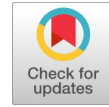# Experimental Assimilation of Various Tuning Rules with Fractional Order Controller in Inverted Pendulum

V. Priya, J. Dhanasekar, G. Vasumathi

Abstract: Modified pendulum is a commonplace trial territory for the investigation of control hypotheses. The adjusting of a reversed pendulum by moving a truck along a flat track is a commonplace issue in the zone of control. So as to improve the capacity of PID controller reacting for the heap unsettling influence, controller tuning guidelines assume fundamental job. This work engaged with enhancement of the PID control parameters for controlling the pendulum in upstanding position particularly with the best heartiness and contrasting it tentatively and ideal settings of a fragmentary PIλDμ controller which can satisfy five distinctive plan details for the shut circle framework, exploiting the fragmentary requests, λ and μ. Since these partial controllers have two parameters more than the customary PID controller improves the presentation of the framework. The pendulum has been adjusted in the upstanding position utilizing the two techniques and the exploratory outcomes are analyzed and announced. The recreation just as exploratory aftereffects of ordinary PID controller demonstrate that the arrangement of new and tuned controller parameters are furnishing the outcomes with better shut circle execution thought about than other tuning methods. And furthermore the control ability and the framework execution furnished by fragmentary request PID controller with the determined new arrangement of parameters has been tentatively demonstrated that the partial request PID controller gives controller execution relatively superior to the customary one along these lines it isn't just controlling the ongoing framework with better adjustment and following control yet additionally have heartiness to aggravations.

Keywords : PID Controller; Inverted Pendulum; Controller Tuning ; Fractional order PID controller

I. INTRODUCTION

The altered pendulum issue is one of the most significant issues in charge hypothesis and has been contemplated too much in charge written works. It is settled benchmark issue that gives many moving issues to control plan. The framework is nonlinear, unsteady, nonminimum stage and underactuated. As a result of their nonlinear nature

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pendulums have kept up their convenience and they are presently used to outline a considerable lot of the thoughts rising in the field of nonlinear control [1]. The difficulties of control made the transformed pendulum frameworks great instruments in charge research facilities. The upset pendulum framework characteristically has two equilibria, one of which is steady while the other is shaky. The steady harmony relates to a state where the pendulum is pointing downwards. Without any control power, the framework will normally come back to this state. The steady balance requires no control contribution to be accomplished and, consequently, is uninteresting from a control point of view. The temperamental harmony relates to a state where the pendulum focuses carefully upwards and, therefore, requires a control power to keep up this position. The fundamental control goal of the reversed pendulum issue is to keep up the flimsy harmony position when the pendulum at first begins in an upstanding position. Since 1940, rise of procedure control in numerous enterprises, PID controllers are utilized in the greater part of the input circles of procedure ventures which are favored because of their straightforward structure, ideal execution and power, pertinence over wide range and simplicity in usage on both simple and computerized stage. The perfect PID has restricted use because of issues in execution and is utilized chiefly for scholastic intrigue. So as to decrease the settling time just as pinnacle overshoot, the requirement for moving toward different tuning standards comes into the psyche. Jia-Jun [2] demonstrated with reenactment reads for having in excess of two PID controllers for transformed pendulum framework. Madhuranthakam et al. [3] exhibited the union and investigation of ideal tuning of relative indispensable subordinate (PID) parameters for various procedure frameworks: first request in addition to time delay (FOPTD), second request in addition to time delay (SOPTD) and second request in addition to time delay with lead (SOPTDLD). This work included advancement of the PID control parameters to accomplish the minimization of the vital supreme mistake (IAE). Lee et al. [4] proposed a tuning technique and contrasted and recurrence reaction strategies which give preferable shut circle execution over the current strategies. The control destinations for this venture are focussing on executing another arrangement of controller parameters discovered utilizing different tuning rules in a PID controller and contrasting it and a fragmentary request PID controller (FOPID) so as to keep the pendulum in the precarious balance position (pendulum upstanding), and keeping up this state[5].

The tuning guideline can be relevantly chosen so as to give less settling time, least pinnacle overshoot and less blunder just as the usage of partial request PID controller for controlling the fair condition of the transformed pendulum. The value of utilizing PID controllers lie in its straightforwardness of plan and great execution including low rate overshoot and little settling time for moderate modern procedures. The presentation of PID controllers can be additionally improved by fitting settings of fragmentary I and partial D activities. This paper endeavors to consider the conduct of partial PID controllers over number request PID controllers. In a fragmentary PID controller, the I-and D-activities being partial have more extensive extent of structure [6]. Normally, other than setting the corresponding, subsidiary and necessary constants Kp, Td and Ti separately, we have two additional parameters: the intensity of s in indispensable and subordinate activities λ and μ individually.

II. MODELLING

The reversed pendulum utilized in this work is a Googol Tech's Product. It comprises of an engine driven truck and a pendulum openly rotated above it, alongside sensors and electronic circuit. The pendulum can move uninhibitedly in the vertical plane. The truck development is constrained by a D.C. engine which is associated with the engine by notched elastic belt. The framework parameters are

M cart mass: M = 1.096 kg
m rod mass: m = 0.109 kg
b friction coefficient of the cart: b = 0.1 Nm/s
l distance from the rod axis rotation center to the rod mass center: l = 0.25 m
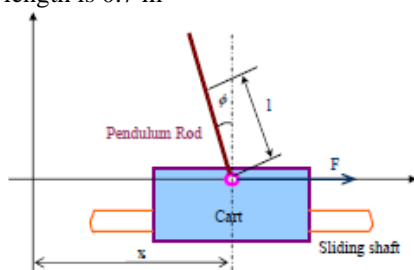I rod inertia: I = 0.0034 kgmm
Total rail length is 0.7 m
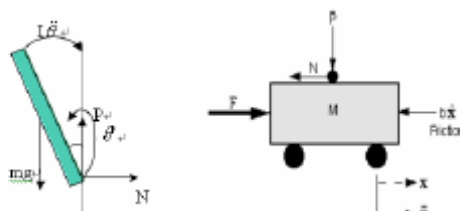

Figure – 1 Single stage Linear Inverted Pendulum Model

Figure 2 - Cart and Rod Force Analysis

Let's consider

F: force acting on the cart
X: cart position
N: interactive force in the horizontal direction
P: interactive force in the vertical direction
θ: angle between the rod and vertically downward direction

The first dynamic equation obtained from the forces and force acting on the rod in horizontal direction as:

$$(M + m)\ddot{x} + b\dot{x} + ml\,\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta = F \quad (2.1)$$

The second dynamic equation obtained from the analysis of the force in the vertical direction is

$$(l + ml^2)\ddot{\theta} + mgl\sin\theta = -ml\ddot{x}\cos\theta \quad (2.2)$$

The transfer function obtained after simplification is

$$\frac{\phi(s)}{U(s)} = \frac{\frac{ml}{q}s^2}{s^4 + \frac{b(l+ml^2)}{q}s^3 - \frac{(M+m)mgl}{q}s^2 - \frac{bmgl}{q}s} \quad (2.3)$$

With the substituted values of all parameters of the inverted pendulum system, the transfer function obtained is

$$\frac{\phi(s)}{U(s)} = \frac{0.02725}{0.0102125s^2 - 0.26705} \quad (2.4)$$

III. PERFORMANCE ANALYSIS OF PID CONTROLLER AND FOPID CONTROLLER

A. Controller Tuning for PID Controller

Albeit a great deal of control calculations are inspected in the frameworks control plan, PID controller is as yet the most generally utilized controller structure in the acknowledgment of a control framework. The overwhelming favorable circumstances of PID controller, which have conspicuously added to its wide acknowledgment, are its effortlessness and adequate capacity to tackle numerous handy control issues. To the present, there is bunches of control methodologies applied to the upset pendulum control. In any case, there is next to no reference about PID control in modified pendulum control. This plan makes the altered pendulum control structure exceptionally straightforward dependent on PID controllers. The general exchange capacity of PID controller is

$$G_c(s) = K_p + T_is + T_ds \quad (3.1)$$

In PID controller itself it is conceivable to improve the reaction of the framework by changing the PID controller parameters discovered utilizing different tuning rules. In such a manner a portion of the tuning guidelines are utilized to discover the PID parameters. The exchange capacity of rearranged pendulum is like the model as given beneath

$$G_m(s) = \frac{K_m e^{-s\tau_m}}{(T_{m1}s - 1)(T_{m2}s + 1)} \quad (3.2)$$

From the comparison of eq. (3.4) and (4.1), we can obtain the values of system gain $K_m = 0.10204$, time co-efficients like $T_{m1} = 0.19556$, $T_{m2} = 0.19556$ and $T_m = 0.038242$ and time constant $\tau_m = 0.01$. As the system model is similar to that of the Unstable SOSPD model with one unstable pole (eq 3.1), the controller parameters for the PID controller will be determined with the help of few tuning rules.

It might be for ideal controller, series controller or any PID based controllers. Among many, the tuning rules which exactly suits for the inverted pendulum by providing minimum peak overshoot and less settling time are given below[7].

Rule: Rotstein and Lewin (1991) Model: Method 1

Here $\tau_m / T_m = 0.2615$. Therefore λ have the values 0.0191 and 0.0726. K_c, T_i and T_d can be calculated with following formula.

$$K_c = \frac{T_{m1}\left[\lambda(\frac{\lambda}{T_{m1}} + 2) + T_{m2}\right]}{\lambda^2 K_m} \qquad (3.3)$$

$$T_i = \lambda\left(\frac{\lambda}{T_{m1}} + 2\right) + T_{m2} \qquad (3.4)$$

$$T_d = \frac{\lambda\left(\frac{\lambda}{T_{m1}} + 2\right)T_{m2}}{\lambda\left(\frac{\lambda}{T_{m1}} + 2\right) + T_{m2}} \qquad (3.5)$$

For λ=0.0191, the values of K_c, T_i and T_d are 1237.7, 0.2356 and 0.03325 with their respective K_p, K_i, K_d are 1237.7, 5253.8 and 41.15. Similarly, for λ=0.0726 K_c, T_i and T_d are 133.726, 0.3677 and 0.0915 whose respective K_p, K_i, K_d are 133.726, 363.68and 12.236.

3.1.2 Rule: Lee et al (2000) Model: Method 1

λ has the values 0.0191 and 0.0726 whose α values can be calculated using the formula eq. (3.6)

$$\alpha = T_{m1}\left[\left(\frac{\lambda}{T_{m1}} + 1\right)^2 e^{\tau_m/T_{m1}} - 1\right] \qquad (3.6)$$

Respective K_p, K_i and K_d can be easily calculated using the formula from eq. (3.7), eq. (3.8) and eq. (3.9)

$$K_c = \frac{T_i}{-K_m(2\lambda + \tau_m - \alpha)} \qquad (3.7)$$

$$T_i = -T_{m1} + T_{m2} + \alpha - \frac{\lambda^2 + \alpha\tau_m + 0.5\tau_m^2}{2\lambda + \tau_m - \alpha} \qquad (3.8)$$

$$T_d = \frac{-T_{m1}\alpha + T_{m2}\alpha - T_{m1}T_{m2} - \frac{\tau_m^2(0.167\tau_m - 0.5\alpha)}{2\lambda + \tau_m - \alpha}}{T_i} - \frac{\lambda^2 + \alpha\tau_m + 0.5\tau_m^2}{2\lambda + \tau_m - \alpha} \qquad (3.9)$$

For λ=0.0191 and α=0.0524, it can be easily calculated with K_p, K_i and K_d as 5033.4, 2333.3 and 522.7. And for λ=0.0726 and α= 0.1914, the values of K_p, K_i and K_d are 4409.8, 2333.3 and 7405.8

Simulation Results

For the values obtained from the various tuning rules, the response of the PID controller can be simulated as following results.
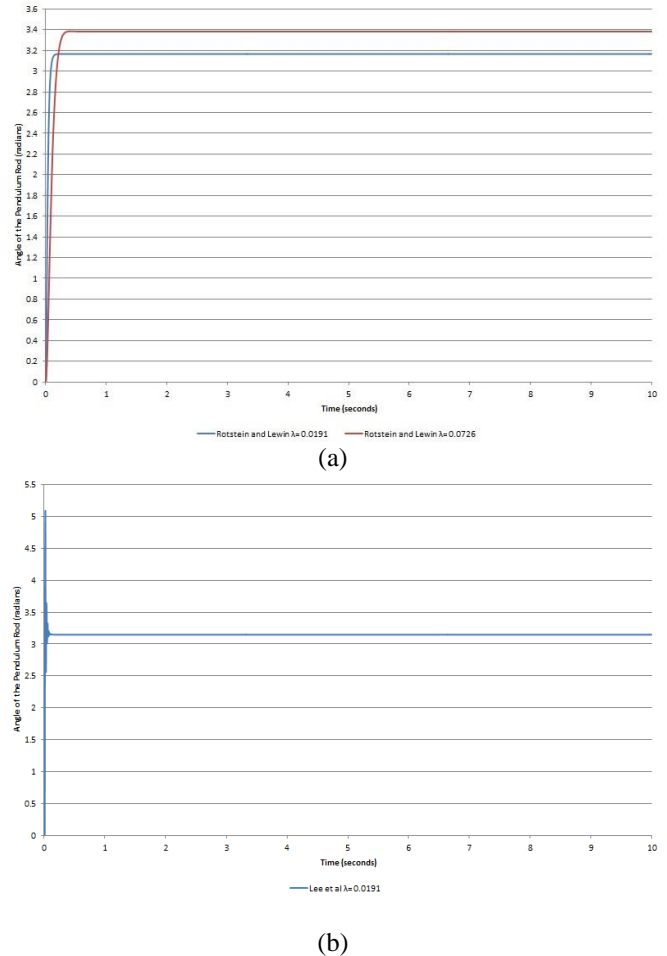

(a)

(b)

Figure – 3 Response of PID Controller for the PID values of (a) Rotstein and Lewin (λ=0.0191, λ=0.0726) and (b) Lee et al (λ=0.0191) Tuning Rules

Specifications	Rotstein and Lewin (1991)		Lee et al (2000)
	λ=0.0191	λ=0.0726	
Ts	0.41	0.81	0.45
M$_{p\%}$	0.8233	7.8	61.64
ISE	45.95682	235.147	35.45853
IAE	73.00363	528.2736	29.79665
ITAE	259.0902	2422.468	75.45552

Table 1 - Comparison of Time Domain Parameters for various Tuning rules

B Fractional Order PID Controller

One of the possibilities to improve PID controllers is to use fractional-order controllers with non-integer derivation and integration parts. A fractional PID controller therefore has the transfer function:

$$Gc(s) = Kp + Tis\text{-}\lambda + Tds\mu \qquad (3.10)$$

The orders of integration and differentiation are respectively λ and δ (both positive real numbers, not necessarily integers). Taking λ =1 and δ =1, it is possible to have an integer order PID controller so that the integer order PID controller has three parameters, while the fractional order PID controller has five. The fractional order PID controller generalizes the integer order PID controller and expands it from point to plane. This expansion adds more flexibility to controller design and it can control the real world processes more accurately[10].

Simulation Results

For understanding the impact of FOPID controller on the Inverted Pendulum system, the system has been simulated with various set of λ and μ values varying from 0 to 2 as the order of the system is simplified to second order already[8].
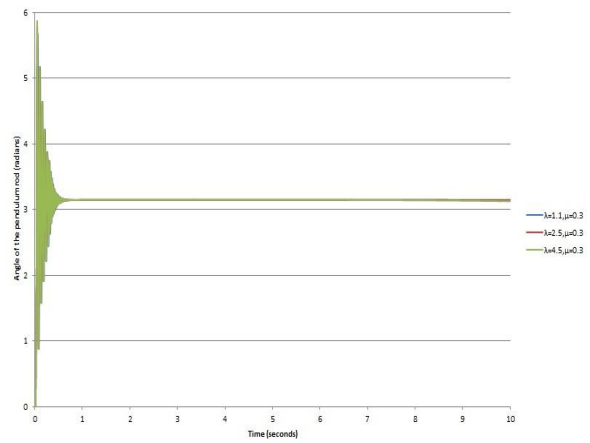
Some of the chosen combinations of λ and μ are λ=1 & μ<1, λ&μ <1 and λ>1 & μ <1. The reason behind choosing these combinations are nothing but the controller should provide a better performance when comparing to other combinations.
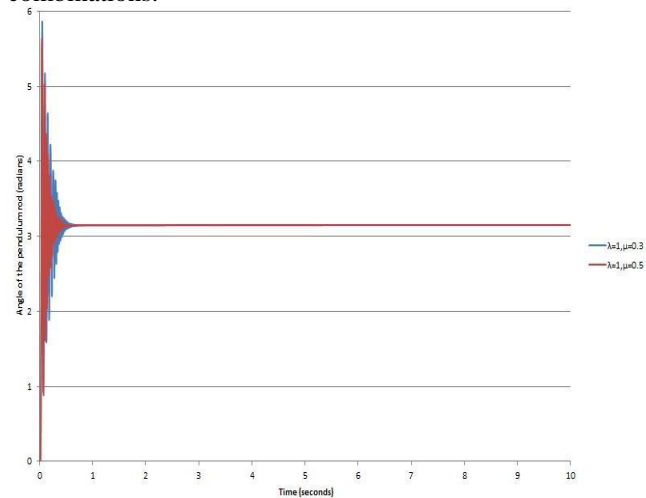
(a)
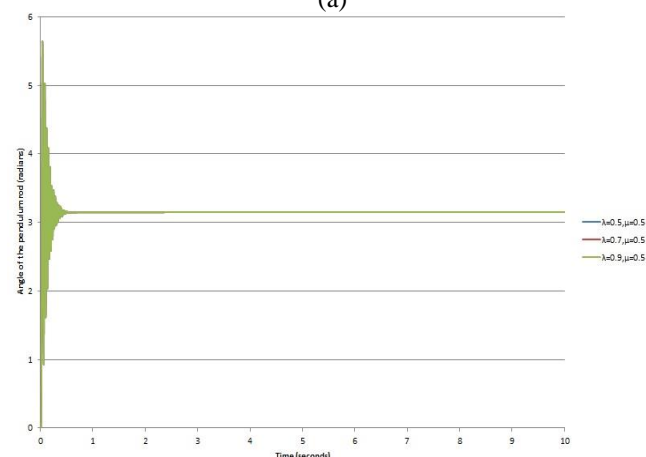
(b)

(c)

Figure – 4 Response of the System with FOPID for (a) λ=1 & μ<1, (b) λ&μ <1 and (c) λ>1 & μ <1

Figure 4 shows the various responses of the system for the various combinations chosen for studying the performance of FOPID over inverted pendulum among which λ=1and μ=0.5 provides better system performance when compared to other combinations[9].

	λ=1 μ=0.3	λ=1 μ=0.5	λ=0.5 μ=0.5	λ=0.7 μ=0.5	λ=0.9 μ=0.5	λ=1.1 μ=0.3	λ=2.5 μ=0.3
Mp%	86.6	79.2	79.6	79.6	79.3	80.9	86.8
ISE	0.218	0.12	0.121	0.121	0.121	0.218	0.057
Ts	0.72s	0.55s	0.55s	0.56s	0.55s	0.74s	0.74s
ITAE	98.09	112.6	114.56	113.85	112.99	97.335	81.714
IAE	0.237	0.175	0.176	0.176	0.175	0.236	0.157

Table 2 - Time Domain Parameters of FOPID Controller for various λ and μ values

IV. CONCLUSION

In This paper proposes the tuning for the parameters of PID in reversed pendulum framework just as the usage of FOPID Controller in it. With the assistance of partial request PID controller, control framework can be intended for the reversed pendulum framework with ideal adaptability. It has been demonstrated that the Fractional request PID controller gives the preferred controller execution over the PID controller with different tuned parameters with settling time of 0.75 seconds and least overshoot of 61.15% for λ=1.1 and μ=0.9. There are other delicate registering based techniques with which the ideal tuning estimations of FOPID can be accomplished. Swarm insight strategies like molecule swarm knowledge (PSO) and subterranean insect province enhancement (ACO) can be utilized as an option of developmental calculations like GA. Fluffy based technique and versatile neuro fluffy based strategy can likewise be utilized to locate the best fit estimations of μ and λ.

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