

Application of virtual physical modeling technology for the development of elements of the autonomous (unmanned) vehicles' systems

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Abstract. The article presents examples of the technical implementation devices' for developing algorithms for controlling brake system modules of autonomous vehicles.

1. Problem

Autonomous vehicle developers' has the question considering developing algorithms for controlling of wheel brake mechanism [1, 9, 14]. At the same time it's necessary to solve the problem of ensuring correct operation of the brake system units in accordance within its signals. The ways of realizing these tasks can be presented in the form of figure 1 [3].

In this process technical progress is possible only extensive use of modeling methods. There are large numbers of software tools for modeling technical systems [8]. However, along this path, there are significant difficulties that can reduce the effectiveness of modeling. In accordance to the class of problems it is an adequate description of the flow of the working fluid along the brake lines and the channels of the antilock system modulator [2, 13]. Often, the elements of the latter are products of pilot production with an unworked technology and therefore with unknown characteristics with the required accuracy. From the theory of the motion of liquids and gases along the main lines, it follows that a change in the angle of the flow axis, the shape of the channel, or the type of clearance in the control valve has a significant effect on local resistance. Aim of improving the design of the multiphase brake system modulator, this creates significant difficulties in finding its characteristics and causes a significant error in determining them for solving the modeling problem. To this, we need to add the need to take into account the transient and resistance forces in solenoids of the control valves. In the case of modeling the elements of the braking system, most often, important elements are recreated for the research, and the others are neglected, this simplifies the model. Both the reconstruction and accurate description is cumbersome or impossible at this stage and level of research. An example is the consideration of technological features of the manufacture of system elements - the shape and arrangement of the channels of the hydraulic drive system. To create a model - absolutely accurately describing the phenomena in the brake drive - is quite a difficult task at this stage.



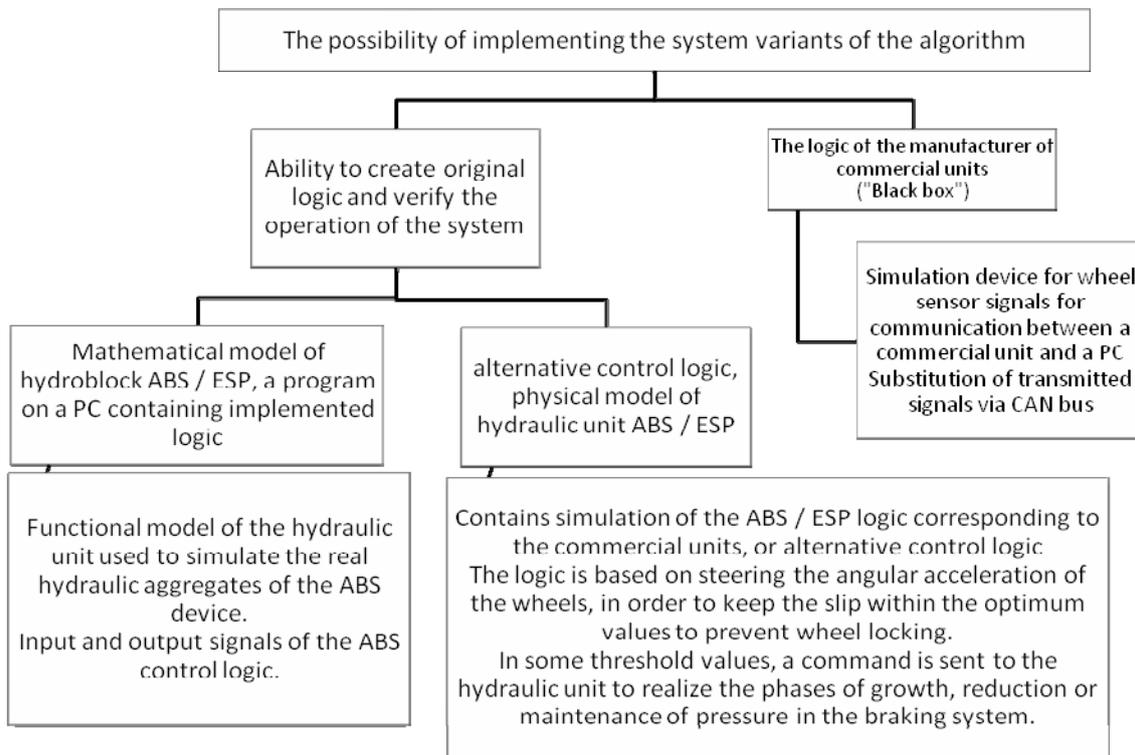


Figure 1. Block diagram of the ways of implementing variants of the system operation algorithm.

2. Solutions

One of the possible solutions of this situation may be using of virtual physical modeling technology [3, 7, 10, 11, 12], i.e. applied to this task, simulating the movement and braking of the vehicle with a virtual mathematical model, and taking into account the technological features of manufacturing the elements of the system can be taken into account by including real physical aggregates and actuating mechanisms in the system.

When applying this method, you can trigger the system and the brake mechanism in two ways:

First. Using a special mode dial that simulates the signals of the wheel speed sensor or software loaded into the control unit, which imitates signals at the program level in a special mode.

Second. Direct control of actuators. This method is more productive if, when designing an unmanned vehicle, researchers need a direct link to the system's executive mechanisms to develop alternative vehicle control logic.

3. Changing the input control signals of ECM (signal simulator)

It is necessary to know the signal parameters for device design process. But often such data are not found anywhere in the literature. This leads to the fact that researchers have to determine the input criteria for the operation of the system.

In this case several well-known vehicles of the same brand, model and model year are taken from the main characteristics of the wheel speed sensor of each wheel, as well as from the vehicle speed sensor to determine the average values. The signals with the received characteristics are supplied to the input of the system control unit with the aid of a master. In this case, a pulse generator capable of providing emulation of the signals from the wheel rotation sensors and the vehicle speed sensor can be used as the setpoint generator. The generator is controlled dynamically as from a personal computer, so it can work according to a predetermined law.

Let us consider an example of the development of a simulator of wheel sensor signals through an inexpensive National Instruments Ni 6008 USB device [4].

All elements of the electronic sensor system receive the supply voltage from a separate integrated circuit, while the "mass" of the sensor is connected by a wire, through which the signal is transmitted, to the "mass" of the computer system ABS or ESR. For Peugeot 307, the minimum sensitivity threshold of the sensor is 0.3 km / h. If the vehicle is stationary, the sensor is in standby mode. To activate the sensor, a new signal is required: a six-fold rise and fall in the amplitude. The sensor supply voltage is +12 V.

At a speed of 150 km / h, with car wheels with a radius of 0.316 meters and with 50 teeth on the rotor, the frequency of the pulses induced in the sensor is:

$$50 \left[\left(\frac{150}{3,6} \right) \left(\frac{1}{0,316} \right) \left(\frac{1}{2\pi} \right) \right] = 1050 \text{ Hz}$$

Sampling rate of the used ADC National Instruments Ni 6008 USB is 1000 Hz. This frequency is too low to avoid aliasing, since the consequence of the Kotel'nikov theorem (or the Whittaker-Nyquist-Shannon theorem) states that any analog signal can be reconstructed with any accuracy from its discrete readings taken at a frequency of at least in two greater maximum frequency, which is limited by the spectrum of the real signal.

Therefore, it was decided to make a circuit that converted the voltage in proportion to the gain factor G. This voltage comes to the voltage-frequency converter (hereinafter LPC), where it is converted into waves of rectangular shape with a frequency proportional to the voltage (figure 2).

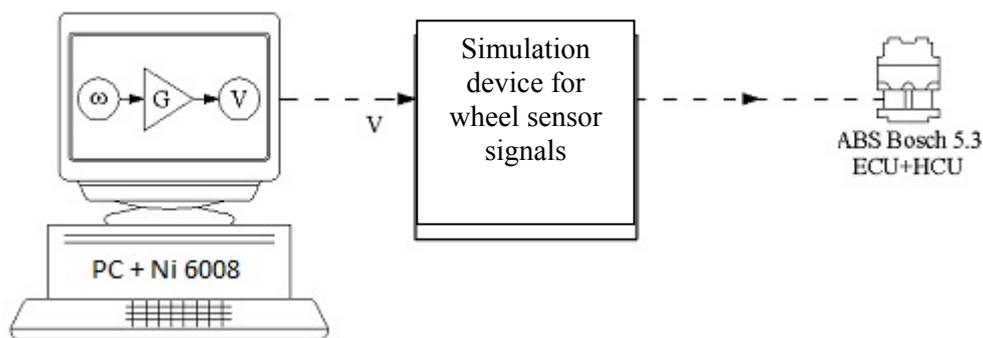


Figure 2. Connection of the device with a PC with connected to it USD and ABS Bosch 5.3.

The proportionality factor G is a voltage function that depends on the maximum angular velocity ω of the vehicle model wheel, and the maximum voltage V that supports the channels of the Ni 6008 - 5 V digital-to-analog converter (DAC). If you consider that the model must include the braking simulation at a speed of 150 km / h, it follows that the upper limit of the frequency will be 1050 Hz.

Voltage-frequency converter (VFC)

VFC is a circuit that converts the voltage into square waves of a modulated signal with a frequency proportional to the input voltage. The general principle underlying the operation of the VFC in the basic law of charging a capacitor.

Early research stages of the VSTU this task was solved on the domestic elemental basis, so in figure 3 the scheme used at the end of the last century of the VFC based on the KR1108PP1 chip is presented, which allows to reliably simulate the operation of the induction sensor, which is used as a sensor for the state of rotation of the wheels. The basis of the device created is the conversion of the voltage U_{bx} , which is an electronic analogue of the angular velocity of the wheel, into a frequency signal whose value of the period T is determined by the value of the input voltage. At the same time, the voltage source U_{bx} is a digital-to-analog converter (L-154 card manufactured by the company "L-card") installed in a personal computer, which calculates the angular velocity of the wheel in real time.

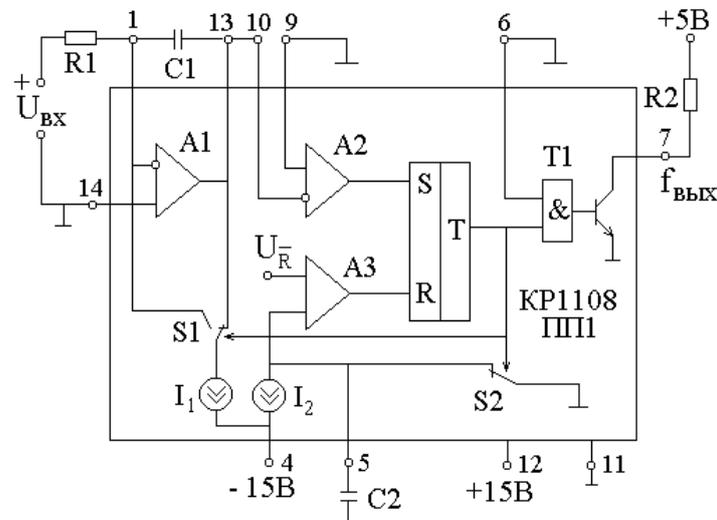


Figure 3. Functional diagram of the integrating VFC based on the KR1108PP1 chip.

At an even earlier stage in the 70s of the last century this problem was solved using electrohydraulic voltage converters [2, 3, 13] (figures 4-5).

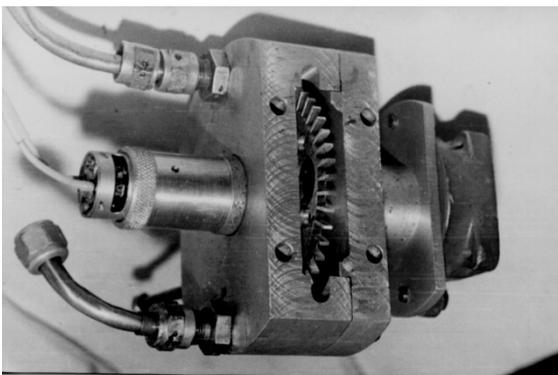


Figure 4. External view of the hydroturbine.

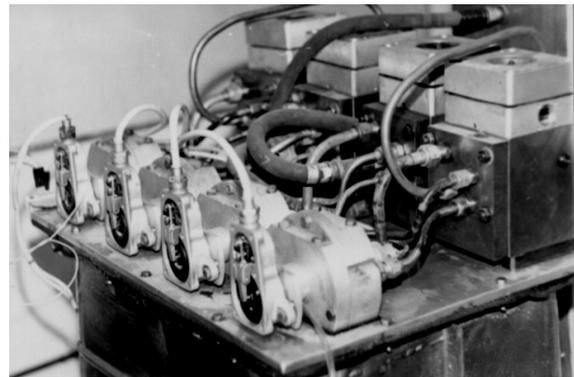


Figure 5. Appearance of the block of electrohydraulic voltage converters.

At the moment, most manufacturers of converter electronic converters guarantee 0.01% linearity and thermal stability of 0.005% / °C.

The developed scheme uses the National Semiconductor VFC model LM331. The output of the LM331 VFC is an open collector transistor, which allows the output of the f_{OUT} signal with the required voltage by supplying a V_{in} voltage through a pull-up resistor. At this low voltage level will be 0 V, and high - V_{in} (figure 6).

Modulation of the output frequency is obtained by changing the high-level signal transit time. The time interval T in which the signal at a low level depends only on the nominal values of the parts in the RC circuit of the circuit represented by $R2$ and $C2$. Thus, after the choice of nominal values, this interval remains fixed. For example, the Bosch ABS 5.3 technical documentation indicates that the system operates with a signal with a duty cycle of 30% to 70%.

To solve this problem, the output of the VFC is connected to the D-trigger. Trigger is a digital circuit that preserves one of its two stable equilibrium states for an arbitrary period of time and switches in an abrupt manner from a signal from outside from one state to another.

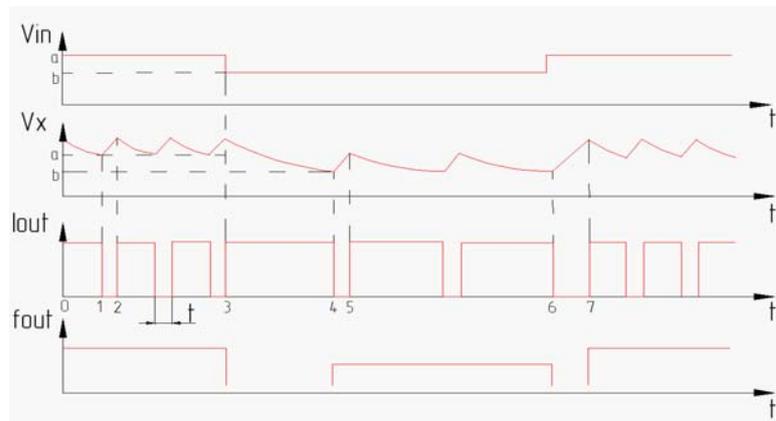


Figure 6. Dependence of the input and output characteristics of the VFC on time.

Linking the output to the input and feeding the signal from the LPCH to the input, the D-flip-flop functions as a frequency divider (figure 7), that is, it divides into two frequencies of the voltage applied to the input. The output will be a duty cycle equal to 50%. Thus, it is enough to feed the signal of the double frequency, which should be obtained at the output, and the duty cycle at the output will be equal to 50%.

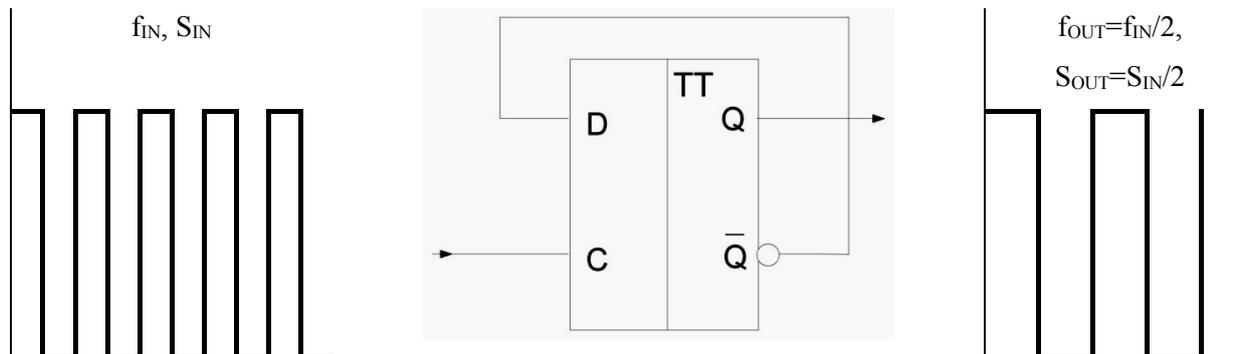


Figure 7. D-trigger as a frequency divider.

Current or voltage

To interact with ABS Bosch 5.3, the signal, in addition to the voltage level and duty cycle, must comply with the manufacturer's tolerances for the low and high current level of the signal from the wheel sensors. These tolerances are shown in figure 8.

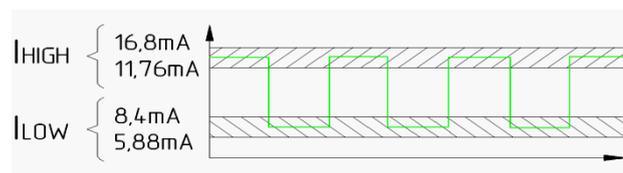


Figure 8. Technical requirements for current levels on wheel sensors.

The signal voltage of the wheel sensors, after exiting the trigger, has a high level of 12 V and a low of 0 V.

The signal comes to the base of the npn-transistor (figure 9). When the transistor is in a saturated state, the input signal rises, the current is reset directly to the "mass" via R_1 . Through R_2 , the current to

the transistor does not go; This is prevented by the diode VD, but goes to the ABS computer. This mode is the lower threshold value I_{LOW} . When the transistor is locked, the input signal drops, the current that goes to the ABS computer must match the resistance values R_1 and R_2 in the parallel. This is the high-current mode I_{HIGH} .

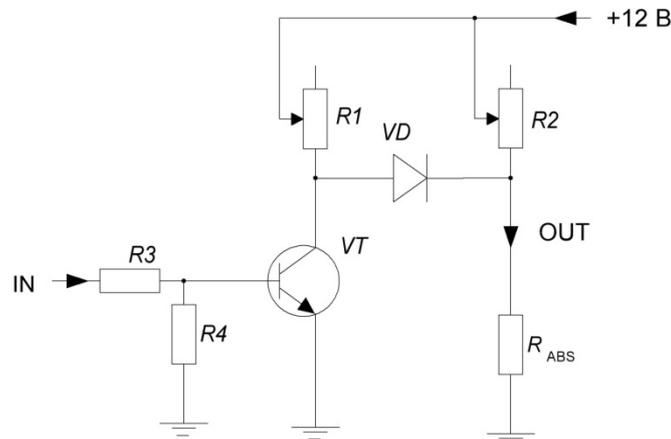


Figure 9. Schematic diagram of the current voltage.

Unlike previously used, in this improved scheme, instead of two resistances R_1 and R_2 , two variable resistors were installed, in order to more accurately adjust the current level (figure 9).

This solution, if necessary, is easily scaled by the number of wheels used to control and control the movement of the vehicle (figures 10-11).

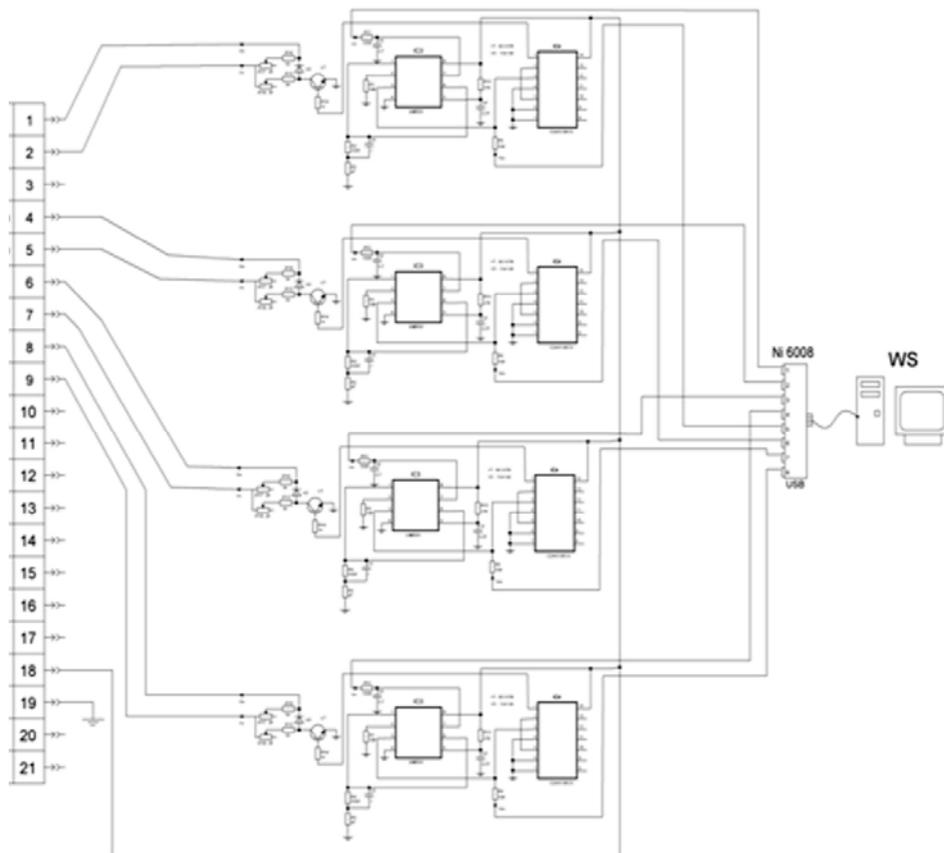


Figure 10. Diagram of connecting the device to the ABS pad LADA Kalina.

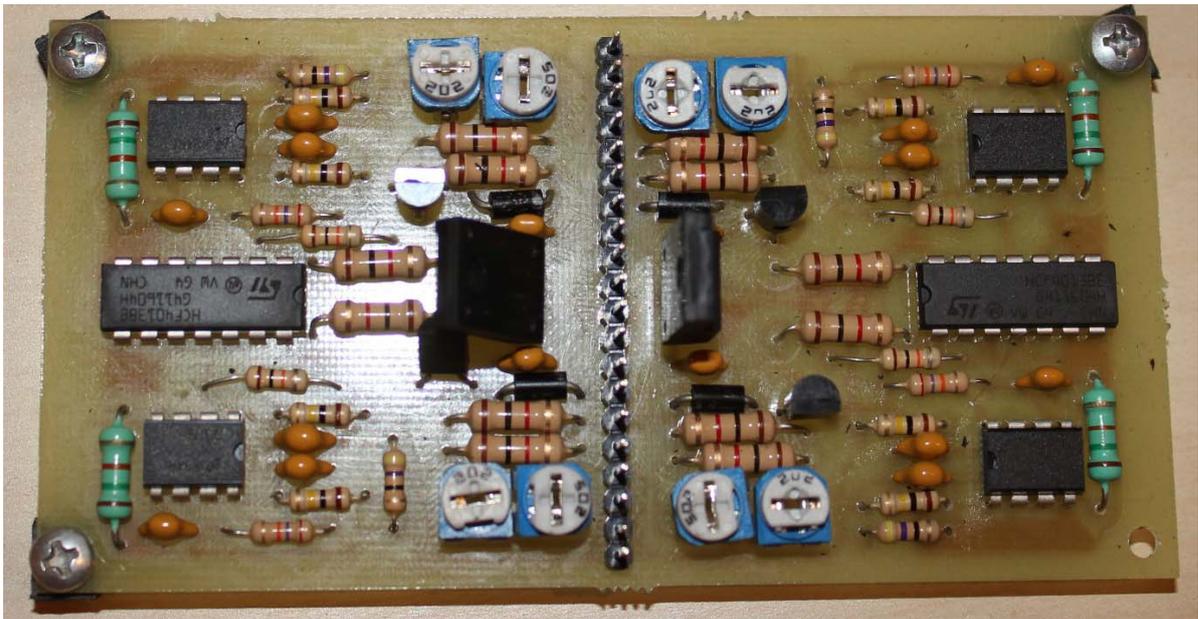


Figure 11. Appearance of the collected board.

Verification of the braking system of the car is carried out on the basis of the analysis of the oscillogram by the method of "comparing the states" of the tested vehicle and taken for the standard of a known serviceable car (figure 12).

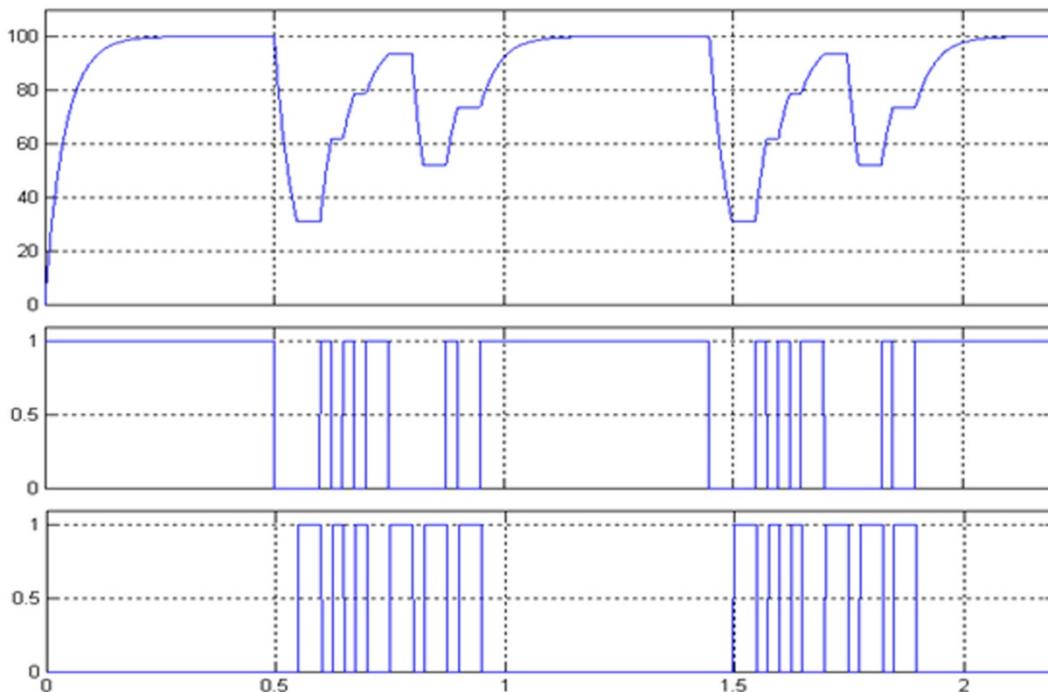


Figure 12. Generated signals.

At the present time, the researchers, in addition to the method described above, apply the method of signal substitution transmitted via the CAN. However, this method has its drawbacks, for example, the

bus activity shown under certain circumstances leads to a distortion of the measurement results or a "floating break".

4. Direct control of the solenoid valves of the unit

The basic idea is to directly connect the unit to the solenoids with the appropriate communication interconnection, since almost all modern units consist of a hydraulic and electric module combined into a single unit (figure 13). The solenoids are used as a control element of the actuating mechanisms.

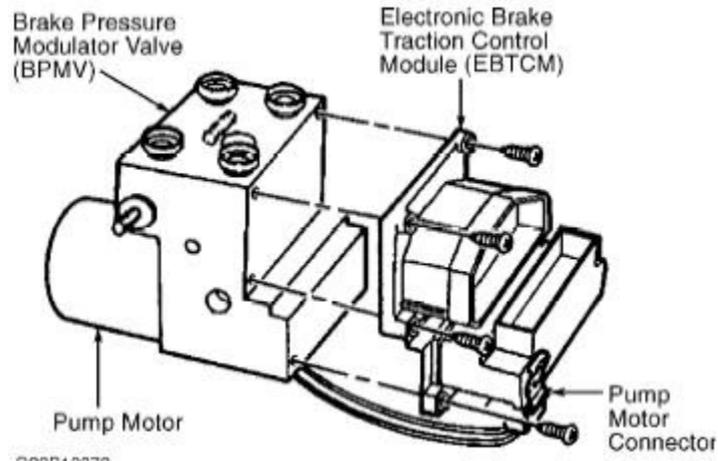


Figure 13. Hydraulic and electrical modules combined into a single unit.

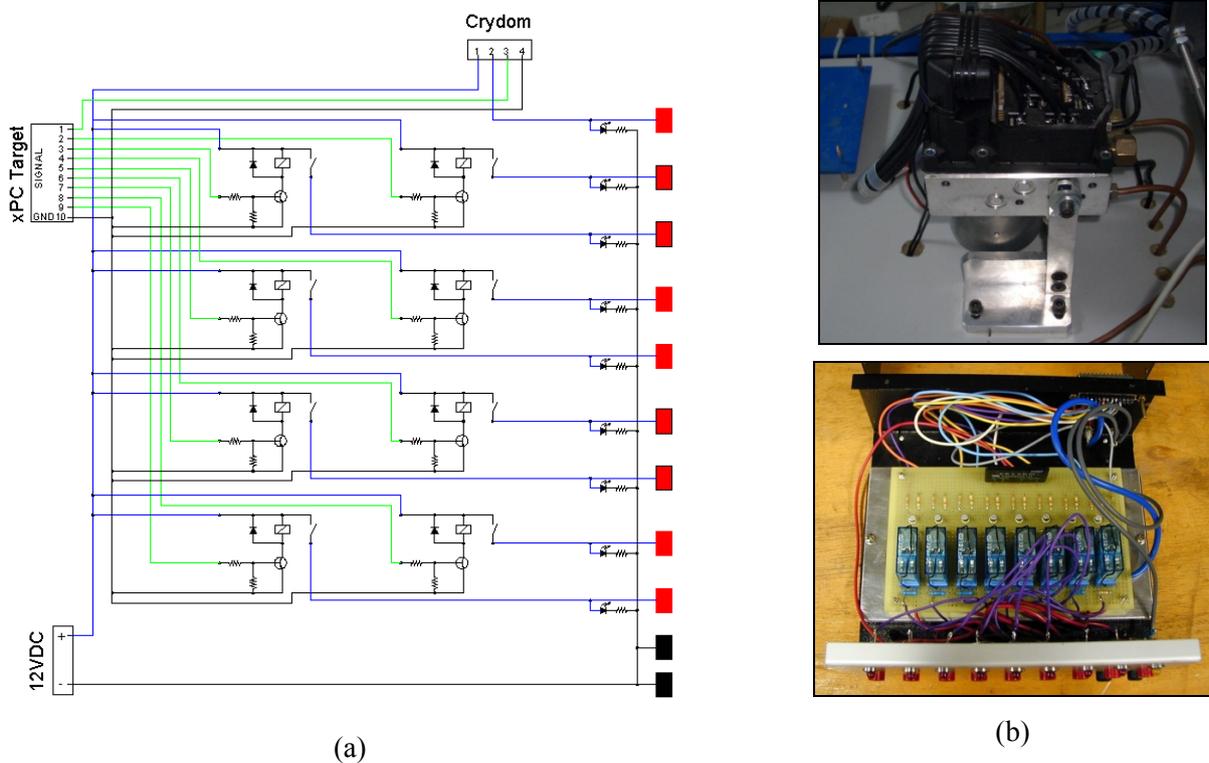


Figure 14. Direct connection to solenoids (examples of technical implementation).

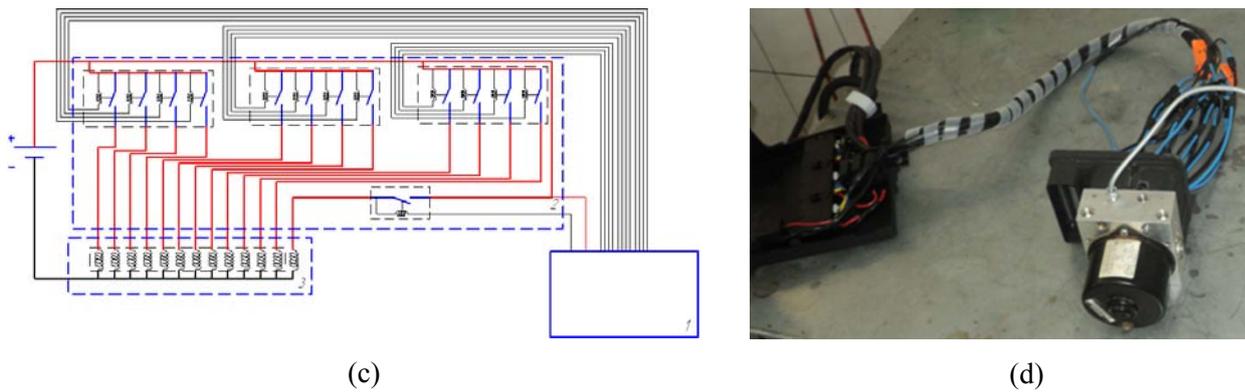


Figure 14. (Continued).

This technical solution was applied at VSTU and in the 2000s (figure 14) and was widely used in the course of the work carried out jointly with the research group of Prof. Mauro Velardochia at the Turin Polytechnic Institute [5, 6]. The technical implementation of this method has confirmed its efficiency and effectiveness. In the course of the experiments, the simulation of the ABS and ESP logic was performed, corresponding to the commercial units (figure 15), and also the algorithms for the operation of the electro hydraulic brake system have been developed, which makes it possible to apply this technique in the development of unmanned vehicle modules.

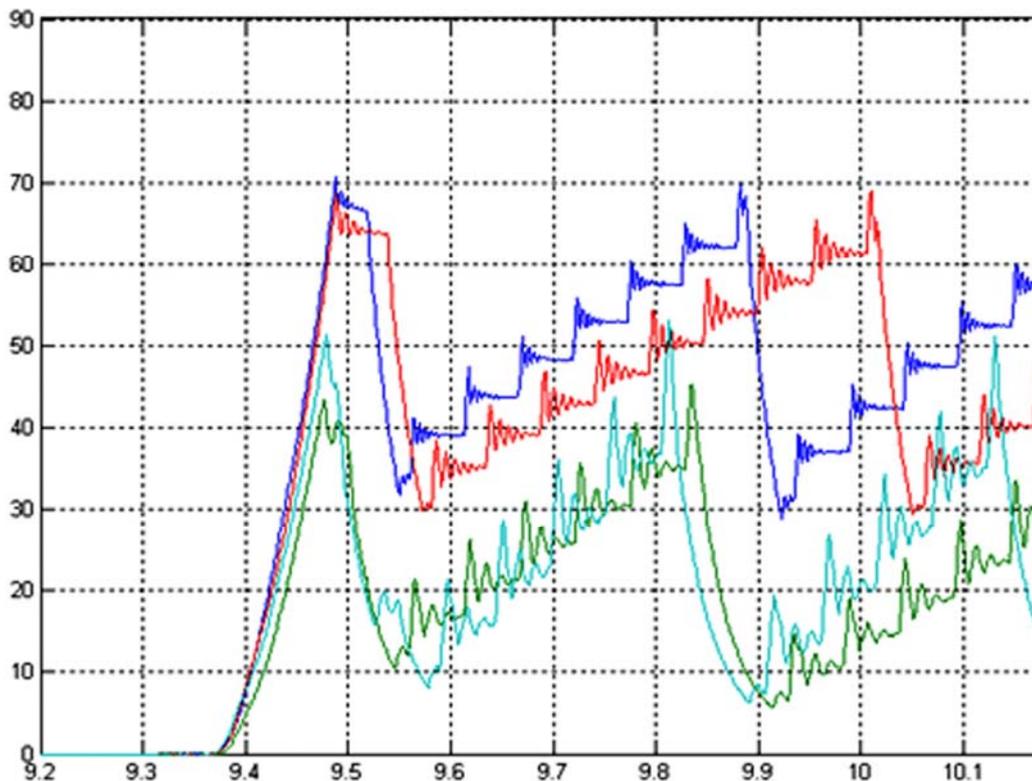


Figure 15. Oscillogram of pressure changes in wheel brake cylinders in the implementation of the algorithm of ABS and direct control of solenoids.

5. Conclusions

The application of virtual physical modeling technology that combines physical and mathematical modeling of the complex object under study, which assumes its conditional division into the full-scale and model parts connected by feedback sensors, allows developers to implement and execute algorithms of the control system of the executive mechanism of the brake system of an unmanned vehicle.

The effectiveness of Virtual-physical simulation technology is largely determined by the correctness of the accepted "division" (virtual-physical) of the research object and by the choice of the type of control computing complex.

These two approaches to the implementation of the method allow the developers to solve the tasks at different levels of integration of the unmanned vehicle control system.

References

- [1] Revin A A 2014 Formation of the main operational properties of vehicles in the braking mode *Automobile industry* vol 11 pp 3–5
- [2] Dygalo V G and Revin A A 2012 *Technology testing of active safety systems for motor vehicles: monograph* (Moscow: Mechanical Engineering) p 387
- [3] Dygalo V G 2015 *Methodology of virtual physical tests of automated brake systems of wheeled vehicles: dis. ... Dr.Sci.Tech* (Volgograd: Volgograd State Technical University) p 348
- [4] Dygalo V G 2012 Development of a simulation device for the signals of wheel sensors of the active safety system *Izv. VSTU. Series "Land transport systems"* vol 5 pp 32–5
- [5] Dygalo V G, Revin A A, Sorniotti A and Velardocchia M 2005 Hardware in the loop with an electro-hydraulic brake system *Zbior referatow IX Miedzynar. Sympozjum IPMiT, (Rynia)* vol 1 (Wojskowa Akad. Techn.) pp 217–26
- [6] Dygalo V G, Revin A A, Sorniotti A and Velardocchia M 2006 Stand for complex laboratory tests EGTS *Automobile industry* vol 3 pp 34–6
- [7] Dygalo V G and Revin A A 2015 Alternative (virtual-physical) tests of automated brake systems of wheeled vehicles *Technology of wheel and caterpillar vehicle* vol 1 pp 37–43
- [8] Smorchkov A E, Kurbanov I Sh, Dygalo V G, Dygalo L V and Boyko G V 2016 Analysis of means and test methods for active safety systems of cars *Science of the XXI century: the experience of the past - a glimpse into the future: the mother. II Intern. scientific-practical. Conf. (Omsk, Russia)* (FGBOU VO "The Siberian state. Automobile and Road Academy (SibADI)") pp 238–46
- [9] Dygalo V G 2011 Virtual physical modeling technology in the design cycle of automated brake systems for multi-purpose wheeled vehicles *Bulletin of the Academy of Military Sciences* vol 2 pp 122–5
- [10] Dygalo V G and Revin A A 2006 Virtual physical technologies for testing automated brake systems in the laboratory *Designing Wheeled Vehicles: Mater. Intern. n.t. Conf., cons. 70th anniversary of the cafe. "Wheeled vehicles" MSTU. N.E. Bauman (Moscow)* pp 461–3
- [11] Dygalo V G and Revin A A 2005 Virtual physical testing technology for the design of automated brake systems *Mashinostroene & Electrical Engineering (Bulgaria)* vol 5 pp 26–9
- [12] Tumasov A V, Groshev A M, Kostin S Yu, Saunin M I, Trusov Yu P and Gypsy V G 2011 Investigation of the properties of active safety of vehicles by the simulation simulation method *Journal of Automotive Engineers* vol 2 pp 34–7
- [13] Revin A A and Dygalo V G 2001 *Research of brake dynamics of the car by methods of complex modeling technology* (Volgograd: Volgograd State Technical University) p 122
- [14] Dygalo V G and Revin A A 2014 Principles of synthesis of virtual-physical models intended for the development of the brake system of a car with ABS *Automobile industry* vol 8 pp 17–9