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Development of a Universal Module for Connecting Sensors to the CAN-bus for the Formula Student Electric Car

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Abstract

The ways to reduce the number of wires suitable for the main control unit were considered. A block diagram of the algorithm of actions of the created special device is proposed, which allows minimizing the number of wires. The format of CAN-messages containing data from all polled sensors and an electrical circuit diagram is presented. A general view of the developed device is presented, which made it possible to reduce the number of signal wires running through the entire vehicle to two pieces.

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Keywords: Formula Student; electric car; CAN-bus; block diagram; circuit diagram.

1. Introduction

The market share occupied by electric vehicles is increasing every year. Since 2018, the number of such cars has more than tripled. An important thing to consider is that the price gap is reduced in comparison with internal combustion cars. The greatest progress has been made in China, where electric vehicles cost only 10% more on average than conventional vehicles. Much of the growth in sales in many countries is driven by government policies aimed at reducing carbon emissions.

All of the mentioned above invariably affects the knowledge and skills that an enterprise employee should have, as well as the competencies which a higher educational institution graduate, who will deal with design and development

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of new car concepts, needs to have. One of the directions for solving this issue is practice-oriented training in interdisciplinary projects, such as Formula Student.

In line with the global trend towards supporting environmental initiatives and the transition to the use of electric vehicles, the organizers of Formula Student are increasingly focusing on the EV (electric vehicles) class (Formula SAE, 2021). Formula Student project creates a learning environment where participants are motivated to gain knowledge through active learning and interaction with other students and stakeholders. The goal of Formula Student Electric project is to design and manufacture an electric racing car within one year which would be in compliance with the technical regulations and economic restrictions.

In recent years, more and more countries have taken part in the Formula Student competition with electric cars, where original ideas implemented in a manufactured racing car are presented during technical inspections. When communicating with judges, new ideas often come up for further implementation in new cars.

Thus, the issue of creating a charger for a racing car is considered (Gritsenko et. al., 2020), taking into account the adaptability of battery charging modes and the selection of elements of the protection system. The result was the development of a schematic diagram of the charger and the project of a simplified model of the CC/CV charging process in Simulink. In (Sivakumar and Mohanty, 2020; Tarle et. al., 2019), the emphasis is on the development of a battery management system. In (Wang and Zhang, 2014), battery system matching and battery system container design are described in detail. Battery system matching is discussed without consideration of regenerative braking, which is used by some teams to improve energy efficiency. And battery system container design is presented considering cooling, insulation and fire resistance. The authors of (Biswas and Yadav, 2021) suggest reducing wheel slip by introducing a control system that will allow maintaining the optimal slip mode and thereby creating maximum traction force. In this case, MATLAB/Simulink software was also used to develop the vehicle model. In the article (Vozmilov et. al., 2015), various layouts of the electric car are analyzed and their features are indicated. The composition of the main and auxiliary components of the electric car is presented. There are also such works (Hu et. al., 2017), which describe the process of developing a synchronous motor with permanent magnets for an electric racing car made by students.

At the same time, all schemes for the interaction of electronic components and devices can be adapted to the mass production of electric vehicles, if desired.

2. Problem Statement

While developing a Formula Student electric car, Togliatti Racing Team faced a problem – at least 3 wires are suitable for each sensor – power and signal, and if power is combined into several buses, for example +12V, +5V, then it will not work with signal ones. In addition, the signal transmission by a simple electrical pulse is not protected from electrical interference induced in the car from two three-phase motors. In addition, the frequency of these interferences is not constant, but depends on the engine speed, and it is either impossible or impractical to protect oneself from them programmatically or schematically.

Thus, as the complexity of a racing car increases, the number of signal wires running through the entire car to the main control unit increases, and it is necessary to find a solution to reduce the number of wires.

A very limited number of offers are available on the market to solve this task. For example, CSS Electronics produces two devices designed to poll sensors and send information to the CAN-bus:

- CANmod.temp: 4 x Thermocouple-to-CAN. This module outputs temperature data in CAN from 4 sensors. The module is completely autonomous – no PC is required. The module supports all types of thermocouples (B, E, J, K, N, R, S, T) and can be connected in series to receive 8, 12, 16, ... channels;
- CANmod.gps: GPS-to-CAN with 3D Inertial Sensor and UDR. This standalone GPS-to-CAN module creates GNSS position data and three-dimensional data (via gyroscope and accelerometer) and outputs them via configurable messages to the CAN-bus. The module supports "Untethered Dead Reckoning" which means that even if the GNSS signal is completely lost, the module can provide continuous positioning using IMU-based estimates (position sensors).

These devices have a significant drawback – you can connect only your own, pre-defined type of sensors to each of them, and also, the company does not produce devices for connecting, for example, a steering wheel position sensor or an accelerator pedal.

In general, the market for such devices is very small, and it is simply impossible to find a device that meets all the requirements.

3. Materials and Methods

A special device has been developed to solve the problem described. On the printed circuit board there are: a Teensy 4.0 microcontroller running FreeRTOS, a CAN tja1051 transceiver, a DC/DC step-down converter of 12 V/5 V, and several voltage dividers for matching the voltage of signal pulses of sensors from different manufacturers.

The reason for choosing the Teensy 4.0 is that T4 board is a board with an ARM cortex M7 architecture microcontroller at a frequency of 600 MHz, with 1984 Kb of flash memory, 1024 Kb of RAM, with built-in support for the CAN protocol standard CAN FD and 2.0, as well as a 12-bit analog-to-digital converter. It is also important to support RTOS systems, in this particular case FreeRTOS.

The usage of FreeRTOS is due to the fact that the device is responsible for critical signals, such as accelerator level sensors, steering wheel position sensor and recovery paddle shifter. Thus, it is necessary to exclude any software errors and failures. That is why it was decided to use FreeRTOS as an operating system. It allows you to create multitasking systems with the possibility of exclusive access to certain tasks to the I/O ports. A strict order ensures that there are no duplicate messages and eliminates the possibility of resending a message after clearing the buffer. The special software Percepio Tracealyzer allows you to embed a logger into the program, and visually displays all the work of the system, for example, switching between tasks and the state of all variables, which also increases reliability, preventing an unobvious error in the design of the software part.

The TJA1051 chip is a popular solution used by many Formula Student teams that meets all the requirements, such as the rated voltage of 5 V and the price – the cost of one chip does not exceed 1 US dollar.

To be able to connect sensors with a signal level other than 3.3 V, which is the maximum voltage level on the ports of the Teensy 4.0 microcontroller, resistive voltage dividers are placed on the board. Their nominal value, which directly affects the division coefficient of the incoming voltage, is set in each individual case. Figure 1 shows the algorithm of actions.

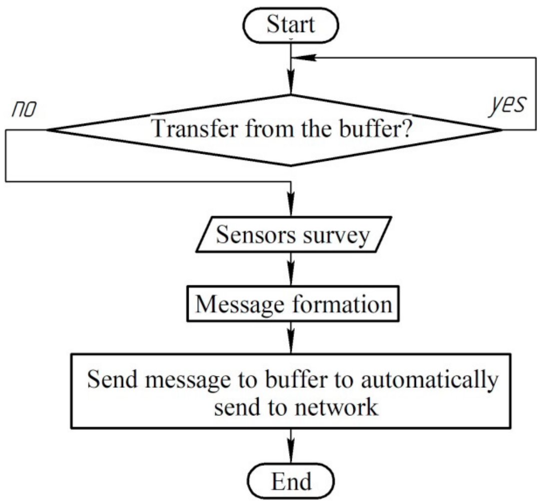

Fig. 1. Block diagram of the algorithm.

Thus, three messages are sent to the connected CAN network (Table 1), with a known ID, containing data from all the surveyed sensors.

Table 1. CAN-messages format.

ID	0x17F81140A	0x17F81140B	0x17F81140C
Type	Expanded	Expanded	Expanded
Length	4	4	3
[0]	Digital10 – 4	Analog19	Analog15
[1]	Analog22	Analog18	Analog14
[2]	Analog21	Analog17	CPU temperature
[3]	Analog20	Analog16	Not used

The schematic diagram is shown in Fig. 2, and in Fig. 3 the manufactured printed circuit board installed in the device housing.

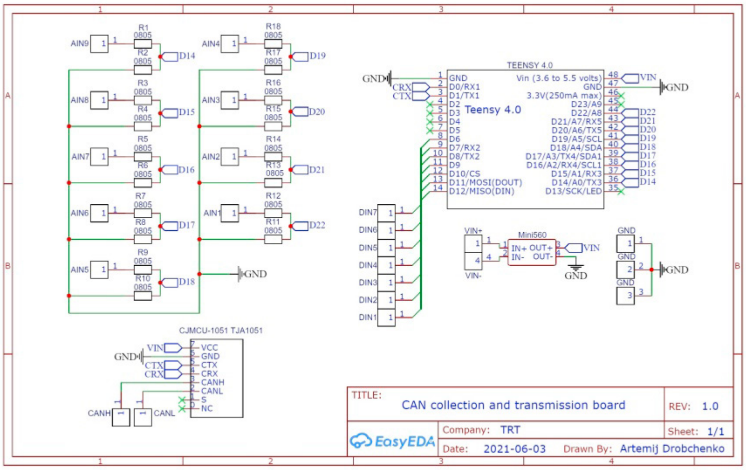

Fig. 2. Electrical schematic diagram.

Fig. 3. The device is assembled with a manufactured board.

4. Conclusion

The module developed and implemented by Togliatti Racing Team allows to reduce the number of signal wires running through the entire Formula Student electric racing car to two, if the signal cable complies with the CAN J1939/11 physical level standard, it is possible to connect up to 16 sensors designed for any constant voltage and transmit their status to a distance of up to 40 meters with loss protection information.

In the future, it is planned to improve the device in the form of size reduction due to the rejection of the use of modules and the location of electronic components directly on the printed circuit board.

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