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АДАПТИВНИЙ КОМП’ЮТЕРНИЙ ЗІР
ADAPTIVE VISION AI

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Abstract. *As of today, computer vision systems are continuously developing and systematically improving. Machines see visual content in the form of numbers, in which each pixel represents its own piece of information. Computer vision, as a component of artificial intelligence, allows machines to see, observe and understand everything. It enables computer systems to obtain useful information from digital images, video, visual data and perform programmed actions. Computer vision technologies rely on pattern recognition, machine learning, and neural networks to allow computers to break down images, interpret data, and identify features. Tracking moving objects and their identification is a difficult task, as it requires the accuracy of pattern recognition. An untrained computer vision algorithm is unable to understand the relationship between the shapes in the image and the objects. Therefore, the algorithm must be trained. The paper considers models that are trained on a high-performance computing cluster with GPU support. The developed open source software allows detection, tracking and recognition of blurry moving objects with the help of artificial intelligence that adapts to any video camera. A significant increase in accuracy is achieved thanks to machine learning.*

Анотація. *На сьогоднішній день системи комп'ютерного зору постійно розвиваються і систематично вдосконалюються. Машини бачать візуальний вміст у формі чисел, у яких кожен піксель представляє власну частину інформації. Комп’ютерний зір, як компонент штучного інтелекту, дозволяє машинам бачити, спостерігати та розуміти все. Це дозволяє комп’ютерним системам отримувати корисну інформацію з цифрових зображень, відео, візуальних даних і виконувати запрограмовані дії. Технології комп’ютерного зору покладаються на розпізнавання образів, машинне навчання та нейронні мережі, щоб дозволити комп’ютерам розбивати зображення, інтерпретувати дані та ідентифікувати особливості. Відстеження рухомих об'єктів та їх ідентифікація є складним завданням, оскільки вимагає точності розпізнавання образів. Ненавчений алгоритм комп’ютерного зору не в змозі зрозуміти зв’язок між формами на зображенні та об’єктами. Тому алгоритм необхідно навчити. У статті розглядаються моделі, які навчаються на високопродуктивному обчислювальному кластері з підтримкою GPU. Розроблене програмне забезпечення з відкритим кодом дозволяє виявляти, відстежувати та розпізнавати розмиті рухомі об’єкти за допомогою штучного інтелекту, який адаптується до будь-якої відеокамери. Значне підвищення точності досягається завдяки машинному навчанню.*

Ключові слова*:* штучний інтелект, розпізнавання образів, комп’ютерний зір, машинне навчання, нейронні мережі, нечіткі рухомі об’єкти

Keywords: artificial intelligence, pattern recognition, computer vision, machine learning, neural networks, fuzzy moving objects

Introduction

Today, various services using computer vision technologies, which allow machines to visually observe, conduct video analytics and understand the environment, are appearing en masse in the world. The need to automate management processes in a digital society, the development of artificial intelligence and machine learning, and the use of high-performance computing systems by business create a demand for computer vision (Computer Vision, CV).

IT market giants that have adopted a strategy to develop computer vision industry: Intel Corporation, Texas Instruments Incorporated, Cognex Corporation, Keyence Corporation, Sony Corporation, Basler AG, Omron Corporation., Mediatek Inc., National Instruments Corporation, Teledyne Technologies Incorporate intensively develop and implement new IT products, which contribute to the growth of demand for computer vision technologies around the world. According to the computer vision market study conducted by Allied Market Research, the global computer vision market was valued at USD 15 billion in 2022 and is forecast to reach USD 82.1 billion by 2032, growing at 18.7% on average from 2023 to 2032 [1].

Over the past ten years, the accuracy of computer vision has grown significantly. It is expected that the technology will improve to an unprecedented level thanks to modern algorithms and image segmentation methods [2].

Artificial intelligence models are capable of self-learning and creating completely new content. The well-known research company Gartner publishes a list of the ten most important strategic technological trends for the next year every year. According to the conducted research, among the 10 strategic technological trends for 2024, generative artificial intelligence was identified (artificial intelligence, AI). According to forecastsAccording to Gartner, by 2026, more than 80% of companies worldwide will work with generative APIs and artificial intelligence models or implement GenAI support in production environments [3].

The potential of artificial intelligence allows you to instantly collect and analyze extremely large volumes of data from various sources, predict various unforeseen situations, and reduce the risks associated with decision-making. That is, the main direction of this industry is the development of technological solutions that work according to the principle of human intelligence.

Ukraine is a member of the Special Committee on Artificial Intelligence of the Council of Europe. The concept of the development of artificial intelligence in Ukraine envisages the introduction of artificial intelligence technologies in the fields of education, economy, public administration, cyber security, defense and other fields to ensure Ukraine's long-term competitiveness in the international market [4].

The Ministry of Digital Transformation, in turn, presented the Roadmap for regulating artificial intelligence in Ukraine. The goal of the road map is to build the brand of Ukraine as a digital nation in the field of artificial intelligence. In particular, it is planned to create national information systems, platforms and products using artificial intelligence that will detect, prevent and neutralize information threats [5].

As noted by James Anderson, former US Deputy Secretary of Defense, artificial intelligence technologies will increase the speed and lethality of new military platforms; air, sea, ground and space unmanned platforms controlled by artificial intelligence will spread in the coming years [6].

Machine learning is needed to teach computers to classify images by providing them with thousands of images of objects. Each image has labels and tags that identify the object itself. CNN enhances machine learning processes to help a computer create a pixel representation of an object. Using the pixels and their associated labels, the computer predicts what the object is and continuously checks its accuracy until it makes a consistent and correct identification. Computer vision extends even to rows of images and videos using a recurrent neural network (RNN). Using RNN allows computers to identify and connect multiple images [7].

The second technology of modern artificial intelligence is image recognition [8]. Based on the analysis, we list the main differences between these two artificial intelligence technologies: computer vision and image recognition in Table1.

Table 1 - Main differences between computer vision and image recognition technologies

N with/p	**Name**	**Model of computer vision**	**Image recognition model**
1.	opportunities	analysis of images for their recognition and classification of the object in the image, as well as responding to these objects	analyzing and interpreting visual content to derive meaningful information
2.	the main purpose of the model	identification and recognition of patterns or objects in digital media, including images and videos, tracking the movement of an object in a frame	image classification based on predefined labels and categories, train the model to recognize objects in images
3.	use of technology	uses machine and deep learning algorithms to detect objects in an image by analyzing each individual pixel in the image	uses machine and deep learning models to identify objects by analyzing each individual pixel in an image, the algorithm transmits as many labeled images as possible
4.	Work process: 1st step	collect sufficient data, which may include images, GIFs, videos or live streams; the data is then processed to remove any noise or unwanted objects	collecting and labeling a dataset with images, for example, an image with a car should be labeled as "car"; the larger the data set, the better the results
5.	Work process: 2nd step	from the training data, the model detects and localizes objects by characteristics and classifies them according to predefined labels or categories	labeled images are fed to neural networks for image training
6.	Work process: 3rd step	semantic segmentation, dividing the image into several segments, each of which represents a separate object or area of the image; selected parts of the image help to get meaningful information.	training of neural networks on dataset, CNN models are able to detect features in the data without any additional human intervention
7.	Work process: 4th step	data analysis, data is analyzed and processed according to the location of the object	testing unknown images, the model uses its knowledge from the test data set to recognize objects or patterns present in the image

As can be seen from the analysis, the purpose of image recognition is to detect and identify objects in the image. Instead, computer vision aims not only to recognize objects in digital media, including images and videos, but also to respond to them. Thus, the main difference between image recognition and computer vision is that image recognition is only concerned with detecting an object in an image, whereas computer vision not only focuses on object detection but also tries to understand the content of the image. and determine its spatial location.

Under unclear objects we will understand visual objects that reflect an object, the image of which contains obstacles, obstacles, distortions of varying intensity, which do not allow to clearly and unambiguously identify this object.

Analysis of literary data and statement of the problem

Richard Szelski's seminal book Computer Vision: Algorithms and Applications [9] serves as an important resource for understanding the early development of computer vision. Szelski's work provides a comprehensive overview of the algorithms that laid the foundation for modern computer vision techniques.

It covers a range of topics from image formation and feature detection to more complex aspects of scene reconstruction and object recognition. This book not only provides historical context, but also delves into the mathematical and algorithmic foundations of key computer vision operations, making it an indispensable resource for understanding the evolution of the field of artificial intelligence. The evolution of computer vision technologies from their initial forms to modern complex systems has been a path of constant innovative development and improvement.

Basic bookDeep Learning by Ian Goodfellow, Joshua Bengio, and Aaron Corville [10] provides a comprehensive overview of the underlying theories of deep learning. This text dives into the mechanics of neural networks, discussing concepts such as convolutional neural networks (CNNs) and their importance in image recognition and classification tasks.

The use of CNNs in computer vision, a key focus of modern research, has led to significant improvements in the accuracy of object detection and tracking. Unlike traditional methods that have relied heavily on manual feature extraction, CNNs automatically learn to identify the most relevant features from input images. This capability has not only improved the accuracy of object detection systems, but also enabled the development of real-time tracking algorithms capable of handling dynamic scenes and diverse conditions.

The advent of deep machine learning has introduced solutions to some of these challenges. For example, the use of Recurrent Neural Networks (RNNs) and Long-Term and Short-Term Memory (LSTM) networks has improved the ability of tracking systems to deal with temporal dependencies and object closures. These networks are able to remember past states, which is important for maintaining the identity of an object over time, even when it temporarily disappears from view [11-16].

Over the last decade, the world has developed various information technology tools and algorithms for recognizing visual images and moving images using neural network architectures, computer vision for controlling robots, and video surveillance in crime prevention systems. Modern scientists N. Klingler (Nico Klingler), M. Rezai (Mahdi Rezaei) and M. Azarmi (Mohsen Azarmi) have developed a hybrid system of computer vision based on personal learning to automate the recognition of people in the crowd using ordinary video surveillance cameras.

The available achievements of computer vision have high indicators, but mainly in conditions specially created for this. In real life, the performance of computer vision is significantly reduced due to various weather conditions, insufficient lighting, blurring and interference of the image, non-uniformity of the background, unstable position of the video camera itself.

All this determines the need for further research aimed at the development of complex computer vision systems that mutually take into account the collection, processing, storage, and recognition of moving video content in conditions of insufficient visibility. This existing problem determined the direction of my research.

The purpose and tasks of the research

The aim and task of the research are:

1. To analyze the capabilities of image recognition models, computer vision and image classification based on predefined labels.
2. To analyze the application of computer vision algorithms for video image recognition.
3. Choose technologies for creating software using methods of artificial intelligence - machine learning.
4. To develop an adaptive computer vision system that will automatically change the algorithm of its functioning in order to achieve the optimal result when external conditions change.
5. Create a demonstration version of practical scenarios for using the developed adaptive computer vision for recognizing video images of fuzzy moving objects.

Research methods and materials

The materials of research are the processes of collection, processing, analysis and interpretation of static or video data obtained with the help of cameras or sensors in various environments.

Research methods include image processing, pattern recognition, machine learning, neural network training, and artificial intelligence technologies.

Based on these research methods and materials, computer vision is capable of classifying a wide range of images, detecting moving and stationary objects, segmenting them, tracking and recognizingfuzzy objects.

Research results

This work is devoted to the study of computer vision methods suitable for processing fuzzy video images in real time. The significance of this research lies in the development of an adaptive automated system based on artificial intelligence capable of self-learning for the recognition and identification of unclear objects in conditions of insufficient visibility.

Object of study- computer vision processes that identify, track and recognize fuzzy moving objects in video images and video sequences.

Subject of study- models and methods of information technologies for the identification and classification of dynamic objects to solve the problems of recognizing fuzzy objects in real-time video images using the architecture of deep neural networks used to work in conditions of difficult visibility;

- in the development of computer vision models based on deep neural networks, machine learning methods, data augmentation technologies (data augmentation), data preprocessing technologies (cleaning, Gaussian blur filtering, color conversion, adaptive threshold processing, Ot algorithm) were used

Development tools -Python acts not only as a programming language, but also as a core tool that offers a rich ecosystem of libraries and frameworks, especially useful for applications in the field of artificial intelligence and machine learning. Its simple syntax and powerful data processing capabilities make it ideal for processing and analyzing complex visual data. OpenCV is the basis of our computer vision tasks. Its extensive library offers tools for real-time image processing, which is essential for accurate and efficient object detection and tracking. OpenCV's ability to interact with Python improves our system's ability to handle complex visual tasks.

Deep learning frameworks, which are integrated into the Python environment, provide the foundation for our artificial intelligence models. These frameworks facilitate the development of sophisticated neural networks capable of learning and recognizing complex patterns in visual data. The adaptability and reliability of these frameworks are critical for handling the nuances of object detection and tracking.

The Open Neural Network Exchange (ONNX), which is a necessary element of our methodology, offers a platform-independent format for artificial intelligence models. This interoperability capability makes our models flexible and adaptable, able to be deployed on different platforms without significant modifications.

Real-time processing technology is an integral part of system reactivity. It provides fast analysis of visual data and allows the system to track objects in dynamic real conditions. Integrating real-time processing with artificial intelligence models results in a system that is not only accurate, but also capable of working in different environments and conditions.

Together, these technologies form a complex and interwoven system. Their integration is key to achieving our research goals, which allows for high detection and tracking capabilities of fuzzy objects, and provides a framework for continuous learning and improvement.[4]

Discussion of results

Let's consider the adaptive system of detection, identification and tracking of fuzzy objects based on artificial intelligence developed by us. This self-learning computer vision system allows real-time detection, analysis, identification and tracking of fuzzy objects even in difficult climatic conditions. We will demonstrate the work of the created adaptive computer vision in Figures 1, 2.

draw - a draw – b draw - c

Fig. 1 - demonstration of tracking operation:
a – default AI work, b – error in work, c – launching "Tracking" self-study

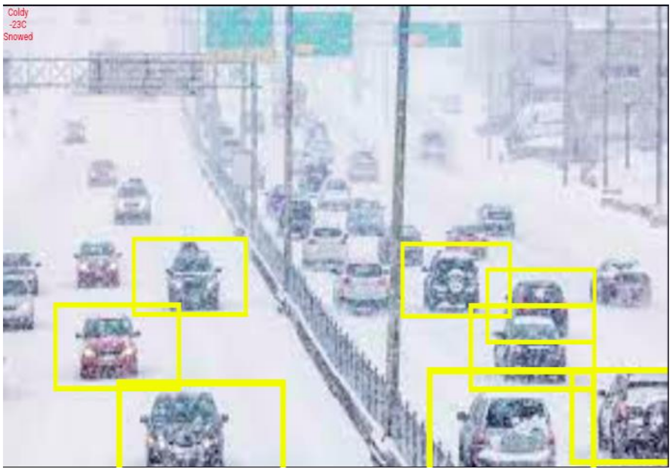
To automate the processing of the results, we need a different number of videos that we collected from open sources.

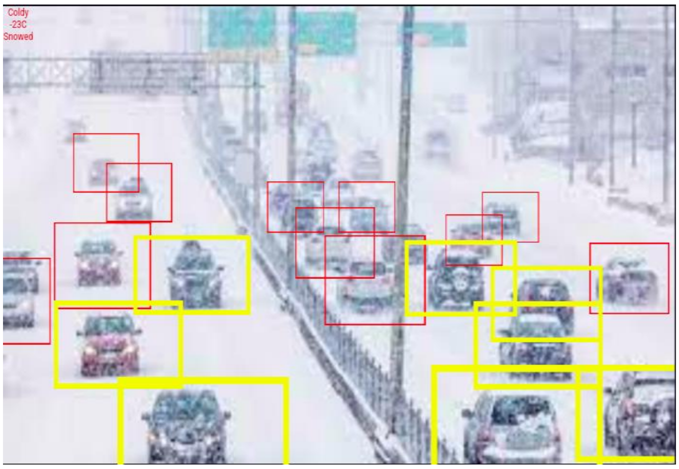
The artificial intelligence-based system is designed to automate and improve the process of detecting and tracking objects in a defined visual field. It is aimed at applications that require high accuracy and speed, such as surveillance, autonomous navigation and interactive media. The system integrates algorithms with an interface that promotes ease of use. To highlight features in the digital processing of video images, we will use the classic Gaff transformation algorithm. The purpose of this algorithm is to find imperfect instances of objects of a certain class of shapes using a voting procedure.

Suppose the figure is given by a set of parameters (a1, a2, ..., an), which acquire values in the set S - the space of this figure. The Gaff transform can be interpreted as the inverse transformation of the probability distribution in the image space to the shape space. All pixels in the image space provide independent evidence. Figure detection is evaluated as the most plausible.

We will describe the technical characteristics of the developed system.

Software Architecture: The system is primarily built using the Python programming language, which was chosen for its versatility and extensive support for data science and machine learning libraries. The main components of the system are the OpenCV library for image processing and computer vision tasks, as well as TensorFlow and PyTorch for implementing and running deep learning models.





draw - a draw - b

draw - c

Fig. 2 - demonstration of tracking operation in snowy conditions
a – standard detect, b/c tracking learning

Deep learning models:at the heart of the system are convolutional neural networks (CNNs), chosen for their effectiveness in image recognition and classification tasks. These models are trained on large datasets to detect various objects, and their layers are tuned to optimize performance for specific uses.

Hardware integration: To provide real-time processing capabilities, the system is optimized for high-performance computing environments. It uses GPU acceleration to handle complex calculations and large data sets efficiently, reducing latency and improving response time in real-time applications.

Implementation of algorithms:the object detection module uses algorithms such as YOLO (You Only Look Once) or Faster R-CNN, known for their speed and accuracy in detecting objects in images. To track objects, the system uses advanced algorithms that take into account object movement, size changes and dimming, ensuring stable tracking even in complex scenarios. Thus, the author proposed a solution that can work with high accuracy in real scenarios, and therefore can be used in various fields of computer vision applications.

The authors formed training samples from open and publicly available data sets of the Internet, as well as from their own sources, which provides a variety of visual information. This set of images is a basic collection of data for computer vision, containing up to a thousand images of cars. A variety of images and video streams provide a wide range of scenarios in which the system operates and learns. The dataset includes different lighting conditions, object sizes and movements, which increases the ability of the model to generalize.

To increase the robustness of the model, we used data augmentation techniques such as rotation, scaling, and image mapping. Each image and video frame was annotated in detail to identify and label different objects. This process was partially automated using existing tools and partially performed manually to ensure accuracy.

To build adaptive computer vision, we chose convolutional neural networks (CNNs) for their known effectiveness in image recognition tasks. In particular, architectures such as YOLO and Faster R-CNN have been experimented with for object detection and tracking. The architecture of the model is shown in Fig. 6.

The Open Neural Network Exchange (ONNX), which is a necessary element of our methodology, offers a platform-independent format for artificial intelligence models. This interoperability capability makes our models flexible and adaptable, able to be deployed on different platforms without significant modifications. Object detection algorithm: DNN (Deep Neural Network) downloaded from ONNX is used. The algorithm analyzes video frames, detects objects and draws their contours using bounding boxes.

NanoTrack (Fig. 3,4) is a technology focused on highly efficient tracking of objects in real time, even with limited computing resources, which makes it ideal for embedded systems or mobile applications.

```
params = cv2.TrackerNano_Params()
params.backbone = 'nanotrack_backbone_sim.onnx'#contains the architecture and
weights of the "main" part of the neural network
params.neckhead = 'nanotrack_head_sim.onnx'#includes determining the exact
position of the object (via bounding boxes), predicting the class of the object or
tracking the trajectory of the object's movement
```

Fig. 3 - NanoTrack parameters

Backbone (Fig. 3) is a model that contains the architecture and weights of the "main" part of the neural network, which is responsible for extracting features from input data (images or videos).

Head (Fig. 3) is a model that represents the head of the network, which specializes in specific tasks, such as classification, localization of objects, or, in the case of tracking, tracking of specific objects in a video stream. "Head" uses high-level features derived from "Backbone" to perform specific tasks.

```
bbox = None
tracker = cv2.TrackerNano_create(params)
while True:
    ok, or_image = cap.read()

    #detect(or_image)

    if bbox != None: ##algoritm used to track objects in a video stream using
OpenCV and Nanotracker
        ret, bbox = tracker.update(or_image)
        if ret and bbox:
            print(f"Tracker ${bbox}")
            (x,y,w,h) = [int(v) for v in bbox]
            cx = x + w/2
            cy = y + h/2
            x_offset = cx - or_image.shape[1] / 2
            y_offset = cy - or_image.shape[0] / 2
            cv2.rectangle(or_image, (x,y), (x+w, y+h), (255,0,0), 2)

    cv2.imshow("Img", or_image)
    key = cv2.waitKey(15)
    if key == ord("c"):
        bbox = cv2.selectROI(or_image)
        tracker.init(or_image, bbox)
```

Fig. 4 - use of the NanoTracker model

Thresholds of sensitivity thresholds for object detection. The confidence threshold of detection (Confidence Threshold) is a parameter in object detection and tracking systems that determines the minimum level of confidence that an algorithm must have regarding the detection of an object before it is considered valid. This threshold is used to filter the results, reducing the number of false detections and improving the overall accuracy of the system, in the application, this parameter is equal to 0.3, it is the most successful parameter for training, which ensures the reliability of detected objects.

The threshold for filtering non-maximum overlaps (Non-Maximum Suppression threshold) is a critical parameter in object detection algorithms, which is used to reduce the number of overlapping detection areas so that each object is marked with only one frame, in the application the parameter is set to 0.4 balanced a parameter that can be increased if necessary to increase the overlap.

Application architecture (Fig.5) for object detection and tracking can be presented as follows:

-User Interface (UI): The initial point of user interaction with the system, where they can upload videos or images and adjust processing parameters.

-Input/output module: Provides reading of input data and saving of output processing results.

- Preprocessing module: Performs basic operations on input data, such as scaling and normalization, preparing it for further processing.

- Object detection module: Uses deep learning algorithms or traditional computer vision methods to identify objects in an image.

- Tracking module: Responsible for tracking the movement of objects from frame to frame, using different tracking algorithms.

- Analysis and output module: Processes the data received from the tracking module to generate final results, such as motion trajectories.
- Database / Storage System: Stores all relevant data and results for later use or analysis.

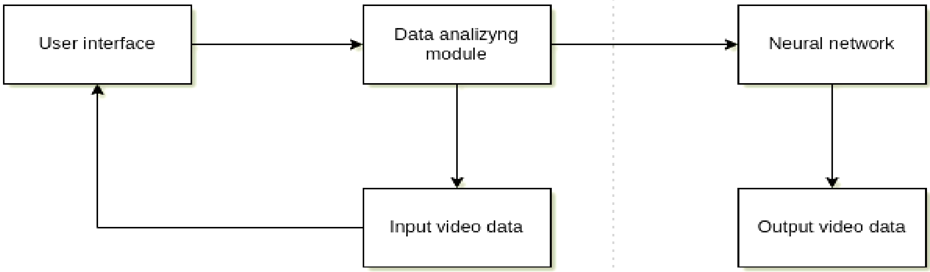


Fig. 5 - model architecture

The models were trained on a high-performance computing cluster with GPU support. We used a combination of training with the training data and transfer learning where pre-trained models were refined using our dataset.

A large number of experiments were conducted to tune hyperparameters such as learning rate, batch size, and number of epochs to optimize the performance of the model.

The implementation phase involved integrating the trained models into a single system capable of real-time processing.

Object detection algorithms (eg YOLO, Faster R-CNN) have been integrated with tracking algorithms to maintain object identification over time.

Special attention was paid to optimizing the models and overall system architecture to provide real-time processing capabilities.

A thorough testing and validation phase was essential to ensure the reliability and efficiency of the system.

The system was tested on a separate set of images and videos that were not used during training to evaluate its generalization ability.

Performance metrics such as accuracy, response, and area-of-object intersection (IoU) were used to quantify system performance. Tracking accuracy was also measured to assess the system's ability to maintain object identification over time.

The performance of the system was compared with existing state-of-the-art systems to assess its competitiveness and effectiveness.

This methodology ensured a thorough and robust development process, from data collection to system implementation, underlying the system's performance and reliability in real-world scenarios.

Algorithms were optimized for speed without compromising accuracy. This included improvements in neural network architectures and the use of techniques such as pruning and quantization of models. In addition, using the power of GPU acceleration helped reduce the processing time significantly.

To manage a large and diverse data set, we used high-level data preprocessing techniques. This included automated data cleaning techniques and the use of advanced data augmentation strategies to increase the diversity and quality of the training data.

Ensuring that the model performed well on unseen data required extensive testing and validation on a variety of datasets. Transfer learning techniques were also used, using pre-trained models on large datasets and further tuning them for our specific tasks. The process of the developed adaptive system based on artificial intelligence is schematically shown in fig. 6.

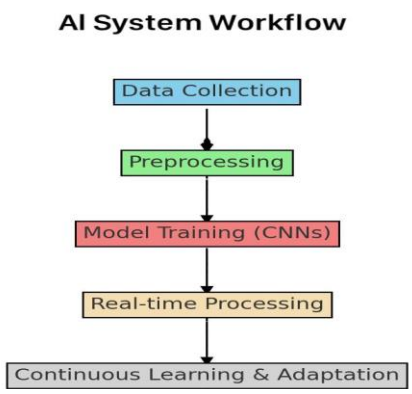


Fig. 6 - scheme of work of AI

This developed computer vision system can be adapted to other scenarios in any field. A fragment of the developed adaptive computer vision code is shown in Figure 7.

```
bbox = None
tracker = cv2.TrackerNano_create(params)
while True:
    ok, or_image = cap.read()

    #detect(or_image)

    if bbox != None:
        ret, bbox = tracker.update(or_image)
        if ret and bbox:
            print(f"Tracker ${bbox}")
            (x,y,w,h) = [int(v) for v in bbox]
            cx = x + w/2
            cy = y + h/2
            x_offset = cx - or_image.shape[1] / 2
            y_offset = cy - or_image.shape[0] / 2
            cv2.rectangle(or_image, (x,y), (x+w, y+h), (255,0,0), 2)

    cv2.imshow("Img", or_image)
    key = cv2.waitKey(15)
    if key == ord("c"):
        bbox = cv2.selectROI(or_image)
        tracker.init(or_image, bbox)
```

Fig. 7 - part of the developed artificial intelligence tracker code

Conclusions

The developed self-learning system is used in technologies for creating artificial systems. The use of models and information technology of computer vision for the detection, tracking and recognition of unclear moving objects on highways allowed us to conclude about their effectiveness in terms of increasing the accuracy of recognition, reducing the time for data processing in video sequences and reducing the time for the system to respond and perform self-learning tasks instructions The system's ability to quickly recognize and track blurred images of vehicles, pedestrians, obstacles and violations can save humanity from road accidents.

The accuracy of recognition can be affected by extreme environments, such as complete lack of lighting, blizzards, snowdrifts. Therefore, the current model must be adapted to new scenarios, retrained, trained and debugged to adapt to new extremesscenarios.

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