Hardware implementation of the monitoring system and control units of the robotic vehicle "Modular controller"

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Abstract

The modular controller is designed for complex automation of vehicles and provides a universal interface for the integration of devices for various purposes. In the basic kit, three modules represent the modular controller: discrete inputs, DC motor control and an ultrasonic sensor controller. All modules have two types of interfaces designed to build a network: CAN (Controller Area Network) and Ethernet. This allows to successfully integrate various equipment. The paper describes the experience of designing modules of a distributed system for operation in an industrial environment. The requirements of industrial standards in the field of electromagnetic compatibility, climatic design and mechanical stability are taken into account.

Keywords: Ultrasonic sensors module, modular controller, DIO, ISO1212, digital input, encoder, DPT driver, switching power supply, planar transformer.

1. Introduction

In the modern world, robotic platforms are widely used both in various industries (transport robots), and for work in hazardous and inaccessible places (areas with chemical and radioactive contamination, underwater research). An important task when building platforms for various applications is the development of a control system. To date, there are two approaches to designing SC. The first is the development of a control system for a specific task, the use of the most rational solutions. The second method is the assembly of the control system from ready-made modules. Both have advantages and disadvantages. Development from scratch allows you to get the most suitable solution for each specific task, but significantly increases the cost of design and commissioning. The second approach, although it is not applicable or redundant in special cases, but reduces the cost of designing a control system, which reduces the complexity and reduces the cost of production. These advantages have allowed the modular control system to become universally used in the design of robotic platforms.

Despite the variety of ready-made modules available on the market, there are tasks for which the offered products either do not fit the reliability criteria or are too redundant in terms of performance or price. That is why it was decided to design our own modules for the control system.

In the framework of this article, we will consider the features of the development of a modular controller using the example of designing a DC motor control module, an ultrasonic sensor module, and a digital input module. The proposed circuit solutions will be considered and the most preferred ones will be selected from the point of view of reliability, module circuits and printed circuit boards will be developed.

The modular controller is a compact, high-performance device for autonomous control of a robotic vehicle. The solution will simplify the design and configuration of unmanned transport systems.

Figure 1 shows the structural diagram of the controller module when connected via the CAN interface.
Figure 1. Block diagram of a modular controller

Technical requirements for the modular controller:
1. Supply voltage 12 to 24V
2. CAN, Ethernet interface
3. Waterproof IP rating: IP67
4. Operating conditions +40 to -40 (° C)
5. Galvanic isolation
6. Supply protection, current protection, temperature protection, reverse polarity protection

2. Ultrasonic Sensor Module

Today, ultrasonic obstacle scanning systems are widely used in the automotive industry. However, a common drawback of samples available on the market is the relatively small (∼2.5 m) scanning range, the inability to reprogram both for various modes of polling sensors, and for suitable environmental conditions.

The development of a module of ultrasonic sensors (parking sensors) is due to the need to obtain a reliable and easy-to-use system for determining distances to various objects.

One of the main advantages of the developed module of ultrasonic sensors over existing analogues is:
1. The ability to configure and reprogram the module for a specific task, taking into account the characteristics of the propagation of ultrasound in the environment;
2. Echo processing directly in the sensor itself, which significantly increases noise immunity;
3. Using a transformer to swing the membrane of the ultrasonic sensor, which in turn increases the scanning range;
4. Using the industrial communication interface IO-Link for connecting ultrasonic sensors to the module head board, which significantly increases the distance between the installed sensors.

The main components of the ultrasonic sensor module are shown in Figure 2.
The propagation of an ultrasonic wave in air depends both on the state of the medium in which the waves propagate and on the parameters of the waves themselves. The state of the environment includes:

1. Air temperature;
2. Humidity;
3. Height above sea level;
4. Flow rate.

The wave parameters include:

1. Ultrasonic wavelength;
2. Ultrasound diffraction;
3. Amplitude of ultrasonic pressure;
4. Reflection from an obstacle.

From all of the above it follows that the state of the environment in which the measurements are carried out should not be neglected, as this greatly affects both the accuracy of the measurement and the possibility of measurement. Also, the received echo signal must be filtered from a lot of noise arising both during the measurement process due to the physical properties of the propagation of ultrasound in the environment, and from noise coming from other objects in the form of unwanted signals. In this regard, it is worth using several types of filters, such as:

1. Band Pass (BP);
2. Peak hold filter;
3. Low Pass (LP) filter.

To achieve this goal, there is a typical solution, which is the Texas Instruments PGA460 family of chips. In accordance with the conditions of the task, a suitable ultrasonic head is selected, and a microcontroller capable of working together with the PGA460 are selected. The microcontroller must read the received data and start the following measurement cycles. Depending on the results of processing the obtained data, the operating parameters of all internal nodes of the PGA460 chip are changed to achieve optimal measurement results.

3. DC motor control module

The DC motor driver is designed for stepless control of the rotation speed of the collector motor over a wide range. The developed module must meet several requirements. Firstly, the developed driver should be easily reconfigured to work with engines of different power in a certain range of values. Secondly, it is necessary to have CAN and Ethernet interfaces, which are common communication protocols for the modules. Since all other control system modules use galvanic isolation between circuit components to increase reliability, it will not be superfluous to increase the reliability of the system in the same way.
The module is planned to be used in robotic platforms, therefore, feedback must be provided. Based on the formulated technical requirements, a structural diagram of the future module was built.

3.1 Driver DC

To control DC motors, use the H-bridge circuit shown in Figure 4 (a).

There are several ways to control power transistors VT1-VT4. The easiest - directly by signals from the microcontroller, or through a simple amplifier. However, with such a scheme, there is no protection of the power keys against overloads, and they can easily fail. An additional circuit that implements current and temperature protection will take up a lot of space on the board. Another control method is the use of integrated circuits, such as DRV8703 from Texas Instrument. A large number of useful
systems is implemented inside the chip. The first is the so-called dead time - a small delay during the switching of the keys of
the H-bridge in order to avoid short circuits during operation. Secondly, current protection is integrated into the microcircuit,
which turns off the power supply of the DCB for a short time, as shown in Figure 4 (b).

When the current through the DCB reaches the value of \( I_{CHOP} \), a short-term shutdown of the motor power occurs. If, after
power is restored, the current again exceeds the maximum permissible value, then the cycle repeats again. The current through
the motor is determined by the voltage drop on the current shunt connected to it in series.

The third important advantage of using an integrated solution for power key management is the ability to diagnose errors
(overheating of circuit components, excess current through the DCB, various internal errors) via the SPI interface.

SPI-Ethernet Converter

Industrial microcontrollers typically use 2 types of converters with the same characteristics. These are CP2201 from Silicon
labs and ENC28J60 from Microchip. Since CP2201 is much more expensive than ENC28J60 (11 cu versus 4.5 cu) and has
poorer documentation, we will choose ENC28J60 for use in the driver. The converter allows you to exchange data over Ethernet
with a speed of up to 10 Mbps and transmit data in duplex and half duplex mode.

Discrete Input Isolation

For discrete inputs, the data transfer speed is not significant, but when using an encoder, the data flow rate can exceed 1
Mbit / s. Therefore, to isolate the inputs, we use the ISO1212 chip. One chip has 2 digital inputs. It can accept a wide voltage
range (9-300V) including AC. The maximum data transfer rate can be 4 Mbps. The chip also has built-in protection against
static electricity.

Driver DC Isolation

The power switch control chip operates on the outputs with voltage values of the order of 5V, so the above solution does not
suit her. In addition, SPI data rates can go up to 10 Mbps. The ISO7231 chip, which has 2 digital inputs and one output,
supporting a data transfer rate of up to 25 Mbps, became the most preferred.

CAN bus isolation

To isolate the CAN bus, a CAN ISO1050 insulator with built-in protection against static electricity and power surges in the
data bus itself was used.

Ethernet Isolation

The supply voltage of the ENC28J60 chip does not exceed 3.3 volts. This voltage level cannot damage the microcontroller,
therefore, isolating them among themselves is excessive. Danger can come from high frequency interference and static
discharges coming through the Ethernet cable. Therefore, in the developed circuit solution, Ethernet connectors with built-in
galvanic isolation based on miniature transformers and an RF interference filter were used. Protection against static electricity
is provided by a bi-directional protective diode (suppressor) with a breakdown voltage of not more than 6 volts, namely
USBLC6-4SC6, designed for use in Ethernet transceivers.

4. Digital input module

The development of a digital input module is necessary for matching the level of various input signals. The following technical
requirements were presented to the circuit:
- dimensions less than 200x200x100mm;
- protection against moisture and dust;
- input voltage range 12 V - 60 V;
- input voltage range 12 V - 60 V;
- the module must comply with the standard for electromagnetic compatibility in accordance with GOST IEC 61131-2-2012.

To implement the module, three main solutions were considered: a voltage divider, a solution on an optocoupler and using
a specialized circuit.

Voltage divider

The simplest scheme is the use of a voltage divider, which has the highest speed. However, the voltage divider is unstable
to changes in the input voltage and does not allow to receive signals of different amplitudes equally well. This makes the voltage
divider unsuitable for use in level matching circuits used in the digital input modules of industrial controllers. Also, such a
solution does not provide galvanic isolation.

Optocoupler solution

Advantage of the solution with optical isolation of components:
- galvanically isolated circuit eliminates the occurrence of spurious currents on the ground bus, which reduces inductive
  pickups caused by these currents;
- reduction of common-mode voltage at the input of the differential analog signal
- input and output protection against breakdown by large common-mode voltage;
A solution based on an optocoupler has similar disadvantages with a voltage divider, namely: the input stage is a voltage divider in which one of the resistors is replaced by a nonlinear element - a diode. This does not eliminate this decision from the dependence of the response level on the magnitude of the input voltage. This disadvantage can be compensated by installing a current stabilizer in series with the diode. A scheme using an optocoupler provides galvanic isolation, but the speed of data transmission through a potential barrier is determined by the optocoupler.

Solution using a special chip

The most suitable way to solve the problem of digital inputs is to use a specialized chip. The input stage of the microcircuit is a voltage divider, supplemented by a current stabilizer. Galvanic isolation is provided in the following ways: optical isolation of the serial control interface, capacitive or inductive coupling between the input and output stages.

Three chips were considered: CLT01-38SQ7 from STMicroelectronics, ISO11811T from Siemens and ISO1212 from Texas Instruments.

To provide galvanic isolation in the solution from STMicroelectronics, additional optocouplers ACPL-K73L and ACPL-W70L are required. Siemens does not have a current limit. As a result, an integrated circuit from Texas Instruments ISO1212 was chosen to isolate the digital inputs, as it satisfies the technical requirements for a modular controller.

Figure 5 shows a functional diagram of ISO1212. An external resistor, R_sens, installed at the channel's signal input, precisely sets the current limit and helps minimize system power consumption. Resistor R_THR is used to increase the voltage threshold. The input signal is interpreted as a logic high or low level using a voltage comparator with hysteresis. A hysteresis loop is used to increase noise immunity.

The block diagram of the digital inputs and outputs module is shown in Figure 6. In addition to the control microcontroller, the diagram contains CAN and Ethernet modules for receiving control commands from a computer, as well as 8 inputs for connecting buttons and pulse sensors. In order to increase the overall reliability of the circuit, each of the building blocks is separated from the rest using isolation circuits. Modules should also be powered by a power supply with integrated insulation.

To unify the modular controller, the CAN and Ethernet interfaces, as well as the microcontroller and the power supply are used the same as in the DC motor driver module.
5. Power Supply
Since the modules use data bus isolation, it is also necessary to use separate galvanically isolated power supplies for each structural unit. The control system for each of the modules is constructed in the same way, therefore, it is possible to determine the approximate required power by considering it for only one unit, in this case, for the DPT driver. The data is combined in table 1.

Table 1. The main characteristics of consumers

| Name             | Number | Maximum current (mA) | Supply voltage (V) |
|------------------|--------|----------------------|--------------------|
| ENC28J60         | 1      | 250                  | 3.1-3.6            |
| STM32F303VCT6    | 1      | 100                  | 2.3-3.6            |
| ISO1050DUBR      | 1      | 3.6                  | 3.3                |
| ISO7231CDWR      | 2      | 11                   | 3.3                |
| ISO1212DBQR      | 3      | 2                    | 3.3                |
| Encoder          | 1      | 100                  | 25 ±5%             |

It is convenient to develop not separate power supply modules for each structural unit, but one universal power supply unit with separate isolated outputs. We use a transformer as galvanic isolation, which, in order to reduce the dimensions, is planar. For a switching power supply, we use a ready-made circuit based on the UCC28C43D with a sampling frequency of 500 kHz. The calculated power of the pulse converter was about 7 watts, but a certain margin was made on the power components of the circuit, which made it possible to increase the output power. This may come in handy in the future development of more energy-intensive modules.

PCB layout was constructed in Altium Designer. The layout was made in such a way as to minimize the length of the tracks along which high-frequency currents go [5]. The final model of the power supply with its overall dimensions is shown in Figure 7.
Figure 7. General view and overall dimensions of the power supply

6. Conclusion
A module controller design based on the STM32 microprocessor has been developed. Communication with the electronic components of the vehicle is via CAN or Ethernet interface. The following modules are in the process of debugging and testing:

- The module of ultrasonic sensors, which serves to determine obstacles and orientation in a limited space.
- Digital input module that allows you to measure the signal of pulse sensors.
- The module "DC Motor Drivers", designed to control and receive data from the vehicle electric motor.
A power supply module was also designed to power all three circuits.

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