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DESIGN AND TUNING OF PID ALGORITHM FOR OPTIMUM PERFORMANCE OF PVTOL SYSTEM

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ABSTRACT

In this paper different design scheme for a PID controller have been introduced for a single axis of a quadcopter. This type of model is also known as PVTOL (planar vertical take-off and landing) system. The PVTOL system possess complicated roll control schemes, non-linearity, low stability and is a second order type process. This paper aims to present a comparison between different controllers used in a dynamic model of a PVTOL platform. Performance comparison of classical Zeigler Nicholas (ZN-PID) is done against Genetic Algorithm (GA) based controller optimization. The results are obtained using MATLAB and SIMULINK, the (ZN-PID) and (GA) based controller is designed for disturbance rejection, close loop response and set point tracking.

I. INTRODUCTION

During the years 1950 – 1970 experiments related to Vertical Take Off and landing (VTOL) vehicle came into existence. It is also named as Short run Take Off and Landing. VTOL consists of three types of configurations i.e. Wining type configuration which has fixed wings with vector thrust engine, Helicopter type configuration consist of moving wings with engine, Ducted type configuration consist of ducted rotor which helps to lift. All the configuration helps to take off and land vehicle vertically. VTOL has ability to fly slowly and land in small places as well. Due to increase in demand of VTOL vehicles, aircrafts and quadrotors, The Hover eye platform from Bertin Technologies was introduced. It was a first step towards Unmanned VTOL [1]. In [2] study of different types controllers for Unmanned Aerial Vehicle is given.

In [3] [4] stability control of VTOL system is discussed. Due to which usage of these types of system increased in various fields. As the demand of VTOL systems is increasing day by day it is used in field of aerospace and photography. According to recent research, VTOL uses batteries or motors instead of fuel, it reduces maintenance cost value. Usage of motors helps in reduction of noise pollution and gas emission as well. Nonlinear controller can be developed to stabilize the altitude by considering dynamic behavior of motors [5].

There are two forms of motors used for distinct purposes. The primary one is Brushed DC motor, typically known as Ordinary direct current motor. It acquires large space with giving less amount of torque with less efficiency and low power density. This type of motor is not suitable for developing generation equipment. New generation equipment must consist of great stability, low cost maintenance, reduced development time, adaptive to various conditions, as well as is must involves higher performance parameters such as high efficiency and reduced electromagnetic interferences [6].

After considering all the above required parameters, another form of motor adequately fulfils the conditions.

Another form of motor is Brushless DC Motor (BLDC). In [7] performances of BLDC motors are mentioned. BLDC motors are highly demanded in areas which requires interpretative performance due to their small size, torque and compatible structure. In [8] parameters of motor and aspects related electronic devices is focused.

The BLDC motor works on same principles as of brushed DC motor which is internal shaft position feedback. In BLDC motor mostly we use hall effect sensor method. Here the current carrying conductor is stationary while the permanent magnet moves. When the stator coils are electrically switched by a supply source, they become electromagnet and starts to produce a uniform field in air gaps. Even the supply is DC, switching generates an AC waveform with trapezoidal shape. Most BLDC motors have three Hall sensors fixed firmly into stator on the non-driving end of the motor. When the magnetic pole of rotor passes near from hall sensors, they give a high or low signal. Due to switching of windings as high and low signal, corresponding winding energized as North and South poles. The motor produces torque because of development of attraction forces and repulsion forces. Due to this motor moves in a clockwise direction and compensation technique one can apply as per requirement [9].

Dynamic equation is established between rotor and stator to represent the synchronization error in [10].

The absence of brushes in a BLDC Motor is perhaps biggest advantage. It generates less noise and it is also less prone to sparking due to the lack of a commutator. The BLDC motor requires low maintenance than Brush DC motors. BLDC motors has higher speed ranges, high dynamic responses and it lasts longs in total operating hours. BLDC motors required less space and are lighter in weight. Working of BLDC motors under variable loads and reference speeds are given in [11].

This paper specifically aims to design a system of single axis quadcopter in which PID controller is used. The rest of the paper is arranged as follows. Section 2 shows the system and its description, in this section physical description of system is mentioned. Section 3 depict the dynamic modelling of system, in this section forces acting on the system is explained. Section 4 deals with designing of PID controller, in this different method for designing of controller is mentioned with its simulation model w.r.t MATLAB. While section 5 and section 6 deal with results and conclusion respectively.

II. SYSTEM AND DISCRIPTION

The PVTOL prototype is rather designed to move on an inclined plane. The general view of our experimental setup is depicted in Figure 1. The PVTOL moves on an inclined plane, which defines our two-dimensional (2-D) workspace. The size of the inclined plane is 60cm(L) * 5cm(W). A 10cm(L) threaded rod is used to fix the clamps at the center of the inclined plane. The threaded rod is fixed exactly at the midpoint of the inclined plane so that a pivot point is achieved. A pivot point is required so that the inclined wooden plane can roll in a particular axis. The inclination of the wooden plane is 30deg. The size of each propeller is 10-cm long. Two high speed and high torque BLDC motors are fixed at the end of the inclined wooden plane. One motor rotates in clockwise direction and other rotates in counter-clockwise. The two BLDC motors are driven by driven by two separate ESC (electronic speed controller). The total thrust is the sum of the thrusts of individual motors. The rolling moment is obtained by increasing the speed of one motor while decreasing the speed of the second motor and vice versa. Each motor is linked to a speed variator which is itself linked to an IMU (inertial moment unit).

Figure 1: System model (Hardware).
Source: Authors, (2020).

It is a device capable of measuring the force (acceleration) and speed. Generically it consists of an Accelerometer and a Gyroscope. The IMU is placed at the center of the inclined wooden plane, over the pivot point. The gyroscopes improve the maneuverability and the stability of the system. Dimensions of the components used in Figure 1 are listed in the Table 1.

Table 1: Parameters of the system.

Beam Length	60 cm * 5 cm
Beam weight	250gm
Propeller size	10 cm(L)
Motor operating voltage	12V
Motor weight	55gm
ESC output	30A
ESC weight	22gm

Source: Authors, (2020).

III. DYNAMIC MODELLING

The PVTOL is a model of a flying object that evolves in a vertical plane. More specifically, this aerial vehicle basically consists of two propellers at the end of the single axis. This model has minimum number of states and inputs but retains many of the features that need to be considered while designing control laws for a real aircraft. It has three degrees of freedom (x, y, φ) corresponding to its position and orientation in the plane. It has two thrusters that produce a force and a moment on the system as seen in Figure 1 [12]. Here F1 and F2 are the vertical forces and z is the rolling moment. The factor g denotes the acceleration due to gravity. Thus, PVTOL is an underactuated system with three degrees of freedom and two inputs.

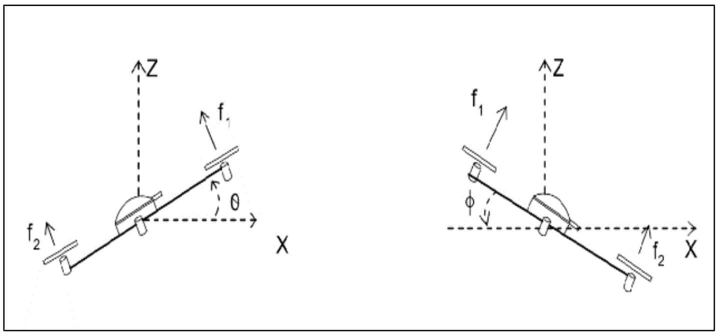

Figure 2: Schematic diagram of system.
Source: Authors, (2020).

We are going to propose the control of X axis rotation of the system, therefore we assume that the Y and Z axes as zero. Hence the equation of the rolling dynamics is:

$$\emptyset = F \cdot d - \mathcal{C}\,\ell_{\phi} \cdot \dot{\phi} \qquad (1)$$

Where, F=f1-f2 is the force produced by the thrust difference of the motors, d is the center of mass of each motor and Cl0 is the coefficient of damping on the x-axis. In this case Cl0 is 0.36.

The equations and parameters needed to generate the matrices are estimated based on empirical experimentation and measurments on control of unmanned vehicle. This work assumes the equations presented in [13] as described below.

The simplified transfer function that describes the rolling dynamics of the system is shown in Equation (2).

$$\frac{\phi(s)}{F(f)} = \frac{5}{S^2 + 25s} \qquad (2)$$

IV. DESIGN OF PID CONTROLLER

In this section designing of PID controller is developed using different methods. The PID controller is most commonly used versatile technique. Given Figure 3 shows the simulation model of PID controller executed in Simulink. The form of PID controller is given in Equation (3) below.

$$\text{PID Output} = k_p + \frac{k_i}{s} + k_d s \qquad (3)$$

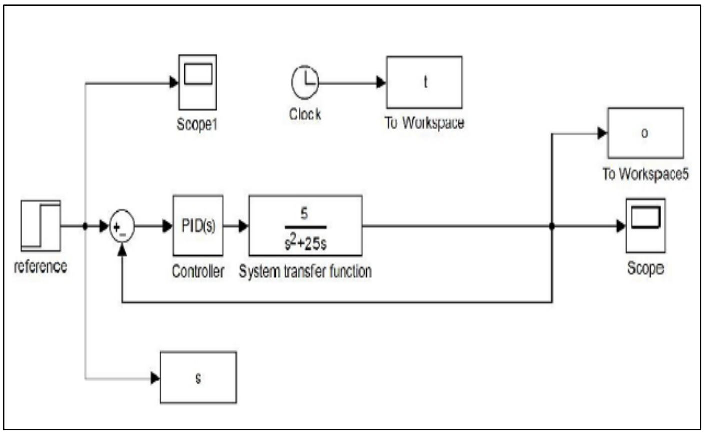

Figure 3: Simulation model.
Source: Authors, (2020).

IV.1 ZIEGLER NICHOLAS (ZN) - PID

The Ziegler–Nichols tuning method is an experimental method for tuning a PID controller by controlling. It is also known as ultimate cycle method. This tuning method is employed to avoid disturbance by PID loops. It is performed by adjusting the I (integral) and D (derivative) gains to zero. The proportional gain, is then increased from zero to the ultimate gain. The oscillation period are then used to set the P, I, and D gains depending on the type of controller used and its behavior [14]. The Ziegler-Nichols rule assumes that the system has a transfer function of the following form:

$$K \cdot \frac{e^{-sT}}{a + s} \qquad (4)$$

This method can be easily put in to tune a PID controller by using the relations provided in Table 2.

Table 2: Relations between controllers.

Type of controller	k_p	T_i	T_d
PID	$0.6K_u$	$0.5T_u$	$0.125T_u$

Source: Authors, (2020).

Iterations are carried out with the help of MATLAB to find optimal values of K_u and T_u. Based on the results of

K_u and T_u, the corresponding values of controllers are:

$k_p = 150$

$T_i = 0.08$

$T_d = 0.02$

IV.2 GENETIC ALGORITHM (GA) - PID

A Genetic algorithm (GA) is a process of natural selection that belongs to the larger class of evolutionary algorithms (EA). Genetic algorithm has the same role as Artificial Intelligence. Genetic Algorithm is sometimes considered to be robust. Genetic Algorithms are known for its high performance in complex areas without experiencing the difficulties. In [15] the GA tuned (proportional, integral and differential) PID controller surpass the developed PID controller. GA adjusts on changing inputs and also be able to handle noisy or fuzzy input. GA is able to handle complex problems better. Genetic algorithms simulate the process of natural selection that means those parameters who can adapt to external changes and are able to work and give required output. The GA based optimization tool in MATLAB is used for finding optimum PID settings are given in this paper. The fitness function is designed according to optimize the performance criteria.

```
1/5/10 10:25 AM   C:\Users\vmsdemonuser\Doc...\pid_optim.m     1 of 1

function [J] = pid_optim(x)
s=tf('s');
num=[5];
den=[1 25 0]
Plant=tf(num,den);

Kp=x(1)
Ki=x(2)
Kd=x(3)

cont = Kp+Ki/s+Kd*s;

step(feedback(Plant*cont,1));

e = 1 - step(feedback(Plant*cont,1),t);

J=sum(t'.*abs(e)*dt);
```

Figure 4: MATLAB code.
Source: Authors, (2020).

Table 3: Performance indices comparison.

Performance Index	ZN – PID	GA – PID
Settling time(s)	0.525	3.81
Peak Response	1.37	1.08
Overshoot %	37.3	7.51
Rise time(s)	0.0513	0.517
Final Value	1	1

Source: Authors, (2020).

Based on the results of MATLAB corresponding values of controllers are:

$k_p = 4.51$

$T_i = 13.51$

$T_d = 4.51$

The effects of lead and lag compensator shows in oscilloscope Figure 2 and 4. Normally damping which will be more in case of led compensator. Due to this less rise time and less overshoot.

With the observation from oscilloscope one can easily find the lead and lag phase difference. Depending on the values of register and capacitor, the circuit behaves as lead and as well as lag. Any type of correction if a system will require then compensator circuit is very useful. Some cases lead lag compensator that is combination circuit is also useful. Satellite lunching, automobile, robotic control it's use is more.

V. SIMULATIONS AND RESULTS

In this section, we present some simulation results using MATLAB and SIMULINK in order to observe performance of proposed systems. We have considered two different types of controlling systems. The performance evaluation of the controllers is done by rating based on settling time, overshoot and peak response for open loop response and set-point changes and disturbance rejection. The Performance indices obtained for ZN-PID and GA are presented in Table 3 and Figure 5-6 show responses of the system for reference tracking set-point change and disturbance rejection.

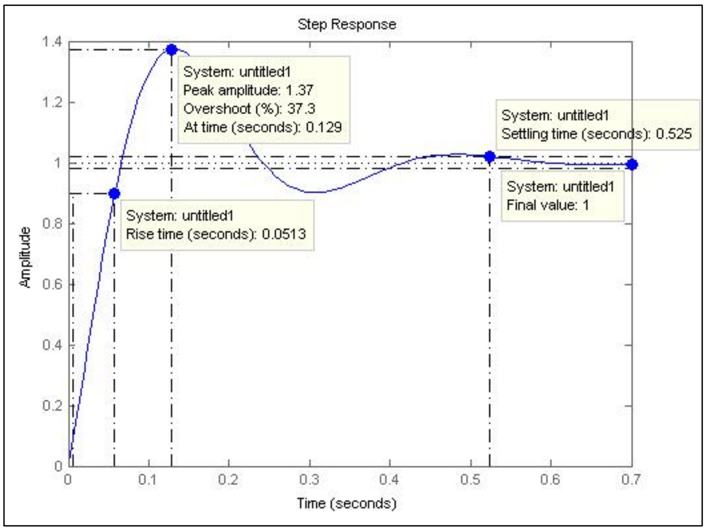

Figure 5: Ziegler Nicholas Simulation model.
Source: Authors, (2020).

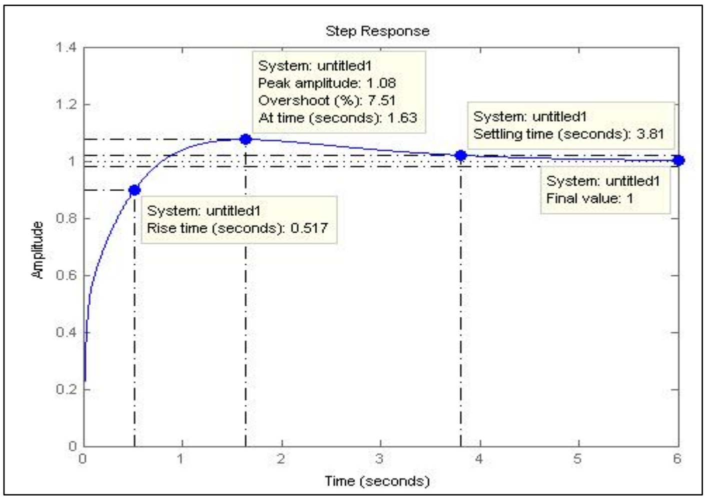

Figure 6: Genetic algorithm simulation model.
Source: Authors, (2020).

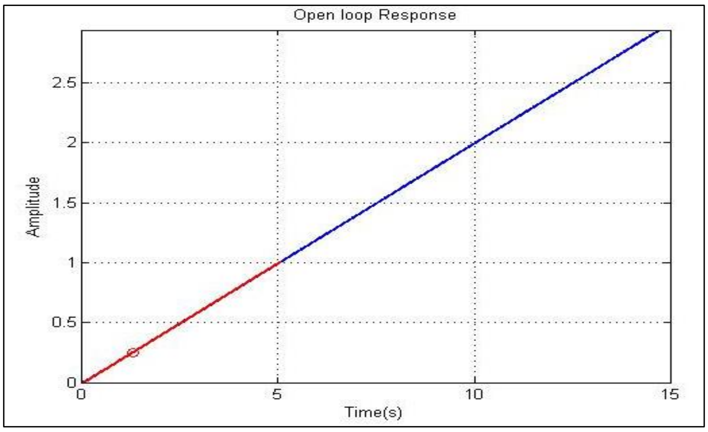

Figure 7: Open loop response model.
Source: Authors, (2020).

Figure 7 depicts the open loop response of the proposed system. It shows as the input values increases output increases accordingly, results given by the system in open loop graph depicts the graph in linear way which shows that the input given is directly proportional to the requires output as there is no feedback given. Present system is unstable as pole and zero lies on right side.

The output response of system shows the relation between input given to the system and Rolling effect.

In this paper single axis of a quadcopter is consider it deals with rolling effect (i.e. tilt left or tilt right) of an axis. From Figure 7 it shows that Rolling effect of the system increases with increase in input.

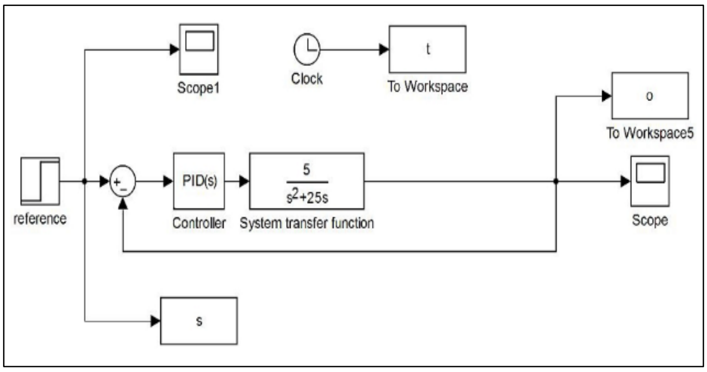

Figure 8: Close loop simulation model.
Source: Authors, (2020).

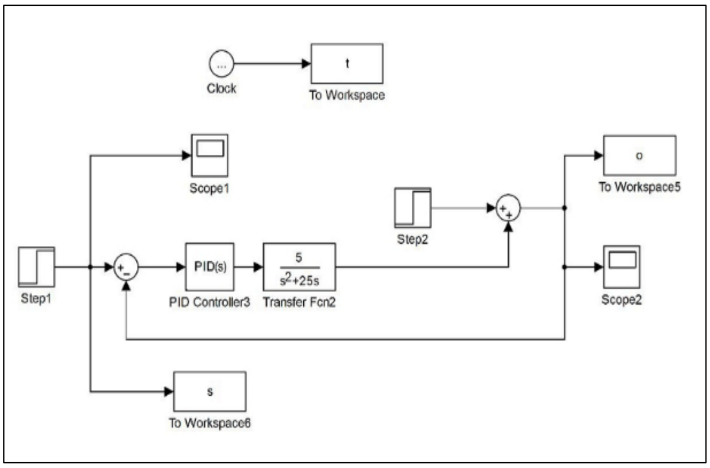

Figure 9: Disturbance rejection simulation model.
Source: Authors, (2020).

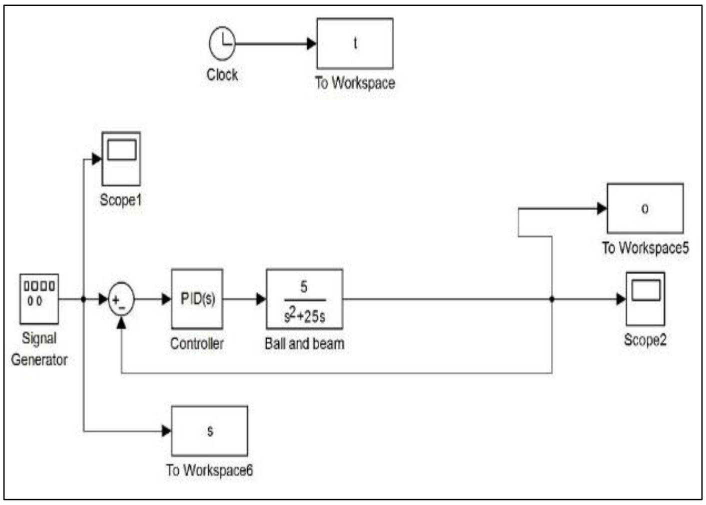

Figure 10: Set-point simulation model.
Source: Authors, (2020).

The Figures 8-10 shows Simulation model for a system proposed for finding closed loop response, set point tracking and disturbance rejection of the system. For closed loop response a step signal is used whereas for set point tracking a square wave with 0.5HZ frequency is used and for disturbance rejection a spike of 0.5 amplitude is introduced in the system at 3 seconds time interval.

The above Simulink models are used to generate system results which are given below:

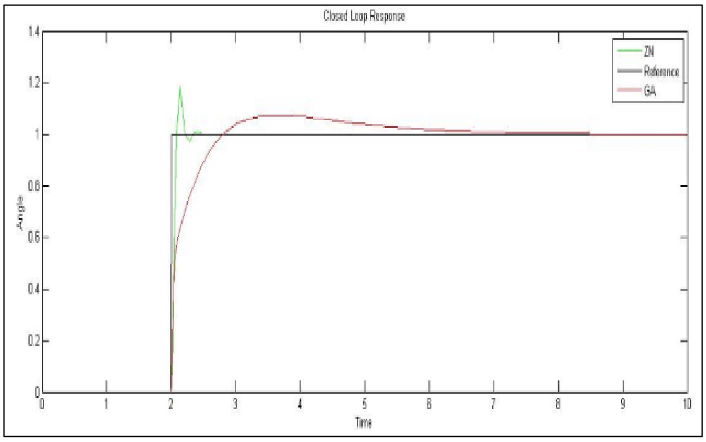

Figure 11: Close loop response.
Source: Authors, (2020).

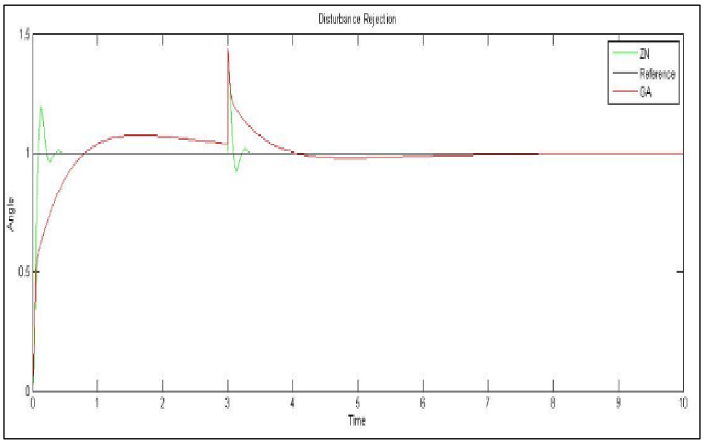

Figure 12: Disturbance rejection response.
Source: Authors, (2020).

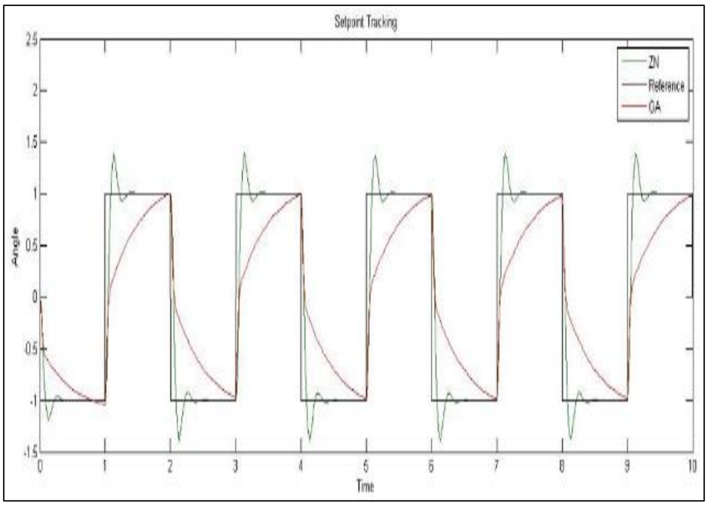

Figure 13: Set-point response.
Source: Authors, (2020).

VI. CONCLUSIONS

The PID controller was tuned using Zeigler Nicholas and Genetic Algorithm optimization method and the simulations are carried on MATLAB SIMULINK environment. Considering the analysis of the data found in this work the different control methods present satisfactory results. Performance evaluations of both the controllers are done on the basis of set point tracking and disturbance rejection. A square wave is used as a reference for the set point tracking and disturbance rejection is evaluated by introducing a spike in system at three seconds interval. Each of this controller provide singular characteristics that makes it difficult to say which one is the best. The settling time obtained from Zeigler Nicholas tuning method is less, while the overshoot is large which cause non-linearity in the system. The Genetic Algorithm optimization method has comparatively higher settling time, but the overshoot is less making the system more responsive in the speed control of linear brushless DC motors.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Dr. Badri Narayan Mohapatra, Shubham Gadekar and Rutuja Zate.
Methodology: Dr. Badri Narayan Mohapatra and Shubham Gadekar.
Investigation: Shubham Gadekar and Dhavalsinh Bhosale.
Discussion of results: Dr. Badri Narayan Mohapatra, Shubham Gadekar, Rutuja Zate and Dhavalsinh Bhosale.
Writing – Original Draft: Shubham Gadekar and Rutuja Zate.
Writing – Review and Editing: Dr. Badri Narayan Mohapatra and Shubham Gadekar.
Resources: Rutuja Zate and Dhavalsinh Bhosale.
Supervision: Dr. Badri Narayan Mohapatra and Shubham Gadekar.
Approval of the final text: Dr. Badri Narayan Mohapatra, Shubham Gadekar and Rutuja Zate.

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