PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

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

Research paper

Identification of Dynamic Models of Vertical Motion for a Multi-rotor Flying Platform

Michał DUDA (michal.duda@wat.edu.pl)

ORCID: https://orcid.org/0000-0002-7953-9206

Military University of Technology
2 gen. Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland

Received: June 30, 2023 / Revised: July 10, 2023 / Accepted: January 9, 2024 / Published: June 30, 2024.

2024, 15 (2), 47-54; https://doi.org/10.5604/01.3001.0054.6153

Cite: Chicago Style

Duda, Michał. 2024. “Identification of Dynamic Models of Vertical Motion for a Multi-rotor Flying Platform”. *Problemy mechatroniki. Uzbrojenie, lotnictwo, inżynieria bezpieczeństwa* / *Probl. Mechatronics. Armament Aviat. Saf. Eng.* 15 (2) : 47-54. https://doi.org/10.5604/01.3001.0054.6153

Abstract. The article presents the results of identifying dynamic models for an unmanned multi-rotor platform. Due to such an object's highly complex mathematical model, it was decided to identify dynamic models based on experimental data. The identification concerns vertical movement parameters, but also energy consumption when performing maneuvers, which is a key factor for autonomous aircraft.

Keywords: UAV, multi-rotor platforms, dynamic models, identification

1. INTRODUCTION

The growing popularity of multi-rotor flying platforms contributes to the search for new applications for this type of device. Unmanned aerial vehicles (UAVs) are used in many civil fields, such as cartography, patrolling, inspection of large areas or agriculture [1]. They are also used in military tasks where they may serve as defensive, offensive or surveillance measures [2]. Many solutions use more than one aircraft instead of a single robot. We call such a system a “group” or “swarm”. They are used due to greater reliability and scalability. Due to the synergy of their work, a group of robots have greater capabilities than a single robot, even if much more technically advanced. This applies especially to tasks that require dispersion over a large area [3,4].

In the introductory phase of swarm system design, a control algorithm is developed to meet the task requirements. First, the solution is developed theoretically and then simulationally in virtual space. The more thoroughly the solution is tested at this stage, the less likely it is that errors will occur when trying to implement the algorithm to the real system. To correctly model the behaviour of a swarm in virtual space, one must first develop models for a single object in the swarm.

This issue is particularly important in the case of a swarm composed of multi-rotor flying platforms. Knowing the motion parameters of a single robot, such as accelerations, velocities or inertia, allows one to plan and optimise the flight trajectory [5]. Additionally, knowledge of quantities such as deceleration distance is necessary in the case of collision avoidance algorithms, which are an essential part of a swarm of autonomous robots [6].

UAVs, especially multi-rotor platforms, are characterised by relatively low battery capacity. This parameter defines the flight duration on a single charge [7]. When planning a mission, it is necessary to determine how many robots to use and whether they will be able to complete it without having to recharge [8]. Therefore, identifying the characteristics of power consumed from the battery while performing manoeuvres is also a vital part of preparation for working with a swarm of unmanned flying robots.

2. IDENTIFICATION OF DYNAMIC MODELS

The use of dynamic models in computer simulation enables an accurate representation of the variability of a real phenomenon over time. The more precise the model is, the better quality of the representation. The flight dynamics of a multi-rotor platform is a complex issue. Many factors, such as rotor efficiency or aerodynamic drag, make creating a perfect mathematical model almost impossible. [9]. Estimating the flight duration is an equally complicated issue. Battery endurance modelling is based on modelling the power demand while performing various manoeuvres. In addition to determining the propulsive force, it is necessary to consider factors such as the efficiency of the gearbox, the efficiency of the rotor blades or the intensity of energy consumption in given flight conditions [10]. The combination of these factors also makes developing a complete mathematical model a very difficult task.

The complexity of the mathematical apparatus required for a multi-rotor platform justifies a different approach. Access to a real object makes it possible to equip it with necessary sensors and conduct a series of experimental flights. Data recorded during tests can be used to identify dynamic models using computer technologies. This solution does not provide insight into the system’s structure and therefore does not allow distinguishing the values of individual coefficients and parameters of the object. However, the identified models provide a picture of the variability of processes over time. If only the system’s response is important in research, and there is no need to delve into its structure, then the model obtained in this way can be successfully used in computer simulations.

2.1. Acquisition of experimental results

Test flights were conducted to generate and record experimental results. Various vertical movement manoeuvres, i.e. ascent and descent, were performed during the tests. The platform was also brought to hover at a specified altitude. The parameters were recorded during the tests with appropriate frequencies and specific time signatures. Among other things, the flight altitude and the current and voltage drawn from the battery were recorded. Control signals were also recorded, which made it possible to synchronise the control signal with the system’s response in time.

2.2. Dynamic motion models for vertical maneuvers

The developed dynamic models were presented for vertical motion. First, the displacement was studied for a change in the preset flight altitude by 400 metres in four successive stages.

On one occasion, the robot climbed 100 metres and then hovered. After reaching the maximum altitude, the robot began its descent. The flight altitude changed every 100 metres until it landed. The following diagrams present a summary of the control signals and the actual curves, as well as the curves obtained by simulation. The curves represent selected sessions of the entire test to highlight the system's behaviour for a 100 m change in the flight altitude. With each relative altitude change, the robot behaved similarly, regardless of the absolute altitude.

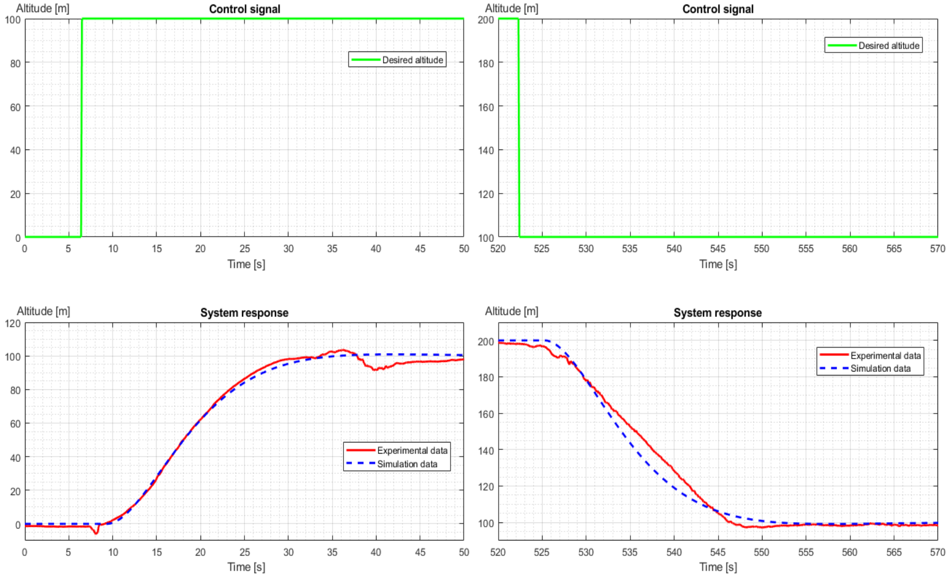

Fig. 1. Flight altitude change during ascent and descent

Using statistical methods, it was possible to compare the curves and determine the extent to which the model coincides with the actual curve. The models can be implemented directly into a computer simulation. Their response to control signal during virtual tests will correspond to the object's behaviour in the real system.

The presented diagrams show that the experimental data are disrupted by noise, which is not visible in the simulation model. However, the model reflects the general nature of the curve with high accuracy. An additional processing of the simulated signal would be required to add noise to it.

.

2.3. Dynamic power models during vertical manoeuvres

A similar identification was performed for the change in battery power consumption during ascent and descent manoeuvres.

The temporary power consumption was calculated as the product of the instantaneous voltage and the current drawn from the battery. Thanks to this, the entire sequence of dependencies between the battery and the generated propulsive force (e.g. efficiency of the drive systems) was omitted. The analysis gives a direct answer about the energy needed to perform a given manoeuvre.

The analysis was performed for the power difference relative to the hovering state. To do this, the average power needed to remain in hover at a given altitude was determined and subtracted from the experimentally obtained curve. The control signal was also given as a relative change in the desired altitude. Therefore, the diagrams represented only the deviation from the equilibrium state, making it easier to understand the nature of the curve. A diagram of power consumption change over time for climb is shown below.

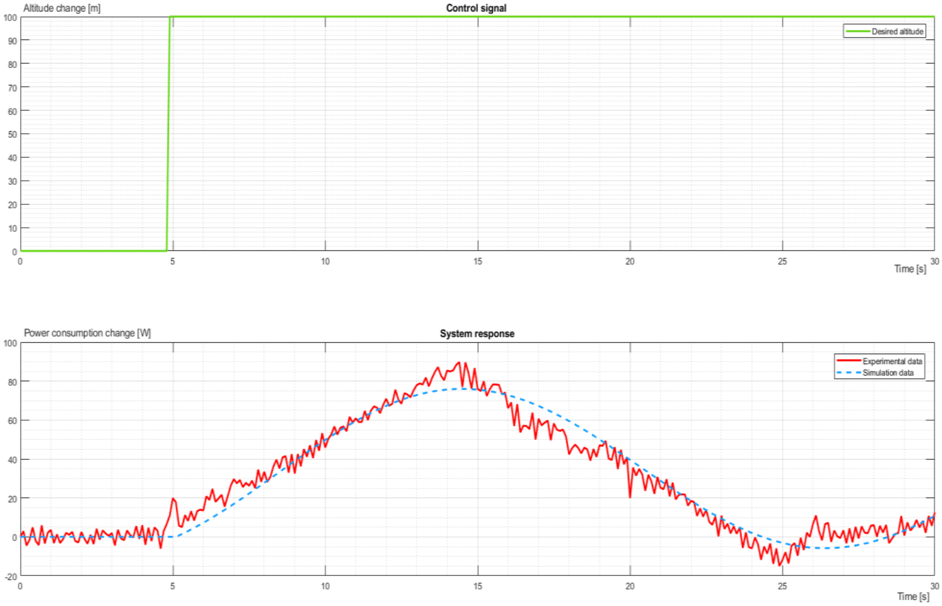

Fig. 2. Power consumption change during climb

Analysing the diagram, it can be seen that there was a rapid increase in battery power consumption after the change in the desired altitude. This was due to the robot revving its engines to generate additional propulsive force and accelerate upwards. The power consumption increased and then began to decrease. After achieving sufficient speed, the robot started to decelerate gradually.

In the final stage, the change in the power consumption dropped below zero because the robot decelerated due to gravity. At the end of the climb, the temporary power consumption stabilised at the value needed to hover at the preset altitude.

In the case of descent, the power drawn from the battery also varied in relevant sequence. Initially, power consumption decreased as the robot reduced the thrust and began to accelerate downwards.

At a certain point, the motors accelerated, and the UAV began to gradually slow down its descent. In the final phase, the propulsive force was increased in order to finally reduce the ground-bound speed. This is reflected in a relatively rapid increase in instantaneous power consumption. Finally, the power consumption decreased, and the robot began hovering at the desired altitude. The power consumption change graph for descent is presented below.

In both temporal power consumption analyses, it can be seen that noise in the real values is significant. This is because the power consumption is calculated as the product of the instantaneous voltage and the current drawn from the battery. The measurement of the current was particularly noisy, which was reflected in the visible fluctuations in the power input graphs.

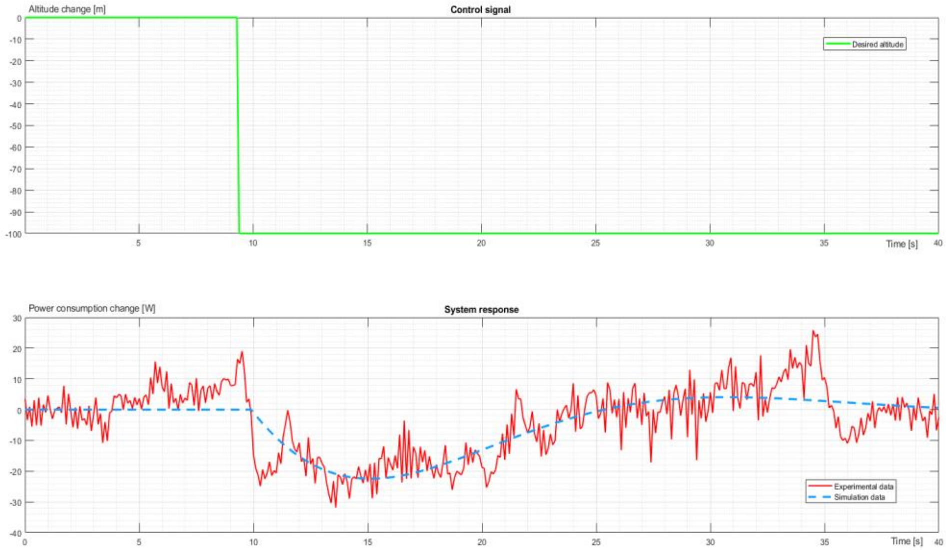

Fig. 3. Power consumption change during descent

3. SUMMARY AND CONCLUSIONS

The article demonstrates that it is possible to identify dynamic models of unmanned multi-rotor platforms without preparing a complete mathematical description. Preparing a precise mathematical model for this type of object is a very complex task, and the presented method skips this step. Computer identification is a simpler and faster solution if researchers have access to a real object and can carry out experimental flights with data acquisition.

The dynamic models obtained in this way do not provide insight into the system's structure under study and, therefore, do not enable the isolation of its individual parameters or coefficients. If knowledge of these physical quantities is not required to conduct further research, the presented method is a solution that allows relatively easy mapping of the behaviour of a real object onto the virtual space.

The results presented here concern only some of the manoeuvres that a multi-rotor platform can perform. However, they provide an insight into the potential of the presented method. If experimental data acquisition is possible, analogous analysis can be performed for any manoeuvre or flight condition. Of particular interest is the issue of identifying changes in battery energy consumption during manoeuvres. Due to the relatively low flight endurance of this type of object, the energy consumed is one of the key factors when planning a mission.

FUNDING

The project was financed by the Polish National Center for Research and Development as part of the SZAFIR-4 program.

REFERENCES

[1] Muchiri, G.N., and Stephen Muchai Kimathi. 2016. A review of applications and potential applications of UAV. In *Proceedings of the 2016 Annual Conference on Sustainable Research and Innovation*. p. 280-283. Jomo Kenyatta University of Agriculture and Technology, , Kenya, Nairobi 4-6 May 2016.

[2] Nawaz, Haque, Husnain Mansoor Ali, and Shafiq-ur-Rehman Massan. 2019. "Applications of unmanned aerial vehicles: a review". *3C Tecnologia. Glosas de innovación aplicadas a la pyme.* November 2019 : 85-105.

[3] Sahin, Erol, and Alan FT Winfield. 2008. "Special issue on swarm robotics". *Swarm Intell*. 2 (2-4) : 69-72.

[4] Khaldi, Belkacem, and Cherif Foudil. 2015."An overview of swarm robotics: Swarm intelligence applied to multi-robotics". *International Journal of Computer Applications* 126 (2) 31-37.

[5] Yang, Guang, and Vikram Kapila. 2002. Optimal path planning for unmanned air vehicles with kinematic and tactical constraints. In *Proceedings of the 41st IEEE Conference on Decision and Control*, vol.2, pp. 1301-1306. 10-13 December 2002, Las Vegas, NV, USA.

[6] Maini, Parikshit, and P.B. Sujit. 2016. Path planning for a UAV with kinematic constraints in the presence of polygonal obstacles. In *Proceedings of the International Conference on Unmanned Aircraft Systems (ICUAS)*. 7-10 June 2016, Arlington, VA, USA.

[7] Cesare, Kyle, Ryan Skeele, Soo-Hyun Yoo, Yawei Zhang, and Geoffrey Hollinger. 2015. Multi-UAV exploration with limited communication and battery. In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*. 26-30 May 2015, Seattle, WA, USA.

[8] Li, Jing, Yonghua Xiong, Jinhua She, and Min Wu. 2020. “A path planning method for sweep coverage with multiple UAVs”. *IEEE Internet of Things Journal* 7 (9) : 8967-8978.

[9] Koehl, Arnaud, Hugues Rafaralahyet, Mohamed Boutayebal, and Bastien Martinez. 2012. "Aerodynamic modelling and experimental identification of a coaxial-rotor UAV". *Journal of Intelligent & Robotic Systems* 68 : 53-68.

[10] Abdilla, Analiza, Arthur Richards, and Stephen Burrow. 2015. Power and endurance modelling of battery-powered rotorcraft. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 28 September - 02 October 2015, Hamburg, Germany.

Identyfikacja modeli dynamicznych ruchu pionowego dla wielowirnikowej platformy latającej

Michał DUDA

Wojskowa Akademia Techniczna
ul. gen. Sylwestra Kaliskiego 2, 009-8 Warszawa

Streszczenie. W artykule zaprezentowano wyniki identyfikacji modeli dynamicznych dla bezzałogowej platformy wielowirnikowej. Ze względu na wysoce skomplikowany model matematyczny takiego obiektu zdecydowano się na zidentyfikowanie modeli dynamicznych na podstawie danych eksperymentalnych. Identyfikacja dotyczy parametrów ruchu pionowego, ale również zużycia energii podczas wykonywania manewrów, które jest kluczowym czynnikiem dla autonomicznych statków powietrznych.

Słowa kluczowe: BSP, platformy wielowirnikowe, modele dynamiczne, identyfikacja