Adaptive control methods

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DEVELOPMENT OF A METHOD FOR CORRECTING THE PLACEMENT OF THE REGION OF INTEREST

Abstract. Objective. The process of developing a method for correcting the placement of the region of interest for a tracker has been investigated. The method is based on a nonlinear variable combination methodology that accounts for horizontal and vertical gradients. The justification for selecting the optimal method was carried out considering the number of operations per pixel and the computational complexity of the studied area. The accuracy criterion for region of interest placement correction was variance. To demonstrate the advantages of the proposed method, multiple video streams with varying frame counts were input into the tracker. A comparison was made with the well-known Channel and Spatial Reliability Tracker combined with a Kalman filter featuring different configurations. **Results.** A method for correcting region of interest placement using a nonlinear methodology requiring 8 operations per pixel has been developed. This method operates in conjunction with the tracker. In experimental videos, the variance decreased by an average of 10.25%, whereas existing methods showed deterioration ranging from -3.61% to -47.63%. The obtained results confirmed compliance with Technology Readiness Level 4. **Scientific Novelty.** The developed method for correcting the placement of the examined area in the object tracking task differs from existing ones by using combinations of nonlinear variables that take gradient analysis into account. This allows determining the displacement point of the region of interest based on horizontal and vertical gradients. **Practical Significance.** The proposed method can be used as an additional tool for real-time object tracking.

Keywords: nonlinear variables; object tracking; placement correction; computer vision; artificial intelligence.

Introduction

Modern computer vision tools facilitate the automation of object tracking in video streams. In addition to tracking algorithms, object tracking involves auxiliary tools [1] that depend on the type of tracking algorithm used. Broadly speaking, these include noise filtering, data normalization, and the use of additional algorithms for predicting the placement of the region of interest. The listed procedures require optimization to enhance tracking performance. Therefore, powerful hardware platforms such as NVIDIA Jetson [2] or custom-designed single-board computers [3] are employed. Another approach to improving real-time object processing efficiency is simplifying the computational complexity of algorithms [4].

User requirements in object tracking often involve video resolutions of 1280 × 720 or higher, complicating the processing of each frame. As a result, deep neural networks and high-performance computing systems are utilized [5]. However, existing object tracking tools insufficiently account for nonlinear methods and variable combinations. This research focuses on advancing and exploring this particular direction.

The aim of this study is to improve the efficiency of tracking objects with complex shapes moving along linear and nonlinear trajectories.

Object of study the process of tracking objects with complex shapes.

Subject of study a real-time region of interest placement correction method.

Research Tasks: 1. Develop a method for correcting region of interest placement for a known tracking algorithm in real-time object tracking.

2. Test the region of interest placement correction method to ensure a Technology Readiness Level of at least 4.

A review of related scientific publications. Recent advances in computer vision have been primarily focused on solving segmentation and tracking tasks, often in combination with other tools. In study [6], the integration of neural networks and edge detection methods into a unified approach for analyzing objects in images is explored. The method operates as follows: formation of input images, preprocessing through object edge detection, integration of edge-detected images into a training dataset, and training the model using both original and edge-enhanced images. Study [7] investigates a segmentation algorithm based on fuzzy clustering. The method works by expanding the number of features, then automatically selecting the most significant ones, performing clustering using the T2FCM method, and merging the clustering results with the input data. Several transformations follow, resulting in a halftone image, which is then processed by an adaptive histogram equalization method.

In work [8], image segmentation is performed using the particle swarm optimization algorithm. The main advantage of the proposed method is its ability to select the color of the target area for analysis. A similar study is presented in [9], where machine learning is used to detect the boundaries of objects of interest. One of the key tools used in the research is the EfficientNet-B0 architecture, which performs effectively in cartographic tasks.

A comparable work to that mentioned is study [10], which presents a real-time object tracking system. The authors examine the Cam-Shift algorithm and advanced Kalman filter-based algorithms.

A significant advantage of this study is not only the software implementation and laboratory testing but also practical deployment on dedicated hardware platforms. Real-world applications of computer vision are also discussed in [11], where an onboard camera was used to detect LED colors for controlling a robot. A proportionalintegral-derivative (PID) controller was employed to ensure precise positioning.

When multiple tools–such as audio microphones, infrared cameras, YOLOv2, classifiers, and Kalman filters – are integrated into a single solution, a multisensory object detection system is achieved, as shown in [12]. The value of this research lies in its application for monitoring restricted-access areas. For rapid deployment, tripods are used.

A common characteristic of studies [6–12] is the need for high computational power, as noted in [13]. According to the conclusions in [13], only deep learning models can perform high-quality object detection at 40–60 frames per second. For efficient data processing, the use of remote servers is recommended. Therefore, the authors of study [14] propose tools for error monitoring and correction within a modular arithmetic system. This approach allows for error correction during data processing, thereby enhancing the computational capacity of a single-board computer. A similar development is discussed in [15], where a residue number system is applied.

As stated in [16], existing computer vision algorithms face challenges related to camera occlusion and object motion. One potential solution is the use of convolutional neural networks in combination with Channel and Spatial Reliability Tracking from the OpenCV library [17].

In work [18], the use of deep-learning convolutional neural networks is examined. For moving objects, multispectral image recognition theory and mathematical statistics methods are additionally applied. A similar approach is used in [19].

Another solution is the neural-network training method for intelligent decision-support systems proposed in [20]. To reduce computational complexity, one can employ the approaches discussed in [21].

The methodological approach of using a linear method with nonlinear parameters was proposed in a 2021 study [22]. This method was applied for diagnosing complex systems and had not been explored in computer vision tasks. Between 2021 and 2025, the underlying principle of the method was employed to solve various problems, including those in the economic domain [23]. It was only in 2025 that a decision was made to adopt the principle of constructing nonlinear parameters as the foundation for a region of interest correction method, integrated with a specific tracking technique. While the combination of tracking and filtering for region of interest correction is a well-known approach [24], the proposed study introduces a customized correction method tailored to this purpose.

Formal statement of the research task

To determine the displacement coordinates of the object of interest, it is proposed to use the Channel and Spatial Reliability Tracker [25] in combination with a region of interest correction method. The task is reduced to finding the coordinates of the point to which the region of interest should be shifted. To achieve this, it is necessary to compute the gradient values x1, x2, ...xn and construct the function (1):

$$Ki = f_i(x1, x2, ..., xn),\ i = 1, 2, ..., n. \qquad (1)$$

where f_i – wanted function.

The variance of the position of the object of interest is used as the quality criterion for the correction.

Research methodology

The study of the region of interest correction method involves the use of video materials. To justify the choice of the correction method, Video No. 1 containing 650 frames was used, while the testing of the complete solution was conducted using Video No. 2, which includes over 1150 frames. A well-known challenge in object tracking is the inaccurate determination of the tracked object's position within the bounding box. To correct the position of the object of interest, gradients are used alongside the tracker. These gradients are integrated into a nonlinear evaluation map. The computation of horizontal and vertical gradients forms the basis of the proposed nonlinear correction method.

To reduce the processing load, the calculation of the object's position is performed within the region of interest along with an additional margin area.

The research process includes the following steps:

0. Initialization of the Channel and Spatial Reliability Tracker [25].

1. The input frame undergoes filtering using the Gaussian Blur method [26] with parameters (gray_roi, (3, 3), 0).

2. Gradients are then calculated using the Sobel method [27] with ksize=3.

3. For accurate direction estimation during correction, the gradients are normalized to the [0, 1] range.

4. At this stage, the nonlinear correction method is defined and normalized. This method represents the target function composed of nonlinear combinations of gradients. To determine the optimal number of nonlinear variables, methods based on horizontal gradients as well as combined horizontal and vertical gradients were explored. After each test, the variance was recorded along with the number of operations per pixel and the overall computational complexity of each method. One of the key quality metrics of the proposed method is its computational complexity. Therefore, the developed methods were evaluated by counting the number of operations required for a 100x75 region of interest.

5. Displacement estimation.

6. Exponential smoothing of the tracked object's position.

7. The region of interest position is then updated, and the above computations are repeated.

8. To evaluate the performance of the developed tools, the variance of the tracked object's position with and without correction was used as a quality criterion.

A traditional element of this study is the comparative analysis between the developed correction tool and an existing method based on the variance criterion. As a baseline, the Channel and Spatial Reliability Tracker was also used. For correction, the Kalman filter [28] was employed. To increase the reliability of the comparative analysis, the existing method was evaluated in several configurations. Initially, default Kalman filter parameters were used, including the noise and measurement matrices. Subsequently, these parameters were adaptively tuned. Finally, a modification combining the Channel and Spatial Reliability Tracker, the Kalman filter, and phase correlation was examined.

The main limitation of the study is the video stream performance, which ranges from 25 to 30 frames per second at a resolution of 1280x720.

Experimental research

First and foremost, it is necessary to develop a method for correcting the position of the object of interest based on nonlinear variables. In accordance with the research methodology, several correction methods for object positioning are considered, as shown in Table 1.

As shown in Table 1, methods K1 through K6 consider the approach to locating the displacement point of the tracked area based on horizontal gradients, whereas K7 is constructed using both horizontal and vertical gradients. Let us examine in more detail the number of operations for each Ki, conduct a performance test, and determine the variance of the tracked object's position both without correction and with region of interest position correction.

Among the Ki methods based on searching the displacement point using horizontal gradients, K1 has the lowest number of operations per pixel at 3, which is expected. The highest, 36 operations per pixel, is demonstrated by K5. Considering computational complexity for a specific region of interest – for example, 100x75 pixels – with 36 operations per pixel, the total amounts to 270.000 operations. This significantly complicates the object tracking and region of interest position correction procedure. Other methods exhibit lower computational complexity values.

We take K1 as a baseline and extend it to incorporate both horizontal and vertical gradients, resulting in K7, which requires 8 operations per pixel, equating to 60.000 operations for a 100x75 region. Compared to the others, this is an optimal value, especially considering it processes two types of gradients. The testing results for each implemented Ki method are summarized in Table 2.

Table 1 – **Proposed methods for correcting the position of the object of interest and their computational complexity for a 100x75 region**

The investigated formula for correcting the position of the object of interest	Number of operations per pixel	Computational complexity for a 100×75 region
K1=x1 · x2 + x2 · x3	3	22500
K2=0.5 · (x1 · x2 + x2 · x3)	4	30000
K3=np.sqrt(0.5 · (x1 · x2 + x2 · x3))	14	105000
K4= np.sqrt(0.5 · (x1 · x2 + x2 · x3 +x3·x4))	16	120000
K5=0.5· (√x1√x2 + √x2√x3 + √x3√x4)	36	270000
K6=(√x1√x2 + √x2√x3 + √x3√x4)	35	262500
K7=(x1 · x2+x2 · x3)/2+(y1 · y2+y2 · y3)/2	8	60000

Table 2 – **Results supporting the selection of the object tracking error correction formula**

The investigated formula for correcting the position of the object of interest	Number of operations per pixel	Variance of the tracked object's position without region of interest position correction	Variance of the tracked object's position with region of interest position correction
Method for determining the displacement point of the tracked region based on horizontal gradients			
K1=x1 · x2 + x2 · x3	3	x=2619.43, y=240.67	x=830.42, y=125.22
K2=0.5 · (x1 · x2 + x2 · x3)	4	x=2414.95, y=6.07	x=449.14, y=4.57
K3=np.sqrt(0.5 · (x1 · x2 + x2 · x3))	14	x=1666.16, y=319.71	x=440.84, y=85.51
K4= np.sqrt(0.5 · (x1 · x2 + x2 · x3 +x3·x4))	16	x=3887.49 y=202.89	x=940.58 y=151.34
K5=0.5□(√x1√x2 + √x2√x3 + √x3√x4)	36	x=7674.58 y=36.35	x=1413.59 y=50.57
K6=(√x1√x2 + √x2√x3 + √x3√x4)	35	x=7174.86 y=22.43	x=1300.19 y=46.43
Method for determining the displacement point of the tracked region based on horizontal and vertical gradients			
K7=(x1·x2+x2·x3)/2+(y1·y2+y2·y3)/2	8	x=6961.63, y=79.47	x=2403.98, y= 141.81

Table 2 reveals obvious trends, Ki methods with higher computational complexity per pixel exhibit greater variance along the X-axis. The optimization and specific usage of variables in the Ki methods result in varying levels of variance on the X-axis. Since methods K1 through K6 did not achieve the desired accuracy in correcting the position of the object of interest, only K7 will be used in subsequent studies. This approach combines both horizontal and vertical gradients and demonstrates a more precise correction outcome.

An object tracking experiment was conducted by combining the Channel and Spatial Reliability Tracker with the proposed region of interest position correction tool, as shown in Fig. 1.

As shown in Fig. 1, the proposed tool demonstrates a variance of the tracked object's position without ROI position correction of x =3199.55, y =1517.38, and with correction, x=2885.37, y=1354.75. In percentage terms, the variance decreased by 9.8% along the X-axis and by 10.7% along the Y-axis, averaging a 10.25% reduction overall.

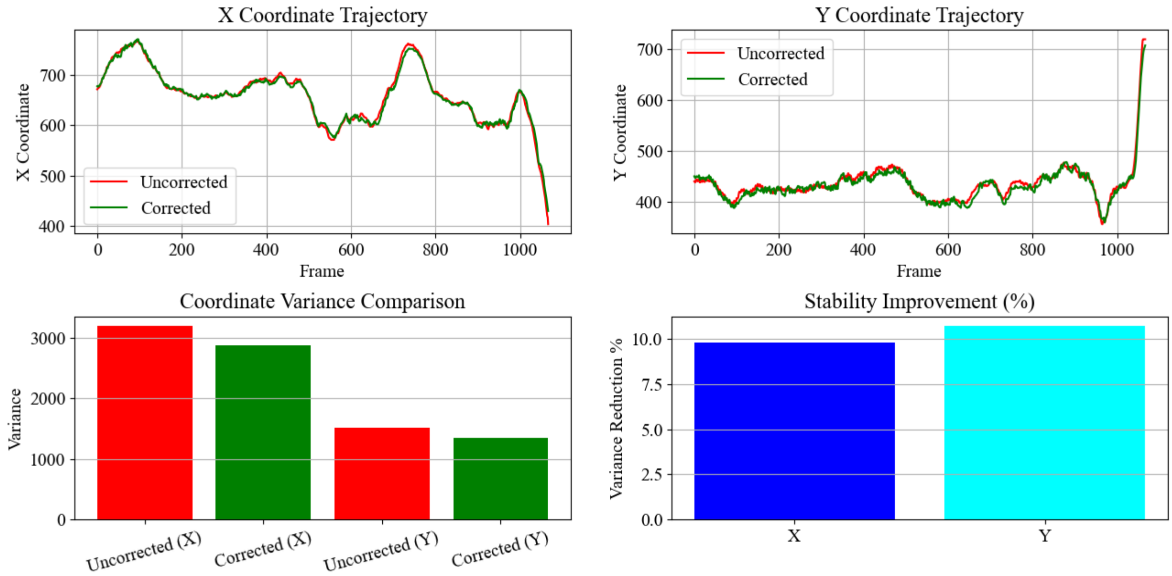

Fig. 1. Experimental Results of the Channel and Spatial Reliability Tracker Combined with the Proposed ROI Position Correction Tool Based on Nonlinear Variables

Let's conduct a comparative analysis of the results obtained by the proposed method and the existing one. The Kalman filter was used with the parameters np.eye(4, dtype=np.float32) · 0.01 and np.array([[1, 0, 0, 0], [0, 1, 0, 0]], np.float32). The use of these parameters demonstrated a negative result, where the correction of the region of interest placement failed. The obtained variance without correction was x=3189.10, y=1520.88, while with correction, it was x=4739.98, y=2230.04, which meets the expected results and proves the superiority of the proposed method. Let's conduct a few more experiments, this time using an adaptive Kalman filter, Fig. 2.

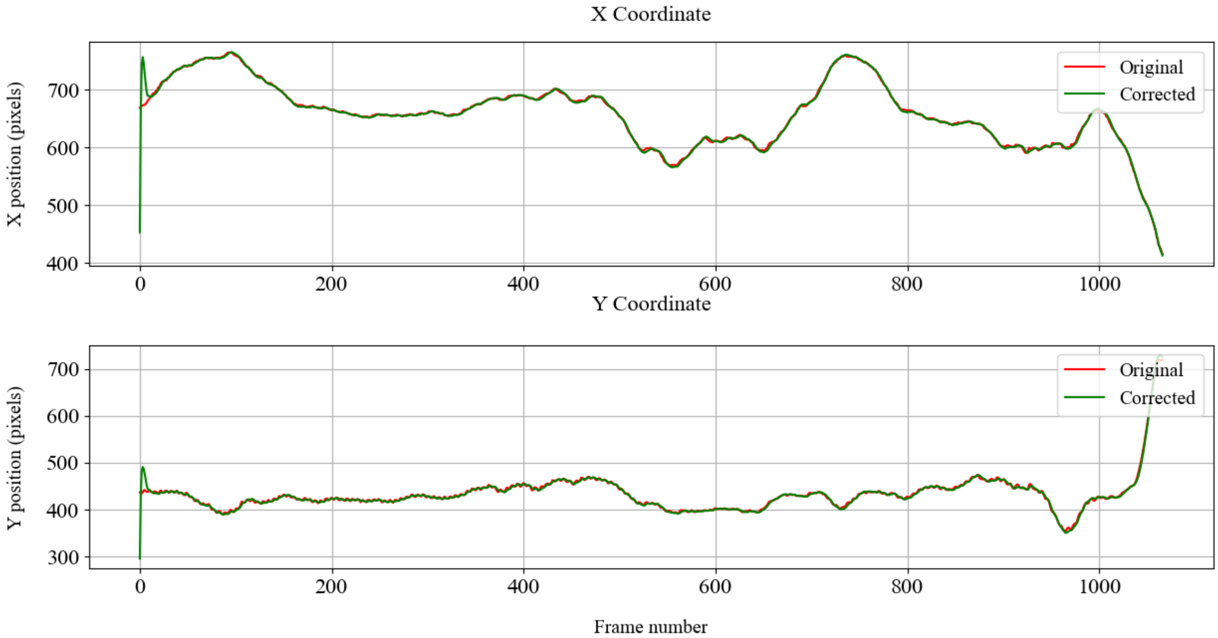

Fig. 2. Experimental results of the Channel and Spatial Reliability Tracker with an adaptive Kalman filter

As can be seen from Fig. 2, the variance without correction is x=3162.22, y=1512.44, while with correction, it is x=3259.23, y=1575.23. In percentage terms, this represents a difference of x= -3.1%, y= -4.2%. This means that with correction, the quality of object tracking deteriorates. Let us consider the results demonstrated by the Channel and Spatial Reliability Tracker with Kalman filter and phase correlation, shown in Fig. 3.

The conventional method without object-of-interest placement correction demonstrates a variance of x=3213.86, y=1504.34, whereas with correction, the variance increases to x=4742.69, y=2179.70. The corrected results were worse than those obtained without object placement correction. To rule out potential errors and subjective factors, the existing method was tested five additional times, yielding similar results. The observed variance was negligible (less than 1%), depending on the size of the region of interest manually outlined by the operator. Let us summarize the obtained research findings for comparative analysis, Table 3.

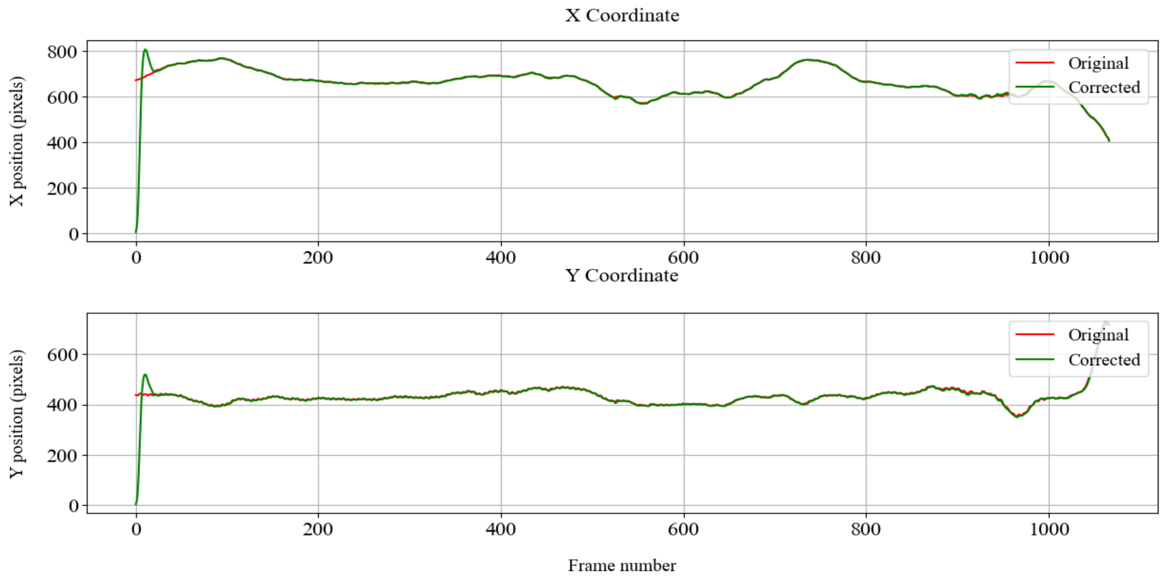

Fig. 3. Experimental results of the Channel and Spatial Reliability Tracker with Kalman filter and phase correlation

Table 3 – **Summary results of the study on methods for correcting the placement of the region of interest in tracking tasks**

Method Name	Variance of the tracked object's position		Variance difference	Conclusion
	without region of interest placement correction	with region of interest placement correction		
Channel and Spatial Reliability Tracker with the proposed correction tool	x=3199.55, y=1517.38	x=2885.37, y=1354.75	x= –314.18 y= –162,63	Decrease in variance, – improvement in tracking accuracy, average improvement of 10.27%
Channel and Spatial Reliability Tracker with Kalman filter	x=3189.10, y=1520.88	x=4739.98, y=2230.04	x=+1550.88 y=+709.16	Increase in variance, – deterioration in tracking accuracy by 47.63%
Channel and Spatial Reliability Tracker with adaptive Kalman filter	x=3162.22, y=1512.44	x=3259.23, y=1575.23	x=+97.01 y=+62.79	Increase in variance, – deterioration in tracking accuracy by 3.61%
Channel and Spatial Reliability Tracker with Kalman filter and phase correlation	x=3213.86, y=1504.34	x=4742.69, y=2179.70	x=+1528.83 y=+675.36	Increase in variance, – deterioration in tracking accuracy by 46.23%

As shown in Table 3, the proposed correction tool is the optimal method for adjusting the region of interest, as it demonstrates improved tracking accuracy through reduced variance. This can be attributed to the specific design of the correction approach, which incorporates combinations of nonlinear variables along with gradient analysis. In percentage terms, the proposed method enhances object tracking performance by 10.27%, whereas existing methods degrade performance by between -3.61% and -47.63%. The obtained research results can be used as additional tools for the information security system [29–32].

Conclusions

1. The task of developing a method for correcting the region of interest placement for a tracker is addressed by using a combination of nonlinear variables while accounting for gradient analysis. This approach allows for the consideration of gradients along both the vertical and horizontal planes with optimal computational complexity, requiring only 8 operations per pixel or 60.000 for a 100x75 region. Naturally, as the region of interest increases, the computational complexity will also rise. Testing the method for determining the shift point of the tracked object's region while accounting for horizontal and vertical gradients demonstrated a reduction in the variance of the tracked object's position with region-of-interest correction.

2. The task of testing the region-of-interest placement correction method to ensure a technology readiness level no lower than 4 is addressed by using known videos for controlled testing. Laboratory studies have shown that the proposed method improves the object tracking process by 10.27%, whereas existing methods degrade performance, ranging from –3.61% to –47.63%. The technology operates in laboratory conditions and is ready for further testing in real-world scenarios.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

REFERENCES

1. Mirakhorli M. and Cleland-Huang J. (2016), "Detecting, Tracing, and Monitoring Architectural Tactics in Code", *IEEE Transactions on Software Engineering*, vol. 2, no. 3, pp. 205–220, doi: https://doi.org/10.1109/tse.2015.2479217
2. Sarvajcz, K., Ari, L., and Menyhart, J. (2024), "AI on the Road: NVIDIA Jetson Nano-Powered Computer Vision-Based System for Real-Time Pedestrian and Priority Sign Detection", *Applied Sciences*, vol. 14(4), article number 1440, doi: https://doi.org/10.3390/app14041440
3. Yanko, A., Krasnobayev, V., Hlushko, A., and Goncharenko, S. (2025), "Neurocomputer operating in the residue class system", *Advanced Information Systems*, vol. 9, no. 2, pp. 84–92, doi: https://doi.org/10.20998/2522-9052.2025.2.11
4. Lackner, M., and Skowron, P. (2023), *Multi-Winner Voting with Approval Preferences*, Springer International Publishing, doi: https://doi.org/10.1007/978-3-031-09016-5
5. Dai, Y., Kim, D., and Lee, K. (2024), "An Advanced Approach to Object Detection and Tracking in Robotics and Autonomous Vehicles Using YOLOv8 and LiDAR Data Fusion", *Electronics*, vol. 13(12), doi: https://doi.org/10.3390/electronics13122250
6. Radionov, Y. D., Kashtan, V. Y., Hnatushenko, V. V., and Kazymyrenko, O. (2024), "Aircraft detection with deep neural networks and contour-based methods", *Radio Electronics, Computer Science, Control*, no. 4, pp. 121–129, doi: https://doi.org/10.15588/1607-3274-2024-4-12
7. Akhmetshina, L. G., Yegorov A. A., and Fomin A. A. (2025), "Segmentation of low-contrast images in the basis of eigen subspaces of type-2 fuzzy membership functions", *Radio Electronics, Computer Science, Control*, no. 1, pp. 164–174, doi: https://doi.org/10.15588/1607-3274-2025-1-15
8. Khudov, H., Khudov, V., Makoveichuk, O., Khizhnyak, I., Hridasov, I., Shamrai, N. and Lisohorskyi, B. (2025), "Development of an image segmentation method from unmanned aerial vehicles based on the particle swarm optimization algorithm", *Technology Audit and Production Reserves*, vol. 3(2(83)), pp. 88–95, doi: https://doi.org/10.15587/2706-5448.2025.330973
9. Kashtan, V. Y., and Hnatushenko, V. V. (2024), "Machine learning for automatic extraction of water bodies using Sentinel-2 imagery", *Radio Electronics, Computer Science, Control*, no. 1, pp. 118–127, doi: https://doi.org/10.15588/1607-3274-2024-1-11
10. Fiyad, H. M. N., Abozied, M. A. H., Metwally, H. M. B., and Abd El-Naeem, M. A. E.-H. (2023), "Improved Real Time Target Tracking System Based on Cam-shift and Kalman Filtering Techniques" *Journal of Applied Research and Technology*, vol. 2, pp. 297–308, doi: https://doi.org/10.22201/icat.24486736e.2023.21.2.1565
11. Zou, J.-T., and Dai, X.-Y. (2022), « The Development of a Visual Tracking System for a Drone to Follow an Omnidirectional Mobile Robot", *Drones*, vol. 6(5), 113, doi: https://doi.org/10.3390/drones6050113
12. Svanström, F., Alonso-Fernandez, F., and Englund, C. (2022), "Drone Detection and Tracking in Real-Time by Fusion of Different Sensing Modalities", *Drones*, vol. 6(11), 317, doi: https://doi.org/10.3390/drones6110317
13. Ahmad Bilal Zaidi, and Sadaf Zahera. (2023), "Real-time object detection and video monitoring in Drone System", *International Research Journal of Engineering and Technology*, vol. 10, issue 8, pp. 432–443, available at: https://www.irjet.net/archives/V10/i8/IRJET-V10I873.pdf
14. Krasnobayev V., Yanko A. and Kovalchuk D. (2023), "Control, Diagnostics and Error Correction in the Modular Number System", *Computer Modeling and Intelligent Systems*, vol. 3392, pp. 199–213, doi: https://doi.org/10.32782/cmis/3392-17
15. Krasnobayev, V., Kuznetsov, A., Yanko, A., and Kuznetsova, T. (2020), "The analysis of the methods of data diagnostic in a residue number system", *3rd International Workshop on Computer Modeling and Intelligent Systems (CMIS-2020)*, 2608, pp. 594–609, doi: https://doi.org/10.32782/cmis/2608-46
16. Farkhodov, K., Lee, S.-H., and Kwon, K.-R. (2020), "Object Tracking using CSRT Tracker and RCNN", *7th International Conference on Bioimaging*, SCITEPRESS – Science and Technology Publ., doi: https://doi.org/10.5220/0009183802090212
17. Datsenko, S., and Kuchuk, H. (2023), "Biometric authentication utilizing convolutional neural networks", *Advanced Information Systems*, vol. 7, no. 2, pp. 67–73, doi: https://doi.org/10.20998/2522-9052.2023.2.12
18. Yaloveha, V., Hlavcheva, D., Podorozhniak, A. and Kuchuk, H. (2019), "Fire hazard research of forest areas based on the use of convolutional and capsule neural networks", *2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering, UKRCON 2019 – Proceedings*, doi: http://dx.doi.org/10.1109/UKRCON.2019.8879867
19. Kuchuk, H., Podorozhniak, A., Liubchenko, N. and Onischenko, D. (2021), "System of license plate recognition considering large camera shooting angles", *Radioelectronic and Computer Systems*, vol. 2021 (4), pp. 82–91, doi: https://doi.org/10.32620/REKS.2021.4.07
20. Kashkevich, S., Kuchuk, H., Plekhova, G., Davydov, V., Yefymenko, O. and Beketov, Y. (2024), "The development of methods of learning artificial neural networks of intelligent decision-making support systems", *Information and Control Systems Modelling and Optimizations*, pp. 102–137, doi: https://doi.org/10.15587/978-617-8360-04-7.CH4
21. Kuchuk, H., Mozhaiev, O., Kuchuk, N., Tiulieniev, S., Mozhaiev, M., Gnusov, Y., Tsuranov, M., Bykova, T., Klivets, S., and Kuleshov, A. (2024), "Devising a method for the virtual clustering of the Internet of Things edge environment", *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 9 (127), pp. 60–71, doi: https://doi.org/10.15587/1729-4061.2024.298431
22. Laktionov, A. (2021), "Improvement of methods for determination of quality indices of interaction elements of system subsystems", *Eastern-European Journal of Enterprise Technologies*, vol. 6(3(114)), pp. 72–82, doi: https://doi.org/10.15587/1729-4061.2021.244929
23. Onyshchenko, S., Hlushko, A., Laktionov, O., and Bilko, S. (2025), "Technology for determining weight coefficients of components of information security", *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, vol. 1, pp. 96–103, doi: https://doi.org/10.33271/nvngu/2025-1/096
24. Omeragic, T., and Velagic, J. (2020), "Tracking of Moving Objects Based on Extended Kalman Filter", *2020 International Symposium ELMAR*, IEEE, doi: https://doi.org/10.1109/elmar49956.2020.9219021
25. (2025), *GitHub – abhiWriteCode/Object-Tracking: Object tracking using OpenCV*, public, GitHub, available at: https://github.com/abhiWriteCode/Object-Tracking

26. (2025), *OpenCV: Smoothing Images*. OpenCV, available at: https://docs.opencv.org/4.x/d4/d13/tutorial_py_filtering.html
27. (2025), Sobel – *SciPy v1.16.0, Manual. Numpy and Scipy Documentation – Numpy and Scipy documentation*, available at: https://docs.scipy.org/doc/scipy/reference/generated/scipy.ndimage.sobel.html
28. Pei, Y., Biswas, S., Fussell, D. S., and Pingali, K. (2019), "An elementary introduction to Kalman filtering", *Communications of the ACM*, vol. 62(11), pp. 122–133, doi: https://doi.org/10.1145/3363294
29. Kyrychok, R., Laptiev, O., Lisnevsky, R., Kozlovsky, V. and Klobukov V. (2022), "Development of a method for checking vulnerabilities of a corporate network using Bernstein transformations", *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 9 (115), pp. 93–101, doi: https://doi.org/10.15587/1729-4061.2022.253530
30. Onyshchenko, S., Yanko, A., Hlushko, A., Maslii, O. and Cherviak, A. (2023), "Cybersecurity and Improvement of the Information Security System", *Journal of the Balkan Tribological Association*, vol. 29 (5), pp. 818–835, available at: https://scibulcom.net/en/article/L8nV7It2dVTBPX09mzWB
31. Rezanov, B., and Kuchuk, H. (2023), "Model of elemental data flow distribution in the Internet of Things supporting Fog platform", *Innovative Technologies and Scientific Solutions for Industries*, vol. 2023(3), pp. 88–97, doi: https://doi.org/10.30837/ITSSI.2023.25.088
32. Onyshchenko, S., Yanko, A., and Hlushko, A. (2023), "Improving the efficiency of diagnosing errors in computer devices for processing economic data functioning in the class of residuals", *Eastern-European Journal of Enterprise Technologies*, vol. *5*(4(125)), pp. 63-73, doi: https://doi.org/10.15587/1729-4061.2023.289185

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Розробка методу корекції розміщення регіону інтересу

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Анотація. Мета. Процес підвищення ефективності супроводу об'єктів складних форм, що рухаються із лінійними та нелінійними траєкторіями. **Методика.** Досліджено процес розробки методу корекції розміщення регіону інтересу для трекери. В основу методу покладено методологію комбінацій нелінійних змінних, що враховують горизонтальні та вертикальні градієнти. Обгрунтування вибору оптимального методу здійснювалося із врахуванням кількості операцій на піксель та обчислювальної складності досліджуваної області. Критерієм точності корекції розміщення регіону інтересу була дисперсія. Для доведення переваг запропонованого методу використовувалося кілька відеопотоків із різною кількістю кадрів, які подавалися на вхід трекеру. Порівняння здійснювалося із відомим трекером Channel and Spatial Reliability Tracker у поєднанні з фільтром Калмана, що мав різні налаштування. **Результати.** Розроблено метод корекції розміщення регіону інтересу з використанням нелінійної методології, що має 8 операцій на піксель. Він використовується у взаємодії із трекером. На експериментальному відео дисперсія зменшилася у середньому на 10,25%, у той час як існуючі методи продемонстрували погіршення від -3.61% до -47.63%. Отримані результати підтвердили підтримку вимог Technology Readiness Level 4. **Наукова новизна.** Розроблений метод корекції розміщення досліджуваної області у задачі супроводу об'єктів відрізняється від існуючих використанням комбінацій нелінійних змінних із врахуванням аналізу градієнтів. Це дозволяє знаходити точку зсуву регіону інтересу на основі горизонтальних і вертикальних градієнтів. **Практична значимість.** Розроблений метод може бути використаний як додатковий інструмент супроводу об'єктів у онлайн режимі.

Ключові слова: нелінійні змінні; супровід об'єктів; корекція розміщення; комп'ютерний зір; штучний інтелект.