



System for Periodic Monitoring of Railway Automation and Remote Control Facilities Based on Unmanned Aerial Vehicles



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ABSTRACT

Modern diagnostic information collection systems do not allow obtaining a complete set of diagnostic data on the floor-mounted technological equipment of railway automation and remote control. This is due to the technical features of the railway automation and remote control facilities themselves, the conditions of their operation and the technologies of safe data acquisition. The study focuses on improving the principles of obtaining primary diagnostic information on railway automation and remote control facilities using unmanned aerial vehicles. Using methods of discrete mathematics, graph theory, Boolean algebra and technical diagnostics, the study has developed and scientifically substantiated the principles of obtaining diagnostic information on the floor-mounted technological equipment of railway automation and remote control using unmanned aerial vehicles.

The unmanned aerial vehicle is equipped with a payload for obtaining diagnostic information on railway automation and remote control facilities located in close proximity to the railway track. The system solves several diagnostic problems at once in relation to

the railway automation and remote control system: it collects objective data on the technical conditions of the floor-mounted process equipment (including defects), automates a certain share of routine maintenance operations, and verifies the facts of maintenance work performed by specialised personnel of signalling, interlocking, and blocking divisions.

The solution to these problems helps to increase the dependability and safety of railway automation and remote control devices thanks to the timely detection of incipient gradual failures and the prompt identification of already occurred failures that did not manifest themselves during the normal operation of the railway system. It is proposed to integrate data from all existing monitoring systems in a single corporate cloud storage for further processing using a secure intelligent data analytics platform, as well as automatically transfer the results of technical diagnostics to participants in the transportation process for their prompt consideration in train traffic control.

Keywords: railway automation and remote control devices and systems; floor-mounted process equipment; unmanned aerial vehicle; technical diagnostics; automated monitoring system; dependability and safety of railway automation and remote control devices.

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BACKGROUND

Railway automation and remote control devices and systems (RARC) ensure uninterrupted and safe train traffic control. As means directly responsible for the course of critical technological processes, RARC devices and systems are embodied as highly reliable and capable of safe behaviour in case of failures – a transition to a fail-safe state [1–4]. These properties are achieved by using highly reliable components, safe logical elements in construction, redundancy and diverse protection systems, self-checking and testable blocks and units, etc. [5; 6]. To ensure high readiness of RARC devices and systems, measures are taken to maintain their operability, which include maintenance work according to specially developed instructions¹ and process maps², as well as the operation of automated technical diagnostics and monitoring equipment [7; 8]. The use of these components during operation allows the operating personnel of signalling, interlocking and blocking (SIB) divisions to promptly respond to developing pre-failure conditions of RARC devices and systems at the stages of gradual failure initiation, as well as to sudden and catastrophic failures.

However, the practices of operating RARC show that the above measures often do not prevent events that reduce their reliability. This is due to the specifics of the work performed and the specifics of operation of RARC devices and systems – they operate around the clock with a constant load and readiness to execute control commands, and floor-mounted [*ground-level or trackside equipment further referred to as floor-mounted one*] technological equipment operates in the open air and is subject to external destabilising factors (the impact of the environment, moving trains, the interfering effect of shunting operations at stations, changes in the state of the track ballast under the action of transported goods, etc.). Maintenance work is not carried out continuously, but according to the regulations with some frequency, and a defect

¹ Instructions for maintenance and repair of devices and systems of signalling, interlocking and blocking. Moscow, JSC RZD, 138 p. [Electronic resource]: http://static.scbist.com/scb/uploaded/4574_1443330750.pdf?ysclid=m9u10aqtndn367269283. Last accessed 22.05.2024.

² Signalling, interlocking and blocking devices. Maintenance technology. Collection of process charts. Moscow, JSC RZD, 2010, 416 p. [Electronic resource]: http://static.scbist.com/scb/uploaded/1056_teh_kart.pdf?ysclid=m9u13yqk15210108415. Last accessed 22.05.2024.

may occur between procedures for performing work. In addition, the role of the human factor in working with safety devices is high. Thus, in accordance with [1], the probability of human erroneous actions is determined by the order of magnitude of $10^{-2} \dots 10^{-3}$ (an error per 100...1000 actions performed). Moreover, according to [9], one of the tasks of automated monitoring systems for railway automation devices is to control the facts of technical maintenance and the correctness of actions performed by service personnel, which only contributes to increasing their reliability and safety.

If we talk about the use of automated monitoring tools, then they are mostly used to equip RARC devices located at electrical interlocking posts (EIP) and in transportable modules, which allows for measuring procedures to be performed only based on the electrical parameters of the objects being diagnosed and often provides only an indirect assessment of the actual technical condition [7; 8]. Among the floor-mounted technological equipment of the railway automation and control system, only the equipment of relay cabinets of numerical code automatic blocking and crossing automation is equipped with automated diagnostics and monitoring tools, and these are, as a rule, logical signals about the technical condition and a small part of the analogue electrical parameters [10; 11]. Of course, the devices appear abroad that are mounted in floor-mounted RARC facilities and transmit diagnostic data both via a wired interface and wirelessly (see, for example, [12] or [13]). However, in general, monitoring of floor-mounted technological equipment is organised based on the readings of RARC post devices.

Thus, it becomes clear that it is simply impossible to consider the full set of states of RARC located near the railway tracks (floor-mounted process equipment of RARC). But here such defects as the improper state of throttle and rail jumpers, bypass and welded connectors, insulating joints, insulation on turnouts, violations of geometric parameters (skewing, deviations from the design axes, displacement of objects, etc.), traces of developing corrosion of reinforced concrete structures, lack of grounding, violations of the visibility of signals and much more are missed. In addition, the lack of marking on RARC facilities is also improper, which also cannot be checked using stationary monitoring tools. Therefore, the task of automating the

receipt of diagnostic data that fills this gap arises. And they can be obtained using unmanned aerial vehicles (UAV) with a payload required to form a complete set of «raw» diagnostic data for the purpose of high-quality and effective monitoring of the condition of the floor-mounted technological equipment of RARC.

The objective of the study is to develop a method for obtaining diagnostic information about RARC floor-mounted technological equipment using UAVs and to provide scientific justification for creating a periodic monitoring system based on them. To achieve the objective of the study, the authors used *methods* of discrete mathematics, graph theory, Boolean algebra and technical diagnostics.

Despite the fact that the railway transport industry pays attention to the possibilities of using UAVs to obtain data on the state of infrastructure facilities and conducts research in this direction [14–17], the conservative part of the community of scientists and engineers in the field of signalling and interlocking remains sceptical about this technology, which only slows down the development of the already stagnating RARC field. Therefore, this article should be considered as a description of a conceptual solution in terms of using UAVs to obtain data on RARC, as well as material calling for a discussion on the use of unmanned technologies and artificial intelligence to improve the principles of operation of devices and systems to ensure the smooth and safe passage of trains through railway lines.

RESULTS

1. Safe flight route around railway infrastructure

It follows from the practice of operating RARC equipment that up to 80 % of their defects are due to floor-mounted process equipment³. The main floor-mounted process equipment should include: some of the elements of the electric track circuit arrangement (track boxes, connectors, jumpers, choke transformers, etc.), point electric drives (including component fittings, insulating shoes, working and control drives, track boxes, etc.), traffic lights and route

³ Sapozhnikov, V. V., Sapozhnikov, V. I., Efanov, D. V., Shamanov, V. I. Reliability of railway automation, remote control and communication systems: Textbook. Ed. by V. I. Sapozhnikov. Moscow, Training and Methodological Center for Education on Railway Transport, 2017, 318 p. ISBN 978-5-906938-01-5.

indicators, relay and battery cabinets, as well as devices placed in them, crossing automation equipment, cable network elements (branching and connecting sleeves, cables themselves, etc.)⁴.

A helicopter-type UAV (Pic. 1) with a payload that must collect diagnostic data in such a way that its actions do not have a dangerous effect on the transportation process is to be used to collect data on RARC. For these purposes, the UAV must carry out the main types of work in a certain zone, which can be called a *safe flight zone*. It must be located on the side and above the railway infrastructure, as shown in Pic. 2 for a double-track section. In addition, the control process must be either fully automatic with established restrictions, or automated with mandatory restrictions on entering the prohibited flight zone. It is also necessary to solve the problem of eliminating *dangerous failures* of UAV, which in this context mean UAV failures (including those associated with violation of flight algorithms) that will lead to its entry into the area of the location of railway infrastructure facilities and rolling stock.

The diagram in Pic. 2 shows some dimensions according to the data from the rules for the technical operation of railways⁵. The lower line corresponds to the level of the rail heads (LRH). The distance between the track axes is not less than 4 100 mm, the distance from the axis of the outer track to the inner edge of the contact network support is not less than 3 100 mm. Two tolerances are indicated below – δ and ϵ . They are determined for each specific section of the railway line, based on local conditions. Based on this diagram, the safe flight zone of the UAV is determined.

The safe flight zone, as well as the UAV control algorithms, must consider possible external destabilising effects (wind gusts, effects from railway transport, etc.) and prevent it from entering the zone of location of railway infrastructure facilities and movement of trains and shunting trains, highlighted in Pic. 2.

The process of collecting diagnostic data and the UAV flight route are determined from the following initial assumptions.

⁴ Soroko V. I., Fotkina Zh. V. Railway automation and remote control equipment: Handbook: in 4 books. Book 1. 4th ed. – Moscow, LLC «NPF PLANETA», 2013, 1060 p. ISBN: 978-5-901307-21-2.

⁵ Order of the Ministry of Transport of the Russian Federation dated June 23, 2022, No. 250 «On approval of the rules for the technical operation of railways of the Russian Federation». [Electronic resource]: <http://publication.pravo.gov.ru/Document/View/0001202207200026>. Last accessed 21.05.2024.





Pic. 1. Helicopter-type UAV [free Internet access].

1. Requirements for the performance of measurement work are established and regulated, considering preliminary ranking by frequency and the best weather conditions for their implementation.

2. For a specific section of the railway (for example, a station or a section), an electronic 3D map is first created, on which, in addition to other facilities of the railway complex, the operated RARC equipment is indicated as control points (in this case, the locations of all facilities are indicated, including connectors, jumpers and cable facilities). Here, not only ordinates are entered, as in the schematic plan of the station, but also precise geographic coordinates in relation to the terrain profile.

3. The UAV flight route is preliminarily determined, considering the need to:

- cover all control points of the electronic map and obtain data on all RARC facilities;
- ensure safety when flying in the area above the railway infrastructure and a possibility of flying into the area of violation of the approach clearance of buildings only in cases of absence of traffic (flying in is required by rather rare maintenance work, related, for example, to monitoring the visibility of signals);
- ensure power supply to the UAV along the entire flight route.

4. Diagnostic data and monitoring results should be automatically loaded into the database of the intelligent analytics platform, which should also be integrated with the software of stationary automated monitoring systems [18].

As an example, the entire volume of floor-mounted technological equipment of RARC, with which the station is equipped, is shown in the schematic plan of the even neck of an arbitrary intermediate station in Pic. 3, from which one can see the scale of the work

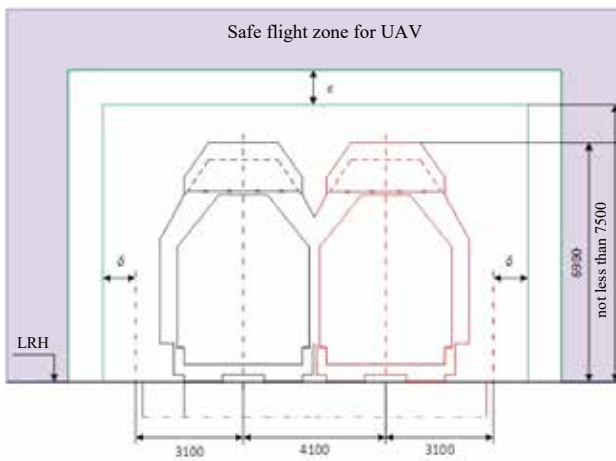
performed by the UAV to collect diagnostic data.

Since the railway infrastructure facilities are geographically dispersed and located at an impressive distance from each other (even for the presented intermediate station, the distances between the entrance traffic lights of the even and odd necks are approximately 2 000 m), it is advisable to fly around the station by along necks, automatically collecting, processing data and entering them into a digital copy of the EIP deployed in an external corporate cloud storage. At the same time, on the electronic map for the UAV flight, control points are applied to each railway infrastructure facility, which must fall into the «coverage zones» of the portable measuring equipment during the flight. It is based on this data that the route for flying around RARC facilities is determined.

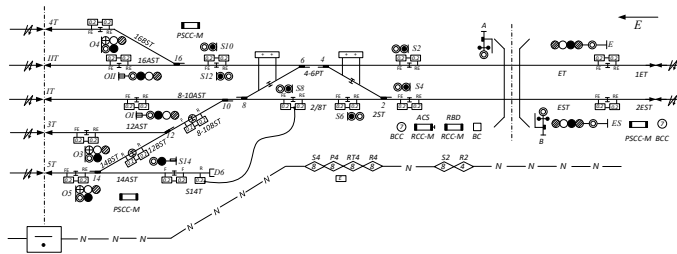
In Pic. 4, RARC floor-mounted facilities are applied as black dots on the schematic plan of the even neck of the station. At the same time, as follows from the schematic plan, a number of facilities are located in close proximity to each other, and a number of facilities are remote. Besides, it should be taken into account that the elements of the track circuits, connectors and jumpers are geographically distributed over large distances (they are plotted on the diagram as conventionally reduced points). These points must be visited during the UAV flight to collect data.

The UAV is equipped with a payload in the form of measuring equipment with a certain coverage radius of the zone, within which the RARC floor-mounted facilities can be identified, and data can be collected from them. The problem arises of covering a flat figure, covering part of the track development of the station and the RARC devices themselves in the form of control points, with circles of the same radius, as is approximately shown in Pic. 5. The solution to this problem is given in [19].

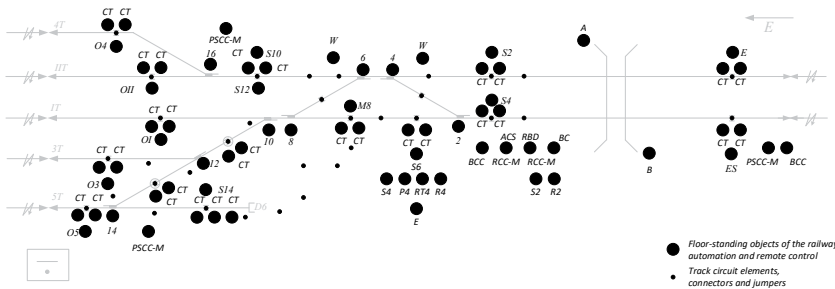
After obtaining coverage of the neck's control points with circles, a graph is formed, the vertices of which are the centres of the circle (Pic. 6). This graph can be complete. However, since the control points are obviously located sequentially on the station plan along the railway line, some arcs can be excluded. Arcs are assigned a weight determined by the distance between the vertices connected by them (therefore, constructing a complete graph is not required, since several



Pic. 2. Safe flight zone for UAV over the railway facilities [performed by the authors].



Pic. 3. Schematic plan of a station in a single-line design for an arbitrary intermediate station (even neck) [performed by the authors].



Pic. 4. Control points for receiving UAV data over the railway infrastructure (even neck) [performed by the authors].

weights will initially be overestimated⁶). Nevertheless, in order not to miss a single vertex, the UAV software can form a complete graph with the subsequent exclusion of a few arcs. In general, the number of arcs will depend mainly on the radius of coverage of facilities by the UAV portable equipment – the larger is the radius, the fewer will be there.

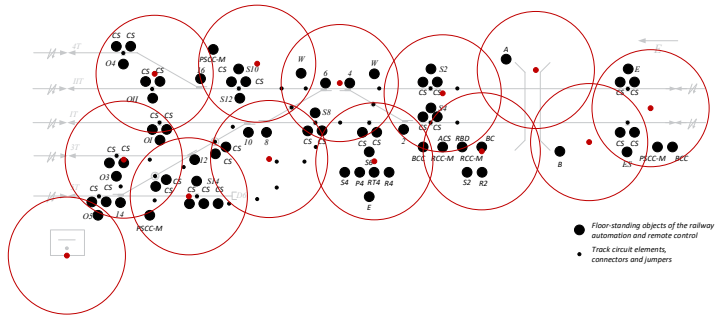
Next, a search is made for an optimal (or close to it) bypass path, in which from the

initial vertex A the UAV, having flown around each vertex, gets to the same vertex A (in this case, it is not necessary to visit the vertex once or, having visited it along the route, shorten the path). In Pic. 6 the flight route around the considered station neck is highlighted in red (in colour Web-version).

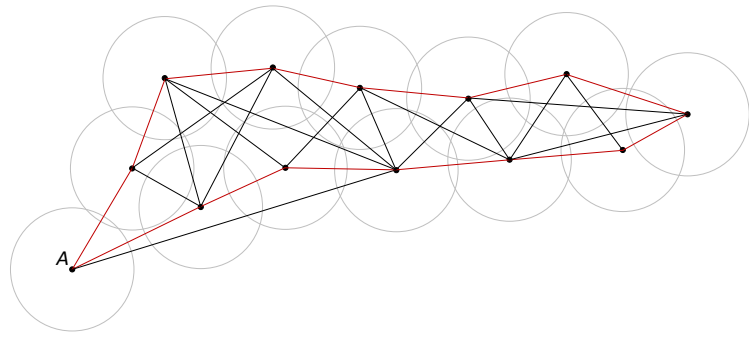
In essence, the authors considered an approach related to determining the projections of floor-mounted process equipment onto the plane in which the UAV moves. With the development of technologies and the establishment of opportunities for safe data collection with violation of the safe flight zone

⁶ In general, in this case, an algorithm for not including arcs in the graph under a certain restriction can be used. We will not consider this problem within the framework of this (conceptual) work.





Pic. 5. Covering control points with circles of equal radius (even neck) [performed by the authors].



Pic. 6. Graph selection for flying around an even neck and route [performed by the authors].

(see Pic. 2), for example, to obtain accurate data on the visibility of signals or the technical condition of the structural elements of floor-mounted process equipment, the graph ceases to be located in a plane, and the principles of implementing the flight route are somewhat modified. In this paper, we will not focus the reader's attention on this.

2. Objects of diagnostics and monitoring and data on them

The objects submitted to diagnostics and monitoring, as noted above, are the floor-mounted technological equipment of RARC. Its main defects, distinguishable from the UAV, are listed in Table 1.

In addition to the above-mentioned states of RARC devices, determined during a planned safe flight of the UAV with the collection of primary diagnostic data, it is possible to simplify the maintenance procedures for some types of routine work. The analysis of the instructions for the maintenance of RARC devices, performed by the authors, shows that a number of works can be performed using UAV (naturally, with a clearly defined sequence of actions while ensuring the absolute safety of train traffic).

To one degree or another, some of the actions can be performed using UAV for the following types of work:

- Checking the visibility of signal lights of green luminous stripes and light indicators of traffic lights with incandescent lamps, as well as traffic lights with LED light-optical systems from the track.
- Checking the visibility of the call-on light.
- Checking the visibility of traffic lights along the main tracks from the locomotive level.
- Checking the lamps and LED light-optical systems of traffic lights with emergency power supply (by direct current).
- Checking the implementation and performance control of the automatic block direction change function (main and auxiliary modes) for double-track and multi-track sections.
- Checking the condition of electric drives, turnout sets, external contactors, position locks of the movable core of the frog, wheel-throwing shoe by external inspection, as well as the tightness of the tongue to the stock rail and the movable core of the frog to the guardrail on switches that cannot be switched.
- Checking the condition of the working rod of the movable core of the frog to detect fatigue cracks (except for the working rods of frogs with an external contactor).
- Checking the condition of the insulating elements of track circuits, butt connectors and jumpers at the station.

Table 1

Conditions of floor-mounted RARC devices [performed by the authors]

| Floor-mounted RARC devices | Defects visible from UAV |
|---|---|
| Traffic lights and route signs | Unsealed traffic light head housings, rusty coatings; abnormal condition of the head from the outside; faulty canopies; missing caps on metal masts; head offset relative to brackets and mast; dirty lenses; missing markings; installation dimensions not within specifications; distortions and abnormal vibration effects; proximity to contact wire, etc. |
| Electric switch mechanism | Damage to the insulation of the fittings, point collars, tie strips and turnout spacers; absence of a stake; absence of marking; irregularities in the arrangement; bending of point collars; presence of snow cover on the drive; defects in the drive cover; irregularities in the coupling and drive connections; absence of marking, etc. |
| Choke-transformers | At least one jumper is disconnected from the rail; insulation wear; housing cover is open (bolts are missing); bracket is missing; choke-transformer jumpers are painted to prevent them from short-circuiting when wire is thrown in; choke jumpers and connectors are worn out; insulation damage to jumpers and connectors; location errors; no markings, etc. |
| Level crossing automation devices | Damage to the barrier beam of the auto barrier; structural damage; broken parts; defects in crossing automation shields, etc. |
| Insulating joints | Lack of clearance between the rail base and the upper layer of ballast; contamination of ballast with salts and conductive loads; contamination of water drainage from the floor-mounted RAT; damage to the integrity of the insulating joint gaskets; lack of paint; presence of conditions for the formation of metal shavings, etc. |
| Transformer boxes, track boxes, cable joints, relay cabinets, electric heating control cabinets, etc. | Opening of drawer and box lids or cabinet doors; violation of geometric parameters of arrangement (tilts and distortions); presence of rust; cracks, chips and dents on bodies and lids, fracture or chipping of the lid or body; wear of jumpers and connectors; absence of a peg; absence of markings, etc. |
| Rail connections | Lack of welded or bypass connectors; wear of welded or bypass connectors, etc. |
| Track superstructure | Significant contamination of ballast with fertilizers and oil products |

- Checking the visibility of the lights of barrier and crossing traffic lights when powered by alternating and direct current.

- Checking the impossibility of opening the barrier with the emergency opening button when the barrier alarm is on, without a time delay.

- Checking the operation of the barrier alarm at entrance, exit, route, passage and shunting traffic lights used as barriers (one traffic light per group is checked).

- Checking the condition and operation of automation at pedestrian crossings, checking the visibility of traffic light lights for pedestrians, the serviceability of sound signals.

- External inspection of the overhead signal line.

- Checking the condition of cable boxes.

- Participation in the inspection of intersections of overhead power lines with overhead SIB lines, carried out by employees of the power supply section.

- Checking the condition of the above-ground part of reinforced concrete structures.

- Checking the operation of tunnel (bridge) signalling.

- Checking the operation of the barrier signalling and the visibility of the lights of the barrier traffic lights.

- Checking the condition of the supporting structure and the control device of the control and dimensional devices.

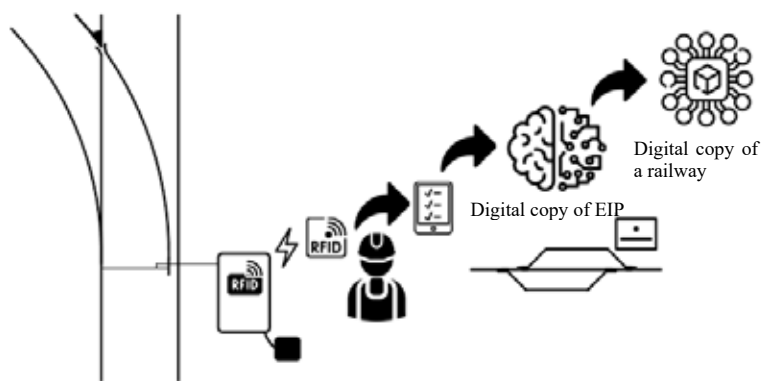
- External inspection of the track boxes containing the floor equipment of the axle counting systems.

It will be important to use UAV in the tasks of checking the presence and correctness of the marking of the floor-mounted process equipment of RARC, including the presence of poles, letter plates of traffic lights, drives, etc.

3. Principles of equipping railway automation facilities with radio frequency tags

In addition to the above-mentioned tasks of technical inspection, collection of data on the state of RARC floor-mounted devices and some maintenance work, when using UAV, it is possible to automate the verification of the





Pic. 7. «Movement» of information in the subsystem for recording data on RARCT facilities [performed by the authors].

timeliness of work performed by operating personnel, and it is also possible to take into account the remaining resource to predict the service life and replacement of equipment. This problem can be solved by using radio frequency identification technology, which is widely used in transport applications [20; 21].

For this purpose, a number of RARC facilities can be equipped with industrial-grade radio-technical tags (RFID tags), which record physical data on the facility, data on all equipment operation indicators (installation date, maintenance procedures performed, replacements, etc.), maintenance work performed (with time stamps and data on the performer) and other information, the consideration of which is advisable when organising the operation process. Such tags should be passive, rewritable (RW type), operating in an ultra-high range to enable long-range identification. The data in the tags fixed to the floor-mounted process facility must be rewritten by the operating personnel upon completion of the scheduled maintenance work (Pic. 7). RARC is equipped with a device for collecting data from RFID tags placed on specific floor-mounted RARC devices. Note that this task is similar to that considered in [22] for collecting data from tags located at specific points along the route, naturally considering the specifics of the location of RARC facilities and the possibility of approaching them under flight safety restrictions.

Not all RARC facilities must be equipped with radio frequency tags, but only the main ones, which include large-sized facilities indicated on the station schematic plan (traffic lights, turnout drives, cable joints, track boxes, choke transformers, relay and battery cabinets, etc.).

For floor-mounted RARCT devices, it is advisable to use a specific system of designations

of radio frequency tags in relation to the types of specific diagnosed objects and to the numbering on the schematic plan, taking into account the known principles of their designation⁷.

Table 2 provides an example of conventional designations of radio frequency tags of the main floor-mounted facilities of RARC. When marking radio frequency tags, the same clear principle is used as when designating RARC facilities on schematic plans. In this case, before the identifier of RARC facility, a designation of the R## type is introduced, where R indicates the type of tags (radio frequency), and the entry ## is a specific two-digit number corresponding to a certain type of devices. After this designation, the identifier of a specific object is indicated through a dot. The last column of Table 2 provides examples in relation to the schematic plan of the station bottleneck, shown in Pic. 2.

The provided system of symbols is used to link specific tags to specific devices in the software of the monitoring system to create a digital diagram of EIP indicating the parameters of the floor-mounted process equipment, the consideration of which is advisable during their operation. Such a system allows for automatic analysis of the operation of RARC equipment, forecasting changes in operation, assessing the remaining resource, generating roadmaps for unscheduled maintenance and repairs, as well as promptly updating data when receiving it from a UAV or rewriting it into tags.

Receiving data from radio frequency tags of floor-mounted RARC equipment, the UAV can

⁷ Sapozhnikov, V. V., Kokurin, I. M., Kononov, V. A., Lykov, A. A., Nikitin, A. B. Operational principles of automation and remote control. Moscow, Training and methodical centre for education on railway transport, 2006, 247 p. ISBN 5-89035-360-8.

Table 2

Conventional designations of radio frequency tags for floor-mounted process equipment of RARC [performed by the authors]

| Device type | Marking | Examples |
|--|---------|---------------------------|
| Electric switch mechanism | R01.### | R01.002, R01.004 |
| Traffic lights and route signs | R02.### | R02.CH, R02.M2 |
| Equipment for crossings | R03.### | R03.A, R03.B |
| Relay and battery cabinets | R04.### | R04.UZP, R04.APS |
| Elements of track circuits | R05.### | R05.TYA4-6_1, R05.DT16-KT |
| Elements of cable networks | R06.### | R06.P4, R06.C2 |
| Other floor-mounted facilities of RARC | R##.### | – |

transmit data to corporate cloud storages with subsequent integration into digital copies of stations, sections and entire railway lines for accounting in the «cyberspace of the railway system» and, ultimately, the use of objective data on the means of safe train traffic control with the support of the decisions of the train dispatcher. In this sense, the set of tools for obtaining data in digital twins of railways is expanded and, consequently, the possibility of their more complete consideration in the tasks of reliable rational train traffic control is created.

Pic. 8 shows a simplified architecture of the monitoring system, in which peripheral objects are highlighted – essentially, the railway infrastructure and, directly, the floor-mounted process equipment of RARC and its components. The architecture is shown in intuitive notations. Unlike traditional solutions, for example, the automated system of technical diagnostics and monitoring «Hardware and software complex of dispatch control» [7; 8], the presented solution uses a corporate cloud storage, allowing access to data of a secure intelligent analytics platform, which, in turn, allows the formation of digital copies of EIP and a railway as a whole based on data from external monitoring systems.

Separately, we can talk about such issues as the possibility of organising the collection of diagnostic data using UAV from other facilities of the railway infrastructure (tracks, contact network, artificial structures). In addition, in the future, it is possible to implement the function of online processing of diagnostic information with automatic linking with decision support systems for the operational personnel of the traffic service. This will allow considering emerging defects in the processes of organising and managing train traffic. A useful function could be the linking of UAV software for flight control with data from the centralised dispatching

system, which simplifies the task of choosing the flight time and carrying out measurement procedures considering the real train situation. However, this technical solution seems to be a relatively distant prospect.

CONCLUSION

In our opinion, a third tool should be added to two existing main tools for obtaining data on RARC devices. To routine maintenance by signalling and interlocking station personnel and automated diagnostics and monitoring tools a data collection tool using UAV should be added. UAV do not only automate part of the work on servicing railway automation and control systems but also improve the principles of quality control of the work performed by signalling and interlocking station personnel; they allow for the prompt collection and analysis of an additional «layer» of diagnostic data that modern monitoring systems are unable to obtain. The availability of «additional» data, if used correctly and with intelligent analytics, will ultimately improve the efficiency of operation of RAT devices. It should be noted that it is necessary to correctly select measuring equipment with the required characteristics (the authors did not try to solve this problem in their study).

We should also note that many studies raise the issue of creating low-maintenance RARC devices. However, they are not isolated from the destabilising effects of the environment: all RARC facilities lose their functionality over time. And here the technologies that allow to timely determine the conditions of damage development and their transition to failures come to the fore. The ideal option would be the implementation of devices with controllable and self-checking structures, which can be done only for certain classes of devices and with respect to specified models of faults [6]. Additional



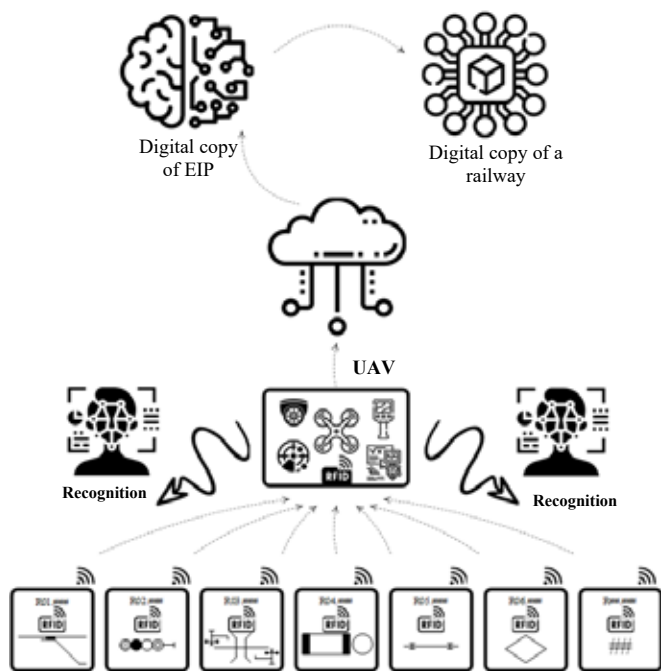


Fig. 8. Simplified architecture of a monitoring system integrated with a digital copy of the electrical interlocking of switches and signals and a railway [performed by the authors].

equipping of RARC devices with automated monitoring tools, as well as data collection using UAV, allows to significantly expand the volume of objective data on the objects in operation⁸. This, in turn, when using intelligent analysis tools, allows to promptly process large volumes of data, developing recommendations for maintaining the fault tolerance and safety of RARC devices.

In conclusion, it should be noted that monitoring data, including from UAV, when ensuring a given level of their reliability and safety, should be taken into account in feedback circuits when developing control actions to ensure the train traffic. And here we are talking not only about RARC tools, but about railway infrastructure facilities as a whole. The development of railway transport will certainly follow the path of gradual integration of automated diagnostics and monitoring tools, both stationary and portable (on mobile units, laboratory cars, UAV, etc.), which will allow us to reach a qualitatively new level of safety for

⁸ It should be noted that it is important to consider the economic issue of improving monitoring technologies and for each individual section, taking into account factors of increasing social significance, indicators of train traffic safety and reducing labour costs for maintenance, to preliminarily calculate and evaluate economic indicators.

the entire transportation process [23–25]. Further closer integration of railway infrastructure, rolling stock, and operational control apparatus will facilitate the creation of intelligent dispatch control systems capable of automatically responding to deviations in operating parameters from specified indicators (due to both infrastructure and rolling stock defects and disruptions in train schedules) and will allow the creation of a self-regulating transport system.

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