Electronic component base for controlling the engine, mechatronic transmission and adaptive brake force limitation system as part of the electronic platform of the Formula SAE class sports vehicle

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Abstract. The article presents a description of the research and development work carried out by NSTU employees as part of their participation in the international project Formula Student. The paper deals with the process of creating an electronic platform for a sports car of the Formula SAE class, which includes electronic control units for the engine, mechatronic transmission and brake system, united into a common data bus. The process of selection and adaptation of the engine control unit based on the required parameters, the prototyping process of mechatronic transmission systems is described, the concept of the development of the brake control unit is reflected.

1. Introduction
Among the most important parts of a modern sports car, as the suspension, frame, braking system, there are electronics and mechatronics controlled by it. Over the past decades, there has been a tendency in the modern automotive industry to transfer control over a number of vehicle components to mechatronic systems that can ensure accurate, coordinated and error-free operation of vehicle components. A number of vehicle systems are shifting from the control of the driver to the control of electronic systems, those systems make it possible to concentrate on solving a wide range of tasks, reducing driver fatigue and increasing the safety of the vehicle as a whole. The elements included in the electronic control system must meet the high requirements of safety, reliability and resistance to environmental influences. In the process of solving the problems of creating a control system for the internal combustion engine, transmission, and information output to the driver, there is a need to create an electronic platform This solution minimizes the laboriousness of setting and adjusting the operating parameters of the executive systems.

2. Creation of an engine management system
The engine of the sports car is a four-stroke internal combustion engine of the Honda CBR 600 RR motorcycle with a modified air-fuel intake system. To be able to control the systems of the engine, with the above changes, it is possible to install the following control units: Mega Squirt ECU, Speduino ECU, RusEFI Frankenso ECU (Figure 1). A comparative analysis of the characteristics of these control units can be seen in Table 1.
Table 1. Characteristics of the control units

| Models                  | Mega Squirt ECU | Speduino ECU | RusEFI Frankenso ECU |
|-------------------------|-----------------|--------------|----------------------|
| Parameters              | Motorolla HC9S12C64 | ATmega2560 | STM32F407            |
| Microprocessor          |                 |              |                      |
| Number of fuel injectors connected to the ECU | 8 with phased fuel injection and 12 with non-phased injection | 4 | 12 with phased fuel injection |
| CAN-BUS support         | +               | +            | +                    |
| Source                  | Closed          | Open         | Open                 |
| Electronic circuit      | Closed          | Open         | Open                 |
| Types of shafts position sensors which are possible to use | Hall, VR | Hall, VR | Hall, VR |
| System upgrade options  | No              | Yes. It is possible to upgrade the ECU with modules: Throttle - By - Wire , GDI , etc. | Yes. It is possible to upgrade the ECU with modules: Throttle - By - Wire , GDI , etc. |

Based on the data in Table 1 and the technical characteristics of the ECU, the RusEFI Frankenso ECU electronic control unit is a universal solution with the possibility of expanding the electronic platform within the framework of the project being developed. The open source code of this ECU and publicly available options for expansion allow you to upgrade the control unit for specific tasks. With CAN bus support and electronic throttle control, this ECU can be used even in driverless vehicles [1].

Figure 1. Engine electronic control unit RusEFI Frankenso ECU

Figure 2. Oscillogram of signals from crankshaft and camshaft position sensors

During adapting the control unit, the problem of reading the signal parameters from the crankshaft and camshaft position sensors was discovered, because both of the sensors have a VR (variable reluctance)
signal with an analog signal generation. Figure 2 shows an oscillogram of the signals from the crankshaft and camshaft sensors with the correlation between the pulse tops. These pulse peaks can be used to track the strokes of each cylinder.

During test measurements with the connection of the crankshaft and camshaft sensors to the RusEFI Frankenso ECU, the presence of distortions in the read signal parameter was detected. Figure 3 shows an oscillogram obtained directly from the engine control unit. In this signal image, there is no correlation between the sensor signals.

**Figure 3.** Signals recognized by the control unit before applying the noise reduction circuit

To minimize the influence of distortion of signal parameters, when reading these parameters through the RusEFI Frankenso ECU, a noise reduction circuit was developed. Based on the application of the noise reduction circuit, an oscillogram was obtained without signal distortion (Figure 4).

**Figure 4.** Signals recognized by the control unit after applying the noise reduction circuit

The ignition system, controlled by the RusEFI Frankenso ECU, required the manufacture of control modules for Denso OEM coils installed on the engine by the manufacturer. These modules have been developed due to the lack of proposals on the market that satisfy in terms of dimensions and characteristics. The ignition modules (Figure 5) are based on an IGBT transistor that allows a signal to be applied to the primary coil of the selected ignition coil.

**Figure 5.** Ignition module for OEM coils

**Figure 6.** Transmission ECU of a FORMULA STUDENT sports car

OEM sensors installed on the engine of the Honda CBR 600 RR motorcycle are part of a group of sensors that can interact with the RusEFI Frankenso ECU. Tests have shown that there is no need to adapt Frankenso to read signal parameters routinely.

### 3. Creation of a mechatronic transmission control system.

In terms of creating mechatronic control systems for shifting the gearbox and clutch stages, the key parameters are the speed and time of switching, the force of the actuators, as well as the synchronization of these parameters to ensure the operability of the system [2].
The creation of a prototype of the mechatronic system is based on the use of the Arduino Mega 2560 microcontroller (Figure 6). The system being developed is capable of working not only in stand-alone mode, but also in the mode of an electronic assistant, displaying recommendations on gear shifting on the dashboard screen.

A key feature of the development of the mechatronic gear shifting system is the selection of actuators for the implementation of gear shifting, as well as the implementation of the clutch drive. In the course of the work, a group of actuators were tested, consisting of a stepper motor (Figure 7), a linear actuator (Figure 8) and a DC motor (Figure 9).

![Figure 7. Stepper motor](image1.png)  ![Figure 8. Linear actuator](image2.png)  ![Figure 9. DC motor](image3.png)

The actuators shown have been tested down from the following key parameters:
1. Switching time
2. Maximum force/torque
3. Power consumption
4. Element weight
5. Overall dimensions

In order to test the actuators, unique mounting systems were created to interact with the transmission mechanisms. The development was carried out using 3D scanning, rapid prototyping using additive technologies and CNC machines [3].

Table 2 shows the comparative characteristics of the actuators based on the tests performed.

|                      | Stepper motor | Linear actuator with hall sensor | DC motor |
|----------------------|---------------|---------------------------------|----------|
| 1. Torque, N / m     | 3, 3          | -                               | 3        |
| 2. Maximum effort, N | -             | 3500                            | -        |
| 3. Shaft rotation frequency, rpm | 60       | -                               | 65       |
| 4. Starting torque, N / m | 3, 3    | -                               | fourteen |
| 5. Maximum speed of movement of the slider, mm / sec | sixteen | -                               | -        |
| 6. Weight, kg        | 2             | 0.64                            | 0.95     |

Tests of the stepper motor show the possibility of gear changes in a cycle of 0.36 seconds when integrated into the gearbox system of a Formula Student sports car. This time indicator can be optimized downward due to the use of a complicated operation algorithm and the expansion of the hardware complex for collecting and processing information.

During the tests of the stepper motor, positive operation as an actuator was recorded in the entire range of shifting gears in the transmission of the Honda CBR 600 RR engine. However, the following disadvantages were identified that limit the use of this element in the mechatronic control system:

1. During testing this electric motor as a clutch release actuator, the inability of this electric motor to release the clutch was revealed.
2. The mass of the actuator is - 2 kg, which, taking into account the use of the gearbox as a gear change element and clutch drive, doubles the weight.

3. The time of the complete switching cycle of one gearbox stage is 0.71 seconds.

4. Overall dimensions in combination with the weight impose additional requirements on the load-bearing elements of these components in terms of high strength.

5. Significant overall dimensions of the stepper motor control unit.

6. The presence of additional electromagnetic fields caused by the operation of the electric motor, which can have a negative impact on the complex of operation of all electronic control systems of the engine.

Tests of the linear actuator have shown that the maximum angle of rotation of the gearbox shaft when changing gears is within 24 degrees from the initial mark. That is, an angle of 24 degrees is the range for up and down gears. To implement gear shifting based on the use of a linear actuator, within the entire angular range, it is necessary to comply with the requirements for maintaining maximum force. To realize the maximum force, the shoulder of the impact on the gearbox shaft must be at least 10 mm when measured from the center of the shaft. With this leverage, the effort required to shift gears is 658.8 N.

Based on additional criteria for the shift time and comparing this parameter with a force of 658.8 N, the actuator speed is 12 mm / s. At this travel speed, it will take no more than 0.35 seconds to change gear.

When evaluating a linear actuator for the ability to disengage the clutch, it was found that the time required for the linear actuator to release the clutch is 0.78 seconds. At the same time, the same period of time is required to return the clutch to its original position, in view of this, the time for the working process doubles.

The advantages of using a linear actuator are:
1. The mass of the actuator is 640 grams.
2. The time of the complete switching cycle of one gearbox stage is 0.35 seconds.
3. Availability of feedback systems for position determination. The linear actuator design includes a Hall sensor. The presence of this element excludes the use of additional sensors on the gear shift shaft.

The disadvantages of using a linear actuator are:
1. The parameters of the overall dimensions of this type of actuator are associated with the need to use massive and geometrically developed fastening components, as well as the integration of these fasteners into the design of the engine and gearbox.
2. The need to change the design of the linear actuator to adapt to the gearbox drive mechanisms.

In the DC motor test, the time to complete a gear change cycle was 0.35 seconds, which is comparable to the changeover time using a linear actuator. The time taken to disengage the clutch was 0.76 seconds.

Advantages of using DC motor:
1. Mass of the actuator - 950 grams.
2. The time of the complete switching cycle of one gearbox stage is 0.35 seconds.

The disadvantages of using a DC motor are:
1. The need to adapt the design of the electric motor to the standard gearbox system.
2. Lack of feedback systems for position determination.

To solve the problem of the lack of systems for tracking the position of the DC motor shaft, the accelerator pedal position sensors of a motorcar were used. A key feature of the accelerator pedal position sensor is the presence of a second channel for position sensing and troubleshooting when determining the application of the shift shaft and clutch lever.

4. ECU of the brake system.
To increase the level of safety, control precision of a sports car, as well as control of skids, it is necessary to use driver assistance systems capable of proactively locking and unlocking the wheels, as
well as controlling the torque. For this, a brake system control unit is being developed, the basis of which will include the tasks of controlling the steering wheel angle, acceleration along each of the three spatial axes, the angular speed of each of the four wheels, pressure in the brake circuits and comparison and processing of the obtained data to control the position car on the track.

Having a communication bus, the control unit can not only influence the operation of the brake circuits, but also send signals to the engine and gearbox control units. These operational capabilities will allow system to control the torque on the drive wheels. Important criteria for the development of the entire system are its modularity, compatibility with different types of vehicles, safety, reliability, efficiency and low cost. Figure 10 shows a schematic diagram of the developed brake control unit.

![Figure 10. Schematic diagram of the ECU of the brake system](image)

5. Conclusion
At the current stage, two components have been fully implemented: the mechatronic transmission ECU and the engine ECU. The created control systems, united in a data bus supporting the Controller Area Network standard, become part of the modified electronic platform. The implementation of extensions to this platform, including the electronic brake control system, will make it possible to adapt this system to an unmanned racing car platform.

References
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