PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891; E-ISSN 2720-5266 **https://promechjournal.pl/**

Remote Thermal Signature Point Target Acquisition System Using Continuous PID Algorithm and Thermal Image Filtration for UAV Systems

Robert MATYSKO* (matyskor@imp.gda.pl)
Weronika WIŚNIEWSKA (wwisniewska@imp.gda.pl)

*Corresponding author
ORCID: https://orcid.org/0000-0002-8817-7227

Institute of Fluid-Flow Machinery of the Polish Academy of Science
14 Fiszera Str., 80-283 Gdańsk, Poland

Received: June 15, 2022 / Revised: September 13, 2022 / Accepted: September 26, 2022 / Published: June 30, 2023.

2023, 14 (2), 19-34**;** https://doi.org/10.5604/01.3001.0053.6669

Cite: Chicago Style

Matysko, Robert, and Weronika Wiśniewska. 2023. "Remote Thermal Signature Point Target Acquisition System Using Continuous PID Algorithm and Thermal Image Filtration for UAV Systems". *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 14 (2) : 19-34. https://doi.org/10.5604/01.3001.0053.6669

Abstract. The aspects relating to unmanned aircraft and their target acquisition systems are continuously being developed. The subject of the study is a target acquisition system with a thermal camera. A control system is presented consisting of three subsystems. Open- and closed-loop control systems are used. Experimental results unambiguously show that this is a promising line of research and form the basis for further efforts on the topic.

Keywords: thermovision, unmanned aircraft, target acquisition

1. INTRODUCTION

An increased interest is observed in unmanned aerial vehicles (UAVs) and target acquisition systems. This study presents a concept of a thermal target acquisition and object tracking system. A thermal system enables searching for remote thermal signatures. The thermal system in the study is integrated into the UAV drive system. Signals from the thermal camera are scaled and converted to follow-up control errors in the flight control system. Both flight and image processing functions are executed using only a single microprocessor system.

2. BACKGROUND

An unmanned aerial vehicle (UAV), commonly known as a drone, is defined as a device that may execute automatic flight. UAV testing has been carried out for many years, and an increasing interest in this topic is still being observed. In this way newer designs are developed. According to the Civil Aviation Authority [1] in Poland, five UAV categories are distinguished: aircraft, helicopters, multi-rotors, airships, and other unmanned aerial vehicles. They may have different dimensions (Fig. 1). Various UAV designs are also presented in Fig. 2.

a) b)

Fig. 1 Rotorcraft a) CH-47F Chinook twin-rotor helicopter (USA) [2], b) a four-rotor microdron [3]

Multi-rotor UAVs are VTOL (Vertical Take Off and Landing) aerial vehicles that take off and land in a vertical manner. Multi-rotor UAVs, in particular the quadcopters described below, have multiple advantages, such as simple design or maintenance.

They also allow for the use of increasingly advanced automatic control solutions. The above features have motivated in recent years the development of the swarms of quadcopters for cooperative tasks using advanced MIMO communication and control systems [5–7]. The solutions for UAVs cooperating within a swarm are increasingly frequently considered as systems for military applications. An example may be the intelligent swarm solution proposed by the US Army [8]. Quadcopters are also used for civil applications in terms of inspection and surveillance.

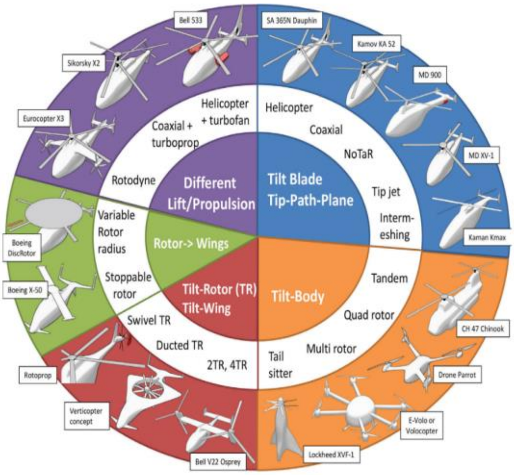
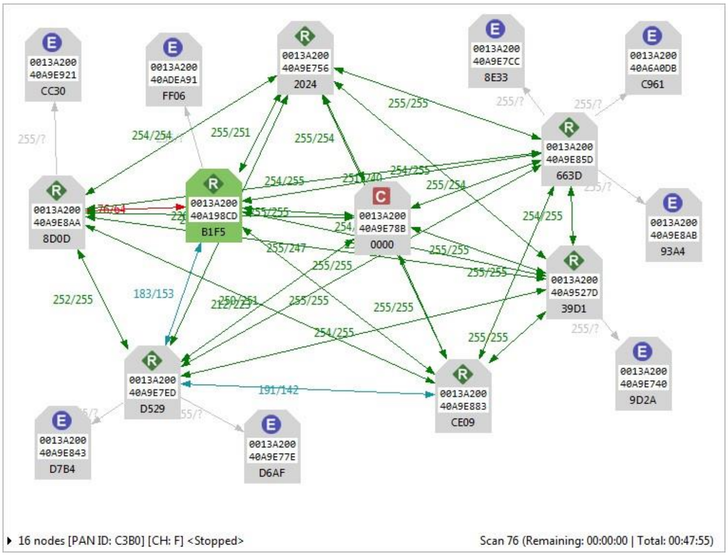


Fig. 2. Classification of rotorcraft flying machines [4]



16 nodes [PAN ID: C3B0] [CH: F] <Stopped>

Scan 76 (Remaining: 00:00:00 | Total: 00:47:55)

Fig. 3. Network of radio connections between transmitters used to control the swarm drones

Figures 3 and 4 present communication between a UAV swarm using a protocol and X-Bee transmitters.

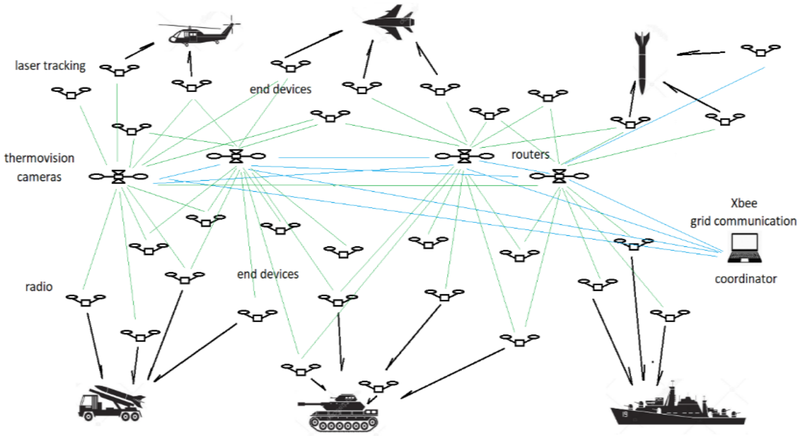


Fig. 4. Drones that can attack several targets simultaneously.

The possibilities of delivery of such a UAV swarm to the vicinity of potential targets (military objects) are also presented. An important aspect that is currently the subject of research in the UAV systems is the capability to acquire and track targets. Such use is utilised by the rescue, security, or uniformed services.

For this purpose various target acquisition systems are used, from extremely expensive LIDAR (Light Detection and Ranging) systems, RGB systems, thermal cameras, to low-cost systems based on sound and radio systems. The subject matter of this study is target acquisition using thermal cameras. Papers dealing with similar subjects are provided below.

Article [9] presents the possibilities of thermal image processing using a neural network.

Fig. 5. View from the thermal imaging camera installed in the UAV system

A UAV ground target acquisition and identification system is presented that may be suitable for detecting moving objects. Such an analysis requires an advanced data processing system with high computing and memory capacity, allowing for the performance of real-time image analysis.

Article [10] suggests an automatic object tracking system called Persistent Aerial Tracking (PAT) for unmanned aerial vehicles. In this case, a UAV network with an RGB camera is integrated for the surveillance of people, animals, cars, and other objects. Article [11] describes a system utilising predictive algorithms implemented to process images obtained using a thermal camera integrated into a microcomputer that identifies the thermal signatures of a target animal from a specified height and sends its GPS coordinates. The results presented in that study indicate that this system is able to locate animals automatically from a specified height and generate a map with animal locations.

The growing popularity of UAVs in recent years, accompanied by the reduction of costs and higher availability of thermal sensors, have paved the way for this technology to be commonly used, in particular in precision agriculture and plant phenotyping. Article [12] presents the capabilities of commercial thermal cameras in terms of processing images and classifying forest and agricultural areas.

3. CONTROL OBJECT

The control object is an in-house UAV. It has a design of a standard quadcopter with two pairs of countercurrent rotors. The first and third rotors rotate clockwise, and the second and fourth rotors rotate counterclockwise (Fig. 6).

Vertical thrust is controlled by modifying the rotor rotational speed (Fig. 6a). The UAV’s pitch relative to a reference system can be controlled by increasing the speed of one rotor and reducing the speed of the opposite rotor (Fig. 6c and 6d). Rotation in relation to the vertical axis is obtained by maintaining the rotational speed difference between the opposite rotor pair and the other rotor pair. For example, counterclockwise rotation is generated by simultaneously increasing the speed of the first and third rotors and decreasing the speed of the second and fourth rotor (Fig. 6b).

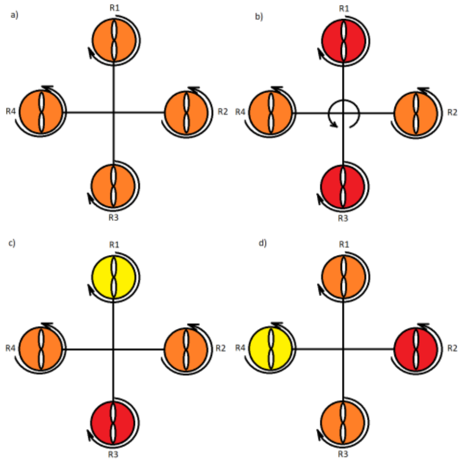


Fig. 6. The basic kinematics of the rotors allowing to perform:
a) vertical ascent / descent flight (displacement in relation to the OZ axis),
b) rotation in relation to the vertical axis OZ (Yaw), c) rotation in relation to the horizontal axis OX (Roll), d) rotation in relation to the horizontal axis OY (Pitch)

4. CONTROL SYSTEM

The control system consists of three subsystems, and the control signals obtained for all of these subsystems, were summed before being received by the individual motors. The first subsystem is used to maintain the UAV in a defined position. The second subsystem is used to control the UAV using a pad (telemetry system transmitter).

The third subsystem uses a signal from the thermal camera to allow the UAV to track a given point. To design the control systems, nomenclature was introduced related to the motion around individual axes (Fig. 7).

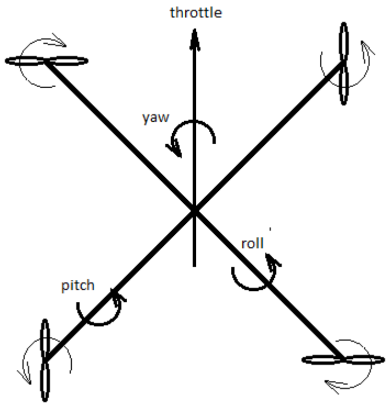


Fig. 7. Nomenclature used to describe the kinematics of the UAV system

4.1. Control system to maintain the UAV in a fixed position

The UAV's position may be deflected as a result of various interferences, e.g. wind. The task of the control system is to maintain the UAV in a fixed position. The measurement system consists of a gyroscope and an MPU6050 accelerometer. On the basis of the measurements obtained, Euler angles are calculated according to the following dependencies:

$$\alpha_{pitch} = atan\left(\frac{a_x}{\sqrt{{a_y}^2 + {a_z}^2}}\right)$$

$$\alpha_{roll} = atan\left(\frac{a_y}{\sqrt{{a_x}^2 + {a_z}^2}}\right)$$

where:

α_{pitch} — angle of rotation around the 0Y axis;
α_{roll} — angle of rotation around the 0X axis;
a_{x} — acceleration on the 0X axis;
a_{y} — acceleration on the 0Y axis;
a_{z} — acceleration on the 0Z axis.

There were attempts to minimise the above deviations, i.e. to reset them to zero, using a PID (proportional–integral–derivative) controller. Actuators in this control system are motors (connected to propellers). A diagram of the control system is presented in Fig. 8.

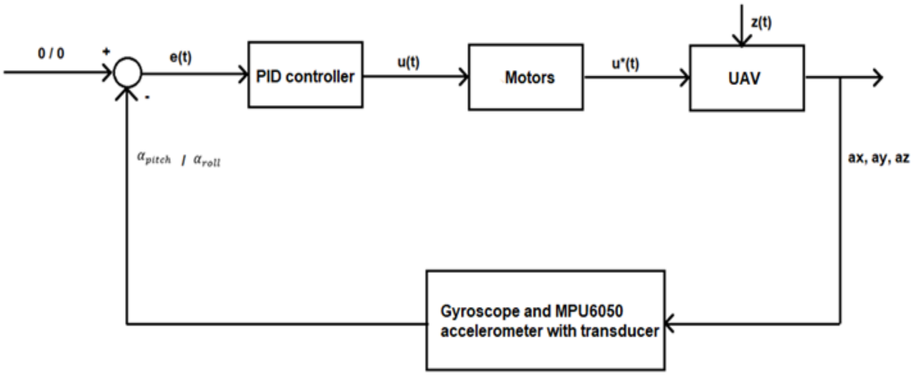


Fig. 8. Diagram of the control system that keeps the UAV in a fixed position

The control system is based on the ARM Cortex. The implemented code is provided below.

```
accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
m_gravityx = (float)ax ;//* (MPU6050_ACCEL_RANGE / 32768.0f);
m_gravityy = (float)ay ;//* (MPU6050_ACCEL_RANGE / 32768.0f);
m_gravityz = (float)az ;//* (MPU6050_ACCEL_RANGE / 32768.0f);
m_ratex = (float)gx ; //(MPU6050_GYRO_RANGE / 32768.0f);
m_ratey = -(float)gy;  //(MPU6050_GYRO_RANGE / 32768.0f);
m_ratez = (float)gz;  //(MPU6050_GYRO_RANGE / 32768.0f);
m_yprx = (atan(m_gravityy / sqrt(sq(m_gravityx) +
sq(m_gravityz))) * RAD_TO_DEG);
m_ypry = (atan(m_gravityx / sqrt(sq(m_gravityy) +
sq(m_gravityz))) * RAD_TO_DEG);
PidR=0.6*Kcrity*(m_ypry-nastay)+loop_time*Tcritiy*0.5*(m_ypry-
nastay)+0.13*Tcritdy* (m_ypry-nastay)/loop_time;
PidP=0.6*Kcritx*(m_yprx-nastax)+loop_time*Tcritix*0.5*(m_yprx-
nastax)+0.13*Tcritdx* (m_yprx-nastax)/loop_time;
```

4.2. Control system allowing remote control of the UAV

An essential aspect is to control the flight of the UAV in a remote manner using a controller, known as a “pad” (telemetry system transmitter). To complete this task, an open-loop system is used, as presented in Fig. 9. A PWM signal representing the rotational speed of individual motors is given at the output of the telemetry system receiver. This signal is processed so that it allows the set flight parameters to become effective.

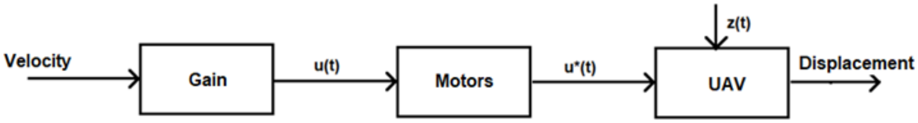


Fig. 9. Diagram of the control system enabling remote control of the UAV

4.3. Control system utilising a thermal camera signal

The UAV system presented here is capable of tracking a selected object using a thermal camera. A thermal camera image can be considered as a matrix where each value corresponds to the measured temperature (Fig. 10).

The operation of the control system was based on the motion of the UAV, so that the highest temperature point is in the central area of the image. For this purpose the distances between the locations of the highest temperature points and the central point were calculated. Then a control signal was generated using feedback loops and the P controller (Fig. 11).

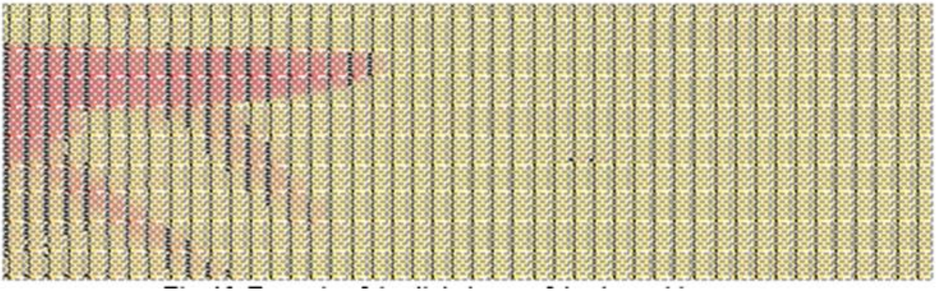


Fig. 10. Example of the digital map of the thermal image

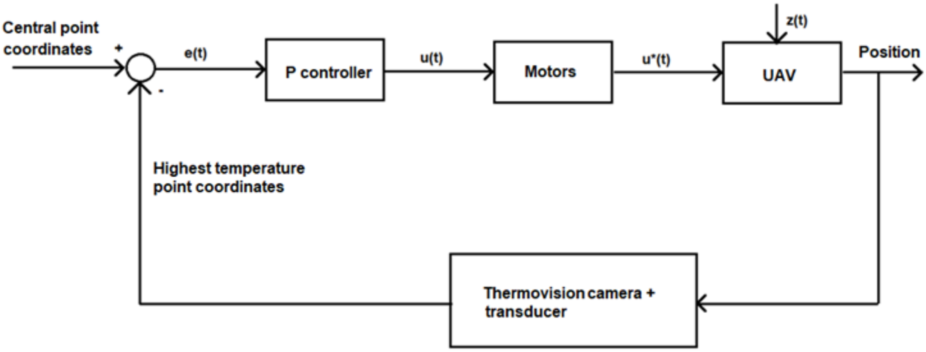


Fig. 11. Diagram of the control system using the signal from the infrared camera

The code implemented for the control system operation is provided below.

```
for(i=14;i<79;i++)
 {
       for(j=0;j<59;j++)
{
     if (image[i][j] > mxval)
{
mxval = image[i][j];
minj= j;mini= i;
    }
    }
    }
pidflirleftright=(float) (46-mini);
pidflirfrontbuck=(float) (29-minj);
RFservovalk=(kalthrottleR+PidR-PidP-
PidY+pidflirleftright+pidflirfrontbuck) *(maxspeed);
RBservovalk=(kalthrottleR-PidR+PidP-PidY+pidflirleftright-
pidflirfrontbuck)*(maxspeed);
LBservovalk=(kalthrottleR-PidR-PidP+PidY-pidflirleftright-
pidflirfrontbuck)  *(maxspeed);
LFservovalk=(kalthrottleR+PidR+PidP+PidY-
pidflirleftright+pidflirfrontbuck)  *(maxspeed);
```

5. EXPERIMENTAL TEST

5.1. Test stand

To test the control concept, a test stand was constructed, see Fig. 12. During the test a LEPTON 80x60 matrix was used to ensure precise and fast target acquisition. A single-processor 32-bit ARM CORTEX M3 system was also used to allow continuous image processing and to execute the flight function.

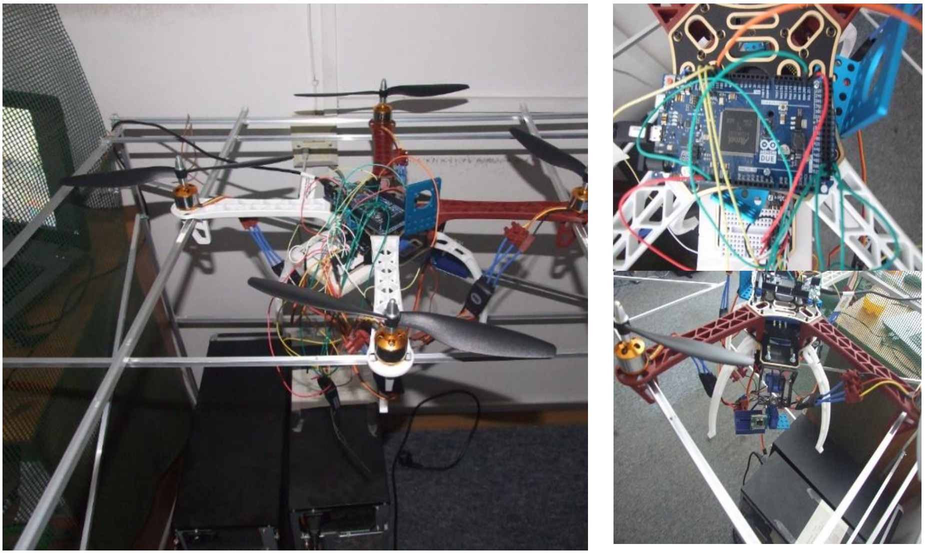


Fig. 12. Test stand of the UAV system

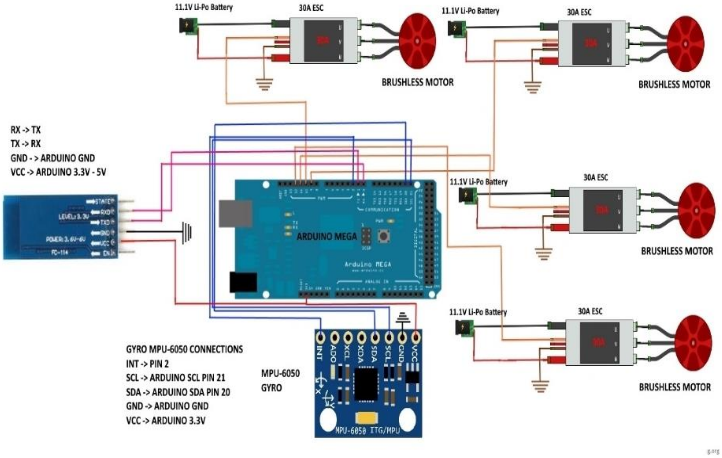


Fig. 13. The MPU-6050 3-axis gyroscope / accelerometer adapter connected to the microprocessor platform, power supply and drive system

Figure 13 presents a diagram of the connections for the MPU-6050 3-axis gyroscope/accelerometer to the microprocessor platform, power supply and drive system. Figure 14 presents connections of the thermal camera unit to the central processor system.

Ref.	Arduino	Ref.	Lepton Module
7	PIN 10	1	CS
5	MOSI	2	MOSI
1	MISO	3	MISO
2	CLK	4	CLK
6	GND	5	GND
4	5V	6	VIN
8	PIN 20 (SDA)	7	SDA
9	PIN 21 (SCL)	8	SCL

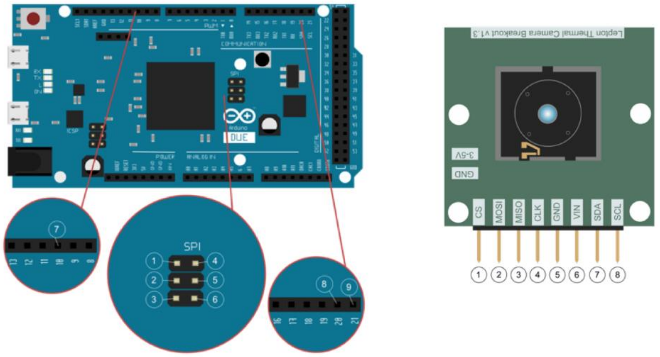


Fig. 14. Connecting the thermal imaging camera to the microprocessor

5.2. Experimental results

The measurement and flight stability systems were tested during the experimental work. The figures below show example diagrams relating to the telemetry and the lift of all the drive motors (Fig. 15), the MPU6050 measurement system (Fig. 16), and signals from the PID controllers (Fig. 17) set to the drive motors ESC systems.

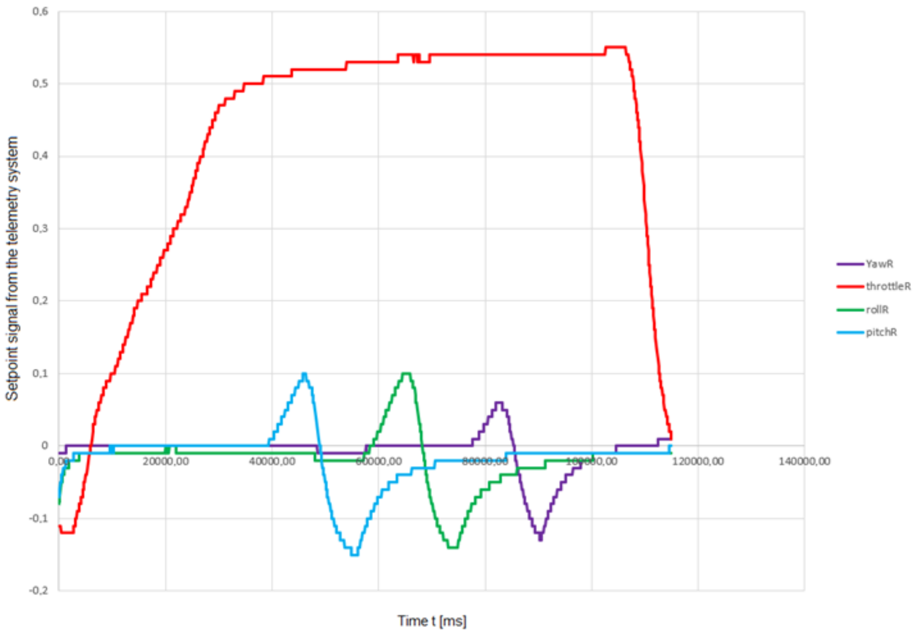


Fig. 15. Control signals from telemetry

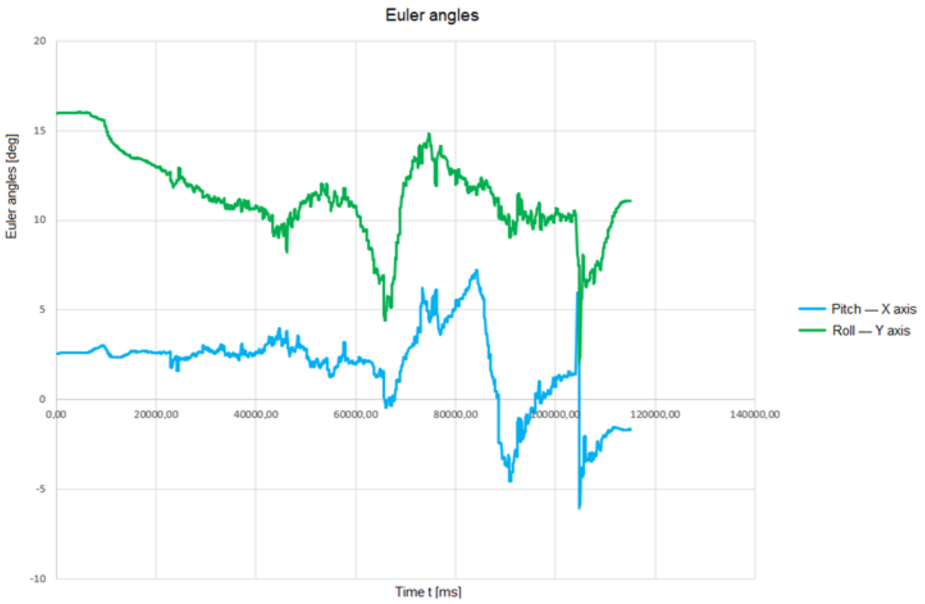


Fig. 16. Measurement signals from the MPU-6050 system

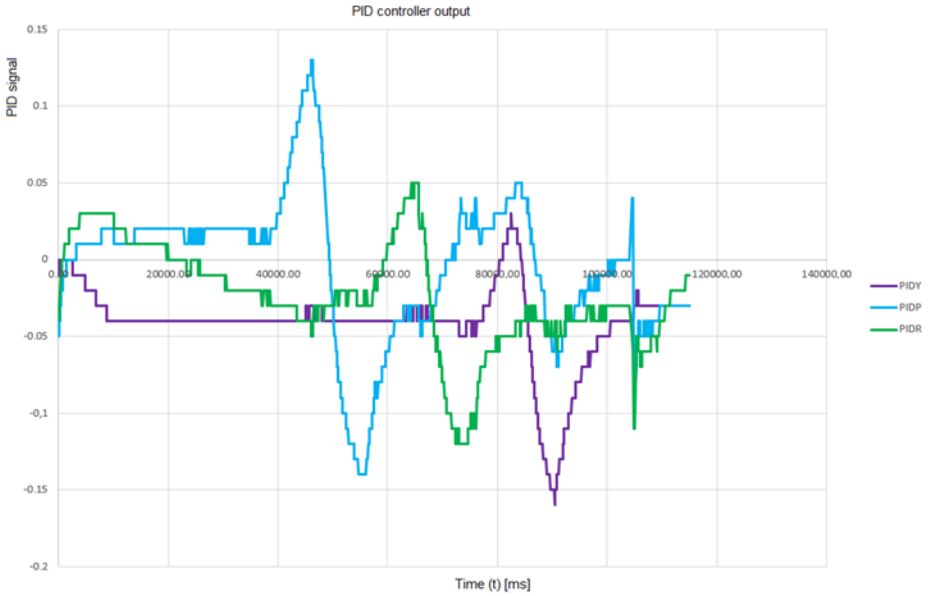


Fig. 17. Control signals coming from the PID control systems to the flight coding matrix.

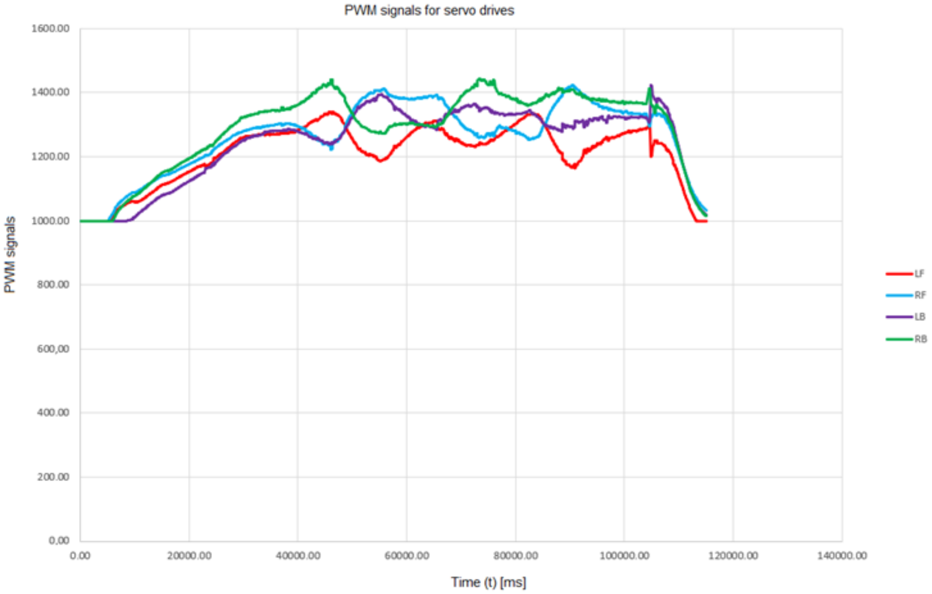


Fig 18. PWM signals for servo drives

For the diagrams of the signals for servo drives presented in Fig. 18, it can be noted that during the rotation with respect to the 0Z axis, the LF and RB drives are more diverse than the diagrams for the RF and LB drives. This stems from the higher load exerted by the empty weight of the arm on which the RB drive is mounted. A higher rotational speed of this drive is used to eliminate this load during steady flight (time up to 60,000 ms).

Tilt in relation to the X axis and then to the Y axis was performed from 60,000 ms to 90,000 ms, and it was forced by an external control signal from the telemetry system. Disabling the control signal from the telemetry system and landing were performed after a lapse of 90,000 ms.

The results showed that the use of a thermal camera allows for target acquisition. The quality of target acquisition is related to the capabilities of the matrix used as the targets, which are acquired with an accuracy of a single pixel. The selection of camera resolution is an optimisation task. The lower the camera resolution, the faster the image analysis. However, higher camera resolution extends the analysed area and requires and the use of more efficient microprocessor systems. Excessive loading of the microprocessor with thermal image processing may disturb the flight functions.

6. CONCLUSIONS

The aim of this study was to develop a control algorithm that would allow the “partially automatic” flight of the UAV using the thermal camera from which the acquisition signal was obtained. To this end a control system was designed, which consisted of three subsystems: to maintain an object in a fixed position, allowing remote control, and allowing target acquisition using a thermal camera. The test results are satisfactory and form the basis for further efforts on the subject matter. The control matrix allows stable flight in the event of external disturbances, e.g. a gust of wind, as well as disturbances related to a displacing or an unequally distributed load installed under the UAV. The use of more complex target acquisition algorithms, such as based on optimisation “swarm” algorithms, may allow for the acquisition of several separate targets and the selection of an optimum target for further surveillance. This may require, however, the use of a more complex microprocessor system or even two such systems (one for image processing and one for flight control).

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

[1] Wyszywacz, Wiktor. 2016. *Drony – budowa, loty, przepisy*. Brzezia Łąka: Wydawnictwo Poligraf.

[2] http://www.military-today.com/helicopters/top_10_transport_helicopters.htm

[3] http://www.kaibracher.de/portfolio-type/3d-printed-wasp-case-for-micro-drone/

[4] Basset, Pierre-Marie, A. Tremolet, and Thierry Lefbvre. 2014. "Rotary Wings UAVs presizing: Past and present methodological approaches at Onera". *Journal Aerospace Lab* 8 : 1-12.

[5] Alvissalim, M., B. Zaman, Z. Hafizh, M. Anvar Ma'sum, Grafika Jati, Wisnu Jatmiko, and Petrus Mursanto. 2012. Swarm quadrotor robots for telecommunication network coverage area expansion in disaster area. In *Proceedings of the SICE Annual Conference* 2256–2261. August 2012.

[6] Jaimes, Aldo, Satyanarayana Kota, and Jose Gomez. 2008. An approach to surveillance an area using swarm of fixed wing and quad-rotor unmanned aerial vehicles UAV(s). In *Proceedings of the IEEE International Conference on System of Systems Engineering* 1-6. June 2008.

[7] Chandhar, Prabhu. Dayno Donev, and Erik G. Larsson. *Massive MIMO for Communications with Drone Swarms* https://arxiv.org/pdf/1707.01039.pdf

[8] https://www.youtube.com/watch?v=KLmmPnMvwNY

[9] Wang, Ye, Yueru Chen, Jongmoo Choi, C.C. Jay Kuo. 2019. "Towards Visible and Thermal Drone Monitoring with Convolutional Neural Networks". *APSIPA Transactions on Signal and Information Processing* 8 (1) : 1-13.

[10] Mueller, Matthias, Gopal Sharma, Neil Smith, and Bernard Ghanem. 2016. Persistent Aerial Tracking system for UAVs. In *Proceedings of the 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* 1562-1569. 09-14 October 2016, Daejeon, Korea (South).

[11] Ward, Sean, Jordon Hensler, Bilal Alsalam, and Luis Filipe Gonzalez. 2016. Autonomous UAVs wildlife detection using thermal imaging, predictive navigation and computer vision. In *Proceedings of the 2016 IEEE Aerospace Conference* 1-8, 05-12 March 2016, Big Sky, MT, USA.

[12] Sagan, Vasid, Maitiniyazi Maimaitijiang, Peheding Sidike, Kevin Eblimit, Kyle T. Peterson, Sean Hartling, Flavio Esposito, Kapil Khanal, Maria Newcomb, Duke Pauli, Rick Ward, Felix Fritschi, Nadia Shakoor, and Todd Mockler. 2019. "UAV-Based High Resolution Thermal Imaging for Vegetation Monitoring, and Plant Phenotyping Using ICI 8640 P, FLIR Vue Pro R 640, and thermoMap Cameras". *Remote Sensing* 11 (3) : 330-1-29.

System namierzania punktowego sygnatury termicznej odległej od otoczenia z wykorzystaniem ciągłego algorytmu PID i filtracji obrazu termowizyjnego dla układów UAV

Robert MATYSKO, Weronika WIŚNIEWSKA

Instytut Maszyn Przepływowych im. Roberta Szewalskiego Polskiej Akademii Nauk
ul. Fiszera 14, 80-283 Gdańsk

Streszczenie. W pracy przedstawiono badania własne procesu sterowania BSP Bezzałogowym statkiem powietrznym z uwagi na możliwości namierzania i śledzenia obiektu o sygnaturze termicznej odległej od otoczenia. W procesie sterowania zaimplementowano algorytm PID dla falowników zasilających silniki napędowe. Opisano możliwości, koncepcję oraz zaimplementowaną w układzie mikroprocesora ideę sterowania z termowizyjnym systemem śledzenia oraz wykrywania obiektów. Opracowany algorytm procesu sterowania dronem z zastosowaniem sygnałów wyjściowych z kamery termowizyjnej przedstawia tylko przykładowe możliwości automatycznego nadążania co ma znaczenie w przypadku autonomicznych układów nadążnych. Możliwości wykrywania źródeł o temperaturze odbiegającej od otoczenia wraz z możliwością ich automatycznego śledzenia i nadzoru w najbliższym czasie może być wykorzystywane w systemach poszukiwania, nadzoru jak i namierzania. Zastosowanie bardziej skomplikowanych algorytmów namierzania np. bazujących na algorytmach optymalizacyjnych „np. swarm” może pozwolić na poszukiwania kilku odrębnych celi, oraz wybieranie optymalnego celu podlegającemu dalszemu nadzorowi - może to jednak wymagać bardziej rozbudowanego układu mikroprocesorowego lub nawet dwóch takich układów (jeden do obróbki obrazu i drugi do nadzoru nad lotem).

Słowa kluczowe: termowizja, bezzałogowy statek powietrzny, namierzanie celu