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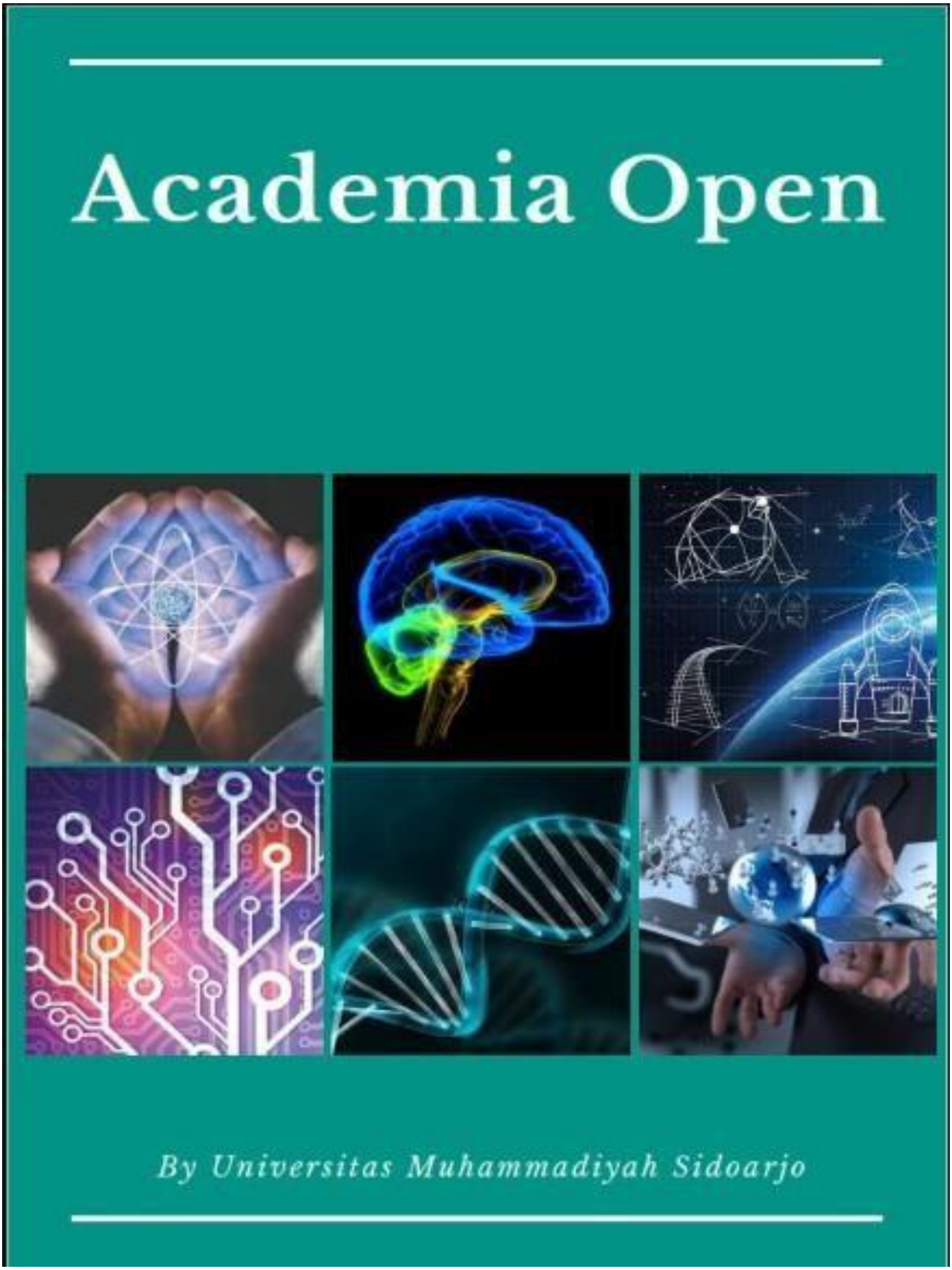

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Digital Modernization Of Railway Interlocking Systems Using Microprocessor Shunting Signal Modules

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Abstract

General Background Automation devices significantly increase transport network throughput, safety, and operationalcapacity. **Specific Background** The rapid development of digital technologies offers new opportunities for upgrading traffic control infrastructure. **Knowledge Gap** Traditional block-route relay architectures fail to meet modern technical requirements, yet completely replacing their existing infrastructure remains economically unfeasible. **Aims** This study investigates the integration and two-stage testing of NM2P-M and NM2AP-M microelectronic units designed to control station operations within legacy systems. **Results** Experimental laboratory evaluations and real-time station monitoring confirmed proper command exchange, accurate route setting, and functional compatibility with electromagnetic standards. **Novelty** The research demonstrates a step-by-step technological transformation methodologythatseamlessly integrates microelectronic controllers into existing block housings without requiring significant structural modifications. **Implications** These findings provide a practical framework for the gradual digitalization of transport automation, accelerating fault detection and reducing maintenance costs while securing operational safety.

Highlights:

• The developed NM2P-M and NM2AP-M units successfully process automated commands during route setting without structural modifications.

• Two-stage testing confirmed operational stability, correct hardware configuration, and electromagnetic compatibility under real-time monitoring.

• Gradual technological transformation reduces maintenance costs and accelerates fault detection while preserving legacy infrastructure.

Keywords: Railway Automation, Relay Infrastructure, Route Setting, Real-Time Monitoring, Functional Testing

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I. Introduction

One of the most important directions of scientific and technical progress in railway transport is the development and implementation of automation and telemechanics devices and systems, which allow for the full and efficient use of all technical means of transport. With relatively small capital investments, automation and telemechanics devices allow for a significant increase in the throughput of lines and the processing capacity of stations, increase labor productivity and improve working conditions for railway workers, and increase train safety. [1] In particular, the reliability of traffic lights and their control systems used in the organization of shunting operations directly affects the overall efficiency of the railway infrastructure. Currently, traditional block-route relay centralization (BMRM) systems are used at many stations of the railway network of our country, but their technical capabilities do not fully meet modern requirements.

The rapid development of microprocessor technologies is creating new opportunities for the modernization of railway automation and telemechanics systems.[2] In particular, the development and implementation of microprocessor modules controlling shunting traffic lights will increase control accuracy, quickly detect faults, expand monitoring capabilities, and reduce operating costs. At the same time, it is economically feasible to gradually modernize existing relay systems without completely replacing them.Before introducing improved microprocessor modules into practice, it is important to thoroughly analyze their performance, assess their reliability indicators, and test them under operational conditions. Based on industrial electronics standards, the average failure rate of elements is as follows:

• PLC CPU (λ1): 2 × 10-6 h-1

• Expansion module (λ2): 1.5 × 10-6 h-1 (each)

• Basic degradation rate (λk) for screw connection in single wire connection/contact standard: 0.1 × 10-6 h-1

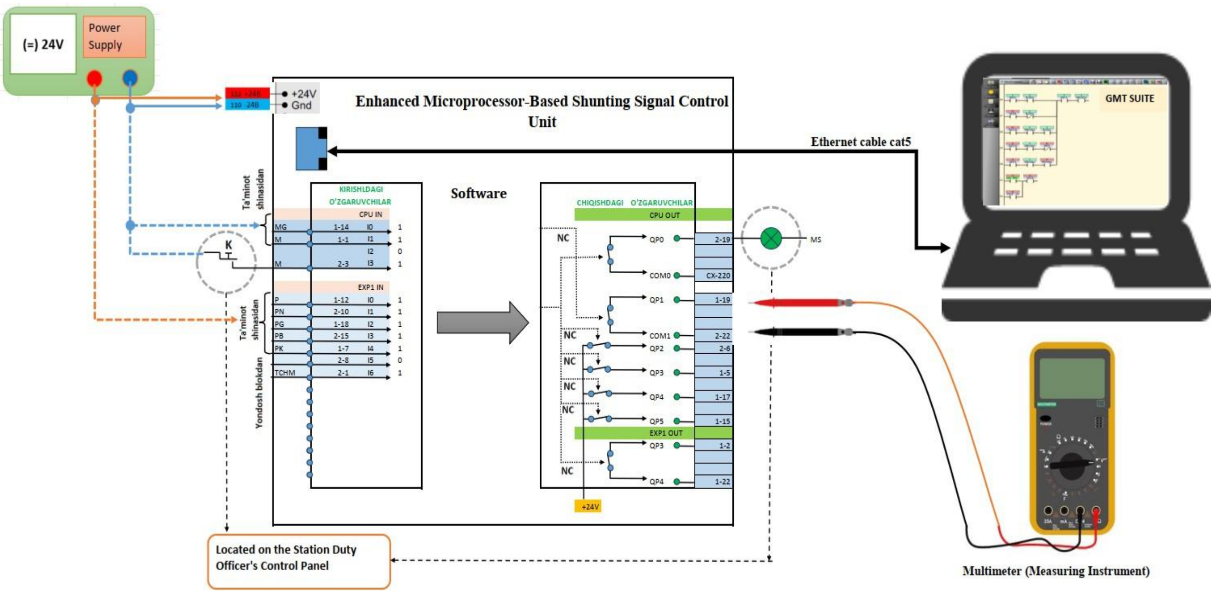
The above values are used to calculate the reliability of the device based on the exponential law. [13,14]

Such tests allow determining the stability of the hardware and software, its resistance to external influences, fault tolerance, and compliance with safety requirements. [5,8] In addition, during the experimental connection of microprocessor modules to existing block-route relay systems, special attention should be paid to the issues of their electromagnetic compatibility, signal exchange, and functional integration.

II. Methods

Microprocessor-based shunting signal control units are an integral part of railway automation and telemechanics systems. They are microelectronic devices designed to provide remote control of railway shunting signals and continuous monitoring of their operational status. Any newly developed technical solution or device can directly affect train traffic safety; therefore, the developed microprocessor units must undergo a two-stage testing procedure in the presence of members of a specially established commission. Upon completion of the tests, official reports and acceptance records are prepared based on the obtained results [3,4].

Figure 1. Schematic diagram of the testing procedure for the enhanced microprocessor-based shunting signal control units.



During the first stage, the actual installation is compared with the design documentation, and all cable connections and system configurations are thoroughly inspected. Positive results obtained at this stage provide the basis for proceeding to the next phase of testing.

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The second stage consists of autonomous (stand-alone) verification tests carried out at the control point of the Signaling and Communication Department according to the testing scheme shown in Figure 1. A 24 V DC power supply, a multimeter, and a computer with the GMT SUITE software installed are the main tools used during the testing process[15,16].

By operating the microprocessor module autonomously, without connecting it to the operational network and supplying it with an artificial power source, the following aspects are verified:

- correct reception and execution of commands by the microprocessor-based shunting signal control units;
- integrity of the unit housing, contact connections, and cable entries;
- status of the indication LEDs, which should not display any error signals under normal operating conditions;
- correspondence between the information reported by the unit and its actual operating state;
- compatibility with other interlocking and signaling devices;
- correctness of the software version and configuration settings;
- proper execution of all functional capabilities of the unit in accordance with dedicated test procedures and test tables.

III. Results

No.	Relay State	Input and Output Conditions	Result
1	All relays de-energized (normal state)	Commutation exists between the following terminals	
2		Terminals 2-17 and 2-13	Yes
3		Terminals 1-2 and 2-2	Yes
4		Terminals 1-3 and 1-20	Yes
5		Terminals 1-4 and 2-4	Yes
6	K relay energized	PK supply is present at terminal 1-7	Yes
7		P supply is present at terminal 1-12	Yes
8		P output is present at terminal 2-7	Yes
9		P output is present at terminal 1-15	Yes
10		M supply is present at terminal 2-3	Yes
11		Commutation exists between the following terminals	Yes
12		Terminals 2-22 and 1-19	Yes
13		ChM supply is present at terminal 2-14	Yes
14		ChM output is present at terminal 1-8	Yes
15	KN relay energized	Positive (+) supply at terminal 2-8 and negative (-) supply at terminal 1-1	Yes
16		Positive (+) supply at terminal 2-1 and negative (-) supply at terminal 1-1 (when the K relay is energized)	Yes
17		PN supply is present in the KN relay self-locking circuit	Yes
18		Commutation exists between the following terminals	
19		Terminals 2-18 and 2-21	Yes
20		SX supply is present	Yes
21		SX output is present at terminal 2-19	Yes
22		PG supply is present	Yes
23		PG output is present at terminal 1-5	Yes
24		PG output is present at terminal 1-15	Yes
25		PB supply is present	Yes
26		PG output is present at terminal 2-6	Yes

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27		P supply is present	Yes
28		P output is present at terminal 1-17	Yes
29		Commutation exists between the following terminals	
30		Terminals 1-2 and 1-22	Yes
31		Supply is present at terminal 1-6	Yes
32		Output is present at terminal 1-8	Yes
33	MP relay energized	ChM supply at terminal 2-14 and MG supply at terminal 1-14 are present	Yes
34		P supply is present	Yes
35		P output is present at terminal 1-11	Yes
36		SX supply is present	Yes
37		SX output is present at terminal 2-19	Yes
38		Commutation exists between the following terminals	
39		Terminals 1-3, 1-21 and 1-20	Yes
40		Terminals 1-4 and 2-21 (when the K relay is de-energized)	Yes
41		Supply is present at terminal 1-9 for the MP relay self-locking circuit	Yes
42		P supply is present	Yes
43		P output is present at terminal 1-13 (when the KN relay is de-energized)	Yes
44		P output is present at terminal 1-15 (when the KN relay is de-energized)	Yes
45		PG supply is present	Yes
46		P output is present at terminal 1-13 (when the KN relay is energized)	Yes
47		P output is present at terminal 1-15 (when the KN relay is energized)	Yes
48	VP relay energized	NCh supply at terminal 1-16 and MG supply at terminal 1-14 are present	Yes
49		SX supply is present	Yes
50		SX output is present at terminal 2-19	Yes
51		M input is present at terminal 1-10	Yes
52		M output is present at terminal 2-5	Yes
53		Supply is present at terminal 2-12 for the VP relay self-locking circuit	Yes
54		Commutation exists between the following terminals	
55		Terminals 1-3, 1-21 and 1-20	Yes
56	VKM relay energized	NM supply at terminal 2-16 and MG supply at terminal 1-14 are present	Yes
57		SX supply is present	Yes
58		SX output is present at terminal 2-19	Yes
59		M input is present at terminal 1-10	Yes
60		M output is present at terminal 2-17	Yes
61		M output is present at terminal 1-4	Yes
62		Commutation exists between the following terminals	
63		Terminals 1-3, 1-21 and 1-20	Yes
64		Supply is present at terminal 2-12 for the VKM relay self-locking circuit	Yes

Taking the above considerations into account, Table 1 presents, as an example, the experimental testing schedule (test matrix) of the NM2P-M microprocessor-based shunting signal control module. Successful completion of all categories of the second-stage tests confirms the reliability and proper operational performance of the microprocessor-based shunting signal control modules.

The technical implementation of the developed devices is based on the following requirements [2]:

- The NM2P-M and NM2AP-M microprocessor modules are intended for generating control commands during automatic route setting in block-route relay interlocking (BRRI) systems.

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• The application area of these modules is railway station automation and telemechanics systems.

• When installed on the shelves of relay racks, the microprocessor modules shall be interchangeable with conventional NM2P and NM2AP relay blocks under operating conditions.

According to the applicable GOST standards, the developed modules can be classified as follows [9-12]:

• By functional purpose: devices intended for generating control commands for shunting signals and performing a specific operational function;

• By operating mode: technical devices designed for long-term continuous operation;

• By consequences of failure: products whose failure does not result in catastrophic consequences;

• By recoverability after hazardous failure: repairable (recoverable) products;

• By the nature of processes leading to the limit state: ageing products;

• By maintenance capability during operation: maintenance-free products;

• By restoration of technical resources through scheduled repairs: non-repairable products;

• By inspection requirements: products subject to inspection both prior to commissioning and during operation.

The general appearance of the developed NM2P-M and NM2AP-M microprocessor modules is shown in Figure 2, while Figure 3 presents their installation inside the housing of the existing relay blocks for experimental integration into the BRRI system.

Figure 2. General view of the developed NM2P-M and NM2AP-M microprocessor modules.

Figure 3. Installation of the developed microprocessor modules inside the existing relay block housing for experimental integration into the BRRI system.

IV. Discussion

After obtaining positive test results at the inspection and measurement point, the functional compatibility of the developed modules with the existing relay equipment was investigated according to the following procedure:

• First, the shunting signals controlled by the NM2P-M and NM2AP-M modules at the selected railway station were chosen as experimental objects.

• The relay blocks controlling these shunting signals, installed on the relay rack in the relay room, were replaced with the developed microprocessor modules.

• The turnout position monitoring system at the control panel was then checked.

To verify the operation of the NM2P-M and NM2AP-M modules, a shunting route involving the selected shunting signals was established by considering them as an initial node. Successful route setting was confirmed by the appearance of a

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permissive white signal on the shunting signal. In addition, real-time monitoring on a computer connected to the microprocessor module confirmed the energization of the K, KN, and MP relays in accordance with the operating algorithm[6].

At the next stage, a shunting route was established considering the selected shunting signals as a final node. The successful formation of the route up to the shunting signal was confirmed by the indication lamp on the control panel. Real-time monitoring further verified the energization of the K, KN, and VKM relays in accordance with the control algorithm[6,7].

At the final stage, the selected shunting signal was considered an intermediate node, and a shunting route was established accordingly. Successful route formation was confirmed by the indication lamp on the control panel. Simultaneously, real-time monitoring of the connected computer verified the energization of the AKN, KN, and VP relays according to the operating algorithm.

In all cases, the modules operated under normal conditions, the routes were formed correctly, and the permissive indications of the shunting signals were successfully displayed. Following these successful tests, the stability and reliability of the microprocessor modules were further evaluated through long-term continuous operation under prescribed operating conditions.

V. Conclusion

The conducted research analyzed the possibility of integrating enhanced microprocessor modules for shunting signal control with existing block-route relay interlocking systems and evaluated their functional characteristics. The results demonstrated stable operation of the developed modules under various operating conditions, timely processing of control commands, and proper signal exchange with relay-based equipment.

The test results showed that the microprocessor modules can be integrated into existing relay interlocking systems without significant structural modifications. Furthermore, the implementation of these modules expands diagnostic capabilities, accelerates fault detection, reduces maintenance costs, and improves the overall reliability of railway automation systems.

During the experimental integration process, the electromagnetic and functional compatibility of the microprocessor modules with the block-route relay interlocking system was successfully confirmed. In addition, the possibility of modifying control algorithms through software provides favorable conditions for further modernization and the introduction of new functionalities.

Therefore, the integration of enhanced microprocessor-based shunting signal control modules with existing relay systems represents one of the promising directions for the gradual digitalization of railway automation and telemechanics equipment. The obtained results provide a scientific and practical basis for the wider implementation of microprocessor-based control technologies in railway automation and telemechanics systems, contributing to improved traffic safety and increased operational efficiency of railway stations.

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