Development of Variable Arm to Control the Manoeuvrability of Quadrotor

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Abstract

This paper introduces the concept of a variable arm for a quadrotor which is able to perform the manoeuvrability of the quadrotor by changing the arm length's. The variation in arm's length affects the bending moment generated by the thrust force, resulting in the tilting and movement of the quadrotor. The primary goal of this project is to develop a quadrotor with an adjustable arm length to control its manoeuvrability effectively, thus minimizing the need for additional thrust force during flight control. The study focuses on designing a quadrotor with the capability to extend or retract its arms. The proposed concept relies on altering the bending moment through the variable arm to control the quadrotor's manoeuvrability. A quadrotor equipped with a variable arm was successfully designed and tested, with its performance evaluated in executing agile maneuvers. The experiment demonstrated that the variable arm induced body rotation in the quadrotor, effectively regulating its manoeuvrability and the study validates the potential of the variable arm approach for controlling quadrotor movement.

Keywords: N Retract, Control, Agile maneuvers, Body rotation, Performance evaluation, Validation.

1. Introduction

The quadrotor's working principle can be elucidated through Newton's Third Law of Motion, which states that every action has an equal and opposite reaction [1]. When the quadrotor's motor rotates the propeller, it generates a downward force on the air, a phenomenon explained by Bernoulli's Principle [2]. In a standard quadrotor, different motor speeds in the four motors allow for thrust generation, enabling precise control of the quadrotor's movements [3]. As the size and weight increase, greater thrust must be produced to lift the quadrotor effectively [4]. Typically, achieving this entails designing the quadrotor with higher-speed motors or larger propellers to generate the necessary thrust to counter the quadrotor's weight [5]. Consequently, this results in higher current consumption and increased power usage, leading to reduced flight endurance [6]. In this context, designing the quadrotor using conventional methods can be both costly and inefficient [7]. This project proposes a variable arm approach to control the quadrotor, utilizing different arm lengths to regulate its manoeuvrability [8].

The research on variable arm-controlled quadrotors draws on a foundation of related work in the fields of sensor networks, IoT applications, and intelligent systems. Kousik et al. leveraged a hybrid Convolution Recurrent Neural Network for improved salient object detection [9], showcasing advancements in intelligent systems. Singanamalla et al. addressed reliability and energy efficiency in emergency transmission within wireless sensor networks [10], contributing to the broader context of networked systems. Alzubi et al. conducted a survey on specific IoT applications, providing insights into the diverse applications of IoT across various domains [11]. Furthermore, Kallam et al. explored low-energy aware communication processes in IoT through a green computing approach [12], aligning with the focus on energy efficiency in the development of the variable arm-controlled quadrotor. Suresh et al. proposed an energy-efficient mechanism for leveraging IoT [13], setting the stage for considerations related to energy efficiency in unmanned aerial systems. Mekala et al. presented a computational intelligent sensor-rank consolidation approach for the industrial Internet of Things (IIoT) [14], providing valuable insights into intelligent systems applied to industrial contexts. Additionally, Reddy et al. focused on smart assistance for elderly individuals in emergency situations using IoT [15], showcasing the potential applications of intelligent systems in healthcare scenarios. Collectively, these works contribute to the foundation of knowledge necessary for understanding and advancing the development of innovative systems, such as the variable arm-controlled quadrotor presented in the current paper.

2. Materials and Methods

The quadrotor, depicted in Fig. 1, is designed in the form of a variable arm quadrotor, comprising 10 essential components. These components include the Arduino Mega, serving as the microcontroller, an ESC controller responsible for regulating the RPM of the brushless DC motor, the MDD3A driver for controlling the electric actuator's movement, and an MPU 6050 sensor located at the quadrotor's center to detect its acceleration and rotation. Additionally, there are two sets of variable arms and fixed arms, a LiPo Battery for power supply, an A2212 2200KV brushless DC motor, and a base frame. Specifically, the variable arm is engineered as an electric actuator with a linear guide and designed to securely hold the brushless DC motor.

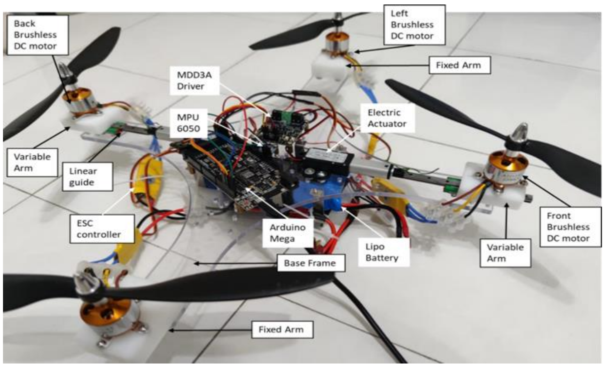


Fig. 1. Variable arm quadrotor.

3. Conceptual Modelling

The standard quadrotor achieves manoeuvrability by adjusting its speed to generate varying thrusts. The quadrotor's design follows a plus configuration, which offers simplicity in both calculation and analysis compared to the cross configuration. Hence, the calculations are conducted with two propellers while assuming the other two propellers remain constant. In Fig. 2, a free-body diagram illustrates both the normal quadrotor and the variable arm quadrotor, showcasing the relationship between angle, acceleration, and the difference in thrust production with various arm lengths. Fig. 2(a) displays the normal quadrotor, controlled by different thrust forces, while Fig. 2(b) demonstrates the variable arm quadrotor, which relies on adjusting the arm length for control.

$$W = L\,cos(Angle) + R\,cos(Angle) = 3L_y + R_y \quad (1)$$

$$F = ma \quad (2)$$

Based on Fig. 2, the quadrotor weighs 1.94 kg, and each arm requires a thrust force of 4.76 N to maintain equilibrium. By assuming that only one thrust is changed while the other three remain constant, Eq. (1) can be utilized to determine the force R required for the quadrotor to attain a specific angle. The acceleration generated by Eq. (2) is depicted in Fig. 3(a) while Fig. 3(b) illustrates the vertical force produced by both constant thrust (L_y) and the changed thrust (R_y).

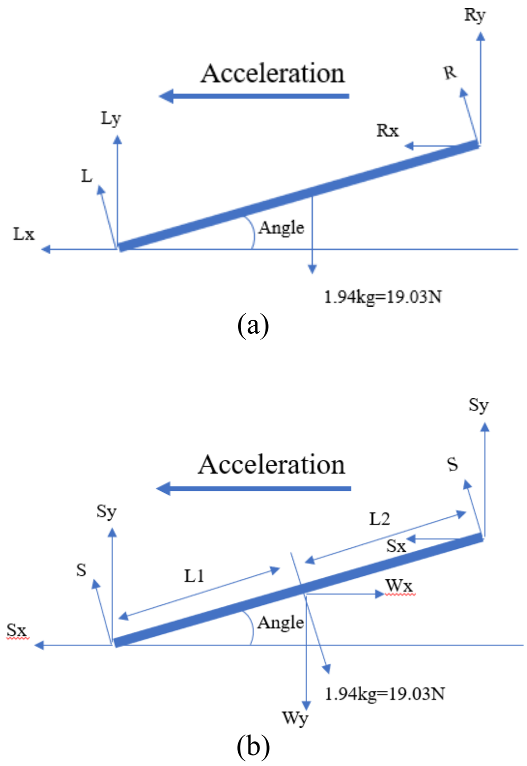


Fig. 2. Free body diagram for (a) normal quadrotor and (b) variable arm quadrotor.

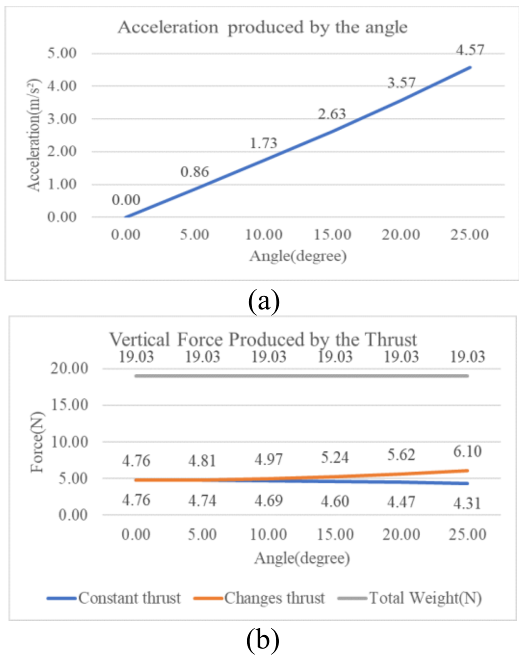


Fig. 3. (a) The acceleration and (b) changes of vertical force.

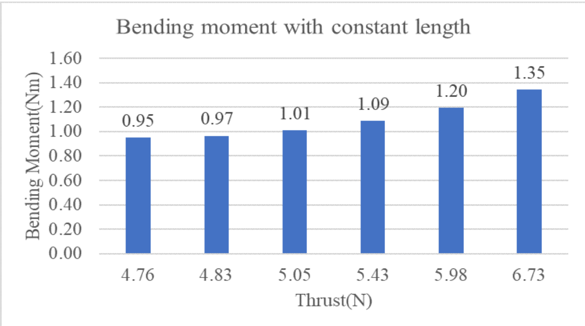
When the angle increases, the constant thrust generates less vertical force. Therefore, to achieve equilibrium for the quadrotor, the changed thrust should be increased to enhance the vertical force produced.

Additionally, this will result in a bending moment, as shown in Fig. 4(a), where the constant length of 200 mm is used in Eq. (3).

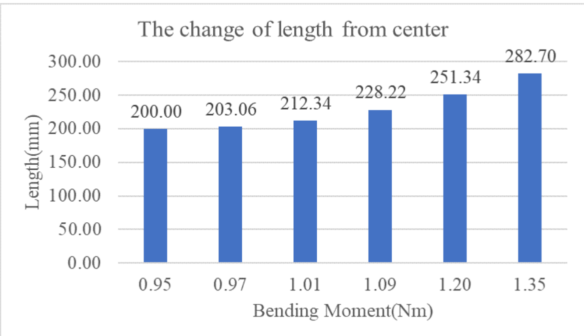
$$M = FL \tag{3}$$

Based on the bending moment in Fig. 4(a), the concept of a variable arm is introduced, as demonstrated in Fig. 2(b). In this configuration, the quadrotor can be adjusted in angle by modifying the variable arm. When keeping the thrust constant, altering the length of the thrust from the quadrotor's center affects the bending moment, as indicated by Eq. (3).

By maintaining L1 and constant thrust S, the bending moment on the quadrotor can be made equivalent to that in Fig. 4(a) by adjusting the length of L2, as shown in Fig. 4(b). Consequently, increasing the length will lead to a higher bending moment.



(a)



(b)

Fig. 4. Bending moment with (a) different thrust and (b) different length.

4. Result and Discussion

Based on the previous conceptual modeling, a prototype was developed to observe and gather data regarding the quadrotor's movement with varying arm lengths. The quadrotor is secured by a gripper and positioned in a way that allows testing for rotation and acceleration. To measure these parameters, an MPU6050 sensor is utilized, providing data along the X, Y, and Z axes.

The quadrotor's design consists of 2 variable arms and 2 fixed arms. Consequently, altering the length of the variable arm causes the quadrotor to rotate along one axis and move along another. Specifically, the quadrotor rotates on the Y axis to move along the X axis. Additionally, data from other axes are used to assess the stability and functionality of the variable arm.

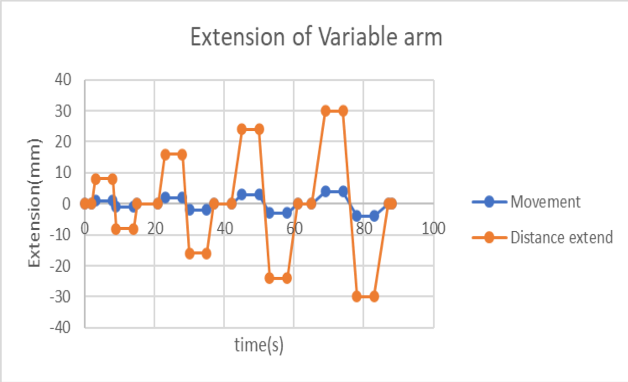


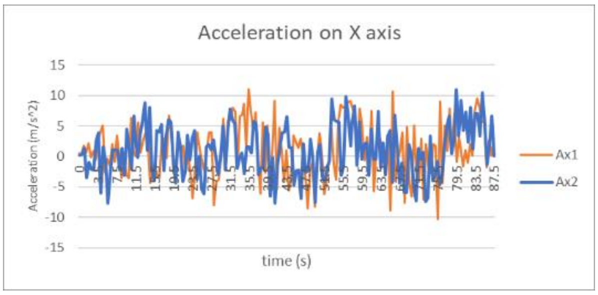
Fig. 5. Input signal and movement of the variable arm.

To control the extension or retraction of the variable arm, a signal is sent from the Arduino Mega microcontroller to the MDD3A driver. Fig. 5 illustrates the input signal for extending the variable arm. The positive values indicate forward movement, while negative values indicate backward movement. The electric actuator's extension speed is set at 8 mm/s with a 30 mm stroke length. By incorporating program delay time, the extension length of the variable arm can be precisely controlled.

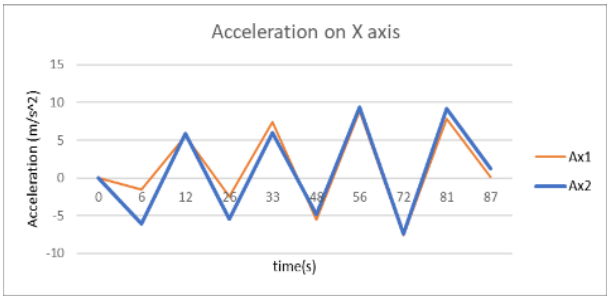
For data collection, the variable arm is extended to different lengths (8 mm, 16 mm, 24 mm, and 30 mm) and held for a few seconds at each length to gather relevant information. The entire extension cycle takes approximately 88 seconds.

4.1. *With Constant Thrust Force*

Fig. 6 and Fig. 7 demonstrate that as the arm length increases, the rotation and acceleration of the quadrotor also increase. However, it is evident that the relationship between extension length and these variables is not linear. To address this, a simplified graph for Fig. 6(b) and Fig. 7(b) was created, selecting the second highest positive value or lowest negative value to minimize the influence of noise from Fig. 6(a) and Fig. 7(a).

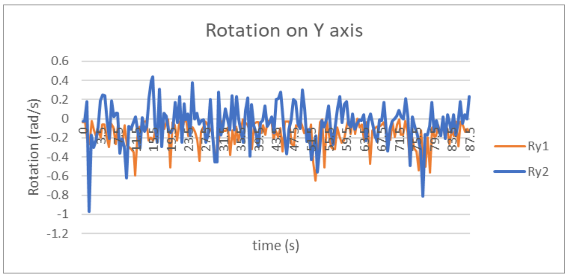


(a)

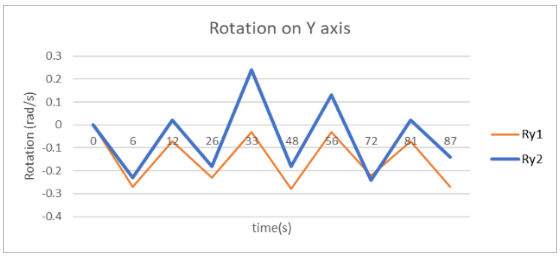


(b)

Fig. 6. (a) Acceleration on X axis for dataset 1 (Ax1) & dataset 2 (Ax2) and (b) simplify data for acceleration on X axis for dataset 1 (Ax1) & dataset 2 (Ax2).



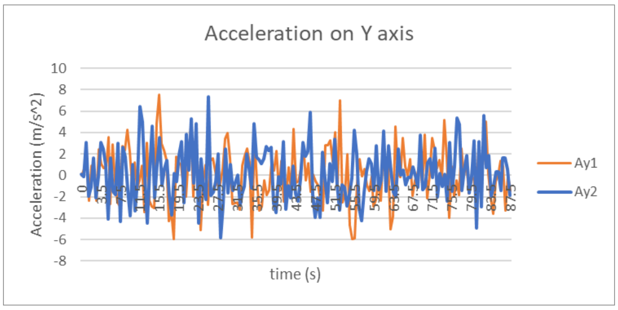
(a)



(b)

Fig. 7. (a) Rotation on Y axis for dataset 1 (Ry1) & dataset 2 (Ry2) and (b) simplify data for rotation on Y axis for dataset 1 (Ry1) & dataset 2 (Ry2).

On the other hand, Fig. 8 and Fig. 9 display readings for Ax, Az, Rx, and Rz, but with considerable noise. Observing the graphs, most of the data for Ax, Az, Rx, and Rz falls within a range of values from 3 to -3, 5 to 15, 0.2 to -0.2, and 0.15 to -0.15, respectively. However, there is a significant amount of data that exceeds these ranges, indicating an unstable condition for the quadrotor. This instability could be attributed to various factors such as environmental conditions like surrounding air flows, unstable signals from the microcontroller, inconsistent power supply, and the accuracy and sensitivity of the sensor being used.



(a)

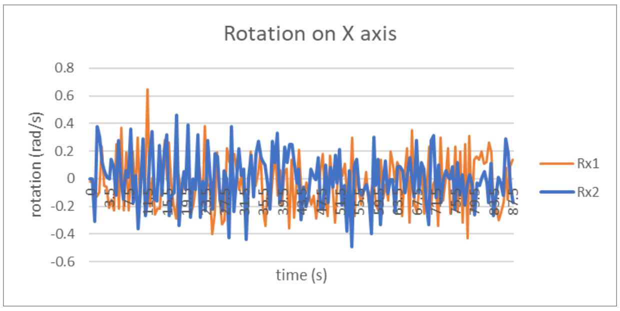


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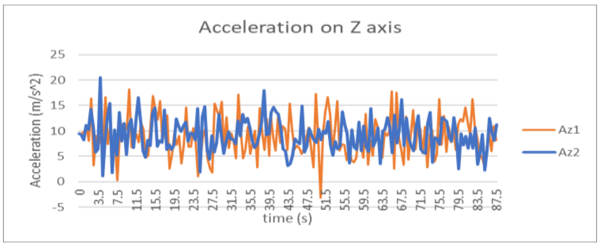
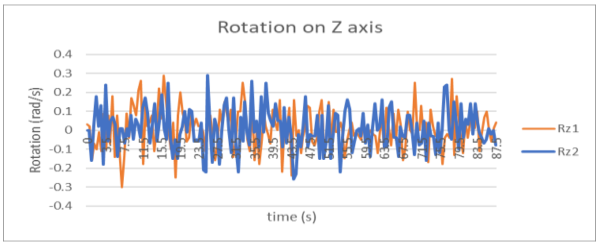
Fig. 8. (a) Acceleration on Y axis for dataset 1 (Ay1) & dataset 2 (Ay2) and (b) rotation on X axis for dataset 1 (Rx1) & dataset 2 (Rx2).



(a)



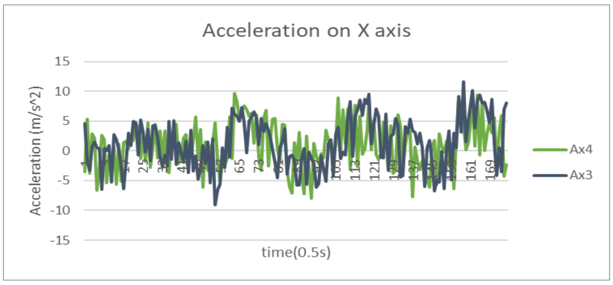
(b)

Fig. 9. (a) Acceleration on Z axis for dataset 1 (Az1) & dataset 2 (Az2) and (b) rotation for Z axis for dataset1 (Rz1) & dataset 2 (Rz2).

4.2. With Variable Thrust Force

The variable thrust force incorporates a straightforward program for regulating the RPM of brushless DC motors, utilizing the range established from earlier findings. During quadrotor operation, the craft is tilted at an angle to facilitate movement, and thus, the Rx, Rz, and Az ranges are utilized, with Ax being disregarded. Az comes into play to ensure the quadrotor remains in an equilibrium state and maintains its position.

Consequently, this approach has the potential to reduce noise and enhance the quadrotor's overall stability.



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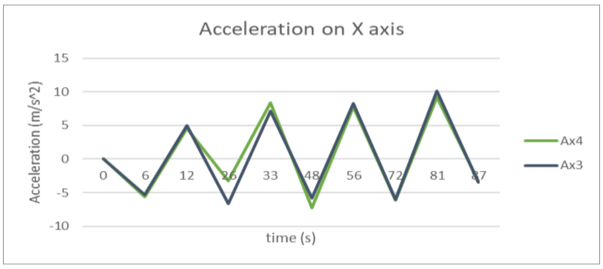
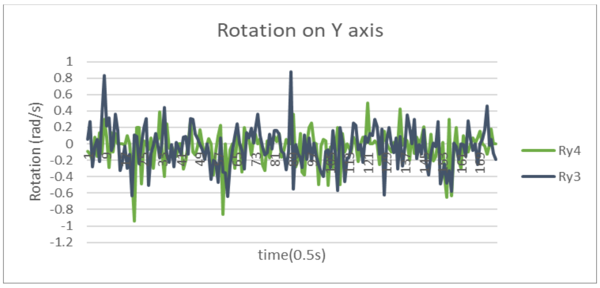


(b)

Fig. 10. (a) Acceleration on X axis for dataset 3 (Ax3) & dataset 4 (Ax4) and (b) simplify data for acceleration on X axis for dataset 3 (Ax3) & dataset 4 (Ax4).



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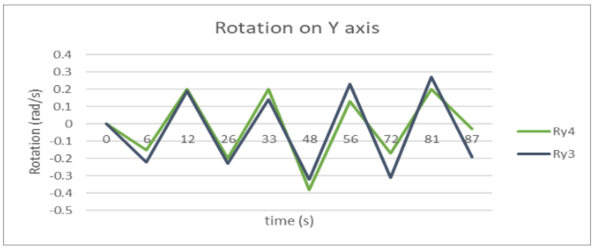
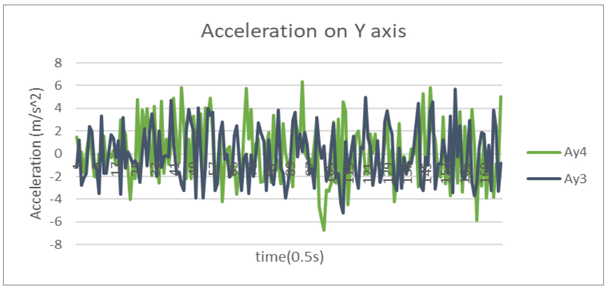


(b)

Fig. 11. (a) Rotation of Y axis for dataset 3 (Ry3) & dataset 4 (Ry4) and (b) simplify data for rotation on Y axis for dataset 3 (Ry3) & dataset 4 (Ry4).

In Fig. 10 and Fig. 11, as the variable arm length increases, both rotation and acceleration also experience a corresponding increase. To create a simplified representation, we referred to the movement depicted in Fig. 5 and extracted the second-highest positive value or lowest negative value for Fig 10(b) and Fig. 11(b). This approach helps mitigate any potential noise influence from Fig. 10(a) and Fig. 11(a) on the graphs.



(a)

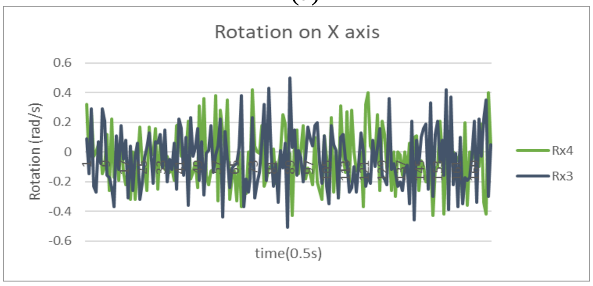


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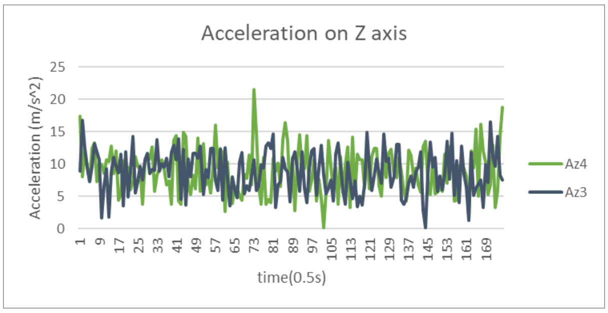
Fig. 12. (a) Acceleration on Y axis for dataset 3 (Ay3) & dataset 4 (Ay4) and (b) rotation on X axis for dataset 3 (Rx3) & dataset 4 (Rx4).



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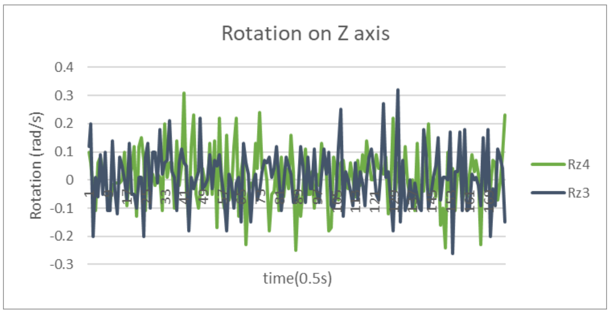
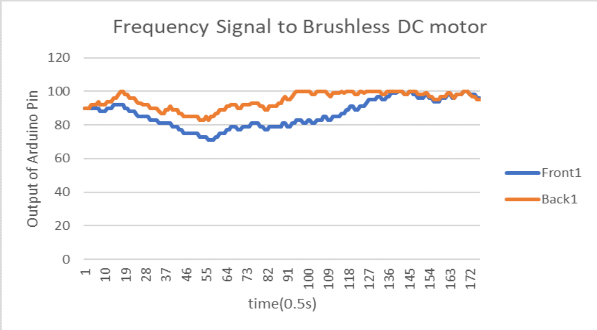


(b)

Fig. 13. Acceleration on Z axis for dataset 3 (Az3) & dataset 4 (Az4) and (b) rotation on Z axis for dataset 3 (Rz3) & dataset 4 (Rz4).



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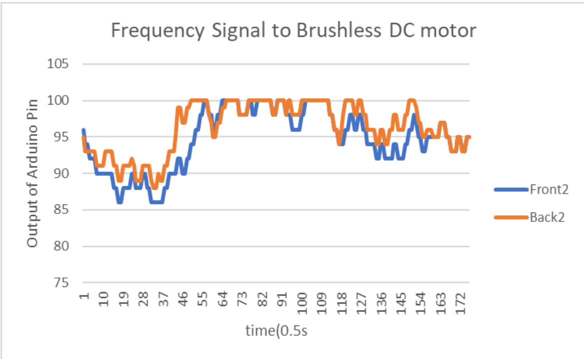

(b)

Fig. 14. Frequency signal to brushless dc motor for (a) dataset 3 and (b) dataset 4.

In Fig. 12 and Fig. 13, the presented results still exhibit some degree of noise. However, upon comparison with the outcomes from the previous section, it becomes evident that the quadrotor demonstrates enhanced stability and balance. Fig. 14 illustrates that the frequency signal sent to the motor undergoes alterations in a random pattern, without showing any discernible relationship to changes in the variable arm.

5. Conclusion

In this project, a quadrotor with a variable arm length was constructed. The variable arm is used to control the manoeuvrability of the quadrotor. Data were collected in four sets, consisting of two with constant thrust force and two with variable thrust force. The analysis of the constant thrust force data indicated that the quadrotor exhibited instability, likely resulting from factors such as surrounding airflow, an unstable signal from the microcontroller, and fluctuations in the power supply. To address these issues, a variable thrust force was implemented to minimize noise and stabilize the quadrotor. The results displayed a clear linear relationship between the variable arm length and the rotation and acceleration of the quadrotor. As the arm length increased, both the rotation and acceleration of the quadrotor also increased. Additionally, the findings revealed that extending the variable arm eliminated the need for extra thrust force, enabling the motor to fully utilize its capacity in carrying the payload. The graphs further indicated some noise variation, potentially caused by vibrations in the brushless DC motor. In conclusion, a concept utilizing an electric actuator and linear guide for the variable arm was introduced, proving suitable for enhancing the manoeuvrability of the quadrotor by adjusting the arm length.

Acknowledgment

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