MULTI-AGENT COLLABORATIVE ROBOTS WITH ADAPTIVE SENSOR FUSION FOR MONITORING AND MITIGATION OF EMERGENCY SITUATIONS

Vladyslav Yevsieiev, Nataliia Demska
Kharkiv National University of Radio Electronics
Ukraine, 61166, Kharkiv, Nauky av., 14
E-mail: vladyslav.yevsieiev@nure.ua

***Annotation*:** The paper considers an approach to using multi-agent collaborative robotic systems with adaptive sensor fusion for monitoring and mitigation of emergency situations. A system architecture is proposed in which a group of mobile robots cooperatively collects, integrates, and analyzes sensor data to form a consistent representation of the environment and support decision making. It is shown that the use of adaptive sensor information integration increases the system's robustness to noise and failures of individual agents. The presented results of numerical simulations confirm the effectiveness of the proposed approach under dynamic and uncertain conditions..

Key words: multi-agent systems, collaborative robots, sensor fusion, adaptive systems, emergency response.

БАГАТОАГЕНТНІ КОЛАБОРАТИВНІ РОБОТИ З АДАПТИВНОЮ СЕНСОРНОЮ ІНТЕГРАЦІЄЮ ДЛЯ МОНІТОРИНГУ ТА ЛІКВІДАЦІЇ НАДЗВИЧАЙНИХ СИТУАЦІЙ

Владислав Євсєєв, Наталія Демська
Харківський національний університет радіоелектроніки,
Україна, 61166, Харків, пр. Науки 14
E-mail: vladyslav.yevsieiev@nure.ua

Анотація: У роботі розглядається підхід до використання багатоагентних колаборативних робототехнічних систем із адаптивною сенсорною інтеграцією для моніторингу та ліквідації надзвичайних ситуацій. Запропоновано архітектуру системи, у якій група мобільних роботів кооперативно збирає, інтегрує та аналізує сенсорні дані для формування узгодженої картини середовища та підтримки прийняття рішень. Показано, що використання адаптивної інтеграції сенсорної інформації підвищує стійкість системи до шумів і відмов окремих агентів. Наведені результати чисельного моделювання підтверджують ефективність запропонованого підходу у динамічних та невизначених умовах.

Ключові слова: multi-agent systems, collaborative robots, sensor fusion, adaptive systems, emergency response.

Emergency situations are characterized by spatial scale, rapid change of the situation and high level of risk, which complicates their effective monitoring and liquidation. The use of individual autonomous robots is limited due to their local observation zone and computing resources, while groups of robots are able to provide spatiotemporal coverage of the environment and increased reliability due to redundancy. The Industry 5.0 paradigm emphasizes human-oriented, adaptive and interpretable systems that combine the autonomous capabilities of artificial intelligence with human control and responsibility.

The purpose of this work is to develop and analyze a multi-agent collaborative robotic system with adaptive sensor integration to increase the effectiveness of monitoring and supporting the liquidation of emergency situations.

The proposed system consists of a group of mobile robot agents, each of which is equipped with a set of sensors for sensing the environment and its own state. Sensor data from individual agents are combined using adaptive sensor integration mechanisms that take into account the level of credibility

and reliability of each information source. This allows for the formation of a consistent map of the environment and the assessment of risks taking into account the spatial distribution of hazards. An example of implementations of the multi-agent architecture of the system is presented in Figure 1.

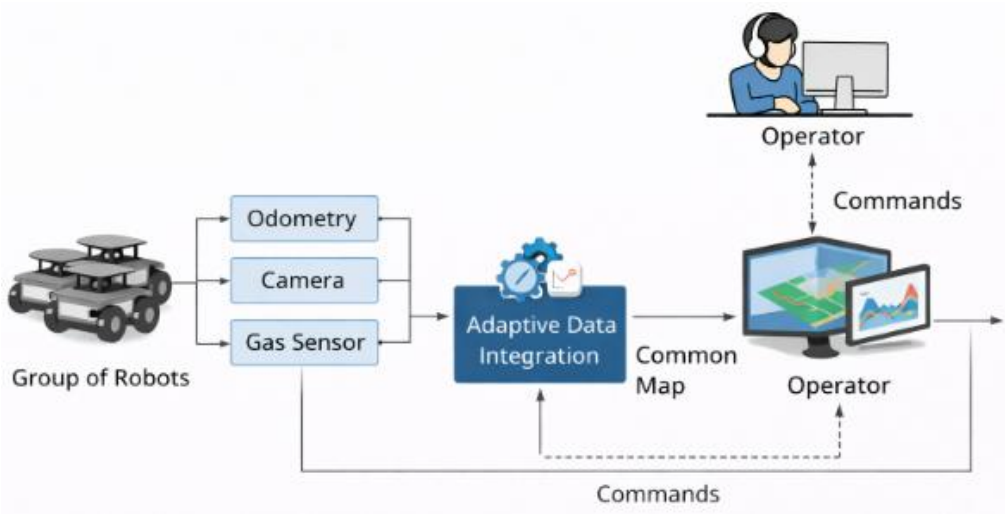

Figure 1. - Multi-agent system architecture diagram

Agent coordination is carried out through distributed coordination algorithms that ensure conflict avoidance, optimal coverage of the territory and adaptation to the loss of individual robots. The operator remains in the control loop, receiving generalized information and the ability to adjust the mission or behavior of the group of agents.

Numerical modeling was carried out for scenarios of monitoring of technogenically hazardous areas with random sources of risk. The results showed that the use of a multi-agent approach allows reducing the time for detecting dangerous areas by 30–40% and increasing the accuracy of risk localization compared to single robots. Figure 2 shows a graph comparing Environment Coverage vs Time.

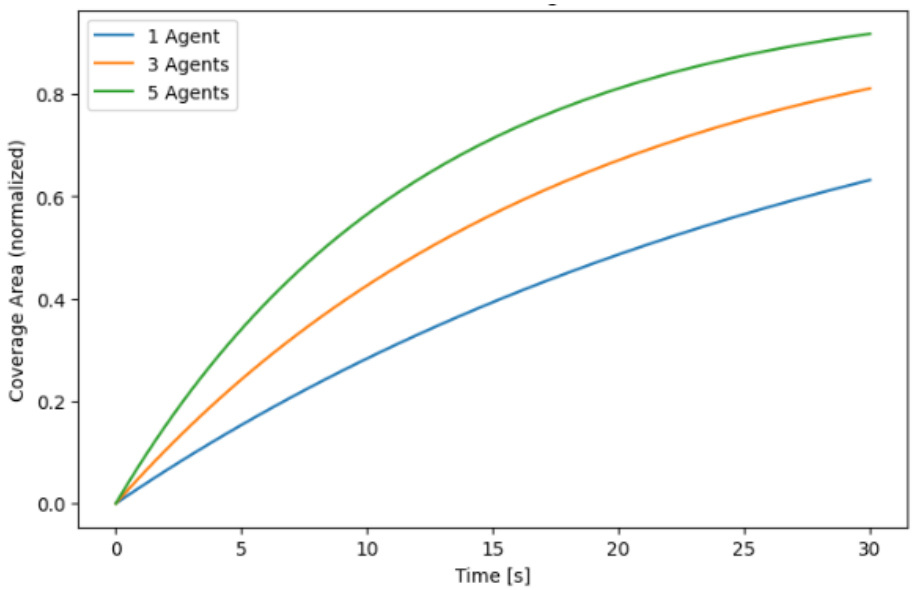

Figure 2. - Environment Coverage vs Time

To assess the impact of the number of agents on the effectiveness of monitoring, a comparative analysis of the main performance indicators of a multi-agent system in emergency situations was conducted. The analysis allows us to quantitatively characterize the speed of detection of dangerous zones, the accuracy of their localization, and the system's resistance to failures of individual robots. The results obtained reflect the dependence of monitoring efficiency on the level of agent cooperation and adaptive data integration. The generalized numerical values of the indicators are given in Table 1.

Table 1. - Comparison of monitoring effectiveness

Number of agents	Risk detection time, s	Localization accuracy	Failure tolerance
1	30	0.65	Low
3	18	0.82	Medium
5	12	0.91	High

According to Table 1, increasing the number of agents from 1 to 3 reduces the risk detection time from 30 s to 18 s, i.e. by 40%, and when using 5 agents - to 12 s, which corresponds to a 60% reduction compared to a single robot. The localization accuracy increases from 0.65 to 0.82 and 0.91, respectively, which means an increase of 26% and 40% in relative terms. At the same time, the system's resistance to failures goes from low to high, which indicates a significant increase in the reliability of monitoring in multi-agent mode.

CONCLUSIONS. It is shown that multi-agent collaborative robotic systems with adaptive sensor integration are an effective tool for monitoring and eliminating emergencies. The proposed approach provides increased response speed, accuracy of risk assessment, and resilience to individual agent failures. The results obtained confirm the feasibility of using such systems within the framework of the human-oriented Industry 5.0 paradigm.

References:

1. Liu, Y., Tian, G., Sheng, H., Zhang, X., Yuan, G., & Zhang, C. (2026). Batch EOL products human-robot collaborative remanufacturing process planning and scheduling for industry 5.0. Robotics and Computer-Integrated Manufacturing, 97, 103098.
2. Ghanghorkar, Y., Deshpande, A., & Misal, A. N. (2026). Human-robot interaction (HRI) and social robotics in industry 5.0: Drivers, barriers, and implications for sustainable development. In Intelligent Systems for Neurocognition and Human-Robot-Computer Interaction (pp. 127-152). Academic Press.
3. Hammad, M., Ali, H., Hussain, G., & Wang, X. (2026). Core Technologies Enabling Industry 5.0. In Industry 5.0: The Human-Centric Future of Industry (pp. 47-74). Cham: Springer Nature Switzerland.
4. Li, H., He, X., Wu, Y., Liu, G., Wang, H., Wen, X., & Li, L. (2026). Digital twin and AI-driven robotic embodied control system: a novel adaptive learning and decision optimization method. Robotics and Computer-Integrated Manufacturing, 98, 103138.
5. Qin, Q., Liu, Z., Zhong, R., Wang, X. V., Wang, L., Wiktorsson, M., & Wang, W. (2026). Robot digital twin systems in manufacturing: Technologies, applications, trends and challenges. Robotics and Computer-Integrated Manufacturing, 97, 103103.
6. Liu, C., Song, J., Tang, D., Wang, L., Zhu, H., & Cai, Q. (2026). From insight to autonomous execution: VLM-enhanced embodied agents towards digital twin-assisted human-robot collaborative assembly. Robotics and Computer-Integrated Manufacturing, 98, 103176.

7. Attar, H., & et al.. (2022). Zoomorphic Mobile Robot Development for Vertical Movement Based on the Geometrical Family Caterpillar. Computational Intelligence and Neuroscience, 2022, Article ID 3046116, https://doi.org/10.1155/2022/3046116.

8. Nevliudov, I., Yevsieiev, V., Maksymova, S., Demska, N., Kolesnyk, K., & Miliutina, O. (2022, September). Object Recognition for a Humanoid Robot Based on a Microcontroller. In 2022 IEEE XVIII International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH) PP. 61-64. DOI: 10.1109/MEMSTECH55132.2022.10002906

9. 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.

10. Невлюдов, І., Євсєєв, В., Максимова, С., & Артюх, Р. (2025). Математична модель адаптивного ієрархічного високорівневого керування триланкового колаборативного робота-маніпулятора. Сучасний стан наукових досліджень та технологій в промисловості, (2 (32)), 58-68.

11. Yevsieiev, V., Ababneh, J., Maksymova, S., & Abu-Jassar, A. (2025). DEVELOPMENT OF A MATHEMATICAL MODEL FOR SIMULATING A DECENTRALIZED CONTROL SYSTEM FOR COLLABORATIVE ROBOT NETWORKS. Multidisciplinary Journal of Science and Technology, 5(5), 1187-1202.

12. Nevliudov, I., Yevsieiev, V., Maksymova, S., Gopejenko, V., & Kosenko, V. (2025). Development of mathematical support for adaptive control for the intelligent gripper of the collaborative robot manipulator. Advanced Information Systems, 9(3), 57-65.

13. Culbertson, P., Slotine, J. J., & Schwager, M. (2021). Decentralized adaptive control for collaborative manipulation of rigid bodies. IEEE Transactions on Robotics, 37(6), 1906-1920.

14. Hameed, A., Ordys, A., Możaryn, J., & Sibilska-Mroziewicz, A. (2023). Control system design and methods for collaborative robots. Applied Sciences, 13(1), 675.

15. Nevliudov, I., Yevsieiev, V., Baker, J. H., Ahmad, M. A., & Lyashenko, V. (2020). Development of a cyber design modeling declarative Language for cyber physical production systems. J. Math. Comput. Sci., 11(1), 520-542.

16. Yevsieiev, V. Comparative Analysis of the Characteristics of Mobile Robots and Collaboration Robots Within INDUSTRY 5.0. / V. Yevsieiev, D. Gurin // Sectoral research XXI : characteristics and features : collection of scientific papers "SCIENTIA" with proceedings of the VI International Scientific and Theoretical Conference, September 8, 2023. - Chicago : European Scientific Platform, 2023. - P. 92-94.

17. Yevsieiev V. Development of a program for modeling the control of a mobile manipulation robot in the unity environment / V. Yevsieiev, N. Starodubcev // Science in Environment of Rapid Changes : proceedings of the 2nd International Scientific and Practical Conference, Brussels, Belgium, February 6-8, 2023. - Brussels : De Boeck, 2023. - Scientific Collection «InterConf» . - № 141. - P. 331-334.

18. Yevsieiv, V. Using the Triangulation Method to Measure the Distance to Objects in the Working Area of a Collaborative Manipulator Robot / V. Yevsieiv, S. Starikova // Manufacturing & Mechatronic Systems 2024 : Proceedings of VIII st International Conference, October 25-26, 2024. - Kharkiv, 2024. - P.107-109.

19. Yevsieiev V. Simulation of the operation of the sensor system of a mobile robot in the Autodesk tinkercad environment / V. Yevsieiev, S. Starikova // Комп'ютерні ігри і мультимедіа як інноваційний підхід до комунікації-2023 : матеріали III Всеукр. наук.-техн. конф. молодих вчених, аспірантів і студентів, Одеса, 28-29 жовтня 2023 р. - Одеса : ОНТУ, 2023 . – С. 21-23.