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Pure Electric Vehicle Complete Vehicle Controller Hardware Circuit Design

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Abstract: *The importance of pure electric vehicles is increasing in the automotive industry, and the vehicle controller is a critical component that plays a vital role in monitoring, controlling, ensuring safety, and distributing energy throughout the entire vehicle, thereby affecting its economy, safety, and reliability. This paper presents the design and development of various module functions, circuit hardware design, and working principles of the vehicle controller for pure electric vehicles. The micro-controller used in this study is the STM32, and detailed design methods for circuits such as CAN communication, input-output signal processing, and power management are provided.*

Keywords: *automotive industry; pure electric vehicle; complete vehicle controller; hardware design*

1. Composition and working principle of the electric control system of pure electric vehicles

1.1. Composition of the electronic control system

In the realm of electric vehicles, there are several categories, including pure electric vehicles, hybrid electric vehicles, and fuel cell vehicles. Of these, pure electric vehicles reign supreme in terms of economic efficiency, environmental impact, and energy utilization efficiency. The electric control system of pure electric vehicles is composed of several critical components, such as the vehicle control unit, power battery, battery management system, motor controller, DC/DC converter, and instrument display[1], as depicted in Figure 1. The intricate design of this system is pivotal in ensuring the efficiency and environmental sustainability of pure electric vehicles. As the world shifts towards a greener and more sustainable future, understanding the complexities of the electric control system in pure electric vehicles is increasingly important.

The vehicle control unit serves as the central component in the electric control system of electric vehicles, encompassing the following key functions:

Motor drive control: By considering parameters such as vehicle speed, rotational speed, and acceleration, the vehicle control unit adjusts the motor's current, voltage, and frequency parameters to enable efficient motor drive and control.

Energy management control: The vehicle control unit effectively manages and allocates energy from the battery pack based on power requirements and load demands, ensuring a stable and optimal power supply for the vehicle.

Fault diagnosis and control: The vehicle control unit actively monitors and diagnoses the entire electric control system of the vehicle. In the event of a fault, it promptly triggers an alarm and implements appropriate measures to address the issue.

During operation, the vehicle control unit communicates with other vehicle modules through the CAN bus to obtain data such as vehicle speed, rotation speed, and acceleration, analyzes and processes the data, and finally determines the appropriate motor control strategy to achieve overall vehicle control and management.

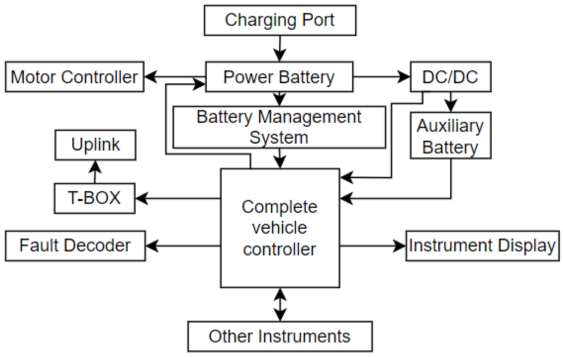

Figure 1: Block diagram of the components of the electronic control system.

1.2. Working principle of the electronic control system

Electric vehicles have become a crucial aspect of the automotive industry, with pure electric vehicles being the most efficient[2]. These vehicles employ a power battery as the core power source, and the Battery Management System (BMS) ensures real-time monitoring of the battery pack's working condition[3]. The motor controller controls the motor's operation direction in the vehicle, while the DC/DC converter converts high voltage into low voltage for use by low-voltage equipment[4]. The Vehicle Control Unit (VCU) is responsible for processing real-time information from the power battery pack, DC/DC converter, and other components to ensure the safety of the entire vehicle[5]. The T-BOX is used to upload information collected and processed by the VCU to the upper computer, allowing remote monitoring of the vehicle's operating status. The fault decoder interprets the fault information collected, processed, and stored by the VCU, which facilitates vehicle maintenance. The instrument display shows the current electric vehicle's operational states and information, making it easier for the driver to understand the vehicle's operating status[6]. Furthermore, the Vehicle Control Unit also manages other instruments such as air conditioning, heating, lights, windows, and the brake pedal.

2. The working principle and hardware design of the whole vehicle controller

2.1. The working principle of the complete vehicle controller

The vehicle controller is a critical component of pure electric vehicles, serving as the central control unit for the battery management system (BMS), DC/DC converter, motor controller, and other vehicle components[7]. It reads the driver's operating information and feedback from various systems to monitor and ensure the safety of the vehicle. Efficient distribution of power supply enables reasonable energy usage, thereby reducing waste and improving the vehicle's economy. Moreover, the vehicle controller can detect and respond to vehicle faults promptly, minimizing the risk of personal injury. The fault information is stored, facilitating maintenance personnel to read and maintain the vehicle. The vehicle controller utilizes the CAN communication protocol to facilitate safe and efficient data transfer among the BMS, DC/DC converter, and other vehicle systems. This communication ensures that data is transferred reliably and efficiently while maintaining normal communication between the vehicle's systems.

2.2. Composition of the functional modules of the complete vehicle controller

The whole vehicle controller mainly consists of a microcontroller module, power module, EEPROM storage module, CAN communication module, serial port 232 communication module, TTL input and output module, 12V input and output module, and analog input module.

2.2.1. Microcontroller module

In the field of pure electric vehicles, the vehicle controller plays a crucial role in processing, computing, and controlling the operation of other devices based on collected information[8]. The microcontroller chip, as the core component of the vehicle controller, is responsible for executing these functions. In this paper, we have chosen the STM32F103ZET6 microcontroller chip due to its good costeffectiveness, low power consumption, and large memory capacity. This chip supports multiple communication methods, including UART, CAN, I2C, and SPI, and has multiple functions, making it easy to operate and meeting the functional requirements of the entire vehicle controller. The microcontroller module mainly consists of a power circuit, clock circuit, reset circuit, and program download circuit[9]. These components work together to provide efficient and reliable operation of the microcontroller[10].

Power circuit: The selected AMS1117-3.3 chip is a high-efficiency linear regulator that outputs a stable 3.3V voltage with an accuracy of ±2%. It has a maximum output current of 1A, making it suitable for use in the microcontroller module. It can work in a temperature range of -20°C to 125°C. Coupled with capacitors, it can decouple and filter, providing stable 3.3V voltage for the microcontroller chip.

Clock circuit: The clock circuit is a critical circuit that controls whether the controller can work normally. It can generate clock pulses, which is equivalent to the heartbeat of a person, to ensure the normal operation of the microcontroller. STM32F103ZET6 only needs an 8MHz pulse to work normally, coupled with a 1M crystal oscillator resistor and two 22pF oscillation capacitors.

Reset circuit: For easy debugging of the microcontroller chip, a reset switch is installed. Pressing the reset switch will send a low-level signal to reset and restart the program of the microcontroller.

Program download circuit: The STM32F103ZET6 microcontroller can be downloaded and debugged online through an SWD interface connected to the emulator.

2.2.2. Power supply module

The power supply of the whole vehicle controller is 12V, through the power supply module to step down the 12V voltage to 5V voltage or step up to 15V voltage, for the other chips on the whole vehicle controller to work. GODSEND is an industrial grade power supply module, which has the advantage of stability and safety, its input voltage can reach up to 36V, the lowest is 9V, the output voltage can reach 5V/20W and 15V/20W, it is particularly convenient to use, there is no complicated peripheral circuit, only a capacitor can be used normally, so that the whole car controller is in a relatively stable working environment.

2.2.3. CAN communication module

In a vehicle, various control devices communicate with each other through CAN communication. The STM32F103ZET6 microcontroller has an integrated CAN communication module, and only an external CAN transceiver is needed to use it normally. The TJA1050T model of CAN transceiver is selected, which has a working voltage of 5V, differential transmission, strong anti-electromagnetic interference, and high-speed data transmission characteristics. A 104 capacitor is placed between the positive and negative poles of the CAN transceiver to maintain a relatively stable working voltage. In addition, to enhance the anti-interference and security of data communication, a 120Ω resistor needs to be added between CANH and CANL. This CAN communication is set to a high-speed transmission rate of 500Kb/s and is mainly used for communication with BMS, MCU, and other devices.

The communication between the whole vehicle controller and the vehicle equipment, such as air conditioning, windows, doors and vehicle instrumentation, is a low-speed 250Kb/s transmission rate, and the STM32F103ZET6 chip only has one CAN communication, so the serial communication external module is used to extend one CAN communication. The TTL-CAN-D1 converter from Qinhuangdao Lanma Electronic Technology Co., Ltd. is used. The converter has a TTL serial port and a CAN interface, which can be used as a standard CAN node and can be directly connected to microcontrollers, ARM and other controllers to achieve bi-directional transmission of data reception and transmission. It is widely used in industrial control, security monitoring, intelligent buildings, automotive electronics and other fields. Moreover, the serial to CAN converter is very stable and easy to operate.

2.2.4. Memory modules

The vehicle control unit needs an EEPROM storage module, which is mainly used for storing and accessing parameters such as fault codes, calibrated data, and vehicle information. The chosen storage chip is the 24C02, which communicates with the microcontroller via I2C protocol and requires two 4.7K pull-up resistors to improve communication stability and noise immunity, as shown in Figure 2.

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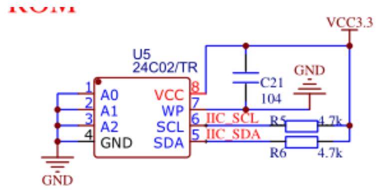

Figure 2: Memory module circuit.

2.2.5. Serial 232 module

Serial communication is generally at TTL level with short communication distance. To improve the communication distance and anti-interference ability, TTL level is converted to RS-232 level, which has better anti-interference ability and longer communication distance compared to TTL level. The MAX232 chip from Maxim Integrated is selected for this purpose. This chip is powered by a 5V power supply and has low power consumption, which can be reduced to less than 5uW. It is compliant with all RS-232C technical standards and can communicate with a PC. Refer to Figure 3 for details.

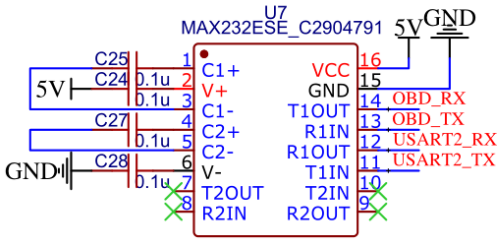

Figure 3: Serial 232 module circuit.

2.2.6. TTL input module

The whole vehicle controller is designed with 8 channels of digital TTL level collection ports, which are used to collect switch signals of 5V voltage. An optocoupler is placed between the voltage collection and the microcontroller to isolate the TTL level from the microcontroller chip, providing protection to prevent the microcontroller from being burned out due to breakdown. The PC817 optocoupler chip is selected, which has the advantages of small size, long lifespan, no contact, strong anti-interference ability, and one-way transmission signal. The input terminal of the optocoupler has a maximum input voltage of 5V and can operate at a maximum temperature of 100°C. To divide the output voltage, a 1K resistor is connected to the output of the optocoupler. The output is connected to the microcontroller, which collects the voltage of 3.3V through the I/O port. When a 5V digital switch signal is collected, the green LED will illuminate. Please refer to Figure 4 for more details.

2.2.7. TTL output module

To increase the output voltage of the microcontroller from 3.3V to 5V, the vehicle controller is equipped with 8 TTL output circuits[11]. These circuits are designed to ensure compatibility with 5V input devices, while still being controlled by the 3.3V microcontroller output. When the microcontroller outputs a high level, the optocoupler conducts, thereby outputting a 5V level, and the blue LED lights up. See Figure 5 for details.

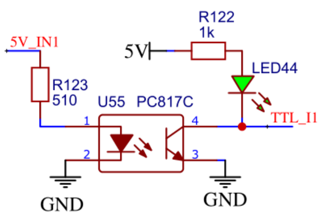

Figure 4: TTL input module circuit.

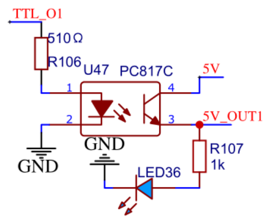

Figure 5: TTL output module circuit.

2.2.8. 12V input module

To collect digital switch signals of 12V voltage in the whole vehicle controller, a 16-channel collection circuit is designed. A 10nF capacitor is placed between the positive and negative poles of the input of the optocoupler to provide a relatively stable input environment. A 1K resistor is placed for voltage division. The maximum voltage at the input end of the optocoupler is 5V. When a 12V voltage is collected, the green LED will light up. As shown in Figure 6.

2.2.9. 12V output module

The whole vehicle controller requires a 12V output voltage to control relays or motors, and the output voltage of the microcontroller cannot directly start these devices[12]. Therefore, a circuit with 16 channels has been designed to output a 12V voltage. When the microcontroller outputs a high level, the blue LED lights up, and the optocoupler's output turns on, outputting the 12V voltage. The output end of the optocoupler is connected to an ULN2804A eight-channel Darlington transistor array chip, which has an inverter that converts the high level output by the optocoupler to a low level. To control the operation of the relay or motor, connect the negative pole of the 12V device to the output end of the ULN2804A[13], as shown in Figure 7 and Figure 8.

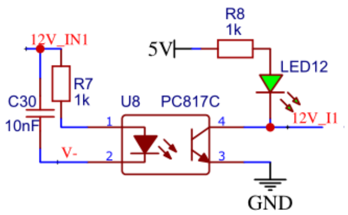

Figure 6: 12V input module circuit.

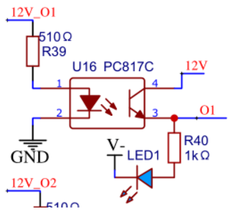

Figure 7: 12V output module circuit.

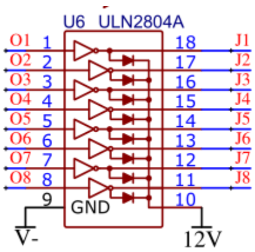

Figure 8: ULN2804A circuit.

2.2.10. 72V input module

The vehicle controller is designed with 2 channels of 72V digital switch quantity collection circuit to collect 72V high-voltage level signals. A 10K resistor is placed at the input end of the optocoupler for voltage division to prevent breakdown and damage of the optocoupler. When the 72V voltage is collected, the green LED will light up. Please refer to Figure 9 for details.

2.2.11. Analogue input modules

In addition to digital signal acquisition, pure electric vehicles also need to acquire continuous analog signals. The STM32F103ZET6 chip has multiple ADC acquisition channels, which can real-time collect changes in analog signals. The whole vehicle controller is designed with 14 channels of analog signal acquisition circuit, including 4 channels for temperature acquisition, 6 channels for 5V voltage acquisition, and 4 channels for 72V voltage acquisition.

Temperature acquisition: Temperature sensors can continuously collect temperature data in real-time. Inside the sensor is an NTC thermistor, which changes its resistance value with temperature, and the voltage also changes accordingly. When the voltage value changes are collected, the corresponding temperature can be read from the data table. To obtain the current analog voltage changes, a temperature sensor is inserted into the slot and a 10K voltage divider resistor is added. This allows the microcontroller to obtain the necessary information[14]. See Figure 10 for details.

5V voltage acquisition: The analog voltage input range of the STM32F103ZET6 chip is 0~3.3V. To collect a 5V voltage, voltage conversion is required. Placing a 2.2K and a 3.3K resistor in series can divide the 5V voltage. Then, by using an operational amplifier (LM741M/TR) with a working voltage of ±15V, the voltage that the microcontroller can safely acquire can be obtained. The voltage value is linearly proportional to the 5V voltage. The circuit diagram is shown in Figure 11.

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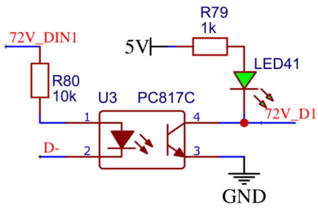


Figure 9: 72V input module circuit.

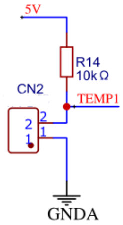


Figure 10: Temperature acquisition circuit.

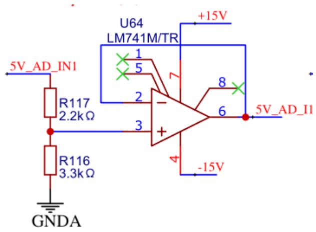


Figure 11: 5V voltage acquisition circuit.

72V voltage acquisition: DC/DC converter is used to convert the 72V voltage to 12V/24V voltage, therefore real-time acquisition of the 72V voltage is necessary for controlling the DC/DC converter. A 10K, a 3.3K, and a 1K resistor are placed in series to create a voltage divider to reduce the 72V voltage. After processing by the LM741M/TR operational amplifier, it is connected to a HCNR201-500E linear optocoupler. The optocoupler processes the voltage and finally provides a safe voltage for the microcontroller to acquire. The HCNR201-500E optocoupler not only isolates the voltage to protect the microcontroller from high voltage breakdown, but also linearly converts the acquired voltage. As shown in Figure 12.

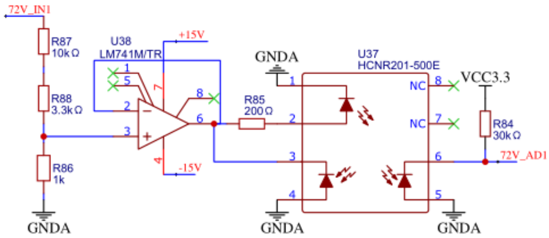
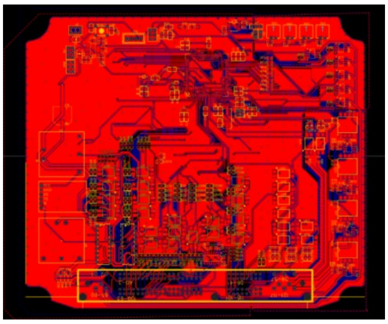


Figure 12: 72V voltage acquisition circuit.

2.3. PCB design



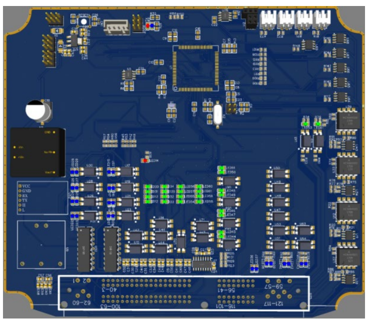


Figure 13: PCB diagram of the VCU. Figure 14: 3D view of the VCU.

The PCB design of the whole car controller was initiated after the design of each module was completed. The PCB is a double-layer board, designed in accordance with the PCB design specifications, taking into consideration the grounding arrangement, power line arrangement, component placement, and alignment[15]. Different ground properties are separated by copper cladding, which can be connected through the 0 Ohm resistor. The width of the power lines is appropriately adjusted according to the power supply size to prevent power line burnout caused by excessive voltage and current or too thin power lines. Components are best placed in accordance with the modular placement, with all components of a module placed on one board as far as possible. The top and bottom double layer placement principle is used when

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there are too many components. The placement of alignment takes into account distance, layout, and other factors to rationalize its location[16]. It is best to avoid right angles and sharp angles in the mid-way around the bend, which can change the width of the line, resulting in impedance discontinuity. See Figures 13 and 14 for details.

3. Conclusions

As time evolves, energy conservation, emission reduction, and environmental protection have become the mainstay of technological progress and innovation. The emergence of new energy technology has promoted the reform process, and pure electric vehicles are a reflection of this process. This article takes pure electric vehicles as an example, focusing on the construction and basic principles of the electric control system, and introducing the core role of the whole vehicle controller in the entire electric control system. At the same time, it elaborates on the functional characteristics and electronic circuit design of each module in the whole vehicle controller. The microcontroller uses an STM single-chip microcontroller chip, which, combined with the corresponding circuit, can efficiently complete all the functions that the whole vehicle controller possesses. PCB design is the most critical step in the design of the whole vehicle controller. Reasonable layout of components and standardized routing ensure the normal operation and use of the whole vehicle controller.

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