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Neural Network Control Systems For Mobile Robots On EDGE Platforms For Industry 5.0

Vladyslav Yevsieiev
ORCID 0000-0002-2590-7085
Department of Computer Integrated Technologies, Automation, Robotics and Safety Engineering
Kharkiv National University of Radio Electronics
Kharkiv,Ukraine
vladyslav.yevsieiev@nure.ua

Nataliia Demska
ORCID 0000-0002-9931-9964
Department of Computer Integrated Technologies, Automation, Robotics and Safety Engineering
Kharkiv National University of Radio Electronics
Kharkiv, Ukraine
nataliia.demska@nure.ua

Abstract — **The paper considers an approach to building a neural network control system for mobile robots based on EDGE platforms for Industry 5.0 applications. An architecture combining Raspberry Pi and ESP32 is proposed for local collection, processing and analysis of sensor information, execution of compact neural networks and decision-making in real time without the use of cloud services. The developed system provides integration of modules for environmental assessment, route planning and adaptive motion control, which allows to increase the autonomy, response speed and reliability of mobile robots in dynamic production environments. The results obtained confirm the prospects of using EDGE computing and compact neural networks for creating intelligent robotic systems of the new generation.**

Keywords — Industry 5.0, mobile robot, EDGE computing, neural networks, Raspberry Pi, ESP32, autonomous navigation, intelligent control, cyber-physical systems, robotic control systems

I. INTRODUCTION

In the current conditions of the development of the Industry 5.0 concept, the creation of intelligent mobile robots capable of autonomously performing tasks in a dynamic production environment without constant connection to cloud services is of particular importance [1,2]. The use of EDGE platforms allows transferring the processing of sensory information and decision-making directly to the board of the robotic system, which ensures the minimization of data transmission delays, increased reliability of operation and reduced dependence on external network infrastructure [3]. At the same time, the development of compact neural networks creates the prerequisites for the implementation of complex algorithms for computer vision, navigation and prediction directly on low-power computing devices, such as Raspberry Pi and ESP32, which makes this area of research one of the most relevant for modern robotics and cyber-physical systems [4].

Let us analyze the latest publications within the framework of this study.

In the article, Minghui Wang, Yuchao Niu and co-authors proposed a comprehensive review of modern learning methods for motion planning and control of mobile robots, focused on the implementation of the concept of embodied intelligence, which investigated the use of deep learning, reinforcement learning and neural network approaches for autonomous navigation and interaction with the environment [5]. The proposed approach allows to increase the adaptability of mobile robots to complex and uncertain operating conditions by using previous training data and experience of interaction with the environment. The use of the presented solutions in mobile robot control systems on EDGE platforms for Industry 5.0 is limited due to the significant computing resources required for the operation of most modern artificial intelligence models, which complicates their implementation on low-power Raspberry Pi and ESP32 devices.

In the study by Muhammad Imran, Md. Al Billah et al. developed a hybrid fuzzy-PID controller to improve the accuracy of trajectory tracking of a differential mobile robot by adaptively adjusting the control parameters according to the current state of the system. The proposed method provides a reduction in motion error and improves the stability of the control system compared to classical PID controllers during maneuvers of varying complexity [6]. This approach is focused mainly on low-level motion control and does not take into account the tasks of neural network analysis of the environment, local artificial intelligence and autonomous decision-making, which are key components of mobile robot control systems on EDGE platforms for Industry 5.0.

In their work, Chia-Chi Lai, Bo-Jhang Yang, and Chien-Jung Lin proposed a hybrid control system that combines the Deep Q-Network algorithm and a PID controller with multi-sensor data fusion to improve the efficiency of automatic docking of autonomous mobile robots in complex environments. The developed approach allows to increase the positioning accuracy, reduce the time of docking operations, and ensure more reliable operation of the robot in the presence of obstacles and uncertainties [7]. The practical use of this solution within the EDGE architecture of Industry 5.0 is complicated by the orientation of the method to a highly specialized docking task and the need to implement a computationally complex deep reinforcement learning algorithm.

In the article, Wei Bi, Wei Bi, Wenjun Wang, and co-authors investigated the problem of adaptive formation of a group of omnidirectional mobile robots with guaranteed convergence time and constraints on the initial parameters of the system. The proposed method provides stable formation and maintenance of the structure of a robotic group even in the presence of dynamic changes and external disturbances, which is important for multi-robot systems [8]. The presented approach is focused on the tasks of group control and coordination of mobile robots and does not consider the issues of local neural network processing of sensor data, computer vision and autonomous decision-making on EDGE platforms. In the study, Ihor Sh. Nevliudov, Vladyslav V. Yevsieiev and Elvin A. Jabrayilzade developed an intelligent method for planning the movement of a collaborative mobile robot in a dynamic environment based on the VFH+ algorithm and semantic processing of LiDAR and video camera data. The proposed approach allows to improve the quality of navigation by combining geometric analysis of space and semantic object recognition, which provides a more substantiated formation of the robot's movement trajectory [9]. Despite the high level of intellectualization of navigation, the work does not consider the issues of building a distributed EDGE architecture based on Raspberry Pi and ESP32, as well as optimizing compact neural networks for local execution of artificial intelligence algorithms in real time.

The analysis of modern scientific publications indicates a significant interest of researchers in the use of artificial intelligence, neural networks, adaptive control and intelligent planning of the movement of mobile robots [9-14]. At the same time, most of the existing works are focused on solving individual tasks of navigation, control, docking or group coordination of robots and do not take into account the comprehensive implementation of all stages of data processing and decision-making directly on low-power EDGE platforms. This confirms the relevance of research aimed at developing neural network control systems for mobile robots based on Raspberry Pi and ESP32 for Industry 5.0, which combine local processing of sensory information, compact neural networks, autonomous route planning and adaptive control in a single intelligent architecture.

II. GENERAL ARCHITECTURE OF A NEURAL NETWORK CONTROL SYSTEM FOR MOBILE ROBOT ON EDGE PLATFORMS

The proposed architecture is intended for the implementation of an autonomous mobile robot control system that performs data collection from sensors, local information processing, neural network analysis of the environment, route planning, and formation of control actions without the use of external servers or cloud platforms [15-16]. The developed architecture of the neural network control system for mobile robots on EDGE platforms is presented in Figure 1.

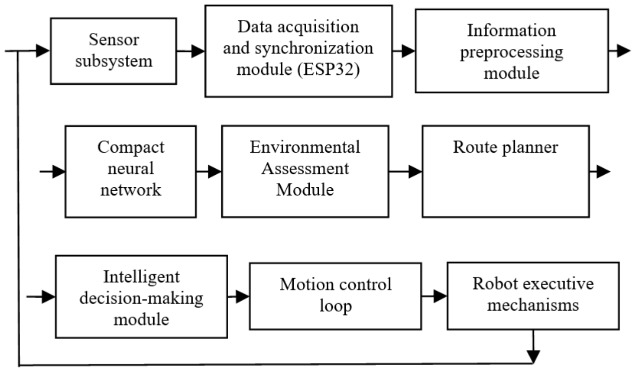

Figure 1 - The architecture of a neural network control system for mobile robots on EDGE platforms has been developed

Let us describe the purpose of each module of the proposed architecture of the neural network control system for mobile robots on EDGE platforms (Fig. 1):

Sensor subsystem - provides information about the environment and the internal state of the mobile robot using cameras, rangefinders, inertial modules and other sensors, forming the primary information flow for further processing.

Data acquisition and synchronization module (ESP32) - performs real-time sensor polling, synchronizes the received measurements and performs their primary processing before transmission to the central computing node of the control system.

Information preprocessing module - performs noise filtering, normalization and reconciliation of data from heterogeneous sensors in order to increase their reliability and prepare for further neural network analysis.

Compact neural network module (Raspberry Pi) - implements local execution of artificial intelligence algorithms for object recognition, scene analysis and prediction of potentially dangerous situations without using external computing resources.

Environmental assessment module – generates a digital representation of the workspace based on the results of neural network analysis and sensor data, determining the level of risk, passability and degree of uncertainty of individual sections of the environment.

Route planner – calculates a safe and effective trajectory of movement of the mobile robot, taking into account the configuration of the environment, current constraints and predicted changes in the situation.

Intelligent decision-making module – analyzes the results of planning and assessment of the environment to select the optimal strategy for robot behavior in accordance with the task and the current situation.

Motion control loop – converts high-level navigation commands into actuator control signals, ensuring accurate trajectory processing and stability of the mobile platform movement.

Executive mechanisms – implement the physical execution of the formed control influences by controlling the motors, servo drives and other devices of the mobile robot.

The feedback between the executive mechanisms and the sensor subsystem provides continuous control of the parameters of the movement and the state of the system, transmitting current data to the control loops for correcting the robot's actions in real time.

The proposed architecture of the neural network control system for a mobile robot on EDGE platforms provides the execution of a full cycle of data analysis, navigation and decision-making directly on board the robot, which significantly reduces information processing delays compared to traditional cloud solutions and increases the efficiency of responding to environmental changes. Unlike classical control systems that use predefined algorithms or centralized computing resources, the proposed approach combines the capabilities of compact neural networks, local processing of sensor data and intelligent route planning, which allows adapting the robot's behavior to conditions of uncertainty and dynamic obstacles in real time. The use of a distributed architecture based on Raspberry Pi and ESP32 ensures a rational distribution of the computational load between the system nodes, increases its fault tolerance and reduces power consumption compared to solutions that require high-performance servers or permanent network connectivity [17-19]. Due to this, the architecture is more effective for tasks of autonomous navigation, monitoring and adaptive control of mobile robots in Industry 5.0 environments, where the speed of decision-making, reliability of operation and independence from external infrastructure are of critical importance [20,21].

CONCLUSION

The paper proposes an architecture of a neural network control system for mobile robots based on the Raspberry Pi and ESP32 EDGE platforms, which provides local execution of the processes of collecting, processing and analyzing sensory information, as well as autonomous decision-making in real time without the use of cloud services. The developed approach combines the capabilities of compact neural networks, environmental assessment, route planning and adaptive motion control, which contributes to increasing the autonomy, speed and reliability of mobile robots in dynamic Industry 5.0 environments. The results obtained confirm the prospects of using EDGE computing to create intelligent robotic systems of a new generation and determine the feasibility of further research in the direction of optimizing neural network models for low-power embedded platforms.

REFERENCES

[1] Industry 5.0 та колаборативна робототехніка: динамічний опис навколишнього середовища роботів-маніпуляторів з використанням мови Python: монографія / І. Ш. Невлюдов, В. В. Євсєєв, С. С. Максимова. – Харків : Видавництво Іванченка І. С., 2026. – 279 с. https://doi.org/10.30837/978-617-8332-95-2

[2] Langås, E. F., Zafar, M. H., & Sanfilippo, F. (2026). Exploring the synergy of human-robot teaming, digital twins, and machine learning in Industry 5.0: a step towards sustainable manufacturing. Journal of Intelligent Manufacturing, 37(3), 999-1022. https://doi.org/10.1007/s10845-025-02580-x

[3] Belcastro, L., Marozzo, F., Orsino, A., Talia, D., & Trunfio, P. (2026). Navigating the edge-cloud continuum: A state-of-practice survey. IEEE Access. https://doi.org/10.1109/ACCESS.2026.3673012

[4] Abu-Jassar, A., Attar, H., Hafez, M., Hamdan, M., Yevsieiev, V., & Lyashenko, V. (2025, December). Adaptive System for Constructing a Mobile Robot Trajectory Using Neural Network and Stochastic Optimizer. In 2025 26th International Arab Conference on Information Technology (ACIT) (pp. 422-428). IEEE. https://doi.org/10.1109/ACIT68900.2025.11510567

[5] Wang, M., Niu, Y., Wang, B., Zhang, W., & Wang, C. (2026). A survey on learning motion planning and control for mobile robots: Toward embodied intelligence. IEEE Transactions on Neural Networks and Learning Systems. https://doi.org/10.1109/TNNLS.2026.3656889

[6] Imran, M., Billah, M., Hanip, A., Aizat, M., & Rahiman, W. (2026). Hybrid Fuzzy-PID Controller for Enhanced Trajectory Accuracy in Differential Drive Mobile Robots. International Journal of Robotics and Control Systems, 6(1), 556-576. doi:https://doi.org/10.31763/ijrcs.v6i1.2294

[7] Lai, C. C., Yang, B. J., & Lin, C. J. (2026). A Hybrid DQN–PID Control Framework with Multi-Sensor Fusion for Enhanced Docking Performance of Autonomous Mobile Robots in Complex Environments. IEEE Sensors Journal. https://doi.org/10.1109/JSEN.2025.3650455

[8] Bi, W., Bi, W., Wang, W., Sui, S., & Philip Chen, C. L. (2026). Adaptive Predefined-Time Formation Control for Multi -Omnidirectional Mobile Robot Systems With Output Constraints. International Journal of Robust and Nonlinear Control, 36(1), 19-30. https://doi.org/10.1002/rnc.70036

[9] Nevliudov I. Sh., Yevsieiev V. V., Jabrayilzade E. A. Intelligent Motion Planning of a Collaborative Mobile Robot in a Dynamic Environment Based on VFH+ and Semantic Processing of LIDAR and Video Data // Visnykof Kherson Nationaltechnical University. 2026. 2(97). P. 295-309. https://doi.org/10.35546/kntu2078-4481.2026.2.36

[10] Yevsieiev V. Digital Twin in Modeling and Control of Collaborative Robots: Analysis, Comparison and Application Recommendations / V. Yevsieiev, S. Starikova // Computer-integrated technologies, automation and robotics 2026 : Proceedings of III st All-Ukrainian Conference, May 14-15, 2026. - Kharkiv .: [electronic version], 2026. - P. 89-92.

[11] Model with Neural Network Component for Adaptive Manipulator Control under Variable Load / Amer Abu-Jassar, Mohammad Hamdan, Nowfal Aweisi, Mahmoud Howaidi, V. Yevsieiev, V. Lyashenko // International Journal of Intelligent Engineering and Systems. –19(1). – 2026. – P. 855-868. https://doi.org/10.32403/10.22266/ijies2026.0131.51

[12] Abu-Jassar, A., Attar, H., Hafez, M., Hamdan, M., Yevsieiev, V., & Lyashenko, V. (2025, December). Adaptive System for Constructing a Mobile Robot Trajectory Using Neural Network and Stochastic Optimizer. In 2025 26th International Arab Conference on Information Technology (ACIT) (pp. 422-428). IEEE. https://doi.org/10.1109/ACIT68900.2025.11510567

[13] Yevsieiev V. Using Historical Data in the NNARX Model to Improve the Accuracy of Microclimate Parameter Forecasting / V. Yevsieiev, I. Holod // Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт 2026 : матеріали I-ої Всеукраїнської конфер.12-13 лютого 2026 р. - Харків: [електронний друк], 2026. – С. 44-48.

[14] Yevsieiev V. Multi-Agent Collaborative Robots With Adaptive Sensor Fusion for Monitoring and Mitigation of Emergency Situations / V. Yevsieiev, N. Demska // Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт 2026 : матеріали I-ої Всеукраїнської конфер.12-13 лютого 2026 р. - Харків: [електронний друк], 2026. – С. 162-165

[15] Nasar, M., Kausar, M. A., & Nayyer, M. A. (2026). Towards next-generation agriculture: An AI-driven industry 5.0 model for IoT-enabled smart farming. Next Research, 101526.

[16] Jiang, Z., Ma, N., Yao, X., Zhou, J., Wang, K., Xie, T., & Meng, J. (2026). From smart manufacturing in Industry 4.0 to industrial metaverse for Industry 5.0. International Journal of Computer Integrated Manufacturing, 39(4-5), 610-641.

[17] Vladyslav Yevsieiev, Ihor Holod. Integration of the NNARX Model in Python/Keras for Predictive Microclimate Control of Industrial Premises // In Proceedings of the 7th International Scientific and Practical Conference «Science and Education in Progress», May 16-

18, 2026. Dublin: JAPAGA, 2026. P. 244-24 https://doi.org/10.51582/interconf.2026.294

[18] Yevsieiev V., Holod I. Development of a Self-Learning and Adaptation Algorithm for Microclimate Control System Using Sensor Networks // In Proceedings of the 7th International Scientific and Practical Conference «Innovative Development in the Global Science», May 26-28, 2026. Boston: Independently Published, 2026. P.152-157. https://doi.org/10.51582/interconf.2026.296

[19] Yevsieiev V., Holod I. Prospects for the Implementation of Cyber-Physical System for Monitoring and Control of Microclimate in the Context of Industry 4.0 // The Proceedings of the 16th International Scientific and Practical Conference "Challenges in Science of Nowadays", April 26-28. 2026. Washington, USA. P. 254-260. https://doi.org/10.51582/interconf.2026.292

[20] Yevsieiev V. Digital Twins of Collaborative Robotic Systems for Decision Support in Emergency Situations / V. Yevsieiev, S. Svetlana // Intelligent Civil Safety Technologies and Robotic Systems for Emergency and Rescue Operations (ICSTRO-2026) : Proceedings of I-st All-Ukrainian Conference, February 12-23, 2026. – Kharkiv, 2026. - P. 153-156.

[21] Abu-Jassar, A., Attar, H., Hafez, M., Hamdan, M., Yevsieiev, V., & Lyashenko, V. (2025, December). Adaptive System for Constructing a Mobile Robot Trajectory Using Neural Network and Stochastic Optimizer. In 2025 26th International Arab Conference on Information Technology (ACIT) (pp. 422-428). IEEE. https://doi.org/10.1109/ACIT68900.2025.11510567