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Universal drone system design and orbit control

Gokul Krishna P.S[1], Gyan P.S[2], Nimitha Mohan[3]

Student, Bachelor of Computer Applications, SNGIST Arts and Science College,N Paravoor, India[1,2]

Assistant Professor, Dept. of Computer Applications, SNGIST Arts and Science College, N. Paravoor, India[3]

Abstract: This study proposes a new universal drone design that can be used in a variety of applications. The drone system has four to twelve rotors and is equipped with movable arms. For the proposed universal drone simulations, a standard eight rotors (Octocopter) and independently controlled twelve rotors (Dodecacopter) configurations are chosen as a comparison study to benchmark the trajectory performance. Furthermore, because the arm lengths of this drone system can be altered, the effect of varied arm lengths can be seen. The lengths of this performance are also investigated. Both systems are compared in five different operating conditions, including without disturbance, with periodic disturbances, and with non-periodic disturbances. When the amplitude was increased by 100% under the periodic disturbing effect, the root mean square of the position errors of the Octocopter and Dodecacopter systems increased by 69.7% and 47.6%, respectively, in the simulations. Similarly, for non-periodic disruptions, both systems saw a 13 percent and 7 percent increase, respectively. According to the obtained results, the octocopter system is partially more stable without disturbing effect while the dodecacopter system is more stable flight than octocopter systems as the disturbance effect grows.

Keywords: Control and design of multirotor UAVs, Modeling in motion simulation

I. INTRODUCTION

Because of widespread use and ease of manufacture, multirotor air vehicles have piqued scholarly attention in recent years. They can be built in a variety of structures, ranging from low-load multicopters for recreational use to high-load multicopters for military and agricultural use. Multirotor air vehicles typically have 4, 6, or 8 rotors, and the number of rotors affects both flight capabilities and load capacity. By adjusting the angular velocity of the rotors, they can move both rotationally and translationally. These movements are either manually or autonomously controlled. The engine, propeller, battery, electronic speed controller (ESC), frame, controller, and sensors make up the majority of a multicopter's hardware. Controllers and sensors are the components that have the most direct impact on the vehicle's flying performance.

Design criteria such as rotor number, rotor diameter, and rotor diameter are commonly used in the literature. The system's arm length and total weight carrying capacity are dictated by the working conditions and usage areas of the system.The system in general, a quadcopter with four rotors is a multicopter with four rotors is sufficient for simple imaging, the rotor count should be increased. In circumstances where the load carrying capacity is higher, the load carrying capacity should be raised.such include professional photography, agricultural spraying, and cargo. However, a strategy for realising a universal goal and a self-contained system that can be adapted to various working environments.The use of conditions is uncommon.

The creation of a model that can be reconfigured according to different usage reasons by changing the number of rotors and arm length is the most important contribution of the novel design produced in this study. Furthermore, it is feasible to test models with several configurations on the same vehicle for instructional purposes. Furthermore, having up to twelve rotors that may be operated individually allows for a more stable flight, especially in the event of adverse weather or rotor failure.

Nomenclature

M	mass of drone, kg	ω_b	vehicle body angular speed, rad/s
T	thrust, N	ω_g	vehicle body angular speed according to ground frame, rad/s
T_e	experimental thrust, N	V_b	vehicle body translational speed, m/s
τ	torque, Nm	V_G	vehicle body translational speed according to ground frame, m/s
τ_r	reaction torque, Nm	F_b	force affecting on drone body, N
k_f	thrust constant, Ns^2/rad^2	M_b	moment affecting on drone body, Nm
k_m	torque constant, Nms^2/rad^2	τ_{gyr}	gyroscopic torque, Nm
Ω	rotor angular speed, rad/s	F_d	disturbance force, N
Ω_e	experimental rotor angular speed, rad/s	BR_G	rotation matrix body to ground
l_1	long arm length, mm	n_r	number of rotors
θ_1	long arm angle, deg	$\mathbf{U_d}$	desired system input vector
l_2	short arm length, mm		
θ_2	short arm angle, deg		

II. CURRENT STATE OF ART

Control on quadrotor, hexarotor, and octorotor, which are standardised designs according to rotor number in multicopter has been studied in the literature. Various research have been conducted in addition to standardised configuration designs. Niemiec et al presented a concept with four to ten interchangeable rotor structures. The proposed model's rotors are all in the same plane. Adding more than one rotor to one arm increases the number of rotors. The 10-rotors model performed worse in the study when compared to other models in terms of power consumption for hovering, but they did better for forward motion.

The performance of a vehicle can be affected by design changes. The vehicle's modelling is largely concerned with the vehicle's predicted performance. As a result, a detailed model of the vehicle is required during the design process in order to achieve the predicted performance in the end. Air vehicles, as is well known, can fly according to aerodynamic principles. It is, however, nearly hard to obtain a flawless aerodynamic model. As a result, events that have little impact on the vehicle's movement or are difficult to model mathematically are frequently overlooked. Similar assumptions are made for the geometrical structure of the vehicle or the mechanical qualities of the materials used in the cars, with the same justifications. As a result, the cars are regarded as rigid and symmetrical.

The aforementioned assumptions were kept in mind when designing the new drone system. The independent controllable 12-rotor dodecacopter design was one of the most remarkable characteristics of the planned universal drone system. Only one study on a multicopter with 12-rotors controlled independently exists in the literature, to the best of the authors' knowledge. Zabunov and Mardirossian investigated a device with 12 rotors installed beneath the vehicle body. In the initial model, the 12 rotors were reversed and placed under the body. The rotors are positioned in the same plane on the body of the second variant. They compared the mass-to-power-to-watt ratios of the first and second models. They came to the conclusion that the first model had a better g W ratio. Brischetto et al proposed a drone model with a modular framework that may be modified between three and eight. They claim that the model's structural components can be printed using a 3D printer.

The arm lengths are adjustable in this revolutionary design, allowing the propellers installed on the rotors to be used in a variety of sizes. The influence of arm length on multicopter performance has been studied in the literature. Xiu et al changed the angles of the arms to which the rotors were linked to change the distance between the rotors and the vehicle centre. The manoeuvrability and stabilisation were compared. According to their findings, the model with the longest arm lengths produces superior results.

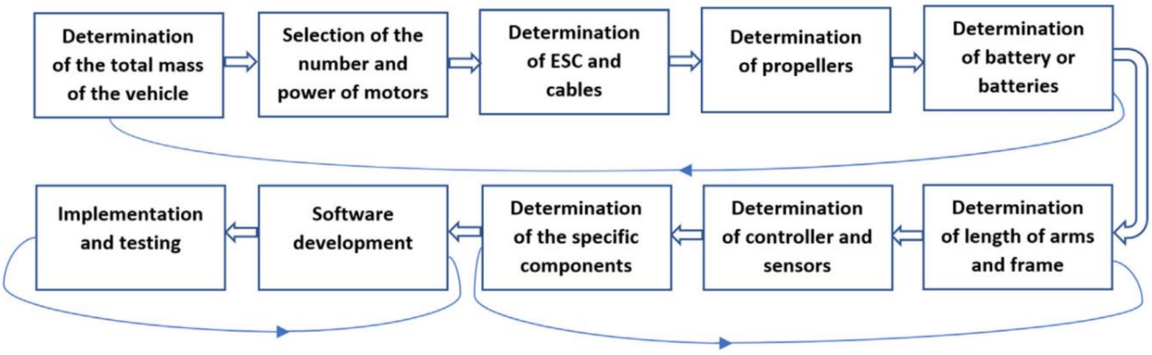

Fig. 1. Design process representation of multirotor drone systems.

The key reason for determining up to 12 independent rotor configurations in this work is that the vehicle is projected to deliver more stable flight than the model with fewer motors in the event of rotor malfunction or any disruptive factors such as wind . Many strategies have been offered to lessen the impact of such undesirable conditions in multicopter utilising both software and hardware methods. Kuric et al suggested a new technique for detecting and isolating propulsion system defects in octorotor based on Recursive Least Squares (RLS). They observed noteworthy tracking performance, according to the findings. By modifying the air vehicle layout, McKay et al investigated the performance of the hexacopter in the event of a single rotor failure. According to the data, the setup they proposed increased the hexacopter's performance. In the literature, there are numerous control systems for air vehicles. In addition, investigations comparing these approaches have been published in the literature. The Proportional-Integral-Derivative (PID) control mechanism is the most popular. In this work, cascade, i.e. nested PID, was preferred as a version of this approach.

Fig. 2. Solid model of the universal drone system.

III. MECHANICAL DESIGN OF THE UNIVERSAL DRONE SYSTEM

Figure 2 depicts a solid model of the entire system. Some of the rotors are in the lower plane, while others are in the upper plane, as seen in the diagram.

- The proposed system in this study was created with the following goals in mind.
- The system can have up to 12 rotors, each of which can be operated separately.
- The upper plane has eight rotors, while the bottom plane has four.
- The number of rotors can be adjusted depending on the system's purpose.
- Arm lengths can be adjusted to meet the system's requirements.

IV. THE UNIVERSAL DRONE SYSTEM'S MODELLING AND CONTROL

The system's mathematical model expression is obtained in the following section. There is no specific study on the system's control mechanism because it is not one of the study's priorities. Initially, simulation was carried out using PID control, which is a well-known control method.

IV.1 The system's modelling

The universal drone system's dynamic behaviour can be mathematically represented. The Newton – Euler technique was used to build the mathematical model, which included dynamic variables and constants. Reference coordinate systems are required to define the movements of the drone system in order to generate the mathematical model of the vehicle. The vehicle moves because to thrust forces and reaction torques created by the rotors and propellers. The thrust forces of propellers are determined by their structural features. The propellers' thrust forces are proportional to the rotors' angular velocity, and the relationship between the rotors' angular velocity and the propellers' thrust forces can be parameterized using a set thrust constant.

IV.2 Controlling the system

Air vehicles can be controlled in two ways: manually or autonomously. Direction commands are entered into the system for hand controlled operation. It is requested to follow a desired trajectory from the vehicle in autonomous controlled operation. According to the planned trajectory and speed limit, the controller calculates the required forces and torques for vehicle motion. Because this research is about autonomous flight, the controller design algorithm is presented below. The simulation can be broken down into four stages depending on the intended positions for autonomous flight.

- The required forces and torques are calculated by the controller based on the intended drone position and system feedback
- The controller determines the rotor speed based on the calculated forces and torques, which are the system inputs.
- The generated forces and moments owing to rotor speeds and external disturbances are calculated using the system model.
- The system outputs the vehicle dynamics, which are controller feedbacks.

V. THE UNIVERSAL DRONE SYSTEM'S SIMULATION RESULTS

In this study, simulation was evaluated in three parts. The first was the dodecacopter's trajectory tracking performance, the second was the octocopter's trajectory tracking performance, and the third was to look at the effect of arm lengths on both systems' trajectory tracking performance. The identical controller with the same parameters was utilised in all three simulations.The simulations were conducted in both a non-disturbing and a disruptive environment. In five separate instances, the simulations were run using the trajectory for autonomous flight. There was no disruptive effect in the first case. Periodic disturbance force was provided to the drone body in the second and third cases. As demonstrated in the fourth and fifth cases, random signals were applied to the drone's body as a disconcerting effect.

VI. CONCLUSION

This study proposes a simulation approach for trajectory tracking control of 12 and 8 rotor drone systems utilising a typical PID controller. The typical PID controller has satisfactory performance, eventually high-level disturbances, as shown by the results of the drone system's trajectory. The study analysed two alternative designs as dodecacopter and octocopter systems. In this study, an independent controllable rotors dodecacopter system and traditional octocopter systems were compared in five different instances using the same trajectory for autonomous flight simulation.

According to the simulation results, when the amplitude was increased by 100 percent under periodic disturbing effect (Case 2 to Case 3), the root mean square of the position errors of the Octocopter and Dodecacopter systems increased by 69.7% and 47.6%, respectively. Similarly, for non-periodic disturbances, when the amplitude was increased by 100% under periodic disturbing effect (Case 4 to Case 5) for both systems, the root mean square of the position errors increased by 13% and 7%, respectively. As the disturbance impact rises, the dodecacopter delivers more stable flying than the octocopter under both periodic and random disruptive forces. When the disturbance effect is not used (Case 1), both systems provide almost the same trajectory tracking performance, but the octocopter produces a superior result.

The interchangeability of arm lengths is another key feature of this revolutionary drone technology. Although the primary goal of arm length interchangeability is to allow the use of different propeller diameters, simulations were conducted for various arm lengths to investigate the implications of changing arm lengths on flying performance. According to the second case's simulation findings. Changes in arm lengths appear to have little effect on flying performance. Finally, the proposed universal drone system, which supports a wide range of rotor configurations, can be used to investigate flight performance for various multirotor drone configurations, as well as to develop advanced control methods such as adaptive control laws and algorithms that are independent of the PID controller used in this study.

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