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Real-Time Parameters Identification for a Quad-rotor Mini-aircraft Using Adaptive Control

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Abstract— **In this article an adaptive controller is developed in order to estimate the inertia tensor, the mass and the wind parameters (considering wind as a parameter in the input) for the underactuated quad-rotor mini-aircraft. Experimental tests are performed in an educational platform. The proposed control scheme uses the parameter estimation issued from gradient type algorithm. Finally simulations and experimental results are included to illustrate the performance of the parameters identification for the quad-rotor helicopter.**

I. INTRODUCTION

Unmanned Aerial Vehicles (UAV) such as quad-rotor aircraft systems are an important research topic in recent decades due to the wide range of applications [1], [2]. Fi-gure 1 shows the educative experimental platform based on quad-rotor mini-aircraft. The control of UAVs involve research in various areas such as digital filtering, estimation of the position based on GPS [3], data fusion of sensors, etc. Now is well known that in the real world does not exist an ideal or perfect system without certain disturbances or uncertainties affecting the performance of the vehicle. Due this facts several researchers worldwide have focused on the dynamical model [4] and control techniques including adaptive control [5], [6], [7], [8], [9]. The adaptive control is a strategy used for different robots as in [10] where uses an algorithms for identifying parameters of a cylindrical robot and in [11] uses an adaptive nonlinear control of braking in a railway vehicles. Recently in [12] the authors have proposed an adaptive feedback control law for asymptotic attitude and altitude stabilization of a quad-rotor mini-aircraft using angular rates and absolute orientation with respect to the inertial frame. The unknown parameters of the quad-rotor mini-aircraft model are inertia matrix and mass. As we know, it is somewhat difficult to know exactly the inertia tensor of a quad-rotor mini-aircraft due to irregularities in its structure. Moreover the most of authors assume many considerations in relation with the structure of the vehicle. So we present an algorithm for identifying parameters which involves directly the moment of inertia tensor of a quad-rotor mini-aircraft using an adaptive control law for each axis in which the helicopter evolves. Besides the application of adaptive control to estimate the mass of the vehicle as a parameter that changes from one moment to another is presented, this means that the vehicle loses or gains weight when throw or add any payload. Finally is presented an estimate of torques produced by the wind that affects the attitude of the vehicle. Adaptive control is a design approach tailored for high performance applications in control systems with uncertainty in the parameters. That is, uncertainty in the dynamic system is assumed to be characterized by a set of unknown constant parameters. However, the design of adaptive controllers requires the precise knowledge of the structure of the system being controlled. The advantage of estimating the unknown parameters is obtain a better quad-rotor mini-aircraft's mathematical model.

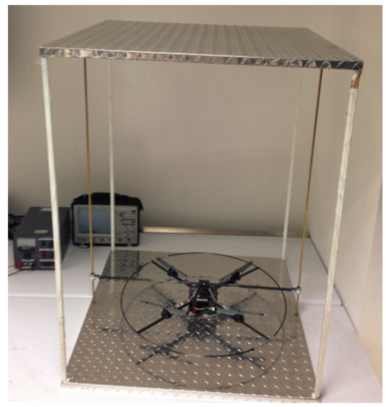

Fig. 1. Miniature Aerial Vehicle: Quad-Rotor Aircraft (Experimental Plataform).

This article is organized as follows: section 2 presents the description of the educative platform. Dynamic model of the quad-rotor mini-aircraft system and the parameter identification of the inertial tensor, mass and

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wind using adaptive control for the quad-rotor mini-aircraft are described in section 3. The simulation results of the parameter identification for the quad-rotor mini-aircraft using Simulink environment are described in section 4. In section 5 the experimental results are shown. Finally we present some conclusions.

II. DESCRIPTION OF THE EDUCATIONAL SETUP

The dynamics of a real flying quad-rotor aircraft has 6 degrees-of-freedom (DOF) movement [13]. The educational setup platform proposed allows movement in roll, pitch angles and y and z axes. The coordinated control of all four rotors will provide the desired altitude z, y movement is produced by changing $(f_1 + f_4) - (f_2+f_3)$. The pitch torque is a function of the difference $(f_1+f_4)-(f_2+f_3)$, the roll torques is produced by the difference $(f_1+f_2)-(f_3+f_4)$ (see Figure 2). According to this setup we can obtain a similar result as a real aircraft in a limited space. The quad-rotor mini-aircraft is fixing with two metal bars which limit the movements.

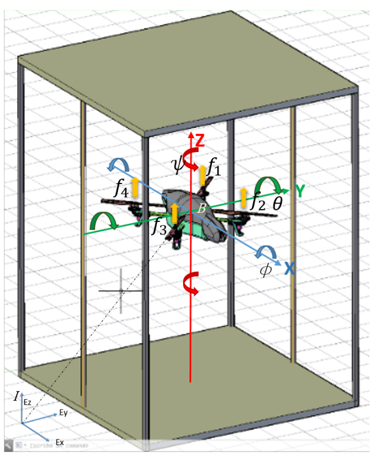

Fig. 2. Schematic Educational Testbed.

III. PROBLEM FORMULATION

A. The quad-rotor mini-aircraft model

Consider the following model of the quad-rotor mini-aircraft, as derived through Euler-Lagrange formalism in [14], for the translation motion are:

$$\begin{pmatrix} m\ddot{x} \\ m\ddot{y} \\ m\ddot{z} \end{pmatrix} = \begin{pmatrix} -u\ sin\,\theta \\ u\ sin\,\phi\ \cos\,\theta \\ u\ \cos\,\phi\ \cos\,\theta \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ -mg \end{pmatrix} \quad (1)$$

where m is the mass of the quad-rotor mini-aircraft, $u = f_1+f_2+f_3+f_4$ and for $i = 1, ..., 4$, f_i is the force produced by the motor Mot_i. and define the position vector as $\xi = (x, y, z)^T$

The equations for the rotational motion are:

$$\mathbb{J}\ddot{\eta} \;=\; \tau_\eta - C(\eta, \dot{\eta})\dot{\eta} \quad (2)$$

where x and y are the coordinates in the horizontal plane and z is the vertical position, whereas that ϕ is the roll angle around the x-axis, θ is the pitch angle around the y-axis and ψ is the yaw angle around the z-axis for the vector $\eta = (\psi, \theta, \phi)^T$. knowing that:

$$\mathbb{J} = W_\eta^T I W_\eta. \quad (3)$$

where $W_(\eta)$ is a transformation matrix and is given by

$$W_\eta = \begin{bmatrix} -\sin(\theta) & 0 & 1 \\ \cos(\theta)\sin(\theta) & \cos(\phi) & 0 \\ \cos(\theta)\cos(\phi) & -\sin(\phi) & 0 \end{bmatrix} \quad (4)$$

The η-dynamic [14] can be written in the general form as:

$$M(\eta)\ddot{\eta} + C(\eta, \dot{\eta})\dot{\eta} = \tau_\eta \quad (5)$$

where

$$M(\eta) = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

$$C(\eta, \dot{\eta}) = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}$$

with

$$\begin{aligned} m_{11} &= (I_{xx}s_\theta^2) + (I_{yy}c_\theta^2 s_\phi^2) + (I_{zz}c_\theta^2 c_\phi^2) \\ m_{12} &= c_\theta c_\phi s_\phi(I_{yy} - I_{zz}) \\ m_{13} &= -I_{xx}s_\theta \\ m_{21} &= c_\theta c_\phi s_\phi(I_{yy} - I_{zz}) \\ m_{22} &= (I_{yy}c_\phi^2) + (I_{zz}s_\phi^2) \\ m_{23} &= 0 \\ m_{31} &= -I_{xx}s_\theta \\ m_{32} &= 0 \\ m_{33} &= I_{xx} \end{aligned}$$

and

$$
\begin{aligned}
c_{11} &= I_{xx}\dot{\theta}s_{\theta}c_{\theta} + I_{yy}(-\dot{\theta}s_{\theta}c_{\theta}s_{\theta}^2 + \dot{\phi}c_{\theta}^2 s_{\phi}c_{\theta}) \\
&\quad -I_{zz}(\dot{\theta}s_{\theta}c_{\theta}c_{\phi}^2 + \dot{\phi}c_{\theta}^2 s_{\phi}c_{\phi}) \\
c_{12} &= I_{xx}\dot{\psi}s_{\theta}c_{\theta} - I_{yy}(\dot{\theta}s_{\theta}s_{\phi}c_{\phi} + \dot{\phi}c_{\theta}s_{\phi}^2 \\
&\quad -\dot{\phi}c_{\theta}c_{\phi}^2 + \dot{\psi}s_{\theta}c_{\theta}s_{\phi}^2) + I_{zz}(\dot{\phi}c_{\theta}s_{\phi}^2 - \dot{\phi}c_{\theta}c_{\phi}^2 \\
&\quad -\dot{\psi}s_{\theta}c_{\theta}c_{\phi}^2 + \dot{\theta}s_{\theta}s_{\phi}c_{\phi}) \\
c_{13} &= -I_{xx}\dot{\theta}c_{\theta} + I_{yy}\dot{\psi}c_{\theta}^2 s_{\phi}c_{\phi} - I_{zz}\dot{\psi}c_{\theta}^2 s_{\phi}c_{\phi} \\
c_{21} &= -I_{xx}\dot{\psi}s_{\theta}c_{\theta} + I_{yy}\dot{\psi}s_{\theta}c_{\theta}s_{\phi}^2 + I_{zz}\dot{\psi}s_{\theta}c_{\theta}c_{\phi}^2 \\
c_{22} &= -I_{yy}\dot{\phi}s_{\phi}c_{\phi} + I_{zz}\dot{\phi}s_{\phi}c_{\phi} \\
c_{23} &= I_{xx}\dot{\psi}c_{\theta} + I_{yy}(-\dot{\theta}s_{\phi}c_{\phi} + \dot{\psi}c_{\theta}c_{\phi}^2 - \dot{\psi}c_{\theta}s_{\phi}^2) \\
&\quad +I_{zz}(\dot{\psi}c_{\theta}s_{\phi}^2 - \dot{\psi}c_{\theta}c_{\phi}^2 + \dot{\theta}s_{\phi}c_{\phi}) \\
c_{31} &= -I_{yy}\dot{\psi}c_{\theta}^2 s_{\phi}c_{\phi} + I_{zz}\dot{\psi}c_{\theta}^2 s_{\phi}c_{\phi} \\
c_{32} &= -I_{xx}\dot{\psi}c_{\theta} + I_{yy}(\dot{\theta}s_{\phi}c_{\phi} + \dot{\psi}c_{\theta}s_{\phi}^2 - \dot{\psi}c_{\theta}c_{\phi}^2) \\
&\quad -I_{zz}(\dot{\psi}c_{\theta}s_{\phi}^2 - \dot{\psi}c_{\theta}c_{\phi}^2 + \dot{\theta}s_{\phi}c_{\phi}) \\
c_{33} &= 0
\end{aligned}
$$

B. Inertia Parameter estimation

In this section, we present an adaptive control to estimate the parameters of the inertia tensor for a controlled quad-rotor mini-aircraft system. The nonlinear system (5) has a property called "Linearity in the parameters", this means that the model can be rewritten as the product of a matrix of known function $Y_\eta(\eta, \ddot{\eta})$ which contains nonlinear terms of the state (the generalized coordinates and its derivatives) and the vector of dynamic parameters, p_η, as:

$$M(\eta, p_a)u_\eta + C(\eta, w_\eta, p_a)v_\eta = Y_\eta(\eta, u_\eta, v_\eta, w_\eta)p_\eta \tag{6}$$

where, we defined

$$u_\eta = \ddot{\eta}_d + \Lambda_\xi \dot{\tilde{\eta}}$$

$$v_\eta = \dot{\eta}_d + \Lambda_\xi \tilde{\eta}$$

$$w_\eta = \dot{\eta}$$

where $\tilde{\eta} = \eta_d - \eta$ is the position error and Λ_η is a nonsingular constant matrix. The vector of the unknown dynamic parameters p_η depends only on the dynamic parameters of the system. Taking this into account, the unknown parameters are the inertias I_{xx}, I_{yy} and I_{zz}, we identify the vector of dynamic parameters as

$$
\begin{aligned}
p_{\eta 1} &= I_{xx} \\
p_{\eta 2} &= I_{yy} \\
p_{\eta 3} &= I_{zz}
\end{aligned}
$$

now, considering p_η we need to build a matrix Y_η necessary to satisfy the property of linearity in the parameters with the form:

$$\gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{bmatrix} \tag{7}$$

and the terms of this matrix are:

$$
\begin{aligned}
\gamma_{11} &= s_{\theta}^2 u_1 - s_{\theta}u_3 + w_2 s_{\theta}c_{\theta}v_1 + w_1 s_{\theta}c_{\theta}v_2 \\
&\quad -w_2 c_{\theta}v_3 \\
\gamma_{12} &= c_{\theta}^2 s_{\phi}^2 u_1 + c_{\theta}c_{\phi}s_{\phi}u_2 + (-w_2 s_{\theta}c_{\theta}s_{\phi}^2 \\
&\quad +w_3 c_{\theta}^2 s_{\phi}c_{\phi})v_1 - (w_2 s_{\theta}s_{\phi}c_{\phi} + w_3 c_{\theta}s_{\phi}^2 \\
&\quad -w_2 c_{\theta}c_{\phi}^2 + w_1 s_{\theta}c_{\theta}s_{\phi}^2)v_2 + w_1 c_{\theta}^2 s_{\phi}c_{\phi}v_3 \\
\gamma_{13} &= c_{\theta}^2 c_{\phi}^2 u_1 - c_{\theta}c_{\phi}s_{\phi}u_2 - (w_2 s_{\theta}c_{\theta}c_{\phi}^2 \\
&\quad +w_3 c_{\theta}^2 s_{\phi}c_{\phi})v_1 + (w_3 c_{\theta}s_{\phi}^2 - w_3 c_{\theta}c_{\phi}^2 \\
&\quad -w_1 s_{\theta}c_{\theta}c_{\phi}^2 + w_2 s_{\theta}s_{\phi}c_{\phi})v_2 - w_1 c_{\theta}^2 s_{\phi}c_{\phi}v_3 \\
\gamma_{21} &= -w_1 s_{\theta}c_{\theta}v_1 + w_1 c_{\theta}v_3 \\
\gamma_{22} &= c_{\theta}c_{\phi}s_{\phi}u_1 + c_{\phi}^2 u_2 + w_1 s_{\theta}c_{\theta}s_{\phi}^2 v_1 \\
&\quad -w_3 s_{\phi}c_{\phi}v_2 + (-w_2 s_{\phi}c_{\phi} + w_1 c_{\theta}c_{\phi}^2 \\
&\quad -w_1 c_{\theta}s_{\phi}^2)v_3 \\
\gamma_{23} &= -c_{\theta}c_{\phi}s_{\phi}u_1 + s_{\phi}^2 u_2 + w_1 s_{\theta}c_{\theta}c_{\phi}^2 v_1 \\
&\quad +w_3 s_{\phi}c_{\phi}v_2 + (w_1 c_{\theta}s_{\phi}^2 - w_1 c_{\theta}c_{\phi}^2 \\
&\quad +w_2 s_{\phi}c_{\phi})v_3 \\
\gamma_{31} &= -s_{\theta}u_1 + u_3 - w_1 c_{\theta}v_2 \\
\gamma_{32} &= -w_1 c_{\theta}^2 s_{\phi}c_{\phi}v_1 + (w_2 s_{\phi}c_{\phi} + w_1 c_{\theta}s_{\phi}^2 \\
&\quad -w_1 c_{\theta}c_{\phi}^2)v_2 \\
\gamma_{33} &= w_1 c_{\theta}^2 s_{\phi}c_{\phi}v_1 - (w_1 c_{\theta}s_{\phi}^2 - w_1 c_{\theta}c_{\phi}^2 \\
&\quad +w_2 s_{\phi}c_{\phi})v_2
\end{aligned}
$$

now we introduced the vector of adaptive parameters $\hat{p}_\eta$ such that, for a given adaptive system, if the limit of $\hat{p}_\eta(t)$ when $t \to \infty$ exists and is such that

$$\lim_{t\to\infty} \hat{p}_\eta(t) = p_\eta \tag{8}$$

then we say that the adaptive system guarantees parametric convergence. Substituting $\hat{\theta}_a$ by the vector of unknown, dynamic parameters θ_a we obtain

$$M(\eta, \hat{p}_\eta)u_\eta + C(\eta, w_\eta, \hat{p}_\eta)v_\eta = Y_\eta(\eta, u_\eta, v_\eta, w_\eta)\hat{p}_\eta \tag{9}$$

Taking into account, is proposed a control law as follows:

$$\tau = K_{p\eta}\tilde{\eta} + K_{d\eta}\dot{\tilde{\eta}} + Y_\eta \hat{p}_\eta \tag{10}$$

where, $K_{p\eta}$, $K_{d\eta}$ are symmetric positive definite gain matrices for rotational control, an adaptive control law used for the continuous adaptive systems is the so called integral law or gradient type

$$\hat{p}_\eta(t) = \Gamma_\eta \int_0^t Y_\eta^T[\dot{\tilde{\eta}} + \Lambda_\eta \tilde{\eta}]ds + \hat{p}_\eta(0) \tag{11}$$

where $\Lambda_\eta = K_{v\eta}^{-1} K_{p\eta}$ and Γ_η is the adaptive gain whose magnitude is proportional to the adaptation speed, and $\hat{p}_\eta(0)$ is an arbitrary vector even though in practice, the adaptive gain is chosen to obtain the best approximation of the unknown parameters vector p_η.

C. Mass parameter estimation

Using a similar strategy of adaptive control to estimate the mass of the quad-rotor mini-aircraft, the control law has the form

$$F = K_{p\xi}\tilde{\xi} + K_{d\xi}\dot{\tilde{\xi}} + Y_\xi \hat{p}_\xi \qquad (12)$$

where, $K_{p\xi}$, $K_{d\xi}$ are symmetric positive definite gain matrices for translation control. we define u_ξ

$$u_\xi = \ddot{\xi}_d + \Lambda_\xi \dot{\tilde{\xi}}$$

where $\tilde{\xi} = \xi_d - \xi$ is the altitude error and Λ_ξ is a nonsingular constant matrix. Applying the property of the linearity in the parameters in equation (1) we obtain:

$$mu_\xi + \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} = Y_\xi(u_\xi) p_\xi$$

In this case the dynamic parameter is only the mass ($p_\xi = m$) and the Y_{xi} is a vector of known functions with the form:

$$Y_\xi = \begin{bmatrix} u_{\xi 1} \\ u_{\xi 2} \\ u_{\xi 3} + g \end{bmatrix}$$

an the integral law is

$$\hat{p}_\xi(t) = \Gamma_\xi \int_0^t Y_\xi^T [\dot{\tilde{\xi}} + \Lambda_\xi \tilde{\xi}] ds + \hat{p}_\xi(0) \qquad (13)$$

where $\Lambda_\xi = K_{v\xi}^{-1} K_{p\xi}$ and Γ_ξ is the adaptive gain whose magnitude is proportional to the adaptation speed, and $\hat{p}_\xi(0)$ are a design parameters.

D. Wind force estimation

In this section we estimated the wind affecting in Euler angles of the quad-rotor mini-aircraft based in [15]. If considering wind as a parameter in the input we can use the Model-Reference Adaptive Control (MRAC). So the model (5) is rewritten as

$$M(\eta)\ddot{\eta} + C(\eta, \dot{\eta})\dot{\eta} = \tau_\eta + W \qquad (14)$$

where $W = (W_\psi, W_\theta, W_\phi)^T$ is the vector containing the wind parameters affecting in yaw, pitch and roll. The following reference model is used:

$$\ddot{\eta}_m + \lambda\dot{\eta}_m + \lambda^2 \eta_m = r(t) \qquad (15)$$

Considering $\tilde{\eta} = \hat{\eta} - \eta$. Following control law is proposed:

$$u = M(\eta)v + C(\eta, \dot{\eta})\dot{\eta} - \hat{W} \qquad (16)$$

with $v = (\ddot{\eta}_m - \lambda\dot{\tilde{\eta}}_m - \lambda\tilde{\eta})$ and note that the control contains the adjustable parameter $\hat{W}$. Substituting the control law (16) in the model (14) we obtain

$$\dot{s} + \lambda s = M(\eta)^{-1}(\tilde{W}) \qquad (17)$$

where s a combined tracking error measure, is defined by $s = \dot{\tilde{\eta}} + \lambda\tilde{\eta}$ and $\dot{s} = \ddot{\eta} - \ddot{\eta}_m$. The adaptation law of the adjustable parameter is given by:

$$\dot{\tilde{W}} = \dot{\hat{W}} = -\Gamma(M(\eta)^{-1})^T s \qquad (18)$$

Using the following Lyapunov function candidate [16]:

$$V = \frac{1}{2}s^T s + \frac{1}{2}\tilde{W}^T \Gamma^{-1}\tilde{W} \qquad (19)$$

Its derivative can be easily shown to be

$$\dot{V} = s^T \dot{s} + \tilde{W}^T \Gamma^{-1} \dot{\tilde{W}} \qquad (20)$$

Using equations (17) and (18) in equation (20) it is obtained:

$$\dot{V} = -s^T \lambda s < 0 \qquad (21)$$

This mean that V decreases along the trajectory of the system and using Barbalats lemma: *If the differentiable function $f(t)$ has a finite limit as $t \to \infty$, and if $\dot{f}$ is uniformly continuous, then $\dot{f}(t) \to 0$ as $t \to \infty$*, one can easily show that s converges to zero. Due to the relation ($s = \dot{\tilde{\eta}} + \lambda\tilde{\eta}$), the convergence of s to zero implies that the position tracking error $\tilde{\eta}$ and the velocity tracking error $\dot{\tilde{\eta}}$ converge to zero too.

IV. Simulation Results

A. Inertia Tensor Tests

The main objective is the parameters estimation of the inertia tensor of our quad-rotor mini-aircraft. To obtain the value of inertia on the y axis (I_{yy}) the values of the Euler angles of roll and yaw must be ($\phi = 0$ and $\psi = 0$), while the angle pitch (θ)must follow a desired trajectory generated with the following functions:

$$\eta_d = C_1(1 - e^{-2t^3})\sin(\omega_t) \qquad (22)$$

where $C_1 = 10 * (pi/180)$ and $\omega_t = 15 * (pi/15)$. This signal works like a persistent excitation during the estimation of unknown dynamical parameters, the Figure (3) presents the desired trajectories and the actual position of the Euler angles.

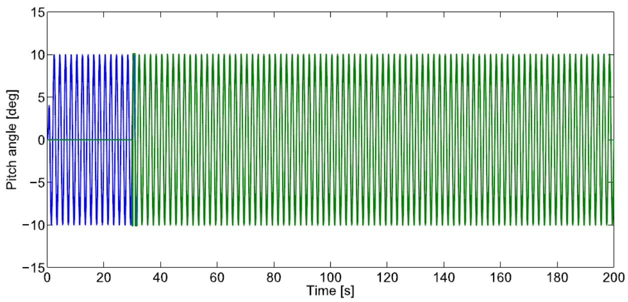

Fig. 3. Persistent disturbance signal applied on pitch axis of the quad-rotor mini-aircraft, to identify the unknown moment inertia parameters.

The quad-rotor mini-aircraft begins to tracking the desired trajectory at 20 seconds after the start of the simulation, before at this time, the quad-rotor mini-aircraft must be blast off the ground,this time was considered in the simulation. Figure (4) shows the graph of the estimated parameter value $\hat{\theta}_a$, corresponding to movement of the pitch angle. The estimation begins when the tracking begins.

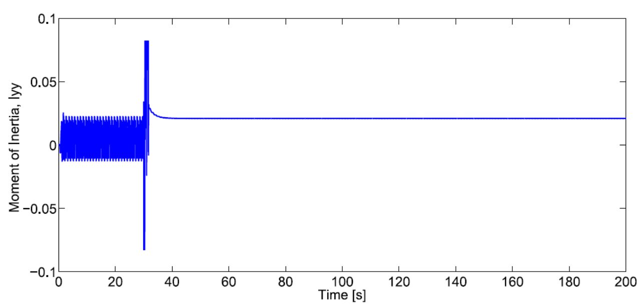

Fig. 4. Parameter identification of the vehicle's inertia tensor.

B. Mass

The quad-rotor mini-aircraft must be tracking a sinus signal in the altitude to estimate the mass, this signal is a persistent disturbance necessary for the estimation (Figure 5).

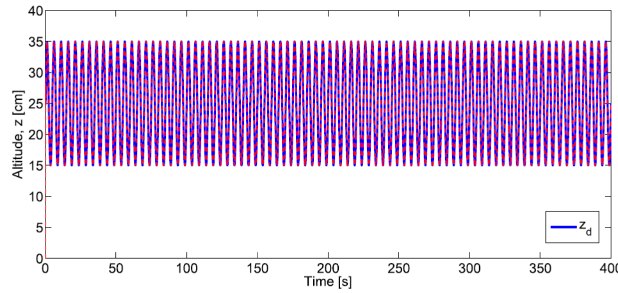

Fig. 5. Persistent disturbance applied on altitude z of the quad-rotor mini-aircraft to identify the mass.

The test consist in estimated the initial mass of quad-rotor mini-aircraft and increasing the mass (0.1 kg) in a determinate time ($t = 200s$) to test the adaptation to the new parameter. In Figure (6) we can see the simulation.

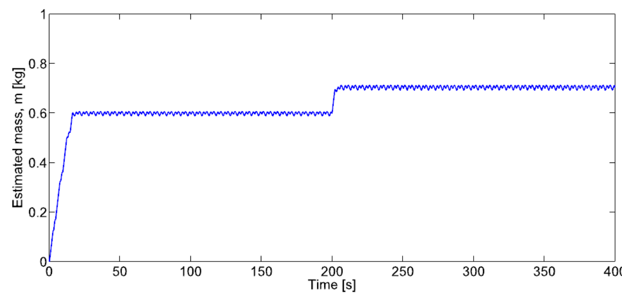

Fig. 6. Parameter identification of the vehicle's mass changed the parameter in $t = 200s$.

C. Wind

Figure (7) shows the stabilization in attitude of the quad-rotor mini-aircraft, from a different to zero angle in the Euler angles, this means that placed the vehicle in hover mode is the goal of the control law

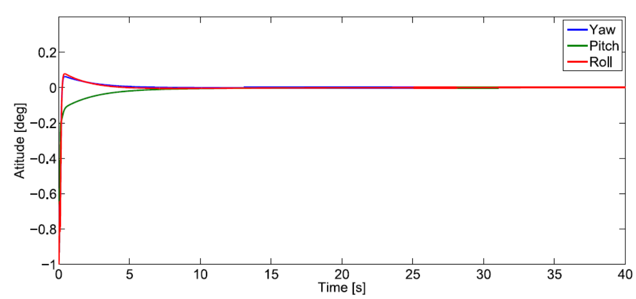

Fig. 7. Stabilization in attitude of the quad-rotor mini-aircraft using Adaptive Control.

The estimation of the perturbation which affecting the control input is used in a feedback to cancel these terms, in Figure (8) we can see this parameter estimated.

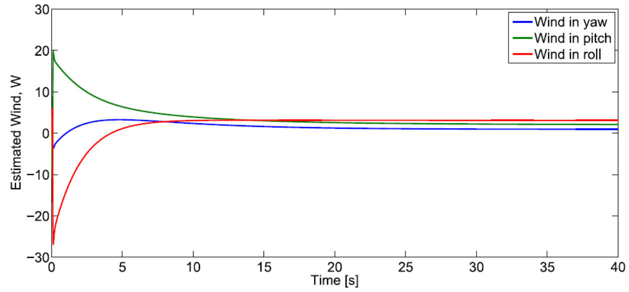

Fig. 8. Estimation of the wind parameters disturbance.

V. Experimental results

This section shows the experimental results, we can observe in Figure (9) desired trajectory tracking in pitch angle in real time. Figure (10) shows the results of the estimation of the unknown parameter I_{yy}, which is approximately 0.018. because that it was considered that the quad-rotor mini-aircraft has a symmetrical shape, the value should be the same to I_{xx}, while for I_{zz} should be doubled ($I_{zz} = 0.036$).

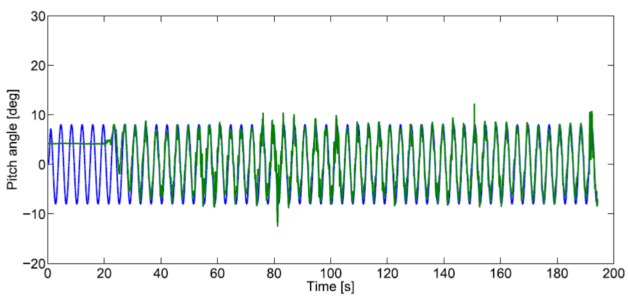

Fig. 9. Persistent disturbance applied on pitch axis of the quad-rotor mini-aircraft to identify the unknown moment inertia parameters.

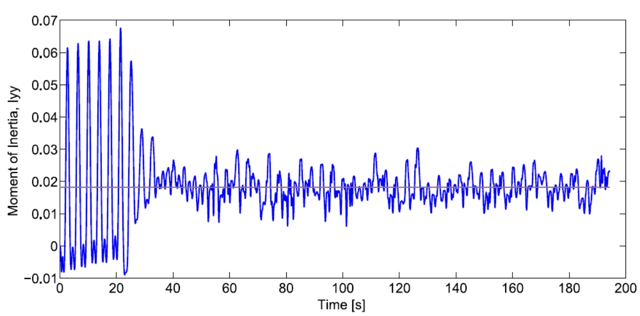

Fig. 10. Parameter identification of the vehicle's inertia tensor.

The experimental results about the adaptation to the changed mass parameter was show in the next graphics, the Figure (11) shows the sinus signal is used as persistent disturbance in altitude (z axis) and the tracking performed by the quad-rotor mini-aircraft.

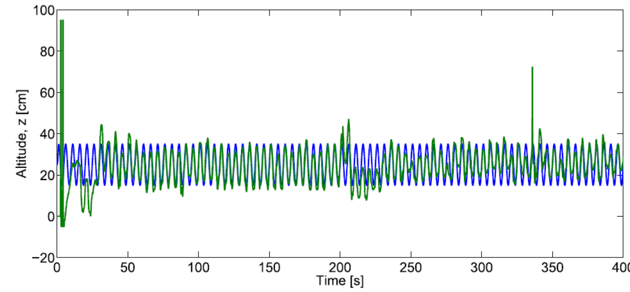

Fig. 11. Persistent disturbance applied on z axis of the quad-rotor mini-aircraft to estimate the mass.

The Figure (12) shows initial and final mass estimation, In the time $t = 200s$ we increased the mass when placing extra weight ($0.1kg$) to the vehicle.

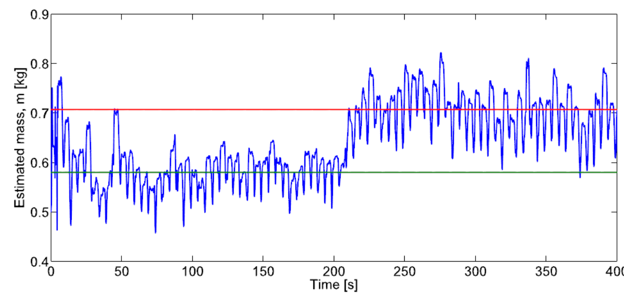

Fig. 12. Parameter identification of the vehicle's mass, changed the parameter in $t = 200s$.

VI. Conclusions

In this paper we have presented an algorithm for identifying parameters of the moment of inertia (I_{xx}, I_{yy}, I_{zz}) the mass (m) and the wind (W_ψ,W_θ,W_ϕ) are presented for a quad-rotor mini-aircraft based on an adaptive control scheme. This control algorithms allows to obtain a better description of the behavior of the quad-rotor mini-aircraft in relation to the parameters involved in the mathematical model. The convergence of inertia tensor and mass parameters needs a persistent excitation signal but the torque produced by wind is estimated without a persistent excitation. Closed loop stability was shown by a suitable Lyapunov function and the Boundedness Lemma. The experimental results were obtained using educational platform.

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