An ILC-PID Based Control Scheme for SISO

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Abstract: Iterative learning control (ILC) is a simple and effective method for the control of systems that perform the same task repetitively. ILC algorithm uses the repetitiveness of the task to track the desired trajectory. This paper includes literature survey which is focused on ILC and PID related work; details of Aircraft (SISO), implementation and results using PID as well as ILC based PID for SISO. An ILC based PID (proportional plus integral and derivative) type controller is used to control SISO system performing non repetitive tasks. Convergence condition is obtained in terms of the PID coefficients. In case of non optimum, the gains (the parameters k_p, k_I and k_D) are selected on the basis of convergence condition and in case of optimum gains they are obtained as per the steps given in [1]. We implement ILC based PID algorithm, with both optimum and non-optimum gains, on illustrative example of SISO system to demonstrate the effectiveness of the ILC-PID based technique. Simulation results of an ILC based PID type controller and classical PID are compared.

Keywords: **Iterative learning control (ILC), Single Input Single Output (SISO), Proportional Derivative Integral (PID)**

I ITERATIVE LEARNING CONTROL

ILC is based on the notion that the performance of a system that executes the same task multiple times can be improved by learning from previous executions (trials, iterations, passes). E.g. pick and place robot, induction molding machine etc.

ILC as a distinct field is perhaps less than 30 years old it is difficult to assess its past history its present value and the potential future impact it may have in the world of control systems. Regarding the past of ILC it is clear that the pioneering work of Arimoto and his colleagues stimulated a new approach to controlling certain types of repetitive systems. The concept of *iterative learning* is quite natural but had not been expressed in the algorithmic form of ILC until the early 1980's. The present status of the field reflects the continuing efforts of researchers to extend the earlier results to broader classes of systems to apply these results to a wider range of applications and to understand and interpret ILC in terms of other control paradigms and in the larger context of learning in general. Looking to the future it seems clear that there are number of areas of research in ILC that promise to be important.

These include

- Integrated higher order ILC/current-cycle feedback: continuous ILC/repetitive control
- Robustness and convergence analysis
- System-theoretic analysis
- Connections to more general learning paradigms
- Wider Variety of Applications

In the work presented by Ali Madady in [1], PID type ILC update law is used to control discrete-time single input single-output (SISO) linear time-invariant (LTI) system performing repetitive tasks. In this approach, the input of controlled system in current cycle is modified by applying the PID strategy on the error achieved between the system output and the desired trajectory in a last previous iteration. The convergence of the presented scheme is analyzed and its convergence condition is obtained in terms of the *PID coefficients*. An optimal design method is proposed to determine the PID coefficients. It is also shown that under some given conditions, this optimal iterative learning controller can guarantee the monotonic convergence.

With detailed literature review we found PID plays a significant role when used along with ILC. The P-component has a stabilizer role in the ILC system and causes monotonic convergence; I- component rejects the effect of non-zero initial errors and increases the convergence rate, while D-term reduces the effect of disturbance inputs.

For above merits of each of PID components in the ILC action, the PID controller is a popular scheme in designing ILC. Therefore presenting any new PID type controller using ILC domain is a significant task. Many researchers have made an attempt to combine ILC with PID for SISO and MIMO systems.

The ILC based PID scheme discussed in [1] is a straightforward extension of standard PID scheme in order to improve the transient tracking performance through ILC. We observed that this algorithm is applicable only for SISO system.

Other researchers have used different strategies to develop ILC algorithms for MIMO systems like Tae-yong Doh and Jung Rae Ryoo [4] used *feedback based* ILC for MIMO and another author B.J. Drissen used ILC based on *bounded inputs* for MIMO.

We found that there are many PID based ILC algorithms developed to achieve the specific characteristics of ILC like monotonic convergence, robustness, etc.

II EXISTING WORK

Detailed literature reviews and categorization can be found in [5]. Major categories in this are A) literature related to ILC applications and B) literature related to ILC theories.

Since our work is based on ILC and PID, falls the major categorizations A and B. Although there are many publications and theory focused literature on ILC very few of them are related to PID based ILC among which only some are related to ILC, PID for MIMO system. Here we are discussing the work related to the PID based ILC for SISO as well as for MIMO. During survey we observed that many researchers have used different strategies to develop ILC algorithms for MIMO systems like Tae-yong Doh and Jung Rae Ryoo [4] used *feedback based* ILC for MIMO.

In[6], Kevin L. Moore, YangQuan Chen, and Vikas Bahl discussed the feedback controller design to ensure monotonic convergence in discrete-time using p-type iterative learning. They consider the design of current cycle feedback controllers for the plant so that these requirements are met, thereby ensuring that any p-type learning control algorithm that converges will also converge monotonically. In [7], Shengdun Zhao, Ji Wang, Lihong Wang , Chunjian Hua and Yupeng He, discussed iterative learning control of electro-hydraulic proportional feeding system in slotting machine for metal bar cropping. In this a non-linear method, iterative learning control (ILC), is proposed to control the electro-hydraulic feeding process of a new slotting machine. The method attempts to acquire high precision of feeding length and trapezoid feedrate, whereas the complexity of iterative learning control algorithm does not increase much more than that of industrial PID controller. It is experimentally found that the proposed control scheme is more effective to improve the tracking accuracy of hydraulic feeding system of the slotting machine than that of fuzzy PID controller.

In [8] an adaptive type PID type Iterative learning Controller for unknown nonlinear systems is designed. Y. C. Wang, C. J. Chien and D. T. Lee discussed that optimal PID gains for the best approximation are unavailable; the control parameters are tuned between successive iterations to insure the stability and convergence. Kevin L. Moore, Yang Quan discussed PI –Type Iterative Learning Control [5] in which they show that error integral in ILC updating scheme is useful in achieving a monotonic convergence. In PD type they show a tradeoff between noise suppression and rate of monotonic convergence of the ILC process.

In [10], Feedback-Based Iterative Learning Control for MIMO LTI Systems, Tae-Yong Doh and Jung Rae Ryoo proposed a necessary and sufficient condition of convergence in the L2 -norm sense for a feedback-based iterative learning control (ILC) system including a multi-input multi-output (MIMO) linear time-invariant (LTI) plant. They showed that the convergence conditions for a nominal plant and an uncertain plant are equal to the nominal performance condition and the robust performance condition in the feedback control theory, respectively. Moreover, no additional effort is required to design an iterative learning controller because the performance weighting matrix is used as an iterative learning controller. By proving that the least upper bound of the L2 -norm of the remaining tracking error is less than that of the initial tracking error, this paper shows that the iterative learning controller combined with the feedback controller is more effective to reduce the tracking error than only the feedback controller. The validity of the proposed method is verified through computer simulations.

We found that there are PID based ILC algorithms developed to achieve the specific characteristics of ILC like monotonic convergence, robustness, etc. Specific characteristics are achieved using feedback controller design, PI, PD and PID controller design. But it is observed that not much work has been done on MIMO systems using ILC based PID. The aim of this work is to extend the proposed method discussed in [1] to an aircraft system. But here we extended it differently. We used ILC to find out gain values and then implemented these values using PID controller. With this we get the advantages of PID as well as ILC.

III AN AIRCRAFT SYSTEM – SISO SYSTEM

The equations governing [11] the motion of an aircraft are a very complicated set of six non-linear coupled differential equations. However, under certain assumptions, they can be decoupled and linearzed into the longitudinal and lateral equations. Pitch control is a longitudinal problem, and in this example, we designed an autopilot that controls the pitch of aircraft. The basic coordinate axes and forces acting on an aircraft are shown in the figure1.

Assume that the aircraft is in steady-cruise at constant altitude and velocity; thus, the thrust and drag cancel out and the lift and weight balance out each other. For this system, the input will be the elevator deflection angle (δ), and the output will be the pitch angle (θ).

The transfer function for the system is

$$\frac{\theta(s)}{\delta(s)} = \frac{1.115s + 0.1774}{s^3 + 0.739s^2 + 0.921s} \quad (1)$$

The state space model is obtained for above transfer function and is given below:

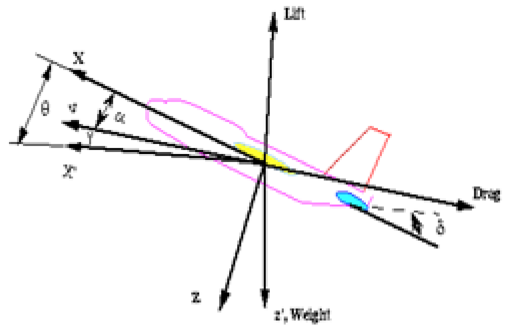

Figure 1: The basic coordinate axes and forces acting on an aircraft

The state space model is obtained for above transfer function and is given below:

$$A = \begin{bmatrix} -0.313 & 56.7 & 0 \\ -0.0139 & -0.426 & 0 \\ 0 & 56.7 & 0 \end{bmatrix}, B = \begin{bmatrix} 0.232 \\ 0.0203 \\ 0 \end{bmatrix}, C = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}, D = \begin{bmatrix} 0 \end{bmatrix}$$

Where A, B, C matrices are used to find out the convergence condition and optimal gains for implementation of PID control using ILC based approach as given in [1]

IV IMPLEMENTATION DETAILS FOR AIRCRAFT SISO SYSTEM

Referring the state space A, B, C matrices for aircraft system following discrete *num* and *den* is obtained using matlab c2d command.

$$num = \begin{bmatrix} 0.00189 & 0.005586 & -0.005498 & -0.001807 \end{bmatrix}$$

$$den = \begin{bmatrix} 1 & -2.92 & 2.849 & -0.9288 \end{bmatrix}$$

Again using this transfer function g_1 is obtained referring steps given in an appendix.

$$g_1 = 0.0111$$

$$\left|1 - g_1(k_P + k_I + k_D)\right| < 1 \quad (2)$$

From above equation we obtain following conversion condition [1]

$$0 < k_p + k_I + k_D < 180.18 \qquad (3)$$

From this we select non optimum gains by trial and error but satisfying the condition as shown above. Here we select

$$K_p = 5, K_i = 0.5, K_d = 30.21$$

With time duration (M), we select M=10, the optimal values for gain are (using steps given in [1])

$$K*_p = 99.660, K*_i = 0.2065, K*_d = 54.2113$$

These values are further used to tune the PID controller. Simulation results are shown below. Figure 2 shows Open-loop step response for aircraft system. Figure 3 shows traditional PID controller response for aircraft system. In traditional PID controller traditional tuning method is used. We select $K_p = 2, K_i = 4, K_d = 3$ for traditional PID controller. Figure 4 shows ILC based PID controller with non optimum gains for aircraft system. Figure 5 ILC based PID controller with optimum gains for aircraft system.

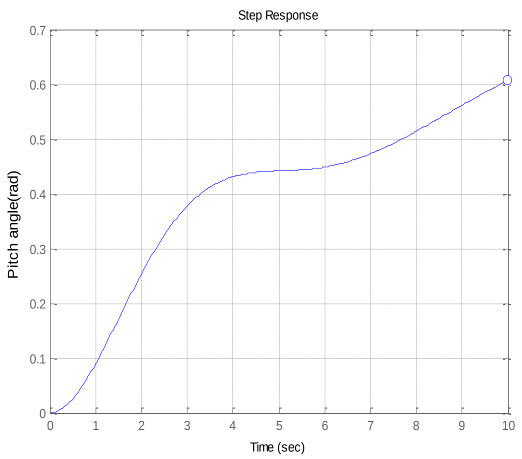

Figure2:Open loop response for aircraft system

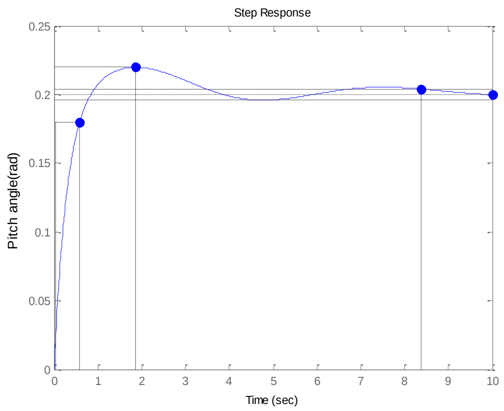

Figure 3: PID controller response for aircraft system

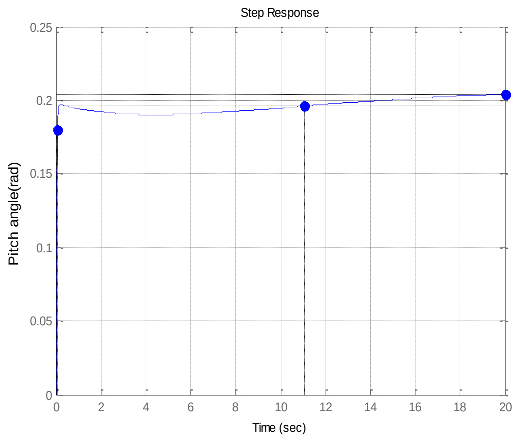

Figure 4: ILC based PID controller with non optimum gains for aircraft system

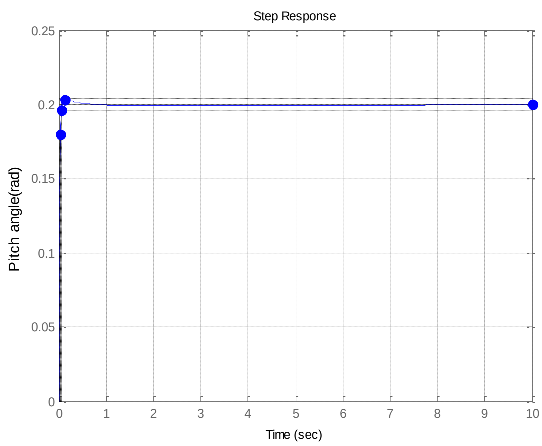

Figure 5: ILC based PID controller with optimum gains for aircraft system

From the above responses it is observed that the performance of ILC based optimum controller shown in figure 5 is better than PID controller shown in figure 3 and ILC based non optimum controller shown in figure 4. Peak overshoot is nil in case of ILC based non optimum controller whereas settling time and rise time is improved in ILC based optimum controller. The performance comparison between ILC based Non Optimum and ILC based Optimum Results for Aircraft System is shown in Table 1.

Table 1: COMPARISON OF RESPONSES OF PID,

AN ILC BASED PID ALGORITHM WITH OPTIMUM

AND NON OPTIMUM GAINS FO**R** AIRCRAFT SISO SYSTEM

Controller	**Measuring Parameters**			
	Rise Time	***Settling Time***	***Overshoot***	***Settling value***
PID	*0.554*	*8.83*	*9.91*	*0.2*
ILC based Non Optimum	*87.54 %*	*-24.32 %*	*100 %*	*0.2*
ILC based Optimum PID	*94.04 %*	*99.32 %*	*84.15 %*	*0.2*

- % values give percentage improvement compared to PID.

V OBSERVATIONS

Looking at the result, we therefore conclude that an ILC based optimum algorithm performs better than other two controllers. The non-optimum ILC algorithm works well towards peak overshoot and optimum ILC algorithm works better towards the setting time and rise time. The performance of both the technique is far much better than that of conventional PID controller.

VI CONCLUSIONS WITH FUTURE SCOPE

So taking into considerations the advantage of this method for SISO we applied this algorithm for interacting MIMO system i.e. a CSTH system. We observed satisfactory results. However this needs further investigations. Extension of this technique for study of usability of optimum gains for MIMO system

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