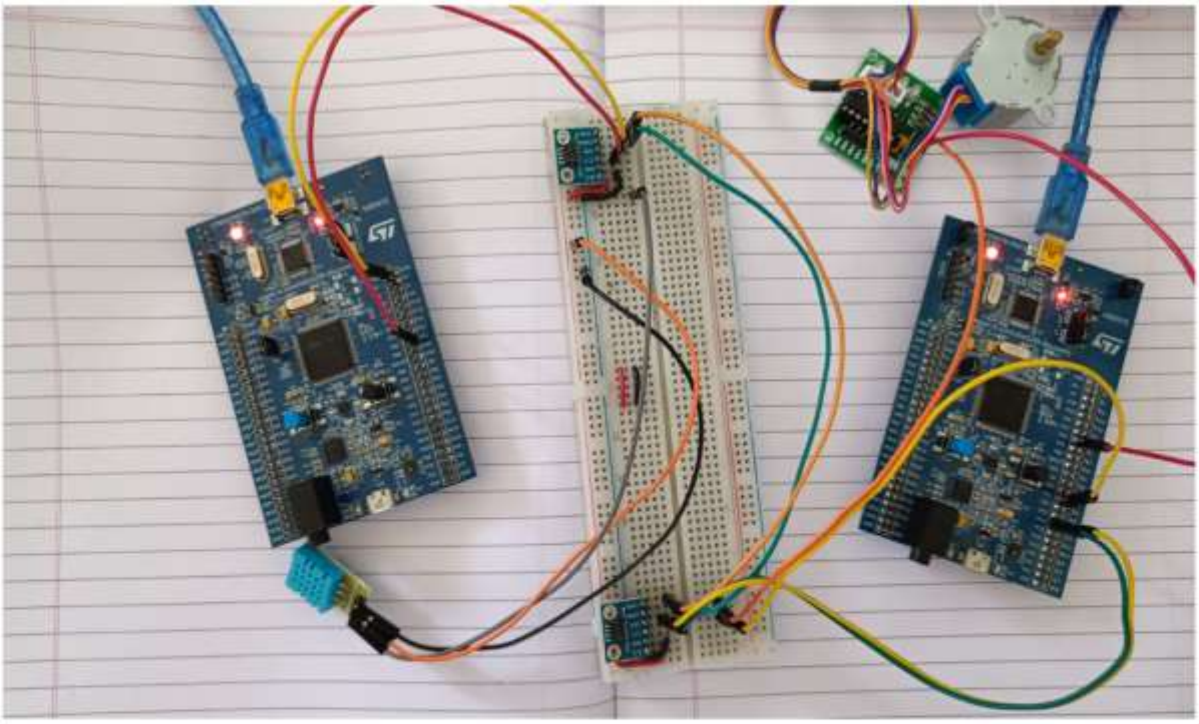
V. METHODOLOGY

The methodology for the proposed research involves a comprehensive approach to developing and testing the coolant control system for EVs [1]. The methodology encompasses several key steps, including system design, hardware implementation, software development, and performance evaluation. Firstly, the system design phase involves defining the requirements and specifications of the coolant control system. This includes determining the optimal coolant flow rate based on the vehicle's thermal management needs, selecting appropriate sensors and actuators, and designing the overall system architecture. Next, the hardware implementation phase involves assembling and integrating the components of the coolant control system. This includes connecting the stepper motor, temperature sensors, microcontroller, CAN [4] bus interface, and power supply according to the system design. The software development phase focuses on programming the microcontroller to control the stepper motor based on temperature feedback. This includes developing algorithms for reading temperature data from sensors, processing this data to determine the required coolant flow rate, and sending control commands to the stepper motor.

Once the hardware and software components are integrated, the performance evaluation phase begins. This phase involves testing the coolant control system in a simulated EV environment to assess its effectiveness in maintaining optimal thermal conditions. The system is tested under various operating conditions to evaluate its accuracy, responsiveness, and efficiency.

VI. RESULTS AND DISCUSSION

The project aims to develop a coolant control system for electric vehicles (EVs) that utilizes a stepper motor to regulate coolant flow based on real-time temperature feedback from sensors. Control commands are transmitted through the Controller Area Network (CAN) bus, enabling seamless integration with the vehicle's existing control systems. The system's effectiveness in maintaining optimal thermal conditions in EVs is demonstrated, showcasing improved accuracy, efficiency, and reliability compared to traditional cooling systems. The project also focuses on the hardware and software aspects, including the selection of components such as the stepper motor, temperature sensors, and CAN bus interface. The project offers a practical and innovative solution for enhancing thermal performance and component longevity in electric vehicles.



VII. CONCLUSION

In conclusion, our research project has demonstrated the successful development and implementation of a coolant control system that utilizes STM32 microcontrollers, a stepper motor, temperature sensors, and Controller Area Network (CAN) [4] communication. The system's primary objective, which is to maintain a specific environment's temperature by regulating the flow of coolant, has been achieved with precision and efficiency. This project not only offers a practical solution to temperature control challenges but also brings several significant contributions to the field of embedded systems and automation.

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