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ENHANCING CONTROL EDUCATION WITH REAL-TIME EXPERIMENTS

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Abstract: *In this paper, real-time experimentation platforms for enhancing the control education are presented. Electronics Engineering Department in Turkish Air Force Academy aims to motivate cadets by control experiments especially on flight related platforms. In this paper, real-time lever and quadrotor UAV experimentation sets with PD control are presented. The lever experimentation set is used as an introductory study before starting experiments with the quadrotor, since the dynamic equations of the lever is only a simplified version of the quadrotor and control method is the same. The structures of both systems are custom manufactured in laboratory according to educational requirements. They are considered to enhance the motivation of control related courses and laboratories.*

Keywords: *UAV, quadrotor, control, education*

1. INTRODUCTION

Turkish Air Force Academy (TurAFA) follows engineering discipline and has four departments, which are electronics, computer, aeronautical and industrial engineering. Upon graduation students get bachelor degree in one of those departments. Logically, basic motivation of cadets is concentrated around flight and pilotage every educational activity in the Air Force Academy should have a rich sense of applied flight practices where possible. Automatic Control Systems, Control System Theory and Design, Introduction to Robotics, Control Systems Laboratory and other control related courses are enriched with experimentation sets.

In recent years four rotor mini unmanned air vehicles has become very popular. There are several reasons behind this popularity some of which are; reduced mechanical complexity compared to helicopters, ease of manufacturing and maintenance, presenting a good control problem due to coupled and highly non-linear dynamics [1]. The quadrotor platform is utilized as an educational setup in TurAFA. The processor platform used is an industrial standard in real-time control systems, dSpace ds1103. Some advantages relating to educational aspect are; very high real-time processing power which is not available under PC architecture [2], programming in a well-known software MATLAB/Simulink with block diagrams and compiling directly to dSpace target [3], using dSpace ControlDesk GUI based software to modify Simulink variables in real-time, monitor and record data easily [4].

The presented quadrotor experimentation set has various types of usage for both graduate and undergraduate level education. The lever mechanism is an introductory set for the quadrotor UAV. It is first aimed to make cadets familiar with rotor based platforms. The effect of vibration, thrust vector and propellers are investigated and then quadrotor UAV is introduced.

The paper is organized as follows. First, dynamic model of both systems are given. Then the control method is explained. Finally the educational environment is depicted and the experimental results are given.

2. DYNAMIC MODEL

The quadrotor experimental system described here is fixed on a 3DOF (Degree-Of-Freedom) universal joint with ±10° freedom in roll and pitch, ±360° freedom in yaw axis. Currently there is no movement in z-axis. Roll, pitch and yaw movements are accomplished by simply varying rotor angular velocities. This phenomenon is depicted in Figure 1. Bigger and smaller circles represent faster and slower rotors respectively. Roll and pitch movements are obtained by increasing and decreasing opposite (1-3 and 2-4) rotor the speeds.

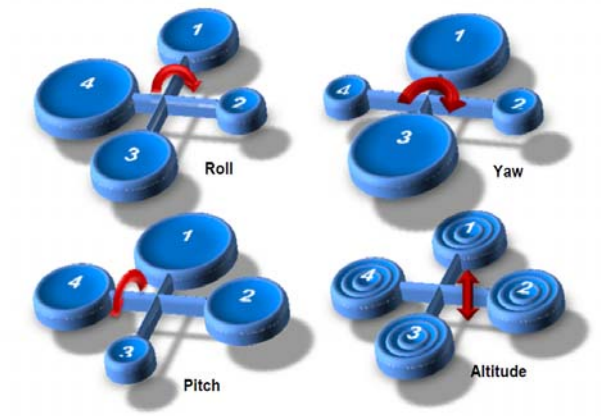

Figure 1 Basic maneuvers vs. angular velocities

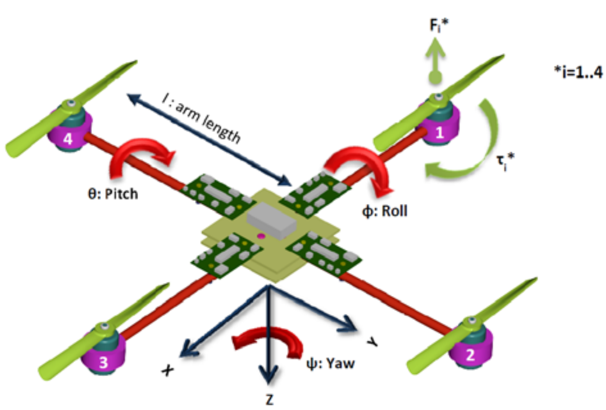

Figure 2 Quadrotor coordinate system

The simplified dynamic equations in accordance with the above assumptions and small angle approximation are [5]:

$$\ddot{\phi} = \frac{I_{rotor}\dot{\theta}(\Omega_1+\Omega_3-\Omega_2-\Omega_4)}{I_{xx}} + \frac{I_{yy}-I_{zz}}{I_{xx}}\dot{\psi}\dot{\theta} + \frac{bl(\Omega_2^2-\Omega_4^2)}{I_{xx}} \quad (1)$$

$$\ddot{\theta} = \frac{I_{rotor}\dot{\phi}(-\Omega_1-\Omega_3+\Omega_2+\Omega_4)}{I_{yy}} + \frac{I_{zz}-I_{xx}}{I_{yy}}\dot{\psi}\dot{\phi} + \frac{bl(\Omega_3^2-\Omega_1^2)}{I_{yy}} \quad (2)$$

$$\ddot{\psi} = \frac{d(-\Omega_2^2-\Omega_4^2+\Omega_3^2+\Omega_1^2)}{I_{zz}} + \frac{I_{xx}-I_{yy}}{I_{zz}}\dot{\theta}\dot{\phi} \quad (3)$$

In equations (1-3); ϕ, θ and ψ are roll, pitch and yaw angles respectively. Ω_{1-4} represent rotor speeds, b stands for the thrust coefficient, d is the drag coefficient and l is the arm length Body inertia values are denoted with I_{rotor}, I_{xx}, I_{yy} and I_{zz}. Due to symmetrical properties of the quadrotor body, inertia matrix is diagonal, I_{xx} and I_{yy} are assumed to be equal. From equations (1-3) all forces and moments acting on the body can be written as seen in **Error! Reference source not found.**.

$$F_i = b\Omega_i^2 \qquad b\text{: thrust factor} \quad (4)$$

$$\tau_i = d\Omega_i^2 \qquad d\text{: thrust factor} \quad (5)$$

$$\tau_{\phi:roll} = bl(F_2-F_4) = bl(\Omega_2^2-\Omega_4^2) \quad (6)$$

$$\tau_{\theta:pitch} = bl(F_3-F_1) = bl(\Omega_3^2-\Omega_1^2) \quad (7)$$

$$\tau_{\psi:yaw} = d\sum_{i=1}^{4}\tau_i = d(\tau_1-\tau_2+\tau_3-\tau_4) = d(\Omega_1^2-\Omega_2^2+\Omega_3^2-\Omega_4^2) \quad (8)$$

The lever mechanism is much simpler than the quadrotor. There is only 1DOF with ±30° freedom. The movement might be considered as either roll or pitch. The equations of motion are same for both cases. The dynamic equations of the lever mechanism are obtained by equating all parameters related to pitch and yaw axis to zero in equation (1). The resulting formulas are given below.

$$\ddot{\phi} = \frac{bl(\Omega_{lever1}^2-\Omega_{lever2}^2)}{I_{lever}} \quad (9)$$

$$\tau_{lever} = bl(F_{lever1}-F_{lever2}) \quad (10)$$

$$bl(\Omega_{lever1}^2 - \Omega_{lever2}^2)$$

To avoid confusion with the quadrotor formulas, the parameters related to rotors are named as lever. All control method and related formulas are derived using these equations.

3. CONTROL METHOD

A PD control scheme is utilized for the quadrotor and the lever experimentation set. Similar control approach for quadrotor platforms is widely used [5,6]. Control architecture for the quadrotor and the lever mechanism are given in Figure 3 and Figure 4 respectively.

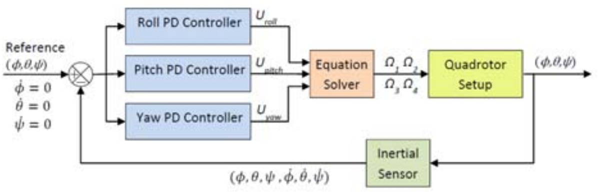

Figure 1 Quadrotor Control Architecture

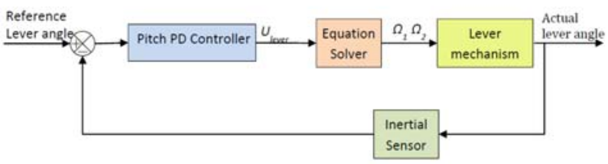

Figure 2 Lever Mechanism Control Architecture

Main PD control block has three separate loops for roll, pitch and yaw. The resulting control signals $U_{\varphi:roll}$, $U_{\theta:pitch}$ and $U_{\psi:yaw}$ are the moments (6-8) of their axes as written in following equations (9-11).

$$U_{\varphi:roll} = K_{p:\varphi}(\varphi_{ref} - \varphi) + K_{d:\varphi}(-\dot{\varphi}) = bl(\Omega_2^2 - \Omega_4^2) \quad (11)$$

$$U_{\theta:pitch} = K_{p:\theta}(\theta_{ref} - \theta) + K_{d:\theta}(-\dot{\theta}) = bl(\Omega_3^2 - \Omega_1^2) \quad (12)$$

$$U_{\psi:yaw} = K_{p:\psi}(\psi_{ref} - \psi) + K_{d:\psi}(-\dot{\psi}) = d(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \quad (13)$$

A similar control approach is used for the lever. The lever angle is controlled by the difference of thrusts, which are generated by the two motors. Hence this difference is equal to the control signal that is the output of the PD loop.

$$(Lever_{ref} - Lever) + K_{d:lever}(-\dot{Lever}) = bl(\Omega_{lever1}^2 - \Omega_{lever2}^2) \quad (14)$$

The MATLAB Simulink model for the whole system and the PD control block is given in Figure 3. Same model is used for the lever by equating pitch and yaw axes parameters to zero.

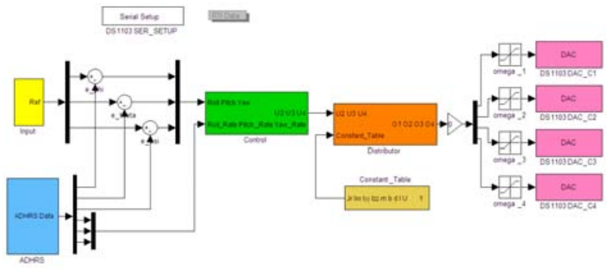

Figure 3 MATLAB Simulink model

4. EDUCATIONAL ENVIRONMENT AND EXPERIMENTAL RESULTS

Control Desk provides a comprehensive GUI for students as well as researchers. The most commonly used ControlDesk layout of the experimentation platform can be seen in Figure 4.

The quadrotor UAV and the lever mechanism experimentation set photos are given in Figure 5.

Sample experimental results for the quadrotor and the lever mechanism are given in Figure 8 and Figure 9.

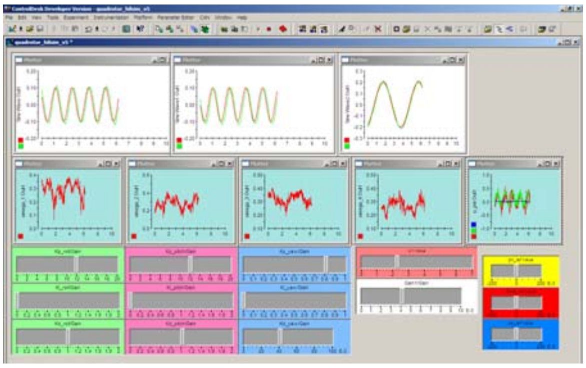

Figure 4 ControlDesk layout

Figure 5 The Quadrotor and Lever Experimentation Sets

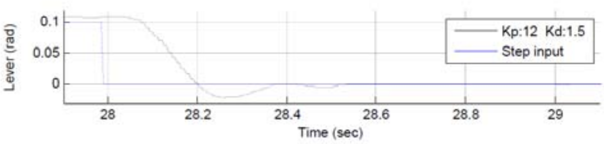

Figure 6 Lever angle step response

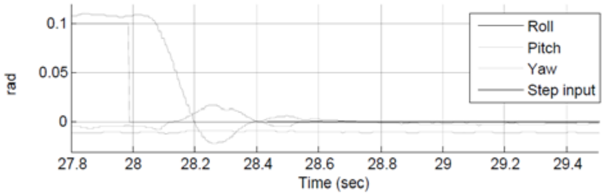

Figure 7 Roll angle step response

5. CONCLUSION

As explained in related paragraphs, both experimentation sets are intended to be a real-time working environments for various control laboratory practices in TurAFA. They are designed, built and tuned in the laboratory according to the educational and academic requirements of both undergraduate students and graduate researchers who are and will be involved in pilotage or flight related activities. The sets are considered to support the engineering education in TurAFA.

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