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IMPROVEMENT OF THE CONTROL SYSTEM MODEL OF A MOBILE PLATFORM UNDER THE INFLUENCE OF ELECTROMAGNETIC SPECTRUM THREATS IN THE INFORMATION ENVIRONMENT

Abstract. The article presents a control system model for a mobile robotic platform (unmanned vehicle) and proposes methods for improving the control system elements under the influence of electromagnetic spectrum threats in the information environment. The control model for the robotic platform includes the ability to operate the platform mechanisms in two modes: manual and automated. The use of the mobile platform in manual mode is necessary for operational control in the absence of electromagnetic interference aimed at disrupting the data transmission devices of the robotic platform. To ensure the operation of the mobile platform under the presence of electromagnetic interference, the control system must be capable of managing the platform devices in an automated or automatic mode. **The aim of the article** is to formalize the control system model for the mobile platform, identify the shortcomings of existing control systems, and explore ways to eliminate these shortcomings. **The results obtained:** quantitative indicators from the conducted research indicate the potential use of video information processing models, used by the unmanned vehicle operator for spatial orientation, for the autonomous operation of the unmanned vehicle. **Conclusions:** the implementation of data processing models in the mobile platform's control system will enable the automation of control processes for the unmanned vehicle under conditions of electromagnetic interference affecting the data transmission devices of the robotic platform.

Keywords: control system, unmanned vehicles, electromagnetic spectrum threats, video processing, mobile platform.

Introduction

Ensuring the safe and correct functioning of systems that utilize information computer technologies presents a range of challenges from the macro level [1] to the micro level.

The aim of this research was to formalize the control system model for a mobile platform, identify the shortcomings of existing control systems, and explore ways to eliminate these shortcomings. With the rapid development of mobile platforms in Ukraine and worldwide, a number of models are available on the market [2–4], whose configurations are characterized by a set of common features from an engineering perspective.

An analysis of the use of existing unmanned vehicles (UVs) indicates that controlling the platform can be complicated due to the limitations of data transmission systems, which, in turn, can lead to damage or loss of the mobile platform. The risks of damage or loss of unmanned vehicles significantly increase when UVs are used under conditions of electromagnetic interference.

Active use of the electromagnetic spectrum leads to the creation of interference that can affect both the control channel and the video data transmission channel, which are used by the mobile platform operator for spatial orientation.

One possible way to mitigate the risks of using UVs under conditions of electronic warfare is to utilize data processing models within the control system itself, which is integrated into the mobile platform.

Control System Model

The control system of a mobile platform can be conditionally divided into two subsystems.

The first subsystem, the manual control system, consists of the following main components:

- Control panel with a radio transmitter.
- Radio signal receiver.
- Antennas for receiving and transmitting control and video signals.
- Video camera and video signal transmitter (VTX).
- Controller (motor controller).
- Electric motors.
- Batteries, voltage converters, switching devices.
- Video output device.
- Actuators (determined based on the specific application of the UV).

In this configuration, direct control of the mobile platform's movement and its actuators is achieved by sending control signals via the control panel. The radio signal receiver ensures the transmission of the signal to the controller, which, in turn, generates the appropriate control signals for the electric motors and actuators of the robotic platform.

The second subsystem is the automated or automatic control system, which is designed to ensure the operation of the mobile platform under conditions of electronic warfare.

The tasks of this system include autonomous video signal processing, decision-making, and the generation of control signals, which the system sends to the controller (motor controller).

As hardware for the automated or automatic control system, single-board computers can be used. These computers are characterized by relatively low power consumption and have sufficient operational functionality for processing video data, generating, and sending control signals through data input/output ports. Single-board computers have the capability to run software that utilizes algorithms incorporating elements of artificial intelligence [5] and modern data processing algorithms [6–8].

Analysis of Object Tracking Models Usage

To ensure the autonomy of the automated or automatic control system, typical tasks of robotic platforms need to be defined. One such task is the capture and tracking of objects in the surrounding environment.

This task can be addressed using modern video data processing models. One such technology is OpenCV [9], implemented as an open-source computer vision library used for real-time video data processing. This library implements a variety of models for object capture and tracking.

One of the tasks of this research is to analyze models implemented as video data processing algorithms.

Conducting this analysis is necessary to determine the models that can be implemented in the automated or automatic control system.

This research involves several steps:

1. **Implementation of Software**: Develop software to conduct experiments aimed at obtaining quantitative metrics of the performance of different data processing models.
2. **Model Selection**: Choose the data processing model(s) for experimentation using the technical equipment that can be used to implement the automated or automatic control system for the mobile platform.
3. **Implementation of Data Processing Model**: Implement the selected data processing model, conduct testing, and debug the control system.

In this article, the results of the first stage of the research are presented. To conduct the experiment and determine quantitative metrics, software was developed using the C++ programming language and the OpenCV 4.8 library [10].

The following data processing models were used for comparative analysis:

- MIL (Multiple Instance Learning),
- CSRT (Discriminative Correlation Filter with Channel and Spatial Reliability),
- KCF (Kernelized Correlation Filters), BOOSTING, MedianFlow,
- MOSSE (Minimum Output Sum of Squared Error),
- TLD (Tracking, Learning, and Detection).

To determine the quantitative performance metrics of each model, the following criteria were defined:

1. **Average Deviation between Object Center and Calculated Region Center**: This criterion measures the average difference between the center of the tracked object and the center of the region calculated and used by the model for displaying the captured object – the average tracking error.
2. **Average Frame Processing Time**: This criterion measures the average processing time of one video frame.

These criteria were chosen to assess the accuracy and efficiency of each model in tracking objects in real-time video streams.

The experiment involved running the software with the collection of quantitative metrics for 14 videos selected based on the following criteria:

- The video stream depicted changes in the environment with high dynamics in the object's position.
- The videos were obtained using technical equipment (camera) commonly used in modern robotic mobile platform models.

These criteria ensured that the selected videos provided a challenging and realistic scenario for testing the performance of the object tracking models.

Quantitative metrics were obtained for processing each individual frame of the video stream and recorded in a log file, structured and provided in Tables 1 and 2.

The notation "∞" in the tables indicates that the model lost track of the captured object.

The results of the OpenCV models investigation demonstrate that the effectiveness of tracking algorithms can significantly vary depending on the type of video fragment. Some algorithms perform well on videos where objects gradually change their position within the frame, but they may lose tracking on video fragments with unpredictable movements.

Thus, the choice of tracking model should take into account the specific requirements of the task and the characteristics of the video stream.

Analytically, the following characteristics of the models can be determined:

- KCF and MOSSE quickly process frames and perform well in tracking objects with uniform and smooth motion without abrupt movements. However, these algorithms are not suitable for tracking objects with unpredictable trajectories, as the object loss rate and tracking error are quite high.
- TLD can handle videos where objects enter obstacles or go beyond frame boundaries. It restores tracking but is characterized by longer frame processing time and higher tracking error compared to other models.
- MedianFlow demonstrates moderate quality for objects with uneven motion, but its accuracy heavily depends on the initially selected region of interest (ROI). It's important to precisely define object boundaries to avoid background capture.
- CSRT and BOOSTING, according to the obtained quantitative metrics, are characterized by relatively high performance in the conducted experiment, but BOOSTING has a sufficiently high frame processing time, and CSRT more frequently loses track of the object.
- MIL algorithm, based on the experiment results, is characterized by high quality in tracking objects. According to observations, this model enables object tracking in dynamic scenarios, with moderate frame processing time and the lowest average tracking error and object loss percentage.

Table 1 – **Average Tracking Error (px)**

No. of video	**Model implemented in OpenCV**						
	MIL	**CSRT**	**KCF**	**BOOSTING**	**MedianFlow**	**MOSSE**	**TLD**
1.	35.9	∞	∞	113.2	31.3	∞	∞
2.	45.4	∞	147.4	37.5	125.3	97.1	∞
3.	18.6	18.3	∞	16.9	∞	∞	65.3
4.	21.3	28.4	∞	39.9	107.6	∞	∞
5.	29.3	∞	∞	57.6	58.9	35.4	53.5
6.	38.0	117.7	∞	50.8	124.6	∞	52.9
7.	60.2	14.0	∞	21.2	43.1	∞	∞
8.	12.7	15.0	∞	15.2	118.4	∞	26.3
9.	12.5	14.2	∞	13.3	∞	∞	∞
10.	∞	∞	∞	∞	72.5	∞	∞
11.	37.7	7.5	∞	11.0	∞	∞	∞
12.	9.4	9.9	∞	42.2	110.9	∞	150.4
13.	8.1	∞	∞	∞	29.3	∞	∞
14.	∞	∞	∞	6.1	30.0	∞	64.6
Average tracking error, px	27,43	28,13	147,40	35,41	77,45	66,25	68,88
Object loss percentage, %	14,29	42,86	92,86	14,29	21,43	85,71	57,14

Table 2 – **Average frame processing time (ms)**

No. of video	**Model implemented in OpenCV**						
	MIL	**CSRT**	**KCF**	**BOOSTING**	**MedianFlow**	**MOSSE**	**TLD**
1.	243.9	∞	∞	415.0	48.2	∞	∞
2.	262.4	∞	158.6	698.0	153.4	73.9	∞
3.	237.0	166.6	∞	432.6	∞	∞	949.6
4.	215.0	122.7	∞	372.5	130.9	∞	∞
5.	236.4	∞	∞	533.9	72.7	13.8	598.1
6.	255.9	117.7	∞	475.5	144.1	∞	853.0
7.	260.8	149.4	∞	395.1	53.7	∞	∞
8.	206.5	103.4	∞	338.1	89.8	∞	966.0
9.	193.3	119.2	∞	341.7	∞	∞	∞
10.	∞	∞	∞	∞	44.0	∞	∞
11.	220.7	123.6	∞	393.8	∞	∞	∞
12.	218.9	110.7	∞	372.0	81.8	∞	1276.3
13.	195.3	∞	∞	∞	36.7	∞	∞
14.	∞	∞	∞	308.1	41.8	∞	961.2
Average processing time (ms)	228,84	126,66	158,60	423,03	69,01	43,85	934,03

Conclusions

This article presents a formalized model of ground mobile platform control system, identifies the main technical components, and principles of their interaction.

An analysis of the drawbacks of existing platforms under active electromagnetic spectrum utilization is conducted. A combined control system model utilizing manual and automated or automatic control subsystems is proposed.

An overview of typical tasks for unmanned vehicles operation is provided, and avenues for improving the control system model of UVs to eliminate existing drawbacks are identified.

An experiment is conducted to investigate the potential use of modern object tracking models, obtaining quantitative metrics.

Based on these metrics, a data processing model is selected for further implementation into the mobile platform control system.

The next steps of this research involve conducting an experiment to obtain quantitative indicators of the data processing model performance based on the technical equipment used for implementing the mobile platform control system.

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Удосконалення моделі системи керування мобільної платформи в умовах дії загроз електромагнітного спектру інформаційного середовища

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Анотація. В статті наведено модель системи керування мобільною роботизованою платформою (безпілотного апарату), а також запропоновано методи удосконалення елементів системи керування, в умовах дії загроз електромагнітного спектру інформаційного середовища. Модель керування роботизованою платформою передбачає можливість управління механізмами роботизованої платформи у двох режимах: ручному та автоматизованому. Використання мобільної платформи в ручному режимі необхідне для оперативного керування за умов відсутності дії електромагнітного впливу з метою створення завад на пристрої передачі даних роботизованої платформи. Для забезпечення оперування мобільної платформи в умовах наявності дії електромагнітного впливу система керування повинна мати можливість керувати пристроями мобільної платформи в автоматизованому або автоматичному режимі. **Метою статті** є формалізація моделі системи керування мобільною платформою, виявлення недоліків існуючих систем керування та пошук шляхів усунення цих недоліків. **Отримані результати:** кількісні показники проведеного дослідження вказують на можливості використання моделей обробки відеоінформації, яка використовується оператором безпілотного апарату для орієнтації в просторі, для автономної роботи безпілотного апарату. **Висновки:** імплементація моделей обробки даних в систему керування мобільною платформою дозволить автоматизувати процеси керування безпілотного апарату в умовах дії електромагнітного впливу на пристрої передачі даних роботизованої платформи.

Ключові слова: система керування, безпілотні апарати, загрози електромагнітного спектру, обробка відео, мобільна платформа.