



UAVs' Flight Control Optimization for Delivering Motion-Sensitive Blood Products

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Abstract—

This paper proposes the rules of proper flight control and the design of an intelligent controller for the UAVs' used for carrying blood and motion-sensitive medical equipment such as optical tubes that are used in industrial health monitors and glass vacuum tube structures. This equipment may be damaged if the device falls or vibrates. We proposed a new algorithm called UAVs' Flight Optimization (DFO) that separates the couplings between the four main channels of the quadcopter, and in order to separate the rotational and roll motions from the yaw movement, we consider a new motion mechanism and the corresponding equations and relationships are extracted. The yaw movement of quadcopter during rotation and roll is eliminated. For this purpose, the nonlinear model of the quadcopter is extracted using Newton-Euler rules and the decision-making process is performed for this purpose to move to the desired point (target point) and the appropriate speed of the engines using the control rules. We simulated our algorithms over two controllers called proportional–integral–derivative (PID) and linear square adjusters (LQR) and compared our results against an adaptive sliding-mode control algorithm. Simulation studies show that DFO has achieved minimum 91% less motion of yaw movements.

Index Terms—Autopilot, Control engineering, Drones, Remotely guided vehicles.

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I.

I. INTRODUCTION

UAVs' are quadcopters that can autonomously fly and complete their missions unassisted by on-board computers [10]. In recent decades, research on UAVs has come to the attention of many researchers for applications such as extinguishing fires and preventing the spread of fire or using fire extinguishers in tall buildings [2] and even carry medical equipment to remote areas [8]. or the transfer of important and vital medicine for humans and animals, including chemotherapy drugs, vaccines, laboratory samples, blood products, organ

transplants, has attracted the attention of many researchers [9]. The quadcopter flies in different directions by changing the engine speed as the thrust of each motor can be controlled independently. Hence, the speed of the motors can be adjusted according to the control program. In addition, the rotation of the impellers creates an upward thrust that allows the quadcopter to move in three-dimensional space. However, the changes in the 3D movement of quadcopter might be suddenly that cause damages to the load. For example, in the case of transporting blood to remote area, it has been



proven that any vibration causes damage to the red blood cells. The damage to the red blood cells depends on both the peak acceleration and the duration of the shock vibration exposure [6]. The vibration may also increase the amount of enzymes and other components of the blood such as aspartate aminotransferase, folate, lactate dehydrogenase and lipid index [11].

Many researchers have investigated the quadcopter modeling and control using LPV and Nonlinear [7] proportional-derivative PD [5], proportional-integral-derivative PID [4], LQR and Fuzzy [3]. introduce the LQR controller with integral effect to control the roll, pitch and yaw angle. Furthermore, the linear system model was compared by the nonlinear system, al control the attitude of quadrotor using the LQR controller and furthermore the performance of the LQR controller was compared by the PD controller [1]. To our best knowledge, most of the works in the literature are related to controlling the angular position of the quadcopter using different controls. Some works consider the route design for the quadcopter [1]. However, elimination of yawning during flight has not been investigated.

This article aims to propose a new algorithm called UAVs' Flight Optimization (DFO) to improve the quality of transportation when it is carrying calibration-sensitive medical equipment such as blood products such that minimum vibration is achieved. We proposed DFO that separates the couplings between the four main channels of the quadcopter, and where all four motors are used simultaneously to perform the turning and roll operation. This process eliminates the effects of the aerodynamic moments that cause the yaw to move, so the quadcopter will no longer yaw when turning, In DFO, the autopilot design can work with any type of controller including classic PID controller or linear optimization controller (LQR). The objective is to avoid severe shocks during transport for calibration-sensitive medical equipment. we were able to remove more than 91% of yaw movements.

Briefly, the contributions of this paper are as follows:

we propose a new algorithm called DFO to eliminate yaw motion during quadcopter flight, implement this algorithm with two controllers, and finally evaluate its performance. We can deliver vibrating blood products and medical equipment to

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deprived and inaccessible places without the slightest harm and all human beings and even all living beings can use the desired and fast services without any harm in all places.

II. SYSTEM MODEL

In this section, quadcopter equations of motion are extracted using Newton-Euler equations. The purpose of extracting the equations is to control and UAVs in guide this in space.

For this purpose, we define three coordinate axes. The first axis of body coordinates that is attached to the body and its origin coincides with the center of mass of the body and rotates with the body. The X-axis of the fuselage is in the direction of the longitudinal axis of the fuselage and towards the engine No. 1 (in front of the bird) and the Y-axis is in the direction of the engines No. 2 and 4 and towards the engine No. 2 The Z axis of the body is also obtained with the help of the law of the right hand. The axis of the body coordinates and the direction of the thrust forces and torques on the UAV can be seen in Figure 1.

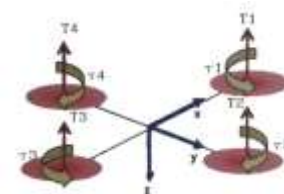


Fig. 1. Axis of body coordinates and thrust forces and aerodynamic moments shown on each propulsion system.

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The second axis is the axis of inertia coordinates, whose axes are represented by X, Y, Z, respectively. This coordinate axis is fixed on the ground. Its XY plane is in the direction of the horizon and its Z axis is in the direction of the earth's gravity towards the center of the earth. And the axes are positioned in such a way that the law of the right hand is true in them.

The third coordinate system is the horizontal coordinate system with the UAV, whose axes are represented by X_v, Y_v, Z_v , respectively. The origin of this axis of coordinates coincides with the center of mass of the bird and moves with the UAV and the direction of its axes is in the direction of the axis of inertia coordinates. With three consecutive periods, the axis of the coordinated horizontal coordinates can be

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adapted to the body system.

The first period around the Z_v axis of the device is as horizontal as ψ and the resulting axes after this period are called X_v, Y_v, Z_v . The rotation matrix from the horizontal device to the device $X1, Y1, Z1$ is called T_ψ .

$$T_\psi = \begin{bmatrix} \cos(\psi) & \sin(\psi) & 0 \\ -\sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The second period is the period of device $X1, Y1, Z1$ as θ around the axis $Y1$. The axes of this device resulting from the period of the coordinates of $X1, Y1, Z1$ are called the coordinates of $X2, Y2, Z2$. The rotation matrix from device $X1, Y1, Z1$ to device is called T_θ .

$$T_\theta = \begin{bmatrix} \cos(\theta) & 0 & -\sin(\theta) \\ 0 & 1 & 0 \\ \sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \quad (2)$$

The rotation of the $X2, Y2, Z2$ devices is equal to the angle ϕ around the $X2$ axis until these axes coincide with the axes of the $X Y Z$ body machine. The rotation matrix from device $X2, Y2, Z2$ to $X Y Z$ body device is called T_ϕ .

$$T_\phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & \sin(\phi) \\ 0 & -\sin(\phi) & \cos(\phi) \end{bmatrix} \quad (3)$$

Using the above three transformations, the total rotation matrix is obtained from the mobile horizontal device to the body device in Equation 4:

$$T_{\psi, \theta, \phi} = T_\psi \cdot T_\theta \cdot T_\phi \quad (4)$$

A. Extraction of motion equations

In our calculations, we consider the ground in flat inertia space and the quadcopter body in space, rigid, and also the effects of body torque on the gearbox dynamics are negligible and the center of mass and the origin axis of the coordinates of the body coincide. We consider the aerodynamic effects of the earth to be negligible and the aerodynamic traction to be in the direction of deviation (in the production of momentary deviation) as well as in the linear motion of the back of the body, In addition, we consider the structure of the quadcopter to be rigid and symmetrical with 6 degrees of freedom (in other words, it is considered a diagonal inertia matrix) in which the free body is exposed to gravity, gyroscopic moments and aerodynamic forces, as well as the force of force and traction proportional to the square of velocity locusts are considered.

We use the Newton-Euler equations for

mathematical modeling.

The equation of linear motion in a physical system is equal to:

$$\vec{F}_{body} = \begin{bmatrix} -mg \cdot \sin(\theta) \\ mg \cdot \cos(\theta) \sin(\phi) \\ -T + mg \cdot \cos(\theta) \cos(\phi) \end{bmatrix} = \begin{bmatrix} m \cdot a_x \\ m \cdot a_y \\ m \cdot a_z \end{bmatrix} \quad (5)$$

The equation of linear motion in an inertial device is equal to:

$$\vec{F}_{inertial} = \begin{bmatrix} (\cos(\psi) \sin(\theta) \cos(\phi) + \sin(\psi) \sin(\phi)) \cdot (-T) \\ (\sin(\psi) \sin(\theta) \cos(\phi) - \cos(\psi) \sin(\phi)) \cdot (-T) \\ mg - (\cos(\theta) \cos(\phi)) \cdot T \end{bmatrix} = \begin{bmatrix} m \cdot a_x \\ m \cdot a_y \\ m \cdot a_z \end{bmatrix} \quad (6)$$

The equation of angular motion of the quadcopter will be as follows:

$$\begin{bmatrix} \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} a_1 (\dot{\theta} \dot{\psi}) - a_4 (\dot{\phi} + \phi \dot{\psi}) \cdot \Omega + b_3 \tau_z \theta + b_1 \tau_x \\ a_2 (\dot{\phi} \dot{\psi}) - a_5 (\dot{\phi} + \theta \dot{\psi}) \cdot \Omega + b_3 \tau_z \phi + b_2 \tau_y \\ a_3 (\dot{\phi} \dot{\theta}) - (a_5 \Omega \dot{\phi} + b_2 \tau_y) \cdot \phi + b_3 \tau_z \end{bmatrix} \quad (7)$$

The general form of the equations of rotational motion in terms of state variables, control inputs and term of perturbations is as follows, it is observed that the above equation is nonlinear and longitudinal, transverse and lateral motions are coupled to each other.

$$\begin{cases} \dot{x}_{1(t)} = x_{2(t)} \\ \dot{x}_{2(t)} = a_1(x_{4(t)}, x_{6(t)}) - a_4(x_{4(t)}, x_{1(t)}, x_{6(t)}) \cdot \delta + b_3 u_{3(t)} x_{3(t)} + b_1 u_{1(t)} \\ \dot{x}_{3(t)} = x_{4(t)} \\ \dot{x}_{4(t)} = a_2(x_{2(t)}, x_{6(t)}) + a_5(x_{2(t)}, x_{3(t)}, x_{6(t)}) \cdot \delta + b_3 u_{3(t)} x_{1(t)} + b_2 u_{2(t)} \\ \dot{x}_{5(t)} = x_{6(t)} \\ \dot{x}_{6(t)} = a_3(x_{2(t)}, x_{4(t)}) - a_5 \cdot \delta + x_{1(t)} x_{2(t)} + b_2 u_{2(t)} x_{1(t)} + b_3 u_{3(t)} \end{cases} \quad (8)$$

B. The Open Loop Behavior of the System

To investigate the free behavior of the system, we examine the above equations without input and perturbation, and by solving the system of the above equations and for the initial conditions at the Euler angle rate, the free response of the system is obtained as Figure 2. Initially, the quadcopter is in the hover mode with zero Euler angles in the nominal mode, and a perturbation occurs at an angular velocity of $\dot{\phi}(t_0)$. The simulation results show that the turning and roll movements are coupled.

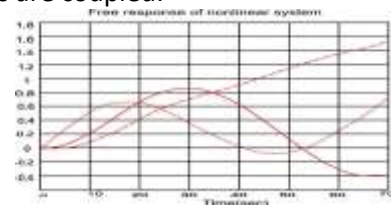


Fig. 2. Free response of the system to an initial perturbation at a roll angle rotation rate of 0.06 (radians per second).



III. UAVS' FLIGHT OPTIMIZATION (DFO)

Originality The movement channels of the quadcopter are four and the verandas are applied to the bird in four separate ways. These channels are: Yaw channel, height increase or decrease channel, turning channel and roll channel. As mentioned in this article, the turning and roll channels are either couplings, which makes it difficult to control the device, and it will be necessary for the turning or roll controller to continuously adjust the angle ripples due to the coupling. Neutralize movement. To solve this problem, a suitable solution is to separate the existing couplings. In order to separate the turning and roll movements from the yaw movement, we considered a new algorithm which is explained and proved in the following, and the relevant relations and equations are extracted.

We propose UAVs' flight optimization (DFO) where all four motors are used simultaneously to perform the turning and roll operation, and the rotation of two motors next to each other increases simultaneously and the rotation of the two motors opposite them decreases simultaneously. This process eliminates the effects of the aerodynamic moments that cause the yaw to move, so the quadcopter will no longer yaw when turning, while in other models, due to the type of movement that moves the roll or turning, two motors are used to move the turning or roll, due to the movement coupling, the yaw action is also created.

A. Extraction of transition equations with DFO

In the new modelling done by DFO, we have also considered the effects of body back forces due to quadcopter movement. In order to write the transfer motion equations in the inertial device, it is sufficient to transfer the output vector T and the back forces that are in line with the axes of body coordinates from body to machine. Transmit inertia. Therefore, it is sufficient to multiply the inverse of the period matrix by the sum of the trust and post vectors. On the other hand, the period matrix is an orthogonal matrix, so its inverse will be equal to its transposition.

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} C\theta.C\psi.D_x & (S\phi.S\theta.C\psi - C\phi.S\psi).D_x & (C\phi.S\theta.C\psi + S\phi.S\psi).(D_z - T) \\ C\theta.S\psi.D_x & (S\phi.S\theta.C\psi + C\phi.C\psi).D_y & (C\phi.S\theta.C\psi - S\phi.C\psi).(D_z - T) \\ -S\theta.D_x & (S\phi.C\theta).D_y & (C\phi.C\theta).(D_z - T) \end{bmatrix} \quad (9)$$

The quadcopter transfer equation in the inertial coordinate system is equal to:

$$\vec{F}_{inertial} = \begin{bmatrix} m.a_x \\ m.a_y \\ m.a_z \end{bmatrix} = \begin{bmatrix} C\theta.C\psi.D_x & (S\phi.S\theta.C\psi - C\phi.S\psi).D_y & (C\phi.S\theta.C\psi + S\phi.S\psi).(D_z - T) \\ C\theta.S\psi.D_x & (S\phi.S\theta.C\psi + C\phi.C\psi).D_y & (C\phi.S\theta.C\psi - S\phi.C\psi).(D_z - T) \\ mg - S\theta.D_x & (S\phi.C\theta).D_y & (C\phi.C\theta).(D_z - T) \end{bmatrix} \quad (10)$$

B. Extraction of positional equations (angular)

To complete the autopilot simulation of this UAV, it is enough to extract the equations of angular motion in the body coordinate system.

Newton-Euler equation The angular equations is:

$$\begin{bmatrix} \tau_x \\ \tau_y \\ \tau_z \end{bmatrix} = \begin{bmatrix} I_x \dot{\omega}_x + \omega_x \omega_z (I_z - I_y) + J_r \Omega \omega_y \\ I_y \dot{\omega}_y + \omega_x \omega_z (I_x - I_z) + J_r \Omega \omega_y \\ I_z \dot{\omega}_z + \omega_x \omega_y (I_y - I_x) \end{bmatrix} \quad (11)$$

We rewrite the above equation in terms of first-order derivatives of angular velocities of the body as follows:

$$\begin{bmatrix} \dot{\omega}_x \\ \dot{\omega}_y \\ \dot{\omega}_z \end{bmatrix} = \begin{bmatrix} \frac{\tau_x - \omega_x \omega_z (I_z - I_y) - J_r \Omega \omega_y}{I_x} \\ \frac{\tau_y - \omega_x \omega_z (I_x - I_z) - J_r \Omega \omega_y}{I_y} \\ \frac{\tau_z - \omega_x \omega_y (I_y - I_x)}{I_z} \end{bmatrix} \quad (12)$$

The new modeling reduces the coupling effects, and this is possible by separating the coupling of the roll and turning movements from the yaw, which is related to the type of movement mechanism in performing the roll and turning operation. DFO defined for the UAV prevents the quadcopter from yawning during operation, which helps to track the path more accurately.

C. Autopilot design for DFO

In the guidance program, the required angle is first determined to align the x-axis of the body with the line that connects the center of mass of the quadcopter to the destination point, and the quadcopter strikes the same amount. After that, the height of the quadcopter decreases to the extent that it increases or decreases with the point in question. The third phase of the steering step is to apply the turning to the flyer so that the quadcopter reaches its desired position and stops at that point. In this regard, two guidance methods were designed using the classic PID control and another guidance method based on the optimal linear control of LQR. We could able to stabilize the system well and execute the guidance commands, and with the final coordinates, guide the quadcopter towards it with good accuracy.

In general, regardless of the type of control, first the desired position of the quadcopter is entered by the user into the software and then entered into the



guidance block. There, according to the guidance program, the necessary commands to reach the desired point are given to the control system and the control system, after processing the guidance commands, sends the necessary signals to increase or decrease the engine speed to the required engine speed. Reach and apply the necessary torques and forces to the quadcopter to meet the desired angular position and meet the nominal path.

In addition to the above actions, the steering block determines when the yaw moves and when the elevation increases, as well as when the cruise and hover action occurs. In other words, it creates the order that we have considered to reach the desired point so that the defined path is carefully followed and the UAV hovers at that point.

D. Autopilot design using the classical control method for DFO:

In this guidance algorithm using the classic PID controller, both distance and speed and angle of the turning can be stabilized using a control channel. This simplified the rule of thumb, increased tracking accuracy and reduced simulation execution time. Low simulation execution time (high solution speed) and its real-time execution will make it possible to apply it to real UAVs.

In the conduction block, 6 signals are generated which enter the control block after production. These 6 signals are related to the error of the yaw angle, height, roll angle, turning angle and speed and distance. The roll angle controller resets the perturbations to zero, because when combining commands, an unwanted roll angle is created due to gyroscopic effects or due to engine saturation, which leads to erroneous movement on the track. But the remaining 5 signals are used to guide the UAV to the target point. In addition to the above tasks, the guidance block also determines the order in which errors are issued so that the UAV moves according to the defined path.

E. Autopilot design using optimal LQR linear control for DFO:

The advantage of this control is its ease of use and optimality. If we want to solve the problem of stabilization and zeroing of the vector of this system from any non-zero initial state as quickly as possible, there are many criteria for expressing the zero speed

of the state. A useful criterion is the quadratic integral criterion. Which is expressed as follows [1]:

$$J = \int_{x_0}^{x_1} x_{(t)}^T Q x_{(t)} dt \quad (13)$$

Therefore, it is obvious that the choice of Q depends on the goal of the designer and is one of the control parameters. Determining the optimal system input by minimizing the J-standard will face the problem of extremely large input domains. To prevent this problem, we also enter the input in the performance index. So we will have:

$$J = \int_{t_0}^t [x_{(t)}^T Q x_{(t)} + u_{(t)}^T R u_{(t)}] dt \quad (14)$$

Where R is a definite positive weight matrix. By entering the second sentence, we will minimize the performance characteristics given. The relative importance of two sentences in the performance index is determined by the R and Q matrices.

By applying Lyapunov's relations, the linear control of the optimal quadratic steady state, which minimizes the performance index presented below, is equal to.

$$J = \int_{t_0}^{\infty} [x_{(t)}^T Q x_{(t)} + u_{(t)}^T R u_{(t)}] dt \quad (15)$$

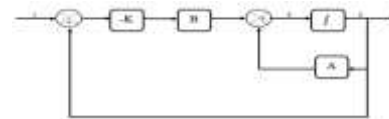


Fig. 3. Linear diagram block on which the optimal linear controller is mounted.

The block diagram of a linear system with an optimal linear controller is shown in Figure 3. Due to the fact that the quadcopter control system is a non-linear system because it has uncertainties and unpredictable events, it must be linear around the operating point (hover flight mode).

In order to calculate the optimum gain matrix for the take-off mode, linearization is performed around the hover mode and the state variables are considered as Z and ψ and their values, and Δu_z and Δu_ψ are considered as system control inputs. Therefore, matrices B and A are obtained as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/C\phi C\theta \\ 0 & 0 & 0 & 0 \end{bmatrix}_{4 \times 4}, B = \begin{bmatrix} 0 & 0 \\ -(C\phi C\theta)(b(\Omega_z \Delta \Omega_z))/m & -(C\phi C\theta)(8b(\Delta \Omega_\psi))/m \\ 0 & 0 \\ 8b(\Delta \Omega_\psi)/I_z & 8b(\Omega_z + \Delta \Omega_z)/I_z \end{bmatrix}_{4 \times 2} \quad (16)$$

By placing numerical values in the above matrices we will have:



$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}_{4 \times 4}, B = \begin{bmatrix} 0 & 0 \\ -0.0972 & 0 \\ 0 & 0 \\ 0 & 0.1080 \end{bmatrix}_{4 \times 2} \quad (17)$$

The rank of the control matrix is of order 4, which is equal to the size of the matrix A, so this linear system is controllable and can be designed for that optimal controller by the linear optimal method. By solving the Ricati equation and placing the P matrix, the optimal interest is obtained as follows:

$$K = \begin{bmatrix} -10.000 & -17.4860 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 10.000 & 16.8874 \end{bmatrix} \quad (18)$$

To calculate the optimum gain matrix for the cruise mode, linearization is performed around the hover mode and the mode variables X, Z, θ and their rates are considered. Δu_θ is the control input to the turning channel that controls the position, speed and angle of the turning. We also consider Δu_z as the control input of the yaw channel. Therefore, matrices A and B are obtained as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}_{6 \times 6}, B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}_{6 \times 2} \quad (16)$$

By placing the numerical values and considering the hover mode as the nominal mode of the system, we will have:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -9.81 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}_{6 \times 6}, B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ -0.0972 & 0 \\ 0 & 0 \\ 0 & 0 \\ -1.8828 \end{bmatrix}_{6 \times 2} \quad (17)$$

We also selected the weight matrices after several times of testing and simulation to face religion:

$$Q = \begin{bmatrix} 0.01 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.01 & 0 & 0 & 0 & 0 \\ 0 & 0 & 10 & 0 & 0 & 0 \\ 0 & 0 & 0 & 10 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.01 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.01 \end{bmatrix}_{6 \times 6}, R = \begin{bmatrix} 0.1 & 0 \\ 0 & 100 \end{bmatrix}_{2 \times 2} \quad (18)$$

The rank of the matrix is controllable by order 4, which is equal to the size of the matrix A. Therefore, this linear system is controllable and can be designed for that optimal controller by the optimal linear control method. By solving the Ricati equation and placing the P matrix, the optimal optimum for the cruise position is obtained as follows:

$$K = \begin{bmatrix} 0 & 0 & -10.000 & -17.486 & 0 & 0 \\ 0.01 & 0.0419 & 0 & 0 & -0.8121 & -0.9288 \end{bmatrix} \quad (19)$$

We put the optimum interest on the linear system and it worked well and stabilized the system. Then we placed the interest matrix on the nonlinear system and again the results had high accuracy and attenuation.

In order to calculate the optimal gain for controlling the roll channel, we also designed an optimal optimal matrix to zero the perturbations in the roll channel. The state variables in this state were the angle of the ϕ and its value and the control input was Δu_ϕ . Therefore, matrices A and B are obtained as follows. Which also meet the condition of controllability:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}_{2 \times 2}, B = \begin{bmatrix} 0 \\ 8bl(\Omega_n + \Delta\Omega_z) / I_{xx} \end{bmatrix}_{2 \times 1} \quad (20)$$

By placing numerical values and considering the hover mode as the status of the system, we will have:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}_{2 \times 2}, B = \begin{bmatrix} 0 \\ 1.8828 \end{bmatrix}_{2 \times 1} \quad (21)$$

We also selected the weight matrices after several tests and simulations to face religion:

$$Q = \begin{bmatrix} 1000 & 0 \\ 0 & 1000 \end{bmatrix}_{2 \times 2}, R = [1]_{1 \times 1} \quad (22)$$

By solving the rickety equation and placing the P matrix, the optimal gain for controlling the roll angle is obtained as follows:

$$K = [31.6228 \quad 32.1495] \quad (23)$$

It is worthwhile mentioning that applying DFO on both the linear and non-linear systems can reduce the roll perturbations to nearly zero. This has been discussed and illustrated in next section.

IV. SIMULATION STUDIES

The specifications of the quadcopter model used in the simulation are given in Table1. The mass of the quadcopter is about half a kilogram. We also used Simulink software to perform the simulation.

To perform the simulation, we used the fixed step solution method (ode 45) with a solution step of 0.01.

TABLE I. SPECIFICATIONS OF THE QUADCOPTER USED IN THE SIMULATION.

Paramete	Value	Unit
r		
M	0.52	kg
J_r	6e-5	$kg.m^2$
b	3.13e-5	$N.S^2$



d	7.5e-7	$N.m.S^2$
I_{xx}	6.23e-3	$kg.m^2$
I_{yy}	6.23e-3	$kg.m^2$
I_{zz}	1.12e-2	$kg.m^2$
L	0.23	M
Ω_n	201.8524	Rad/sec

A. Navigation using PID control for DFO:

In this method, which is designed to guide the quadcopter and deploy it at the end point, we used three separate controllers to control the distance, speed and angle of the turn. First, we designed the turn angle controller and then we designed the two distance and speed controllers as well as the turn angle controller, with the difference that the input signal of their controller is multiplied by a factor. The direction of the output signal of the distance controller, it should be opposite to the output signal of the turn and speed controllers, because of the distance error, the quadcopter moves towards the final target.

Lack of turn angle and speed controllers causes quadcopter imbalance and unstable system and lack of speed controller does not cause system instability, but when the quadcopter reaches the end point, it always moves back and forth around the target point and the amplitude of fluctuations gradually decreases.

After combining the turn angle controller, distance and speed, with input coefficients of 4, 0.1 and 0.01, It can be seen that the quadcopter moves well towards the point of the final target and settles there best.

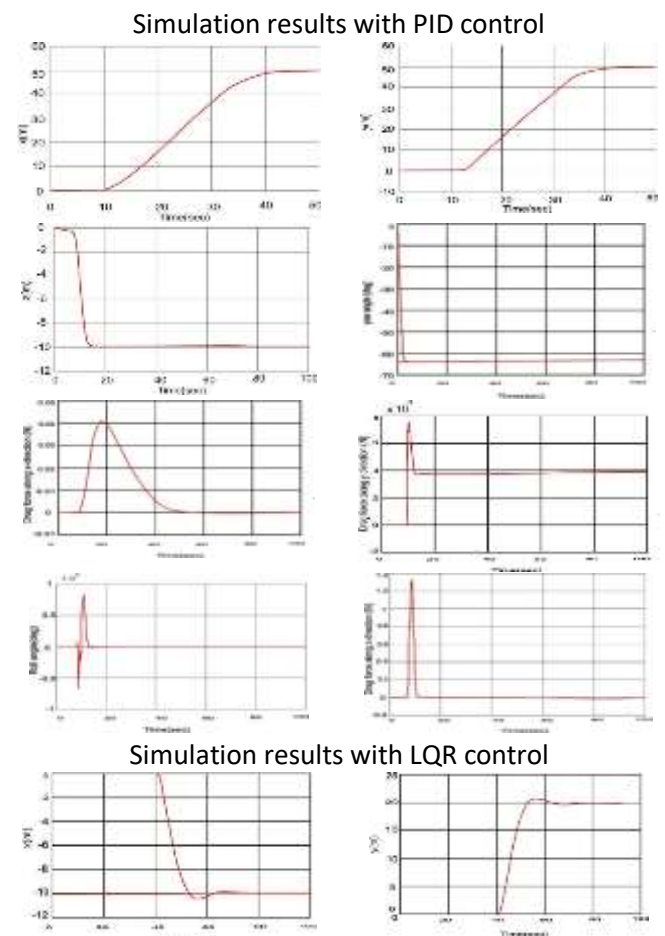
After designing the controller, for the case where the final position of the quadcopter is equal to the coordinates (-10, 20, -10), we performed the simulation, the results of which are shown in Figure 4. As the results show, the quadcopter has reached exactly the final position and is deployed at that point with the least number of Yaws.

The Navigation method is as follows:

The quadcopter flies at 63.4 for yaw to 5 seconds, from then on, it reaches the desired height for 10 seconds. From 10 seconds to 80 seconds, the quadcopter only turns the angle to cruise and reach the desired position. In this method, the quadcopter detects at what angle it will turn to move towards the target point while cruising and the speed becomes zero at that point.

B. Navigation using optimal linear control (LQR) for DFO:

To perform the simulation, we used the fixed solution method (ode4) with a solution step of 0.01. we have considered the final position of the quadcopter (-10,20, -10) and we performed the simulation, the results are illustrated in Figure 4. As the results show the quadcopter reached the final position with the least number of Yaws, at that point, the quadcopter's speed dropped to zero. It takes about 20 seconds for the quadcopter to both angle and increase altitude at the same time, and it takes about 40 seconds for the Cruise movement to reach the destination. In this method, the quadcopter also detects at what angle it will turn to move towards the target point while cruising and speed is also zeroed at that point. As Figure 3 shows, the roll angle of the quadcopter is about zero.



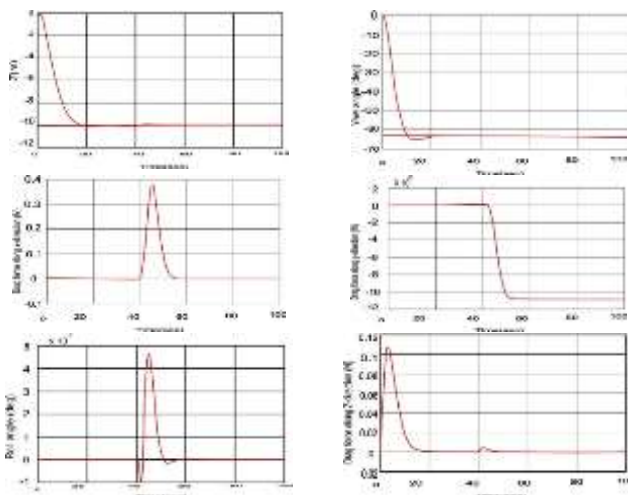
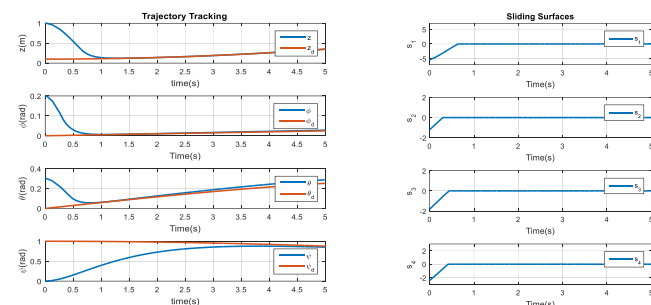


Fig. 4. Simulation results with PID control and LQR control for DFO.

C. Comparison of DFO algorithm with an adaptive controller

To evaluate DFO performance, we compared our algorithm with an adaptive sliding-mode control [12]. The simulation results of the adaptive sliding-mode control are as shown in Figure 5. As can be seen, this comparison shows that the DFO algorithm works very well and can minimize Yaw in flight time.



Quadrotor Attitude/Altitude Finite time convergence states of sliding surfaces

Fig. 5. Adaptive sliding-mode control performance status.

V. CONCLUSION

In this paper, we use a new algorithm called DFO (UAVs' Flight Optimization) to make the quadcopter navigation process smarter and eliminate Yaw motion during rotation and roll, which can damage the carrying of blood products and vibration-sensitive medical equipment. To demonstrate the performance of DFO, we have designed and implemented it with two controllers, PID and LQR, so that it can have the

endpoint coordinates of the path without Yaw when rotating and rolling automatically. Find and move to the desired point and finally settle there.

The use of DFO reduces the effects of motion coupling and causes the quadcopter to no longer yaw during rotation or roll operation. This is due to the simultaneous use of four motors during the rotation or roll operation, which neutralizes the aerodynamic torques that produce Yaw motion. Separating the coupling of the roll and rotation movements from the Yaw helps to control and track the path more accurately, so that we were able to remove more than 91% of yaw movements by doing this algorithm.

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