A Hybrid Flight Control for a Simulated Raptor-30 V2 Helicopter

ARBAB NIGHAT KHIZER*, AMIR MAHMOOD SOOMRO, AND SYED AMJAD ALI*****

RECEIVED ON 13.11.2014 ACCEPTED ON 30.12.2014

ABSTRACT

This paper presents a hybrid flight control system for a single rotor simulated Raptor-30 V2 helicopter. Hybrid intelligent control system, combination of the conventional and intelligent control methodologies, is applied to small model helicopter. The proposed hybrid control used PID as a traditional control and fuzzy as an intelligent control so as to take the maximum advantage of advanced control theory. The helicopter's model used; comes from X-Plane flight simulator and their hybrid flight control system was simulated using MATLAB/SIMULINK in a simulation platform. X-Plane is also used to visualize the performance of this proposed autopilot design. Through a series of numerous experiments, the operation of hybrid control system was investigated. Results verified that the proposed hybrid control has an excellent performance at hovering flight mode.

Key Words: Hybrid Control System, PID, Fuzzy Logic, X-Plane, Helicopter Model.

1. INTRODUCTION

UAV (Unmanned Ariel Vehicles) are observed as a main research application in military, civil and academic fields because of its flying capabilities such as taking off, hovering and landing. UAVs are categorized into fixed wing and rotary wing craft and helicopter relates to rotary wing class. They are known as nonlinear system with unique characteristics that make a challenge for researchers towards its stable control design [1-2]. Its dynamics are multivariable in nature, furthermore, it has strong coupling between states and control inputs, therefore, classical control methods are treating as disregarded. Furthermore, conventional controllers seem inadequate for achieving the stable control due to imprecise mathematical modeling and bad tuning of parameters. This situation gives strong motivation to intelligent control; since fuzzy control is closer to human thinking than conventional control and generally belongs to intelligent control [3-4]. It provides a way through which linguistic control strategy based on expert human knowledge is converted into an automatic control strategy. It can be able to handle inconsistent real data in to a suitable way for variety of control applications. On the other hand, PID is a linear controller, but it has been used on nonlinear systems such as for an UAV quadrotor, UAV fixed-wing and marine craft [5-7]. Literature has reported a large number of effective flight control methods for miniature helicopter including robust adaptive control [8-9], H_∞ control [10], state-dependent Riccati equation control [11], back stepping control [12], fuzzy logic control [13] and neural network control [14].

* Assistant Professor, Department of Electronic Engineering, Mehran University of Engineering & Technology, Jamshoro.
** Assistant Professor, Department of Electrical Engineering, Mehran University of Engineering & Technology, Jamshoro.
*** Assistant Professor, Department of Biomedial Engineering, Mehran University of Engineering & Technology, Jamshoro.

In this paper, a hybrid control is proposed which combines the convenient control of PID together with flexible control of fuzzy for Raptor-30 V2 helicopter. Firstly, model helicopter dynamics are analyzed and then a mathematical model based on dynamical results is developed. Both PID and fuzzy control have their own advantages, based upon their respective performance, PID and fuzzy control is combined together as a hybrid control to investigate the flying motion of Raptor-30 V2 helicopter at hovering. The X-Plane flight simulator is selected to test this proposed hybrid control scheme because it is the most realistic flight simulator in flight aviation domain. Additionally, another main purpose of using this simulator is possibility of demonstration of modifying and testing of this hybrid flight control in a fast and easy way.

The paper is organized as follows. Section2 presented structural dynamics and mathematical model equations of small helicopter. Section3 discussed hybrid control design using PID and fuzzy logic. Simulation results are presented to illustrate the efficiency of proposed control in Section4. Finally, Section5 presented conclusion remarks.

2. HELICOPTER MATHEMATICAL MODEL

The research platform is a Raptor-30 V2 class RC helicopter, which is shown in Fig. 1. It is considered as highly maneuverable vehicle, which transmits large control moments from rotor to its fuselage, a large T/W (Thrust-to-Weight) ratio and a fast rotor speed. It is also equipped with a stabilizer bar like other small helicopters to help the remote human pilot to control attitude dynamics.

2.1 Rigid Body Equations

Equations of motion for model unmanned helicopter were based on rigid body dynamics, basic aerodynamics and helicopter theory [15]. Fig. 2 represents the coordinate system of helicopter where "υ" represents the linear velocity vector and its coordinate vector is $\upsilon^B = [u\ \ \upsilon\ \ w]^T$ and $\omega^B = [p\ q\ r]^T$ is the angular velocity vector. The forces and moments ($\vec{f}$ and $\vec{\tau}$) acting externally on fuselage are sum up as vectors. The $f^B = [X\ Y\ Z]^T$ represents force vector components and $\tau^B = [L\ M\ N]^T$ represents the component of the torque vector. Therefore Newton-Euler equation of motion becomes:

$$\begin{bmatrix} mI_{3\times3} & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \dot{\upsilon}^B \\ \dot{\omega}^B \end{bmatrix} + \begin{bmatrix} \omega^B \times m\upsilon^B \\ \omega^B \times I\omega^B \end{bmatrix} = \begin{bmatrix} f^B \\ \tau^B \end{bmatrix} \quad (1)$$

Where "I" is the inertial matrix w.r.t. body-fixed reference frame and mass of the helicopter is denoted by "m". Finally the external aerodynamic forces and moments are represented by the following Equations (2-3):

$$f^B = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_m + X_f \\ Y_m + Y_t + Y_v + Y_f \\ Z_m + Z_h + Z_f \end{bmatrix} + R_{IB}^T \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} \quad (2)$$

$$\tau^B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = \begin{bmatrix} L_m + L_t + L_v + L_f \\ M_m + M_h + M_f \\ N_m + N_t + N_v + N_f \end{bmatrix} \quad (3)$$

The various forces and torques subscripts are: $()_m$ represents main rotor, $()_t$ represents tail rotor, $()_f$ represents fuselage, $()_v$ represents vertical fin, $()_h$ represents horizontal stabilizer and R_{IB}^T represents the rotational matrix. Equations (2-3) can also be represented as:

$$\dot{u} = (vr - wq) - g\sin\theta + (X_m + X_f)/m \quad (4)$$

$$\dot{v} = (wp - ur) + g\cos + \sin\phi + (Y_m + Y_f + Y_t + Y_v)/m \quad (5)$$

$$\dot{w} = (uq - vp) + g\cos\theta\cos\phi + (Z_m + Z_f + Z_h)/m \quad (6)$$

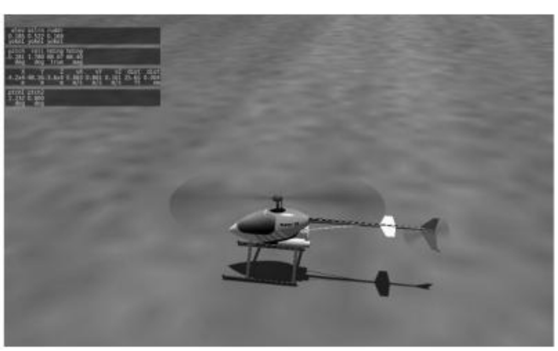

FIG. 1. RAPTOR-30 V2 CLASS RC HELICOPTER

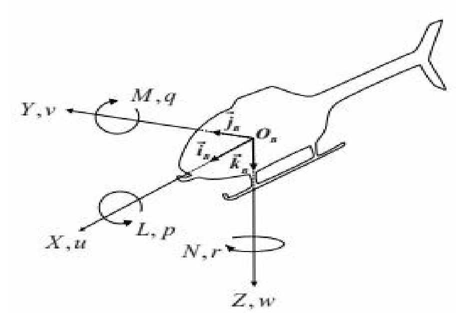

FIG. 2. BODY FIXED COORDINATE SYSTEM

$$\dot{p} = \frac{qr(I_{yy} - I_{zz}) + (L_m + L_t + M_h + M_f)}{I_{xx}} \quad (7)$$

$$\dot{q} = \frac{rp(I_{zz} - I_{xx}) + (L_m + M_h + M_f)}{I_{yy}} \quad (8)$$

$$\dot{r} = \frac{pq(I_{xx} - I_{yy}) + (N_m + N_t + N_v + N_f)}{I_{zz}} \quad (9)$$

The TPP (Tip-Path-Plane) is defined by angles which show the TPP tilt at the longitudinal axis and lateral axis. The dynamic equations of TPP are given as:

$$a = -q - \frac{a}{\tau_f} + \frac{A_{lon}}{\tau_f}\delta_{lon} \quad (10)$$

$$b = -p - \frac{b}{\tau_f} + \frac{B_{lat}}{\tau_f}\delta_{lat} \quad (11)$$

where A_{lon} and B_{lat} are steady state lateral and longitudinal gains, δ_{lon} and δ_{lat} are the longitudinal and lateral control inputs. The term "τ_f" denotes main rotor time constant.

2.2 Helicopter Control Surfaces

A helicopter has four control inputs to control its direction and movement. The first control is aileron servo input (δ_{lat}), controls the main rotor lateral cyclic pitch which results in roll motion. The second control is elevator servo input (δ_{long}), controls the longitudinal cyclic pitch on the main rotor resulting in pitch motion. The third is collective pitch (δ_{col}), controls the collective pitch on the main rotor which results in heave motion that makes the helicopter moves in the vertical direction. Finally the rudder servo input (δ_{ped}) controls the collective pitch on the tail rotor which results in yaw motion as shown in Fig. 3.

3. HYBRID CONTROL DESIGN

The main objective of this work is substitution of a human pilot action with an automatic control system using height/directional control scheme. Hence, helicopter can be moved to a pre-defined location by tilting it effectively, such that sufficient large horizontal forces produced by main rotor. The larger the roll or pitch angle, the bigger the lateral, longitudinal and propulsive force. Fig. 4 portrays the proposed hybrid control structure consisting of two control loops. The PID is proposed for inner loop to control the faster dynamics (height and direction), whilst the outer loop is used for the slower dynamics (forward/backward and sideward translation) and based on fuzzy control.

3.1 Height/Directional PID Control

PID control constitutes of height and directional control of small helicopter and is further divided into four controllers; three for angle control (pitch, roll and yaw) and one for height control. Pitch, roll and yaw angles and z-position are considered as an input while longitudinal pitch, lateral pitch, tail rotor pitch and collective pitch are outputs. The overall PID control structure is depicted in Fig. 5.

Strong coupling is observed between the variables, therefore tuning process of controllers are difficult. In

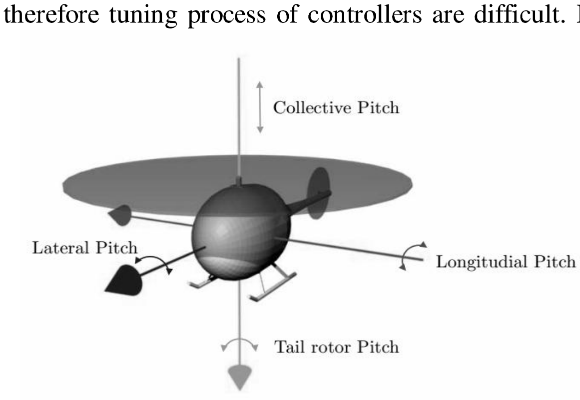

FIG. 3. HELICOPTER CONTROL SURFACES

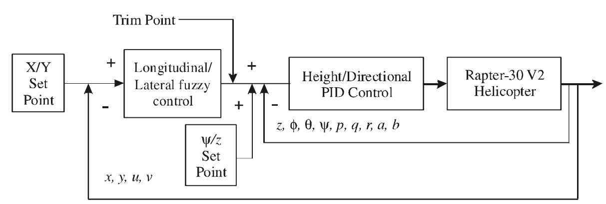

FIG. 4. HYBRID CONTROL STRUCTURE

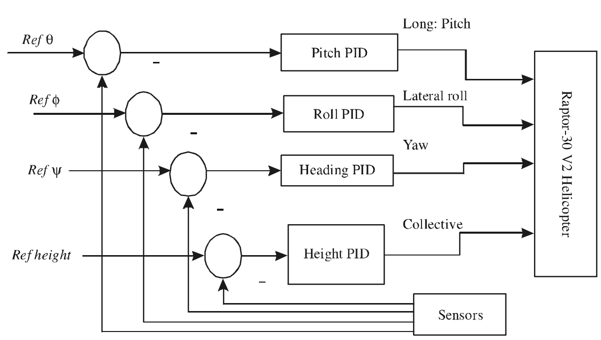

FIG. 5. PID CONTROL STRUCTURE

order to address this issue, all PID controllers have to be tuned simultaneously. At the beginning, sufficient proportional feedback is introduced to all control loops for stabilizing the angles. Initially, it is more desirable to find suitable gain values for the height and yaw PID controllers, while other two controllers keep maintained at small gains. Once stability is achieved in terms of dynamics, the proportional gain values have to be increased. At this time, integral part with a small gain values introduced to reduce the offset and avoiding instability. Finally, derivative part has to be added to improve the stability, thus to obtain a good performance. Now, all PID controllers have their gain values (proportional, integral and derivative) and are tuned using trial and error scheme.It is worth nothing that it is not easy to obtain better results, therefore some parameter criteria should set to obtain good results such as overshoot less than 20%, setting time less than 20s and steady state error less than 1%. Table 1 shows the gain values of four PID control. All PID controller works on following algorithm:

$$\frac{C(s)}{U(s)} = K_p + \frac{K_i}{s} + K_d s$$

3.2 Longitudinal/Lateral Fuzzy Control

This control includes longitudinal and lateral position of Raptor-30 V2 helicopter. The control is mainly handled by main rotor longitudinal pitch and lateral pitch movement. The horizontal and vertical position fuzzy control generates a desired attitude angle (θ_d, ϕ_d), which is further used as input to angle PID controller in order to achieve stability. Positional error (e_x, e_y) and velocity (u, v) are the input and desired pitch and roll angle is the output of this control. Triangular membership function is selected for both input and output and rules are formulated on a heuristic basis. Finally, two fuzzy controllers are designed which effectively determines the desired values for the pitch and roll angle. For trim condition calculation, stabilizer contributions are neglected in force and moment equations, because it is very small. Figs. 6-7 shows the FIS (Fuzzy Inference System) for both longitudinal and lateral control and their analogous rules used to compute the desired pitch and roll angle are:

TABLE 1. FOUR PID CONTROL GAIN VALUES

	Height PID	Pitch PID	Roll PID	Yaw PID
K_p	2.5	2.5	2.5	12
K_i	0.25	0.60	1	1.5
K_d	0.55	0.3	0.3	12.5

1. If (e_x-position is N) and (velocity is N) then (longitudinal_control is NB)
2. If (e_x-position is Z) and (velocity is N) then (longitudinal_control is NM)
3. If (e_x-position is P) and (velocity is N) then (longitudinal_control is ZN)
4. If (e_x-position is N) and (velocity is Z) then (longitudinal_control is NS)
5. If (e_x-position is Z) and (velocity is Z) then (longitudinal_control is ZE)
6. If (e_x-position is P) and (velocity is Z) then (longitudinal_control is PS)
7. If (e_x-position is N) and (velocity is P) then (longitudinal_control is ZP)
8. If (e_x-position is Z) and (velocity is P) then (longitudinal_control is PM)
9. If (e_x-position is P) and (velocity is P) then (longitudinal_control is PB)

1. If (e_y-position is N) and (velocity is N) then (lateral_control is PB)
2. If (e_y-position is Z) and (velocity is N) then (lateral_control is PM)
3. If (e_y-position is P) and (velocity is N) then (lateral_control is ZP)
4. If (e_y-position is N) and (velocity is Z) then (lateral_control is PS)
5. If (e_y-position is Z) and (velocity is Z) then (lateral_control is ZE)

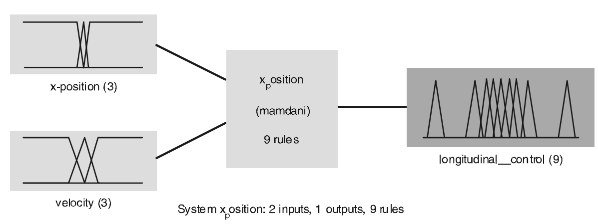

FIG. 6. FUZZY INFERENCE SYSTEM FOR LONGITUDINAL CONTROL

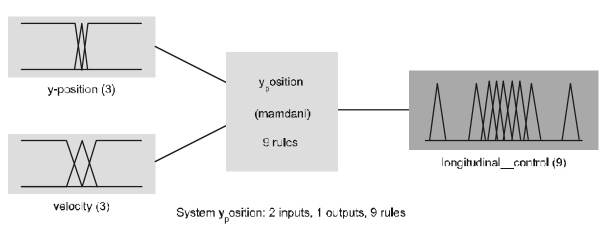

FIG. 7. FUZZY INFERENCE SYSTEM FOR LATERAL CONTROL

6. If (e_y-position is P) and (velocity is Z) then (lateral_control is NS)
7. If (e_y-position is N) and (velocity is P) then (lateral_control is ZN)
8. If (y-position is Z) and (velocity is P) then (lateral_control is NM)
9. If (y-position is P) and (velocity is P) then (lateral_control is NB)

4. SIMULATION RESULTS

The Raptor-30 V2 RC helicopter model used in the simulation platform comes from X-Plane simulator. The Raptor-30 V2 is a highly maneuverable helicopter and it's the physical characteristics are given in Table 2.

To properly control this X-Plane Rapter-30 V2 through the simulink hybrid autopilot, the pattern of packets are sent and receives over the Ethernet connection to X-plane and are repesented in Table 3.

TABLE 2. PHYSICAL PARAMETERS OF EXPERIMENTAL HELICOPTER MODEL RAPTOR-30 V2

Full length of Fuselage	45.27″
Full width of Fuselage	5.51″
Total height	15.75″
Main rotor diameter	49″
Tail rotor diameter	9.3″
Gear ratio	1:9.56:4.57
Full equipment weight	6.6 lb

MATLAB/SIMULINK autopilot and X-Plane model helicopter are operated on two computers and communication is done through a UDP (User Datagram Protocol) data communication bus. The overall hybrid flight control system implemented in SIMULINK using the UDP interface is shown in Fig. 8. Control input signals are applied to four control surfaces of model helicopter and is depicted in Fig. 9. Further, Fig. 10 portrays the stabilization of inertial positions, each one with zero reference. Fig. 11 shows attitude angles stabilization around zero reference and oscillation is observed due to the coupling between inputs (collective and pedal). The flight results indicate that the hybrid controller exhibits satisfactory behavior at the hovering mode and is shown in Fig. 12 where Raptor-30 V2 helicopter achieved hovering with satisfactory three dimensional positions.

TABLE 3. SELECTED PARAMETERS PACKET AND BYTE SIZE

	Parameter Description	Byte Size	Total Size
Header	DATA	5	5
08	Index number	4	36
	Joystick Ail/Elv/Rud	32	
16	Index number	4	36
	Angular Velocities	32	
17	Index number	4	36
	Pitch, Roll, Heading	32	
21	Index number	4	36
	Loc, Velo, distance traveled	32	
39	Index number	4	36

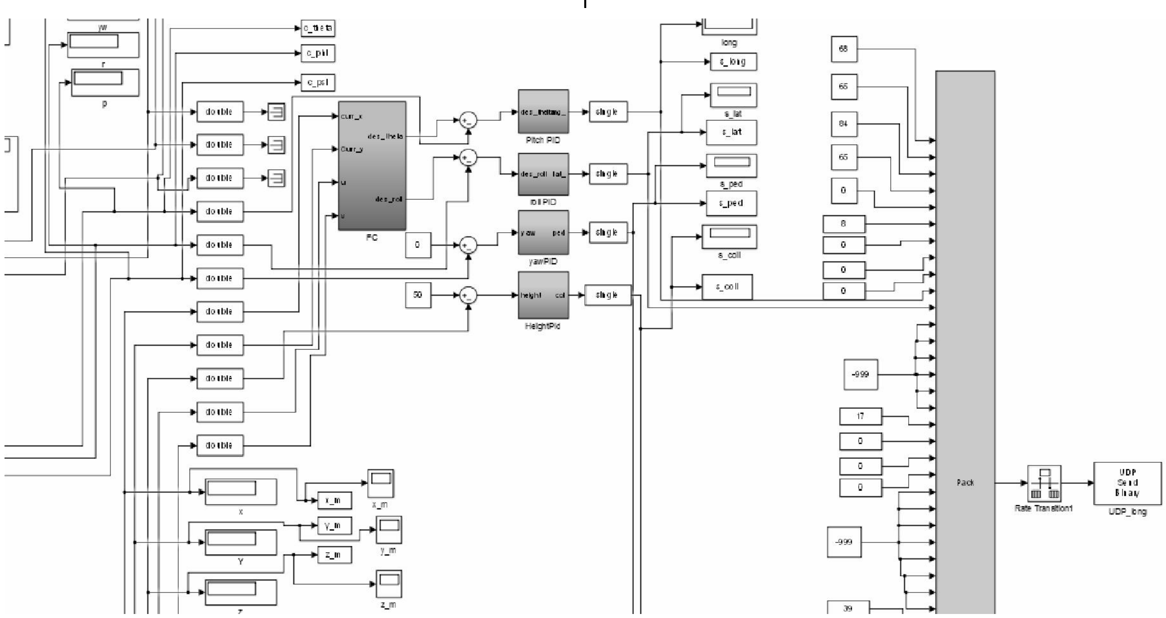

FIG. 8. OVERALL HYBRID CONTROL SYSTEM IN SIMULINK

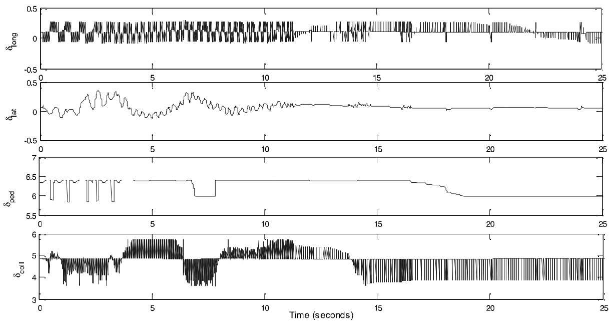

FIG. 9.APPLIED CONTROL INPUT

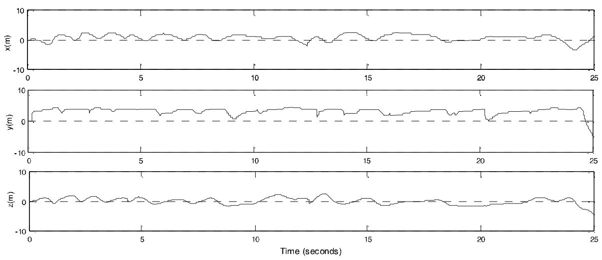

FIG. 10. STABILIZATION OF INERTIAL POSITIONS

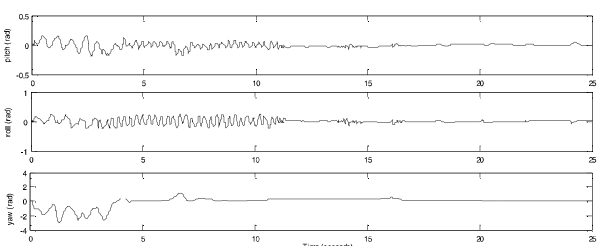

FIG. 11. STABILIZATION OF ATTITUDE ANGLES

5. CONCLUSION

This paper outlines a dynamical model of a small model helicopter. A hybrid control system, consists of intelligent fuzzy and conventional PID algorithm, is proposed to control the height and directional motion of the Raptor-30 V2. This hybrid flight control system is implemented in SIMULINK and model helicopter used comes from X-Plane flight simulator. Two computers are used to investigate the performance of hybrid control at hovering mode and its communication is done by UDP using Ethernet connection. From simulation results, it is clearly show that proposed hybrid control successfully achieved hovering mode. It shows its effectiveness over the helicopter model currently used for UAV research platform and most realistic flight simulator. A simple approach is presented to design the hybrid control based on static and dynamic performance; therefore, the stability and the quick control effect can be obtained simultaneously.

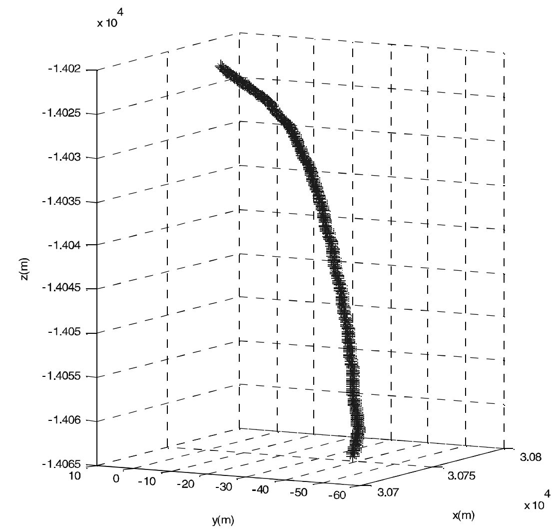

FIG. 12. RAPTOR -30 V2 AT HOVER MODE ALONG WITH x, y, z POSITIONS

ACKNOWLEDGEMENTS

Authors would like to express their gratitude to Prof. Dr. Dai Yaping, Beijing Institute of Technology, Beijing, China, who gave the possible opportunity to complete this work. Authors are also thankful to Mehran University of Engineering & Technology, Jamshoro, Sindh, Pakistan, for providing all necessary facilities for this research.

REFERENCE

[1] Martinez, M.L., Ortega, M.G., Vivas, C., and Rubio, F.R., "Nonlinear L2 Control of a Laboratory Helicopter with Variable Speed Rotors", Automatica, Volume 43, No.4, pp. 655-661, 2007.

[2] Khizer, A.N., Yaping, D.,Ali,S.A., and Xiangyang, X., "Stable Hovering Flightof Small Unmanned Helicopter using Fuzzy Control", Journal of Mathematical Problems in Engineering, USA, September, 2014.

[3] Yongquan, Y., Ying, H., and Bi, Z., "A PID Neural Network Controller", Proceedings of IJCNN, Volume 4, pp. 1933-1938, Portland, USA, 2003.

[4] Oliveira, V.A., Cossi, L.V., Teixeira, M., and Silva, A.M.F., "Synthesis of PID Controllers for a Class of Time Delay Systems", Automatica, Volume 45, No.7, pp. 1778-1782, 2009.

[5] Albaker, B.M., and Rahim, N.A., "Flight Path PID Controller for Propeller Driven Fixed Wing Unmanned Aerial Vehicles", International Journal of the Physical Sciences, Volume 6, No.8, pp. 1947-1964, 18 April, 2011.

[6] Salih, A.L., Moghavvemi, M., Mohamed, H.A.F., and Gaeid, K.S., "Flight PID Controller Design for a UAV Quadrotor", IEEE International Conference on Automation Quality and Testing Robotics, Volume 1, 2010.

[7] Fossen, T., "Mathematical Models for Control of Aircraft and Satellites", Norwegian University of Science and Technology, 2011.

[8] Isidor, A., Marconi, L., and Serrani, A., "Robust Nonlinear Motion Control of a Helicopter", IEEE Transactions on Automation Control, Volume 48, No.3, pp. 413-426, 2003.

[9] Lee, S., Ha, C., and Kim, B., "Adaptive Nonlinear Control System Design for Helicopter Robust Command Augmentation", Aerospace Science & Technology, Volume 9, No.3, pp. 241-251,2005.

[10] Gadewadikar, J., "Structured H_{∞} Command and Control Loop Design for Unmanned Helicopters", Journal of Guidance Control Dynamics, Volume 31, No.4, pp. 1093-1102, 2008.

[11] Bogdanov, A., and Wan, E., "State-Dependent Riccati Equation Control for Small Autonomous Helicopters", Journal of Guidance Control Dynamics, Volume 30, No.1, pp. 47-60, 2007.

[12] Ge, S.S., Ren, B., Tee, K.P., and Lee, T.H., "Approximation Based Control of Uncertain Helicopter Dynamics", IET Control Theory Application, Volume 3, No.7, pp. 941-956, 2009.

[13] Kadmiry, B., and Driankov, D., "A Fuzzy Gain-Scheduler for the Attitude Control of an Unmanned Helicopter", IEEE Transactions on Fuzzy System, Volume 12, No.4, pp. 502-515, 2004.

[14] Ge, S.S., Ren, B., and Tee, K.P., "Adaptive Neural Network Control of Helicopters with Unknown Dynamics", Proceedings of 45thIEEE Conference on Decision and Control, pp. 3022-3027, 13-15 December, 2006.

[15] Padfield, G., "Helicopter Flight Dynamics", Blackwell Science, Oxford, 1996.