ABSTRACT

Thesis of Buribayev Zholdas

on the topic: «Development of efficient parallel machine learning algorithms for a robot orientation system in space» submitted for the PhD degree (PhD) in the specialty «6D075100-Computer Science, computer engineering and Management»

Relevance of the research topic. The modern development of robotics is closely related to artificial intelligence (AI). If robots were previously used mainly for the purpose of replacing human labor in difficult areas or by productive speed performers in factories, then with the beginning of a new era of robots, views on development were replaced by the development and addition of robots to human labor and creativity. The main problems with the introduction of AI were the limited computing resources, as well as the little-studied approaches, solutions, methods, and algorithms of artificial intelligence, which allow to increase the functional intelligence of the robot in decision-making. Modern technologies, with their current capabilities, already allow for calculations of this kind, and now the task is to solve the second problem - implementation.

The functional definition for a robot can be given as the definition of STA - SENSE/THINK/ACT:

SENSE - perception of the surrounding world;

THINK - understanding of the surrounding physical world and the ability to build behavioral models to perform the intended actions;

ACT - impact on the physical world by actions;

and the absence of at least one of these functions, writes off the device from the robot's lists.

The introduction of robots for partial or full automation of enterprises, many sectors of different industries is an urgent problem today. According to research by scientists and analysts on international trade and economists, the agricultural sector for Kazakhstan is a promising industry sector for the development and introduction of robots with artificial intelligence.

A critical aspect of successful agricultural robots is their ability to process sensory information and, in particular, their ability to analyze and interpret visual input. Indeed, by establishing a link between visual data and proper decision-making, machine algorithms can facilitate numerous operations. However, there are a lot of problems associated with machine vision encountered in the agricultural environment: objects of various colors, shapes, sizes, textures and reflective properties; constantly changing lighting and shadow conditions; severe occlusions; are only part of the problems that machine vision must face.

One of the important problems of orientation of robots in space is minimizing errors of perception of the environment, maximizing the functions of recognition of environmental objects in mathematical terms can be solved using metaheuristic methods that allow expanding the functionality of robotic systems with artificial

intelligence. The growth of published works on metaheuristic approaches based on local search with alternating neighborhoods has been constantly growing in recent years. For example, according to ScienceDirect (www.sciencedirect.com), it can be noted that if in 2003 the number of works published each year did not exceed 100 units, then in 2019 their number became more than 2000 publications, and it is assumed that it will only grow further. The main research in this area belongs to foreign scientists. Research shows that the introduction of artificial intelligence will contribute to the further development of automation of the agro-industrial sector. Statistics on published articles for the period from 2017 to 2021 in the Scopus database (www.scopus.com) with the keywords "agrorobots" or "agro", shows a growth trend on this topic, since 161595 documents were published in just 5 years, while 1,399,552 documents were published using the keywords "computervision" or "vision" or "robotics" or "robots". Based on the fact that the number of published articles is increasing every year, we can conclude that the level of study of this topic is relevant to this day.

While machine vision in the systems of agro-industrial robots has not yet reached its full potential, many applications have already been developed for various tasks in the maintenance of gardens and greenhouses. In early 2017 alone, about one-fifth of all lettuce grown in the US was thinned using LettuceBot. This development is being implemented in the United States by several united manufacturers of agricultural technologies, headed by developer George Heraud, who himself opened the Blue River Technology company. This is just one example of the introduction of finished robotics products into the agro-industry.

Almost 90% of the equipment currently used in Kazakhstan is at the end of its life cycle and needs to be replaced. Tractors used for more than 10 years make up 94% of the entire fleet, and harvesters in similar condition make up 77%. As of January 1, 2019, agricultural producers have 147,000 tractors, 79,400 seeders and 249,000 units for tillage for the upcoming planting season. Naturally, the state makes appropriate decisions on the renewal of machinery and equipment. Thus, the import of agricultural equipment in Kazakhstan is subsidized at a rate of 25% of the cost, while financial leasing is provided at a rate of 10%. The level of equipment renewal over the past 5 years has ranged from 3 to 4.9%, but this figure should reach 6-8% annually. Given these figures, it becomes clear that the renewal of the fleet of cars or the introduction of new technologies that allow a more reasonable and economical use of consumables is a priority.

The introduction of the agro-robot samples being developed into the agro-industrial complex, equipped with an intelligent computer vision system that performs the assembly, will provide conditions for fast and proper harvesting of tomatoes, will ensure high labor productivity, will enable monitoring and identification of any changes in the plant growth process due to step-by-step and chronological self-learning, all this should ultimately affect the new level of development of the agro-industrial structure of the country as a whole.

The results obtained provide an incentive to develop science and technology, both for scientific and educational purposes, and at the level of modernization of large and medium-sized enterprises.

In Kazakhstan, this area of research is at the initial stage of development, there are no domestic samples of agro-robots that assemble tomatoes using computer vision and machine learning.

Existing analogues of this development from foreign manufacturers: BoniRob from Deepfield Robotics (Germany), ecoRobotics, Ecorobotics, Switzerland; FarmWise, FarmWise, USA; HortiBot, Denmark; Ladybird, University of Sydney, Australia; Naïo Technologies, France; Oz, Naio Technologies; RoboTrac, Hannes Zeeberg.

Tomato is a product in great demand all over the world, and its consumption is gradually increasing every year. Harvesting tomatoes manually is time-consuming, time-consuming, and inefficient. In addition, the tomato is very soft and prone to bruising, which makes it difficult to harvest and capture the process. Thus, robotization of tomato harvesting can become one of the most effective solutions to eliminate the problems mentioned above. This study offers one of the approaches to the robotization of tomato harvesting.

In this paper, we investigate the processing of visual data coming from the robot's stereo cameras, since the use of cameras as environmental recognition, machine vision is the most widely used, as well as methods that give more data in the information flow.

The level of studying the problem. The use of neural network-based machine learning methods in robotics has an obvious advantage in terms of object recognition accuracy and spatial orientation of robots over simple algorithms focused on sensor readings, but these questions are still being formulated to find optimal implementation paths and implement them. Recent works of leading experts in this field confirm that today's computing resources allow such studies, but we cannot say that this or that algorithm is always applicable to the same problem, that is, many solutions are heuristic and do not have an unambiguous solution.

Taking into account these conditions, we conclude that the study in this area remains open.

The purpose of the thesis. Development of an effective model and technologies for image recognition, computer vision and machine learning designed to perform recognition and assembly of tomatoes.

The tasks of the research:

- Perform a comparative analysis of machine learning methods for classifying objects (tomatoes) with quality assessment based on a computational experiment;

- Develop a modified architecture for a convolutional neural network with an assessment of the quality of image recognition;

- Develop a parallel algorithm for image processing processes with the calculation of three-dimensional coordinates of objects;

- Adapt the developed system that allows you to determine the localization in the space of the object under study in order to introduce it into an agro-robot designed to assemble tomatoes.

The object of study. There are a robotic complex with computer vision and a greenhouse for growing tomatoes.

Research methods and subjects – neural networks, real-time object recognition algorithms, computer vision, artificial neural network theory, software development technology.

Scientific novelty. Based on the architecture of convolutional neural networks, a new modified neural network architecture was developed, with parallel processing of tomato recognition processes, which allows you to double the processing speed and improve accuracy by 3 %.

Theoretical and practical significance. The theoretical significance of the results obtained consists in modifying the existing neural network architecture for object recognition and processing a parallel algorithm for processing graphic information. The practical value of the obtained results lies in the development of a program for recognizing tomatoes and calculating their three-dimensional coordinates for the picker robot based on the provisions submitted for protection.

Testing the work. The main results of the dissertation work were reported and discussed at international and foreign scientific conferences, scientific seminars:

- 5th International Conference on Mechanics and Mechatronics Research (Tokyo, 2018);
- III International Scientific and Practical Conference "Informatics and Applied Mathematics" dedicated to the 80th anniversary of Professor R. G. Biyashev and the 70th anniversary of Professor M. B. Aidarkhanov (Almaty, 2018)
- IV International Scientific and Practical Conference "Informatics and Applied Mathematics", dedicated to the 70th anniversary of Professors T. N. Biyarov and Valdemar Vujcik and the 60th anniversary of Professor E. N. Amirgaliyev (Almaty, 2020);
- 2021 IEEE International Conference on Smart Information Systems and Technologies (Нур-Султан, 2021.г).

The results of the dissertation research are published in 12 papers. These include 4 articles in journals recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 4 articles in international scientific publications included in the Web of science and Scopus database, 4 papers in materials of international and national conferences, 1 author's certificate based on the results of practical implementation of dissertation research.

Relationship of the topic to research program plans. The presented results were obtained during the implementation of the following research and Development projects of the Ministry of Education and Science of the Republic of Kazakhstan (source of funding: Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan):

- Grant financing (GF) of the Ministry of Education and Science of the Republic of Kazakhstan AP05132648 «Creating verbally interactive robots based on modern speech and mobile technologies» in 2018-2020;
- Grant financing (GF) of the Ministry of Education and Science of the Republic of Kazakhstan AP08857573 «Development of intelligent information technologies based on machine vision and image recognition with the construction of a mobile robot for agricultural land maintenance» in 2020-2022.

Main provisions displayed for protection The proposed computer vision system, implemented on the basis of parallel image processing and advanced architecture with a convolutional neural network with the representation of the three-dimensional coordinates of the object under study, showed, as a result of computational experiments, high efficiency in terms of image processing speed (number of frames) and accuracy compared to the original neural network architecture for object recognition (tomatoes).

Personal contribution of the researcher. The researcher's personal contribution consists in reviewing and evaluating the effectiveness of machine vision methods and technologies, modifying the architecture of a convolutional neural network, developing a parallel image processing algorithm, equipping a multi-link robot with machine vision, and conducting computational experiments.

Structure and volume of dissertation. Total volume of dissertation work – 100 paged paged. The paper consists of an introduction, 4 titles, a conclusion, a list of references, and appendices.