Modeling of Closed Loop PID Controller for an Auto-Pilot Aircraft Roll Control

E. Gouthami
Dept. of ECE, JNTUHCEH
Hyderabad, India
Email-id: gouthami_elluru@yahoo.com

M. Asha Rani
Dept. of ECE, JNTUHCEH
Hyderabad, India
Email-id: ashajntu1@yahoo.com

Abstract—An aircraft contains three rotational motions like pitch, yaw and roll. The roll motion is controlled by the ailerons that are present on either side of an aircraft. In this paper, ailerons are considered as plant and its transfer function is used in modeling of the controller. The PID controller modeled performs better roll motion with good stability. From the MATLAB simulation results it is shown that the PID controller has the ability to minimize error between input and output with more stability and less response time with considerable overshoot.

Keywords------Ailerons, PID controller, Roll motion, MATLAB.

I. INTRODUCTION

After the successful development of man-carrying airplane by Wright brothers, the development of auto-pilots emerged. The first auto-pilot (or) automatic flight controller in the world is designed by the Sperry brothers in 1912. Currently, the auto-pilot design relies heavily on automatic control systems to monitor and control the aircraft subsystems [1]. Generally, an aircraft is controlled by three main control surfaces. They are elevator, rudder, and ailerons. These three control surfaces are used to control pitch, yaw, and roll actions of an aircraft respectively.

Elevator, rudder and ailerons are depicted in fig. 1. Pitch control is achieved by changing lift. Yaw control is achieved by deflecting a flap on vertical tail called rudder and roll control can be achieved by deflecting small flaps present toward the wing tips in differential manner and these are called ailerons. The two ailerons are typically interconnected and both ailerons move in opposite direction to each other. The roll motion achieved by these ailerons is used to bank the aircraft.

The rolling motion of an aircraft is controlled by adjusting the roll angle with the use of ailerons. Roll angle control is a lateral problem and this work is developed to control the roll angle of an aircraft for roll control in order to stabilize the system, when an aircraft performs the rolling action.

II. MODELING OF ROLL CONTROL SYSTEM

Consider the following state and output matrix equations describing the lateral directional equations of motion of an aircraft.

\[ \dot{\mathbf{x}} = A \mathbf{x}(t) + B \mathbf{u}(t) \]
\[ y(t) = C \mathbf{x}(t) + D \mathbf{u}(t) \]  

All the four states of ‘x’ are available for the controller. When the parameters in the plant have non-linearities and time-varying dynamics, the control system should possess a mechanism for automatically adjusting them. By using a fixed...
controller we cannot achieve a satisfactory compromise between robust stability and performance. Then we have to use adaptive control. The adaptive control use is justified on complex and mission critical systems exhibiting time-varying dynamics.

The roll angle motion of an aircraft is controlled by adjusting roll angle signal. In this study, an auto-pilot controller is modeled to control the roll angle of an aircraft. The roll motion depends upon many parameters like side slip angle, rolling rate, yawing rate, aileron deflection and so on. The roll control system is shown in fig.2

From the fig.2, $Y_b$ and $Z_b$ represent the aerodynamics force components, $\phi$ and $\delta_a$ represent the orientation of the aircraft i.e.; roll angle in the earth-axis system and aileron deflection angle respectively. Referring to fig. 2 the different forces, moments and velocity components of an aircraft system are shown in fig.3. From the figure 3 we analyze that $L, M, N$ represent the aerodynamic moment components, the terms $p, q, r$ represent the angular rate components of roll, pitch, yaw axis and the terms $u, v, w$ represent the velocity components of roll, pitch and yaw axis.

By applying Newton’s law and making relevant assumptions for simplification and finding the transfer function, the transfer function from aileron deflection angle to roll angle is given by the following equation [3].

\[
\theta = \theta + \Theta \Delta \theta \\
L = L + \Theta \Delta L \\
M = M + \Theta \Delta M
\]

All these parameters are time dependent and time-varying dynamics.

### III. PID CONTROLLER

In most of the research literature, different control algorithms and methods are discussed for reconfigurable control [4]. A discussed in [4] there are different control approaches. Among them adaptive control is widely used because the controller has the ability to analyze nonlinearities and time-varying dynamics that are found in most of the processes. Several control strategies have been proposed in the literature, such as PID [5][6], fuzzy logic [3][7], neural networks [8], LQR [5][6]. Among all, PID is the very simple and easy to control nonlinearities and time-varying parameters. A fixed controller cannot be implemented to achieve satisfactory results. So, continuous adaption to these parameters is required for controlling of roll motion. An adaptive control is modelled for the roll motion i.e., dependent on different dynamic parameters[11].

For the design of PID (proportional-Integral-Derivative) controller, we require the specification of three parameters: proportional gain, integral time constant and derivative time constant. The following transfer function from [9] describes the PID controller.

\[
G_c(s) = \frac{p + \Theta p \circ \Theta q + q + \Theta q \circ \Theta r + \Theta r \circ \Theta c}{p + \Theta p \circ \Theta q + q + \Theta q \circ \Theta r + \Theta r \circ \Theta c}
\]

\[
G_c(s) = K_p + \frac{K_i}{s} + K_d \cdot s
\]

Where $K_p$ is the proportional gain.
Ki = Kp/Ti is the integral gain  
Kd = Kp /Td is the derivative gain of the controller.

The discrete time equivalent expression can be given as

\[ u(k) = Kp e(k) + Ki \sum e(i) + Kd \Delta e(k) \]  

(4)

Where \( u(k) \) is the control signal

\( i \) is considered from 1 to \( n \).

\( e(k) \) is the error signal between reference input and the plant output.

\( Ts \) is the sampling period and 
\( \Delta e(k) = e(k) - e(k-1) \).

The PID parameters \( Kp, Ki, Kd \) are manipulated to produce various response curves for a given plant. The parameters of PID controller can be changed in two types. Firstly, by using Zeigler-Nichols tuning formula [10]. In second way, adaptively the parameters are estimated and hence they are called adaptive controllers.

IV. MODELLING OF PID CONTROLLER

The general structure of a auto-pilot control system will be as shown in [4]. Specifically, the aileron deflection is controlled by the roll control loop. The roll control block diagram is as shown in fig. 4. The deflection of ailerons is achieved from the force initiated by actuators. The amount of force, direction and angle how much the deflection must be, all these parameters are obtained by the control system. The input to the control system is the data from different sensors. The data obtained from the sensors is mixed in data fusion and filtering unit and if any error occurs it is minimized by the controller.

In this study, the controller here in the block diagram is PID controller i.e., implemented by MATLAB simulink. The MATLAB simulink diagram of PID controller is as shown in fig. 5.

\[ Fig. 5: \text{Simulink model of PID Controller} \]

The input to the PID controller is the error signal i.e., obtained by the difference between input and feedback from the plant. In this study, as we are considering the roll angle motion of an aircraft, we limit ourselves for acceptable stability and medium fastness. We modeled a MATLAB simulink model as shown in fig. 5 considering the plant as roll motion control.

After extensive simulation study on various values for parameters of PID controller for roll transfer function implementation, we determined values for \( Kp, Ki, Kd \) as a good compromise between stability and performance.

The \( Ku \) value is tuned and chosen, the point of sustained oscillations. By using \( Ku \) and relationship equations [11], \( Kp, Ki, Kd \) values are determined and the response for the particular values are shown in the results. The \( Kp, Ki, Kd \) values are manipulated for different values and final appropriate response is considered for the better error reduction of the sensed input data. The resultant signal with minimum error will be given to analog to ARINC 429 converter and then to actuators followed by ailerons for the smooth and stable aileron deflection of an aircraft for roll. Always roll motion should be performed in cruise state only.

V. RESULTS

The open loop response of the system is not considered because of its exponentially rising output, as it does not use feedback for necessary corrective measure. The closed loop structure with feedback mechanism provides a better response.
with ringing and longer settling time. To achieve a better response, a PID controller has been modelled with the plant. The response of the system with the plant is more stable with less ringing and settling time, with some considerable overshoot. The transient characteristics of the PID controller are shown in fig. 6.

![Simulation waveform of PID Controller](image)

From fig. 6 it is evident that \( T_r = 0.1 \text{msec} \), \( T_p = 0.3 \text{msec} \), \( T_s = 0.9 \text{msec} \), Overshoot = 16% with \( K_p = 4.2 \), \( K_i = 1 \), \( K_d = 0.12 \). After multiple trials these \( K_p, K_i, K_d \) values are selected as optimum values.

V. CONCLUSION

Due to the limitations of the open loop system we introduce a closed loop system with efficient characteristics using PID controller. The PID controller has dynamic response compared to other normal controllers. The designed controller possesses response time in milliseconds with very good settling time but with considerable overshoot. The modeled PID controller has the capability of controlling roll motion effectively making it suitable for auto-pilot roll control.

References


