International Journal of Application or Innovation in Engineering & Management (IJAIEM)
Web Site: www.ijaiem.org Email: editor@ijaiem.org
Volume 9, Issue 4, April 2020 ISSN 2319 - 4847

Modelling and Control of Roll Dynamics of a Planar Vertical Takeoff Landing Vehicle

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ABSTRACT

In this paper design schemes have been introduced for roll control of a PVTOL vehicle. PVTOL is a category of UAV that has two propulsion systems and can take-off and land in a vertical plane. The working model of roll of the system is found out using black-box modelling technique using system identification toolbox in matlab which requires no insight of the system. A PID controller is incorporated to control the system and the controller parameters are optimized using the genetic algorithm optimization toolbox available in matlab considering ITAE as an optimization criteria. The simulation results for optimized values of controller depictsatisfying time domain characteristics.

Keywords: PID, Black-box modelling, PVTOL, Genetic algorithm.

1. INTRODUCTION

UAVs are becoming very useful day by day due to advancements in aerodynamics, structure,propulsion, design and sensor technologies that allow aircrafts to have capabilities that were not available until recently.**Unmanned aerial vehicle (UAV),** military aircraft are developed to be guided autonomously, by remote control, or both and that carries sensors, target detectors, or electronic transmitters designed to interfere with system or destroy enemy targets. Various types ofdesign of a UAV with Vertical Take-Off and Landing (VTOL) has been developed and tested [1] .Unmanned aerial vehicles (UAVs) have been widely adopted in the military world over the last decade and the success of these military applications is increasingly driving efforts to establish unmanned aircraft in non-military roles.The benefits of the UAVs can be seen in fields like rescue, surveillance, photography [2]. UAVs are also very efficient, offering substantially greater range and endurance as compared to manned systems. Larger UAVs are used for strategic reconnaissance. As UAV roles become more diversified, there is a continuous need to adapt to performing multiple tasks efficiently with a single airframe [3]. This is especially important in VTOL airframes that can exhibit a more number of different tasks. For now, mini UAV platforms are dominated by two main types, i.e., fixed-wing conventional aircrafts and vertical take-off and landing (VTOL) aircrafts, also known as rotorcrafts or multi-copters, and each type has its own inherent limitations. A new and promising trend is to develop a fixed-wing VTOL UAV or the so-called Hybrid UAV, which effectively integrates the features of fixed-wing and VTOL aircrafts and thus inherits the advantages of both. VTOL UAVs have the spot take-off and landing functionality even at hazardous conditions. UAVs can be used for different applications include fire ground inspection, crop and land surveying, emergency communications, and ensure the security of people [4]. A VTOL-UAV is an aerial vehicle that does not require an on board crew to operate. It is therefore a useful tool in many operations, including search and rescue missions, environmental assessments, and remote communications with operator on the field. In [16] some essential control problems of a vertical take-off and landing aircraft are studied, some simple control strategies for state-to-state control were developed. Further effective closed-loop control schemes for stability and trajectory tracking are presented for the system.A method for controller synthesis for a VTOL aircraft has been proposed by using an input-output linearization technique [5]. Unmanned convertible aerial vehicle are also developed and studied [6].In [7]nonlinear tracking controller for the non-minimum phase is proposed to illustrate under actuated model of a vertical take-off and landing (VTOL) .The tilt rotor UAV which is nonlinear due to its complexity and structure is proposed in [8]. The model shows the airframe and motor dynamics and aerodynamic as well as gyroscopic effects on flight conditions [3]. An advanced control strategy is required for maintaining good performance of the controller. Various researchers have evaluated trajectory tracking problem for UAV's in many different ways [9]. Genetic algorithm (GA) is a type of computational model which is used in various control systems. The genetic algorithm is an optimization method which involves iterative search procedures.This algorithm is modeled on the principle of natural selection based on Darwin's theory where the fittest individuals have a higher probability of survival and to produce the next generation of the species.Therefore, the results are executed several times, this algorithm can lead to a different chronological succession of designs and a different problem solution even with the same initial conditions. Genetic algorithms can be used even for mobile or unknown systems or models, given that we have sufficient computational power.Genetic Algorithm has been used as the optimization tool where the control design goal is to have stable vertical flight in the presence of high wind environment [10]. In [20] after data preprocessing, the horizontal and vertical dynamic model of system is constructed for the small unmanned aerial vehicle using adaptive genetic algorithm. The identified model is tested by a series of simulation and tests. In [11] the modelling ofquad rotor system is done as a Vertical Take Off and Landing UAV (VTOL UAV) a nonlinear adaptive controller is designed, to solve trajectory tracking problem in the presence of nonlinearities various disturbances.Some vertical take-off and landing (VTOL) unmanned aerial vehicles (UAVs) have longitudinal and lateral rotor tilting mechanisms are developed using a Newton-Euler formulation for double axis OAT mechanism which is proposed in [12]. In [18] a dynamic model of system having configuration of eight rotors is depicted,here the equations of motion for the VTOL aircraft are obtained using Euler-Lagrange approach.Hybrid Unmanned Aerial Vehicles (UAVs) are also versatile and useful and is reviewed and presented in [13].In [14] the Coriollis and gyroscopic torques are used to propose a control scheme for exponential attitude stabilization of the four rotor unmanned aerial vehicle.In [15] fuzzy adaptive controller is proposed for output feedback tracking control method for VTOL (vertical takeoff and landing) aircraft. The fuzzy adaptive controller is designed to estimate both unknown input coupling coefficient and the input-dependent disturbances of the system. In [17] a new design method for the flight control of a nonlinear non-minimum phase VTOL aircraft is proposed. The non-minimum phase property is caused by the small coupling between rolling moments and lateral acceleration of the system.TheVertical take-off and landing (VTOL) aircraft comprises of both fixed-wing and rotary-wing aircraft. Tail-sitting configuration is the simplest way for the Vertical take-off and landing system to maneuver since it does not need extra actuators. Therefore in [19] hovering control strategy is proposed for a tail-sitter VTOL UAV that increases stability against large disturbance.

This paper specifically aims at addressing the problem of modelling and roll control of a PVTOL vehicle. The rest of the paper is arranged as follows. Section 2 showsthe experimental development and modelling. In this section the physical model of system is described, gathering of the input and output data and preprocessing of the data is done. The model estimation is done and finalized and the response of the system are plotted. Section 3 depict the controller design and simulations. While section 4 and section 5 deal with results and conclusion respectively.

2. Experimental Development and Modelling

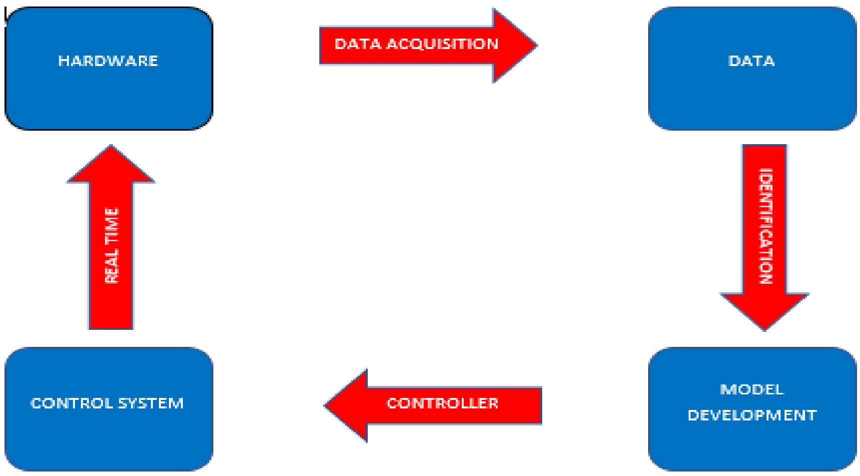

Figure 1 Flow chart.

2.1 Physical description of the system.

This section consists of details about the physical construction of the PVTOL vehicle. The system construction shown is referred from reference [22]. The physical system parameters are tabulated in table1 below. In addition to two propellers the construction of a PVTOL system may consist of many subsystems such as ailerons and elevators as intended for some specific application. This paper deals with roll control of the PVTOL vehicle only. Therefore the construction justifies itself. The PVTOL system consists of a centrally pivoted beam which can rock about the pivot. Two brush less DC motors with propellers are mounted at extreme ends of the beam. The necessary components like ESC's are tied along the beam to control the motors. A gyroscope and accelerometer sensor is mounted on the beam to measure the roll angle of the beam. Arduino Uno is used as controller for the system.

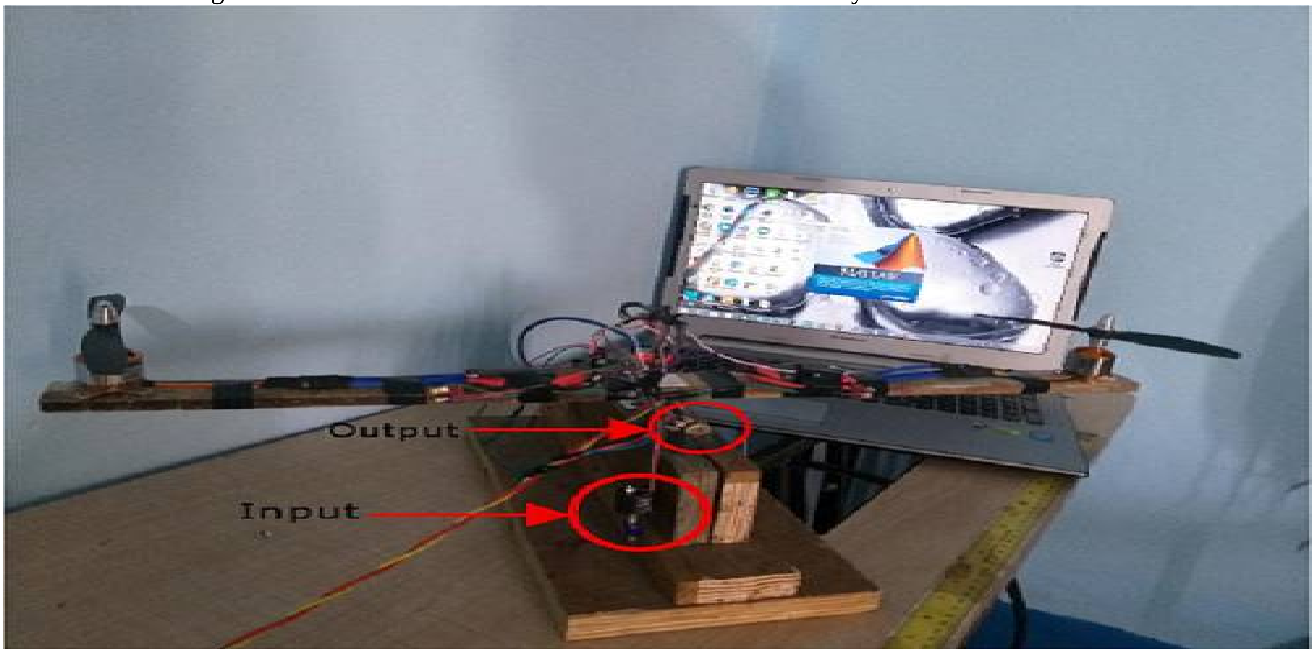

Figure 2 Physical build of the system.

Table 1: Physical specifications

Components	Specifications	Quantity
BLDC Motors	1200KV	2
Propellers	2 blades 3inch	2
ESC	20 amps	2
Gyroscope sensor	MPU 6050	1
ArduinoUno	-	1
Power supply	12V DC	1

2.2 Modelling of the system.

2.2.1 Gathering input and output data

This Paper aims at modelling the roll dynamics of the system and designing a suitable controller for it. Back-Boxmodelling technique is used to model the system. Which requires no insight of the composition of the system components or its working principles. To obtain the model of the system using back box technique input and output data of the system are required which are obtained by making few arrangements as shown in figure 2. Two potentiometers are used to apply input and collect output data from the system. The data obtained is as shown in figure 3and figure 4which is used as estimation data and validation data for obtaining the model of the system using the system identification toolbox available in MATLAB SIMULIMK environment.

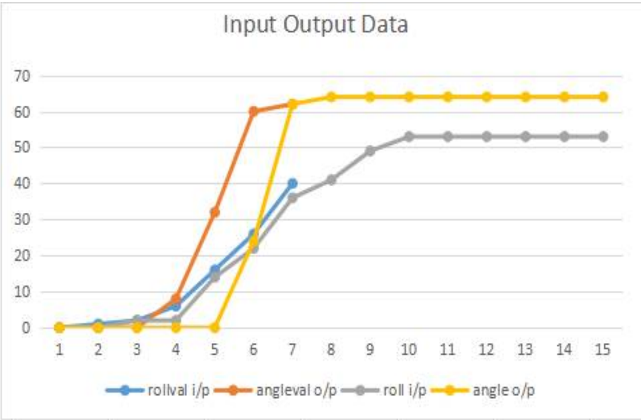

Figure 3 Excel data

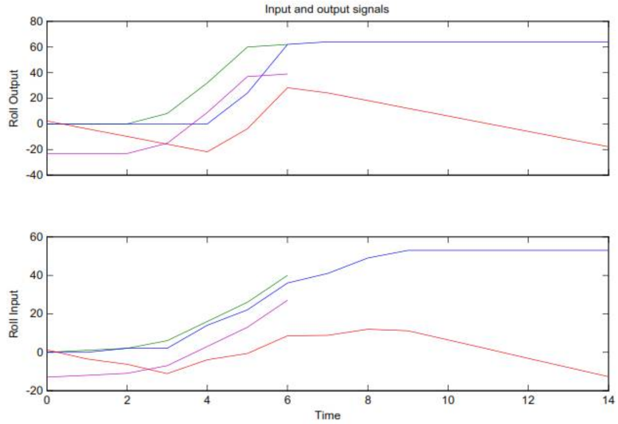

Figure 4 Data plotted in IDENT toolbox

2.2.2 Preprocessing the input output data

The data obtained is further analyzed in the system identification toolbox for finding the model of the system. Data is preprocessed in the system identification toolbox by selecting ranges and de trending it. The system identification toolbox available in the MATLAB SIMULINK environment is very useful to identify the model of the system when there is no insight to the system itself but its input and corresponding data output are known. It lets you select type of model and its order based on our understanding of the system. The figure 5 below shows the IDENT toolbox window used to obtain the model.

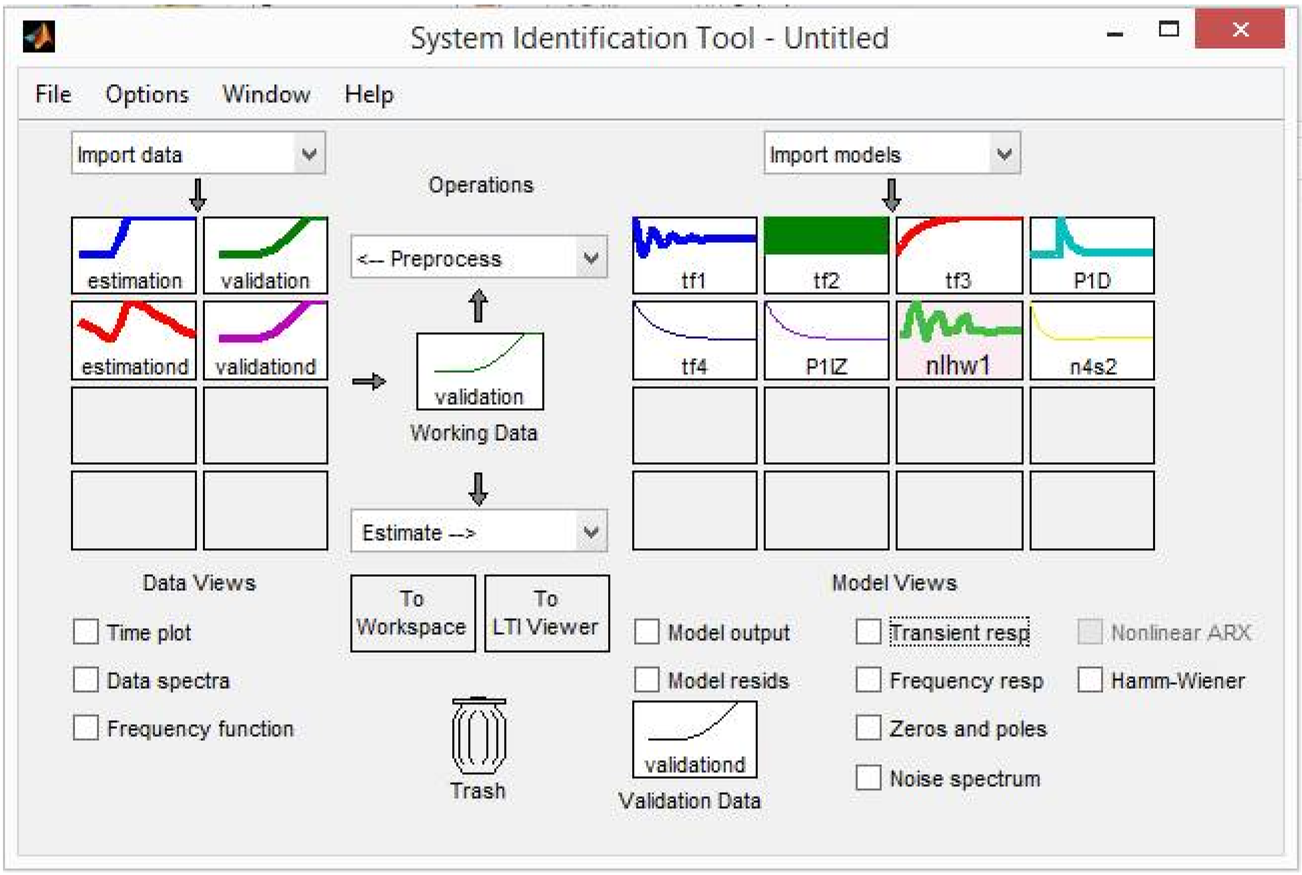

Figure 5 System identification toolbox window

2.2.3 Model estimation and validation

The data obtained from the actual physical system is then used to derive its model. Data obtained is then imported into the toolbox and is pre-processed so as to create estimation data sets and validation data sets. The pre-processed data then is simply dragged into the working data section and validation data section to carry out further analysis.

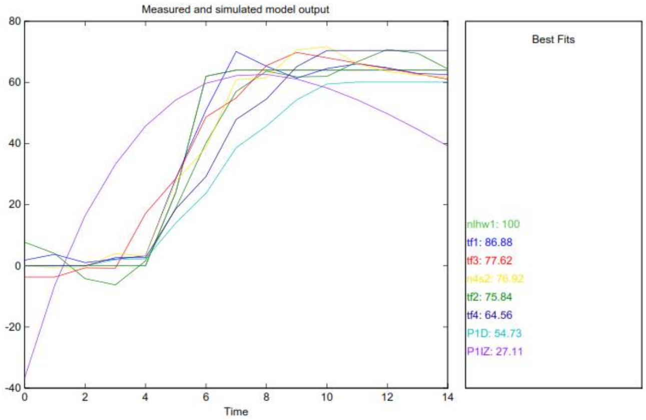

Figure 6 Percentage fit of estimation data

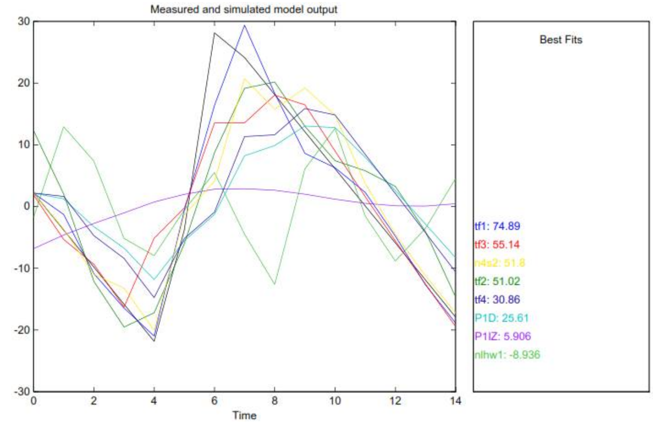

Figure 7 Percentage fit of de trended estimation data

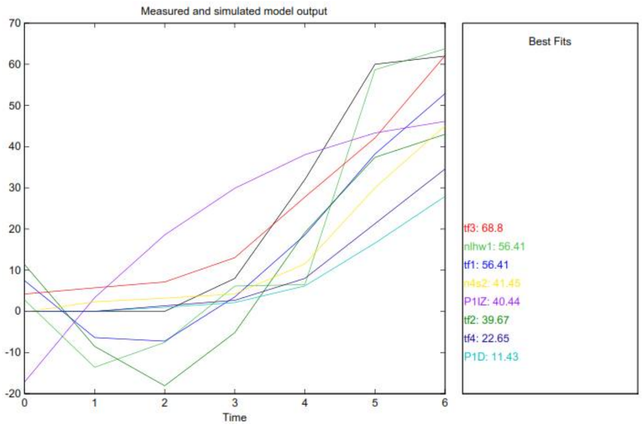

Figure 8 Percentage fit of validation data

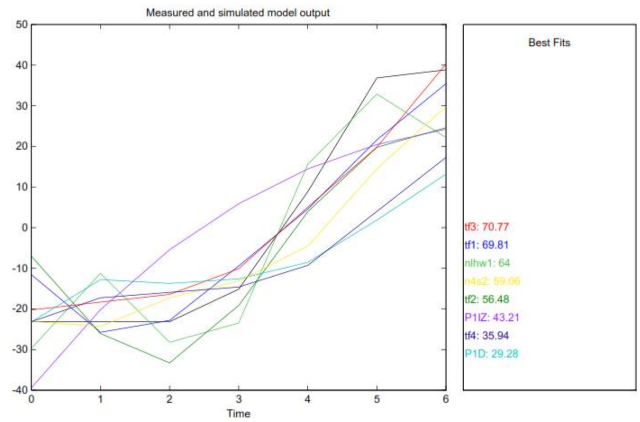

Figure 9 Percentage fit of de trended validation data

The figures 6-9 show the fit curves of various model types with different orders and delays to the estimation data and validation data respectively. It can be seen that the some type of model produce about cent percent fit to the estimation data but the fit percentage to the validation data drops significantly. Therefore model that has decent percentage of fit to the estimation data and validation data as well is selected. This is called as model estimation and validation. In this case transfer function model with two poles and one zero is chosen.

2.2.4 Model finalization and response plotting

The model having the highest fit rate to both estimation data and validation data is chosen to carry out further analysis. Using the toolbox one can obtain various time domain and frequency domain responses of the desired model to get proper insight of the dynamics of the model. Figures 10-12 show pole zero plot, step response and transfer function obtained respectively. The pole zero plot exhibit that poles and zero lie in the LHS of the S-plane which points to the fact that system is open loop stable and controllable. The step response plot shows open loop response of the system to a applied step input. The obtained response shows that the system is oscillatory in nature and requires incorporation of a controller to stabilize it. Figure 11 shows the transfer function generated by the IDENT toolbox. The transfer function generated is a second order.

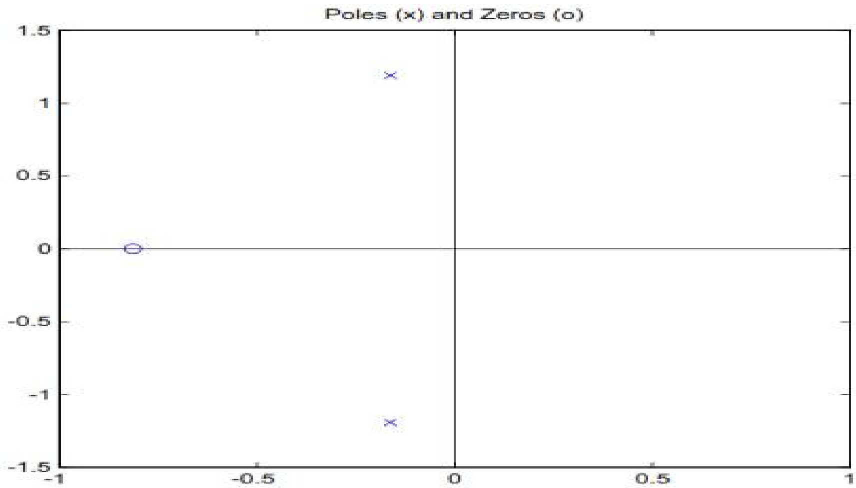

Figure 10 Pole zero plot of the system.

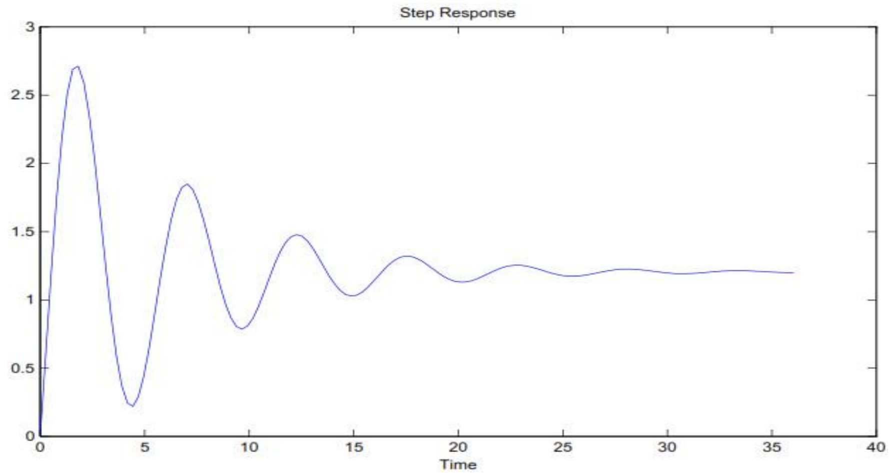

Figure 11 Step response of the system

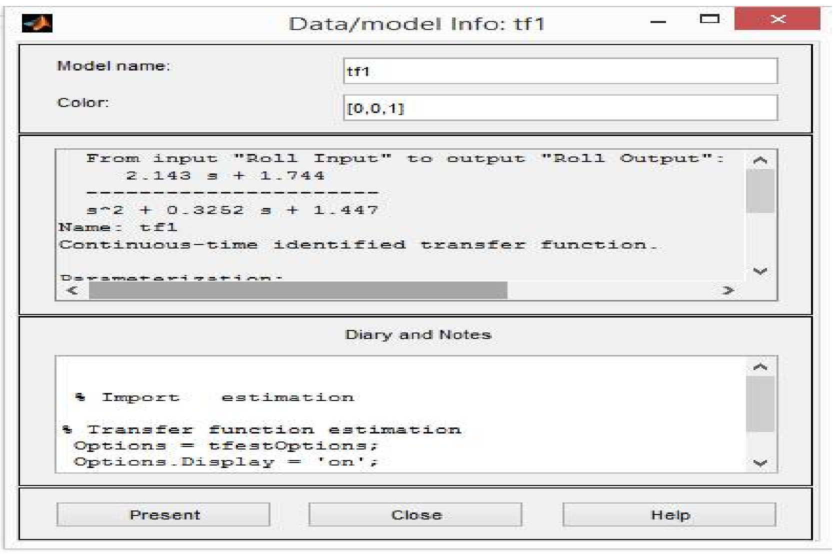

Figure 12 Transfer function model of the system

3. Controller Design and Simulation

In this section a PID controller is designed to control the system for better response. PID controllers are widely used in industrial environment due to its robust nature and few parameters for tuning. PID controllers can be implemented using PLC's, microcontrollers, Pneumatic systems and computer programs etc. Which makes it the most popular type of controller used in industrial environment. The tuning of the controller can be done by many methods including the classical Zeigler Nichols method, Trial and error method and the most popular evolutionary techniques. In this paper the Genetic Algorithm (GA) is used to tune the controller based on the ITAE criteria.

3.1 Genetic algorithm

Evolutionary techniques are some of the algorithms which are inspired and derived from some natural processes in nature. These are some heuristic techniques that can be used to solve a given problem and also optimize it. Many such algorithms are identified from nature and are successfully used to optimize and solve problems in the industrial environment. Genetic algorithm is one such algorithm based on process of natural selection of genes and theory of evolution. It was first introduced in year 1970 by Sir J Holland. Since then there has been a boon in its usage to solve many kinds of problems and optimization including PID controller tuning. In this paper the tuning of the PID controller is done by using the genetic algorithm based optimization tool available in MATLAB. The optimization tool is fed with a fitness function which contains code for calculating ITAE. The toolbox then iterates until the optimized values of PID constants are found that correspond to minimum ITAE. Figure 13[21] and figure 14 shows the fitness function used and the system response parameters after using optimized values of PID constants respectively.

```
25/4/10 5:05 PM   C:\Users\vmsdemonuser\Doc...\pid_optim.m   1 of 1

function [J] = pid_optim(x)
s=tf('s');
Plant = (2.143*s+1.744)/(s^2+0.3252*s+1.447);

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

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

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

dt = 0.01;

t=0:dt:1;

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

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

Figure 13 Fitness function for ITAE criteria

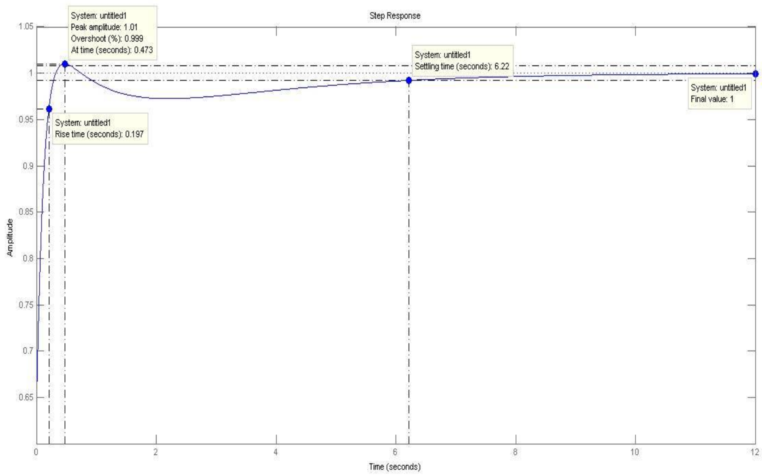

Figure 14 System response for optimized parameters

3.2 Simulations

The parallel form of PID controller is used in all the simulations which is given by the equation 1 below

$$output = Kp + \frac{Ki}{s} + Kds \qquad (1)$$

The figures 15-18 show Simulink model for finding closed loop response, set point tracking, disturbance rejection and calculating ITAE response 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 0.4 amplitude is introduced in the system at seven seconds time interval. The model used for simulation is taken from figure 12 which is a second order transfer function model.

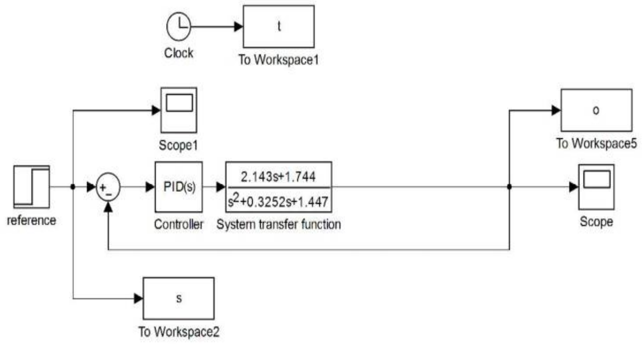

Figure 15 Closed loop response model

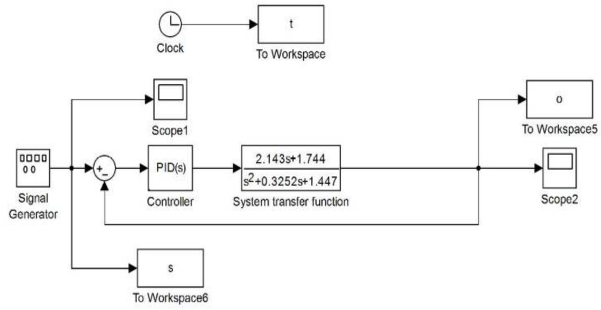

Figure 16 Set point tracking model

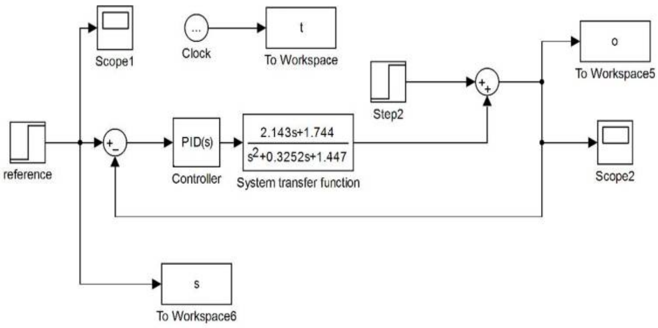

Figure 17 Disturbance rejection model

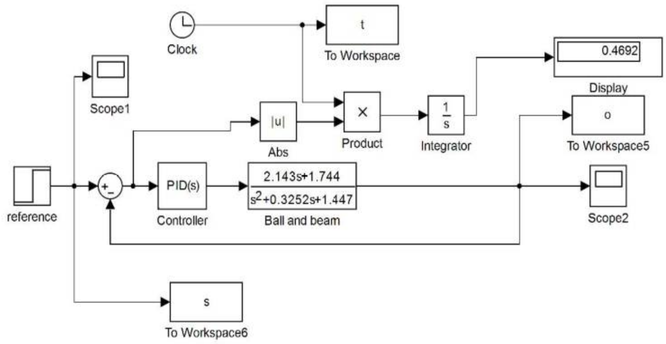

Figure 18ITAE model

4. RESULTS AND DISCUSSION

The figures 19-21 show system response for closed loop, Set point, and Disturbance rejection respectively for optimized values of PID constants for reducing ITAE. Table 2 shows the system parameters for optimized constants.

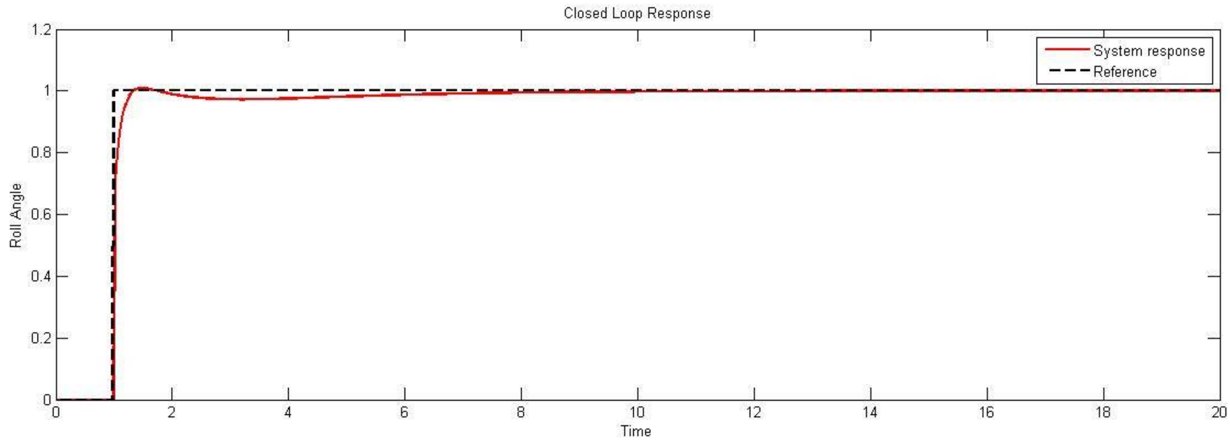

Figure 19 Closed loop response

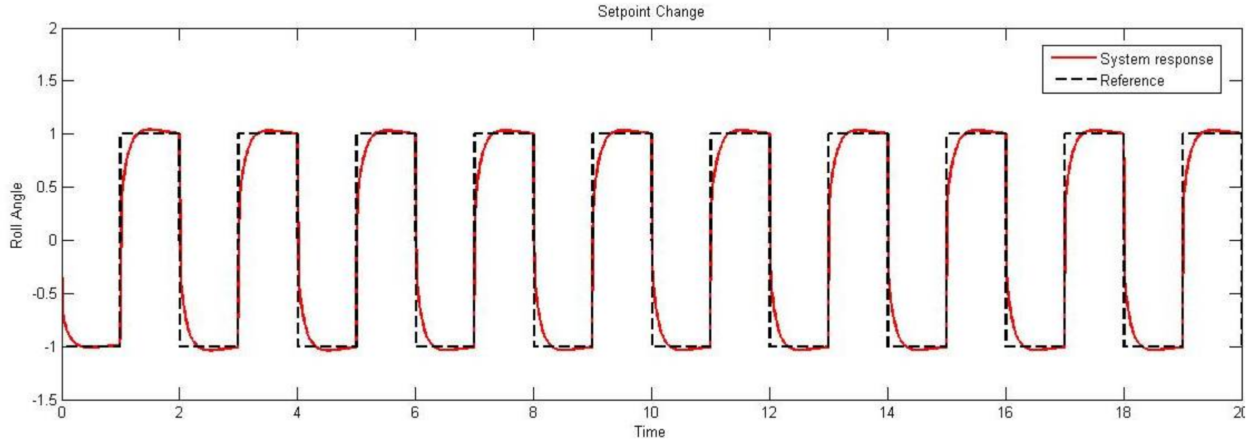

Figure 20 Set point tracking response

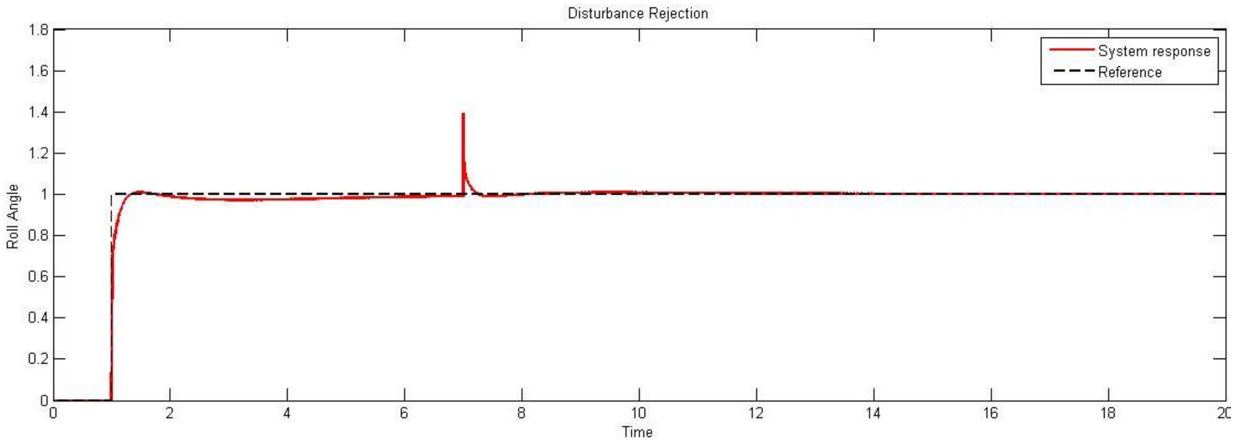

Figure 21 Disturbance rejection response

Table 2: Performance Indices

Sr.no	Performance index	Value
1	Overshoot %	0.99
2	Rise time(s)	0.197
3	Peak response	1.01
4	Final value	1
5	Settling time(s)	6.22
6	ITAE	0.4692

5. CONCLUSION

From this work it is concluded that the system response is improvedaltogether by introducing a controller. In this paper the transfer function model of the roll of PVTOL vehicle is found out using black-box modelling technique in system identification toolbox available in MATLAB environment. Genetic algorithm optimized PID controller is applied to the system based on the ITAE criteria. The proposed controller shows good values of time domain performance indices of the system output.

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