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Virtual Reality Based Visualization and Training of a Quadcopter by using RC Remote Control Transmitter

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Abstract. The idea of this research paper is to simulate the flight of a quadcopter-type UAV, which can help to train drone pilots before the actual flight. We designed the quadcopter's model to help improve the future pilot's accuracy up to the point of a stable control, because it is necessary to know how to control the parameters of the quadcopter prior to a real-world scenario. Our system is based on a MATLAB Simulink model. The remote sensing input is given by the RC remote control, based on virtual reality, in order to train the data and output in 3D visualization environment. It has been developed and used for the measurement of the simulated system behavior and its performance. The objective of this research paper is to create a training environment of the quadcopter's flight parameters for a newly trained pilot. The pilot will be able to follow the simulated model and receive visual feedback. Following the simulated model implies stabilizing the moment of input-output. A visual system with real-time human-computer interaction could provide the intended training experience using this model.

1. Introduction

This paper is backed by the motivation of creating an interactive training system for UAV pilots. Its purpose consists of reducing human error in maneuvering UAVs, thus ensuring better control of the aircraft in real world scenarios. Simulated training presents lower risks and avoids hardware costs of maintenance, repairs and part replacement because of crashes. The system is composed of several components: a user interface for control, a visual feedback component and a simulation. The control user interface consists of a RC controller (transmitter), visual feedback is given through a 3D-graphics virtual reality and lastly, the simulation is based on the model presented in this paper.

To implement the proposed system, the necessary steps can be divided in three parts: to design the Quadcopter model in MATLAB/Simulink, to develop the communication between the RC remote control and the Simulink model as well as display the results using a 3D virtual reality-based form of visualization. All the required steps are as follows:

1. Design the Quadcopter model in MATLAB/Simulink.
2. Design the communication between the RC controller and the MATLAB/Simulink model.

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3. Design the 3D visualization Animation (as output of the system).
4. Interconnect the RC controller model and 3D animation with the main Quadcopter model.
5. Finally simulate input data in the RC model and verify the output results from the virtual reality

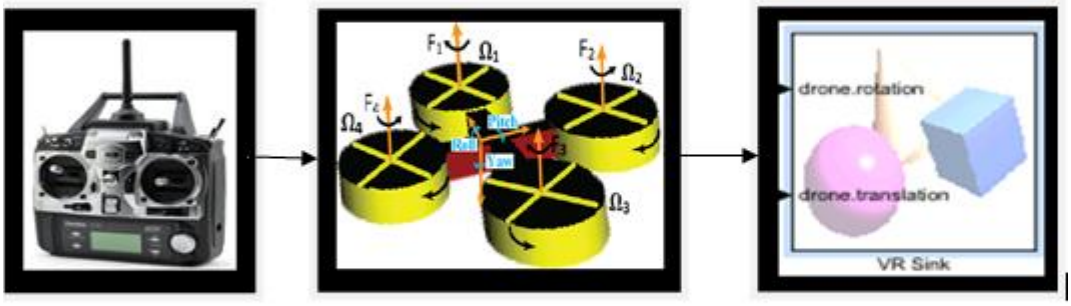

Figure 1. Block diagram of a quadcopter model and hardware controller.

A quadcopter is a type of unmanned aerial vehicle (UAV). Its structure is that of a small rotary aircraft having four rotors. Quadcopters find use in both indoor and outdoor applications related to civilization, detection, military, location, forest fire monitoring and many more[3][7].Initial UAV models had less degrees of freedom (DoF). Additional degrees of freedom determine increased stability and accuracy of the model, but also an increased complexity of the computations involved in the kinematic and dynamic analysis [4].

In this work we are using a six degree of freedom model. In the proposed system the model can be controlled from the RC transmitter by using only 3 channels as input. The 6 DoF model translational and rotational movement. This model is based on two frames of reference: inertial and body frame. Inertial frame is fixed to the Earth and body frame is attached (fixed) to the quadcopter, having its origin in the centre of the body mass. Translation is reflected by changes in the position vector. This position vector is given by the origin of body frame in the inertial frame. There are 3 translational directions named x, y, z given by the axes of the inertial frame. The force of gravity is represented by the z-axis of the inertial frame. Rotation is reflected by changes in the angles between axis of the body frame and axis of the inertial frame. There are 3 rotational angles named roll, pitch, yaw. Roll angle is measured between x-axes, pitch angle is measured between y-axes and yaw is measured between z-axes. Rotation is said to be actuated because it doesn't depend on position (it is not influenced by translation), while translation is under-actuated because it is influenced by rotation. [2][6].

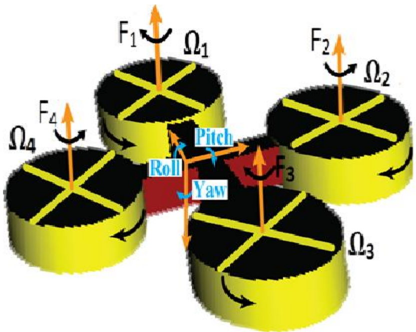

Figure 2. Quadcopter model.

The quadcopter has four propellers in a cross like configuration, as seen in Figure 2. One pair of opposite propellers rotate clockwise and the other pair rotate counter-clockwise. The quadcopter is treated as a rigid body; therefore, its behaviour can be mathematically modelled using Newton second law and Euler equation [1]. In order to develop the model of a quadcopter we make several assumptions: quadcopter is rigid and symmetric, the propellers are rigid, thrust and drag force are proportional to the square of angular velocity of a rotor and the distance from centre to each propeller is the same. In order to analyze the dynamic behaviour of the quadcopter it is necessary to consider the aspects that influence it and account for them in our model: thrust force, gyroscopic effects, friction, moment of inertia and aerodynamic effects.

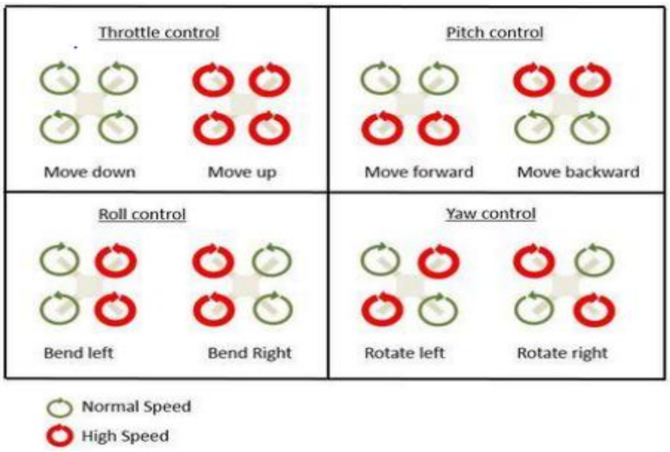

Figure 3. Dynamic movement of a quadcopter.

Figure 3 illustrates the quadcopter's movement. To increase altitude all rotors must rotate with the same increasing speed. Likewise, to decrease altitude, all rotors must rotate with the same decreasing speed. Hovering is achieved when all rotors rotate with a specific speed. Forward movement takes place if the rear rotors have greater speed than the front rotors and backward movement takes place for the opposite relation between front and rear rotor speed. These two movements affect the pitch angle. When the two left or right rotors have higher speed than the other two, a strafe left or right movement is achieved and it affects the roll angle. If the speed of all the rotors moving clockwise is greater than the speed of the rotors moving counter-clockwise (or vice-versa), it generates a rotation around the Z axis which also affects the yaw angle.

1.1 Quadcopter Dynamic Model

The quadcopter is a complex nonlinear system [10]. The rotary UAVs have an advantage over other UAVs of being mechanically simple and not needing a complex set of mechanical linkage equation to change the rotor blade angle. The dynamic of main rotor can be predicted by the thrust force; the thrust force depends upon the induced velocity which affects the torque. If the torque is changed, then the rotational angle is changed as well. Changing the velocity of each rotor will tilt the quadcopter in the direction of the heading of the sensible turning rotor, which speeds up the velocity. Produced thrust depends upon the angle, the larger the angle the more will the angular velocity be. RC transmitter input is translated into changes of position vector or rotational angles and generate the desired movement.

In hovering position all the rotor generates equal amount of thrust force. When the rotor thrust forces become unequal they affect the translational and rotational movement. By varying the rotor speed the thrust force can be changed and rotation occurs. During translation body moves according to position vector x, y and z axis and during rotation the pitch, roll and yaw angles are transformed. In order to achieve the desired position, it is necessary to control the speed of the rotor and doing so will cause the thrust force and torque to change[8]. To construct the dynamics and kinematics mathematical model, the following equations are used, which (according to Newton's second law of rotation) are:

$$J \cdot \dot{\omega} + \omega \times J \cdot \omega + M_G = M_B \tag{1}$$

Moment of a body frame is along x, y and z-axis;

$$M_B = \begin{bmatrix} L \cdot K_f \cdot (-\Omega_2^2 + \Omega_4^2) \\ L \cdot K_f \cdot (\Omega_1^2 - \Omega_3^2) \\ K_M \cdot (\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \end{bmatrix} \quad (2)$$

The gyroscopic moment is not a significant factor at low RPM, but it is nonetheless taken into account in the developed model (because its significance grows at higher RPM). It has the following form:

$$M_G = \begin{bmatrix} \dot{\theta} J_r \Omega_r \\ -\dot{\varphi} J_r \Omega_r \\ 0 \end{bmatrix} \quad (3)$$

To find the translation and rotation of a body with respect to inertial frame we calculate the moment of inertia followed by a symmetrical geometry. In the table below are enumerated the values of a quadcopter model:

Table 1. Quadcopter model initial values

m_m	0.048	kg	motor weight
l_x, l_y	0.0288	m	distance from centre of body to the axis
l_z	0.026	m	
d	0.29	m	distance from centre of a quadcopter to each rotor
m	0.82	kg	mass of quadcopter

Following is an example calculation of inertia including the geometry, mass of a rotor and the position of a quadcopter:

$$I_{x1} = I_{x3} = \frac{1}{12} m_m \left(l_y^2 + l_z^2\right) = 6.0218 \times 10^{-6}\ kg.m^2 \quad (4)$$

$$I_{x2} = I_{x4} = \frac{1}{12} m_m \left(l_y^2 + l_z^2\right) + m_m.d^2 = 0.004\ kg.m^2 \quad (5)$$

$$I_{xx} = 2I_{x1} + 2I_{x2} = 0.0081\ kg.m^2 \quad (6)$$

$$I_{y1} = I_{y3} = \frac{1}{12} m_m (l_x^2 + l_z^2) + m_m.d^2 = 0.004\ kg.m^2 \quad (7)$$

$$I_{y2} = I_{y4} = \frac{1}{12} m_m (l_x^2 + l_z^2) = 6.0218 \times 10^{-6}\ kg.m^2 \quad (8)$$

$$I_{yy} = 2I_{y1} + 2I_{y2} = 0.0081\ kg.m^2 \quad (9)$$

$$I_{z1} = I_{z2} = I_{z3} = I_{z4} = \frac{1}{12} m_m \left(l_x^2 + l_y^2\right) + m_m.d^2 = 0.004\ kg.m^2 \quad (10)$$

$$I_{zz} = 4I_{z1} = 0.0162\ kg.m^2 \quad (11)$$

$$J = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \quad (12)$$

$$J = \begin{bmatrix} 0.0081 & 0 & 0 \\ 0 & 0.0081 & 0 \\ 0 & 0 & 0.0162 \end{bmatrix} kg.m^2 \quad (13)$$

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The rotational matrix R is a mapping from a coordinate system related to the body frame to another coordinate system related to the inertial frame. It has the following form, where *c* and *s* are shorthand notations for *cos* and *sin* respectively:

$$R = \begin{bmatrix} c\theta c\psi & s\varphi s\theta c\psi - c\varphi s\psi & c\varphi s\theta c\psi + s\varphi s\psi \\ c\theta s\psi & s\varphi s\theta s\psi + c\varphi c\psi & c\varphi s\theta s\psi - s\varphi c\psi \\ -s\theta & s\varphi c\theta & c\varphi c\theta \end{bmatrix} \quad (14)$$

The total moment or torque of a body is the difference between the gyroscopic moment and the moment of a body frame. To find the expression of the angular velocity, after evaluating all equations we get:

$$\dot{\boldsymbol{\omega}} = \boldsymbol{J}^{-1}\left(\left[\begin{bmatrix} (I_{yy} - I_{zz})\omega_y\omega_z \\ (I_{zz} - I_{xx})\omega_x\omega_z \\ (I_{xx} - I_{yy})\omega_x\omega_y \end{bmatrix} - \begin{bmatrix} \dot{\theta}J_r\Omega_r \\ -\dot{\varphi}J_r\Omega_r \\ 0 \end{bmatrix} + \begin{bmatrix} L \cdot K_f \cdot (-\Omega_2^2 + \Omega_4^2) \\ L \cdot K_f \cdot (\Omega_1^2 - \Omega_3^2) \\ K_M \cdot (\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2) \end{bmatrix}\right]\right) \quad (15)$$

2. System design and simulation results

Remote sensing has become one of the most frequently utilized tool for effectively managing the analysis of the model behavior [9]. The RC remote control has total 8 axes - it means we can give various types of input from RC remote controller to our model. In this model (seen in Figure 4) we used only three input channels and from these three inputs we can control six degrees of freedom. These three inputs are: forward or backward, left or right, up or down. From these inputs we control the rotational as well as the translational part of a quadcopter.

The first block of the simulation model below shows the open loop control via the RC remote control and is responsible to inject the input command given by a user and validates data in our model for that simulation environment developed in MATLAB Simulink [5]. This open loop model can only analyze the translational part that we are giving from the input RC remote controller on the first channel to move forward-backward; second channel is used to control left-right movement and the third channel is for up-down control. After receiving the user inputs from RC remote controller, we added selection axes block to allow only three axes input via axes selection. We set the RC remote tolerance in the range from -0.3 to 0.3, which means that the Simulink model does not detect any change occurred within this range and does not affect the output within this range. Sensitivity is basically a gain which is a multiple of input to make bigger input so that the user can visualize the changes in output with respect to the input. In the end we used graphical interface for 3D animation to visualize the user input on virtual reality-based environment to feel the realistic movement of the quadcopter model and also see their graphs in a scope with the help of demux for the individual changes that occurs in the input.

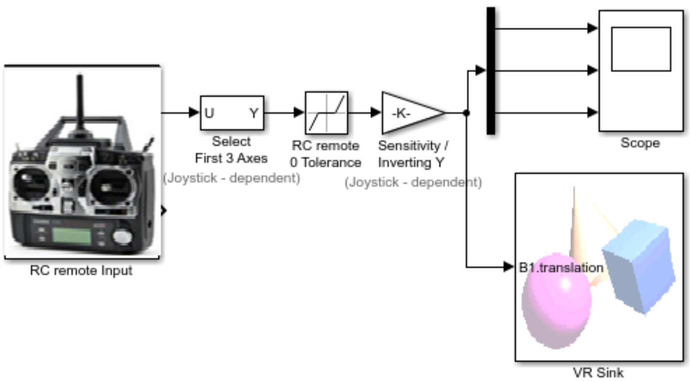

Figure 4. Translation movement control with RC transmitter.

Each possible movement (detailed in Table 2) was tested as can be seen in Figure 5 and 6. The output is represented on two graphs showing pitch and roll angle values (in radians) with respect to input commands given.

Table 2. Translational movement of the quadcopter.

RC transmitter Input	Pitch angle position [rad]	Roll angle position [rad]
No Input/Hover	**0**	**0**
Forward movement	**0**	**1**
Backward movement	**0**	**-1**
Right movement	**1**	**0**
Left movement	**-1**	**0**
Forward diagonal Right	**1**	**1**
Forward diagonal Left	**-1**	**1**
Backward diagonal Right	**1**	**-1**
Backward diagonal Left	**-1**	**-1**

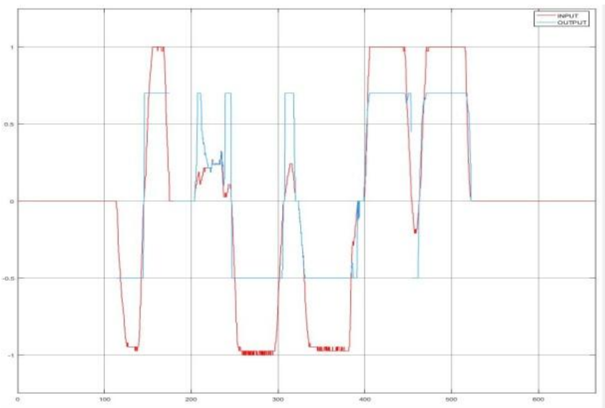

Figure 5. Movement of Output Roll angle w.r.t Time by using RC transmitter.

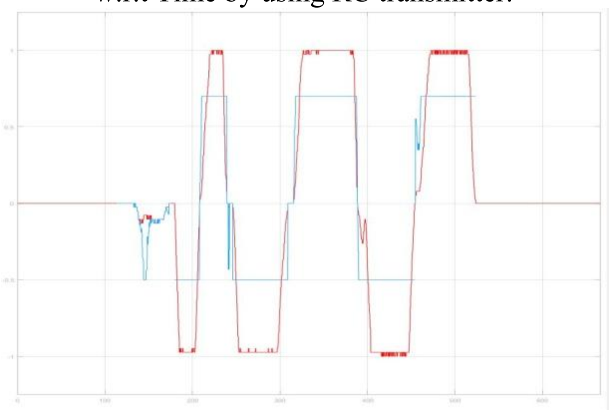

Figure 6. Movement of Output Pitch angle w.r.t Time by using RC transmitter.

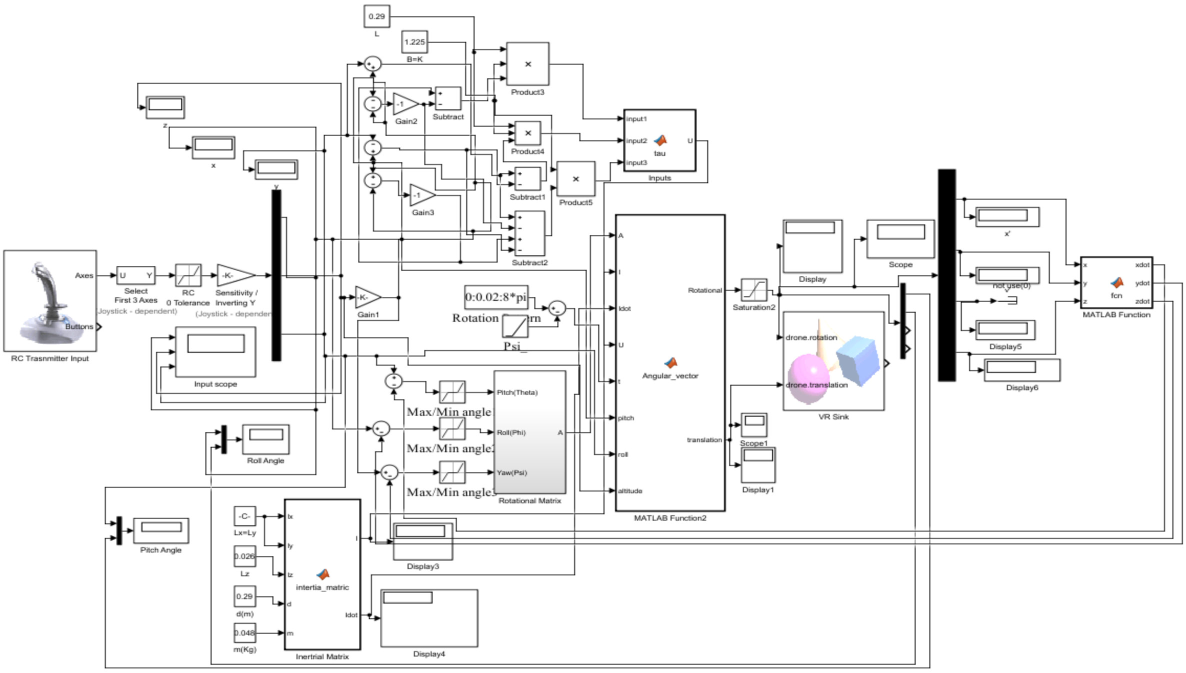

Figure 7. The final Simulink model using RC transmitter for translational - rotational model.

The quadcopter model (as shown in Figure 7) has a rotational matrix, moment of inertia matrix and thrust forces. It is termed a “basic quadcopter model” as it uses Newton’s law equations to get the angular velocity as an output. This quadcopter model was combined with the first part of Simulink model (presented in Figure 4).

By using this model, we can control 6 degrees of freedom (translational and rotational). Figure 7 shows the MATLAB /Simulink model of the whole system. Figure 8 and Figure 9 shows the graph obtained from this final translational-rotational model by giving command from RC transmitter forward-backward, left-right and analysing the effect in terms of roll angle and pitch angle. In Figure 10 and Figure 11 we gave a combined input x and y (diagonally) and observed the rotational changes. In all the figures, the input is coloured red and the output is represented by a blue line. The vertical axis of the graph represents the angle in radians (constrained to the -1 to 1 interval) and the horizontal axis represents time.

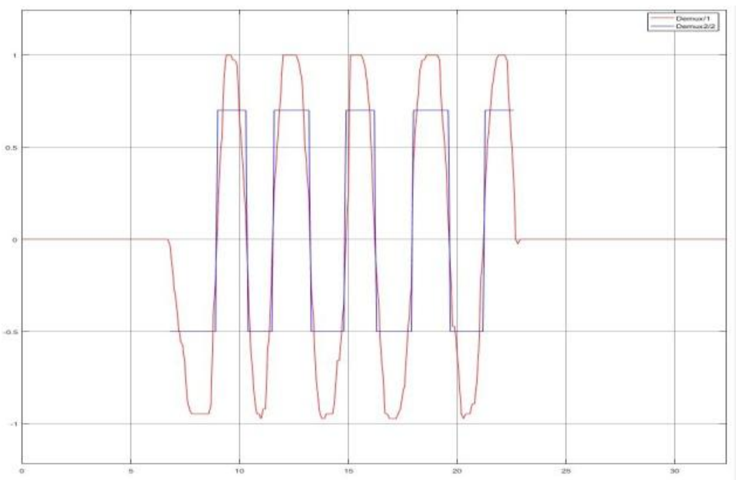

Figure 8. Movement of output roll angle w.r.t time by using forward-backward command through RC transmitter.

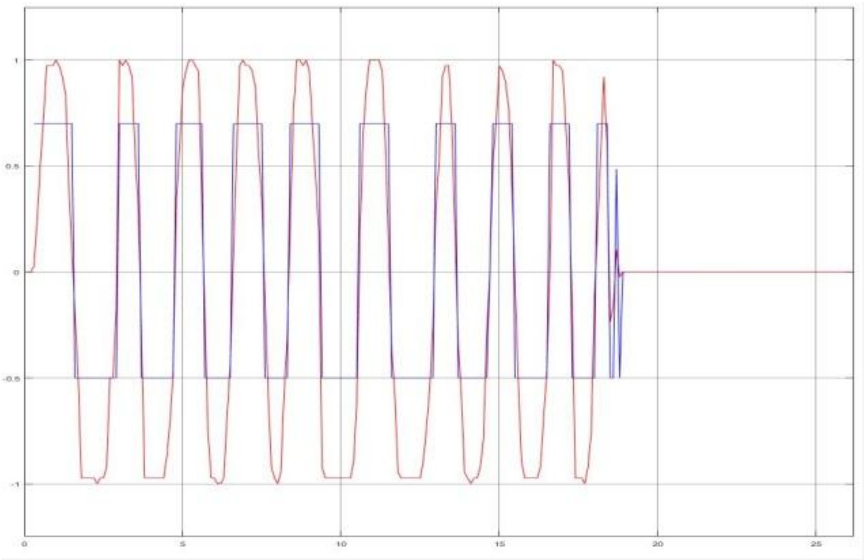

Figure 9. Movement of output pitch angle w.r.t. time by using left-right command through RC transmitter.

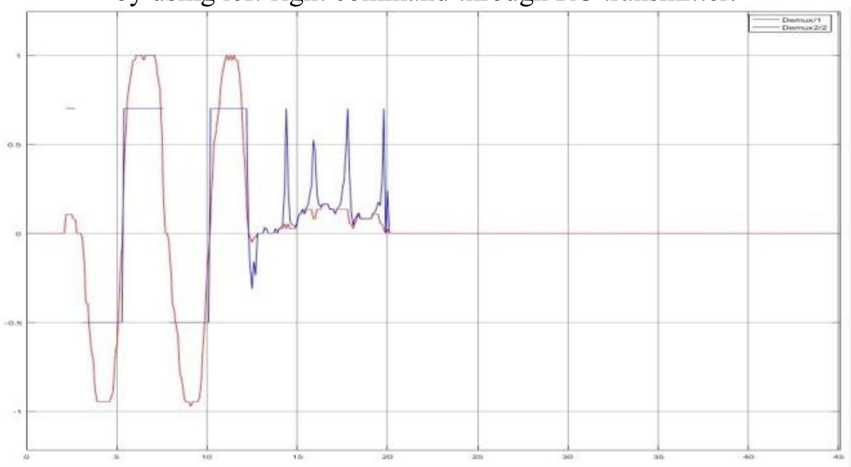

Figure 10. Diagonal movement of forward-backward and left-right from input result observed at pitch angle

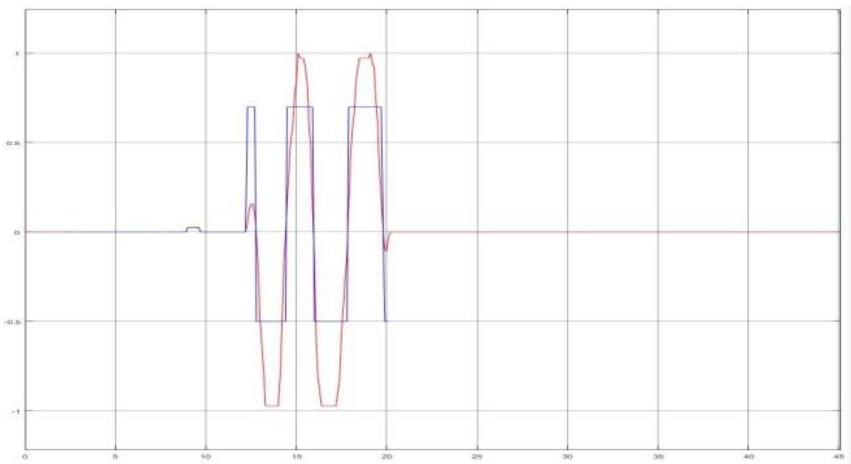

Figure 11. Diagonal movement of forward-backward and left-right from input result observed at roll angle.

3. Conclusion

This paper proposes a Simulink model to simulate a quadcopter flight, which helps in the training of new pilots before actual flights. The benefit of this model is the fact that the pilots can get real experience before even using any hardware, except the RC transmitter. Thus, they can familiarize themselves with the commands and responsiveness of the flight system, and this way we can decrease the possibility of human error during real flights and we are able to get acquainted with a realistic behaviour of the quadcopter.

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