Conférence Internationale en Automatique & Traitement de Signal (ATS-2018)
Proceedings of Engineering and Technology – PET
Vol.36 pp.6-9

Platform design and Experimental Regulation of Twinrotor UAV

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Abstract— **In this paper, we have assembled a small-scale twinrotor UAV. The design is shown as a simpler platform, which requires only two rotors. A dynamic mathematical model is derived using Newton-Euler formalism. Experimental control of roll motion is realized efficiently by changing thrust magnitude through PID/PD controller.**

Keywords—Twinrotor; Two-rotor; UAV; Nonlinear; Control; PID; PD

I. INTRODUCTION

Research and developments related to Unmanned Aerial Vehicles (UAV) have been very active in recent years, motivated by recent technological advances in the fields of miniaturization of actuators and on-board electronics. The design of efficient, low cost UAV systems with autonomous navigation capabilities has become possible. Thus, UAVs presents new tools for both civilian and military applications. The primary mission of UAVs is to deport the human vision beyond the natural horizon, to accomplish missions at risk or difficult to access for humans [1-3].

Two-rotor UAVs have been studied recently by many groups and some have designed small prototypes [5-9]. In our laboratory, we have assembled a miniaturized twinrotor UAV with a simpler platform. In view of the configuration shown in fig. 1, the two-rotor is composed of two rotors radially disposes on the sides opposed. So, the moment of each rotor is compensated and the interaction of the two rotors gives a higher load capacity. Unlike conventional helicopters, this configuration does not require swash plate or anti-torque. Therefore, it is much less complicated mechanically. Moreover, the absence of rods makes it possible to reach higher speeds of rotation

The Newton-Euler formalism is used to derive the defining equations of motion of the six Degree Of Freedom system, complex, highly nonlinear, and under-actuated with only four control inputs. The aforementioned works [3-9] detail the twinrotor control using many strategies. In this paper, we propose PID/PD controller tuned using Ziegler-Nichols method (Z-N) [10] for realizing efficient roll motion control. These controllers reduce significantly the overshoot and the settling time. Also, they do not require a lot of calculations and easy to implement. In the last few years, many projects have controlled Quadrotors using PID/PD controllers [11-14].

The outlines of this paper are as follows: In the first section, we detail the platform design and instrumentation. In section II, we present the twinrotor dynamics and roll angle stabilization. In the last section, we give the simulation results.

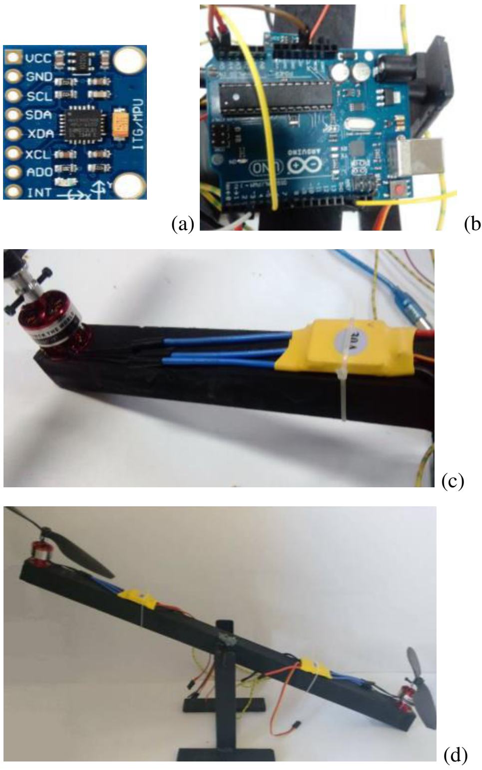
II. PLATFORM DESIGN

Due to research development, new designs aimed to be more stable and sophistically than the previous ones. A good design is the more stable and the more maneuverable. The moments of an UAV depends on the resultant forces and moments applied at the centre of gravity, which is influenced directly by the structure and the design. The Newton-Euler Model shows a good relation of the force and moment about the centre of gravity of a rigid body.

A. Structure

The twinrotor structure contains two brushless DC motors (BLDC), two blades, a gyroscope, a battery, an Arduino UNO card, an Electronic Speed Control (ESC), an aluminum arm, two ball bearings, and a central aluminum chassis. The two ball bearings are coaxial to each other and used to fix a common aluminum arm to the central chassis. In fig. 1, the motors are arranged with parallel axis of rotation and rest on the two ends of the aluminum arm. The motors are placed equidistant from the center on opposite sides to cancel the aerodynamic interaction between the propeller blades.

ISSN 2356-5608



(a) (b) (c) (d)

Fig. 1 (a) Gyroscope, (b) Controller Ardouino card, (c) ESC and DC motor, (d) complete assembled model

B. Instrumentation

Arduino UNO card: The Arduino card is the main tool that performs all kinds of actions. It is able to store data, send and receive information. The Arduino card is used for control, processing and data acquisition.

The gyroscope MPU 6050: The gyroscope MPU 6050 has 6 axes, but we can limit the degrees of freedom.

The brushless motors: The role of the motors is to drive the propellers to create the pushing force. This force is proportional to the speed of the motor. The KV is the rotational speed of an engine for 1 volt. It indicates the number of revolutions / min / volt when the motor turns at no load.

The Electronic Speed Control (ESC): is an electronic circuit dedicated to the control of electric motors. The ESC circuit has a microcontroller, a power circuit and in the case of brushless motors, an acquisition device. They allow managing the angular velocity, the direction and the braking.

III. TWIN ROTOR DYNAMICS

A. The rigid body

In order to develop our analysis, let $I = (E_1, E_2, E_3)$ be the Inertial fixed frame and $B = (E_x, E_y, E_z)$ the Body frame.

The passage between the body frame B and the inertial frame I is given by the transformation matrix T$_R$ in (1). TR contains the orientation and the position of the mobile frame with respect to the fixed frame. Where R is the rotation matrix (describes the orientation of the mobile object), $\xi = [x \quad y \quad z]$ is the position vector. The elements of the rotation matrix R are determined by using Euler angles. The formula of the rotational matrix R is given in (2).

$$T_R = \begin{bmatrix} R & \zeta \\ 0 & 1 \end{bmatrix} \tag{1}$$

$$R = \begin{bmatrix} c\psi\, c\theta & s\phi\, s\theta\, c\psi - s\psi\, c\phi & c\phi\, s\theta\, c\psi + s\psi\, s\phi) \\ s\psi\, c\theta & s\phi\, s\theta\, s\psi + c\psi\, c\theta & c\phi\, s\theta\, s\psi - s\phi\, c\psi \\ -s\theta & s\phi\, c\theta & c\phi\, c\theta \end{bmatrix} \tag{2}$$

Where: c = cos and s = sin

B. Forces/Moments acting on the twinrotor

Gravity force: The gravity force's direction is normal to the surface of the Earth. Its expression in I is given in (3), where g is the acceleration of gravity.

$$F_G^I = mG^I = (0, 0, -mg) \tag{3}$$

Thrust forces: The thrust forces are perpendicular to the plane of the propellers. The expression of the total thrust in the reference B linked to the twinrotor is given in (5), Where C$_l$ is the thrust coefficient, ω_1 and ω_2 are the rotational speed of the rotors 1 and 2 respectively and $P = P_1 + P_2$.

$$\begin{cases} P_1 = C_l\ \omega_1^2 \\ P_2 = C_l\ \omega_2^2 \end{cases} \tag{4}$$

$$F_P^B = P_1^B + P_2^B = \begin{pmatrix} 0 \\ 0 \\ P \end{pmatrix} \tag{5}$$

Actuators torque: The position vectors of the points of application of the thrusts P$_1$ and P$_2$, expressed in B, are $(0, -l_m, 0)$ and $(0, l_m, 0)$, respectively. The torque produced by the thrusts relative to the center of gravity G expressed in B is given in (6), where $u_\phi = l_{/2}\ (P_2 - P_1)$ and l=0.8m.

$$M_P^B = \begin{pmatrix} 0 \\ -l/2 \\ 0 \end{pmatrix} \times P_1^B + \begin{pmatrix} 0 \\ l/2 \\ 0 \end{pmatrix} \times P_2^B = \begin{pmatrix} u_\phi \\ 0 \\ 0 \end{pmatrix} \tag{6}$$

C. Twinrotor dynamics

The twinrotor dynamical model can be obtained using Newton Euler formulation:

$$\begin{aligned} m\ddot{\xi} &= F^{\Im} \\ I\dot{\Omega} + \Omega \times I\Omega &= M^B \end{aligned} \tag{7}$$

Where

- $\dot{\xi} = (\dot{x}, \dot{y}, \dot{z})^T \in R^3$ is the velocity vector of the twinrotor;

ISSN 2356-5608

- m is the total mass of the twinrotor;
- $F^{\Im} \in R^3$ is the sum of forces expressed in I;
- $I \in R^{3\times 3}$: Symmetrical inertia matrix;
- Ω: The angular velocity expressed in I;
- x: The vector product;
- $M^B \in R^3$: The total external moment expressed in B.

We chose to work with a reduced dynamic model where the inertia matrix and the mass of the vehicle are normalized. The differential equations that define the translational and rotational motion are given in (28).

$$\begin{cases} \ddot{x} = P\ S\psi\ S\phi + P\ C\psi\ S\theta\ C\phi \\ \ddot{y} = P\ S\psi\ S\theta\ C\phi - P\ C\psi\ S\phi \\ \ddot{z} = P\ C\theta\ C\phi - g \\ \ddot{\phi} = u_\phi \end{cases} \tag{8}$$

Where Sx (respectively Cx) indicates sin (x) (respectively cos (x)).

IV. ROLL MOTION CONTROL

A. *Roll motion*

The roll motion is controlled by the difference in the angular velocity of the two rotors. The motor that rotates with a higher velocity produces a higher thrust, thus creating a rolling effect in an opposite direction. The altitude is regulated by increasing or decreasing the thrust of the rotors.

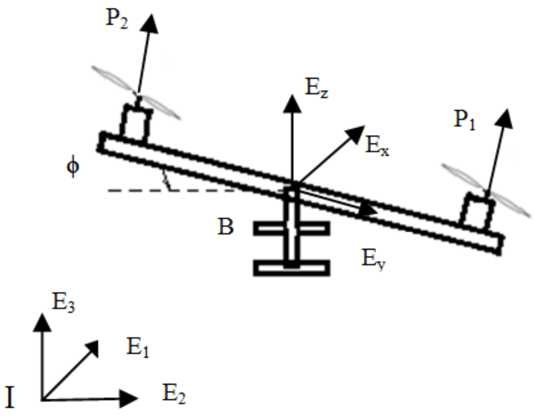


Fig. 2 Roll motion

B. *Roll control*

The twinrotor can be controlled by modifying the thrust of each motor to keep closer to the desired position. For this, we use PID controller (Proportional, Integral, Derivative). Some of the advantages of the PID/PD controller are its simplicity and ease of implementation. In many research papers, PID/PD control technique has been proposed in control system [15-17]. However, its parameters need a good tuning.

The transfer function of the PID controller *C*(*p*) and its parameters (K_p, K_i and K_d) are as specified in (9).

$$C(p) = \frac{u(p)}{\varepsilon(p)} = K_p + \frac{K_i}{p} + K_d\, p \tag{9}$$

The Ziegler-Nichols (Z-N) closed loop method can be used. This tuning method requires the linear transfer function of the system to control. The transfer function of roll angle is given in (10).

$$F_\phi(p) = \frac{(P_2 - P_1)}{\phi} = \frac{l/2}{p^2} \tag{10}$$

The critical gain K_c and the critical period T_c correspond to an oscillatory behavior of the closed loop transfer function. Table I gives the Z-N proposed parameters of PID/PD gains.

TABLE I
PD/PID PARAMETERS BASED ON CLOSED LOOP Z-N METHOD

Controller	**K_p**	**K_i**	**K_d**
PD	0.71 K_c	-	0.15 T_c
PID	0.6 K_c	0.5 T_c	0.125 T_c

V. SIMULATION RESULTS & TEST

The calibration of the motors is done referring to the basic example of the gyroscope given in the Arduino library. For a reference step signal, we obtain the response of the roll angle in closed loop. From fig. 3, it is clearly shown that the system present a high overshoot and needs to be controlled. One of the advantages of PID/PD control is that it can be easily implemented experimentally. The PID/PD parameters that kept the system the most possible stable are obtained by applying Z-N method to the transfer function defined by (10). These parameters are summarized in table II and the results obtained based on these controllers values are presented in fig. 4.

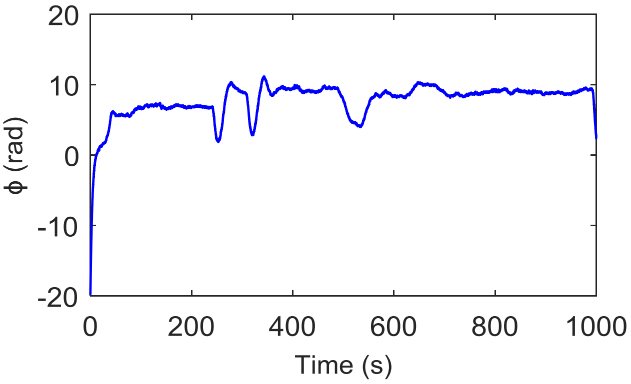


Fig. 3 Step response of the roll angle in closed loop

TABLE II
PD/PID PARAMETERS OBTAINED BY USING ZN

Controller	**K_p**	**K_i**	**K_d**
PD	2.5	-	0.81
PID	2.1	2.7	0.675

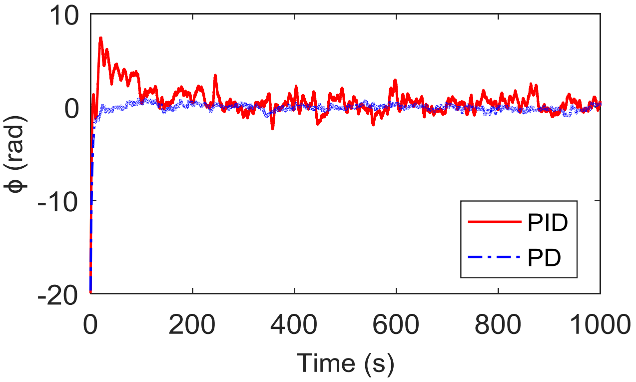


Fig. 4 Step responses of the roll angle with PID/PD controller in closed loop

It can be clearly observed from fig. 4 that the PD controller stabilizes the roll angle response with a short overshoot compared to the PID controller. These results are obtained because the roll transfer function in (29) has already integration. As consequence, we use the PD controllers to provide the appropriate control of the roll variations of the twinrotor.

VI. CONCLUSIONS

In this paper, we proposed a platform design and an experimental control of twinrotor UAV. First, a minimized twinrotor UAV has been designed and explained the description of all the parts comprising the development of the twinrotor. Then, the twinrotor's forces and motion have been clearly explained and the mathematical model has been developed using Newton-Euler formalism. Indeed, experiments show that the control of roll motion is realized efficiently by using PID/PD controller tuned using the conventional Ziegler-Nichols method (Z-N). The simulations carried out on the roll control show us that the PD is more efficient than the PID controller. Finally, the robustness of this controller is proved in presence of disturbances.

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