SYNAPSES: Insights Across the Disciplines
ISSN: 3060-4737
IF(Impact Factor)10.92 / 2024

Volume 1, Issue 5

The Triangulation Method Using for the Distance to the Object Measurement in a Collaborative Robot Workspace

Vladyslav Yevsieiev[1],
Svitlana Maksymova[1],
Dmytro Gurin[1],
Ahmad Alkhalaileh[2]

[1]Department of Computer-Integrated Technologies, Automation and Robotics, Kharkiv National University of Radio Electronics, Ukraine
[2]Senior Developer Electronic Health Solution, Amman, Jordan

Abstract: The article examines the triangulation method for accurately measuring the distance to objects in a Collaborative Robot Workspace. The effectiveness of using HC-SR04 ultrasonic sensors is analyzed, one of which has a blocked TRIG pin, which allows you to focus on receiving reflected signals to calculate the distance. The results of the experiments demonstrate the high accuracy of the measurements, as well as the speed of the system's response to changes in the position of the object. The importance of this approach for improving robotic systems within the concept of Industry 5.0 is highlighted.

Key words: Triangulation, Collaborative Robot, Ultrasonic Sensors, Hc-Sr04, Distance Measurement, Industry 5.0

Introduction

In the era of Industry 5.0, which focuses on the close interaction of humans and robots, the issue of accurate and safe positioning of objects in the working areas of collaborative robots becomes extremely relevant [1]-[16]. This environment involves the adaptation of robotic systems to rapidly changing conditions and the ability to work in close proximity to a person, which requires high accuracy in detecting objects, their sizes and locations [17], [18]. This necessitates the use of different methods and approaches [19]-[36]. One of the effective approaches to solving this problem is the triangulation method, which allows you to calculate the distance to objects with high accuracy using data from several sensors. The application of the triangulation method for collaborative robots creates prerequisites for improving the quality of security systems, navigation accuracy, and also for the formation of a safer and more comfortable environment for the cooperation of humans and robotics [37]-[41]. Since Industry 5.0 is aimed at the development of human-centered technologies that take into account the needs of safety and effective interaction, the triangulation method makes it possible to achieve significant progress in the creation of intelligent monitoring and control systems. Research on the application of triangulation in robotic systems is promising not only for industrial purposes, but also for the development of integrated cyber-physical production systems, where safety and adaptation to human needs are priorities.

Related works

In the modern world, with the ever-widening spread of the Industry 5.0 concept, human safety issues come to the fore. This creates the need to determine the distance to objects, including humans. There are many methods for solving this problem, to which scientists devote their works. Let's consider several such works.

Article [42] considers the problem of underwater observations. Here there is reviewed some key sensing technologies such as underwater acoustic sensing, underwater optical sensing, underwater magnetic sensing, and underwater bionic sensing.

Scientists in [43] analyze multi-object tracking techniques and their application in navigation tasks of assistive mobile robots, with the aim to increase the mobility and autonomy of people suffering from mobility decay, or severe motor impairments, due to muscular, neurological, or osteoarticular decay.

Liu, W., & et al. [44] propose a multimodal flexible sensory interface for interactively teaching soft robots to perform skilled locomotion using bare human hands. And they propose a distance control method that enabled humans to teach soft robots movements via bare hand-eye coordination.

Mavsar, M., & Ude, A. in [45] present a method, capable of predicting human motion during a handover process by utilizing a state-of-the-art pose estimation framework, a single RGB-D camera and a recurrent neural network.

The paper [46] propose to combine Vision-Language Models (VLMs) for object detection, navigation primitives for movement, and grasping primitives for object manipulation. Based on this OK-Robot offers an integrated solution for pick-and-drop operations without requiring any training.

Reserchers in [47] propose MoMa-LLM, a novel approach that grounds language models within structured representations derived from open-vocabulary scene graphs, dynamically updated as the environment is explored. They tightly interleave these representations with an object-centric action space. Given object detections, the resulting approach is zero-shot, open-vocabulary, and readily extendable to a spectrum of mobile manipulation and household robotic tasks.

The study [48] proposes a learned collision model that accepts scene and query object point clouds and predicts collisions for 6DOF object poses within the scene. The model is trained on a synthetic set of 1 million scene/object point cloud pairs and 2 billion collision queries.

Volume 1, Issue 5

Thus, we see that the variety of tasks related to determining distances to an object is enormous. Later in this article, we will present a solution to this problem using the triangulation method.

Mathematical model for the distance to the object measurement taking into account the error based on the triangulation method

Triangulation is a mathematical approach to the distance to an object measurement by measuring angles and distances from two or more observation points. For collaborative robots that work in close proximity to humans and other objects, triangulation provides the ability to accurately estimate the spatial position of objects in the working area, which is critical for ensuring safety and precision of movements. In this method, at least two sensors or sensors are used, placed at a known distance from each other, which are simultaneously directed at the object to read the reflected signals and determine the time of their passage. Using geometric relationships, you can calculate the distance to the object, taking into account the obtained angles and distances. In collaborative robots, the triangulation method allows for accurate data on the location of objects in real time, which helps robots adapt their movements and avoid collisions, increasing safety and efficiency when working with humans. Figure 1 shows the structural diagram of the study of the use of the triangulation method to determine the distance to the object within the framework of the manipulator robot.

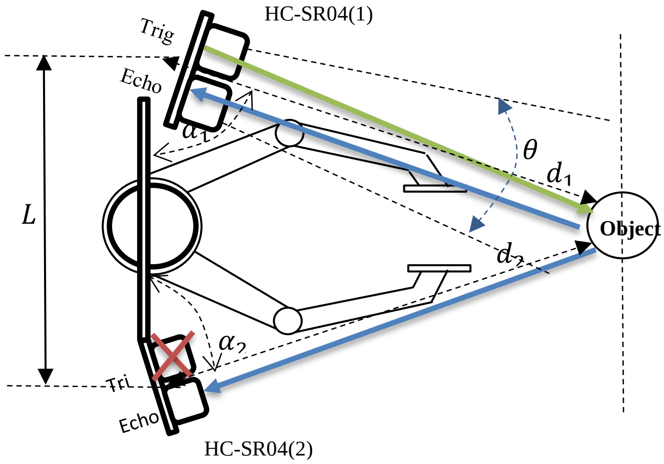

Figure 1: Study scheme of using the triangulation method to determine the distance to the object for the collaborative robot

We will describe the geometry of the system presented in Figure 1: L is the distance between the sensors; α_1 and α_2 are angles from sensor axes to the object; d_1 and d_2 - distances from each of the sensors to the object. Description of system parameters: HC-SR04

(1) and HC-SR04 (2) – ultrasonic sensors with the following technical characteristics: signal frequency ($f = 40kHz$) - frequency of the ultrasonic signal used by the sensors; resolution ($d_{res} = 3mm$) - the minimum distance that the sensor can determine; pulse width ($t_{pulse} = 10\mu s$) - the duration of the TRIG signal, which activates the sensor to start measurement; viewing angle ($\theta = 15^0$) - coverage angle at which the sensor works.

Let us assume that the speed of sound in air (υ) at a temperature of about 20°C is approximately 343 m/s. Then the signal transit time (t) is measured by the HC-SR04(1) sensor and converted into distance according to the formula:

$$d_1 = \frac{\upsilon \cdot t_1}{2} \quad (1)$$

t_1 - pulse transit time from active to receiving sensor HC-SR04(1).

Formula 1 will be similar for the second sensor HC-SR04(2):

$$d_1 = \frac{\upsilon \cdot t_2}{2} \quad (2)$$

t_2 - pulse transit time from active to receiving sensor HC-SR04(2).

To calculate the distance to the object by the triangulation method, we will use the law of cosines, which will make it possible to find the distance (D) to the object from the midpoint between the two sensors:

$$D = \sqrt{\frac{d_1^2 + d_2^2 - 2 \cdot d_1 \cdot d_2 \cdot \cos\theta}{2}} \quad (3)$$

d_1 and d_2 - calculated distances to the object from each sensor;

θ - the angle between the directions of both sensors (which is approximately 15°).

To estimate the error, it is not necessary to take into account the following factors:

- resolution error d_{res} adds uncertainty to d_1 and d_2;
- deviation in the viewing angle can lead to inaccuracy in the measurement θ.

Based on this, the total error (ΔD) can be estimated using the derivative:

$$\Delta D \approx \sqrt{(\frac{\partial D}{\partial d_1} \cdot \Delta d_1)^2 + (\frac{\partial D}{\partial d_2} \cdot \Delta d_2)^2 + (\frac{\partial D}{\partial \theta} \cdot \Delta \theta)^2} \quad (4)$$

Δd_1 and Δd_2 - distance errors due to sensor resolution (3 mm);

$\Delta \theta$ - angle error (set error of the viewing angle in 1-2°).

The proposed mathematical model allows you to calculate the distance to the object, taking into account measurement errors.

To check the validity of the developed mathematical model to calculate the distance to the object, taking into account measurement errors, a prototype was assembled, the photo of which is presented in Figure 2.

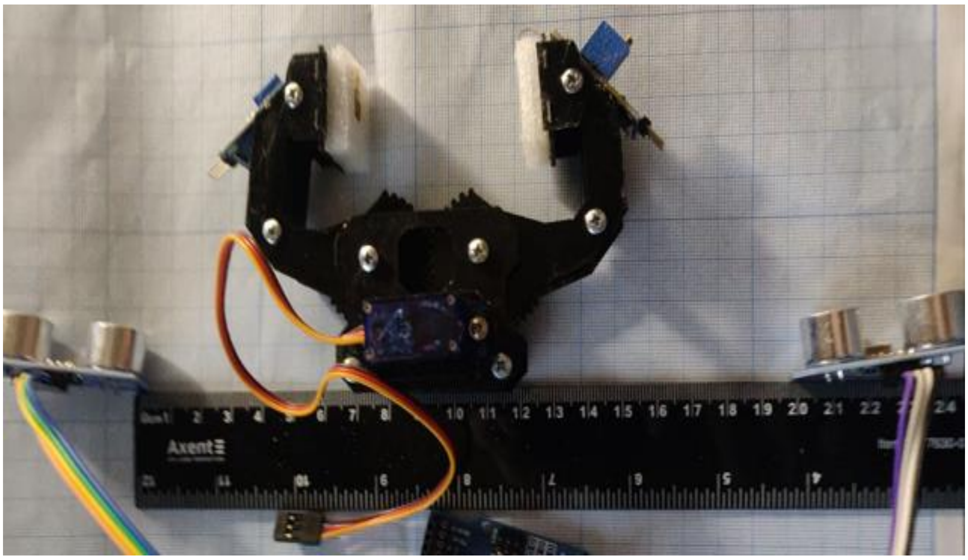

Figure 2: General prototype for research using the triangulation method to determine distance to an object

Development of a program for testing the calculation of the distance taking into account the error to the object by the method of triangulation

The Arduino IDE is the preferred development environment for creating distance-to-object triangulation programs due to its simplicity, broad hardware support, and large user community. This environment offers an intuitive interface and functionality that allows rapid testing and debugging of code, which is essential when working with sensors such as the HC-SR04 for distance and error estimation. Arduino IDE supports direct compilation and loading of programs to microcontrollers, providing a fast development cycle and instant verification of results on real hardware. In addition, the availability of a large number of libraries for working with various sensors and a simple syntax contribute to the effective implementation of algorithms for triangulation calculations.

We will give an example of a software implementation of distance calculation models taking into account the error to the object by the method of triangulation, which was developed in the Arduino IDE environment based on the similar programming language C.

```
const float speedOfSound = 343.0; // Speed of sound in air (m/s)
const float sensorDistance = 0.2; // Distance between sensors (m)
```

This piece of code sets the constants needed for calculations in the program using ultrasonic sensors. The speedOfSound constant specifies the speed of sound in air, which is used to calculate the distance based on the signal's transit time. The constant sensorDistance specifies the distance between two sensors, which is necessary for triangulation calculations, allowing to determine the exact position of the object relative to the sensors.

```
float distance1 = (time1 * speedOfSound) / 2.0;
float distance2 = (time2 * speedOfSound) / 2.0;
```

This piece of code calculates the distance to the object for each of the two ultrasonic sensors using the measured sound pulse travel times (time1 and time2). Each distance is calculated by multiplying the time by the speed of sound and dividing by two, since the pulse travels twice the distance to the object and back. These calculations provide baseline distances that are used to further determine the object's position by triangulation.

```
float theta = radians(15); // Кут нахилу між датчиками (15°)
float D = sqrt((pow(distance1, 2) + pow(distance2, 2) - 2 * distance1 * distance2 * cos(theta)) / 2);
```

This piece of code is used to calculate the distance to the object using the triangulation method, taking into account the angle of inclination between the two ultrasonic sensors. First, the 15° angle is converted to radians for use in trigonometric functions. Then the distance to the object (D) is calculated using the law of cosines, which takes into account the values of the distances from each sensor to the object and the angle between them. This allows you to more accurately determine the position of the object in the robot workspace.

```
float resolutionError = 0.003;
float deltaD = sqrt(pow(resolutionError, 2) + pow(sensorDistance * sin(theta), 2));
```

This piece of code calculates the possible error in measuring the distance to the object, which occurs due to the limitations of the resolution of the sensors and the geometry of their location. The `resolutionError` value defines the base error in the distance measurement for each sensor, while the additional term takes into account the effect of the tilt angle between the sensors. The final error `deltaD` is calculated using the square root of the sum of the squares of these errors, which allows for a more accurate estimate of the total measurement error in the system.

We will conduct a number of experiments to assess the accuracy and speed of distance measurement, taking into account the error to the object by the triangulation method:

Volume 1, Issue 5

- the first experiment is an assessment of the accuracy of distance measurement. The purpose of the experiment is to determine the accuracy of triangulation measurements at different distances to the object and to estimate the error. Experiment procedure:

1. Set the object at different distances (for example, from 10 to 100 cm in steps of 10 cm) from the sensors.
2. For each distance, make 10 measurements, calculate the average value and the error.
3. Display the results as a graph of the average measured value of the distance to the object with an error interval for each point.

- the second experiment is an assessment of the speed of measurement at a variable distance. The purpose of the experiment is to investigate the response time of the system to a change in distance and to evaluate its ability to quickly respond to moving objects. Experiment procedure:

1. Place the object at a distance of 50 cm and quickly move it from 50 to 100 cm.
2. Measure the time required for each data update and plot a graph showing the distance to the object over time.
3. To analyze how quickly the system reacts to a change in distance and how stable the measurements are.

The obtained results of the conducted experiments are shown in Figures 3 and 4.

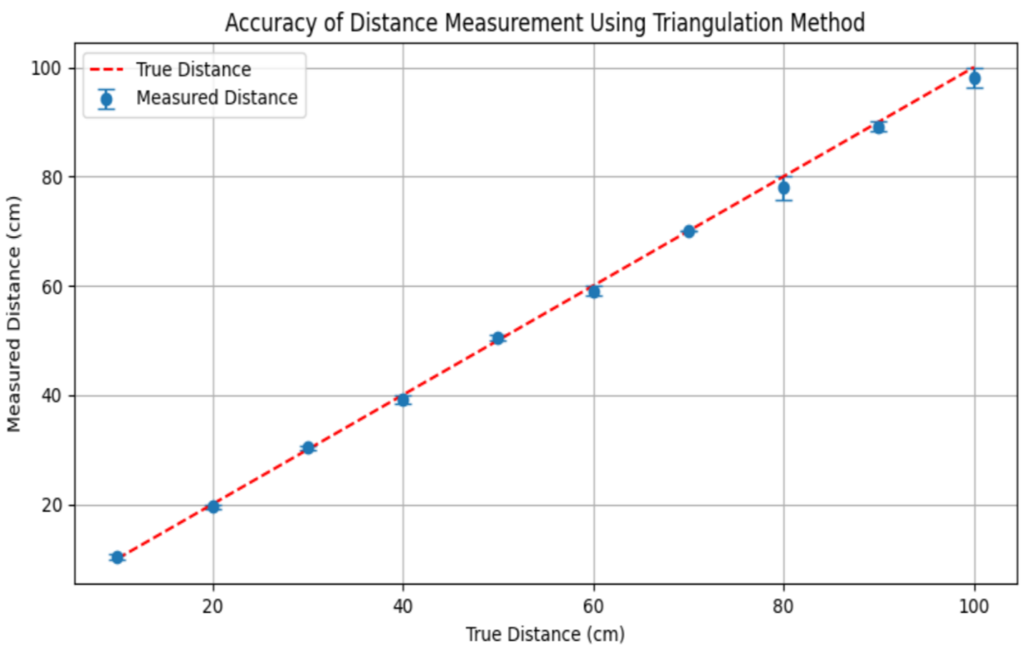

Figure 3: Graph for the first experiment obtained results

As can be seen from Figure 3, the measured values are in good agreement with the real values, although the presence of error is noticeable, especially at long distances. The maximum difference between the real and measured values remains within the margin of error, which indicates the acceptable accuracy of the triangulation method. It can be concluded that the method taking into account the error provides stable results, although with the increase in the distance, some increase in the error may occur, which may be related to the peculiarities of the propagation of sound waves over longer distances.

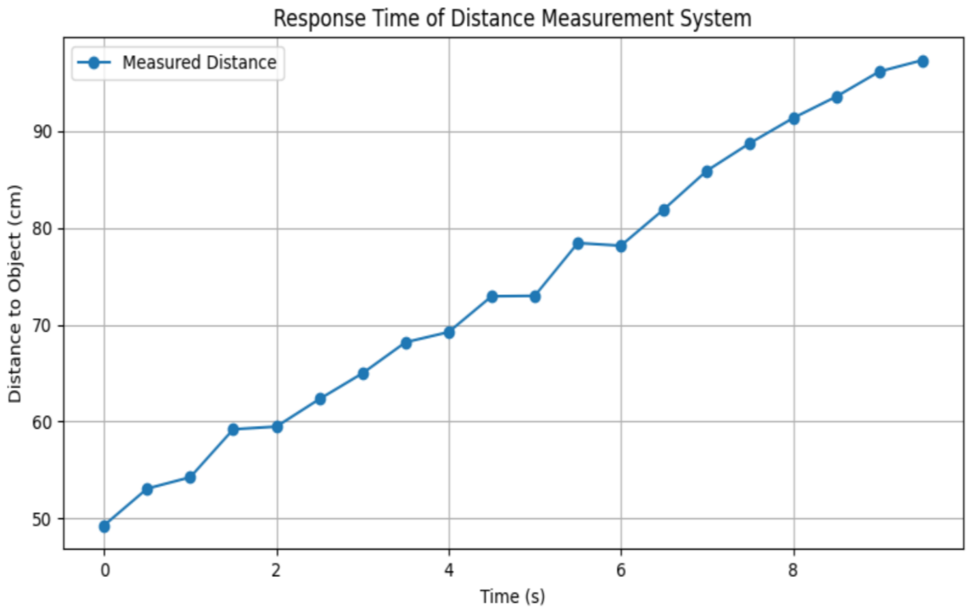

Figure 4: Graph for the second experiment obtained results

As can be seen from the graph of the second experiment, the distance increases approximately linearly with time, which corresponds to the gradual distance of the object. The presence of minor deviations from the main line indicates a random error, which can be caused by both external factors and hardware features of the sensors. The graph demonstrates the stability of the measurements and the prompt response of the system, which indicates the suitability of this approach for tracking dynamic changes in the distance to the object in real time.

Conclusion

The research considered the triangulation method as an effective approach for determining the distance to an object in a collaborative robot workspace. The results of the experiments confirmed that the use of two HC-SR04 ultrasonic sensors allows for high measurement accuracy, even in the presence of errors, which indicates the reliability of this method in dynamic work conditions. The analysis of the obtained data showed that a clear correspondence between real and measured values provides the possibility of successful application of triangulation for tasks of navigation and positioning of robots. In addition, the speed of response of the measurement system to changes in distance confirmed its effectiveness in real conditions, which is an important factor for ensuring the safety and productivity of collaborative robots. The use of triangulation opens up new opportunities for improving robotics algorithms, especially in the context of the concept of Industry 5.0, where interaction between people and machines becomes key. Therefore, this study emphasizes the importance of the development and implementation of new technologies to improve the efficiency and accuracy of collaborative manipulator robots.

References:

1. Gurin, D., & et al. (2024). Using the Kalman Filter to Represent Probabilistic Models for Determining the Location of a Person in Collaborative Robot Working Area. Multidisciplinary Journal of Science and Technology, 4(8), 66-75.
2. Maksymova, S., & et al. (2024). Comparative Analysis of methods for Predicting the Trajectory of Object Movement in a Collaborative Robot-Manipulator Working Area. Multidisciplinary Journal of Science and Technology, 4(10), 38-48.
3. Samoilenko, H., & et al. (2024). Review for Collective Problem-Solving by a Group of Robots. Journal of Universal Science Research, 2(6), 7-16.
4. Chala, O., & et al. (2024). Switching Module Basic Concept. Multidisciplinary Journal of Science and Technology, 4(7), 87-94.
5. Gurin, D., & et al. (2024). Using Convolutional Neural Networks to Analyze and Detect Key Points of Objects in Image. Multidisciplinary Journal of Science and Technology, 4(9), 5-15.
6. Abu-Jassar, A. T., Al-Sharo, Y. M., Lyashenko, V., & Sotnik, S. (2021). Some Features of Classifiers Implementation for Object Recognition in Specialized Computer systems. TEM Journal: Technology, Education, Management, Informatics, 10(4), 1645-1654.
7. Sotnik, S., Mustafa, S. K., Ahmad, M. A., Lyashenko, V., & Zeleniy, O. (2020). Some features of route planning as the basis in a mobile robot. International Journal of Emerging Trends in Engineering Research, 8(5), 2074-2079.
8. Nevliudov, I., & et al.. (2020). Method of Algorithms for CyberPhysical Production Systems Functioning Synthesis. International Journal of Emerging Trends in Engineering Research, 8(10), 7465-7473.
9. Mustafa, S. K., Yevsieiev, V., Nevliudov, I., & Lyashenko, V. (2022). HMI Development Automation with GUI Elements for Object-Oriented Programming Languages Implementation. SSRG International Journal of Engineering Trends and Technology, 70(1), 139-145.
10. Nevliudov, I., Yevsieiev, V., Lyashenko, V., & Ahmad, M. A. (2021). GUI Elements and Windows Form Formalization Parameters and Events Method to

Automate the Process of Additive Cyber-Design CPPS Development. Advances in Dynamical Systems and Applications, 16(2), 441-455.

11. Maksymova, S., Matarneh, R., Lyashenko, V. V., & Belova, N. V. (2017). Voice Control for an Industrial Robot as a Combination of Various Robotic Assembly Process Models. Journal of Computer and Communications, 5, 1-15.
12. Ahmad, M. A., Baker, J. H., Tvoroshenko, I., & Lyashenko, V. (2019). Modeling the structure of intellectual means of decision-making using a system-oriented NFO approach. International Journal of Emerging Trends in Engineering Research, 7(11), 460-465.
13. Lyashenko, V., Abu-Jassar, A. T., Yevsieiev, V., & Maksymova, S. (2023). Automated Monitoring and Visualization System in Production. International Research Journal of Multidisciplinary Technovation, 5(6), 9-18.
14. Abu-Jassar, A. T., Attar, H., Lyashenko, V., Amer, A., Sotnik, S., & Solyman, A. (2023). Access control to robotic systems based on biometric: the generalized model and its practical implementation. International Journal of Intelligent Engineering and Systems, 16(5), 313-328.
15. Al-Sharo, Y. M., Abu-Jassar, A. T., Sotnik, S., & Lyashenko, V. (2023). Generalized Procedure for Determining the Collision-Free Trajectory for a Robotic Arm. Tikrit Journal of Engineering Sciences, 30(2), 142-151.
16. Ahmad, M. A., Sinelnikova, T., Lyashenko, V., & Mustafa, S. K. (2020). Features of the construction and control of the navigation system of a mobile robot. International Journal of Emerging Trends in Engineering Research, 8(4), 1445-1449.
17. Basiuk, V., & et al. (2024). Command system for movement control development. Multidisciplinary Journal of Science and Technology, 4(6), 248-255.
18. Abu-Jassar, A., & et al. (2024). The Optical Flow Method and Graham's Algorithm Implementation Features for Searching for the Object Contour in the Mobile Robot's Workspace. Journal of Universal Science Research, 2(3), 64-75.
19. Vasiurenko, O., Lyashenko, V., Baranova, V., & Deineko, Z. (2020). Spatial-Temporal Analysis the Dynamics of Changes on the Foreign Exchange Market: an Empirical Estimates from Ukraine. Journal of Asian Multicultural Research for Economy and Management Study, 1(2), 1-6.
20. Mustafa, S. K., Ayaz, A. M., Baranova, V., Deineko, Z., Lyashenko, V., & Oyouni, A. A. A. (2020). Using wavelet analysis to assess the impact of COVID-19 on changes in the price of basic energy resources. International Journal of Emerging Trends in Engineering Research, 8(7), 2907-2912.
21. Lyashenko, V. V., Lyubchenko, V. A., Ahmad, M. A., Khan, A., & Kobylin, O. A. (2016). The Methodology of Image Processing in the Study of the Properties of

Volume 1, Issue 5

Fiber as a Reinforcing Agent in Polymer Compositions. International Journal of Advanced Research in Computer Science, 7(1), 15-18.

22. Lyubchenko, V., & et al.. (2016). Digital image processing techniques for detection and diagnosis of fish diseases. International Journal of Advanced Research in Computer Science and Software Engineering, 6(7), 79-83.
23. Lyashenko, V. V., Matarneh, R., Kobylin, O., & Putyatin, Y. P. (2016). Contour Detection and Allocation for Cytological Images Using Wavelet Analysis Methodology. International Journal, 4(1), 85-94.
24. Kuzemin, O., & Lyashenko, V. Microsituation Concept in GMES Decision Support Systems/A. Kuzemin, V. Lyashenko. Intelligent Data Processing in Global Monitoring for Environment and Security (pp. 217–238).–2011.–P, 217-238.
25. Lyashenko, V., Laariedh, F., Ayaz, A. M., & Sotnik, S. (2021). Recognition of Voice Commands Based on Neural Network. TEM Journal: Technology, Education, Management, Informatics, 10(2), 583-591.
26. Orobinskyi, P., Deineko, Z., & Lyashenko, V. (2020). Comparative Characteristics of Filtration Methods in the Processing of Medical Images. American Journal of Engineering Research, 9(4), 20-25.
27. Sotnik S., & et al.. (2022). Key Directions for Development of Modern Expert Systems. International Journal of Engineering and Information Systems (IJEAIS), 6(5), 4-10.
28. Sotnik S., & Lyashenko V. (2022). Prospects for Introduction of Robotics in Service. International Journal of Academic Engineering Research (IJAER), 6(5), 4-9.
29. Lyashenko, V., & Sotnik, S. (2022). Overview of Innovative Walking Robots. International Journal of Academic Engineering Research (IJAER), 6(4), 3-7.
30. Baranova, V., Orlenko, O., Vitiuk, A., Yakimenko-Tereschenko, N., & Lyashenko, V. (2020). Information system for decision support in the field of tourism based on the use of spatio-temporal data analysis. International Journal of Advanced Trends in Computer Science and Engineering, 9(4), 6356-6361.
31. Sotnik, S., & et al.. (2022). Modern Industrial Robotics Industry. International Journal of Academic Engineering Research, 6(1),. 37-46.
32. Lyashenko, V., Kobylin, O., & Baranchykov, Y. (2018, October). Ideology of Image Processing in Infocommunication Systems. In 2018 International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (PIC S&T) (pp. 47-50). IEEE.
33. Lyashenko, V., & Sotnik, S. (2020). Analysis of Basic Principles for Sensor System Design Process Mobile Robots. Journal La Multiapp, 1(4), 1-6.

Volume 1, Issue 5

34. Lyashenko V, Matarneh R, Sotnik S. Modeling of Machine Design with Numerical Control in UG NX 7.5 System. The International Journal of Engineering and Science (IJES), 2018, 7(7), pp. 28-37.
35. Matarneh, R., Sotnik, S., & Lyashenko, V. (2018). Search of the molding form connector plane on the approximation basis by the many-sided surface with use of the convex sets theory. International Journal of Mechanical and Production Engineering Research and Development, 8(1), 977-988.
36. Babker, A. M., Suliman, R. S., Elshaikh, R. H., Boboyorov, S., & Lyashenko, V. (2024). Sequence of Simple Digital Technologies for Detection of Platelets in Medical Images. Biomedical and Pharmacology Journal, 17(1), 141-152.
37. Maksymova, S., & et al. (2024). Balancing System For A Zoomorphic Spot Type Mobile Robot Development Using An Accelerometer MPU 6050 (GY-521). In 2024 IEEE 19th International Conference on the Perspective Technologies and Methods in MEMS Design (MEMSTECH), IEEE, 39-42.
38. Gurin, D., & et al. (2024). Effect of Frame Processing Frequency on Object Identification Using MobileNetV2 Neural Network for a Mobile Robot. Multidisciplinary Journal of Science and Technology, 4(8), 36-44.
39. Kuzmenko, O., & et al. (2024). Robot model for mines searching development. Multidisciplinary Journal of Science and Technology, 4(6), 347-355.
40. Maksymova, S., & et al. (2024). Constructing an optimal route for a mobile robot using a wave algorithm. Journal of Natural Sciences and Technologies, 3(1), 282-289.
41. Gurin, D., & et al. (2024). MobileNetv2 Neural Network Model for Human Recognition and Identification in the Working Area of a Collaborative Robot. Multidisciplinary Journal of Science and Technology, 4(8), 5-12.
42. Cong, Y., & et al. (2021). Underwater robot sensing technology: A survey. Fundamental Research, 1(3), 337-345.
43. Pereira, R., & et al. (2022). Sort and deep-SORT based multi-object tracking for mobile robotics: Evaluation with new data association metrics. Applied Sciences, 12(3), 1319.
44. Liu, W., & et al. (2022). Touchless interactive teaching of soft robots through flexible bimodal sensory interfaces. Nature communications, 13(1), 5030.
45. Mavsar, M., & Ude, A. (2022). RoverNet: Vision-based adaptive human-to-robot object handovers. In 2022 IEEE-RAS 21st International Conference on Humanoid Robots (Humanoids), IEEE, 858-864.
46. Liu, P., & et al. (2024). Ok-robot: What really matters in integrating open-knowledge models for robotics. arXiv preprint arXiv:2401.12202.

47. Honerkamp, D., & et al. (2024). Language-grounded dynamic scene graphs for interactive object search with mobile manipulation. IEEE Robotics and Automation Letters.
48. Danielczuk, M., & et al. (2021). Object rearrangement using learned implicit collision functions. In 2021 IEEE International Conference on Robotics and Automation (ICRA), IEEE, 6010-6017.