

MODELLING, SIMULATION AND PERFORMANCE OF QUADROPTER USING MATLAB SOFTWARE

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ABSTRACT

The quadcopter is one of the most complex flying machines. Its complexity is due to the versatility and maneuverability to perform many types of tasks. Quadcopter is a unique type of aerial vehicle which has the vertical take-off and landing (VTOL) ability. This work is aimed to study the mathematical modelling of quadcopter and the performance of quadcopter has been demonstrated by simulation using versatile simulation package, MATLAB/Simulink. The dynamic model of the quadcopter is obtained via a Lagrange approach. The proposed controller is based on Lyapunov analysis using a nested saturation algorithm. The proposed controller is compared with PID controller using MATLAB/SIMULINK. PID controller exist more oscillations than in the nested saturations control algorithm. Simulation results show that the controller is able to perform the tasks of taking off, hovering, and landing.

Keywords: Aircraft Control, Aircraft Dynamics, Helicopter Control, Lyapunov Methods, Real-Time Systems, Recursive Control Algorithms.

I. INTRODUCTION

1.1 Overview of Quadcopter

Since the beginning of the 20th century, many research efforts have been done to create effective flying machines with improved performance and capabilities. The use of Aerial Vehicles for military, scientific and civilian sectors are increasing drastically in recent years. UAVs (Unmanned Aerial Vehicles) have clear advantages such as higher manoeuvrability, lower cost, decreased radar signature, strength, as well as decreased risk for human life. These advantages lead the use of these vehicles in many applications from military operations to civilian tasks, and extensive research are carried out in many laboratories. Currently, there are various commercial and experimental aerial vehicles of various sizes available, and many more autonomous VTOL (VERTICAL TAKE OFF & LANDING) vehicles are being developed at universities, research centres, and by hobbyists. The quadcopter has been used for many applications and research studies, as well. The studies in quadcopter modelling and control increased rapidly in recent years [1].

Quadcopter is a type of helicopter with four lift-generating propellers mounted on motors. Two of the motors generate thrust by spinning their propellers clockwise and other two counter-clockwise. Control of the machine can be achieved by varying the relative speed of the propellers. Due to the availability of high-speed brush less motor, inertial measurement units based on MEMS (Micro Electro Mechanical Sensors) technology and high power to weight ratio (150 W/Kg) Li-polymer batteries, quadcopter can now be designed and fabricated but their control is still a challenge.

In contrast to a classical helicopter with main and tail rotors, a quadcopter is propelled by four horizontal rotors directly attached to the airframe. But the four propellers are not the same, and they are divided in two pairs that contain two pusher blades and two pullers blades, which work in a contra-rotation manner. The different motions of a quadcopter are generated by varying the speed of four rotors as well as changing the thrust of each blade. As shown in Fig.1.1 The quadcopter consists of four motors on which propellers are mounted. These motors are arranged at the corners of a X-shaped frame, where all the arms make an angle of 90 degrees with one another. As shown in Figure 1.1, two of the rotors or propellers spin in one direction and the other in the opposite direction. Each spinning propeller generates vertically upward lifting force. All the motion of machine is a consequence of this force. Lifting forces generated by the spinning propeller and the weight, are responsible for all the motion of body, as the external effects such as air friction, wind pressure etc. have been neglected. The design of quadcopter motors and propellers is assumed to be such that these thrust forces always act perpendicular to the plane of propellers and therefore plane of quadcopter [2]. The center of mass of machine is located at the centre of the quadcopter and the weight force acts at this point.

One of the limiting factors that prevents further implementation of the helicopters into applications, is the way it moves. It needs to tilt along the desired direction of motion. By doing this it can have necessary acceleration towards that direction. But tilting has the undesired effect of moving the on-board camera's direction of view. This becomes an issue for surveillance and other vision based tasks. There has been considerable innovation in the sensors that are used to control the quadcopter as well. Modern MEMS (Micro Electro Mechanical Sensors) technology makes it easier to add more sensors on a small quadcopter as the space and weight constraints can be stringent. Sensors including basic IMUs (Inertial Measurement Units), GPS (Global Position System) modules.

Due to some unique abilities of the quadcopter such as high manoeuvrability, small size, and easy control mini rotorcrafts are finding many applications. The most significant of them would have to be search-and-rescue and emergency response. Other major applications of quadcopters are in homeland security, military surveillance, and search and destroy. Miniaturization of quadcopter has enabled them to be used for border patrol and surveillance. Quadcopter also have potential applications in other areas like earth sciences where they can be used to study climate change, glacier dynamics, and volcanic activity or for atmospheric sampling. [3].

As the number of applications is significantly increasing, current research goals have created a serious need for specialized air vehicles, able to:

1. Pose certain flight advantages, and
2. Cope up with specific mission requirements.

At the same time these air vehicles must have significant on-board processing power for ensuring that complex and demanding calculations can be performed uninterruptedly. This need arises from the fact that the system must be able to cope with harsh or special environmental conditions (such as high wing perturbations or cramped spaces), which imposes the necessity for complex control laws, taking into account the dynamics of the vehicle's environment and constraints.

The quadcopter is one of the most complex flying machines. Its complexity is due to the versatility and maneuverability to perform many types of tasks. The classical helicopter is conventionally equipped with a main rotor and a tail rotor. However, other types of helicopters exist, including the twin rotor or tandem helicopter and the coaxial rotor helicopter [4].

The quadcopter, shown in Fig. 1.1, have some advantages over conventional helicopters. Given that the front

and rear motors rotate counter clockwise while the other two rotate clockwise, gyroscopic effects and aerodynamic torques tend to cancel in trimmed flight.

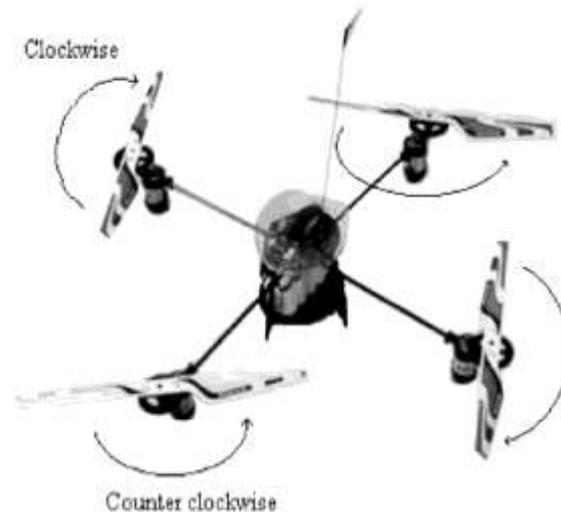


Figure 1.1: The Schematic of Quadcopter

This quadcopter does not have a swash plate. In fact it does not need any blade pitch control. The collective input (or throttle input) is the sum of the thrusts of each motor. Pitch movement is obtained by increasing /reducing the speed of the rear motor while reducing /increasing the speed of the front motor.

The roll movement is obtained similarly using the lateral motors. The yaw movement is obtained by increasing /decreasing the speed of the front and rear motors while decreasing /increasing the speed of the lateral motors. This should be done while keeping the total thrust constant. In view of its configuration, the quadcopter has some similarities with planar vertical take-off and landing (PVTOL) aircraft.

The quadcopter under consideration consists of a rigid cross frame equipped with four rotors as shown in Fig. 1.1. The up (down) motion is achieved by increasing (decreasing) the total thrust while maintaining an equal individual thrust. The forward/backward, left/right and the yaw motions are achieved through a differential control strategy of the thrust generated by each rotor. In order to avoid the yaw drift due to the reactive torques, the four rotor aircraft is configured such that the set of rotors (right-left) rotates clockwise and the set of rotors (front-rear) rotates counter clockwise. The forward/backward, left/right and the yaw motions are achieved through a differential control strategy of the thrust generated by each rotor. There is no change in the direction of rotation of the rotors [6].

Major comparative point with respect to a traditional helicopter can be given as follows:

In traditional helicopters, the yaw motion, due to the reactive torque of the main rotor, is compensated by the torque produced by the tail rotor. The energy spent on the tail rotor makes no contribution to the upward thrust of the helicopter. Comparatively, in the four rotor design, if the four rotors rotate at the same speed, there will be no yaw motion since the reactive torques are cancelled out, as one pair of rotors rotates in the opposite direction of the other pair. In this case, all of the energy spent on the four rotors contributes to generate the upward thrust. The same upward thrust generated by a single rotor in traditional helicopters can be generated by four smaller rotors for the quad rotor; and the fact of using rotors with smaller size helps to reduce the induced mechanical vibrations comparatively to a single large main rotor. On the other hand, traditional helicopters have somewhat complicated mechanisms for achieving controlled flight, while for the four rotor mini rotor craft, controlled flight is achieved easily by differential thrust control of the four rotors[7].

1.2 Aim of the Work

The objective of this project is to study the mathematical modelling of the quadrocopter. The dynamic model of the four-rotor rotorcraft is obtained via a Lagrange approach. Pro-posed controller is based on Lyapunov analysis using a nested saturation algorithm. The proposed controller is compared with PD controller using MATLAB/SIMULINK. PID controller exist more oscillations than in the nested saturations control algorithm. Sim-ulation results show that the proposed controller is able to perform the tasks of taking off, hovering, and landing and propose nested saturations control algorithm exist less oscillations than PID controller.

This project simulate and perform analysis of quadrocopter on three axis x, y, z using MATLAB/SIMULINK simulation package. It also simulate and perform analysis of quadrocopter with trajectory following various paths along X-axis, Y-axis, Z-axis.

1.3 Scope of the Work

This work is divided into three stages. This is to ensure that the project is conducted within its intended boundary and is heading to the right direction to achieve its objectives:

- The first stage is to study working principle of the quadrocopter.
- Secondly, mathematical modeling of the quadrocopter being studied.
- The third stage of the project is to analyze on the comparative performance of the quadrocopter between proposed controller based on Lyapunov analysis using a nested saturation algorithm and PID controller using MATLAB/SIMULINK. with respect to commanded input along x-axis, y-axis and z-axis. Performance of the quadrocopter is also analyzed from the trajectory plotted by quadrocopter against commanded inputs along x-axis, y-axis, z-axis based on the MATLAB/SIMULINK simulation results.

1.4 Thesis Outline

This section will give an outlines of the structure of the thesis. The following is an explanation for each chapter. Background of Control techniques for quadrocopter.

Chapter 2 discusses a mathematical modelling of quadrocopter .

Chapter 3 gives the comparative analysis and simulated output of quadrocopter for translational parameters along x-axis, y-axis and z-axis using MATLAB/SIMULINK. It also shows the performance and analysis of quadrocopter for trajectory.

Chapter 4 presents the conclusion.

II. STUDY OF MATHEMATICAL MODELLING FOR QUADROCOPTER

The purpose of deriving a mathematical model for quadrocopter is to assist in developing controllers for physical mini rotorcrafts. The general method to design a control system is to calculate the dynamic model of the system. The dynamic model of a system is a mathematical equation that comprises of all the forces that can act on the system at a given time. A conventional quadrocopter is an under actuated aircraft with four rotors that have fixed position with respect to the aircraft body frame.

2.1 Assumptions

It is not possible to create a model that conforms to reality completely. Some assumptions need to be made; in this model the following is assumed:

- The quadcopter structure is rigid and its deformation characteristics will be disregarded.
- The quadcopter structure is symmetrical and material inconsistencies will be disregarded.
- The propellers are rigid and deflections will be ignored.
- The cross products of the inertia matrix can be neglected.
- The ground effect is neglected.
- Small body forces are ignored, because they are generally of a much smaller magnitude than the principal control inputs u and τ .
- Force-balance analysis of quadcopter is carried out in steady state conditions only. Turbulent conditions are ignored.

Rigid body representation of the quadcopter is given in Fig. 1. Body fixed frame is assumed to be at the Centre of gravity of the four rotor where z axis is pointing downwards. According to the Euler's angle representation, angles of rotation about the aircraft's Centre of mass in x , y and z axes are defined respectively as roll (ϕ), pitch (θ) and yaw (ψ). The earth's gravitational force is assumed to be constant and in downwards direction.

The generalized coordinates of the mini rotorcraft are $q = (x, y, z, \psi, \theta, \phi)$ where ξ

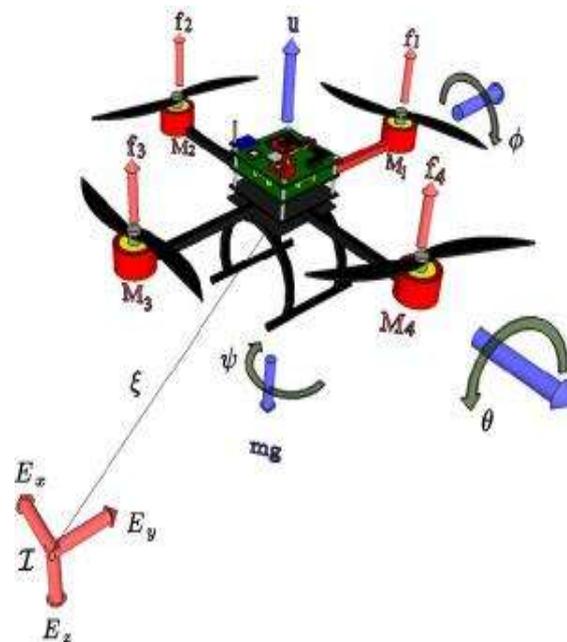


Figure 4.1: Forces Acting on Quadcopter

(x, y, z) denotes the position of the centre of mass of the mini rotorcraft relative to a fixed inertial frame I , and $\eta = (\psi, \theta, \phi)$ are the Euler angles, ψ is the yaw angle around the z -axis, θ is the pitch angle around the modified y -axis, and ϕ is the roll angle around the modified x -axis, which represent the orientation of the rotorcraft.

The translational kinetic energy of the rotorcraft is

$$T_{trans} = \frac{1}{2} m \dot{\xi}^T \dot{\xi} \quad (4.1)$$

Where m denotes the mass of the rotorcraft. The rotational kinetic energy is

$$T_{rot} = \frac{1}{2} \dot{\eta}^T J \dot{\eta} \quad (4.2)$$

The matrix J acts as the inertia matrix for the full-rotational kinetic energy of the rotorcraft expressed directly in terms of generalized coordinates η . The only potential energy which needs to be considered is the standard gravitational potential energy given by

$$U = mgz \quad (4.3)$$

z is the rotorcraft altitude, ω is the angular velocity, I is the inertia matrix, and g is the acceleration due to gravity. The angular velocity vector ω resolved in the body fixed frame is related to the generalized velocities η (in the region where the Euler angles are valid) by means of the kinematic relationship

The Lagrangian is

$$L(q, \dot{q}) = T_{trans} + T_{rot} - U \quad (4.4)$$

Small body forces may be ignored because they are generally of much smaller magnitude than the principal control inputs (u)

$$u = f_1 + f_2 + f_3 + f_4 \quad (4.5)$$

The thrust of rotor i is equal to $f = K \cdot \omega^2$. While, the rotation speeds of the motors are described by ω , the rotor thrust force is also equal to $f = K \cdot \omega^2$, where parameter K is a constant namely the push factor.

III. SIMULINK MODEL AND ITS COMPARATIVE PERFORMANCE ANALYSIS

The main goal is to achieve a stable flight of the quadcopter, this is done using two control strategies: a linear PID control and nonlinear nested saturations control. This chapter details MATLAB Simulink model of quadcopter. Figure 5.1 below shows the Simulink model for quadcopter using nested saturation control algorithm

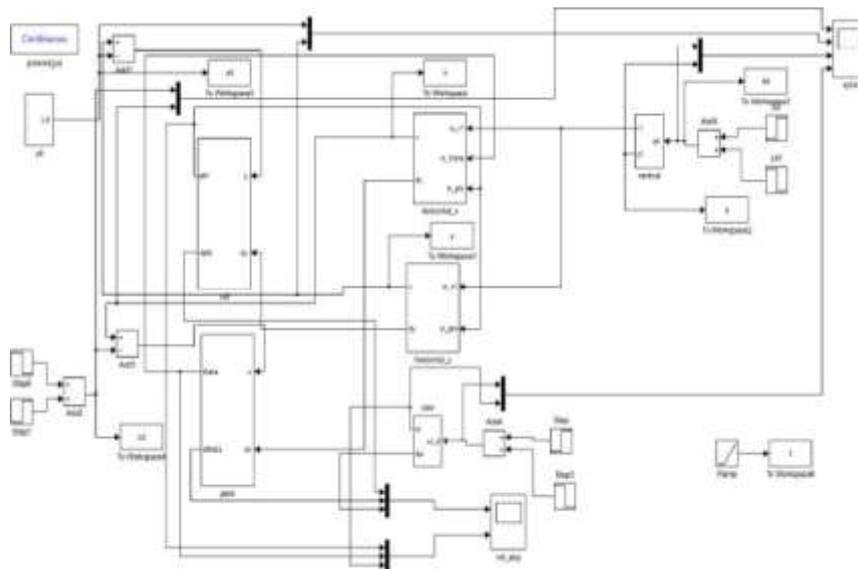


Figure 5.1: Simulink Model for Quadcopter Using Nested Saturation Control Algorithm

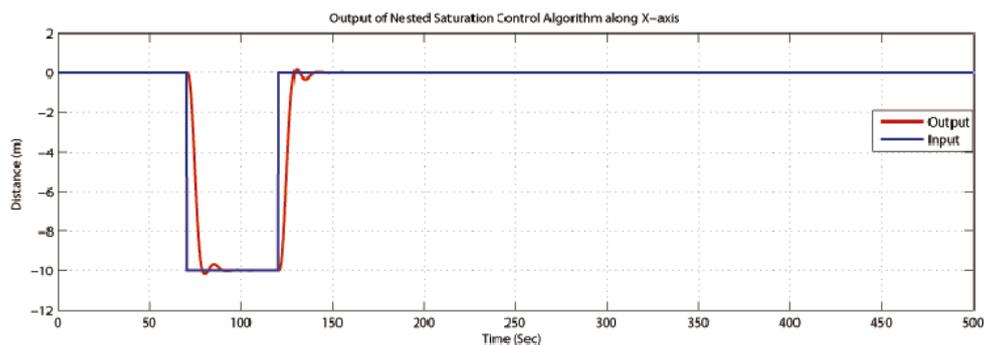


Figure 5.2 Shows The Output Of Nested Saturation Control Algorithm Along X-Axis

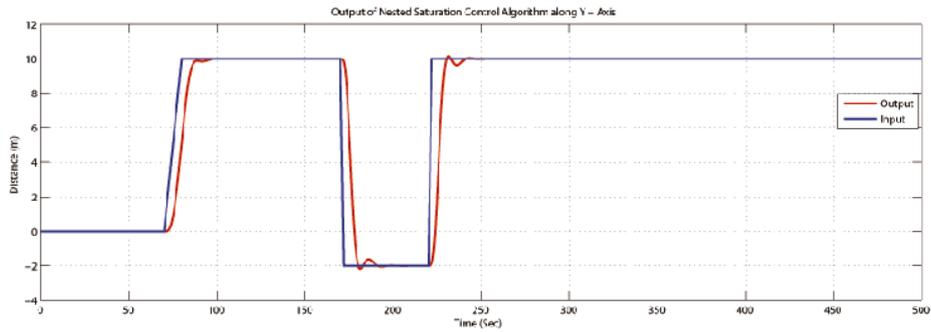


Figure 5.3 shows the output of nested saturation control algorithm along y-axis.

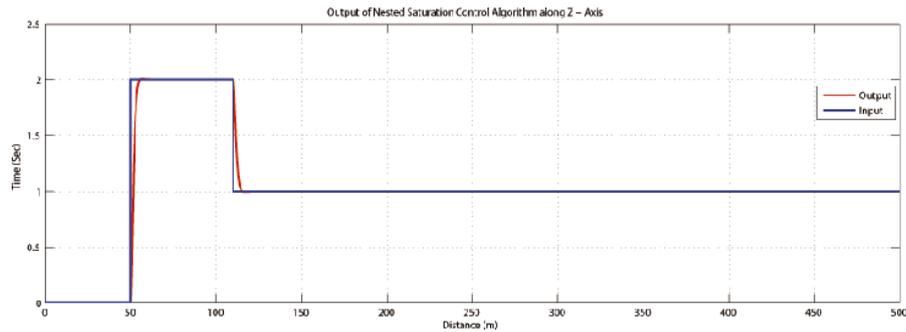


Figure 5.4 shows the output of nested saturation control algorithm along z-axis.

3.1 PID Controller

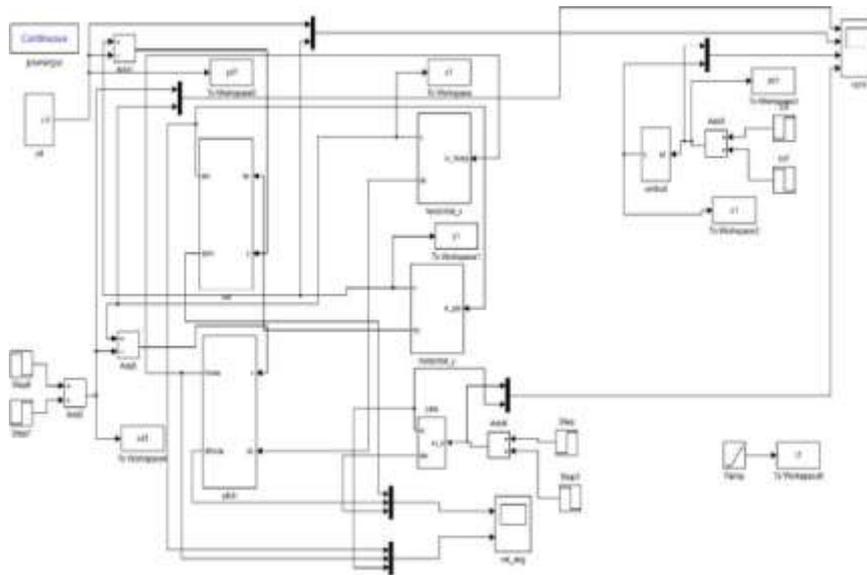


Figure 5.5 above shows the Simulink model for quadcopter using PID Controller

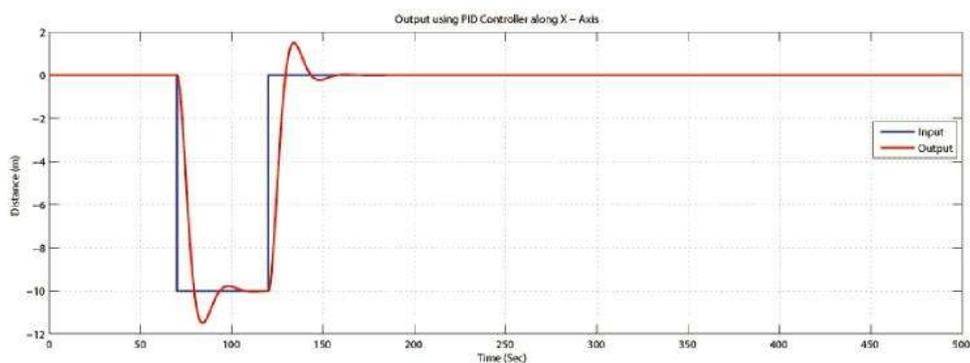


Figure 5.6: output using PID Controller along x-axis

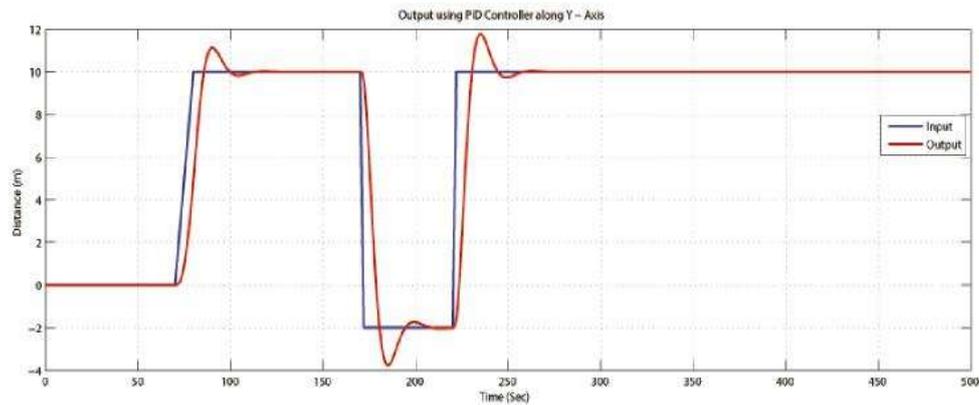


Figure 5.7: output using PID Controller along y-axis

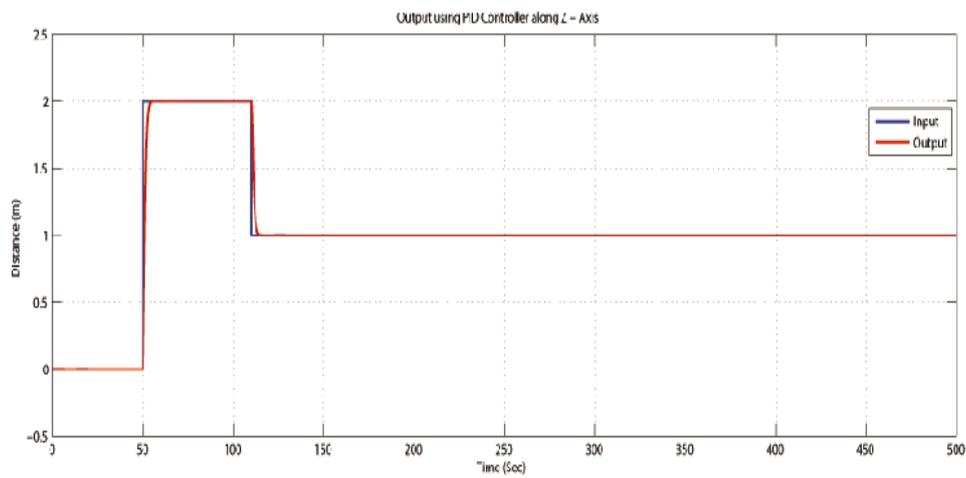


Figure 5.8: output using PID Controller along z-axis

IV. CONCLUSION

In this report, proposed a control algorithm for a quadcopter. The dynamic model of the quadcopter obtained via a Lagrange approach is studied and the proposed control algorithm based on Lyapunov analysis using nested saturations also been implemented using MATLAB/SIMULINK software.

The proposed controller has been successfully applied using MATLAB/SIMULINK software. Quadcopter follows the applied/commanded input very closely. From the obtained results of three translational moments along x-axis, y-axis and z-axis, it can be concluded that the controller performs satisfactorily.

The proposed control algorithm in this report is easy to understand and simple implement. From performance analysis it can be conclude that the response is almost similar for both controllers (i.e Nested Saturation Control Algorithm and PID Controller), but the PID controller exist more oscillation than in the nested saturations control algorithm. It is also observed that PID controller output takes more settling time as compared to output of nested saturation control algorithm.

Simulation results shows that the proposed controller is able to perform the tasks of taking off, hovering, landing and it offers more stable flight as it has less oscillations compared to PID controller . The results show that MATLAB paired with Simulink is a good simulation tool for modelling and to analyse quadcopter performance.

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