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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Modernization of railway signaling systems

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Abstract: In the conditions of digitalization of the transport sector, the development of innovative train traffic control systems becomes very important. Such systems must provide high reliability, safety, and efficiency of the transportation process. Traditional signaling methods, based on track circuits and electromechanical relays, have several limits: they are sensitive to electromagnetic noise, use more energy, have delays in fault diagnostics, and need high maintenance costs.

This paper presents a developed system for signal control and information exchange on railway lines. The system is based on the integration of microcontrollers, ACS712 current sensors, inductive sensors, RFID modules, and fiber-optic data channels. The structural diagram of the traffic light control unit is analyzed, the functions of the main elements are described, and a digital comparison of the parameters of traditional and modern systems is made. The results show that the proposed solution increases the reliability of data transmission by 10 times, reduces signal delay 20–30 times, decreases energy consumption up to 60%, and lowers maintenance costs by 30–40%.

Keywords: automatrailway transport; train traffic control; digitalization; signaling system; RFID technology; fiber-optic data transmission

1. Introduction

The development of railway transport in the time of digitalization requires new innovative systems for train traffic control. These systems must give a high level of safety, reliability, and efficiency. Classical methods of traffic organization, based on track circuits and traditional automatic block signaling, have shown their effectiveness for many decades. However, modern operating conditions bring new requirements. The increase of train flow, the growth of passenger and freight train speeds, and the need for integration into intelligent transport systems make it necessary to move to more advanced technologies of data transmission and processing.

One of the key problems of traditional signaling systems is their sensitivity to electromagnetic interference, dependence on the state of track circuits, and limited capacity. Also, fault diagnostics in such systems is often delayed, which reduces the speed of decision making. Modern approaches, on the contrary, use digital technologies, programmable logic controllers (PLC), fiber-optic communication lines, and contactless data transmission systems, including RFID technology.

Effective train traffic control is not possible without fast information exchange between the main elements of the infrastructure: locomotives, signals, trackside devices of automatic block, and station control posts. The most important condition is real-time data transmission and reception. This allows the driver to make correct decisions when driving the train, and the station operator to check the state of block sections and coordinate all actions.

The development of new train traffic control systems on railway lines is directed to two main tasks. First, it is the continuous and accurate monitoring of block sections and signal aspects, which is directly connected with transport safety. Second, it is the increase of automation and the replacement of old elements that reduce the reliability of railway infrastructure.

This paper describes a developed system for signal control and information exchange on railway lines. The system is based on the integration of current sensors, inductive sensors, microcontrollers, RFID modules, and fiber-optic communication channels. The block diagram of the signal control unit is analyzed, the functions of each element are defined, and the advantages of the system are explained in comparison with the traditional automatic block system.

2. Research methodology

Modern trends in the development of railway transport show the need for innovative technical solutions. These solutions must increase the safety and efficiency of train traffic control. For this reason, special attention is given to the analysis and improvement of trackside devices placed along the railway line. These devices play a key role in the system of automatic block and station control.

The methodological basis of the research is the system approach. Each device is studied as a part of one complex that provides data transmission, reception, and processing in real time.

The main signal light (pass signal) is the central element of the signaling system on the railway line. Its main task is to give the driver clear signals about the possibility to continue movement or the need to stop when the train moves from one block section to another. Traditionally, such devices work with 12 V AC power and have three signal lightsgreen, yellow, and: red. To control the current state of the lamps, a current sensor is used. This improves the reliability of information transfer and reduces the risk of accidents [2,3].

Current sensors have an important diagnostic function. They check if the signal lamps are switched on or off, detect possible faults, and send data to the central control system. In the studied system, ACS712 current sensors are used. These devices can measure the current in the power circuit of each lamp with high accuracy. The received data automatically goes to the microcontroller, which removes the human factor and provides stable operation of the device.

The microcontroller is considered the "brain" of the signal control unit. It receives and processes data from all connected devices, the signal light, current sensors, relay controller, RFID module, and inductive sensors. The main functions of the microcontroller are to control the state of the signal, to check the condition of the lamps, and to change the signal automatically depending on the occupancy of the block section. For example, using information from the inductive sensor, the microcontroller detects the position of the train and the occupancy of the track section. Then it changes the signal aspect according to the set algorithms [4,5].

Information transfer to the central monitoring system of the station is done through a Media Converter, which changes the electrical signal into an optical one. This gives high communication reliability over long distances and allows synchronization of several signals. In addition, the system uses RFID technology: the data about the state of the signal is written into an RFID tag, which is read by the locomotive during movement. This method provides two-way information exchange and removes delays in signal transmission.

The system also makes operational diagnostics. In particular, current sensors help to detect lamp faults in real time, which strongly improves the safety level. Constant information exchange between signals and the central system reduces the probability of critical situations and gives reliable control of train traffic.

The relay controller is the executive part of the system. It switches the signal lamps on and off according to the commands of the microcontroller. This makes the work stable and gives the correct logic of signals: the green or yellow light is on when the block section is free, and the red light is on when the section is occupied.

A special role belongs to the RFID (Radio Frequency Identification) system. It allows contactless transfer of data about the signal state directly to the locomotive. The RFID writing device saves the data into a tag installed on the sleepers, and the RFID reader placed on the locomotive receives this information while moving and sends it to the on-board control system. This method gives accuracy, speed, and security of data exchange.

Inductive sensors are used to detect the arrival of a train and to monitor the condition of block sections. Their work is based on fixing the change of the magnetic field when the metal parts of the rolling stock pass above. The contactless principle reduces equipment wear and gives long service life [6,7].

3. Results

Effective train traffic control on railway lines requires a complex system that unites several functional devices placed in signal points. These devices provide the creation, processing, and transfer of information about the state of block sections and signals both to the locomotive and to the station control posts. The developed system is based on the principles of digitalization, integration, and modular design, which makes it possible to adapt the system to different operating conditions.

Figure 1 shows the structural diagram of the signal control unit. The main elements are: the main signal light, current sensors, electromechanical relays, inductive sensors, programmable logic controller (PLC), power converters, fiber-optic data channels, and RFID modules. Each of these devices has its own function, but only together they form one system that provides reliability and safety of train traffic.

In the presented diagram, the main signal light, located in the signal point, gives permission or prohibition for the train to move from one block section to another. This signal works from a 12 V AC power source. Each lamp of the signal is connected to the electric circuit through an ACS712 current sensor. This makes it possible to detect the presence of current in the circuit and its value. Based on this data, the state of the signal in the point can be fixed automatically and shown in the PLC. The ACS712 sensor is always connected to a 5 V DC power supply. When current appears in the circuit of a certain lamp, the sensor sends information to the controller. The signal formed in the PLC is then sent to the previous signal on the route, because this information must go to the locomotive when entering the previous block section [8].

Electromechanical relays connected to the electric circuits of the signal lamps provide their switching on and off. Depending on the commands from the PLC, the relays open or close the power circuit of the needed lamp. This command is formed on the basis of the block section state: if the next block section is free, the permissive signal (yellow or green) is on; if it is occupied, the prohibiting red signal is on. On the line, the normal mode of the signal is the green permissive light, so the relay of the green lamp is normally open and works only when the train is on the block section. Considering energy use, the lamp circuits of the signal do not work at the same time, so the electromechanical relays also switch at different moments. For example, when the red signal is on, the relays of the yellow and green lamps are automatically in the off state. The electromechanical relays work with 5 V DC control and can switch signal lamps powered by AC from 10 to 24 V [9].

For the power supply of current sensors and electromechanical relays with 5 V DC, a DC–DC converter is used. It reduces the voltage from 24 V to 5 V.

The inductive sensor is used in signal points to form a signal about the train entering the block section. Based on this information, the occupancy of the block section is defined, and the signal of the previous section is changed automatically. The inductive sensor is connected to the PLC. When the train passes above the sensor, it detects the presence of the train by the change of the magnetic field and sends the data to the controller. Based on this, the PLC forms a signal about the train entering the block section. The formed signals are sent both to the control unit of the previous signal and to the station. For this process, a Media Converter is used. It is connected to the PLC through an Ethernet switch, changes the electrical signal to an optical one, and sends it by fiber-optic cable to another Media Converter in the control unit of the previous block section. Transmission of data by optical cable over long distances gives high reliability and safety, and removes the problems of ALS codes transfer by track circuits. The Media Converter and Ethernet switch work from a 24 V DC power source [10,11].

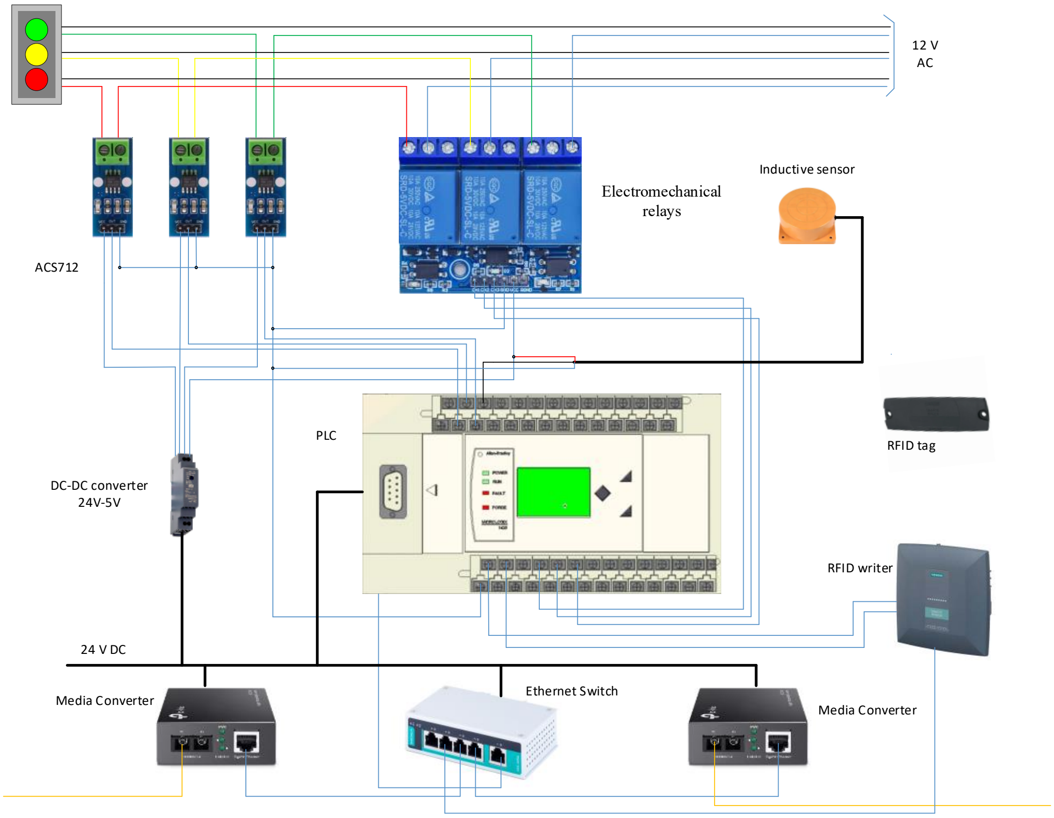

Fig. 1. Structural diagram of the signal control unit in the signal point

In the signal point, RFID technology is used to send information to the locomotive about the aspect of the next signal. The information about the signal state comes from the control unit of the next signal, then the signal formed in the PLC is sent to the RFID writing device. It saves the data in an RFID tag. When the locomotive, equipped with an RFID reader, passes above the sleepers where the tag is installed, it reads the coded data and sends it to the KLUB system. In this case, an active RFID system working in the high-frequency range is used, which gives high speed and long distance of data exchange.

To prove the efficiency of the proposed train traffic control system, a comparative study of the main characteristics of traditional track circuits and the developed digital system was made. The new system is based on the use of microcontrollers, RFID modules, and fiber-optic communication channels.

The digital system shows important advantages: an increase of reliability by 10 times; a reduction of data transfer delays by 20–30 times; a decrease of energy consumption by 60%; and a reduction of maintenance costs by 30–40%.

Table 1

Comparative analysis of traditional and digital signaling systems

Indicator	**Traditional system (track circuits and relay schemes)**	**Modern digital system (PLC, RFID, fiber optics)**	**Advantage**
Data transmission reliability (average failure probability)	~0.01 per 1000 km/year	<0.001 per 1000 km/year	10 times higher reliability
Signal transmission delay	200–300 ms	<10 ms	20–30 times faster
Power consumption of control unit	20–25 W	8–12 W	Up to 60% saving
Fault diagnostics	Manual, with delay	Automatic, in real time	Lower risk of emergency
Equipment wear	High (mechanical relay contact)	Low (contactless sensors, fiber optics)	Service life longer by 1.5–2 times
Maintenance cost	High (frequent replacement of track circuits and relays)	Medium (minimal service of fiber optics and sensors)	Cost reduction by 30–40%
Possibility of integration into intelligent transport systems (ITS)	Limited	High (compatible with IoT, AI, KLUB-U)	Full digitalization

Thus, the introduction of digital technologies in train traffic control makes it possible to reach a high level of safety and efficiency, and also to create a base for integration into intelligent transport systems.

4. Conclusion

The developed signal control system for railway lines, based on the integration of microcontrollers, current sensors, inductive sensors, RFID modules, and fiber-optic data channels, has shown high efficiency in solving key tasks of safety and reliability of the transportation process. The use of modern digital technologies made it possible to achieve stable system work in real time, to reduce the influence of the human factor, and to increase the speed of information exchange between the locomotive, signals, and station control posts.

The comparative analysis with traditional signaling systems confirmed the clear advantages of the new architecture: an increase of information reliability by 10 times due to the removal of track circuits and the use of fiber-optic lines; a reduction of signal response time by 20–30 times, which gives timely information for the driver and the station operator; a decrease of equipment energy consumption up to 60% because of energy-efficient components and optimized circuits; a reduction of maintenance costs by 30–40% through the elimination of frequent service of relay schemes and track circuits; and the possibility of automatic diagnostics and integration into new generation intelligent transport systems.

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