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EXPLORING

THE DIGITAL LANDSCAPE:

INTERDISCIPLINARY PERSPECTIVES

EXPLORING THE DIGITAL LANDSCAPE: INTERDISCIPLINARY PERSPECTIVES

Monograph

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5.7. Modern computer vision technologies

Computer vision (Computer Vision, CV) – is a branch of artificial intelligence that deals with the analysis, classification and recognition of images and videos. The basis of CV are algorithms based on machine learning. These algorithms are constantly learning to navigate in the environment, distinguish one object from another correctly, without errors, see patterns and regularities.

Computer vision is a complex information technology that tries to reproduce some parts of the human vision system using specially developed software algorithms. That is, computer vision involves teaching a computer how to view and correctly interpret images. Artificial intelligence, machine learning, neural networks, and pattern recognition help computer vision interpret data and identify objects (Chernyak, 2024).

Machine learning trains computers to classify images by feeding them thousands of images of the same object. Each image has its own labels and tags that identify what kind of object it is. 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.

Until recently, the most popular use of computer vision technology was facing recognition. For example, Facebook uses facial recognition to help users tag people in shared images. Facial recognition helps law enforcement agencies identify violators, bank and financial institution employees monitor ATMs in real time and increase the security of financial transactions.

Cameras can detect speeding cars and alert police officers of traffic violations. New technologies are used in vehicles that have applications for automatic parking and cruise control. Self-driving vehicles rely on a range of computer vision technologies to operate without a driver, without him driving the car. Top-tier vehicles have enough cameras and data to safely maneuver through city streets.

Large-scale agribusiness farmers can automate their work with computer vision software that monitors planting and harvesting.

Today, artificial intelligence technologies, in particular computer vision, are being actively implemented in drones. drone – it's a flying machine, which moves without a pilot (drone, UAV).

Non-military drones are used in peacetime to perform a wide range of tasks: airspace monitoring, meteorological observations, patrolling various areas and facilitiesiv, monitoring of traffic on railway and highway routes, control of shipping, monitoring of crops, search for minerals, monitoring of dangerous natural phenomena, application of fertilizers in fields, delivery of goods, conducting search and rescue operations, evacuation measures, etc.

Military drones are increasingly used during hostilities, for conducting military intelligence, video surveillance, and for adjusting artillery fire strikes on enemy targets. It is known that after a full-scale invasion, Ukrainian non-military drones are constantly being modernized and can conduct reconnaissance in the deep rear of the occupiers. Attack drones are used to destroy targets by the method of self-destruction or by the method of dropping a payload on an enemy military target (Horbik, 2024).

In the industrydrone computer vision is used by equipping drones with cameras and using algorithms to analyze the data received by these cameras. The combination of computer vision and drones allows for advanced analysis, interpretation and decision-making based on visual information.

Computer vision gives drones virtual eyes and helps them analyze and understand their environment. That is why drones can notice objectsassess terrain and assess potential hazards. This increases the safety and efficiency of decision-making. Drones can plan safer routes and perform tasks with greater precision. By combining environmental perception and action, computer vision is helping drones reach their full potential, changing industries along the way (Vishnuvartan, 2023).

Cameras capture images or videos of the environment during flight. These can range from RGB cameras to specialized sensors such as thermal or multispectral cameras, depending on the application. Captured images or video frames are processed using computer vision algorithms that can highlight different visual characteristics, detect objects, or segment the image into meaningful areas.

Image processing algorithms are used to recognize and track objects in images obtained from drones. This includes detecting specific elements such as vehicles, buildings, people and other moving or stationary objects. By analyzing patterns, measuring distances and dimensions, and using visual data, image processing algorithms transform the data into understandable information.

In addition, drones can make decisions on their own based on processed data. For example, they can detect obstacles or hazards in their path and automatically adjust their flight path to avoid collisions.

Drones can also create complex 3D models of landscapes, buildings and infrastructure. They capture slanted images using laser scanning and aerial photogrammetry techniques. Special software is then used to analyze and process the aerial photographs taken by the drone to create a 3D model with GPS coordinates and precise measurements. Below are examples of such applications of drones with computer vision in some industries.

In urban planning, drones with computer vision give planners and architects a bird's-eye view of the city. 3D models created by drones offer detailed information on building structures, road networks and land use, aiding in the design of townships. Similarly, when inspecting infrastructure, drones equipped with computer vision can capture high-resolution images and create detailed 3D models of bridges, power lines and pipelines. This allows engineers to assess structural integrity, identify potential problems, and accurately plan future maintenance.

In military operations, drones controlled by computer vision provide valuable data for strategic planning. Drones can capture visual data of complex terrain, allowing the military to gain a complete understanding of the battlefield. 3D models generated by computer vision algorithms help identify potential hiding places, plan optimal routes, and optimize success rates of planned actions.

Computer vision includes several main stages, we will list the main ones.

The first step is to select the neural network that will be used for image analysis. It can be a regular neural network (Convolutional Neural Network, CNN), which is the basis for many applications of computer vision. The choice of a specific neural network model may depend on the specific task, as well as on the available computing power of the hardware.

After choosing a neural network, you need to choose object detection algorithms that will be used to detect various elements in the images. These algorithms can vary in purpose and complexity, including YOLO, Faster R-CNN, SSD (Single Shot MultiBox Detector), and others.

After detecting objects in the image, the system can use recognition algorithms to identify those objects. These algorithms can use supervised learning, unsupervised learning, or a combination of both methods to determine the class of an object.

In addition to recognizing objects on individual video frames, computer vision can also include object tracking algorithms that track the movement of objects over a period of time. This allows the system to follow objects in a video or image sequence and determine their trajectories and position changes.

The final stage is the integration of all these components into a single computer vision system. This includes building a software architecture capable of interacting with neural networks, object detection and recognition algorithms, and tracking to create a complete system capable of analyzing and responding to visual data in real time.

Object detection and classification algorithms are the basis of many computer vision applications. They allow systems to analyze large volumes of data, identify objects and make appropriate decisions based on this information.

YOLO is a fast algorithm that can detect objects in real time. It works by looking at the image once and immediately determines the class and the rectangular box that surrounds each object. This makes it particularly effective for tasks that require quick reactions, such as driving a car or navigating a drone.

Faster R-CNN is a more complex algorithm that includes two neural networks: one for detecting proposals for regions of interest (region proposals) and another for classifying these proposals. This algorithm usually has better accuracy, but may be less efficient in terms of speed, especially for real-time.

RetinaNet is a model that was created to solve the problem of low accuracy of detecting small objects, smaller than previous algorithms. This model uses a special mechanism called focal loss to focus on complex examples, improving detection accuracy even for small objects.

These algorithms, along with other similar models, form the basis for the development of computer vision systems that are able to recognize objects in images and make decisions based on this data. They are used in a variety of fields, from autonomous vehicles to environmental monitoring and security.

Here is an example of training a neural network based on Yolo V8:

```
from ultralytics import YOLO
 # Завантажуємо модель (Yolo V8 nano).
model = YOLO('yolov8n.pt')
 # Тренуємо модель.
results = model.train(
   data='custom_data.yaml',
   imgsz=640,
   epochs=10,
   batch=8,
   name='yolov8n_custom'
```

Object tracking is a deep learning program in which the program takes an initial set of detected objects and develops a unique identification for each of them, and then tracks the detected objects as they move frame by frame in the video. In other words, object tracking is the task of automatically identifying objects in a video and interpreting them as a set of trajectories with high accuracy. Often there is an indication around the object being tracked, such as a square around the object that shows the user where the object is on the screen. Let's consider several algorithms for tracking.

SORT is a cost-effective implementation of a tracking detection system. In accordance with Occam’s Razor, the algorithm ignores appearance features other than the detection component. SORT uses the position and size of bounding boxes for both motion estimation and data association across frames. The faster RCNN is used as an object detector. The movement of objects in successive frames is estimated by a linear model of constant speed, which does not depend on other objects and the movement of the camera. The state of each target is defined as x = [u, v, s, r, u,' v,' s'], where (u, v) denotes the center of the bounding box r and u denotes the scale and aspect ratio. The other variables are the respective velocities.

Deep SORT (Simple Online and Real-Time Tracking with Deep Associative Metrics) improves on the original SORT algorithm by introducing a deep associative metric that uses deep learning techniques to better handle occlusions and different viewpoints. This allows the algorithm to learn and understand the visual appearance of objects in a more reliable and accurate way, resulting in improved tracking performance in complex scenarios.

By incorporating deep learning into the tracking process, Deep SORT can efficiently handle complex tracking scenarios, including surveillance for autonomous vehicles and sports analytics, for example. Overall, Deep SORT is a significant advance in the field of object tracking, demonstrating the potential of deep learning to extend the capabilities of existing tracking algorithms in real-world settings. Its ability to accurately track objects in complex situations makes it a valuable tool for a wide range of practical applications.

FairMOT is a multi-object tracking model that consists of two homogeneous branches for pixel-by-pixel prediction of objectivity and re-identification functions. Achieved fairness between tasks is used to achieve a high level of detection and tracking accuracy. The detection branch is implemented in an anchor-free style that estimates the centers and sizes of objects represented as position-aware measurement maps.

Similarly, the re-identification branch evaluates the re-identification function for each pixel to characterize the object centered in the pixel. Note that the two branches are completely homogeneous, which is quite different from previous methods that perform detection and re-identification in a cascade style. It is also worth noting that FairMOT works on high-resolution feature maps of step four, whereas previous anchor-based methods work on feature maps of step 32. Removing anchors as well as using high-resolution feature maps better aligns re-ID centers of objects, which significantly increases tracking accuracy.

CSRT (Channel and Spatial Reliability Tracker) is an object tracking algorithm, which is one of the most accurate and stable algorithms. It is based on an improved version of the MOSSE tracker (Minimum Output Sum of Squared Error), which uses both spatial and color information for object tracking. CSRT considers both spatial and color characteristics of the object for tracking. This allows it to be more resistant to changes in lighting and overlapping objects. Also, this algorithm uses an adaptive model for tracking, which is automatically updated on each frame. This allows the tracker to adapt to changes in external conditions, such as changing the speed of the object or changing its shape (Singh, 2021).

The combination of object recognition and tracking algorithms based on OpenCV allows you to create powerful computer vision systems that not only detect objects in images or videos, but also track them over time.

For starters, object recognition algorithms such as YOLO or Faster R-CNN can be used to detect objects on each video frame or on a single image. These algorithms provide coordinates and classes of objects in the image.

Then, to track these objects on the next frames, you can use different tracking algorithms available in OpenCV, such as MOSSE or CSRT, DeepSort. These algorithms first use information from previous frames and subsequently use it to track the movement of objects in subsequent frames.

Combining this recognition and tracking components consists of the following steps.

Initialization of the tracker: The initial coordinates and areas of the objects that were detected in the first frame using the recognition algorithms are used to initialize the trackers.

Tracker update on subsequent frames: After initialization, trackers are used to track objects on subsequent frames. They update their predicted object coordinates based on the motion and shape changes of the objects.

Detection of objects in the current frame, if required: Periodically or in case of loss of the object tracker, detection of objects in the current frame can be performed again using recognition algorithms. This allows you to resume tracking of objects that may be lost due to a change in position or overlapping by other objects.

MAVLink is a lightweight, efficient and extensible communication protocol designed specifically for unmanned aerial vehicles. It allows the transmission of telemetry data, control commands, system statuses and other important information between the autopilot and external applications.

There are different ways to interact with the drone's autopilot via MAVLink:

Ground Control Stations, GCS is software that allows operators to control the drone and receive live telemetry via MAVLink. Examples of such GCS include QGroundControl and Mission Planner.

Control the drone from your own application – developers can integrate MAVLink support into their applications for controlling the drone. This can be useful for creating specialized control systems or automated scripts.

Working with an unmanned aerial vehicle via API – libraries such as MAVSDK (MAVLink Software Development Kit) provide an API for simplified drone control via MAVLink. This allows developers to create applications for different platforms and different programming languages.

Here is an example of drone control using the MavLink protocol and the pymavlink Python library:

```
from pymavlink import mavutil
# Підключення до автопілоту через MAVLink
master = mavutil.mavlink_connection('udpin:127.0.0.1:14550')
# Відправлення команди зльоту
```

```
    master.mav.command_long_send(
        master.target_system, master.target_component,
        mavutil.mavlink.MAV_CMD_NAV_TAKEOFF,
        0, 0, 0, 0, 0, 0, 0)
    # Очікування відповіді
    while True:
        msg = master.recv_match()
        if msg:
            print(msg)
            if msg.get_type() == 'COMMAND_ACK':
                if msg.command ==
mavutil.mavlink.MAV_CMD_NAV_TAKEOFF:
                    if msg.result ==
mavutil.mavlink.MAV_RESULT_ACCEPTED:
                        print('Дрон піднявся успішно!')
                        break
                    else:
                        print('Помилка взльоту')
                        break
```

In this example, we connect to the drone's autopilot via UDP and send a takeoff command. After that, we wait for a response from the autopilot and react accordingly.

Rolet's look at the algorithm of actions for tracking a drone by an object using OpenCV and MAVLink:

1. First, it is necessary to ensure that the camera on the drone captures the video stream. This can be done with the camera built into the drone or by connecting to an external camera.

2. Using computer vision algorithms such as YOLO, the program analyzes the video stream and recognizes the target object. For example, it can be any moving or stationary object that needs to be tracked.

3. After recognition, the computer program determines the position and dimensions of the object in the image. It can be the coordinates of the center of the object or its border.

4. Based on the determined position of the object, the program generates control commands for the drone. For example, if the object moves to the left, a left movement command is generated for the drone. These commands are sent to the drone's autopilot via the MAVLink protocol.

5. When receiving control commands, the drone's autopilot performs appropriate movements to maintain the object in the camera frame. This can include left, right, up, down or rotation movements.

6. The computer program continues to analyze the video stream and update the control commands in real time so that the drone is constantly following the object.

7. Tracking can end when the object goes out of the camera frame or when obstacles appear that prevent further tracking of the object.

Thus, the use of computer vision in drones, combined with artificial intelligence, opens wide prospects in unmanned systems. This allows drones to receive in real time a large amount of information about the environment, which includes object recognition, object location and navigation. This approach provides drones with the ability to make decisions and operate autonomously in environments where they may encounter a variety of tasks and obstacles. In addition, computer vision can be used for a variety of tasks such as object tracking, automatic navigation, and environmental monitoring.

Therefore, the integration of computer vision technologies with artificial intelligence in unmanned aerial vehicles expands their capabilities and ensures more efficient and autonomous functioning in various industries and fields of application in the modern digital society.

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