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Development of Control System Model for Multiple Quad-Copter Under Dynamic Environment

Constance Nneka Eze[1], Innocent I. Ene[2], Princewill C. Ene[3]
[1,2,3]Department of Electrical and Electronic Engineering in Enugu State University of Science and Technology.
Email: nnekaeze713@yahoo.com

Abstract— *Development of control system model methodology in multiple quad-copter under a dynamic environment is proposed in this work. Prodigious and outstanding success have been recorded in the area of multiple drones under a dynamic environment. Appling the control system mathematical model, this research used two research objectives in which the principal aim was to develop a Simulink control model for multiple quad-copter. Which was achieved by developing a mathematical model of a quad-copter using Newton Euler angle method in Simulink in order to enhance the control variables of both rotational and translation movement of the quad-copter. Next was the development of a control system for multiple quad-copter in Simulink was done by comparing the control of multiple drones when proportional integral derivative controller is implemented and when it's not implemented. This model was simulated in order to validate and justify the work. Velocity and time graph were plotted to show the relationships of velocity and time of the quad-copter flight as well as the time of the flight.*

Keywords— *Control system, Quad-copter, Multiple Drones, Dynamic Environment and Proportional Integral Derivative.*

I. Introduction

Nowadays, controlling of more than one drone under dynamic environment has been one of the complex problems for autonomous groups of drones. Some popular approaches to autonomous navigation used combination of different intelligent navigation techniques and algorithms to autonomously navigate drones in both static and dynamic environments. However, real time navigation still holds challenges for drone navigation in complex crowded environment. Control and collision free route have been a major research focus for multiple drones. Due to the increase in the number of multiple drones for technical and other applications, there has been increased interest in the study of embedded sensor and communication devices. Every day, available civil, commercial and even military applications of drones motivated this growing interest. The major interest in drone's navigation under dynamic environment is to find a collision free path from a given start position to a predefined target point in the work space, collision-free route and path planning is one of the vital challenges in achieving navigation in an unstructured environment. Originally, however, drones were conceived and built for military purposes but subsequent developments have shown that they can find use in many diverse applications. Such uses include climate change monitoring, goods delivery, aiding in search and rescue operations, filming, photography, repeaters in broadcast and communication and even in agricultural operations such as weed and pest control. Traditionally, flight controllers, which are circuit used in managing the drone's flight, are used for drone control. Within the drone, an electronic device which uses built-in antennas for the reception of radio signals from the controller completes the transmitter-receiver communication. Controlling multiple dynamic and remotely operated navigation equipment under dynamic environment has been identified as a crucial problem in the operation of drones and the field of robotics in general. The situation is made more complex when the control of multiple drones is involved. Studies have shown that local and global path-planning lacks robustness due to environmental uncertainty especially when drones are operated on environments different from the one in which the drone has been configured. It has also been established that in drone operation as in the field of robotics, to navigate an unknown environment without a preexisting map and without any knowledge of the environment poses a complex problem. The consequences of the identified problems include crashing collision of drones, loss of human lives, destruction of buildings and other structures due to crash of drones, extended time of operation, failure to actualize assigned operation as well as financial losses. The aim of this research is to develop a SIMULINK control model for multiple drone. To achieve the aim stated above, the following specific objectives are proposed. (i) To develop a SIMULINK control model for multiple quad copter. (ii)To design a control system for multiple quad copter.

Materials

The material used in this research are as presented below:

1. Stop watch- time measuring instrument
2. Control device
3. Physical drone model
4. MATLAB Simulink R2014b version
5. Python programming language
6. Flow chart
7. Graphical presentations
8. Laptop computer
9. Wireless Router
10. Robotic operating system (ROS).

II. Methodology

In this research the adopted methodology was largely based on development of a Simulink model for multiple drone from control set-up. A general control set was established for synthesis, analysis of data and information that were fed in from the different sensor fitted on the drone. This was achieved by

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developing a mathematical model in which Newton Euler method was adopted. After that, was the implementation of the mathematical model developed in Simulink using Simulink blocks to represent those control variables and equations. Newton Euler method is based on Newton's second law on the rigid body. Newton Euler method was implemented to develop the quad-copter model equation for the 6 degree of freedom using the control variables. Where X,Y, Z as the rotational movement along their axis. But using Newton Euler method was based on the input voltage supplied to the quad- copter rotors. The mathematical model stated below in which the equations are applied was used for designing the six sub-system. All four propellers rotate at the same speed which is represented as Ω (rad s) to counterbalances the acceleration due to gravity. Even though the quad copter has DOF. It is equipped just with four propellers. four best controller-able variables was implemented in other to related to the four basic movements which allow the quad copter to reach a certain height and attitude it follows the description of these basic movements.

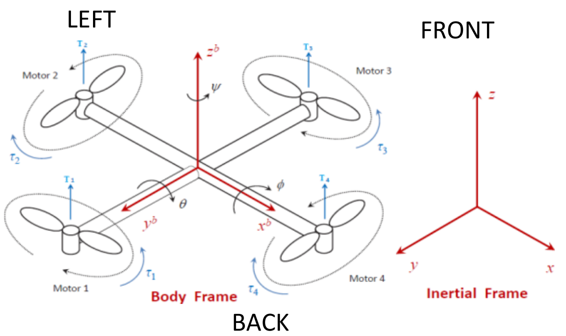

Figure 1: quad copter structure model in hovering condition

The roll pitch and yaw angles are denoted by $(\emptyset, \varphi, \psi)^I$ Respectively it describes its linear and angular positioning of a quad-copter. Why the rotors 1 and 3 rotate clockwise while 2 and 4 rotate connectors clockwise as depicted by the arrows. $T_1, T_2, T_3,\ \& T_4$ And the thrust generated by the rotors about the center of rotation.$T_1, T_2, T_3,\ \& T_4$are the thrust generated by the rotors about the center of rotation. Where all the torques applied to the quad-copter counter torque as a consequences of the spinning of the rotors.

Where the rotational direction are as follows

$$[u, v, w]^T \tag{1}$$

Where the rotational direction as follows

$$[u, v, w]^T \tag{2}$$

Angular orientation approach, this approach uses Newton Euler techniques to develop one of the quad-copter famous model equation for the 6-DOF. Force moment approach was also based on Newton Euler techniques this approach uses relationship between force and moment balance to develop the helicopter equation of motors. Were $I_x, I_Y \& I_z$ are helicopter modeling moment of inertia with respect to $X_B, J_B\ and\ z_B$,axes respectively in this approach for convenience drag coefficients are assumed to be zero since drags are negligible at low speed. Were the following X, Y and Z axis's represented below:

$$I_{xx} = rotational\ inertia\ along\ x - axis \tag{3}$$

$$I_{yy} = rtational\ inertia\ along\ Y - axis \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{4}$$

$$I_{zz} = rtational\ inertia\ along\ z - axis \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{5}$$

Rotor control input modeling.

This control-inputs was used for controlling the rotor by ways of manipulating it angular orientation. It torque-force moment balances Supplied rotor voltages.

Where u_1 is associated with vertical input movement
u_2 = is associated with roll input movement
u_3= is associated with pitch input movement
$u_{4=}$is associated with yaw input motion

Vertical thrust (sum of all thrust)

$$u_{1=l}\ (T_1 + T_2 + T_3 + T_4) \tag{6}$$

Rolling moment (thrust difference between two opposite motors) $U_{2=} L(T_{4-} T_2)$. (7)

Pitching moment (thrust difference between two opposite motors)

$$U_{3=} L(T_{1-} T_3) \tag{8}$$

Yawing moment (algebraic sum of all torques)

$$U_{4=} L(T_{1-} T_2 + T_{3\,-} T_4) \tag{9}$$

Equation to generate the necessary control inputs for the helicopter model.

$$z = g - \frac{u_1}{m} cos\phi \tag{10}$$

$$\ddot{\theta} = \frac{d}{I_{xx}} U_2 - \frac{I_m}{I_{xx}} Q_\Omega + \frac{I_{yy} - I_{zz}}{I_{XX}} \phi\Psi \tag{11}$$

$$\ddot{\phi} = \frac{d}{I_{yy}} U_3 - \frac{I_m}{I_{yy}} Q_\Omega + \frac{I_{zz} - I_{xx}}{I_{yy}} \phi\Psi \tag{12}$$

$$\psi = \frac{d}{I_{ZZ}} U_4 + \frac{I_{xx} - I_{yy}}{I_{ZZ}} \phi\Psi \tag{13}$$

Then the voltage control input approach are as follows:

Vertical thrust $(z - axis)$

$$u_{1=} V_1 + V_2 + V_3 + V_4 \tag{14}$$

Rolling moment (y- axis)

$$U_{2\,=} V_4 - V_2 \tag{15}$$

Pitching moment (X- axis)

$$U_{3=} V_1 - V_3 \tag{16}$$

Yawing moment

$$U_{4\,=} V_1 + V_2 + V_3 + V_4 \tag{17}$$

Voltage based modeling

The equation for the roll sub-system

$$\ddot{\theta} = \frac{2pAL}{I_{xx}} \left(\frac{F_n k_t}{K_q}\right)^{2} (v_2^2 - v_4^2) \tag{18}$$

The equation for the pitch subsystem

$$\ddot{\emptyset} = \frac{2pAL}{I_{xx}} \left(\frac{F_n k_2}{K_q}\right)^2 (v_3^2 - v_1^2) \tag{19}$$

The equation for the yaw subsystem

$$\dot{\psi} = \frac{J}{I_{zz}} (\Omega_1 + \dot{\Omega}_1 - \Omega_2 - \Omega_4) + \frac{D}{I_{ZZ}} (\Omega_1^2 + \Omega_3^2 - \Omega_2^2 - \Omega_4^2) \tag{20}$$

The equation for the attitude subsystem

$$= \frac{2pA}{m} \ddot{Z} \left(\frac{F_n k_t}{K_q}\right)^2 (V_1^2 + V_2^3 + V_3^1 + V_4^2) cos\phi - g \tag{21}$$

The equation for the x-axis subsystem

$$\ddot{x} = \frac{2pA}{m} \left(\frac{F_n k_t}{K_q}\right)^2 (V_1^2 + V_2^2 + V_3^2 + V_4^2) cos\phi\ cos\theta\ cos\Psi + \sin\phi\ sin\Psi \tag{22}$$

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The equation for y axis subsystem

$$\ddot{y} = \frac{2pA}{m}\left(\frac{F_n k_t}{K_q}\right)^2 (V_1^2 + V_2^2 + V_3^2 + V_4^2) sin\phi \; sin\theta \; cos\Psi - \cos\phi \; sin\Psi \quad (23)$$

The mathematical models and equations-of-motions derived via the above aforementioned techniques are nonlinear in nature, this nonlinearity makes it difficult for classical controllers like PID to effectively be used for controlling multiple quad copters. Then the Taylor-series was used to linearize the non- linearized state –space model equation which was given below.

$$x = Ax + Bu < and > Y = Cx + Du \quad (24)$$

Were the matrices A and B are defined as non-linear equations about the initial conditions.

The state variables "x" is given as

$$x = (U, V, W, P, q, r, x, y, z, \emptyset\theta\varphi) \quad (25)$$

Voltage Control Input

Vertical thrust (Z axis)

$$U_1 = V_1 + V_2 + V_3 + V_4). \quad (26)$$

Rolling moment (y axis)

$$U_2 = V_4 + V_2 \quad (27)$$

Pitching moment (x-axis)

$$U_3 = V_1 + V_3. \quad (28)$$

Yam moment

$$U_4 = V_1 + V_2 + V_3 - V_4 \quad (29)$$

Angular orientation model

The equation for roll subsystem

$$\ddot{\phi} = \theta\Psi\left(\frac{I_y - I_z}{I_x}\right) - \frac{J_t}{J_x}\theta\Omega f \frac{l}{I_x} u_2 \quad (30)$$

The equation pitch subsystem

$$\ddot{\theta} = \theta\Psi\left(\frac{I_z - I_x}{I_y}\right) - \frac{J_r}{J_y}\theta\Omega f \frac{l}{J_y} u_3 \quad (31)$$

The equation for the yaw subsystem

$$\dot{\Psi} = \dot{\phi}\dot{\theta}\left(\frac{I_x - I_y}{I_y}\right) + \frac{x_y}{I_x} u_4. \quad (32)$$

The mathematical model stated above in which the equations are applied in designing the six subsystem. And four motors was also designed into a Simulink block using the motor model shown in table 1. Design parameter.

TABLE 1: Model design parameter

Symbol	Parameters	Value	Units
M	Quad copter total mass	0.65	k_g
l	Length of quad copter	0.19	m
l_{xx}	Rotational inertia along x-axis	0.0075	kgm^2
l_{yy}	Rotational inertia along y-axis	0.0075	kgm^2
l_{zz}	Rotational inertia along z-axis	0.013	kgm^2
R_p	rotor blade length	0.16	M
l	Rotor blade figure of merit	0.5	
l_r	Rotors inertia	6.0e-5	kgm^2
R	Motors resistance	0.6	Ohm
K_e	Rotors speed Constant	0.0015	volts $s\,rad^1$
K_q	Rotors speed Constant	0.0056	$N.m\,A^{-1}$
η	Rotor efficiency	0.75	%
k_i	Torque Constant	0.01	$N.s^3$
G	Acceleration due to gravity	0.81	$m.s^3$
D	Drag coefficient	7.50e-7	
P	Air density	1.1	kgm^2

The table 1 stated above, provided a voltage based model of a quad copter which was utilized, and carefully reproduced each equation as a block (subsystem) adopted the motor design parameters. And some modification were made to suite the design All the characteristics of the quad copter system are presented in tabular form with only few alteration but the basic parameters remaining very similar to this work. Finally to test the developed model with the same voltage control input design with previous work this enabled the researcher to have the freedom to make few changes and observe output. The different developed models are shown in Figures 2 to 11.

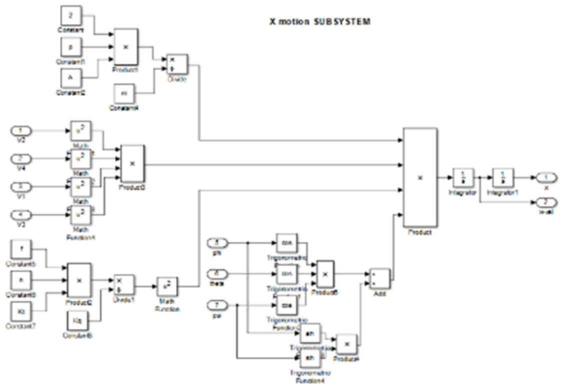

Figure 2: Simulink Model of Quad copter Showing Linear Motion Subsystem, X

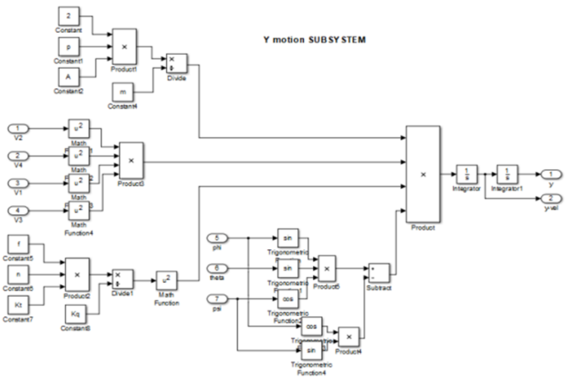

Figure 3: Simulink Model of Quad copter Showing Linear Motion Subsystem, Y

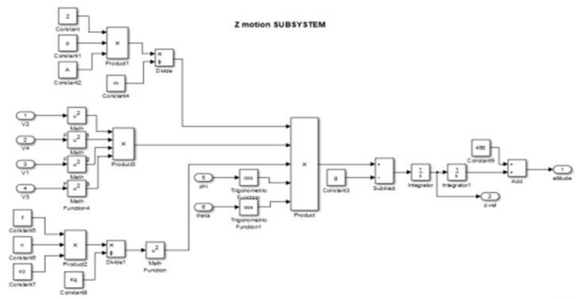

Figure 4: Simulink Model of Quad copter Showing Linear Motion Subsystem, Z

Similarly, the Simulink models of the quad copter showing the angular motion subsystem are shown in Figures 5to 6 and 7.

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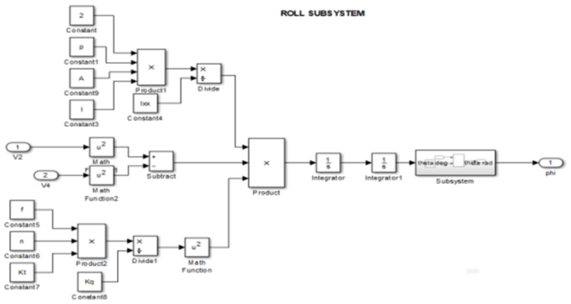

Figure 5: Simulink Model of Quad copter Showing Angular Motion Subsystem, Roll

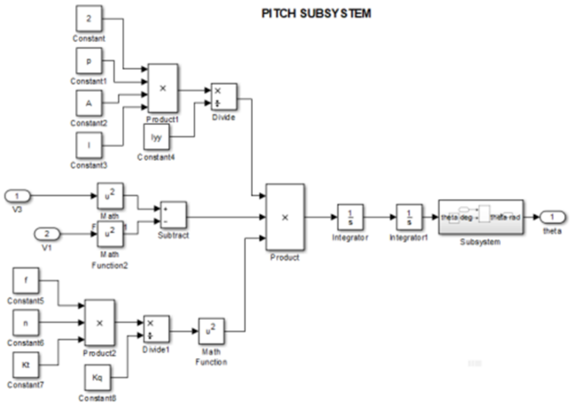

Figure 6: Simulink Model of Quad copter Showing Angular Motion Subsystem, Pitch

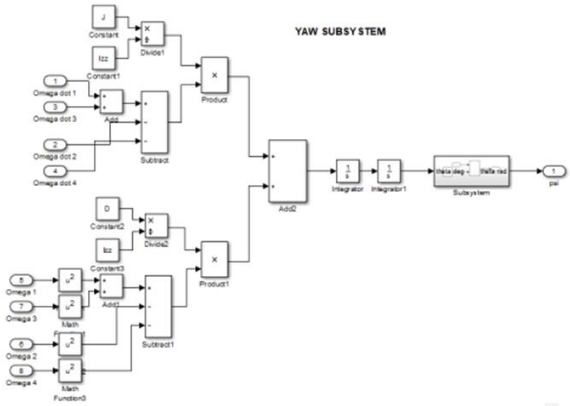

Figure 7: Simulink Model of Quad copter Showing Angular Motion Subsystem, Yaw

The developed model is shown in Figure 8 for conventional multiple drones control.

III. Results and Discussion

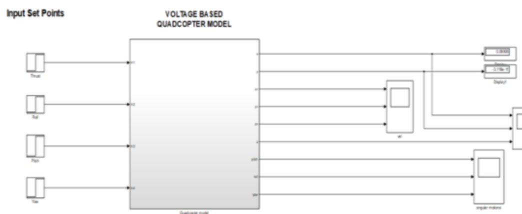

Figure 8: Simulink Model for the Control of Multiple Drones or Quad copters

When the model of Figure 8: is simulated, the results with respect to velocity versus time of reaction are shown in table 2. Designing a Control System for Multiple Drones, The equations and control variables generated from developed mathematical model was used to design a control system for the multiple drones. The control system that was designed in this research was known as PID which is the proportional integral derivative, where the control algorithm was implemented in this work in other to control the hover altitude of the quad-copter. The PID controller was used to calculate the error and difference between a measured output and a desired set point and adjust the system control inputs such that the calculated error is minimized. This developed model is shown in Figure 9.

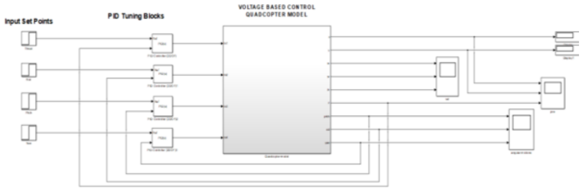

Figure 9: A PID Control System for Multiple Drones

Simulation results of conventional multiple drones control with PID, it shown that there is a time tap before the drone could attain a velocity. At this stage it was only PID was implemented the system showed and exhibited the following: Delay, Stagnation in it operation, Increase in time resulting to increase in velocity, Meaning at different velocities there where changes in time. From the above developed Simulink quad-copter model, the following $v_1 v_2 v_3$ and v4 are the voltage control input which was feed to motor models $m_{1,} m_{2,} m_3$ and m_4 as the input used to control the six degrees of freedom angles (which are x, y, z, Roll, Pitch And Yaw).The graph of Figure 10.Shows the velocities in x, y, z directions when the quad-copter is simulated for upward thrust. The velocity in the Z-direction shows actual change in position of the drone as it moves upwards adjusting its altitude; the velocities in y and x have a negligible impact on this upward motion. This graph shows the Thrust motion is perfectly controlled.

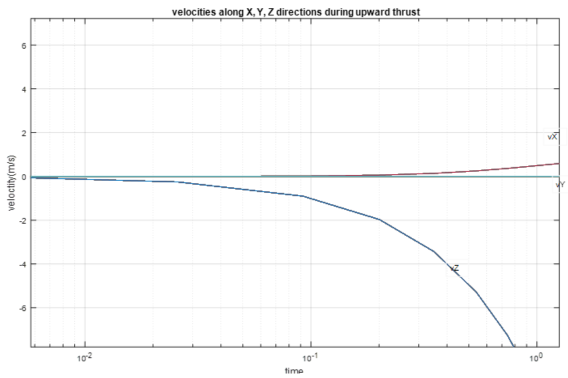

Figure 10: Velocities Along X, Y, Z Directions During Upward Thrust

The graph of Figure 10, is a velocity-time graph showing the relationship between the drone velocity and its upward thrust with respect to time. The velocity appears to be momentarily unchanging with an increase time as the drone makes an upward thrust. As the time of thrust increases, velocity decreases along the z-plane while it records an increase along the x-plane. This is the scenario experienced in a three-dimensional navigational movement which is only made clearer when viewed in a two-dimensional scenario. However, an upward thrust along the x-plane is witnessed as seen in the graph of Figure 11. It is required to develop a Simulink Control system for multiple quad copter. The reason for this, was to provide a control platform for the modeled quad copter. After the design, the control system was simulated and the behavior in relation to velocity and time for an operational was observed the recorded result gave rise to the data in table 2. This table is reproduced for the purpose of explanation.

TABLE 2: Results of Simulation of Conventional Multiple Drones Control

Velocity ms^{-1}	Time
0	0
0	5
0.00037	10
0.00062	15
0.00098	20
0.00147	25
0.00189	30
0.0028	40
0.00375	50
0.0047	60

The table 2, contains simulation results of conventional multiple drones control that is the results gave some very interesting data which forms the basis for the evaluation and justification of the research. The graph of Figure 11, shows the resulting velocity-time graph arising from table 2. This graph is hereby presented and analyzed.

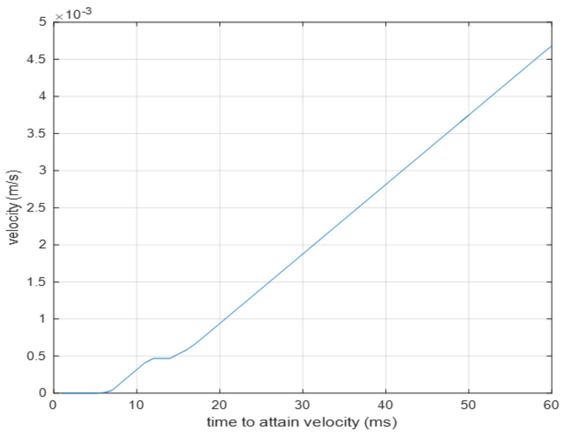

Figure 11: Graph of Conventional Control of Multiple Drones

In the graph of Figure 11, it could be seen that there was a time lag before the drone could attain a velocity. Thereafter, it exhibited a linear or tangential increase in velocity for a momentary delay or stagnation. It continues operation with increase in time resulting to increase in velocity.

IV. Conclusion

The research was undertaken with the aim of developing a Simulink control system model for the multiple drones under dynamic environment. Proportional Integral Derivative controller was used for its implementation. This was followed by a development of a Simulink model of a quad copter. With a successful development of a drone model in Simulink, a design of a control system for multiple drones was carried out. From the graph of the simulated results, the set of drones implemented with PID controllers. This research is spherically apt considering the use of drones in many spheres of human endeavor in particular and the numerous advances in the use and application of artificial intelligence in the highly technological world of today. In the course of achieving the main aim of this research, the contributions added to the body of knowledge in the field of robotics Also to make an autonomous multiple drones to choose optimal path when a global view of the environment is not given to the drones.

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