



Longitudinal Motion Control based on Fuzzy logic for small Unmanned Aerial Vehicle

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Received 15th October 2014 and Revised 12th December 2015

Abstract: This research attempts a fuzzy control design for longitudinal motion of small UAV. Fuzzy logic control is known as an artificial intelligent, nonlinear and rule-based method; therefore no complex model is required for control design. Two loop controls are proposed as an inner loop for pitch control and outer loop for altitude control and a nonlinear small UAV model used comes from simulator based system. The proposed fuzzy flight control is implemented and tested in simulating platform consisting of Mat lab and X-Plane[®] flight simulator. Numerous simulations were conducted to verify the feasibility of proposed controller. It was shown that inner-loop and outer-loop fuzzy control has good capability for longitudinal motion.

Keywords: Fuzzy control, longitudinal motion, X-plane simulator, Unmanned Aerial Vehicle (UAV).

1. **INTRODUCTION**

Aerial robotics knows for several years' considerable interest in both military and civil research. The UAV technology is more popular in civilian areas like remote sensing, mapping, traffic monitoring, geomagnetic detection (Yang, and. Geng. 2011).

UAVs are economical, having no risk of human life and due to smaller in size they are more difficult to control than conventional aerial planes. The UAV system is of strong nonlinearity and time-varying characteristics which can be expressed as a set of complex nonlinear differential equations. A large number of effective flight control methods have been introduced and implemented for small UAVs (Isidor, *et al.*, 2003). (Lee, *et al.*, 2005). (Civita, 2002). (Gadewadikar, 2008). (Bogdanov, and Wan. 2007). (Shan, *et al.*, 2005). (Ge, 2009). (Kadmiry, and Driankov 2004). (Ge, and Tee 2006). Conventional controllers seem inadequate for achieving the stable control because of imprecise mathematical modeling and bad tuning of parameters thus gives strong motivation to intelligent control.

Based on excellent performance of intelligent control, it can be successfully applied in aerospace control field. Fuzzy intelligent control is closer to human thinking than conventional control system (Isidor, *et al.*, 2003). (Lee, *et al.*, 2005). Civita, 2002). (Gadewadikar, 2008). (Bogdanov, and Wan. 2007). (Shan, *et al.*, 2005). (Ge, 2009). (Kadmiry, and Driankov 2004). (Ge, and Tee 2006). Furthermore, it

has an ability to handle the system having nonlinearities (Yongquan, *et al.*, 2003). (Nikolos, 2003). (Tang, 2001). (Khizer, *et al.*, 2014).

The main advantage of the it provides a way through which linguistic control strategy based on expert human knowledge is converted into an automatic control strategy. It can be able to handle inconsistent real data in to a suitable way for variety of control applications. Fuzzy control is introducing the clarity to the development and design, evaluation and maintenance of control systems.

The control system of UAV requires several laboratories simulations and field tests before embedded on real aerial world. There is high risk; generally after an UAV crash few parts remain not usable. Thus, it has to be exhaustively lab tested. Additionally, new emerging technologies require numerous testing of flight; therefore real environment is too expensive and uneconomical. An alternative way is a simulation based environment, therefore, X-plane flight simulator is used as a tool to testify and validate the flight characteristics of UAVs.

In this paper, fuzzy control is proposed for small UAV longitudinal motion. Fuzzy control is divided in to inner and outer loop in order to control the longitudinal motion. Inner loop design contains the velocity control and outer loop constitutes the altitude control. The small UAV model used for this fuzzy control comes from X-Plane flight simulator, which is the most realistic model in flight aviation domain.

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The organization of paper is as follows: The section-2 describes the UAV model dynamics. Section-3 details the proposed fuzzy control design for longitudinal motion. Section-4 presents the obtained simulation results. The conclusion and future research draw in Section-5.

2. MODEL DYNAMICS OF SMALL UAV LONGITUDINAL MOTION

UAV motion is considered as a very complex dynamic process and it is a nonlinear time-varying system in the flight process. The whole movement mainly influenced by various factors such as earth curvature, atmospheric motion, elastic deformation of the plane, acceleration of gravity. The UAV model has different forces, velocities, angles and related reference frame as shown in (Fig.1). The longitudinal dynamics and the kinematics model of the flying wing UAV are built based on the following assumptions (Yang, 2006).

- The UAV is rigid and the quality is constant.
- The earth fixed axis is regarded as an inertial coordinate system
- The acceleration of gravity g is a constant;
- The plane XOZ of the body coordinate system of the flying wing UAV is symmetric, not only the geometry appearance of the UAV is symmetric, but also the internal quality distribution.

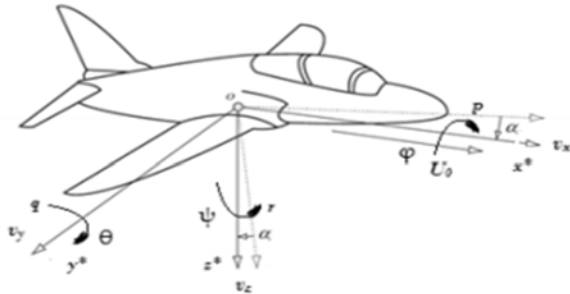


Fig. 1. Variables of aircraft motion about different

The parameters involved in the longitudinal dynamic motion as shown in (Fig. 2) are pitching moment M , drag force X and other variables affecting these quantities.

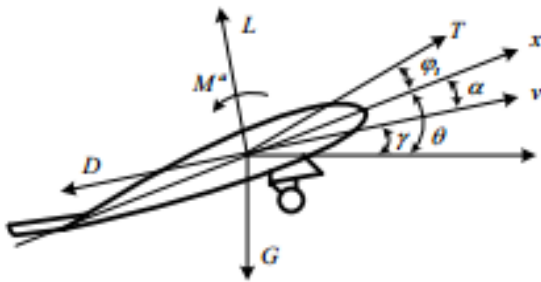


Fig. 2. Longitudinal motion

Longitudinal motion equation of the flying wing UAV can be described as:

$$m\dot{V} = T \cos(\alpha + \phi_t) - D + mg \sin \gamma \quad (1)$$

$$mV\dot{\gamma} = T \sin(\alpha + \phi_t) + L + mg \cos \gamma \quad (2)$$

$$I_z \ddot{\theta} = M_z \quad (3)$$

$$\gamma = \theta - \alpha \quad (4)$$

$$\dot{\theta} = q \quad (5)$$

$$\dot{q} = \frac{M}{I_{yy}} \quad (6)$$

$$\dot{h} = V \sin \gamma \quad (7)$$

Aerodynamic force and aerodynamic moments are nonlinear function about the speed, atmosphere density of the height of flight, pitch rate, angle of attack and the rudder deflection angle. The nonlinear functions are expressed according to the aerodynamic principle as follows:

$$D = \frac{1}{2} \rho V^2 S C_{Dd} = \frac{1}{2} \rho V^2 S (C_{D0} + C_{D\alpha}^{\alpha} + C_{D\dot{\alpha}}^{\dot{\alpha}} + C_{D\delta_e}^{\delta_e} + C_{D\delta_d}^{\delta_d}) \quad (8)$$

$$L = \frac{1}{2} \rho V^2 S C_{Ll} = \frac{1}{2} \rho V^2 S (C_{L0} + C_{L\alpha}^{\alpha} + C_{L\dot{\alpha}}^{\dot{\alpha}} + C_{L\delta_e}^{\delta_e} + C_{Lq}^q) \quad (9)$$

$$M_z = \frac{1}{2} \rho V^2 S C_{Mz} = \frac{1}{2} \rho V^2 S (C_{M0} + C_{M\alpha}^{\alpha} + C_{M\dot{\alpha}}^{\dot{\alpha}} + C_{M\delta_e}^{\delta_e} + C_{M\delta_d}^{\delta_d} + \frac{c}{2V} C_{Mq}^q) \quad (10)$$

Thrust of UAV is a nonlinear function about the atmosphere density, the flight velocity and throttle opening. The expression is:

$$T = T(\rho, V, \delta_t) \quad (11)$$

Substituting the equations 8-11 in to equations 1-7, a complete longitudinal model of the small UAV is obtained. Since the model consists of nonlinear differential equations, thus it is inconvenient and difficult to analyze the system and design an appropriate control law. The linear model is designed so that equations already mentioned above could be easily implemented on small UAV. Small perturbation technique was employed to linearize the nonlinear model around a level flight trim condition. The linear model thus obtained and was used to design fuzzy control for UAV longitudinal motion.

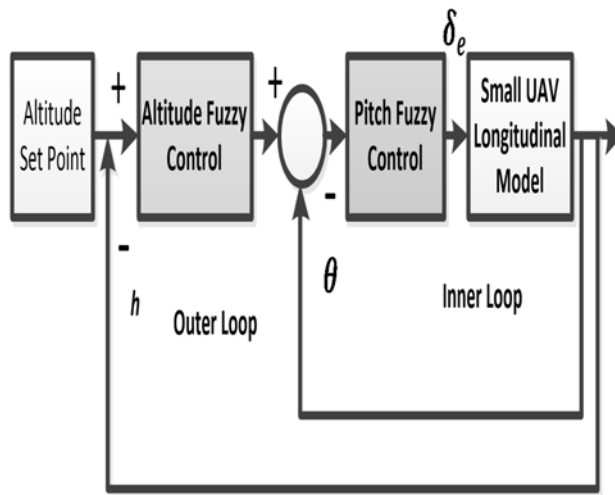
3. FUZZY CONTROL DESIGN FOR LONGITUDINAL MOTION

The first step to design the fuzzy control is to know the active ranges of the different variables, i.e. universes of discourse. The variables ranges are given in (Table-1) (Jose 2011).

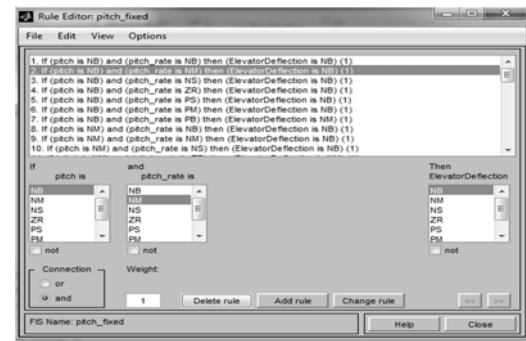
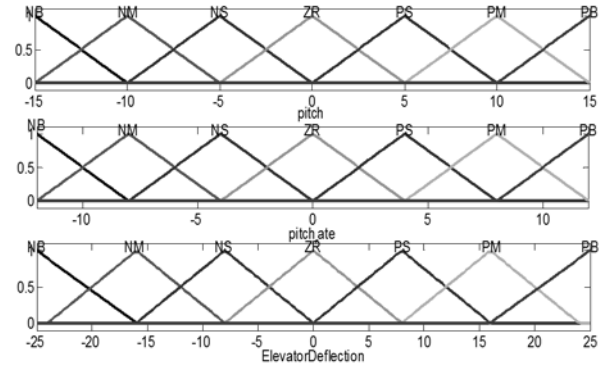
Table 1. Different Variable Ranges

Variable	Actual Range		Range Used	
Altitude Error	-1 km	1 km	-0.5 m	0.5 m
Pitch	-180°	180°	-15°	15°
Altitude Throttle Control	-0.1	0	-0.01	0

After knowing the variables range, the membership functions can properly be chosen. The proposed fuzzy system for longitudinal motion is composed of inner-loop and outer-loop, responsible for pitch and altitude control respectively and is shown in (Fig. 3).

**Fig.3. Fuzzy control system**

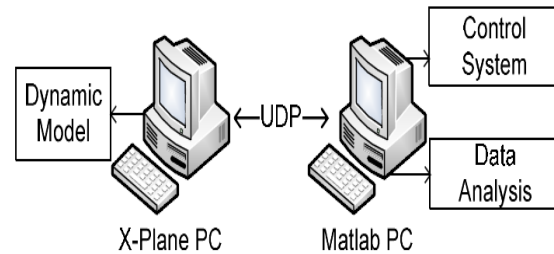
Pitch angle and rate is divided into seven membership functions, named as NB (negative big); NM (Negative Medium); NS (Negative Small); ZR (Zero); PS (Positive Small); PM (Positive Medium); PB (Positive Big); Elevator deflection output is also divided into same seven intervals. The input and output MF for pitch fuzzy control is depicted in (Fig. 4), and associated rules are given below. The range of membership functions were chosen by the detailed study of the aircraft and survey of research (Gomez and Jamshidi. 2011). Altitude fuzzy control is also designed in this similar way.

**Fig. 4. Pitch control MF and rule base editor**

4.

SIMULATION RESULTS

Simulation platform is implemented using Matlab and X-Plane flight simulator. In this work, X-plane is used to provide the UAV model to simulate its longitudinal dynamics. Two computers are used for this simulating platform and communication is done through UDP (user datagram protocol) data communication bus as shown in (Fig. 5, 6).

**Fig. 5. Simulating Platform (Fig. 6), Shows how Matlab/Simulink control system and X-plane UAV model is interconnected for this longitudinal motion.**

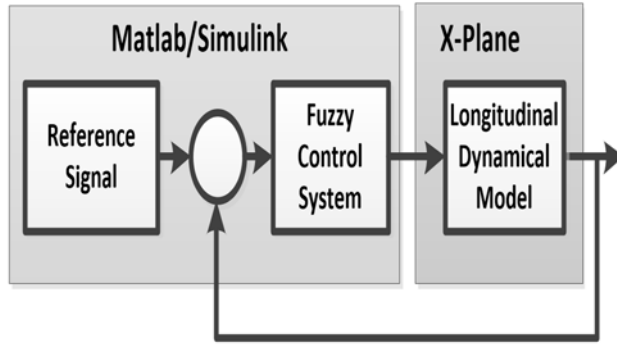


Fig.6. Simulink-X-Plane interconnection

The Aerosonde UAV model is used in this simulation platform. Aerosonde can fly autonomous flights including takeoff and landing. UAV characteristics are given in (Table-2).

Table. 2 Aerosonde UAV characteristics

Length	1.74m
wingspan	2.87m
weight	15kg
speed	10km/h
height	0.60m



The overall flight control system implemented in Simulink is shown in (Fig.7).

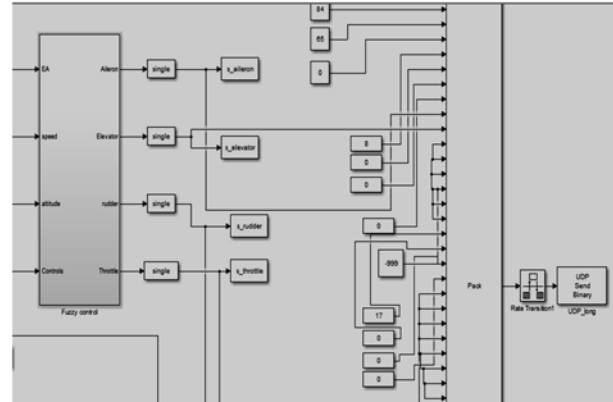
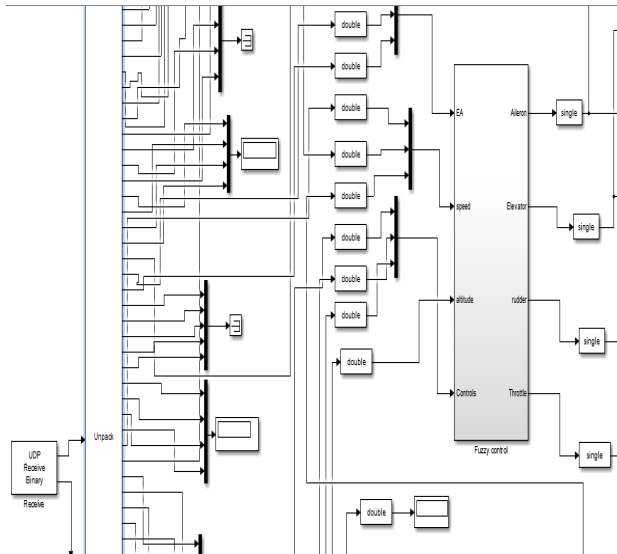
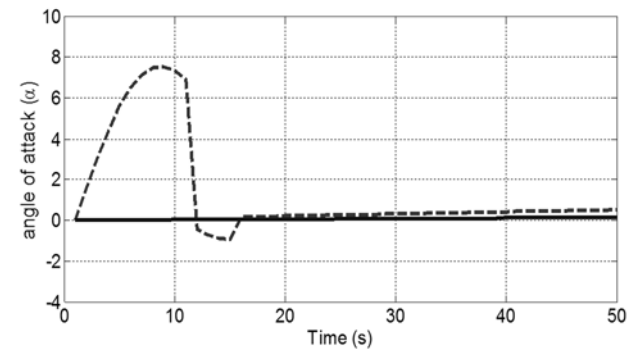
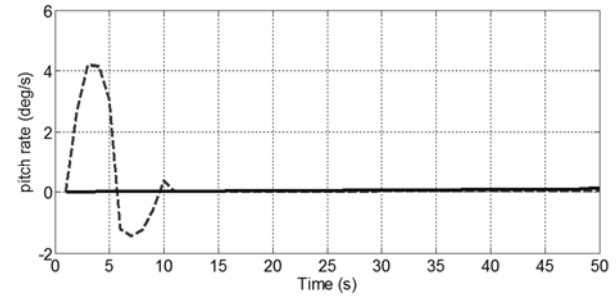
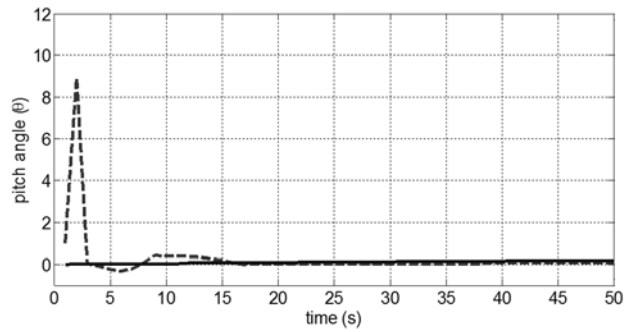


Fig.7. Complete Simulink Model

Fig. 8. Control action stabilizing all states(θ, q, α)

L	Drag Force	D	aerodynamic forces
M_z	aerodynamic moment	T	Thrust
I_z	yaw moment of the inertia	A	Rotor disk area
γ	Flight path angle of the UAV	ρ	atmosphere density
q	pitch rate	α	angle of attack
S	wing reference area	c	geometric chord
ϕ_t	intersection angle between the thrust T and the body axis x	$C_{D0}, C_{D\dot{\alpha}}, C_{D\dot{\gamma}}$	aerodynamic derivatives of the UAV
δ_d	split drag rudder angle	δ_e	elevator angle,
V	Airspeed magnitude	θ	rudder deflection angle
$C_{M0}, C_{M\dot{\alpha}}, C_{M\dot{\gamma}}$	aerodynamic derivatives	δ_t	throttle opening
h	airplane altitude	I_{yy}	Lateral moment of inertia

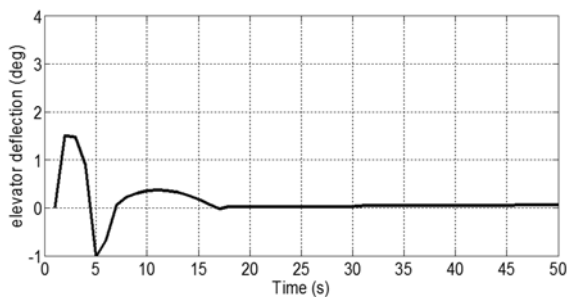


Fig. 9. Elevator deflection control action for stabilizing all states

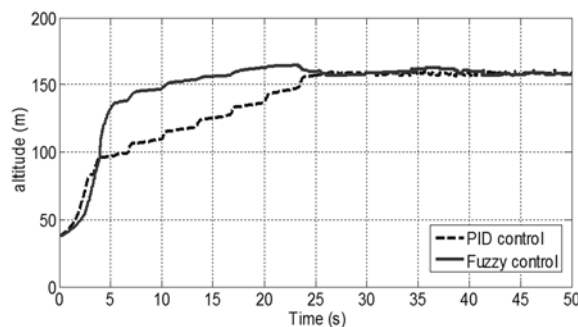


Fig. 10. Unmanned Aerial Vehicle position state

5.

CONCLUSION

A fuzzy control approach for longitudinal motion of small UAV has been proposed in this paper. Keeping in view the characteristics of flight system, an expert knowledge and pilot experiences based inner-loop and outer-loop fuzzy control for altitude and pitch angle were designed. The flight control system in Matlab/Simulink environment on one computer and UAV model on second computer was implemented to investigate the performance of proposed fuzzy control.

The communication between computers is done by UDP. From results, it was clearly shows that proposed fuzzy control successfully achieved longitudinal control with effective performance. The simulated flight test comparison result showed that the simple inner and outer loop fuzzy control was capable of controlling the UAV with better performance than the classical PID for altitude state.

ACKNOWLEDGEMENT

The authors would like to thanks to Mehran University of Engineering and technology, Jamshoro Pakistan, for providing laboratory and research facilities during research. **Nomenclature:**

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