A LOS Guidance Law for Path Following of an Aircraft
Using Fuzzy Self-Tuning PID Controller

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Abstract. The guidance law is required for the aircraft to autopilot along the fixed path. The LOS (Line-of-Sight) guidance law is mainly used to follow the path. In this paper, we propose aircraft guidance systems that consist of LOS guidance law and the fuzzy self-tuning PID controller to follow the path more precisely. In addition, we compared the path following performance and feasibility of various existing research of LOS guidance law using Matlab/Simulink simulation.

Keywords: Path Following, LOS (Line-of-Sight), Guidance Law, Fuzzy Logic, PID Controller, Fuzzy Self-Tuning PID

1 Introduction

LOS guidance law is most commonly used to follow these flight paths. Basic LOS guidance law used the LOS from the current position to the final point of the aircraft. However, for this reason, there are two problems that include errors of the azimuth angle, and decline in the performance of path following as the disturbance such as wind and a change of the aircraft operating environment [1].

To solve these problems, a method for improving the performance of path following was studied by setting the virtual point above a straight line connecting the final point from the initial point into target point [2, 3]. In addition, in order to apply a PID controller to the Cross-Track-Error that is a vertical distance between the aircraft and the straight path, the LOS guidance law considering the vehicle kinematics [4] was suggested, and the research which is the precisely following the path was conducted by forward-feedback a path information based on the PID controller [5].

In this paper, it was designed to set the optimum PID gain by using a fuzzy self-tuning PID controller. And then, through a Matlab/Simulink simulation, we confirmed that the proposed LOS guidance law is very precisely following the path as compared the basic LOS guidance law to the proposed LOS guidance law.

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2 Aircraft Guidance System

The purposed aircraft guidance system is constituted to LOS guidance law and fuzzy self-tuning PID controller. Section 2.1 explains LOS guidance law. Section 2.2 describes fuzzy self-tuning PID controller.

2.1 LOS Guidance Law

The basic LOS guidance law is designed to the azimuth angle of an aircraft velocity ($\psi_{av}$) to converge to the azimuth angle of LOS ($\psi_{LOS}$) connecting the aircraft location ($P_{ac}$) and the final point ($P_f$), as shown in Fig. 1. Thus the azimuth angle of a LOS is used to command the heading angle of aircraft, as equation (1), (2).

$$\psi_{LOS} = \tan^{-1}\left(\frac{x_{ac} - x_f}{y_{ac} - y_f}\right)$$

(1)

$$\psi_{cmd} = \psi_{LOS}$$

(2)

Fig. 1. The Structure of LOS guidance laws

To follow path better than basic line-of-sight guidance law, Calculate virtual point ($P_{vir}$) on the straight path to the final point from the initial point. And the command heading angle of aircraft is the azimuth angle of virtual LOS ($\psi_{LOSvir}$) connecting the aircraft location and the virtual point, as equation (3), (4) [3].

$$\psi_{LOSvir} = \tan^{-1}\left(\frac{x_{ac} - x_{vir}}{y_{ac} - y_{vir}}\right)$$

(3)
Cross-track-error between the aircraft location and the position to perpendicular-projection as the path from the aircraft position is as equation (5). If the aircraft is positioned on the left side of the flight path, d>0. If on the right side, d<0. The angle of virtual (ψ<sub>vir</sub>) between the aircraft position and the virtual point can be obtained by applying PID control to the cross-track-error, as shown in equation (6). Finally, the azimuth angle of the aircraft velocity and the command heading angle of the aircraft are each equation (7) and (8).

\[ d = \sqrt{(x_{ac} - x_i)^2 + (y_{ac} - y_i)^2} \]  \hspace{1cm} (5)

\[ \psi_{vir} = \tan^{-1}\left(\frac{d}{L}\right) = \tan^{-1}\left(\frac{K_D d + K_I \int d + K_P \dot{d}}{L}\right) \]  \hspace{1cm} (6)

\[ \psi_{path} = \tan^{-1}\left(\frac{x_f - x_i}{y_f - y_i}\right) \]  \hspace{1cm} (7)

\[ \psi_{cmd} = \psi_{path} + \psi_{vir} \]  \hspace{1cm} (8)

2.2 Fuzzy Self-Tuning PID Controller

Fuzzy self-tuning PID controller provides better performance than a standalone PID controller. As shown in Fig. 2, fuzzy self-tuning PID controller is configured by adding a fuzzy and PID controller. It uses a cross-track-error and the velocity differential of distance as an input for fuzzy controller. The gain of a PID controller is output through the fuzzy rule table as shown in Table 1. It commands a heading angle of the aircraft through a PID controller using the PID gains.

Fig. 2. The structure of fuzzy self-tuning PID controller
### Table 1. Fuzzy rule table of PID gain (5x3)

<table>
<thead>
<tr>
<th>$K_P/K_I/K_D$</th>
<th>NB</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{d}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>B/B/S</td>
<td>B/M/B</td>
<td>S/S/VB</td>
<td>B/M/B</td>
<td>V/B/B/S</td>
</tr>
<tr>
<td>ZE</td>
<td>VB/M/S</td>
<td>B/S/B</td>
<td>S/S/VB</td>
<td>B/S/B</td>
<td>V/B/M/S</td>
</tr>
<tr>
<td>P</td>
<td>VB/B/S</td>
<td>B/M/B</td>
<td>S/S/VB</td>
<td>B/M/B</td>
<td>B/B/S</td>
</tr>
</tbody>
</table>

### 3 Simulation

In this paper, we compared the LOS guidance law with conventional guidance law using Matlab/Simulink simulation. Aircraft guidance simulation model is configured as shown in the Fig. 3. In the simulation, the aircraft is a linear model of general aviation aircraft NAVION [6]. As shown in Fig. 4, among the various LOS guidance law, the simulation was compared with the basic LOS, modified LOS and PID LOS guidance law. The simulation was performed by creating a path of flight from an initial point (0m, 0m) to a target point (1000m, 1000m).

**Fig. 3.** Aircraft guidance simulation Matlab/Simulink model

### 4 Conclusion

In this study, we describe LOS guidance law using fuzzy self-tuning PID controller for a planned path tracking of aircraft. It was confirmed that after tuning, fuzzy self PID LOS guidance law quickly follows the path compared to other guidance laws. Also, after following the path, we found that an aircraft using fuzzy self-tuning PID LOS guidance law makes a flight without departing from the paths in straight section. As a result, the proposed LOS method is expected to use a mission which has a variety of path.
**Fig. 4.** Compare the flight path of the LOS guidance laws

**References**