DEVELOPMENT OF VARIOUS TUNABLE PID CONTROLLERS FOR A ROBOTIC ARM SYSTEM

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ABSTRACT

In this paper, analysis and comparison of different types of controllers such as P, PI and PID has been done primarily based on error criteria and time domain specifications for controlling the angular position of a robotic arm. The proportional gain (K_p), integral gain (K_i) and derivative gain (K_d) for the controller have been determined using different tuning techniques like Ziegler- Nichols and Tyreus-Luyben. Time domain specifications and error criteria of various controllers were measured and compared in these techniques. The IPD structure was also taken into consideration for analysis. The above proposed techniques are simulated by tuning all the controller parameter with and without disturbances in the MATLAB environment.

Keywords

Robotic arm, PID controller, ZN method, Tyreus Luyben method

I. INTRODUCTION

The accurate control of motion is a fundamental concern in industrial applications as well as biomedical applications, where placing an object in the exact desired location with minimum error at the correct exact time is essential for efficient system operation [1]. Applications of robotic arms are generally found in mechatronic electromechanical systems which aid in automating the industrial processes and reducing human errors. An actuator is required to drive each joint of a robotic arm and control several degrees of freedom, where precise control is a crucial requirement [2].

A DC motor is, widely, used as an electric actuator to drive a robot arm horizontally. A common actuator found in many industrial robots is the direct current DC motor[3]. The non-turning part of the motor- the stator consists of a housing, bearings, and either permanent magnets or electromagnets. These stator magnets establish a magnetic field across the turning part of the motor called the rotor. The rotor consists of a shaft and windings through which current moves to power the motor. The commutator is wired to the various windings (which are also called the armature) in such a way that torque is always produced in the desired direction. The underlying physical phenomenon which causes a motor to generate a torque when current passes through the winding [4].

The goal of the paper is to design P, PI and PID controllers for the robotic arm motor and choose the best tuning strategy based on the time domain specifications and error criteria. For smooth movement of pick up, the designed controller should have minimum settling time and minimum error values. Time domain parameters like rise time, settling time, peak time and peak overshoot are compared for different tuning techniques. The Integral Error (IE), Integral Absolute Error (IAE) and Integral Square Error (ISE) values are also compared.

II. MATHEMATICAL MODELING AND SYSTEM EQUATIONS

The three main parts of robot arm are:an arm, connected to actuator through gear train with gear ratio, n [5]. The following are the nominal values for the robot arm to be designed:

Arm mass, M= 8kg

Arm length, L= 0.4 m

Viscous damping constant, b=0.09 Nsec/m

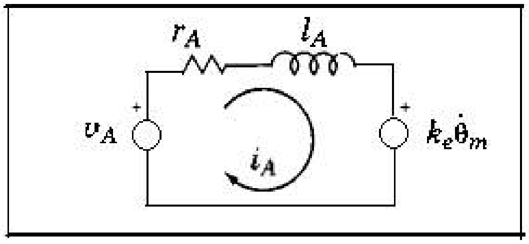


Fig. 1. Circuit diagram of DC motor

The following nominal values for the variousparameters of eclectic motor used [5]:

Input voltage, V_{in}= 12 volts

Armature resistance, r_a= 1 ohm

Armature inductance, l_a= 0.23 Henry

Torque constant, K_t= 0.023 N-M/A

Damping constant, b_m= 0.03

Emf constant, K_b= 0.023 Vs/rad

Moment of Inertia, J_m= 0.02 Kgm^2

Gear ratio, n= 1

The open loop transfer function for the DC motor without any load, relating the input voltage, Vin(s) and the motor shaft output angle, θm(s), is given by:

$$G(s) = \frac{\theta(s)}{V_{in}(s)} = \frac{Kt}{\{[l_a J_m s^3 + (r_a J_m + b_m r_a)s^2 + (r_a b_m + k_t k_b)s]\}} \quad (1)$$

The robot arm is considered as a thin rod with the end effector as part of the arm.

Total equivalent damping

$$b_{eq}=b_m + b_{load}(N_1/N_2)\hat{}2 \quad (2)$$

$$=0.03 + 0.09(1/1)\hat{}2$$

$$=0.12 \text{ Nsec/m}$$

Total equivalent inertia

$$J_{eq} = J_m + J_{load}(N1/N2)\hat{}2 \quad (3)$$

$$J_{load}=1/12(ML\hat{}2)$$

$$=0.107 \text{ kgm}\hat{}3$$

In order to obtain total system transfer function, relating input voltage Vin and Arm-Load output angular position θ_{load}, We Substitute values into transfer function given by (1) with gear ratio, n, gives

$$G(s) = \frac{\theta load(s)}{V_{in}(s)}$$

$$= \frac{Kt * n}{\{[l_a J_{eq} s^3 + (r_a J_{eq} + b_{eq} l_a)s^2 + (r_a b_{eq} + k_t k_b)s]\}}$$

(4)

$$G(s) = \frac{\theta(s)}{V_{in}(s)} = \frac{0.023}{0.0291s^3+0.1543s^2+0.1205s} \quad (5)$$

Simulation is performed for the transfer function given in equation (5) and response curve is obtained in terms of arm angle and time.

III. OVERVIEW OF PID CONTROLLER

The basic PID control scheme is shown in Figure 2 [6]. The error signal e(t) is the difference between the reference input r(t) and desired output y(t),

$$e(t) = r(t) - y(t) \qquad (6)$$

This error is manipulated by the PID controller to produce a command signal for the system given by

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dT + K_D \frac{de(t)}{dt} (7)$$

Where K_P= Proportional gain

K_I= Integral gain

K_D = Derivative gain

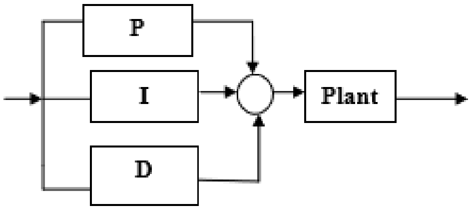


Figure2. Conventional PID controller

A. Design using ZN method

This method which was proposed by Ziegler and Nichols in 1942 is a trial and error tuning method based on sustained oscillations. This method is also known as online or continuous cycling or ultimate gain tuning method which is the most widely used and known method [6]. The controller parameters can be obtained with the knowledge of the ultimate gain and ultimate frequency (Ku and Pu). Table Ⅰ refers to the formula that is necessary to obtain the controller parameters like proportional gain, integral gain and derivative gain for the PID controller to be designed for the given transfer function.

Table Ⅰ
Zn method controller parameters

Controller	Kp	τ_i	τ_D
P	$0.5K_u$	-	-
PI	$0.45K_u$	$P_u/1.2$	-
PID	$0.6K_u$	$P_u/2$	$P_u/8$

B. Design using TyreusLuyben method

The Tyreus-Luyben [7] method is quite similar to the Ziegler–Nichols method but the final controller settings are different. Settings are proposed for PI and PID controllers only and not P controllers. These settings are based on ultimateperiod and ultimate gain.

Table Ⅱ

TyreusLuyben method controller parameters

Controller	Kp	τ_i	τ_D
PI	$K_u/3.2$	$2.2P_u$	-
PID	$K_u/2.2$	$2.2P_u$	$P_u/6.3$

IV. RESULTS AND DISCUSSIONS

A. Simulation by ZN method

The tuning for the given transfer function is carried out using the ZN method. Step response curves are obtained for both with and without disturbances [9]. IPD structure is also taken into consideration for the analysis. The time domain specifications and error values are obtained from the simulation results [8].

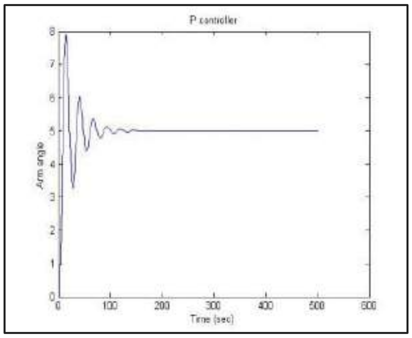
1. Servo Response

Initially simulations are performed without any external load disturbance. Table Ⅲ refers to results calculated for the PID controller without any disturbance.

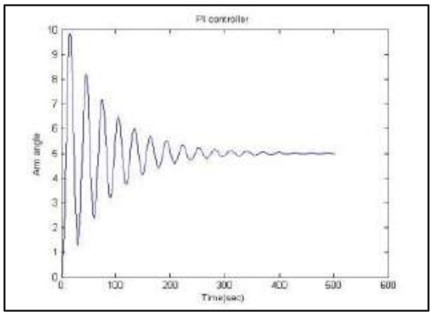
Table Ⅲ
Control parameters and Error values

Controller	Kp	Ki	Kd	IE	IAE	ISE
P	9.2	-	-	2.847	17.79	40.89
PI	8.28	2.486	-	6.346 e-014	57.52	128.7
PID	11.04	5.52	5.52	-4.581 e-008	11.15	26.87

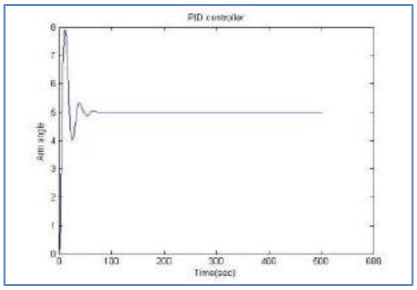
Fig. 2 represents the response curve obtained in term of arm angle and time for the three controller using ZN tuning method.



(a)



(b)



(c)

Fig. 2 . Step response curve for (a) P controller (b) PI controller (c) PID controller

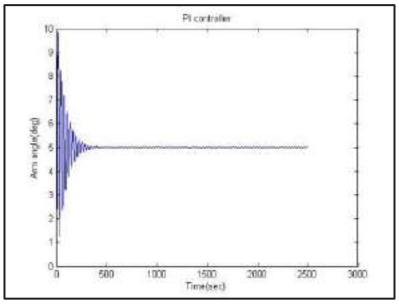
Table Ⅳ

Time domain specifications

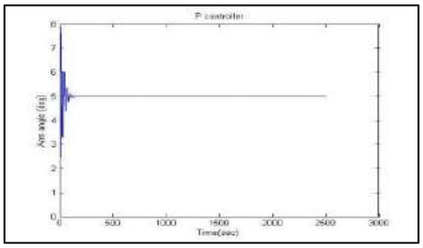
Controller	Settling time(s)	Rise time(s)	Peak time(s)
P	58.6	1.8	2.8
PI	183.6	1.6	3
PID	30.4	1.2	2.2

2. Regulatory Response

Simulation is carried out with a disturbance of magnitude 5 and an initial step time of 100.



(a)



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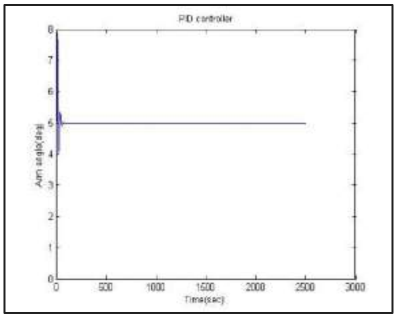


(c)

Fig. 3 . Step response curve with disturabance for (a) P controller (b) PI controller (c) PID controller

B. Tyreus- Luyben tuning method

The tuning for the given transfer function is carried out using the Tyreus-Luyben method. Step response curves are obtained for both with and without disturbances. IPD structure is also taken into consideration for the analysis. The time domain specifications and error values are obtained from the simulation results [8].

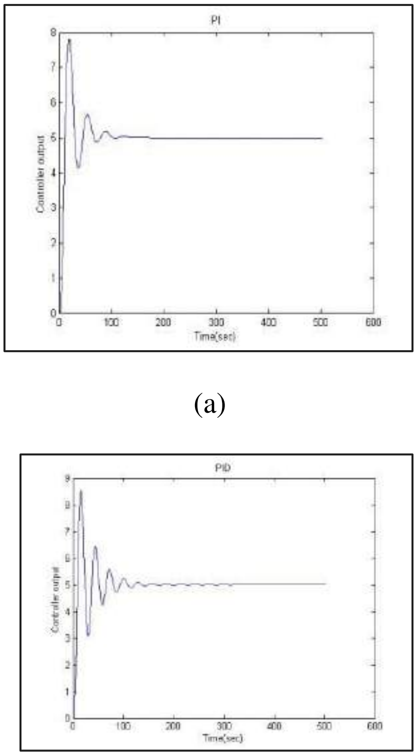
1. Servo Response

Initially simulations are performed without any external load disturbance. Table 5refers to results calculated for the PID controller without any disturbance and the fig. 4 is the response curves after the simulation in terms of arm angle and time.

Table Ⅵ

Control parameters and Error values

Controller	Kp	Ki	Kd	IE	IAE	ISE
PI	5.75	0.653	-	1.62e-05	18.1	45.46
PID	8.364	0.950	5.311	1.574e-05	22.52	52.24



(a)

(b)

Fig. 4 . Step response curve for (a) PI controller (b) PID controller

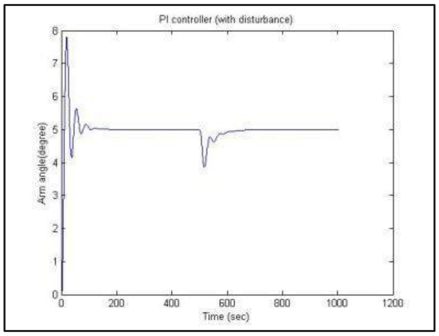
Table Ⅴ

Time domain specifications

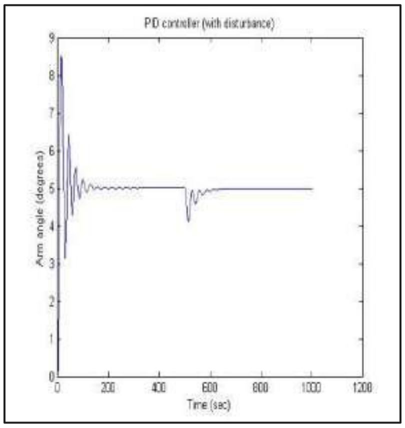
Controller	Settling time (s)	Rise Time(s)	Peak Time(s)
PI	74.6	2.2	3.6
PID	62.6	1.8	3

2. Regulatory Response

Simulation is carried out with a disturbance of magnitude 5 and an initial step time of 100 for the PID controller tuned with Tyreus Luyben method.



(a)



(b)

Fig. 5 . Step response curve with disturbance for (a) PI controller (b) PID controller

C. IPD structure

In an IPD, the integrator is used as the series controller while the derivative is used in the feedback path. In this approach, sudden changes in input do not produce large changes in the controller output due to the P controller. Both Zn method tuning and Tyreus-Luyben method tuning were performed with the IPD structure.

1. ZN method

For the given transfer function, simulations were carried out using IPD structure with the ZN tuning parameters. Minimum peak overshoot and minimum error were observed after the simulations with a run time of 100 seconds.

Table Ⅶ

Error criteria values

IE	IAE	ISE
9.84	22.08	45.48

Table Ⅷ

Time domain specifications

Settling time (s)	Rise Time(s)	Peak Time(s)
57.8	3.4	4.4

Fig. 6 shows the step response between the arm angle and time for the simulated IPD structure using ZN method tuning parameters.

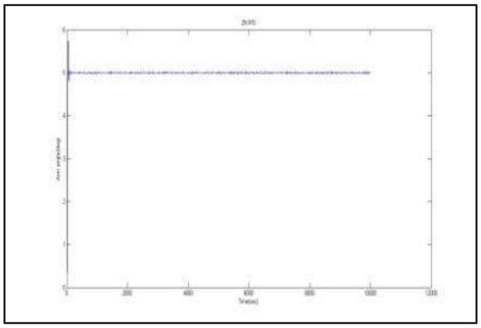


Fig. 6. Step response curve for IPD structure

2. Tyreus-Luyben method

For the given transfer function, simulations were carried out using IPD structure with the Tyreus-Luyben tuning parameters. Minimum peak overshoot was observed after the simulations with a run time of 100 seconds.

Table Ⅸ

Error criteria values

IE	IAE	ISE
38.76	49.28	122.2

Table Ⅹ

Time domain specifications for IPD structure

Settling time (s)	Rise Time(s)	Peak Time(s)
94.9	94.8	94.8

Fig. 7 shows the step response between the arm angle and time for the simulated IPD structure using Tyreus-Luyben method tuning parameters.

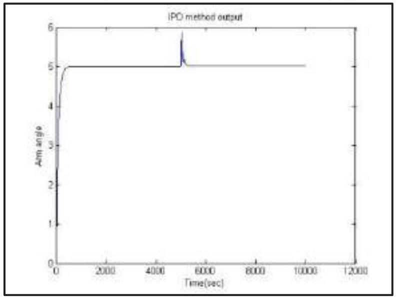


Fig. 7. Step response curve for IPD structure

D. CONCLUSION

This paper represents the designing and performance evaluation of P, PI and PID controller for a robotic arm system. The various results presented above show that Ziegler Nichols is a better technique of PID tuning than TyreusLuyben method for the given transfer function. Simulation results for the process show the effectiveness of the proposed scheme. From the time domain specifications it has been proved that ZN tuned PID controller produce minimum settling time. The performance indices IAE and ISE, under the entire error criterion are observed to be better for the proposed controller. The simulation results for ZN tuning method present a better performance for the considered IPD structure with minimum settling time and error indices.

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