Abstract

of the dissertation on the topic:
"«Development of an artificial vision for robotic systems using M2M technologies»."

submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 6D071900 – "Radio Engineering, Electronics, and Telecommunications"
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Relevance of the Topic. The development of machine vision in robotic systems using Machine-to-Machine (M2M) technologies plays a significant role in the field of communication. This intersection drives innovation and practical applications across various domains. Advanced communication and data transmission systems integrated into machine vision systems enable the generation of large volumes of visual data. M2M technologies ensure the efficient and reliable transmission of this data between robots and central systems, enhancing decision-making processes. Advanced M2M protocols optimize bandwidth usage, ensuring that critical visual data from robotic systems is prioritized and transmitted with minimal latency.

This study focuses on the development of artificial representations of a parallel robot (PR) using M2M communication technologies, emphasizing key components, processes, and potential applications.

Research Objective. To develop machine vision for a parallel robot using M2M technologies.

Concept of the Work. The study leverages analytical methods, computer modeling, and virtual testing. SolidWorks 3D CAD Design software and PDM systems were used as modeling tools, while Arduino IDE programming was utilized for processing the modeling results.

Research Objectives:

In line with the goal set in the dissertation, the following tasks were formulated:

1. Development of a kinematic diagram for a parallel robot based on artificial intelligence controlled by M2M technology.
2. Creation of a 3D model and mechanical design, as well as the control system and electronics for the parallel robot within an M2M system managed by artificial intelligence.
3. Development of computer vision algorithms for object recognition and image processing.

Scientific Propositions Submitted for Defense

1. Definition of the working area with the kinematic parameters of a parallel robot within an M2M system controlled by artificial intelligence.
2. Development of a mechanical design for the parallel robot using the proposed kinematic model, including the creation of a 3D model in SolidWorks 3D CAD Design Software & PDM Systems.

3. Creation and integration of an artificial vision system with the parallel robot and the M2M communication protocol.
4. Integration of the artificial vision system with the M2M communication protocol.
5. Testing and evaluation of the laboratory model of the parallel robot controlled by M2M in a simulated environment for validation and verification.

Key Research Results:

1. Calculation of the positioning error of the center of the parallel robot platform and the error caused by displacement of the platform center.
2. Architecture of the MASK-R-CNN algorithm with an adaptive RGB model.
3. Machine vision framework for detecting and tracking the motion trajectories of objects.
4. Flowchart of the Machine-to-Machine (M2M) interaction system.
5. Operational scheme of the robotic platform for motion trajectory prediction.

Research Objects: A parallel robot with artificial intelligence controlled by M2M.

Research Subject: The development and study of a guided parallel robot (PR) system utilizing M2M communication technologies and machine vision methods, focusing on the accuracy and speed of object identification and sorting.

Scientific Novelty:

– The possibility of developing a kinematic scheme of a parallel robot in the field of artificial intelligence controlled through M2M technologies has been identified.

– Development of computer vision algorithms for object recognition and image processing.

– Presentation of a laboratory model of an AI-controlled parallel robot (PR) using M2M with a software-based mathematical algorithm.

The practical significance of the work lies in the integration of PR algorithms for artificial vision and adaptive object detection using M2M technologies and machine learning methods, which ensures high speed and accuracy of manipulations under various lighting conditions.

The author's personal contribution includes formulating the research tasks, conducting the main theoretical and experimental studies presented in the dissertation, generalizing the obtained results, developing experimental research methods, carrying out the studies, drawing conclusions and recommendations, as well as analyzing and presenting the results in the form of publications and scientific reports.

Publications and Testing of the Work:

The main results of the dissertation were presented at 4 international and scientific-technical conferences, including:

– "Mechanisms and Machine Engineering," Springer, at the International Conference "New Trends in Medical and Service Robotics" (Cluj-Napoca, Romania, 2018);

– At the international conference Mechanisms and Machine Science, Springer, Advances in Mechanism and Machine Science (IFToMM WC 2019) (Krakow, Poland, June 14, 2019);

– IEEE International Conference on Automation, Quality, and Testing, Robotics (AQTR) 2020 (Cluj-Napoca, Romania).

A total of 10 publications have been published on the dissertation topic. Of these, one article is in a journal that is in the 1st quartile according to Scopus (percentile 79%), two papers are in journals ranked in the 3rd quartile according to Scopus (percentile 38%, 45%), four papers are in journals recognized by the Ministry of Education and Science of the Republic of Kazakhstan, and one patent for a utility model was published (Patent No. 5019, 2020).

Volume and Structure of the Work:

The dissertation consists of an introduction, 4 chapters, a conclusion, a list of references, and appendices. The total volume of the dissertation includes 127 pages of typed text, 19 tables, 71 figures, 46 titles, and 1 appendix, with 111 references.

Main Content of the Work:

The work consists of fourth chapters.

Chapter I examines various aspects of the use of Machine-to-Machine (M2M) technology in robotic machine vision systems. It discusses the main concepts of M2M and its significance in the modern world. The key communication protocols, such as MQTT, CoAP, HTTP/HTTPS, AMQP, XMPP, LwM2M, Zigbee, and LoRaWan, are described, along with their specific use cases and advantages.

The application of M2M in healthcare, logistics, agriculture, and robotics, especially in machine vision systems, is analyzed across different fields. Technical challenges related to the integration of M2M with robotics are discussed, as well as the prospects for innovations that M2M can bring to robotic systems.

Chapter II is devoted to the kinematic scheme of a parallel robot in the context of M2M controlled by artificial intelligence. It covers key aspects, including methods for calculating errors in the position of the center of the PR platform, analysis of equations and methods of kinematics of translational motion, determination of the working area of the PR and calculation of errors caused by displacement. This chapter focuses on improving the accuracy, efficiency, and reliability of PR.

Chapter III explores important aspects of developing the parallel robot, including the use of 3D models for planning and analyzing the structure, creating an electronic system with components, schematics, and controllers, developing an artificial vision system using M2M communication protocols for data transmission and control, and integrating the M2M system to improve the robot's interaction.

Chapter IV investigates the design and evaluation of the robot's machine vision system with a focus on part placement and sorting, where manipulation speed and object detection accuracy are crucial. Experimental research in a production environment assessed the system's performance under various lighting conditions. The developed system, using C++ and Python, successfully utilized machine learning methods (LAB) and color space recognition for accurate object detection and placement.

A comparative analysis of YOLOv8 and MASK-R-CNN models showed that YOLOv8 is faster, while MASK-R-CNN provides higher accuracy, especially in challenging lighting conditions. The choice of the correct model is important depending on the task's requirements, and the use of LAB color space improves object filtering and recognition. Overall, the results highlight the potential of modern algorithms for enhancing robotic performance in industrial applications, suggesting that attention should be focused on optimizing models to improve real-world performance.

The conclusion summarizes the results and findings of the dissertation research and outlines the future work planned in the chosen direction.