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Feasibility studies of Three ModeControl for the Control of Cardinal angles of Autonomous Fixed Wing Aircraft

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Abstract: —**Three mode control has been traditionally used since its inception for simple and accurate control of single parameters in simple linear or piecewise linearizable systems. Aircraft cardinal angle control usually is done with more robust controllers due to the complexities and non linearities involved in their construction. But if an SISO equivalent transfer function can be derived, one can test the feasibility of PID. This paper compares the performance of traditional three mode controllers in in-loop and in-feedback configurations in order to understand the feasibility of such frameworks for autonomous flight.**

Index Terms— **Closed loop system, Error Optimization, Feedback systems, Performance efficiency, Stability.**

I. INTRODUCTION

Proportional-Integral-Derivative (PID) Controllers are widely used in all fields due to their easy design and implementation. Mathematical models are usually used to study and predict the system behavior over-time. Control system design methodologies involve analysis of present mathematical models and re-designing them for better performance. [1]

PID's, though are very simple at their architecture, are not always advisable for all types of systems which requires error optimization and stability. PID tuning in itself is an iterative task and there exist no such universal formula or mathematical concept to tune a PID to its highest efficiency. Simulation softwares today use empirical formulae and deduced algorithms to tune PID's. The results obtained from these simulations do not always fulfill the system requirements. [2]

PIDs therefore require effective tuning methods and these tuning methods are application specific. The effective way to analyze a PID integrated Control system is to analyze the system at every summing point and also analyzing error signal after each iteration of tuning the PID. Signal tracking helps in PID control optimization. [3,7]

It is a known fact that designing a Closed loop control system requires in-depth knowledge of the system operation and is always comparatively less stable. Error analysis, error prediction and error minimization requires proper judgement and rich experience, but if once designed it can perform with high accuracy due to presence of feedback.

The latest trends in feedback control systems are employing fuzzy control logic in PID tuning. It also involves signal tracking which is available in most of the simulation softwares. On the other hand, Neuro-feedback controls based on Artificial Neural Networks are being developed for effective PID control tuning. [4]

A direct application of the PID Controllers is in aircrafts. The pitch control mechanism of an aircraft employs a self- correcting system which stabilizes the aircraft against changes in pitch angle. It is a closed loop system with a controller that stabilizes the aircraft by balancing it. [4]

In this paper, an aircraft system is analyzed with its transfer function and a Simulink model of the

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Vol 3, Issue 3, March 2017

system with the control block is designed to study the performance of the PID Controlled system.

The organization of this paper is as follows. In section II the modelling of PID controller using MATLAB/Simulink software is discussed. The tuning parameters of the PID are discussed and its transfer function is defined for the particular application. In section III the aircraft system under study is described and its transfer function and parameters are defined. In section IV, simulation models for in-loop and in-feedback PID systems are built and simulation results are given to show the system response. In section V the results of simulation are compared and the system stability for both the configurations are compared. Section VI contains the conclusions.

II. PID – SIMULATION PARAMETERS

PID controllers can be modelled in two ways:

1. Mathematical Model:

The mathematical model is built by integral, derivative and gain blocks of Simulink Library and connecting them to a summing point. This model can be integrated into one single sub-system. Local Solver configuration can be used to simulate the function.

2. Transfer Function Model:

The transfer function model is defined by the numerator and denominator of the PID transfer function. The numerator and denominator coefficient matrix can be defined and transfer function of the system is obtained.

Alternatively, Simulink library offers a PID Block which can be directly used in the system model. The Kp, Ki, Kd values have to be set as Block Parameters and the model can be simulated.

In this paper, the PID controller block is used directly in the control system modelling. The PID has to be tuned either manually or automatically. In Manual tuning, the P, I and D gain values have to be manually set and simulated.

Automatic tuning is carried out by algorithms deduced for application specific purposes. The simulation software automatically tunes the PID for stable output response.

In PID tuning, various Empirical Formulae have been derived. Ziegler and Nichols Empirical Rules for PID is one of them which was developed by simulation studies. But in most of the cases the empirical rules do not tune the PID efficiently and the systems end up having a constant steady state error or large overshoots.

MATLAB has a PID control block which implements continuous and discrete-time PID control algorithms. The transfer function of a PID Controller is given by:

$$H(s) = Kp + \frac{1}{s} Ki + \frac{N}{1 + \frac{N}{s}} Kd \quad (1)$$

where Kp, Ki and Kd are PID constants of the system. In the above equation, N is called Filter coeffecient which is also a tuning factor of the PID. The above function is the transfer function of the PID block of the Simulink Library of MATLAB.

The PID control block can be cascaded with the actual system or can be fed-back as a negative feedback to the system. The system response and stability for the above combinations will be discussed further in the paper.

III. AIRCRAFT SYSTEM MODELLING

As stated earlier, PID controllers are a direct application of pitch controlling systems in aircrafts, we consider an aircraft with a pitch angle of θ and a correction angle of δ, which stabilizes the aircraft.

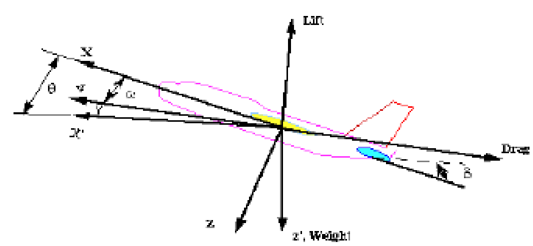

Figure 1: Free-Body diagram of Aircraft

The systems input variable is the deflection angle δ and the output variable is the angle of pitch θ. The angle θ- δ is the error angle. The Laplace transform of the input and output are respectively Δ(s) and θ(s). The transfer function of the aircraft is given by:

$$T(s) = \frac{\theta(s)}{\Delta(s)} = \frac{1.151\, s + 0.1774}{s^3 + 0.739 s^2 + 0.921 s} \quad (2)$$

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The above transfer function is obatined the data of a Boeing Commercial Aircraft . This model of the system is derived from the assumptions that the system is balanced by all the forces externally acting upon it. The velocity of the aircraft is a constant and is independent of the pitch angle. However ,only the longitudinal motion is the governing factor for the pitch of the aircraft. Hence only the longintunidal dynamics of the body is considered for deriving the trasnfer function.

The system once designed, defines some requirements to be fullfilled by the particular model. The system overshoot must not be more than 5%, rise-time must not exceed 1-2 seconds,a maximum steady state error of 1% and settling time of 5 seconds. If such a response is achieved then the system becomes extreemely stable and can be approximated to an Ideal System.

IV. MODEL FOR SIMULATION

The system under consideration is a mechanical system whose transfer function is known from a standard data source. Therefore, we can build a Simulink Model of the system with the PID controller and tune it to obtain the desired response.

While modelling the system, a proper input is to be applied to observe the system response. Practically a sudden change in angle is the input to the controller of the aircraft. Hence an equivalent block of that would be a Step Signal. A step signal indicates a sudden change in value of the input at a particular instant of time (say at time t=1s). Hence by analyzing the step response of the system, we can arrive at the stability of the system for change in pitch angle.

Now the PID Controller can be placed in loop or in feedback of the system under consideration.

A. PID Controller in Loop with the System:

Below is the model of the system with the controller block in loop. A unity feedback is given to the system.

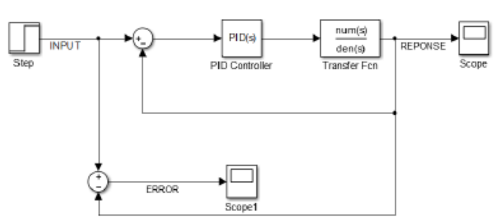

Figure 2: Simulink model of in-loop PID

A transfer function block is designed for the defined system transfer function and step input is applied at t=1s. Both the output and error signals can be observed on the scope. The PID is tuned manually for various values of [Kp Ki Kd] starting from [1 1 1]. Output responses for various combinations is observed by trial and error method.

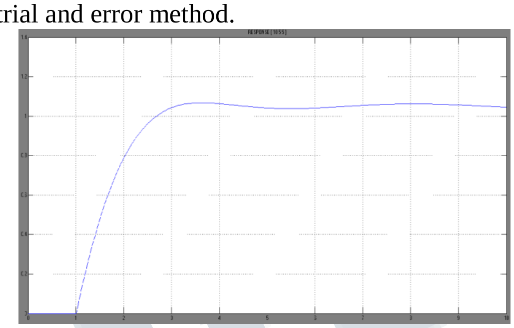

Figure 3: Step Response for PID constants [1 1 1]

In the above graph, we can observe that the system takes 3-4 seconds to settle and possesses a constant steady state error though it has a very less overshoot.

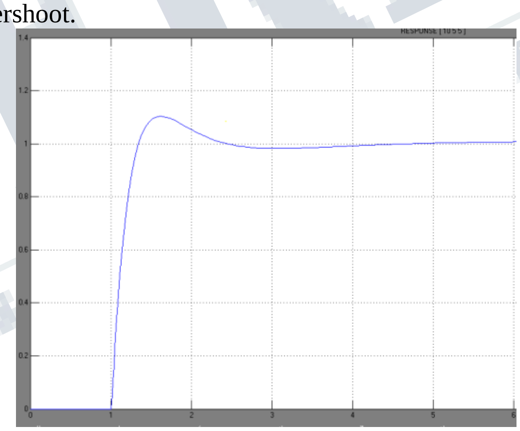

Figure 4: Step Response for PID constants [10 5 5]

This response has a high value of over-shoot and very good steady state error stabilization. The above responses either have a constant steady state error or a higher over-shoot value. The settling time for both above cases is more than 5 seconds. Thus, auto tuning of the PID was carried out. The auto tuned parameter values are [0.6536 0.000647 -5.828]. The auto tuned response also had considerate steady state error and took a rise time of 17 seconds which does not fulfill the system requirement.

Hence by manual tuning, the best response was obtained at [8 5.5 10.5]. The overall system transfer function with the controller and feedback is given by:

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$$T(s) = \frac{12.086\ (s + 0.1541)(s^2 + 0.7619s + 0.5283)}{(s + 11.87)(s + 0.1581)(s^2 + 0.7978s + 0.5199)} \quad (3)$$

By final value theorem, the system converges to a non-zero non-infinite value at infinite time. Then, the system response for a step input with the tuned PID controller is simulated.

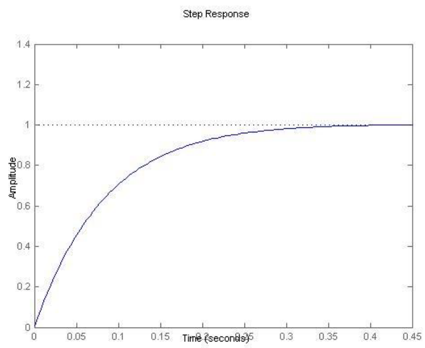

Figure 5: Step response of in-loop PID tuned system

The system response is close the ideal response with a settling time of 0.4 seconds, rise time of 0.2 seconds and a steady state error of 0.5%. The system overshoot is less than 1% and hence this is the most efficient tuning of the in loop PID control system. The root-locus analysis also confirms the stability of system. Also, the overall system with feedback and controller satisfies BIBO Stability criteria. And hence, introducing a PID in loop shall make the system response more ideal and stable.

B. PID controller in Feedback to the System

Alternatively, the PID Controller can also be placed in the feedback path whose output is a negative feedback to the system at its input. The Feedback Control system model is as shown in the diagram:

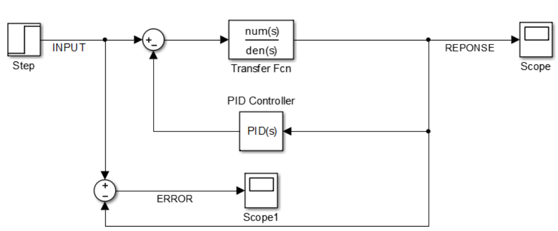

Figure 6: Simulink model of in-feedback PID

The PID control signal goes as a negative feedback to the system. The above model can be simulated by manually or auto tuning the PID. The simulation by auto tuning does not give desired results due to drawback of the simulation software. The auto tuning and System Linearizing algorithm the software follows is only for a loop PID arrangement. Hence manual tuning must be carried out to obtain the system response.

Hence the system transfer function is analyzed for PID Feedback. The system transfer function and the PID transfer function for [1 2 3] is defined. The system transfer function with feedback is obtained.

The system transfer function with PID feedback in ZPK form is given by:

$$T(s) = \frac{3\ s\ (s^2 + 0.333s + 0.667)(s^2 + 0.739s + 0.924)}{(s + 3.658)(s + 0.1642)(s^2 + 0.3696s + 0.5906)} \quad (4)$$

The numerator of the transfer function contains s for any combination of PID constants. By final value theorem to the system defined by equation (4), the above system goes to zero (0) as time tends to infinity irrespective of the PID constants.

Hence the system, though is stable, does not meet the design requirements. The final value of the system must tend to 1 for the system to satisfy the design criteria.

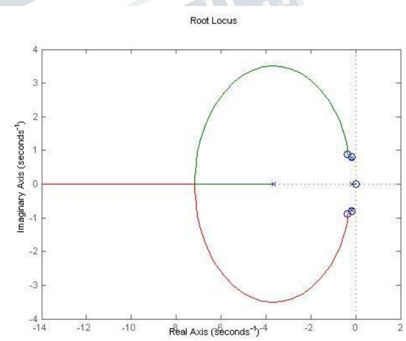

Figure 7: Root-locus of in-feedback PID system

The root-locus also confirms the stability of the system along with the BIBO stability criteria. But the stability of the system does not imply that the system meets the defined requirements.

V. RESULTS

The system with PID in loop gave a response nearing the ideal design requirements. By trial-and-error tuning the system response was achievable for a step input signal. As stated above, the step signal is

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equivalent to a sudden change in pitch, as per the system response, the aircraft takes about 0.4s time to settle to its nil error state if the aircraft experiences a drift in its angle. The steady state error is about 1% which means, the system is stable enough after control signal is applied to the closed loop system.

Also, the feedback PID block system does not give the required response. A steady state error is always there in the system response in the feedback PID. Moreover, integral feedbacks are not usually used for error optimization applications. The transfer function of the complete PID fed-back system has a zero at z=0. By analyzing the transfer function, the system reaches 0 as time tends to infinity (by Final Value Theorem) which is highly undesirable for the system under consideration. Below is the error signal vs time graph of the system with PID in loop.

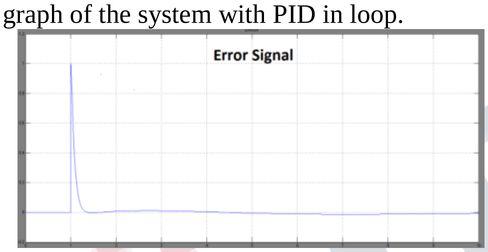

Figure 8: Error signal vs time plot of In-loop PID

The error signal reaches the peak in less than 0.2 seconds and reaches zero in less than 0.5 seconds. This clearly shows the error controlling ability and fastness of the system.

Given below is the error signal vs time plot of PID in feedback system.

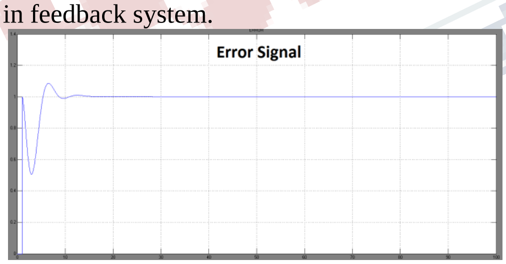

Figure 9: Error signal vs time plot of Feedback PID

Here, one can clearly see that the error settles at close to unity. This can be theoretically verified using the Final Value theorem. This has a direct impact on the steady state response, as the step response hits zero.

VI. CONCLUSIONS

The aircraft transfer function and those of the complete system equipped with the three-mode controller in series and in feedback give one an idea of the system and error dynamics. It may be concluded from this research that while three mode control works exceptionally well in case of series connection in loop, using PID for error control in feedback will most certainly be disastrous for the aircraft.

One can also conclude that three mode control with trial-and-error tuning is sufficient for the most demanding of applications, namely aircraft control.

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