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METHOD OF FPV DRONE STABILIZATION ON AN AUTOMATICALLY DETERMINED TARGET AND ITS FURTHER OBSERVATION

In recent years, the use of FPV (First Person View) drones has gained significant traction across various fields, including recreational activities, infrastructure inspections, search-and-rescue missions, and military operations. The paper considers the problem of the lack of stabilization in FPV drones, which significantly limits their functionality for applications that require precise tracking of a specific target. Such drones, although characterized by high maneuverability and affordable cost, are inferior to commercial quadcopters such as the DJI Mavic, which are equipped with effective stabilization systems, but are significantly more expensive due to the use of proprietary technologies. The paper proposes a new approach to stabilizing FPV drones, based on the use of computer vision algorithms for automatic target detection and tracking. The main concept includes target detection based on image analysis from the drone camera, further determination of its trajectory and transmission of appropriate control commands to the flight controller using the MAVLink protocol. This approach allows to significantly increase the accuracy and stability of FPV drones when performing tasks that require focusing on an object, such as infrastructure inspection, search and rescue operations, or video shooting. The proposed solution is based on accessible and open technologies, which ensures its adaptability and low implementation cost. The paper describes in detail the developed system architecture, which includes a computer vision module for video stream analysis, algorithms for data processing and filtering, as well as integration mechanisms with existing flight controllers. A series of experiments were conducted to evaluate the effectiveness of the proposed approach. The results demonstrate that the proposed system is able to ensure stable drone tracking on a specified target even in difficult flight conditions.
Keywords: stabilization, FPV drone, MAVLink, automatic target detection.

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МЕТОД СТАБІЛІЗАЦІЇ FPV-ДРОНУ ЗА АВТОМАТИЧНО ВИЗНАЧЕНОЮ ЦІЛЛЮ ТА ПОДАЛЬШЕ ЇЇ СПОСТЕРЕЖЕННЯ

Останніми роками використання FPV- дронів набуло значного поширення в різних сферах, включаючи рекреаційну діяльність, інспекцію інфраструктури, пошуково-рятувальні місії та військові операції. У статті розглянуто проблему відсутності стабілізації у FPV-дронах, що значно обмежує їх функціональні можливості для застосувань, які потребують точного спостереження за визначеною ціллю. Такі дрони, хоча й характеризуються високою маневровістю та доступною вартістю, поступаються комерційним квадрокоптерам типу DJI Mavic, які оснащені ефективними системами стабілізації, але є суттєво дорожчими через використання пропрієтарних технологій. У роботі запропоновано новий підхід до стабілізації FPV-дронів, що базується на використанні алгоритмів комп'ютерного зору для автоматичного визначення та відстеження цілі. Основна концепція включає виявлення цілі на основі аналізу зображень з камери дрона, подальше визначення її траєкторії та передавання відповідних команд управління польотному контролеру за допомогою протоколу MAVLink. Цей підхід дозволяє значно підвищити точність і стабільність польоту FPV-дронів при виконанні завдань, що потребують фокусування на об'єкті, таких як інспекція інфраструктури, пошуково-рятувальні операції чи зйомка відеоматеріалів. Запропоноване рішення базується на доступних і відкритих технологіях, що забезпечує його адаптивність і низьку вартість впровадження. У роботі детально описано розроблену архітектуру системи, яка включає модуль комп'ютерного зору для аналізу відеопотоку, алгоритми для обробки та фільтрації даних, а також механізми інтеграції з існуючими польотними контролерами. Проведено серію експериментів для оцінки ефективності запропонованого підходу. Результати демонструють, що запропонована система здатна забезпечити стійке утримання дрона на визначеній цілі навіть у складних умовах польоту.
Ключові слова: стабілізація, FPV-дрон, MAVLink, автоматичне визначення цілі.

Introduction

In recent years, the use of FPV (First Person View) drones has gained significant traction across various fields, including recreational activities, infrastructure inspections, search-and-rescue missions, and military operations. However, despite their versatility and affordability, FPV drones face critical limitations in scenarios where GPS-based stabilization is not feasible. This is particularly evident in combat zones, where GPS signals are either unavailable or intentionally avoided due to security concerns [1].

Traditional stabilization methods relying on geographic coordinates for fixed positioning are rendered impractical in such environments. To address this challenge, this study introduces a novel approach to FPV drone stabilization based on image processing techniques. Leveraging an onboard camera and microcomputer, the system processes captured frames in real-time, comparing the current image to the previous one to compute the necessary adjustments in pitch, roll, and yaw. This enables the drone to maintain a consistent focus on a target or position without the need for external localization.

Furthermore, the proposed approach enhances the drone's resilience against electronic warfare (EW) tactics, a prevalent threat in modern combat scenarios [2]. Adversaries often deploy EW measures to disrupt the communication link between the pilot's controller and the drone's receiver by jamming operational frequencies. This disruption results in a loss of control, rendering the drone vulnerable to capture or destruction. The system's autonomous stabilization capability mitigates such vulnerabilities, allowing the drone to maintain functionality even in the absence of direct operator input.

The integration of image processing for stabilization represents a cost-effective and adaptable solution to the limitations of FPV drones. By eliminating dependence on GPS and providing robustness against EW threats, this approach significantly enhances the operational reliability and versatility of FPV drones. This paper presents the technical details of the proposed system, its implementation, and the results of experimental evaluations, demonstrating its potential to revolutionize FPV drone applications in high-risk and GPS-denied environments.

Domain analysis

In the course of the study, we analyzed recent Ukrainian and foreign publications in the domain of drones' stabilization and target determination.

The research [3] focuses on the designing aspects of a first-person view (FPV) Drone. An FPV drone is an unmanned aerial vehicle (UAV) that transmits Hawkeye's view to the ground control station. The work [4] presents the framework that can achieve up to 99% in detection accuracy over an encrypted WiFi channel using only 170 packets originated from the drone within 820ms time period. The proposed framework is able to identify drone transmissions even among very similar WiFi transmissions (such as video streams originated from security cameras) as well as in noisy scenarios with background traffic. The main objective of [5] is to make the UAV completely autonomous, with the transmitter on standby. By entering the flight plan into the Ground Control System, the UAV will complete the assigned mission autonomously and will be guided by an operational flight plan wherein active waypoints are plotted in the GCS. The GCS can be linked to the Telemetry and the Global Positioning System to have a complete knowledge of the UAV location. The use of drones, or unmanned aerial vehicles (UAVs), in military operations is rapidly expanding. However, controlling these drones has become an increasingly complex task for developers. Gesture recognition is one of the innovative methods being explored for drone control. In [6], the movement of the pilot's head, detected using a gyroscope, is utilized to adjust the angle of an onboard FPV (First Person View) camera. The MPU 6050 sensor captures displacement values across three axes and transmits them to a processor, which interprets these values. After processing and comparison, the data is used to generate output commands. These commands are executed by a servomotor, which drives mechanical adjustments based on the MPU sensor's input. The entire system can be wirelessly linked through an RC (Radio Controller) transmitter and receiver. This motion-controlled setup has versatile applications, such as FPV-enabled drone surveillance, military operations, search-and-rescue missions, and more. In [8] a VTOL (Vertical Take Off and Landing) RPV (Remotely Piloted Vehicle) is created to track a chosen ground target during assigned surveillance missions. The paper [9] presents a unique collaborative computer vision-based approach for target tracking as per the image's specific location of interest. The proposed method tracks any object without considering its properties like shape, color, size, or pattern. It is required to keep the target visible and line of sight during the tracking. The method gives freedom of selection to a user to track any target from the image and form a formation around it.

The ready-made solutions that have been considered do not meet the requirements and the target needs. Therefore, there is a need in developing new approaches and methods.

In our previous work [10] we propose using of computer vision, i.e. OpenCV technology for determining the speed of the car that is moving ahead. In [11] we started working on the concept of improvement the UAV control, proposing video repeater design.

The primary objective of this study is to develop and implement a novel stabilization system for FPV drones that operates autonomously in GPS-denied environments. By leveraging real-time image processing techniques to analyze captured frames and compute stabilization adjustments, the study aims to enhance the drone's operational reliability and functionality. Furthermore, the system is designed to resist electronic warfare (EW) disruptions, ensuring continuous and stable performance in high-risk and contested settings.

Method of FPV drone stabilization on an automatically determined target and its further observation

This study introduces an innovative approach to FPV drone stabilization that relies on image processing techniques instead of traditional GPS-based methods. Unlike existing stabilization systems, this method utilizes real-time analysis of captured frames to compute adjustments for pitch, roll, and yaw, enabling autonomous stabilization without external localization. The integration of onboard cameras and microcomputers into a lightweight, cost-effective system represents a significant advancement in drone technology. Additionally, this approach offers enhanced resistance to electronic warfare (EW) threats, a novel capability not widely addressed in current FPV drone designs.

The expediency of this work lies in the fact that there is usually no GPS at combat positions (and if there is, it is not used for safety reasons), so it is not advisable to focus on the latitude and longitude values to fix the FPV drone at one point. However, as long as we have a camera and a microcomputer on board, we can process the resulting image by comparing the frame with the previous one, and set the necessary shift parameters (along the pitch, roll and yaw axes) for the drone so that the current frame corresponds to the previous one, that is, perform stabilization.

In addition, the advantage of this project is resistance to radio-electronic warfare means. Due to the use of electronic warfare means by the enemy, the connection between the pilot's remote control and the receiver on board is lost (no control), that is, a signal with control commands should have arrived at the RX receiver located on the drone, but the enemy, having determined the frequency of the receiver, begins to jam the channel, as a result, control is lost - the drone along with it.

However, by registering critical situations in the flight controller (if there is no signal from the remote control, we switch to the emergency option - turn on the stabilization mode for the target), we can save the drone.

In this project we use image processing using the OpenCV module [1], as well as the MAVlink protocol [2] to transmit commands to the flight controller from the Orange Pi microcomputer.

Having received the image directly from the onboard thermal imaging camera, we search for the target. The method of FPV drone stabilization on an automatically determined target and its further observation includes the following steps:

1. using the Kenny algorithm, we select the contours of objects;
2. reduce the number of objects, we process the received data: we look for those that are close enough (circles described around the contours give an intersection): potentially represent a single object - and combine them;
3. find the lightest pixel of the image (since the data is from a thermal camera, the lighter the object - the warmer it is, i.e. closer);
4. determine the object whose center is located closest to the lightest point as the main target.

For each step of the proposed method, we develop a mathematical interpretation.

1. Using the Kenny algorithm, we select the contours of objects:

The Kenny algorithm is a method for edge detection and contour extraction in images. Given an image *I(x,y)*, where x and y are the pixel coordinates, the algorithm identifies boundaries of objects in the image by detecting significant changes in intensity or color. Mathematically, this can be expressed with the formula 1.

$$C = \{(x,y) \in I | \nabla I(x,y) > \theta\}, \quad (1)$$

where C represents the set of contour points, $\nabla I(x,y)$ is the gradient of the image intensity, and θ is a threshold for detecting edges.

2. To reduce the number of objects, we process the received data: we look for those that are close enough (circles described around the contours give an intersection): potentially represent a single object and combine them.

After contour detection, the next step is to group close contours into a single object. Suppose each detected contour can be approximated by a circle with center $C_i(x_i,y_i)$ and radius $r_i + r_j$, where i indexes the contours. To find overlapping or close contours, we calculate the Euclidean distance between centers of two circles using the formula 2.

$$d(C_i, C_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

If the distance between two centers is smaller than the sum of their radii, $r_i + r_j$, we combine the two contours:

$d(C_i,C_j) < r_i+r_j \Rightarrow$ merge contours C_i,C_j

This merging step reduces the number of detected objects by combining those that are physically close. This merging step reduces the number of detected objects by combining those that are physically close.

3. We find the lightest pixel of the image (since the data is from a thermal camera, the lighter the object, the warmer it is, i.e., closer).

For the thermal camera data, each pixel has an intensity value corresponding to temperature. The lightest pixel corresponds to the highest intensity value. Mathematically, this is expressed by the formula 3.

$$I_{max} = \max_{x,y} I(x,y), \quad (3)$$

where $I(x,y)$ is the intensity of the thermal image at pixel (x,y), and I_{max} represents the maximum intensity (lightest pixel).

4. We determine the object whose center is located closest to the lightest point as the main target

Let O_i denote the center of the object i and $P_{lightest}$ (x_{max},y_{max}) represent the coordinates of the lightest pixel. The distance between the object center O_i and the lightest pixel $P_{lightest}$ is calculated by the formula 4.

$$d\left(O_i, P_{lightest}\right) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (4)$$

The main target object is the one with the smallest distance that is determined with the formula 5.

$$Main\ target = arg \min_i d\left(O_i, P_{lightest}\right). \quad (5)$$

Experiments and results

After receiving the image directly from the onboard thermal imaging camera, we search for the target as shown in Figure 1.

a) b)

Fig.1. Selecting a target, saving it, determining the distance from the center general picture; b) selected target)

Once we find a target, we save its image and use match-finding techniques to search for the saved target on a new frame. Once we find a match and assume that the target may be moving, we save the updated image to improve accuracy (Figure 2).

a) b)

Fig.2. Search for a specific target and update its image general picture; b) selected target)

At each of the stages of finding a match, we determine how far the target is from the center and in what direction. We process this data and transmit it directly to the flight controller using the MAVlink protocol [13] (Figure 3).

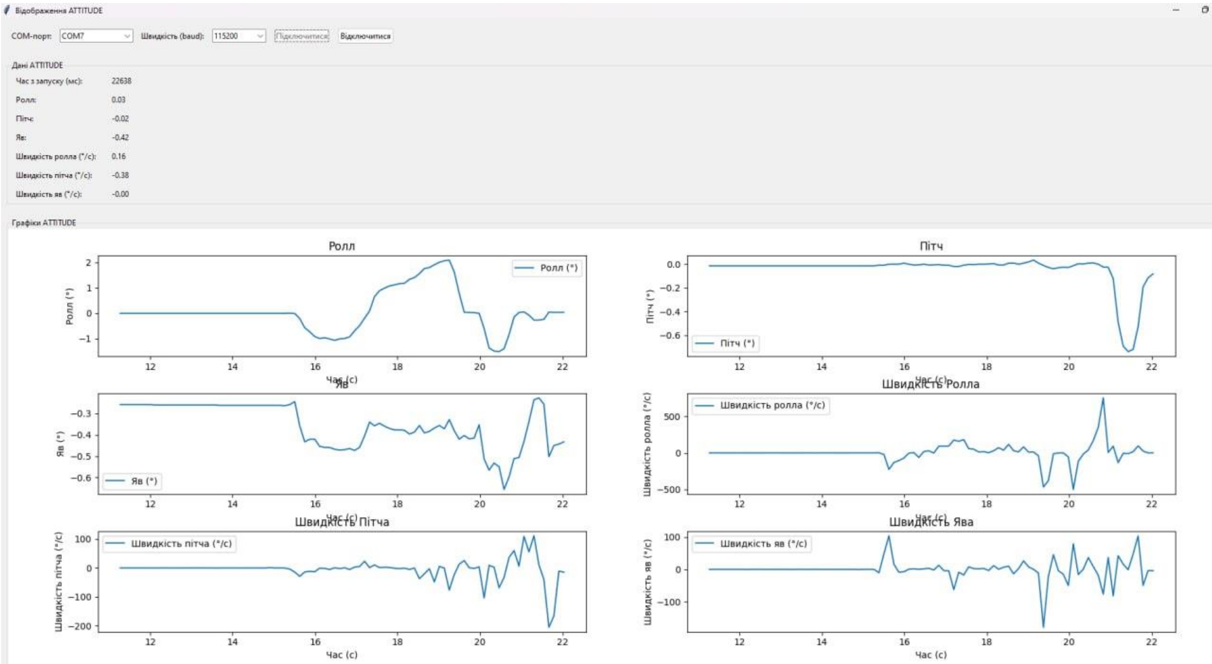

Fig.3. Receiving data using the MAVlink protocol

Therefore, at the output, we get software for FVP drones that automatically detects the target and autonomously controls the drone, setting it the appropriate parameters for each of the axes, to continue monitoring the target if it is moving, or manipulates the drone so that it is in a stable position. Further work consists in transmitting data about the target to the pilot, since now we get a clean image from the camera, without highlighting the target, for example, the coordinates of the target in the image can be transmitted together with the OSD or duplicate the search algorithm on the frames received by the pilot, but in this case, inaccuracy as a result of delay is possible.

Conclusions

This study introduces an innovative approach to FPV drone stabilization that relies on image processing techniques instead of traditional GPS-based methods. Unlike existing stabilization systems, this method utilizes real-time analysis of captured frames to compute adjustments for pitch, roll, and yaw, enabling autonomous stabilization without external localization. The integration of onboard cameras and microcomputers into a lightweight, cost-effective system represents a significant advancement in drone technology. Additionally, this approach offers enhanced resistance to electronic warfare (EW) threats, a novel capability not widely addressed in current FPV drone designs.

The proposed solution addresses critical challenges in operating FPV drones within GPS-denied environments, such as combat zones and areas prone to EW disruptions. By enabling autonomous stabilization and reliable operation under such conditions, this system offers substantial benefits for military applications, search-and-rescue missions, and other high-risk scenarios. The adaptability and cost-efficiency of the approach make it a viable alternative for enhancing the functionality and reliability of FPV drones in diverse operational settings.

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