2024. Volume 8, Number 1 *Pages 32-35*

UOT: 002.6:025.3/.4

DOİ: ***https://doi.org/10.30546/09090.2024.110.216***

MANAGİNG THE MOVEMENT OF A HEXACOPTER İN THE EVENT OF ENGİNE FAİLURE

GULUSH NABADOVA

Baku Engineering University, Baku, Azerbaijan

gnabadova@beu.edu.az

ARTICLE INFO

Article history:

Received:2024-09-17

Received in revised form:2024-09-24

Accepted:2024-10-30

Available online

Keywords: Hexacopter, route, control parameters, failed motor, quaternion, spatial orientation, unmanned aerial vehicle.

ABSTRACT

In this article, the issue of controlling the movement of a hexacopter-type unmanned aerial vehicle (UAV) along a route is investigated. The movement of the hexacopter is modeled as the movement of a rigid body, and in this process, the forces of gravity and aerodynamic resistance are taken into account. The spatial orientation of the hexacopter is expressed using quaternions. The movement route is considered as a broken line consisting of straight segments, and the parameters controlling its flight are determined when one of the hexacopter's motors is not working. Mathematical justification is provided for how the operational motors are controlled to continue the hexacopter's movement in its previous manner when one motor fails.

Introduction

In recent years, due to the widespread use of multi-engine drones and depending on their purpose and the requirements placed on them, various types have become particularly popular [1, 2, 3]. Unlike single-engine drones, the failure of engines in multi-rotor devices can lead to safety-related problems. Many published articles propose solving this problem by redesigning the control law and adjusting the control force [4, 5]. However, this approach is difficult to implement, as it often requires the addition of extra devices to change the control force in this way.

Quadrotor-type unmanned aerial vehicles (UAVs), equipped with four rotors, have garnered significant attention from researchers due to their ability to maintain stationary flight and stable hovering by balancing the forces generated by the rotors. Recently, UAVs with more than four rotors, such as hexacopters and octocopters, have also become a focal point of interest. To evaluate flight characteristics and achieve robust control of UAVs, computer simulations are frequently employed. Various types of UAVs have been developed in Azerbaijan. In this study, the development of a simulation system is presented to experiment with the flight of the hexacopter-type UAV known as Əqrəb 5.0.

Most previous studies have focused only on quadcopters with one engine failure. The second approach is based on quaternion theory, but there is not enough material on how a hexacopter can be controlled using these methods when one engine fails.

This article studies the control of a hexacopter when one of its engines fails, particularly when there are power limitations on the remaining engines. The proposed system can assist in managing flight when an engine malfunctions and increases the chances of a successful emergency landing.

Problem statement. When there are no limitations on the power of the hexacopter's engines (referred to as the normal case below), it can be observed (Figure 1) that even if two symmetrically placed engines of the hexacopter fail, it can still be normally controlled along a straight trajectory. The failure of one of the hexacopter's engines refers to a situation where one of its six engines is not functioning. In such cases, typically, the engine symmetrically placed relative to the center of the hexacopter is turned off. It is clear that when the number of engines decreases from six to four, their power needs to be increased. However, a question arises: if there is a limitation on the power of the engines in the hexacopter, can the work of one engine be compensated by the remaining five? This article investigates this issue. Below, the mathematical formalization and solution of the problem are provided.

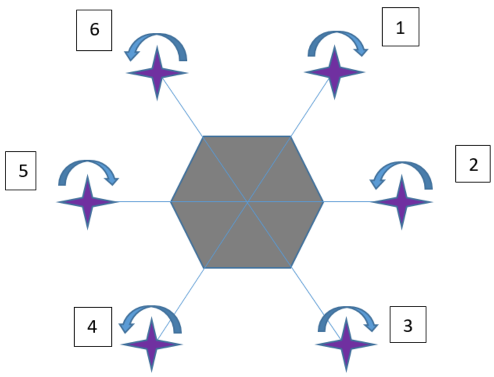

Figure 1. The direction of rotation of the propellers of hexacopter

Coordinate systems. The mathematical model of the hexacopter is expressed through the relationship between quantities calculated in local and global coordinate systems. Let's introduce the coordinate systems used, as shown in the diagram below (Figure 2).

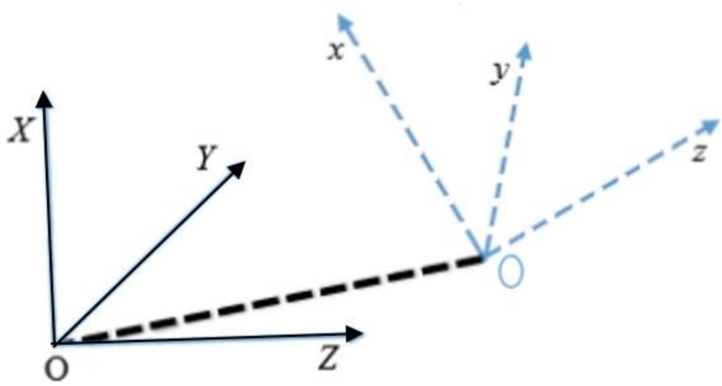

Figure 2. Lokal (body fixed) ($oxyz$) and global ($OXYZ$) coordinate systems

The $OXYZ$ coordinate system is an inertial frame attached to a fixed point on the Earth's surface, while the $oxyz$ system is a local coordinate system related to the hexacopter, with its origin at the center of gravity, used to determine the hexacopter's orientation in space.

Thus, for the hexacopter to fly in a straight line, it first needs to be oriented correctly by adjusting the rotational speeds of the propellers, achieving the necessary pitch. After that, it is controlled along the desired trajectory using the engines operating at the appropriate rotational speeds. (Note that the calculation of propeller rotational speeds for changing the UAV's orientation is not discussed in this article).

Controlling hexacopter with engine failure. The optimal control of straight-line flight, when all motors are functioning normally, is ensured by the propellers rotating at the same frequency. Let's assume that one of the hexacopter's motors has malfunctioned. Without loss of generality, we can assume that the malfunctioning motor is the 6th motor. In the absence of restrictions on the rotation frequencies of the motors, the control of the hexacopter's movement has been examined in [6], and it was shown that when $\omega_3 = 0$, straight-line trajectory control is possible. In this case a question arises: if the power of the motors is limited and they cannot maintain their rotation frequencies, is it possible to control the hexacopter in the previous mode with only 5 motors?

This problem, from a mathematical perspective, is a constrained extremum problem. Various approaches can be applied to solve this problem [7]. During the research, the Kuhn-Tucker method was used [8]. If there is a solution to this problem, then its solution must satisfy all the minimums obtained when each individual additional condition is addressed.

It is clear that a similar result is obtained when one of the 2nd, 3rd, or 5th motors malfunctions. For clarity, if we consider the case where the 1st motor fails instead of the 6th, by solving the system in a similar manner, it is again concluded that the hexacopter cannot be controlled with 5 motors when there is a power limitation on the motors. Naturally, the results are analogous if the 4th motor fails. Thus, this means that under the given constraints, the hexacopter cannot be controlled along a straight-line trajectory with only 5 motors.

Conclusion

Thus, the studies showed that when one engine of the hexacopter fails, its movement along the previous trajectory can be maintained by the other engines, excluding the engine symmetrically positioned relative to the failed one. In this case, when there are no technical limitations on engine power, it is necessary to increase the rotation speed of the propellers to maintain the previous speed of movement.

However, if there are limitations on engine power, continuing the flight along the trajectory can be achieved by reducing the flight speed. It was also mathematically justified that under such limitations, the power deficit across four engines cannot be compensated by the fifth engine to maintain the previous flight speed along a straight trajectory.

REFERENCES

1. Alderete, T.S. 1995. "Simulator aero model implementation." NASA Ames Research Center, Moffett Field, California.
2. Bekir, E. 2007. Introduction to modern navigation systems. World Scientific. ISBN not provided.
3. Cefalo, M., and J.M. Mirats-Tur. 2011. "A comprehensive dynamic model for class-1 tensegrity systems based on quaternions." International Journal of Solids and Structures 48 (5): 785-802.
4. Aoki, Y., Y. Asano, A. Honda, N. Motooka, K. Hoshino, and T. Ohtsuka. 2021. "Nonlinear model predictive control for hexacopter with failed rotors based on quaternions—simulations and hardware experiments—." Mechanical Engineering Journal 8 (5): 21-00204.
5. Wen, F.H., F.Y. Hsiao, and J.K. Shiau. 2021. "Analysis and management of motor failures of hexacopter in hover." In Actuators, Vol. 10, No. 3, p. 48. MDPI.
6. AOKI Y, ASANO Y, HONDA A, MOTOOKA N, HOSHINO K, OHTSUKA T. Nonlinear model predictive control for hexacopter with failed rotors based on quaternions—simulations and hardware experiments—. Mechanical Engineering Journal. 2021;8(5):21-00204.
7. Bertsekas, D.P. 1996. Constrained Optimization and Lagrange Multipliers Methods. Athena Scientific. ISBN 1-886529--04-3.
8. LMS SSEU. „§ 2.4. Методы исключения переменных из системы линейных уравнений”. Accessed: 30.08.2024. Available at: https://lms2.sseu.ru/courses/eresmat/metod/met2/parmet2_4.htm
9. Cheng, G., L. Xu, and L. Jiang. 2006. "A sequential approximate programming strategy for reliability-based structural optimization." Computers & Structures 84 (21): 1353-1367.