Design A New Model of Unmanned Aerial Vehicle Quadrotor Using The Variation in The Length of The Arm

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Abstract

The direction of technological advancement toward autonomous aerial vehicle is increased. As a consequence of this evolution, the quad rotor used to accomplish a complex task in several fields. This paper presents the dynamic model of this miniature aerial vehicle in altitude and new dynamic model for yaw attitude movement, based on varying the arm length of quadrotor instead of varying the speed of motors to obtain a rotation around z-axis. This achieved by fixed a stepper motor in the arm of quadrotor to increase or decrease the length of the arm according to controller command for yawing movement. The controller command achieved by design PID controller with specific parameters to maintain the stability of the quadrotor in the flight path. The equipped energy to the motors during flight and maneuvering is reduced by selecting the motors' speed. The MATLAB software code used to evaluate and presents the comparison between the proposed and conventional quadrotor dynamic model. Simulation results show the robustness performance of the proposed model due to the movement around the z-axis with high system stability

Keywords: *Altitude; Arm's Length; PID; Quadrotor; UAV.*

1. Introduction

The autonomous miniature aerial vehicle has attracted the interest of researchers and represents a challenge in the world of Unmanned Aerial Vehicle (UAV) from few years ago. One of the UAV is the QuadRotor (QR), which has an endless list of applications in civil, military and commercial. The QR is under actuated nonlinear system.

Many methods have been proposed to control the stability of quadrotor. S. Bouabdallah & R. Siegwart, 2007 are focused on the design and the control of quadrotor by using integral backstepping to control position, attitude and altitude. According to the results, the vision sensors and population group must be improved to be dependable. A. Azzam & X. Wang 2010, used PD controller and backstepping based on PID to control the attitude. A.L Salih 2010, used PID controller for developing the stability of pitch, roll, yaw and altitude of the vehicle. Unfortunately, the system contains some transient overshoot because of disturbance and some other reasons like some certain of mechanical parameter and simplification of the controller. M. K. Joyo etc 2013, the position and altitude of quadrotor are controlled by using PID controller in the condition of wind gust and conclude that the controller worked effectively under this condition. H. K. Kim, 2013 proposed PID based on feedback linearization combined with block control technique for controlling the position of QR.

In this paper, a new model for QR yawing attitude is proposed based on varying the length of arms to generate variable torque without altering the motors' speed. This torque can rotate the QR to the desired position and keeping QR balance. Varying the arm's length have been done by using stepper motor in each arm to increase or decrease the length of arm depending on controller command.

2. Architecture and Dynamic Model of Quadrotor

The front motor (m1) and the rear motor (m3) are rotate counter clockwise (C.C.W). The right motor (m2) and the left (m4) are rotate clockwise (C.W). Therefore, the directions of the motors' rotation are maintained a balance torque at the QR frame and try to lift the QR in vertical motion. The lift motion is obtained by increasing the speed of all motors (m1, m2, m3, m4) gradually .

2.1 Dynamic Model of Quadrotor

The motion of any rigid body in space can be represented by rotational and translational motions (L. R. G. Carrillo, 2013). QR is nonlinear system with (6_DOF) and only four inputs which are motor speed and 3-translational and 3-rotational motion.

R represents the rotational matrix from body to earth frame.

$$R = \begin{bmatrix} c\psi\, c\theta & -s\psi\, c\emptyset + c\psi\ s\theta\, s\emptyset & c\emptyset\, c\psi\ s\theta + s\emptyset\, s\psi \\ s\psi\ c\emptyset & c\psi\ c\theta + s\theta\, s\emptyset\, s\psi & c\emptyset\, s\theta\, s\psi - c\psi\, s\theta \\ -s\theta & c\theta\, s\emptyset & c\theta\, c\emptyset \end{bmatrix} \quad (1)$$

Where, c means cos ( ), and s means sin ( ).

The thrust force and control torque which acting on the QR body is generated by the propellers rotation. The thrust vector converts from B frame to E frame by applying Newton-Euler method for the rigid body (L. R. G. Carrillo, 2013) as

$$m\ddot{x} = F.R + [0 \quad 0 \quad -mg]^T - f_a \quad (2)$$
$$I\dot{\omega} = \omega \times I\omega + \tau \quad (3)$$

Where, x¨ is the linear acceleration vector, F is the thrust force generated by motors, fa is the frictional force, τ is the control torque generated by motors, m is the mass of the body, I am the moment of inertia matrix, ω is the angular velocity. Therefore, from (3) and (2), can be write the QR dynamic equation as,

$$\left.\begin{aligned} m\ddot{x} &= u_1(\cos\emptyset \sin\theta \cos\psi + \sin\emptyset \sin\psi) - k_1\dot{x} \\ m\ddot{y} &= u_1(\cos\emptyset \sin\theta \sin\psi - \sin\emptyset \cos\psi) - k_2\,\dot{y} \\ m\ddot{z} &= u_1(\cos\theta\ cos\emptyset) - mg - k_3\,\dot{z} \\ I_y\ddot{\theta} &= (I_z - I_x)\dot{\theta}\dot{\psi} + u_2 - k_4\dot{\theta} \\ I_x\ddot{\emptyset} &= (I_y - I_z)\dot{\emptyset}\dot{\psi} + u_3 - k_5\dot{\emptyset} \\ I_z\ddot{\psi} &= (I_x - I_y)\dot{\theta}\dot{\emptyset} + u_4 - k_6\dot{\psi} \end{aligned}\right\} \quad (4)$$

The thrust induced by variation the speed of the motors is the input vector to the system and defined as

These input vectors are represented a

$$\left.\begin{aligned} u_1 &= b.({\omega_1}^2 + {\omega_2}^2 + {\omega_3}^2 + {\omega_4}^2) \\ u_2 &= b.l(\omega_3^2 - \omega_1^2) \\ u_3 &= b.l(\omega_4^2 - \omega_2^2) \\ u_4 &= d.({\omega_4}^2 + {\omega_2}^2 - {\omega_3}^2 - {\omega_1}^2) \end{aligned}\right\} \quad (5)$$

2.2 Proposed Yawing Movement Dynamic Model1

The UAV-QR has a great advantage in variety fields of work. The main challenges in the UAV-QR design are represented by its size and simplicity, robustness control and reducing the consumption energy.

3. Proposed Design Model

The quadrotor faces many problems the main problem is the consumption energy during flight and maneuverability for long time due to the motors' speed, where the two motors' speed must be increased and two other motors must be decreased to produce the yaw movement.

The QR arms are designed to comprise two parts, first part is fixed with the QR frame and the second part is the sliding arm. This design is proposed to varying the arm's length

4. Control Strategy

The QR requires a stable and robust controller during the maneuverability and flight path (A. L. Salih, 2010). In this paper, a PID controller is applied in altitude and yaw attitude movement.

The parameters of PID are adjusted to a specific value to reach steady- state system. The equation of PID defined mathematically (M. K. Joyo) as

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \quad (6)$$

4.1 Altitude Implementation Control Algorithm

The QR must be at desired value from the ground to maintain this distance the altitude controller is used (M. H. Tanveer). Therefore, the QR lift force must be greater than its weight and the earth's gravity to keep the QR at hovering and take-off (M. H. Tanveer, 2013).

$$u(t) = k_p e_z(t) + k_i \int e_z dt + k_d \frac{de_z}{dt} \qquad (7)$$

4.2 Yaw Movement Implementation Control Algorithm

QR attitude controlled the angles of orientation pitch, roll, and yaw. In this paper, we present only the yaw angle and only choose yaw angle differential equation. Shown in Fig.1.

$$\ddot{\psi} = \frac{u_4}{I_z} + \frac{k_6}{I_z}\dot{\psi} \qquad (8)$$

By solving the differential equation can obtain ψ as the output value, so the control design for the PID controller error signal will be:

$$e_\psi = \psi_{ref} - \psi \qquad (9)$$

Where ψref the desired value and ψ is the measured output signal, then, the PID controller become

$$u(t) = k_p e_\psi + k_i \int e_\psi dt + k_d \frac{de_\psi}{dt} \qquad (10)$$

5. The Results and Discussion

The physical parameter of simulation as mention is shown in Table I.

Table I. System Parameters

mass	**2kg**
Arm length	0.25 meter
Δ*l*	± 0.05 meter
$l_2 = l_4$	0.3 meter
$l_1 = l_3$	0.2 meter
gravity	9.8m/s2
Ix	1.25Ns2/rad
Iy	1.25Ns2/rad
Iz	2.5Ns2 /rad
b	3.31*10-5
d	7.5*10-6
k1= k2=k3	0.010 Ns/m
k4=k5=k6	0.012 Ns/m

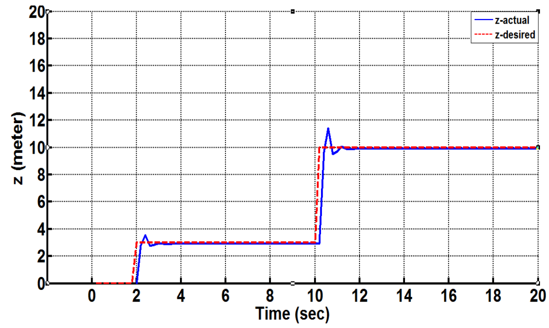
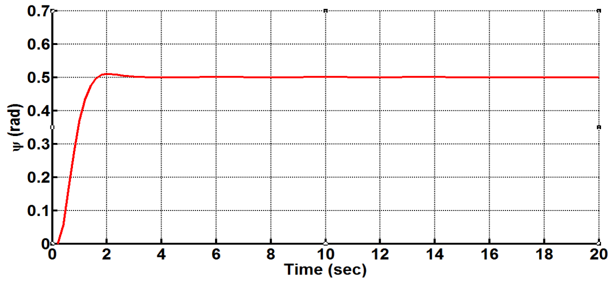
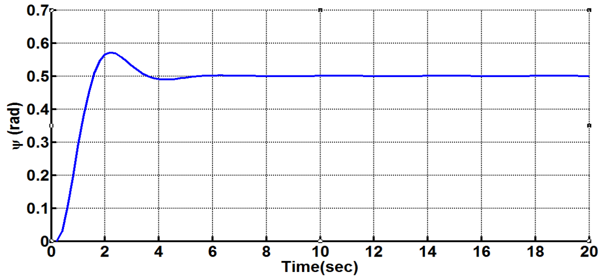


Fig. 1. Altitude and hovering performance

Fig. 1. Shows the yaw movement according the proposed design that based on PID controller and changing the arm's length and shows the ability of the proposed design to orient the QR to the desired angle (0.5 rad) from reference input angle within 3sec.



(a)



(b)

Fig. 2. The comparison of yaw movement between (a) The Proposed Control Design (b) Conventional Control Design

6. Conclusion

The result shows a good performance in altitude motion by automatically tracking the desired path. A new approach was proposed in yaw attitude based on varying the arms' length to ensure the rotation around the z-axis. The arm length is varying by fixed a stepper motor inside each arm to extend or reduce the length of the arm. In addition, the proposed model in this approach is reduced the energy consumption and extend the motor's lifetime through fixing the motors speed (hovering speed).

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