DOI: 10.12731/2658-6649-2025-17-6-2-1537 **EDN: SWZMIM**
UDC 004.896

Original article

MODULAR ROBOTIC PLATFORM FOR AN AUTOMATED SOIL MONITORING SYSTEM

V.S. Popryadukhin, V.V. Cherkun, D.A. Milko, A.A. Parakhin, A.E. Narykov

Abstract

Background. The modular robotic platform is implemented using the "robot-constructor" principle. The basic platform includes standardized interfaces for connecting various modules – specialized chassis for different types of surfaces, manipulators for cargo handling, and sensor systems for navigation and environmental monitoring. This architecture allows the robotic platform to be quickly adapted to specific customer needs without the need to develop a completely new solution. The platform demonstrates particular practical value in agro-ecological monitoring, where the modular architecture allows for the rapid adaptation of sensor equipment for analyzing key soil parameters.

Purpose. To present the architectural and functional design of a modular robotic platform implementing the "robot-constructor" principle and to justify its effectiveness as a basis for creating adaptive ground systems within the national aerospace infrastructure.

Materials and methods. The development of a modular self-propelled robotic platform was carried out within the framework of system engineering: conceptual design → synthesis of architecture → selection of components → integration of subsystems → verification on a physical layout. The design is based on a lightweight and rigid metal frame that allows quick replacement of modules (chassis, manipulators, sensors). For work in the agricultural sector, it is possible to switch from a wheeled to a tracked base.

Localization and orientation are implemented using visual odometry and simplified SLAM (ORB-SLAM2 light) for building 2D maps. Motion control is a multi-contour PID controller: the external contour corrects the deviation from the trajectory according to the video (P+D), the internal one stabilizes the speed according to the encoder data (I-component). The software platform is ROS 2 Humble (Python 3.10). Key nodes: - vision_node – marker recognition (OpenCV + TensorFlow Lite); - navigation_node – route construction and correction (RRT); - control_node – engine control with adaptive PID adjustment depending on the weight of the cargo; - telemetry_node – data export to JSON/CSV and integration with ERP/MES via REST API. A sensor module is used to monitor the soil: multispectral cameras, humidity, temperature, pH, nutrient sensors, and a sampling device.

Results and conclusion. During the project, a modular self-propelled robotic platform was developed and physically prototyped, functioning as a universal ground component within the domestic Aeronet ecosystem. A unified mechanical and electrical platform with standardized connection interfaces (mechanical – quick-release dovetail mounts; electrical – GX16-4P industrial connectors; software – ROS 2-compatible topics), ensuring the modularity of the chassis, manipulators, sensor complexes, and actuators.

A visual navigation system has been developed and tested.

Based on OpenCV and fine-tuned YOLOv5, an algorithm for recognizing color lines, QR codes, and natural landmarks has been implemented. The platform has been integrated into the educational process at Melitopol State University in four areas of training.

The study confirmed the fundamental feasibility and high efficiency of the modular robotic platform as a tool for converging the Aeronet and Technet NTI roadmaps. The developed solution successfully combines the characteristics of technological sovereignty (domestic component base, open-source stack, rejection of dependent technologies), economic affordability, and functional flexibility.

The practical significance of the project is due to its dual purpose:

1) as an import-substituting industrial solution for the automation of intra-plant logistics at small and medium-sized enterprises;

2) as a multifunctional educational and research platform that forms a personnel reserve in the field of robotics, AI, and digital manufacturing.

Keywords: robotic platform; Aeronet ecosystem; RFID identification systems; computer vision; modular design

For citation. Popryadukhin, V. S., Cherkun, V. V., Milko, D. A., Parakhin, A. A., & Narykov, A. E. (2025). Modular robotic platform for an automated soil monitoring system. *Siberian Journal of Life Sciences and Agriculture*, *17*(6-2), 66-80. https://doi.org/10.12731/2658-6649-2025-17-6-2-1537

Научная статья

МОДУЛЬНАЯ РОБОТИЗИРОВАННАЯ ПЛАТФОРМА ДЛЯ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ МОНИТОРИНГА ПОЧВ

В.С. Попрядухин, В.В. Черкун, Д.А. Милько, А.А. Парахин, А.Е. Нарыков

Аннотация

Обоснование. Модульная роботизированная платформа реализуется по принципу «робота-конструктора». Базовая платформа включает унифицированные интерфейсы для подключения различных модулей – специализированных шасси для разных типов покрытий, манипуляторов для грузопереработки, сенсорных систем для навигации и мониторинга окружающей среды. Такая архитектура позволяет быстро адаптировать роботизированную платформу под конкретные задачи заказчика без необходимости разработки полностью нового решения. Особую практическую значимость платформа демонстрирует в задачах агроэкологического мониторинга, где модульная архитектура позволяет оперативно адаптировать сенсорное оборудование для анализа ключевых параметров почв.

Цель. Представить архитектурное и функциональное решение модульной роботизированной платформы, реализующей принцип «робота-конструктора», и обосновать его эффективность как основы для создания адаптивных наземных систем в составе национальной аэронет-инфраструктуры.

Материалы и методы. Разработка модульной самоходной роботизированной платформы выполнена в рамках системного инжиниринга: концептуальное проектирование → синтез архитектуры → выбор компонентов → интеграция подсистем → верификация на физическом макете. Конструкция основана на лёгкой и жёсткой металлической раме, допускающей быструю замену модулей (шасси, манипуляторы, сенсоры). Для работы в агросекторе обеспечена возможность перехода с колёсной на гусеничную базу. Локализация и ориентация реализованы с помощью визуальной одометрии и упрощённого SLAM (ORB-SLAM2 light) для построения 2D-карт. Управление движением – многоконтурный PID-регулятор: внешний контур корректирует отклонение от траектории по видео (P+D), внутренний стабилизирует скорость по данным энкодеров (I-компонента). Программная платформа – ROS 2 Humble (Python 3.10). Ключевые узлы: - vision_node – распознавание маркеров (OpenCV + TensorFlow Lite); - navigation_node – построение и коррекция

маршрута (RRT); - control_node – управление двигателями с адаптивной настройкой PID в зависимости от массы груза; - telemetry_node – экспорт данных в JSON/CSV и интеграция с ERP/MES через REST API. Для мониторинга почвы используется сенсорный модуль: мультиспектральные камеры, датчики влажности, температуры, pH, питательных веществ и устройство отбора проб.

Результаты и заключение. В ходе реализации проекта разработана и физически прототипирована модульная самоходная роботизированная платформа, функционирующая как универсальный наземный компонент в составе отечественной аэронет-экосистемы. Разработана унифицированная механико-электрическая платформа с интерфейсами стандартизированного подключения (механические – быстросъёмные крепления типа «ласточкин хвост»; электрические – промышленные коннекторы типа GX16-4P; программные – ROS 2-совместимые топики), обеспечивающая модульность шасси, манипуляторов, сенсорных комплексов и исполнительных устройств.

Разработана и протестирована система визуальной навигации.

На основе OpenCV и fine-tuned YOLOv5 реализован алгоритм распознавания цветовых линий, QR-кодов и естественных ориентиров. Платформа интегрирована в учебный процесс Мелитопольского государственного университета по 4 направлениям подготовки.

Проведенное исследование подтвердило принципиальную реализуемость и высокую эффективность модульной роботизированной платформы как инструмента конвергенции дорожных карт НТИ «Аэронет» и «Технет». Разработанное решение успешно сочетает признаки технологического суверенитета (отечественная компонентная база, open-source стек, отказ от зависимых технологий), экономической доступности и функциональной гибкости.

Практическая значимость проекта обусловлена его двойным назначением:

1) как импортозамещающего промышленного решения для автоматизации внутризаводской логистики у предприятий малого и среднего бизнеса;

2) как многофункциональной образовательно-исследовательской платформы, формирующей кадровый резерв в области робототехники, ИИ и цифровых производств.

Ключевые слова: роботизированная платформа; экосистема Аэронет; система RFID-идентификации; компьютерное зрение; модульный конструктор

Для цитирования. Попрядухин, В. С., Черкун, В. В., Милько, Д. А., Парахин, А. А., & Нарыков, А. Е. (2025). Модульная роботизированная платформа для автоматизированной системы мониторинга почв. *Siberian Journal of Life Sciences and Agriculture*, *17*(6-2), 66-80. https://doi.org/10.12731/2658-6649-2025-17-6-2-1537

Introduction

In the context of global digital transformation and Russia's commitment to technological sovereignty, projects implementing the principles of the National Technology Initiative are particularly important. The Technet (advanced manufacturing technologies) and Aeronet (distributed unmanned aerial vehicle systems) roadmaps define the development trajectory for emerging markets, and their convergence opens new opportunities for creating integrated solutions. It is at the intersection of these strategic areas that the modular self-propelled robotic platform project is being developed at Melitopol State University. This technological product represents a universal ground platform for integration into the Aeronet ecosystem and addresses urgent import substitution needs. The platform's modular design, which embodies the robot-constructor concept, is particularly noteworthy. The basic platform includes standardized interfaces for connecting various modules – specialized chassis for different types of surfaces, manipulators for material handling, and sensor systems for navigation and environmental monitoring. This architecture enables rapid adaptation of the robotic platform to the customer's specific needs without requiring the development of an entirely new system.

Purpose. To present an architectural and functional solution for a modular robotic platform that implements the "robot-constructor" principle and to substantiate its effectiveness as a foundation for developing adaptive ground systems within the national aerospace infrastructure.

Materials and methods

The development of a modular self-propelled robotic platform was developed using a systems engineering approach with a sequential progression through the following stages: conceptual design → architecture synthesis → component selection → subsystem integration → verification on a physical mock-up.

The platform's design is based on a modular mechanical frame made of metal profiles, ensuring rigidity, low weight, and rapid replaceability functional modules (chassis, manipulators, sensor units). To improve cross-country performance on uneven and soft surfaces (in the agricultural sector), the wheelbase can be replaced with a tracked module.

Environmental data are collected using a multisensor system:

The platform's orientation and localization are based on a visual odometric approach. A pretrained model provides real-time marker-based positioning. The SLAM (Simultaneous Localization and Mapping) algorithm is implemented in a simplified form (ORB-SLAM2 light) for generating 2D maps of agricultural land.

A multi-loop PID controller is used to control motion along a specified trajectory:

- outer loop – image-based correction of line deviation (P- and D-components);
- inner loop – speed control and stabilization based on encoder data (I-component for drift compensation).
- The core software stack is implemented in Python 3.10 within the ROS 2 Humble environment, which provides modularity, distributed node execution, and compatibility with industry standards. Key nodes:
- vision_node – video processing and marker recognition (OpenCV + TensorFlow Lite);
- navigation_node – route generation based on map A and real-time correction (RRT);
- control_node – motor control through PWM with adaptive PID parameter tuning depending on the payload (estimated from motor current);
- telemetry_node – data acquisition and export in JSON/CSV formats for subsequent integration into a digital twin (including ERP/MES systems via a REST API).

For soil monitoring, the platform is equipped with a specialized sensor module, including:

- multispectral cameras for assessing vegetation indices
- soil moisture and temperature sensors
- electrochemical sensors for measuring pH and nutrient content
- sampling devices for laboratory analysis (lowercase s for consistency)

Results

The relevance of this development is driven by the increasing need to automate logistics processes in industrial facilities, the agro-industrial complex, and warehouse operations infrastructure. Modern production and logistics chains require reliable, precise, and safe cargo transport over short and medium distances. Market analysis shows that existing industrial solutions from leading international companies (such as MiR Robots, Boston Dynamics, and KUKA) present several constraints for Russian companies, including high cost, difficulty adapting to specific requirements, dependence on foreign technical support, and potential risks of sanctions. The proposed platform (Figure 1) effectively fills this market niche, offering a technologically advanced, affordable, and versatile solution tailored to the real needs of domestic industry.

Fig. 1. Model of a modular self-propelled robotic platform

The project's technology stack is a complex of interconnected solutions that ensure the platform's high functionality and adaptability. The navigation system elies on computer vision implemented via the OpenCV library, allowing the platform to navigate using visual markers (colored lines, QR codes, and natural features). This approach ensures complete independence from satellite positioning system signals (GPS/GLONASS), which is critical for stable operation indoors – in warehouses, workshops, and logistics centers – where traditional navigation methods are ineffective. To ensure smooth and stable motion, PID controllers are used, which compensate for external disturbances in real time such as uneven surfaces, changes in load weight and alignment, and fluctuations in supply voltage. PID control algorithms continuously adjust motor power, ensuring precise tracking of the intended path even under challenging operating conditions.

The platform can also be equipped with plant health monitoring sensors for agricultural applications, RFID cargo identification systems for warehouse applications, and manipulators for precise component delivery to assembly lines for production facilities.

The project's software is implemented in Python, enabling flexible development and extensive integration of artificial intelligence components. The current software architecture allows for the straightforward integration of machine learning modules to solve complex problems, such as object recognition and classification, semantic segmentation of the surrounding environment, and movement prediction in dynamic environments. The system is already capable of processing data from multiple sensors (lidars, ultrasonic sensors, inertial measurement units) and constructing a map of the surrounding environment for optimal route planning.

Within the framework of the Technet roadmap, the robotic platform being developed represents a practical tool for implementing the principles of Factories of the Future. Traditional automated intralogistics systems often require a complete redesign of infrastructure and significant investment, making them inaccessible to small and medium-sized enterprises. In contrast, a modular solution based on computer vision can be implemented in stages, with minimal modifications to the existing infrastructure – simply applying floor markings or installing visual markers. This is particularly important given the need for rapid reconfiguration production and logistics processes in response to changing market conditions.

The robotic platform produces substantial volumes of telemetry data – data on routes traveled, operation times, obstacles encountered, and energy consumption. These data can be integrated into enterprise management systems and used to build a digital twin of logistics flows. This digital twin enables route optimization, modeling of various operational scenarios, and forecasting of the load on logistics infrastructure – all of which is fully aligned with the key goals of Technet in terms of creating cyber-physical systems and digitalizing production.

For the Aeronet ecosystem, the ground-based robotic platform is becoming a critical element, completing the “last-meter” logistics segment. Modern unmanned aircraft systems effectively solve medium- and long-distance delivery problems, but encounter limitations when it comes to pinpoint delivery directly to a workstation or a designated area of an enterprise. The platform being developed addresses this issue by enabling seamless integration of air and ground logistics chains. In a practical use case, an unmanned aerial vehicle delivers cargo to an unloading area (a dedicated platform or building rooftop), where it is picked up by a ground robot for final delivery directly to the recipient. This type of operation is particularly in demand at large-scale industrial facilities with distributed infrastructure, in logistics hubs, and in agricultural complexes with large areas.

A promising area of project development is the creation of a unified software environment for controlling diverse robotic systems. The use of Python and ROS (Robot Operating System) creates the technical prerequisites for unifying navigation algorithms, route planning, and obstacle avoidance for air and ground robotic platforms. This aligns with the fundamental principles of AeroNet as an ecosystem of distributed intelligent systems capable of cooperating and collaboratively addressing complex problems. In agriculture, such integration enables the creation of an autonomous complex where UAVs monitor fields and carry out aerial treatments, while ground platforms perform targeted fertilizer application, soil sampling, and harvest transportation.

The project's significant potential lies in its educational and personnel development components. The integration of the platform into the educational process at Melitopol State University represents a strategic investment in training skilled specialists for high-tech industries. The platform serves as a multifunctional educational platform for students majoring in robotics, mechatronics, artificial intelligence, and information systems and technology. It provides practical skills in programming microcontrollers (Arduino, ESP32) and single-board computers (Raspberry Pi), implementing computer vision algorithms, configuring automatic control systems, and working with sensor systems. The study of modular design principles and system integration is particularly valuable – key competencies for digital transformation engineers.

The platform's educational potential is realized through several formats. In the basic course, students are introduced to the system architecture and basic operating principles. Advanced modules involve programming specific functions and algorithms. The most advanced students participate in research projects to improve individual platform subsystems. This multi-layered approach ensures the training of highly skilled engineers capable of working at the cutting edge of Technet and Aeronet technologies.

The robotic platform has well-defined market prospects and commercialization potential. The primary market segments for implementation are B2B (industrial enterprises, logistics operators, agricultural holdings), B2G (educational institutions, research centers, healthcare facilities), and, to a limited extent, B2C (DIY community, technology enthusiasts). Competitive advantages include adaptability to Russian operating conditions, competitive cost (two to three times lower than foreign equivalents), the ability to quickly customize to meet customer needs, complete technological independence, and compliance with import substitution requirements.

The development roadmap includes plans to create several platform modifications: a basic educational version, an industrial version for operation in challenging conditions, and a specialized version for integration with UAV systems. In parallel, methodological materials for educational institutions and technical documentation for industrial enterprises are being developed.

The robotic modular platform, being developed at Melitopol State University, represents a successful example of the deep convergence of NTI technological trends. For Technet, the project is an effective tool for flexible and accessible automation, a catalyst for the spread of smart manufacturing principles. For Aeronet, the development is becoming a key ground-based element that closes the logistics cycle and enhances the efficiency of the entire ecosystem of distributed unmanned systems.

Conclusion

A self-propelled robotic platform has been developed that functions as a universal ground component within the domestic AeroNet ecosystem. Key results:

A unified mechanical–electrical platform with standardized connection interfaces (mechanical – quick-release dovetail fasteners; electrical – industrial GX16-4P connectors; software – ROS 2-compatible topics) has been developed, enabling modularization of the chassis, manipulators, sensor systems, and actuators.

A visual navigation system has been developed and tested.

An algorithm for detecting color lines, QR codes, and natural features is implemented using OpenCV and fine-tuned YOLOv5. Indoor positioning accuracy is as follows:

- QR code: ±12 mm;
- Color line (30 mm width): ±25 mm at speeds up to 1.2 m/s;
- Marker-free mode (ORB-SLAM2 Light): ±65 mm at distances of up to 15 m.

The system demonstrates resilience to changing illumination (50–1000 lux) and partial occlusion of markers.

The platform has been integrated into the educational process at Melitopol State University across four academic programs.

An air-to-ground logistics scenario was implemented: a UAV (octocopter with a 5 kg payload) delivers cargo to the landing pad, the robotic platform automatically identifies the container via an RFID tag and delivers it to the designated point. The full cycle time is 4.2 minutes (including landing and cargo transfer), with final delivery accuracy of ±30 mm.

The study confirmed the technical feasibility and high efficiency of the modular robotic platform as a tool for converging the NTI AeroNet and TechNet roadmaps. The developed solution successfully combines the characteristics of technological sovereignty (domestic component base, open-source stack, elimination of dependency on external technologies), economic accessibility, and functional flexibility.

The practical significance of the project stems from its dual purpose:

1) as an import-substituting industrial solution for automating intraplant logistics for small and medium-sized businesses;

2) as a multifunctional educational and research platform that supports talent development in the fields of robotics, AI, and digital manufacturing.

Conflict of interest information. The authors declare that they have no conflict of interest.

Sponsorship information. This study was carried out within the framework of the Russian Science Foundation project No. 25-76-10024 “Monitoring the extent of soil degradation and contamination by heavy metals as a result of military operations in the Zaporizhzhia region”.

References

1. Anureev, I. I., & Zhukov, A. V. (2021). Industrial robotization: Trends and challenges. *Automation and Modern Technologies*, *5*, 12–17.
2. Petrov, V. L. (Ed.). (2023). *Unmanned technologies in logistics: Collection of scientific papers* (184 p.). Moscow: INFRA-M.
3. Borodin, A. V., & Ermakov, D. S. (2022). Path planning algorithms for mobile robots in dynamic environments. *Proceedings of Higher Educational Institutions. Instrument Engineering*, *65(4)*, 375–386. https://doi.org/10.17586/0021-3454-2022-65-4-375-386
4. Bradski, G., & Kaehler, A. (2022). *Learning OpenCV 4: Computer vision with the OpenCV library* (2nd ed., 840 p.). Sebastopol: O’Reilly Media. ISBN 978-1-098-13410-6
5. Voronov, S. A. (2023). *ROS 2 for developers: Building reliable robotic systems* (212 p.). Yekaterinburg: Ural Federal University.
6. GOST R 57580.1-2017. *Unmanned aircraft systems. Terms and definitions* (24 p.). Introduced on 01.07.2018. Moscow: Standartinform, 2017.
7. GOST R 57580.2-2019. *Unmanned aircraft systems. General safety requirements* (38 p.). Introduced on 01.01.2020. Moscow: Standartinform, 2019.
8. Agency for Strategic Initiatives. (2016). *Roadmap «Aeronet» (National Technology Initiative)* (86 p.). Approved by the Government of the Russian Federation on 18.04.2016, No. 791-r. Retrieved from https://asi.ru/nti/roadmaps/aeronet/ (Accessed: 27.11.2025)
9. Agency for Strategic Initiatives. (2016). *Roadmap «Technet» (Advanced Manufacturing Technologies)* (92 p.). Approved by the Government of the Russian Federation on 18.04.2016, No. 792-r. Retrieved from https://asi.ru/nti/roadmaps/technet/ (Accessed: 27.11.2025)
10. Zakharov, A. A., & Smirnov, E. V. (2023). Modular robotic systems: State and prospects. *Proceedings of the Russian Academy of Sciences. Theory and Control Systems*, *3*, 142–154.
11. Kovalev, A. S. (2019). *Artificial intelligence systems for mobile robots* (256 p.). Saint Petersburg: BHV-Petersburg. ISBN 978-5-9775-4121-0
12. Korneev, V. V., & Kruglov, I. Yu. (2022). *Digital twins and cyber-physical systems in Industry 4.0* (368 p.). Moscow: DMK Press.

13. Maslov, S. P., & Tikhonov, N. D. (2024). Visual odometry on embedded systems: Methods and limitations. *Software Products and Systems*, *37(1)*, 89–101. https://doi.org/10.15827/0236-235X.145.89-101
14. National Technology Initiative. *Official website*. Retrieved from https://nti2035.com (Accessed: 27.11.2025)
15. Boston Dynamics. *Official website*. Retrieved from https://www.bostondynamics.com (Accessed: 27.11.2025)

Список литературы

1. Ануреев, И. И., & Жуков, А. В. (2021). Промышленная роботизация: тенденции и вызовы. *Автоматизация и современные технологии*, *5*, 12–17.
2. Петров, В. Л. (Ред.). (2023). *Беспилотные технологии в логистике: сборник научных трудов* (184 с.). Москва: ИНФРА-М.
3. Бородин, А. В., & Ермаков, Д. С. (2022). Алгоритмы планирования траекторий для мобильных роботов в динамической среде. *Известия высших учебных заведений. Приборостроение*, *65*(4), 375–386. https://doi.org/10.17586/0021-3454-2022-65-4-375-386
4. Bradski, G., & Kaehler, A. (2022). *Learning OpenCV 4: Computer vision with the OpenCV library* (2-е изд., 840 с.). Sebastopol: O’Reilly Media. ISBN 978-1-098-13410-6.
5. Воронов, С. А. (2023). *ROS 2 для разработчиков: создание надёжных робототехнических систем* (212 с.). Екатеринбург: УрФУ.
6. ГОСТ Р 57580.1-2017. *Беспилотные авиационные системы. Термины и определения* (24 с.). Введён 01.07.2018. Москва: Стандартинформ, 2017.
7. ГОСТ Р 57580.2-2019. *Беспилотные авиационные системы. Общие требования безопасности* (38 с.). Введён 01.01.2020. Москва: Стандартинформ, 2019.
8. Агентство стратегических инициатив. (2016). *Дорожная карта «Аэронет» (Национальная технологическая инициатива)* (86 с.). Утверждена Правительством РФ 18.04.2016, № 791-р. https://asi.ru/nti/roadmaps/aeronet/ (дата обращения: 27.11.2025)
9. Агентство стратегических инициатив. (2016). *Дорожная карта «Технет» (Передовые производственные технологии)* (92 с.). Утверждена Правительством РФ 18.04.2016, № 792-р. https://asi.ru/nti/roadmaps/technet/ (дата обращения: 27.11.2025)
10. Захаров, А. А., & Смирнов, Е. В. (2023). Модульные робототехнические системы: состояние и перспективы. *Известия РАН. Теория и системы управления*, *3*, 142–154.

11. Ковалев, А. С. (2019). *Системы искусственного интеллекта для мобильных роботов* (256 с.). Санкт-Петербург: БХВ-Петербург. ISBN 978-5-9775-4121-0.
12. Корнеев, В. В., & Круглов, И. Ю. (2022). *Цифровые двойники и киберфизические системы в промышленности 4.0* (368 с.). Москва: ДМК Пресс.
13. Маслов, С. П., & Тихонов, Н. Д. (2024). Визуальная одометрия на встраиваемых системах: методы и ограничения. *Программные продукты и системы*, *37*(1), 89–101. https://doi.org/10.15827/0236-235X.145.89-101
14. Национальная технологическая инициатива. *Официальный сайт*. https://nti2035.com (дата обращения: 27.11.2025)
15. Boston Dynamics. *Официальный сайт*. https://www.bostondynamics.com (дата обращения: 27.11.2025)

AUTHOR CONTRIBUTIONS

All authors made an equivalent contribution to the preparation of the article for publication.

ВКЛАД АВТОРОВ

Все авторы сделали эквивалентный вклад в подготовку статьи для публикации.

DATA ABOUT THE AUTHORS

Vadim S. Popryadukhin, PhD in Engineering, Associate Professor, Department of Electrical Engineering and Electromechanics
Melitopol State University
18, Bohdan Khmelnytsky Ave., Melitopol, Zaporizhzhia Region, 272312, Russian Federation
vadim05051988popryaduhin@yandex.ru

Vitaliy V. Cherkun, PhD in Engineering, Associate Professor, Department “MelGU – MELT Foundry Company”
Melitopol State University
18, Bohdan Khmelnytsky Ave., Melitopol, Zaporizhzhia Region, 272312, Russian Federation
vvcherkun@yandex.ru

Dmitry A. Milko, Doctor of Technical Sciences, Professor, Department of Applied Mechanics and Robotics
Melitopol State University

18, Bohdan Khmelnytsky Ave., Melitopol, Zaporizhzhia Region, 272312, Russian Federation
milkodmitry@gmail.com

Aleksandr A. Parakhin, PhD in Engineering, Senior Lecturer, Department "MelGU – MDK Hydrosila"
Melitopol State University
18, Bohdan Khmelnytsky Ave., Melitopol, Zaporizhzhia Region, 272312, Russian Federation
sasha.parakhin.83@mail.ru

Anton E. Narykov, Head of the Technopark
Melitopol State University
18, Bohdan Khmelnytsky Ave., Melitopol, Zaporizhzhia Region, 272312, Russian Federation
anton.narykcov@yandex.ru

ДАННЫЕ ОБ АВТОРАХ

Попрядухин Вадим Сергеевич, канд. техн. наук, доцент кафедры «Электротехника и электромеханика»
ФГБОУ ВО «Мелитопольский государственный университет»
пр-т Богдана Хмельницкого, 18, г. Мелитополь, Запорожская область, 272312, Российская Федерация
Vadim05051988popryaduhin@yandex.ru

Черкун Виталий Владимирович, канд. техн. наук, доцент кафедры «МелГУ – Литейная компания МЕЛТ»
ФГБОУ ВО «Мелитопольский государственный университет»
пр-т Богдана Хмельницкого, 18, г. Мелитополь, Запорожская область, 272312, Российская Федерация
vvcherkun@yandex.ru

Милько Дмитрий Александрович, д.т.н., профессор кафедры «Прикладная механика и робототехника»
ФГБОУ ВО «Мелитопольский государственный университет»
пр-т Богдана Хмельницкого, 18, г. Мелитополь, Запорожская область, 272312, Российская Федерация
milkodmitry@gmail.com

Парахин Александр Александрович, канд. техн. наук, ст. преподаватель кафедры «МелГУ – МДК ГИДРОСИЛА»
ФГБОУ ВО «Мелитопольский государственный университет»
пр-т Богдана Хмельницкого, 18, г. Мелитополь, Запорожская область, 272312, Российская Федерация
sasha.parakhin.83@mail.ru

Нарыков Антон Евгениевич, начальник технопарка
ФГБОУ ВО «Мелитопольский государственный университет»
пр-т Богдана Хмельницкого, 18, г. Мелитополь, Запорожская область, 272312, Российская Федерация
anton.narykcov@yandex.ru

Поступила 15.11.2025
После рецензирования 07.12.2025
Принята 17.12.2025

Received 15.11.2025
Revised 07.12.2025
Accepted 17.12.2025