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Design and Implementation of a Control and Navigation System for a Small Unmanned Aerial Vehicle

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Abstract: This paper describes the development of a control and navigation system for a small scale unmanned aerial vehicle (UAV) using as strategy a combination of classical control and Fuzzy Inference Systems (FIS). In this sense, the air-plane has been modelled through analytical techniques that use empirical estimations to compute the force and moment components acting on the aircraft. The control systems were designed using the aircraft's transfer functions to reach a desirable response for each command. Finally, the navigation control system is designed using a FIS to control the roll of the aircraft and the yaw control system to control the aircraft's heading. A route composed of waypoints is generated following a rummage of a selected area. The control systems are, then, tested in a simulated environment to ensure they accomplish the desired mission when they work together.

Keywords: UAV, Aircraft control, Aircraft Navigation, Fuzzy inference, Control system, Modeling techniques

1. INTRODUCTION

Unmanned aerial vehicles (UAV) are currently being studied as cheaper and efficient alternatives to different tasks, in civil and military applications, as precision agriculture, natural disaster risk zones and border and critical infrastructure monitoring, etc. In the military, the development of these vehicles are getting great attention in different countries due to their economic advantages and to their main capability which is leaving people out of the combat zone (Yun 2013). In agriculture, their use extends from plantation disease focus detection (in precision agriculture) to terrain mapping and flock management. They also provide superior detailing when compared with other technologies such as satellite imaging (Efron 2015). This class of vehicle's use extends also to natural disaster response as they can be used to identify risk zones and identify victims.

This paper proposes solutions to the control and navigation of a small fixed wing UAV using Fuzzy Inference Systems (FIS) and Classic Control Techniques. A basic requirement of this aircraft is to use a solution that can be implemented in commercial low cost computation platforms, being still able to execute the correct navigation control and the desired movements. The airplane's control should be able to navigate the airplane through waypoints and to control the airplane's attitude between waypoints in the desired way. Initially, these system's implementation will be in a simulated environment using Matlab and Simulink software.

The airplane that is going to be used in this research has been designed specifically to the recognition and sweeping tasks. With a payload of 1 kg, the plane is 1,8 m long in wingspan, has a length of 1,5 m and a height of 0,7 m. The motorization is electric using an induction three phase motor rated at 1036 W and generating a 25 N thrust. The aircraft doesn't have fuselage as all of the payload goes inside the wing (including control and sensor hardware). The tail controls are a rudder and an all moving elevator. One of its important characteristics is the capability of taking off and landing in difficult terrain which is achieved by the use of removable landing gear (being able to use an airstrip or a launcher to takeoff and landing in difficult terrain or in an airstrip). The final design of the aircraft can be seen in Figure 1.

Figure 1. Final aircraft design

2. RELATED RESEARCHES

The small fixed wing UAV's modeling is analogous to the modeling techniques used in bigger aircrafts thus a wide variety of approaches can be used to accomplish this task. Analytic methods are used as proposed in (Roskam 2001; Nelson 1998; Yun 2013) that aim to model the aircraft through aerodynamic and cinematic equations to determine the dynamic response of the airplane. Linearization and approximation techniques are used to simplify the model that is inherently non-linear and very complex. There are alternative approaches to this problem such as the ones used in (Manerowski & Rykaczewski 2005), based in experimental

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data collection. Those methods use numeric regression techniques and are, then, used to help in the control modeling and design.

The control methods used in this kind of aircraft are also very similar to the ones used in bigger planes, in this way, there exists a wide variety of methods as well. In the analytic control theory, there are techniques such as the ones used in (Roskam 2001; Nelson 1998), which involve classic control theory and modern control theory which are the most used. There are alternative techniques using artificial intelligence approach such as Artificial Neural Networks like in (Shin et al. 2005) and Fuzzy Systems as in (Doitsidis et al. 2004), and it is possible to use hybrid approaches that use a combination of more than one method like in (Yu et al. 2011; Narenathreyas 2013; Esper & Rosa 2015). These kinds of approaches have as advantage the reasonable modeling of nonlinearities. In the other hand, they come at high data collection and processing amount as the model's fidelity is very dependent on the quality and quantity of collected data. The analytical approaches can be used without the need of experimental data collection and with lower computational costs. In the other hand, could be necessary to use part by part linearization to achieve a good approximation in operation points far from the equilibrium point.

In terms of navigation, path planning techniques are used as in (Ajami et al. 2013; Grankvist 2006). Those approaches have an elevated computational cost compared to the ones that are going to be used in this research, which are based in classic control reference tracking and through Fuzzy control. These methods are very computationally efficient and can be used to solve the navigation problem for a simple case such as the rummage of a region.

3. MODELING

The method chosen for this research is the analytical as described in (Roskam 2001; Nelson 1998). This was chosen having into account that the aircraft is still under construction while this system is being developed. The variables convention used to de movement description in this paper is the same as used in (Nelson 1998) and a summary of it is shown in Table 1.

Table 1. Variables convention

	Roll Axis	Pitch Axis	Yaw Axis
Angular velocities	p	q	r
Velocity components	u	v	W
Aerodynamic force components	X	Y	Z
Aerodynamic moment components	L	M	N

The aircraft's modeling can be divided in Longitudinal and Lateral, due to the decoupling of these two kinds of movements and can be developed using as reference the gravity center of the vehicle as shown in Figure 2. This approach has some advantages as it allows several simplifications due to the symmetry of the plane as well as to the rotation axis positions. After the modeling in this reference system, this can be transferred to an inertial reference in a fixed point using (1).

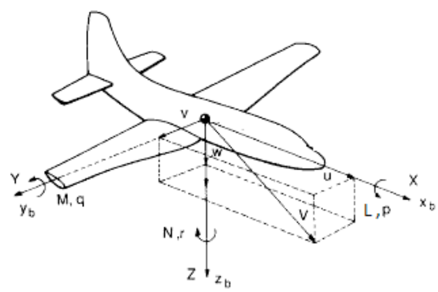

Figure 2. Body fixed coordinate system (Nelson 1998)

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} C_\theta C_\Psi & S_\Phi S_\theta C_\Psi - C_\Phi S_\Psi & C_\Phi S_\theta C_\Psi + S_\Phi S_\Psi \\ C_\theta S_\Psi & S_\Phi S_\theta S_\Psi + C_\Phi C_\Psi & C_\Phi S_\theta S_\Psi - S_\Phi C_\Psi \\ S_\theta & S_\Phi C_\theta & C_\Phi C_\theta \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad (1)$$

Being $\dot{x}$, $\dot{y}$, $\dot{z}$ the aircraft velocities with respect to the inertial coordinate system, Φ, θ and Ψ being respectively the roll angle, the pitch angle and the yaw angle and using $C_\theta = \cos(\theta)$, $S_\theta = \sin(\theta)$ and so on.

3.1 Parameters Posing

The parameters utilized in the aircraft's behavior modeling were determined as described in (Roskam 1973; Roskam 2001; Nelson 1998) and are called stability and control coefficients (or stability and control derivatives). Those parameters define the state equations of the plane and allow the behavior analysis in open and closed loop.

Apart from the dynamic behavior of the airplane, the time response curve of the servomotors that will be used was obtained. To achieve this, a carefully positioned camera was used, capturing images at a frame rate of 118 frames per second. One of the captures frames can be seen in Figure 3

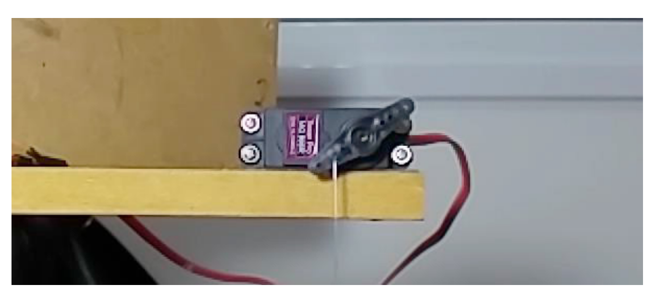

Figure 3. Step response obtaining for the servomotor.

From the obtained images, it was possible to use a CAD (Computer Aided Design) software to get the measurements of each frame and the time step response was obtained. The step response curve can be seen in Figure 4 as well as the first and second order approximations. The first order approximation was realized as proposed in (Bazanella & da Silva 2005), while the second one was obtained using the System Identification tool from the Matlab Software.