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FUZZY CONTROL DESIGN FOR UAVS

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ABSTRACT: An advanced controller based on fuzzy design concepts are introduced for three-dimensional flight of the waypoint tracking design of unmanned aerial vehicle (UAV). For practical implementation purpose, the BIBO stability of overall error dynamic system of UAV can be guaranteed based on the proposed method in this investigation. Besides, a viewable simulation interface is built up for more practical monitor purpose; satisfactory tracking results are also shown in this paper.

Keywords: UAV, waypoint tracking method, fuzzy control, 3D, viewable interface, error dynamic system

I. INTRODUCTION

Unmanned vehicles attract more and more attentions in various ground and air missions for military as well as civil applications with possessing low cost, small size and high maneuverability, etc. The robotic vehicles can offer advantages in the following various ways: reconnaissance, surveillance and artillery adjustment than manned systems. In the past decades, a lot of research efforts focused on cooperation of multi-vehicles for multi-purpose missions. Recently, US navy has enhanced the air strike and defense capability by developing several X-47B unmanned combat aerial vehicles for technology demonstration. The new version X-47B UCAV is inherent automatic take-off and landing capability for shipboard operation, and can achieve a lot more fantastic missions such as cooperative search and strike than one UAV can do individually. Based on this ability improvement of UAV, we believe that there are many researches in the future that will focus on studying cooperative operations of multiple UAVs as well as formation flight strategies. For UAV tracking performance test, how to build up a visible simulation environment is a must issue, hence a virtual reality base display interface is developed by aerospace and virtual reality tool of Matlab software. Totally speaking, this research introduces a lab-based simulation with conventional control concept and virtual reality technology. The overall simulation of tracking design of UAV is conducted on Matlab base.

II. SYSTEM DESCRIPTION

Mathematical Model of UAV

The three-dimensional translation equations of motion are used to compute the unmanned aerial vehicle (UAV)trajectory as shown in Fig. 1. The UAV is modeled as a point mass, and the equations of motion are

$$\begin{aligned}
\dot{x}_m &= v_m \cos\gamma_m \cos\psi_m \\
\dot{y}_m &= v_m \cos\gamma_m \sin\psi_m \\
\dot{h}_m &= v_m \sin\gamma_m \\
\dot{v}_m &= (T\cos\alpha - D_m)/m - g\sin\gamma_m \\
\dot{\gamma}_m &= (L + T\sin\alpha)\cos\phi/(mv_m) - (g\cos\gamma_m)/v_m \\
\dot{\psi}_m &= (L + T\sin\alpha)\sin\phi/(mv_m\cos\gamma_m)
\end{aligned} \quad (1)$$

where

$$L = \frac{1}{2}\rho v_m^2 s C_L, \qquad D = \frac{1}{2}\rho v_m^2 s C_D \quad (2)$$

with

$$C_L = C_{L\alpha}(\alpha - \alpha_0), \qquad C_D = C_{D0} + \mu C_L{}^2$$

In the above, the thrust T and mass m are predefined the functions of time that will be defined in the section about simulation results.

The 3-D pursuit dynamics of UAV and target position is described in Fig. 2. The UAV and the position of presetting up points in the inertial frame are denoted by (x_m, y_m, h_m) and $T = (x_t, y_t, h_t)$, respectively.

Next, we define a tracking error in order to convert the UAV point tracking problem into a line-of-sight (LOS) tracking problem. The origin of LOS frame is located at the UAV. The X_L axis forwards along the LOS to target and the Y axis is horizontally directed to the left of X-Z plane. The concept of LOS control design is to guide the UAV onto the LOS to target. Then the coordinates (R_p, e_1, e_2) represents the UAV position in the LOS frame. The tracking error is defined as

$$e = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} \sigma_m - \sigma_t \\ \gamma_m - \gamma_t \end{bmatrix} \tag{3}$$

Obviously, e_1, and e_2 represent the azimuth and elevation loop tracking errors, respectively. R_p represents the UAV-to-target point range. R_y and R_h represent the components of R_p in axes Y_L and Z_L, respectively. Because e is a small variable, it can be obtained as

$$e = \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} R_y / R_p \\ R_h / R_p \end{bmatrix} \tag{4}$$

So far, we have shown that the 3-D UAV trajectory tracking problem can be formulated as a LOS tracking problem. Let us denote

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_6 \\ x_6 \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ h_m \\ v_m \\ \gamma_m \\ \psi_m \end{bmatrix}, u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \dfrac{(L + T\sin\alpha)\cos\phi}{m} \\ \dfrac{(L + T\sin\alpha)\sin\phi}{m} \end{bmatrix} \tag{5}$$

Using the above notations, Eqs. (1)-(5) can be put into the following form:

$$\begin{aligned} \dot{x} &= f(x,t) + g(x)u \\ e &= h(x,t) \end{aligned} \tag{6}$$

where

$$f(x,t) = \begin{bmatrix} x_4 \cos x_5 \cos x_6 \\ x_4 \cos x_5 \sin x_6 \\ x_4 \sin x_5 \\ \dfrac{(T\sin\alpha - D)}{m} - g\sin x_5 \\ -\dfrac{g\cos\gamma}{v} \\ 0 \end{bmatrix}, \quad g(x) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \dfrac{1}{x_4} & 0 \\ 0 & \dfrac{1}{x_4 \cos x_6} \end{bmatrix},$$

$$h(x,t) = \begin{bmatrix} R_y / R_p \\ R_h / R_p \end{bmatrix}$$

Now, the design objective is to find a fuzzy control law $u = f(e)$ to drive the tracking error e to zero. Before arranging fuzzy control command to drive the UAV plant, the membership functions for waypoint tracking errors should be given firstly, as follows: The input linguistic variables of fuzzy logic-based are given as 1. tracking error in x axis e_1, and 2. tracking error in y axis e_2; besides, the output variable is u. The universe of discourse of the linguistic variable e_1 is [-30,30] meter, and e_2 is [-30,30] meter. About control output, the universe of discourse is set up as [-50, 50] degree for u_1 and [-50,50]degree for u_2. All figures are illustrated as the following figures.

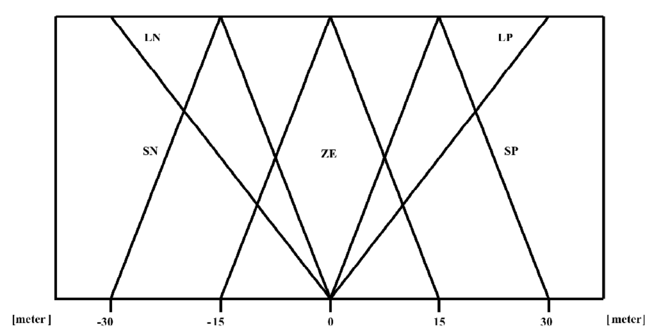

Figure 1: Tracking Error in x axis of UAV

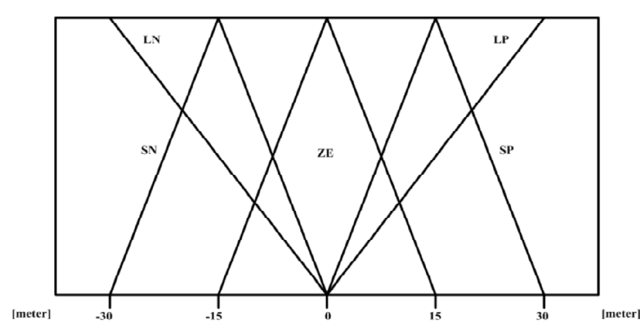

Figure 2: Tracking Error in y axis of UAV

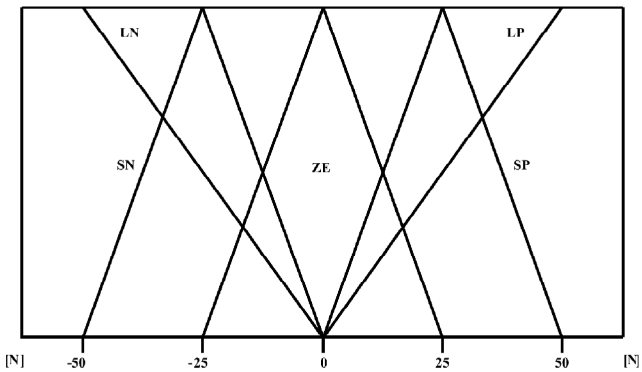

Figure 3: The Control x axis Output of UAV

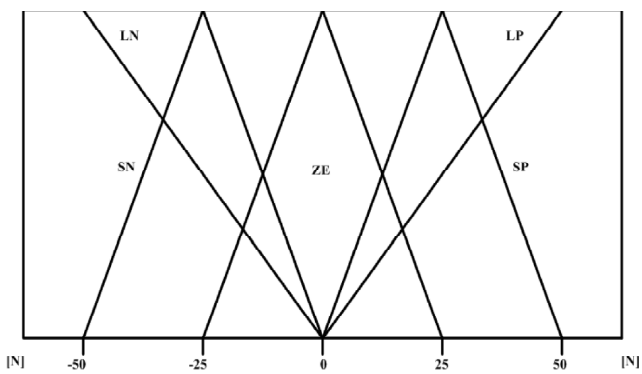

Figure 4: The Control y axis Output of UAV

SIMULATION RESULTS

A closured trajectory test is done as shown in Fig. 4 for checking the performance of our control design for UAV. In this experiment, the controlled UAV is designed to tracking 11 waypoints that are established beforehand. From the simulation results, it is easily to find out that a satisfactory tracking performance is yield by our proposed fuzzy control design. Histories of tracking errors in individual axis of *x, y* and *z* for each waypoint converge to zero dramatically with respect to time. Control commands for angle of attack angle α and sideslip angle ϕ are shown as Fig. 6, and Fig. 6 gives the histories of flight path angle γ and azimuth angle ψ.

Fig. 7 is a viewable display interface of UAV, and from this interface, researcher can monitor the variations of UAV in real time.

CONCLUSIONS

In this study, an easily implementable Fuzzy advance trajectory tracking control design and

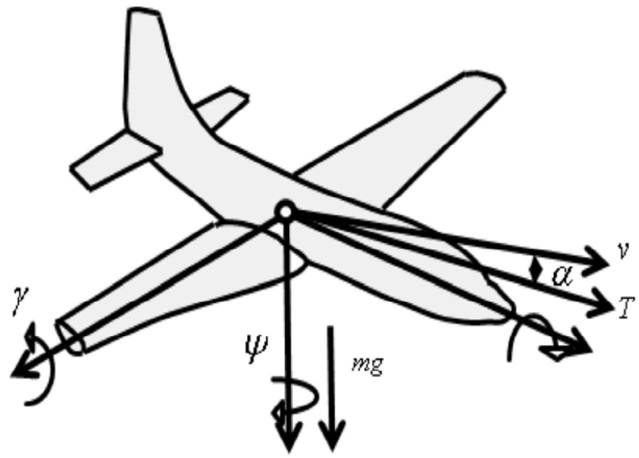

Figure 1: UAV Force Balance and Symbols

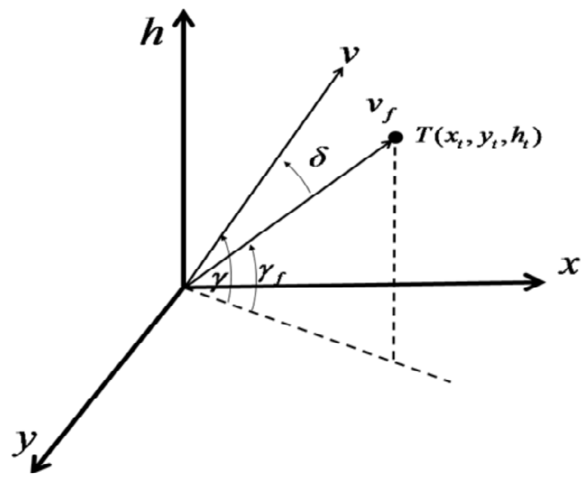

Figure 2: Definition of Tracking Error in Vertical Plane

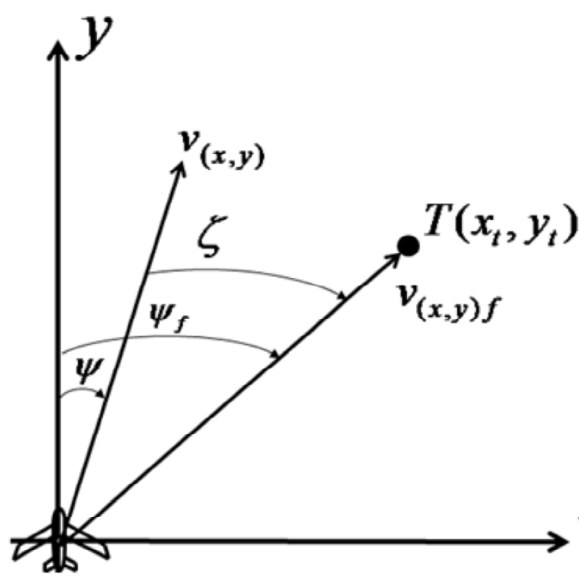

Figure 3: Definition of Tracking Error in Horizontal Plane

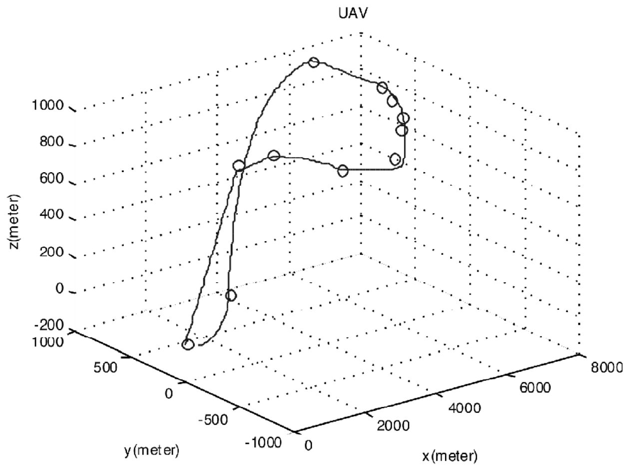

Figure 4: A Closured Trajectory Test of our Proposed Method for UAV

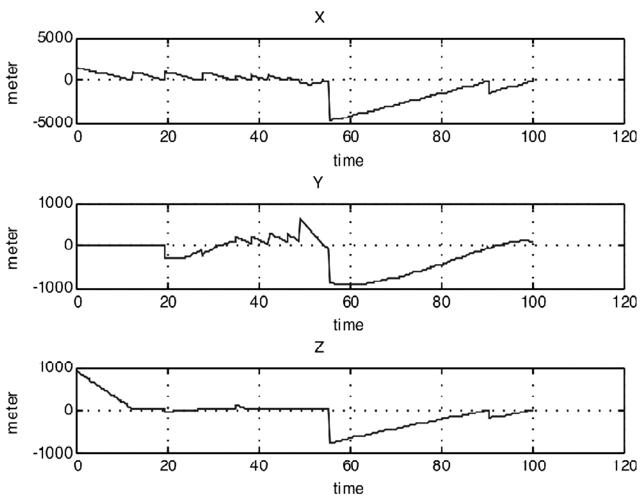

Figure 5: Tracking Errors in three Axes (x, y, z), Respectively

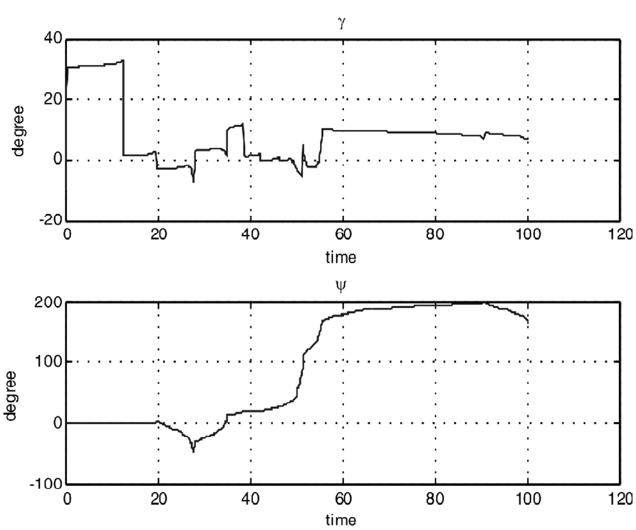

Figure 6: Histories of Flight Path Angle and Azimuth Angle of UAV, Respectively

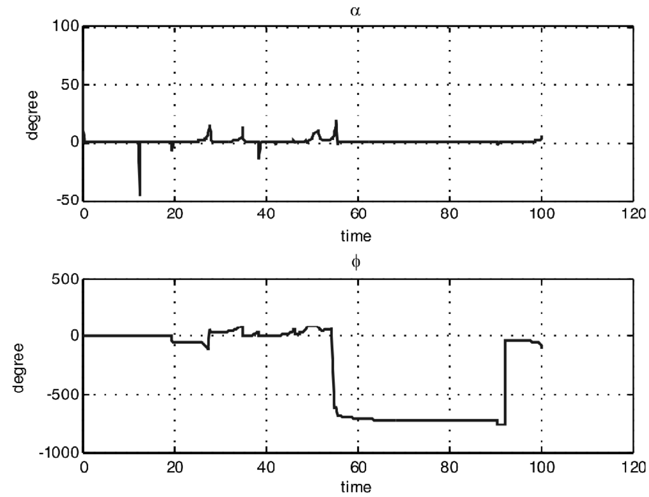

Figure 6: Histories of Angle of Attack Angle and Sideslip angle of UAV

Figure 7: Viewable Tracking Display Interface of UAV

display interface are given for UAV, simultaneously. Form the simulation results, it is easily to find out that a satisfactory waypoint tracking performance by the fusion of control design and display interface is given, and this research offers us friendly interface for monitoring the real-time altitude variations of UAV under the control of our proposed method for tracking several preset up way points.

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