Quadrotor based on fuzzy logic controller

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Abstract – The objective of this work is the application of an intelligent flight system based on fuzzy logic applied on a quadrotor control. The quadrotor is an helicopter witch use four rotors for motion to ensure system stability. A fuzzy control is designed to control the globally quadrotor model. The simulation where carried on Matlab simulink environment after the choice of the mathematical model. The obtained results show the efficiency of the Fuzzy Logic Controller (FLC) compared to the classical PD controller. The FLC presents a response with less error and no overshoot and good dynamical characteristics.

Keywords: intelligent control system, fuzzy control, quadrotor

1. INTRODUCTION

Autonomous flying robots have gained enormous commercial potential during the last years. Recent developments in high density power storage, integrated miniature actuators and MEMS technology sensors have made autonomous miniaturized flying robots possible. This new situation has opened the way to several, complex and highly important applications for both military and civilian markets. Military applications currently represent the lion's part of the unmanned flying vehicle market, and this industrial sector is growing strongly. Depending on the flying principle and the propulsion mode, one can classify aircraft vehicles in multiple categories as shown in figure 1. In the motorized heavier-than-air category, a new generation of MAV with a wingspan less than 15cm and less than 100 grams in mass has emerged. Generally these MAVs are fully equipped with stabilization sensors and miniature cameras. The Black Widow MAV is a 15cm span, fixed-wing aircraft with an embedded color camera. It flies at 48 km/h with an endurance of 30 minutes, and a maximum communication range of 2km. In the same category, bird/Insect-like MAVs seem to be the perfect solution for fast navigation in narrow spaces and perhaps the best approach to miniaturization. The Micromechanical Flying Insects (MFI) project at UC Berkeley [1] uses biomimetic principles to develop a flapping wing MAV [2]. The word helicopter is derived from the Greek words for spiral (screw) and wing. From a linguistic perspective, since the prefix quad is Latin, the term quadrotor is more correct than quadcopter and more common than tetracopter; hence, we use the term quadrotor throughout

Fig.1. Picture of the quadrotor

2. MODELING OF QUADROTOR

The first step before control development is an adequate dynamic system modeling. Especially for lightweight flying systems, the dynamic model ideally includes the gyroscopic effects resulting from both the rigid body rotation in space, and the four propeller's rotation as mentioned in fig.2.

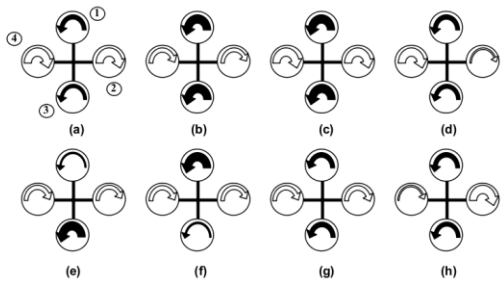

Fig. 2 Quadrotor concept motion description, the arrow width is proportional to propeller rotational speed.

Where,

(a) Yaw (Anticlockwise direction)
(b) Yaw (clockwise direction)
(c) Take-off or Take-up
(d) Roll (clockwise direction)
(e) Pitch(Anticlockwise direction)
(f) Pitch(clockwise direction)
(g) Land or take down
(h) Roll (Anticlockwise direction)

These aspects have been often neglected in previous works. However, the main effects acting on a helicopter are described briefly in table I.

TABLE I MAIN PHYSICAL EFFECTS ACTING ON A HELICOPTER

Effect	Source	Formulation
Aerodynamic effects	Propeller rotation Blades flapping	$C\Omega^2$
Inertial counter torques	- Change in propeller rotation speed	$J\dot{\Omega}$
Gravity effect	Center of mass position	
Gyroscopic effects	-Change in orientationof the rigid body -Change in orientation of the propeller plane	$I\theta\phi$ $J\Omega\theta,\phi$
Friction	All helicopter motion	$C\phi,\theta,\psi$

Let us consider earth fixed frame E and body fixed frame B, as seen in figure 3. The center of mass and the body fixed frame origin are assumed to coincide. Using Euler angles parameterization, the airframe orientation in space is given by a rotation R from B to E, where R SO3 is the rotation matrix. The dynamics of a rigid body under external forces applied to the center of mass and expressed in the body fixed frame as shown in Newton-Euler formalism:

$$\begin{bmatrix} mI_{3x3} & 0 \\ 0 & I \end{bmatrix} \cdot \begin{bmatrix} \dot{V} \\ \dot{\omega} \end{bmatrix} + \begin{bmatrix} \omega \times mV \\ \omega \times I\omega \end{bmatrix} = \begin{bmatrix} F \\ \tau \end{bmatrix} \tag{1}$$

Where $I \in R^{(3x3)}$ the inertia matrix, V the body linear speed vector and ω the body angular speed.
In the frame system figure 3, the equations of motion for the helicopter can be written as:

$$\begin{cases} \dot{\zeta} = v \\ m\dot{v} = RF_b \\ \dot{R} = R\hat{\omega} \\ J\dot{\omega} = -\omega \times J\omega + \tau_a \end{cases} \tag{2}$$

The first-level approximate model (3) of the Quadrotor can be rewritten as:

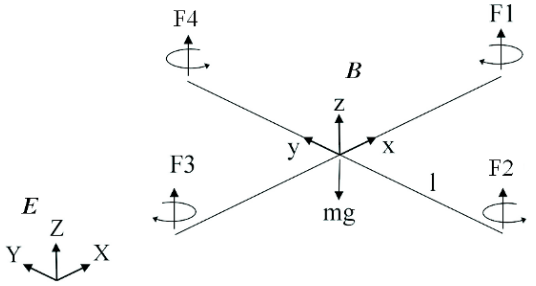

Fig. 3. Quadrotor configuration, frame system with a body fixed frame B and the inertial frame E

$$\begin{cases} \dot{\zeta} = v \\ \dot{v} = -ge_3 + \mathrm{Re}_3\left(\frac{b}{m}\sum \Omega_i^2\right) \\ \dot{R} = R\hat{\omega} \\ I\dot{\omega} = -\omega \times I\omega - \sum J_r\left(\omega \times e_3\right)\Omega_i + \tau_a \end{cases} \tag{3}$$

Where:

Symbole	Definition
ζ	position vector
R	rotation matrix
$\hat{\omega}$	skew symmetric matrix
ϕ	roll angle
θ	pitch angle
ψ	yaw angle
Ω	rotor speed
$I_{x,y,z}$	body inertia
J_r	rotor inertia
τ_a	torque on airframe body
b	thrust factor
d	drag factor
l	lever

The torque applied on the vehicle's body along an axis is the difference between the torque generated by each propeller on the other axis.

$$\tau_a = \begin{pmatrix} lb\left(\Omega_4^2 - \Omega_2^2\right) \\ lb\left(\Omega_3^2 - \Omega_1^2\right) \\ d\left(\Omega_2^2 + \Omega_4^2 - \Omega_1^2 - \Omega_3^2\right) \end{pmatrix} \tag{4}$$

The full Quadrotor dynamic model with the x, y, z motions as a consequence of a pitch or roll rotation is:

$$\begin{cases} \ddot{x} = (\cos\phi \sin\theta \cos\psi + \sin\phi \sin\psi)\frac{1}{m}U_1 \\ \ddot{y} = (\cos\phi \sin\theta \sin\psi + \sin\phi \cos\psi)\frac{1}{m}U_1 \\ \ddot{z} = -g + (\cos\phi \cos\theta)\frac{1}{m}U_1 \\ \ddot{\phi} = \dot{\theta}\dot{\psi}\left(\frac{I_y - I_z}{I_x}\right) - \frac{J_r}{I_x}\dot{\theta}\Omega + \frac{l}{I_x}U_2 \\ \ddot{\theta} = \dot{\phi}\dot{\psi}\left(\frac{I_z - I_x}{I_y}\right) - \frac{J_r}{I_y}\dot{\phi}\Omega + \frac{l}{I_y}U_3 \\ \ddot{\psi} = \dot{\phi}\dot{\theta}\left(\frac{I_x - I_y}{I_z}\right) + \frac{1}{I_z}U_4 \end{cases} \quad (5)$$

Then, the system's inputs are posed U1, U2, U3, U4 and Ω a disturbance, obtaining :

$$\begin{cases} U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \\ U_2 = b(\Omega_4^2 - \Omega_2^2) \\ U_3 = b(\Omega_3^2 - \Omega_1^2) \\ U_4 = d(\Omega_2^2 + \Omega_4^2 - \Omega_1^2 - \Omega_3^2) \\ \Omega = \Omega_2 + \Omega_4 - \Omega_1 - \Omega_3 \end{cases} \quad (6)$$

[1]

3. FUZZY LOGIC CONTROLLER

The fuzzy control strategy implements the logic used to control this quadrotor. The fuzzy logic system used for this simulation is the mamdani system. The controller decisions are taken according to table 2 where the trajectory is based on the z axis. The inputs of the controller are the error of the change of error as is mentioned on fig.4.

TABLE 2 THE DECISION TABLE OF FLC

Δu		e						
		NB	NM	NS	Z	PS	PM	PB
Δe	PB	Z	PS	PM	PB	PB	PB	PB
	PM	NS	Z	PS	PM	PB	PB	PB
	PS	NM	NS	Z	PS	PM	PB	PB
	Z	NB	NM	NS	Z	PS	PM	PB
	NS	NB	NB	NM	NS	Z	PS	PM
	NM	NB	NB	NM	NM	NS	Z	PS
	NB	NB	NB	NB	NB	NM	NS	Z

As seen from Table 2, each interval of each variable is divided into seven membership functions: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM) and Positive Big (PB).

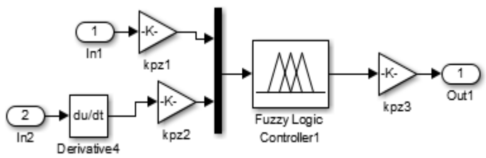

Fig. 4 Implementation of FLC under Matlab/Simulink

The used operators in this simulation are presented on the figure below:

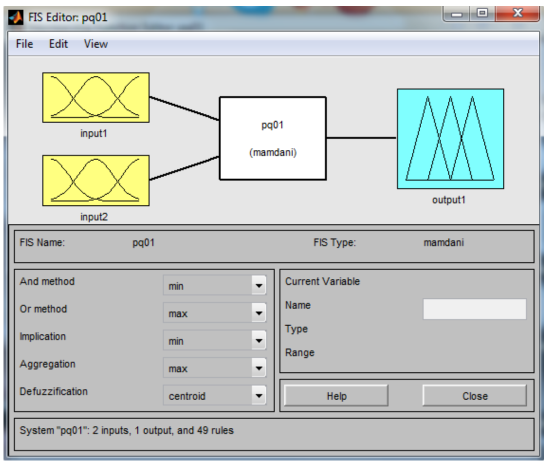

Fig. 5 Fis editor

The used fuzzy inference system is composed by the operators below with two inputs, one output and 49 rules. The weight is unit for each rule and also we have used the **And** operator for the connection between rules.

And method is min

Or method is max

Implication is min

Aggragation is max

Defuzzification is centroid

4 SIMULATION AND DISCUSSION

The simulation has been done with the parameters presented on the table 3.

TABLE 3 QUADROTOR PARAMETERS

name	Param-eter	value	unit [mksA]
inertia on x axis	I_x	7.5e-3	kg.m²
inertia on y axis	Iy	7.5e-3	kg.m2
inertia on z axis	Iz	1.3e-2	kg.m2
rotor inertia	Jr	6e-5	kg.m2
thrust coefficient	b	3.13e-5	Ns2
drag coefficient	d	7.5e-7	Nms2
arm length	l	0.23	m
mass	m	0.650	kg
Gravit Accel	g	9.81	

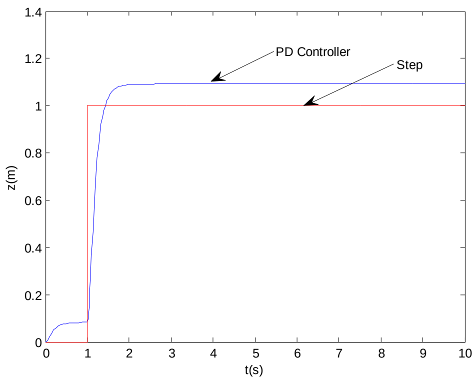

Fig. 6 PD controller's response according z axis

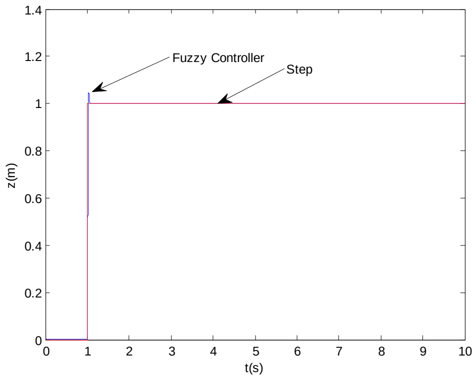

Fig. 7 FLC's response according z axis

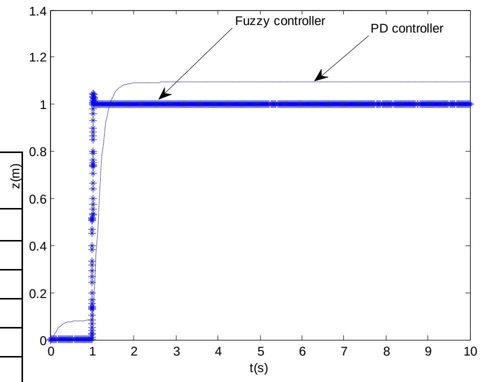

Fig. 8 Comparison between two controllers PD and Fuzzy

Figures 6-7 show the **altitude**'s responses respectively PD and FLC according z axis. In this trajectory the quadrotor has reached the reference value with an overshot for the PD controller. Figure 8 shows the efficiency of the FLC which has given a perfect response without any overshot and also with reduced raise time. The FLC is more suitable for the non linear model such as our case.

CONCLUSION

Autonomous flying robots have gained enormous commercial potential during the last years. In this contribution we have introduced a FLC to improve the quadrotor's response according the z axis. The obtained results show the efficiency of the FLC compared to the classical PD controller. The FLC has reduced the overshot and the raise time of the quadrotor's response according to the z axis.

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