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Technical and economic justification of the use of multirotors for monitoring railway infrastructure

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Abstract. Objective: To research the economic feasibility of creating an experimental model of an electric-powered multirotor unmanned aerial vehicle (UAV) for monitoring the technical condition of railway infrastructure. **Methods:** Statistical method, analysis, synthesis, inductive method, system approach, comparative method. Result: This article presents the technical and economic justifications for the effectiveness of the development and implementation of electric-powered multirotor UAVs to improve the quality of monitoring the technical condition of railway infrastructure. The methodology of planned tests is provided, along with the undeniable advantages, drawbacks, and ways to eliminate them. The advantages of UAVs over analogues and their application areas are formulated. **Practical significance:** The obtained results can be used for monitoring railway infrastructure and for further developments in the automation of control and information gathering in the transport sector.

1 Introduction

Unmanned aerial vehicles are increasingly prioritized over human involvement in activities where quality control, continuous information transmission, object monitoring, research, and other tasks are crucial. Recent technological developments, especially those related to sensors, have sparked interest in UAVs. [1] It cannot be denied that UAVs offer numerous advantages in terms of time [2] and labor costs, as well as the elimination of human error. There is a compelling need for technical specialists to develop and implement UAVs with unlimited flight time for continuous observation and maximum task execution at minimal costs, aligning with innovation imperatives and opening new economic opportunities [3, 4].

Modern UAVs trace their roots back to the development of aerial torpedoes nearly 95 years ago. Efforts continued during the Korean War, with military services experimenting with missions, sensors, and munitions to provide combat and reconnaissance support. In the modern era, the development of UAVs can be traced back to World War I. The interwar period, World War II, and subsequent years ultimately led to the development of cruise missiles, such as the Harpoon and Tomahawk, aerial targets, and the current family of UAVs. UAVs have the capability to provide real-time information to the operator.

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2 Methods and materials

To address this issue, it is proposed to create and test an experimental model of an innovative multirotor UAV with electric propulsion characterized by unlimited flight time under laboratory conditions.

The innovative UAV is proposed to be used for continuous monitoring of the technical condition of railway infrastructure, including the timely detection of faults in the contact network, locomotive electrical equipment, railway tracks, buildings and structures, as well as monitoring the ecological situation and conducting counter-terrorism measures, control of security zones. These factors play a significant role in ensuring the safety of railway transportation [5, 6].

The high cost and capital intensity of railway infrastructure require the development of specific mechanisms to ensure its quality and timely maintenance, repair, modernization, and development with the involvement of the state and private investors [7], taking into account the methods of artificial intelligence using deep learning of defects [8].

A distinguishing feature of the new UAV is the use of a ring electric winding firmly attached to the UAV, which allows for the generation of induced EMF during the UAV's flight in an electromagnetic field created by the traction current in the contact wire of the alternating current network or currents in overhead power lines. According to Maxwell's laws, the presence of the ring winding in a variable magnetic field contributes to the appearance of an induced electromotive force (EMF), which causes currents to flow in the ring winding, allowing the charging of the battery during the UAV's flight [9].

3 Results

The use of UAVs for continuous monitoring allows for the timely detection of faults [10] or intruders with minimal costs, enabling the prompt rectification of defects or the implementation of other measures to ensure safe movement.

The utilization of multirotor UAVs to address the aforementioned issues is driven by several factors: simplicity and reliability of the design; compactness and high maneuverability; ability to hover over the monitoring object for obtaining more detailed and high-quality images; capability for vertical takeoff to address tasks in locations with limited or no runway space; advantageous payload-to-takeoff weight ratio (enabling the installation of additional monitoring and diagnostic equipment for pre-fault conditions of the contact network and track infrastructure); ability to capture videos of objects; high stability and relatively low cost.

In addition to the undeniable advantages, multirotor UAV complexes have certain drawbacks, one of which is the limited flight radius (flight time) due to the small capacity of the battery, resulting in the need for the UAV to return to base for recharging.

There are various methods to increase flight duration. One approach is to increase the battery capacity, but this is not always applicable, as it leads to an increase in the UAV's weight. Another solution is to use propellers with variable pitch angles, which requires special equipment for controlling the propeller position and a unique propeller design, resulting in more complex construction, reduced reliability, and worsened dimensional specifications. Another idea for enhancing flight duration is the installation of photovoltaic converters on the UAV, which convert photon energy into electrical energy to charge the battery, but this method is only effective during daylight hours.

In addition, to increase the overall flight duration, the idea of creating intermediate recharging or battery replacement bases - drone ports, has been proposed. However, this method requires the design, production, and placement of separate facilities for recharging/replacing batteries, which increases the cost of monitoring, establishment of a

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security zone around the drone port and regular technical maintenance. Is this method necessary?

For the continuous monitoring of infrastructure objects in railway transportation and other listed issues using multirotor UAVs, the following solutions are proposed by the authors:

1) Application of a contactless battery charging method to increase the duration of continuous operation without returning to the base;

2) Development of technical solutions and installation of additional charging stations for UAV battery charging at traction substations and other power facilities.

To achieve the set goal, the following tasks are addressed:

1) Providing on-board battery charging during UAV flights using the induction method to transfer energy from the electromagnetic field of the contact network and/or high-voltage air power lines (AC or DC);

2) Providing on-board battery charging during UAV flights through the use of additional charging stations [11] installed at secured railway infrastructure sites, in case of additional time appearing in the train schedule.

To address these tasks, the authors propose equipping the UAV with an additional loop winding (coil) for contactless battery charging using the induction method, harnessing the energy of the electromagnetic field of the contact network and/or high-voltage air power lines (AC or DC). The use of this additional winding will enable the battery charging during UAV flight near the source of the electromagnetic field, thereby extending the duration of continuous flight.

In the absence of the possibility of contactless charging [12] of UAV batteries, as explained above, a method for charging the batteries at specialized charging stations without the need to return to the base has been proposed.

The expected main users of our UAV are presumed to include:

- The infrastructure of Russian Railways (RZD) on electrified railway sections, due to the significant impact of quality and timely diagnostics and identification of pre-fault conditions in the contact network and electrical equipment, as well as the potential for monitoring railway infrastructure in adverse or inaccessible conditions, law enforcement and protection of buildings and structures;
- Energy companies, due to the ability to conduct diagnostics of high-voltage air power lines, control clearing of high-voltage corridors, tree cutting, including in remote and inaccessible areas;
- Search operations [13], as a result of continuous monitoring of artificial objects, monitoring of fire hazardous situations in specific regions, monitoring of floods, landslides, avalanches, and other hazardous natural phenomena;
- Ministry of Interior, where the innovative UAV can facilitate tracking and results of investigative actions, inspection of incident scenes, obtaining evidence, and perimeter control of objects;
- Environmental protection, through the organization of monitoring of landfills, protection of subsoil, forests, river basins [14], control of protected resources, and fishing activities;
- Border control, with the organization of continuous monitoring of border areas for unauthorized crossings, protection of objects, and reconnaissance activities.

4 Discussion

The economic feasibility of implementing the developed UAV implies a reduction in the magnitude of losses from train delays on the section due to the rupture of the contact wire, particularly from icing. The data studied by the authors from the Oktyabrskaya Railway, taking into account the average annual refinancing rates of the Central Bank of Russia,

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indicated estimated losses as of the end of 2023 in terms of downtime per hour, as presented in Table 1.

The sustainability of the growth of productive forces and the provision of economic security to the country depend on the implementation of competitive innovative technologies in transportation systems. [15]

Table 1. Losses due to downtime of the Oktyabrskaya railway, rubles per 1 hour

Type of rolling stock	Amount of loss
Electric train "Sapsan"	26455
Electric train "Lastochka"	7737
Commuter electric trains	5524
Long-distance trains	4451
Freight trains	4648
Total	48815

Considering that the minimum passing interval for electric trains is 8 minutes => 7 trains per 1 hour, and the average time required to eliminate the fault of the contact wire is 2 hours, using the loss calculation formula (1) we determine their size.

$$P = s \cdot t \cdot n \tag{1}$$

Where, s - the cost of an hour delay of a particular type of train, in rubbles.

t - the delay time, in 1 hour;

n - the number of trains following the stage.

The approximate amount of losses for the delay of trains on the stretch will be:

P=26455·2·1+7737·2·1+5524·2·4+4451·2·2+4648·2·4=167564 rub.

According to the Oktyabrskaya Railway, the average delay in train traffic due to a break in the contact wire for a year is 4 cases on the stretch, with the length of the enterprise's area of responsibility – 240 km.

Applying formula (1), an approximate average annual loss amount of 670,256 (167564*4) rubles was calculated. The estimated cost of the proposed UAV for 2023 is 150 thousand rubles. The result is the calculation of the expected annual economic effect Эг and Economic efficiency Ээф from the introduction of a UAV of a new design, produced according to the formulas (2,3)

$$Э_{Г} = \sum С_i \times Q_i - E_H \times K \tag{2}$$

$$Э_{эф} = \frac{Э_{г}}{Р+К} \times 100\% \tag{3}$$

Where, K - capital expenditures, thousand rubles;

E_H - the standard payback factor, for railway transport $E_н = 13.8$;

C_i - the cost of the “i” component of the economy, thousand rubles;

Q_i - the volume of the “i” component of the economy, thousand rubles.

$Э_г$=167.564·4-0.138·150=649.556 thousand rubles.

$$Э_{эф} = \frac{649.556}{167.564 + 150} \times 100\% = 204.54\%$$

5 Conclusion

Thus, the introduction of unmanned technologies in monitoring railway transport infrastructure allows to obtain an annual economic effect in the amount of 650,006 thousand rubles with high economic efficiency and a payback period of less than six months (0.49 years).

References

1. A. Taame I., Lachkar A., Abouloifa. Modeling of an unmanned aerial vehicle and trajectory tracking control using backstepping approach IFAC-Papers On Line 4 August 2022. https://doi.org/10.1016/j.ifacol.2022.07.324
2. Matt Grote Andrew, Oakey Antonio, Martinez-Sykora. The effects of costs on drone uptake in multi-modal logistics systems within a healthcare setting. Transport Economics and Management 15 March 2022 https://doi.org/10.1016/j.team.2024.03.001
3. L. Kazanskaya, E. Shaykina, E3S Web of Conferences. Key Trends in Transportation Innovation **05007** (2020) https://doi.org/10.1051/e3sconf/202015705007
4. E.S. Palkina, L.F. Kazanskaya, *Innovative imperatives for competitiveness of national transport systems in conditions of globalization. Globalization and its Socio-Economic Consequences*. 16th International Scientific Conference Proceedings. ZU - University of Zilina, 5th -6th October 2016, Rajecke Teplice, Slovak Republic (2016)
5. N.V. Saks, L.F. Kazanskaya, Yu.V. Egorov, *Digitalization as a factor of formation of new economic opportunities under globalization conditions._Globalization and its socio-economic consequences*. 18th International Scientific Conference Proceedings (Part V. – Digital Single Market) (2018) https://doi.org/10.22394/2079-1690-2019-1-2-170-175
6. L. Kazanskaya, S. Rizakulov, International Scientific Siberian Transport Forum TransSiberia - 2021. Switzerland (2022) https://doi.org/10.1007/978-3-030-96380-4_53
7. E. Sivertceva, E3S Web of Conferences **383,** 01009 (2023) https://doi.org/10.1051/e3sconf/202338301009
8. R. Santos D. Ribeiro, R. Calçada, Automation in Construction 10 May 2022 (pp. 2-3). https://doi.org/10.1016/j.autcon.2022.104324
9. C. Conte, G. Rufino, G. de Alteriis, V. Bottino, D. Accardo, Aerospace Science and Technology 3 October (2022) https://doi.org/10.1016/j.ast.2022.107921
10. Clinton Purtell, Seock-Jin, Hong Brian Hiatt, Journal of Air Transport Management 5 March (2024) https://doi.org/10.1016/j.jairtraman.2024.102569
11. Gokula Manikandan, Senthil Kumar, Sunliang Cao, Energy Conversion and Management: X27 February (2024) https://doi.org/10.1016/j.ecmx.2024.100552
12. Chutintorn Somnin, Joseph Chamieh, Hervé Cottet, Taylor dispersion analysis using capacitively coupled contactless conductivity detector Talanta 22 February (2024) https://doi.org/10.3390/s130302786
13. Tri NguyenRisto, KatilaTuan, Nguyen Gia, Future Generation Computer Systems 13 October (2022) https://doi.org/10.1016/j.future.2022.10.002
14. R. J. Francis, R. T. Kingsford, K. J. Brandis, Botswana Global Ecology and Conservation15 July (2022) https://doi.org/10.1016/j.gecco.2022.e02231
15. A. Vorobiev, E. Sivertceva, E3S Web of Conferences **460,** 06039 (2023) https://doi.org/10.1051/e3sconf/202346006039

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