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Outdoor & Indoor Quadrotor Mission

Baqir Nassir Abdul-Samed[1], Ammar A. Aldair[2]
[1,2] Electrical Engineering Department, University of Basrah, Basrah, Iraq

Correspondence
*Baqir Nassir Abdul-Samed
Electrical Engineering Department,
University of Basrah, Basrah, Iraq
Email: bakir_68@hotmail.com

Abstract

The last few years Quadrotor became an important topic, many researches have implemented and tested concerning that topic. Quadrotor also called an unmanned Aerial Vehicle (UAV), it's highly used in many applications like security, civil applications, aid, rescue and a lot of other applications. It's not a conventional helicopter because of small size, low cost and the ability of vertical and takeoff landing (VTOL). The models kept an eye on quadrotors were presented, the advancement of this new kind of air vehicle is hindered for a very long while because of different reasons, for example, mechanical multifaceted nature, enormous size and weight, and challenges in charge particularly. Just as of late a lot of interests and endeavors have been pulled in on it; a quadrotor has even become a progressively discretionary vehicle for useful application. Quadrotor can be used in variable, different , outdoor and indoor missions; these missions should be implemented with high value of accuracy and quality. In this work two scenarios suggested for different two missions. First mission the quadrotor will be used to reach different goals in the simulated city for different places during one flight using path following algorithm. The second mission will be an indoor arrival mission, during that mission quadrotor will avoid obstacles by using only Pure pursuit algorithm (PPA). To show the benefit of using the new strategy it will compare with a victor field histogram algorithm (VFH) which is used widely in robotics for avoiding obstacles, the comparison will be in terms of reaching time and distance of reaching the goal. The Gazebo Simulator (GS) is used to visualize the movement of the quadrotor. The gazebo has another preferred position it helps to show the motion development of the quadrotor without managing the mathematical model of the quadrotor. The Robotic Operating System (ROS) is used to transfer the data between the MATLAB Simulink program and the Gazebo Simulator. The diversion results show that, the proposed mission techniques win to drive the quarter on the perfect route similarly at the limit with regards to the quadrotor to go without hitting any obstacle in the perfect way.

KEYWORDS: Quadrotor, PPA, path following, obstacle avoidance, VFH, Gazebo, ROS.

I. Introduction

In recent years, the unmanned aerial vehicle (UAV) becomes more popular than the winged helicopter because the UAV has the ability of vertical takeoff and landing, which needs a small place for takeoff and landing. Moreover, the cost of the UAV is cheap and its structure is simple. For these reasons, the UAV has superiority over the winged helicopter in applying in many application fields such as rescue, search, surveillance, interdiction, and transportation. The dynamic model of quadrotor UAV consists of inherent nonlinearity which makes it not easy to analyze [1-3]. UAV is a very complex, so it will need an accurate algorithm for navigation safely during attempts to complete the different missions. Different algorithms have been suggested and tested for path flowing for mobile robots like Bug1, Bug2, Tangent Bug…etc.

Pure pursuit algorithm (PPA) one of the common path flowing algorithms, so it will be used to navigate the quad--rotor during different tasks [2,3,4].

PPA will force the quadrotor to follow a desired path in either outdoor or indoor. The desired path should be clear of Obstacle so that the quadrature dose not hits and destroyed, for that reason it should need an extra algorithm for obstacle avoidance, also it needs for a quadrotor itself a more of component like sensors to detect these obstacles, this of course will lead to more cost, more complicated, extra weight and longtime processing.

In this paper path following algorithm has been used alone (especially in a well-known environment) to map the path of the quadrotor. It will be possible to make the quadrotor keep away from obstacle to achieve the goal.

Two scenarios suggested and tested to achieve that idea. First one was about moving quadrotor inside a simulated city to reach different goals by flying high to avoid obstacles. Second one about indoor mission with well-known environment, the quadrotor used to move to the target while avoiding obstacles in the way *without* using any *obstacle avoidance algorithm*. Finally, the suggested strategy of using only path following algorithm (PPA) for avoiding obstacles compared with the (VFH) algorithm to show the advantages of using that kind of strategy.

The MATLAB used to implement the simulation for the proposed scenarios with the aid of gazebo & ROS. G**azebo** is an open-source 3D robotics simulator. Gazebo was a component in the Player Project from 2004 through 2011. Gazebo integrated the ODE physics engine, Open Graphic library rendering, and support code for sensor simulation and actuator control. In 2011, Gazebo became an independent project supported by Willow Garage. In 2012, Open Source Robotics Foundation (OSRF) became the steward of the Gazebo project. OSRF changed its name to Open Robotics in 2018.

Gazebo can use multiple high-performance physics engines, such as ODE, Bullet, etc. (the default is ODE). It provides realistic rendering of environments including high-quality lighting, shadows, and textures. It can model sensors that "see" the simulated environment, such as laser range finders, cameras (including wide-angle), Kinect style sensors, etc.[4]

Gazebo simulator used to show the 3D environment of moving quadrotor. Robotic operating system (ROS) will be used as a coordinator between MATLAB and gazebo.
The results show that effectiveness of the proposed scenarios of flying the quadrotor in different environments.

II. QUADROTOR BASIC CONCEPTS

Quadrotor convenient in many applications due to it's a low cost, structure, simplicity and ability of vertical takeoff landing (VTOL). Different models and structure suggested to be suitable of different missions. [3,5].

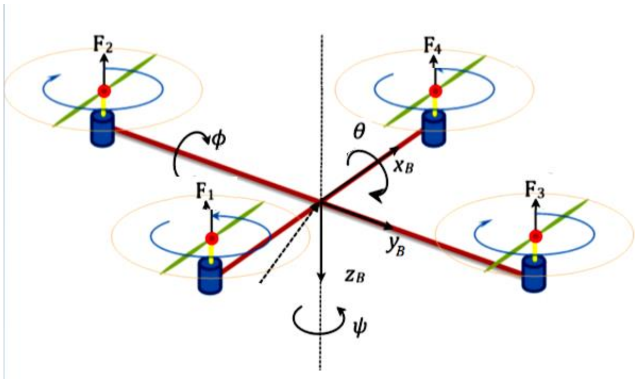

Figure (1) Motor forces of quadrotor

The quarter has four propellers to generate the suitable forces (F_1,F_2,F_3 and F_4) for takeoff, following the trajectory and landing as shown in Figure 1.
The four propellers can be considered as two pairs:
The propeller1 and propeller4 as the first pair while propeller2 and propeller3 as the second pair. In order to balance the torques and make the UAV stabile during the maneuver, the first pair should rotate clockwise while the second pair should rotate counterclockwise or vice versa[5,6,7] .As shown in Figure (2).

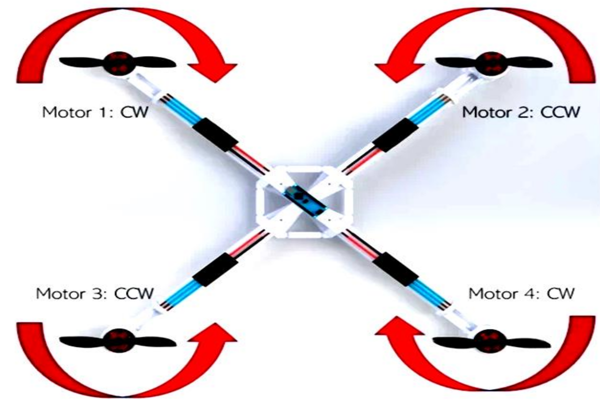

Figure (2) rotation of four motors

A quadrotor has six-degree of freedom (6 DOF): three-degree of freedom represents the *rotational movements*, while the other three-degree of freedom represents the *translation movements*. Quadrotor movements dynamics are simple it depends on the changing speed of the four motors. The changing speed creates the following movements: forward, backward, up, down, right rotation and left rotational [6,8]. Fig. 3 shows the six-degree of freedom of quadrotor

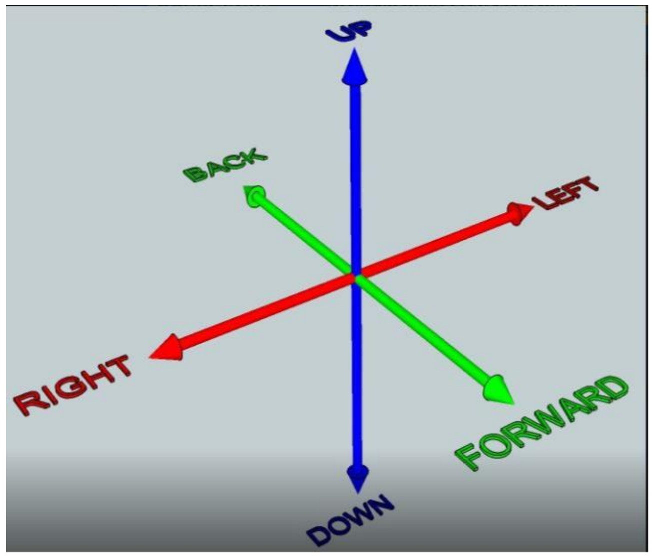

Figure (3) quadrotor six degrees of freedom

To control movements of the quadrotor for different directions like right, left, up and down, these movements can be done by changing the relative speeds of the motors in a way like: -

- Verticals

  It's sometimes called throttle, the movements along the z-axes, this can be achieved by increasing (up) or decreasing (down) the speed of the four motors. Shown in figure 1.

- Yaw movement (ψ)
  The quadrotor moves right or left depends on the speeds of the clockwise or counter clockwise rotation pair of motors. As shown in figure 1

- Roll movements (Ø)
  This movement can be achieved by changing the speed of the left or right pairs of motors. As shown in figure 1

- Pitch movement (Ө)
  This movement causes the quadrotor moving front or back by changing the speed of the front or back pair of motors. As shown in figure 1.

III. PURE PURSUIT ALGORITHM (PPA)

PPA used here to drive and guide the quadrotor to follow a desired path to complete its mission during giving waypoints for single and multi-goals.
PPA widely applied to achieve path following problem for the mobile robots. It is a geometrical method depends on the calculating the curvature that followed by the vehicle to the desired path point. The curvature that connects the current position of the vehicle and the next point on the desired trajectory is constructed (lookahead point).
Figure 4 shows the geometry of the pure pursuit algorithm. [9,10,11]

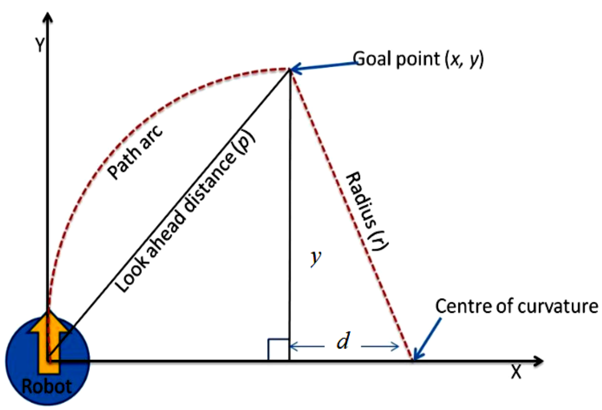

Figure (4) geometry of PPA

According to the pure pursuit algorithm, the quadrotor should move from the current point (0,0) to the goal point through a number of the next points (lookahead point) to reach the goal point (x, y) . It can increase or decrease the next point location to reach the goal fast or slow but that will affect on the smoothness and accuracy of the desired path. [9]

Equation of the larger triangle can be written: -

$$l^2 = x^2 + y^2 \quad (1)$$

The line segment on the x (d) given by: -

$$d = r - x \quad (2)$$

For the smallest triangle the relation is: -

$$r^2 = d^2 + y^2 \quad (3)$$

By solving (1) to (3) the curvature (ρ) can be calculated as: -

$$\rho = \frac{1}{r} = \frac{2x}{l^2} \text{ OR } r = \frac{l^2}{2x} \quad (4)$$

The curvature of the path arc obtained in (4) determines the steering wheel angle of the quadrotor [9]

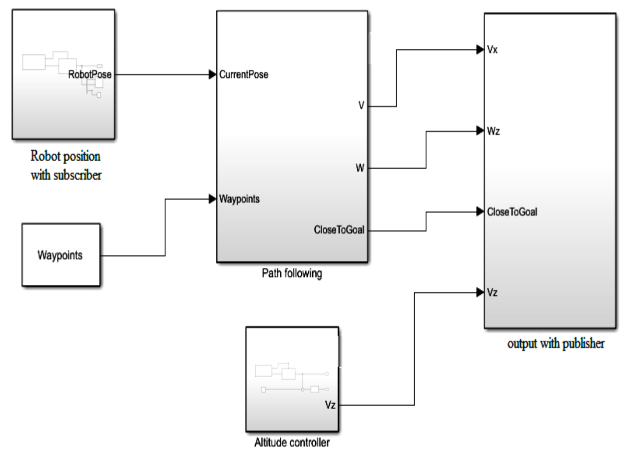

Figure (5) PPA MATLAB simulation

Figure 5 shows the PPA simulation in MATLAB which will connected to Gazebo simulator through ROS to show the quadrotor movement for different environments that will used in the suggested scenarios

IV ROS AND GAZEBO

The simulation of the quadrotor movements implemented by using a 3D Gazebo simulator (GS) to show the simulated world when quadrotor completes different missions. Using gazebo helps to build different environments, even it can be import objects or models from the online library of gazebo or from other 3d graphics programs like solidworks , CAD and SketchUp. The gazebo is not connected directly to MATLAB Simulink , ROS will be the in the middle between MATLAB and gazebo .ROS receive commands from MATLAB and forward it to Gazebo (mainly control signals) to adjust the quadrotor path to the goal , as well as some information should fed to the MATLAB about the current position of the quadrotor all this achieved by the *publisher*. After quadrotor moves again ROS will be responsible to send the new location of the quadrotor to the MATLAB to adjust the angular velocity to enable the quadrotor to choose the best path towards goal using the path following algorithm this will be achieved by *subscriber*. As shown in figure 6 [12,13,14]

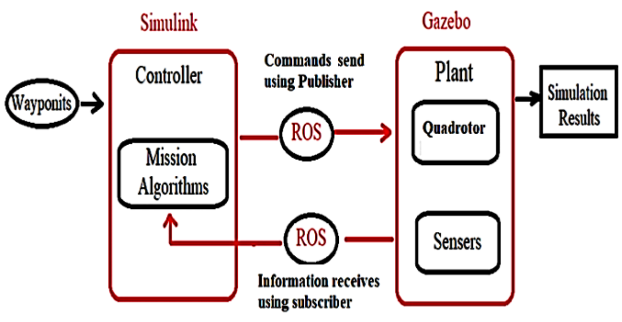

Figure (6) Simulink connected to Gazebo via ROS

V Simulation and Results

Many researches introduced different navigation algorithms for mobile robots likes bug1, bug 2, tangent bug A*….. etc. Each one these algorithms has different applications with some drawbacks, for instant bug algorithms influenced by sensor readings which make the robot slow, A* from other hand is time consuming and not suitable for path with many loops.

In this work we will concentrate on using the pure pursuit algorithm (PPA) to solve the navigation problem of the quadrotor .As mentioned earlier, PPA a geometric algorithm used widely to solve path following problem.PPA will force the quadrotor to move from the current point to the next point until reaching the goal with adjustment linear and angular velocity delivered to the quadrotor to take the best path towards goal .

After reaching goal, PPA stops the quadrotor by sending Goal position to the MATLAB and this is making the linear and angular velocity equals to zero (hold) . All the operation achieved by using the quadrotor sensors to send the position to updates to the MATALB which leads to adjust the quadrotor desired path towards the goal.

Two scenarios suggested and tested to show the ability of the PPA to control the quadrotor path to reach goals. 3D Gazebo used to design two worlds. First one is a simulated city; the second one is a maze with well-known environment the Simulation provides an excellent environment to show the quadrotor flying in the simulated worlds.

First Scenario (outdoor mission)

The first scenario is an outdoor mission it was about using the quadrature to complete several missions and reaching different goals inside a simulated city. The simulated city assumed to have all necessary requirements, designed using 3D gazebo. Quadrotor will fly from start point to the first goal and approach ground in the goal using PPA , then it will fly again to the 2nd goal and so on until reaches the last goal and will landing finally there .

Simulated city consiste of all necessary requirments including :

- Fire station & Trucks
- Diffeernt models of houses
- Gas Station
- Trees
- Grocery stors
- Bus station
- Police Office
- Cras
- Caffe

Second Scenario (path following like obstacle avoidance algorithm) (PFLOA)

The second scenario has different gazebo environments and it will be using new strategy for enable the quadrotor fly from the start point to the goal point though some obstacles. Accomplishing this purpose, led to use an obstacle avoidance algorithm. Many obstacle algorithms used and implemented, these algorithms need extra software, hardware or both. Of course, this will make the robot more expensive, slow because of extra weight and large time for processing, mostly this will used in both known and unknown environments.

In this work, it's assumed that the mobile robot or in our case the quadrotor will fly in well-known environment. It can be determined the position of obstacles, free spaces and shortest path to the goal in each time quadrotor passes an obstacle. This is achieved by making the quadrotor follow a waypoint all the way from start point to the goal. It can minimize or maximize the number of waypoints and this is of course will influence on the path accuracy. Taking a sharp turn from point to point to overcome the obstacle will leads to minimize the time to reach final destination.

The new strategy was very successful and very efficient making the quadrotor avoid different types of obstacles without hitting any of them and in a short time. To show the effectiveness of the suggested strategy for avoiding obstacles, it will compare the results with vector field histogram (VFH) method of avoiding obstacles which is used widely in robotics in terms of time, speed, distance and safety.

After simulation for both algorithms, it is found that the Path following like obstacle avoidance algorithm was fast and take less time than Vector field histogram with also short distance compare to VFH.

PFLOA = 2:09:43 (minute: second: fraction of sec.)

VFH = 2:29:39

First Scenario

Figure 7 shows the enviroment of the simulated city used for nevigation of the quadrotor from the start point .

Figure (7) simulated city

Figure 8 shows the first target house No.1

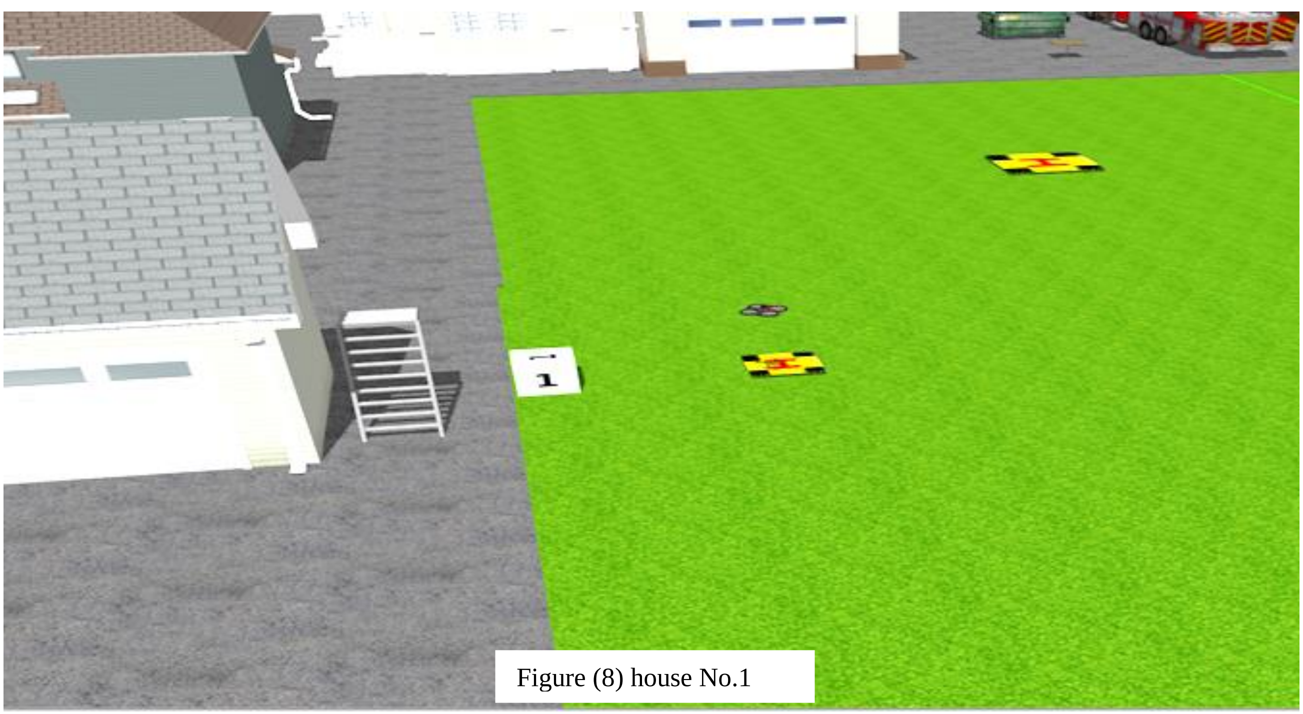

Figure (8) house No.1

Figure 9 shows the second target house no.2

Figure (9) house No.2

Figure 10 shows the third target Fire station.

Figure (10) Fire station

Figure 11 shows the 4th target Grocery store

Figure (11) Grocery store

Figure 12 shows the targets no.5 and the last one the Caffe

Figure (12) Caffe

Second Scenario

Figure 13 show the obstacle environment using 3D gazebo.

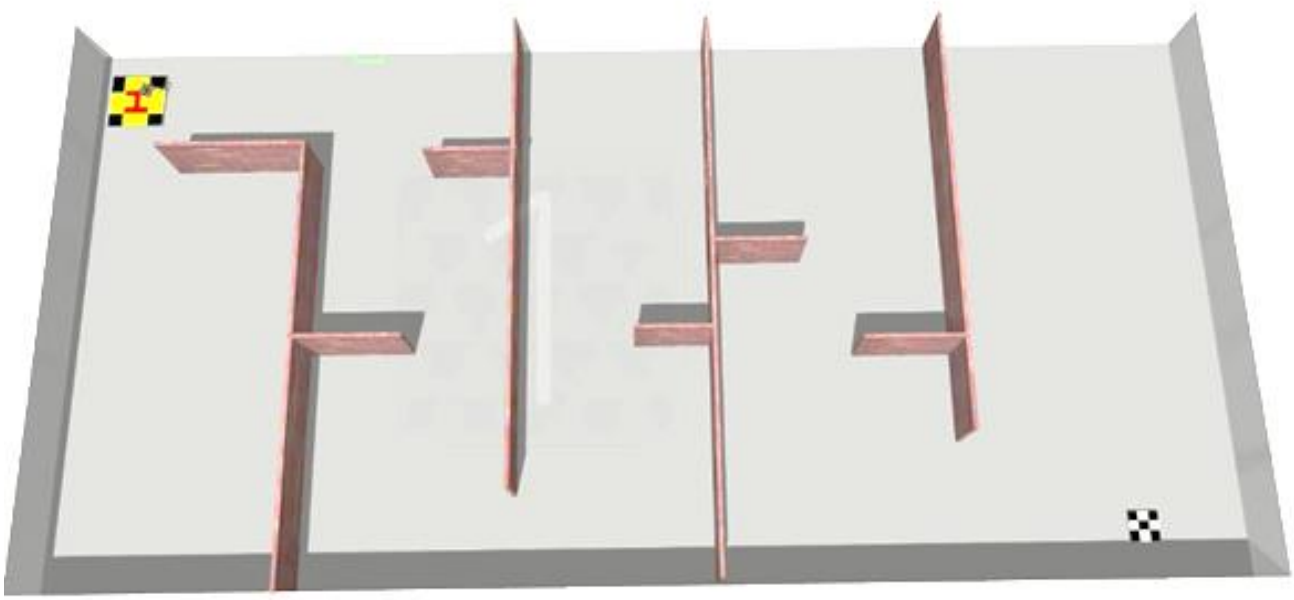

Figure (13) obstacle environment

Figure 14 show the first obstacle

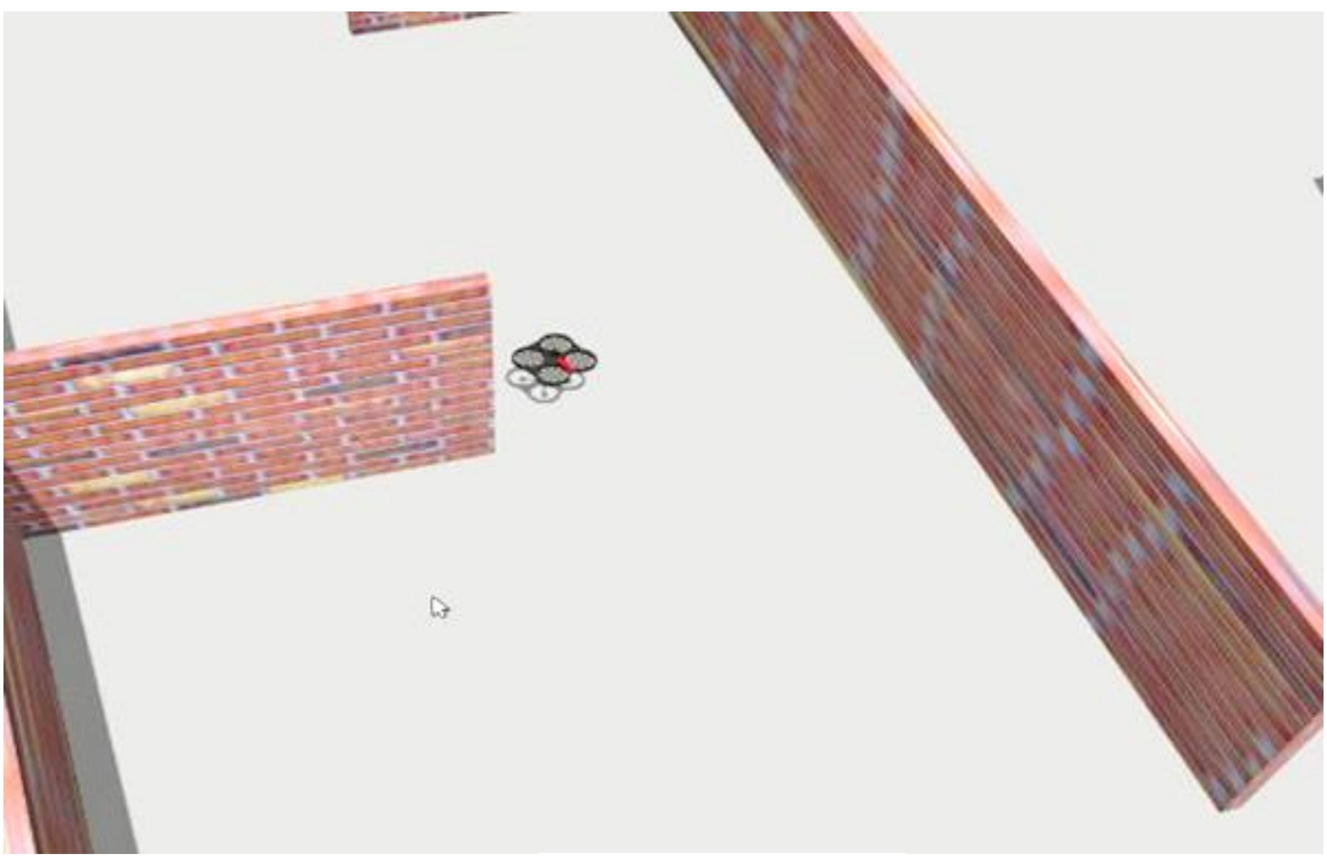

Figure (14) First obstacle

Figure 15 shows the 2nd obstacle

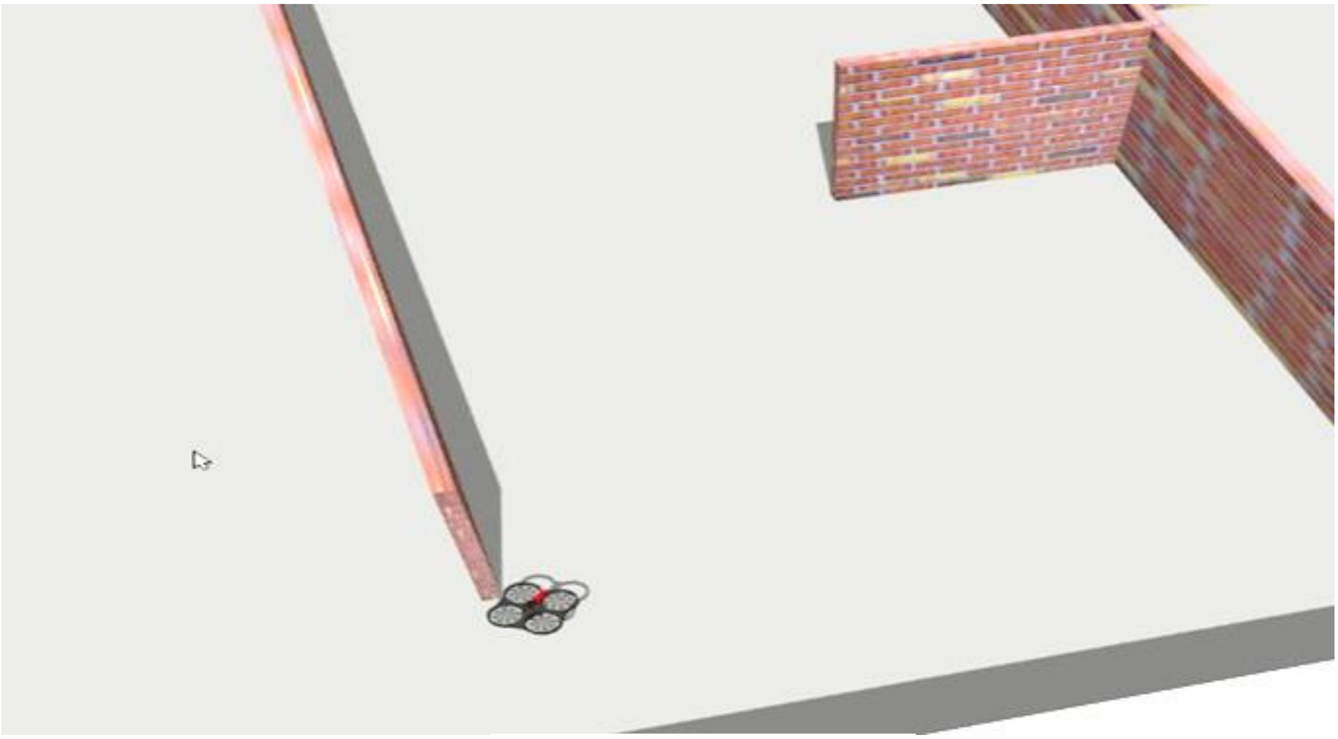

Figure (15) second obstacle

Figure 16 shows the 3rd obstacle

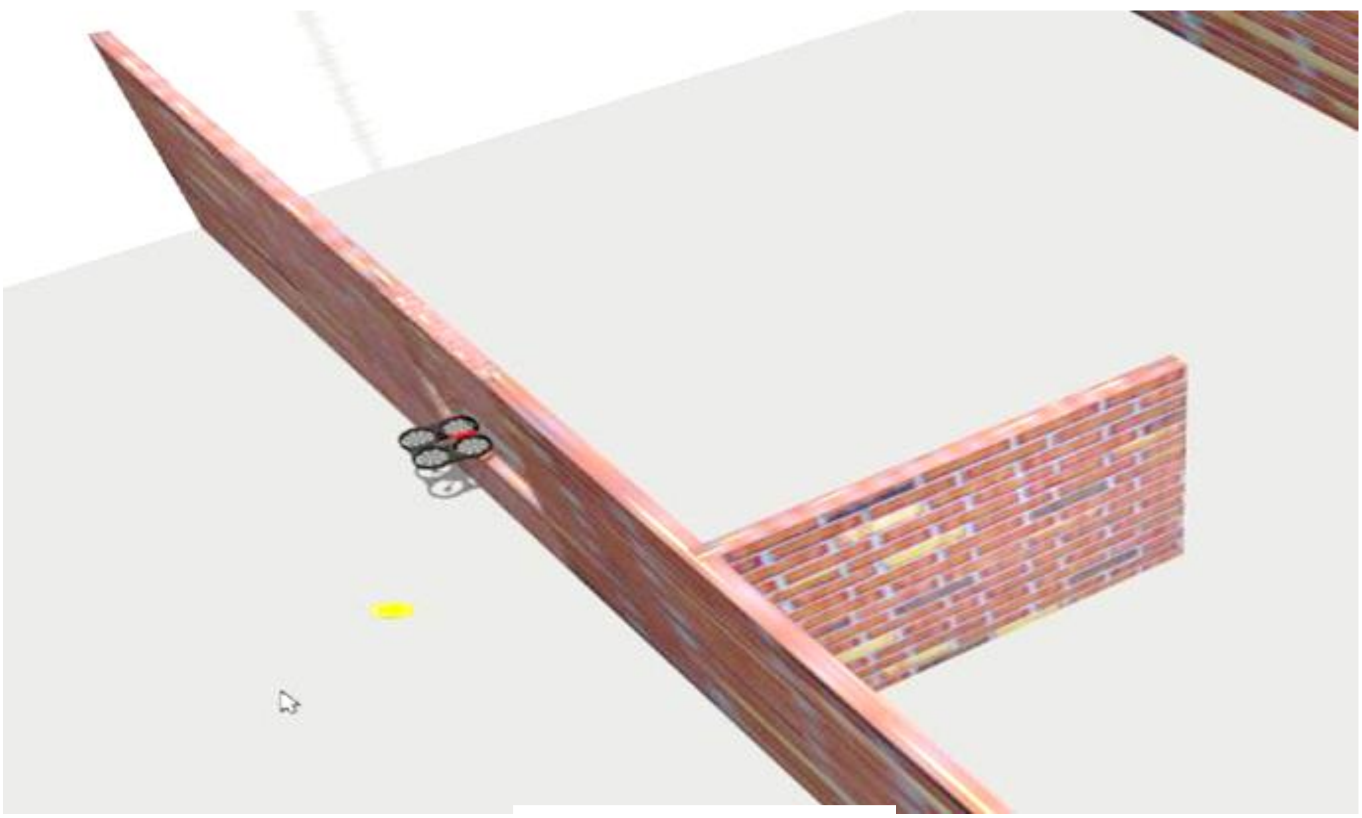

Figure (16) third obstacle

Figure 17 shows the 4th obstacle

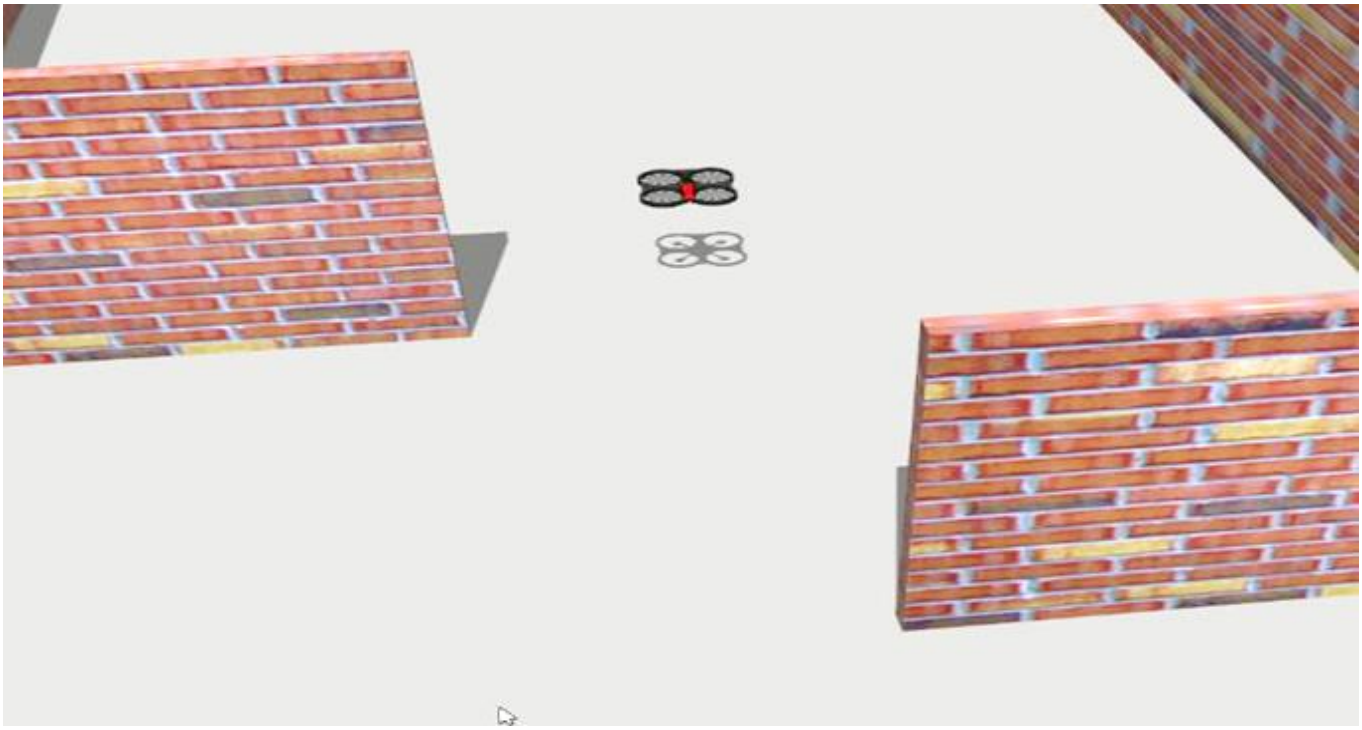

Figure (17) fourth obstacle

Figure 18 shows Reaching the goal

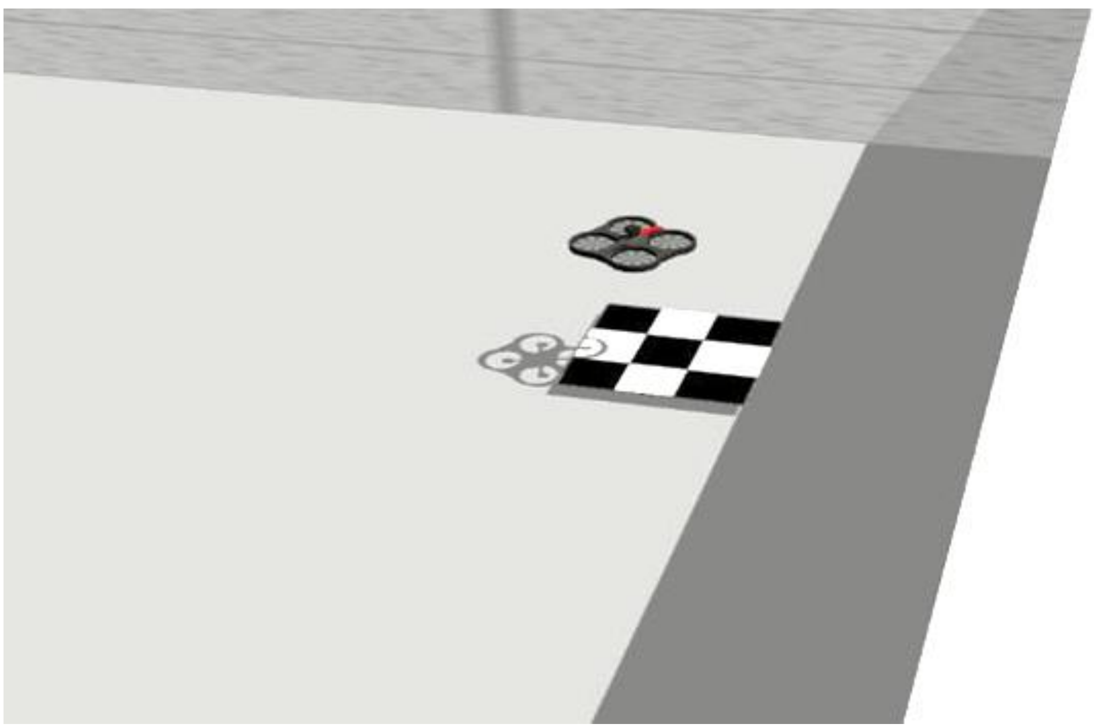

Figure (18) reaching goal

The two below figures showing the path comparison of using the new strategy verses the victor field histogram. Figure 19 show the path of path following like obstacle avoidance algorithm (PFLOA)

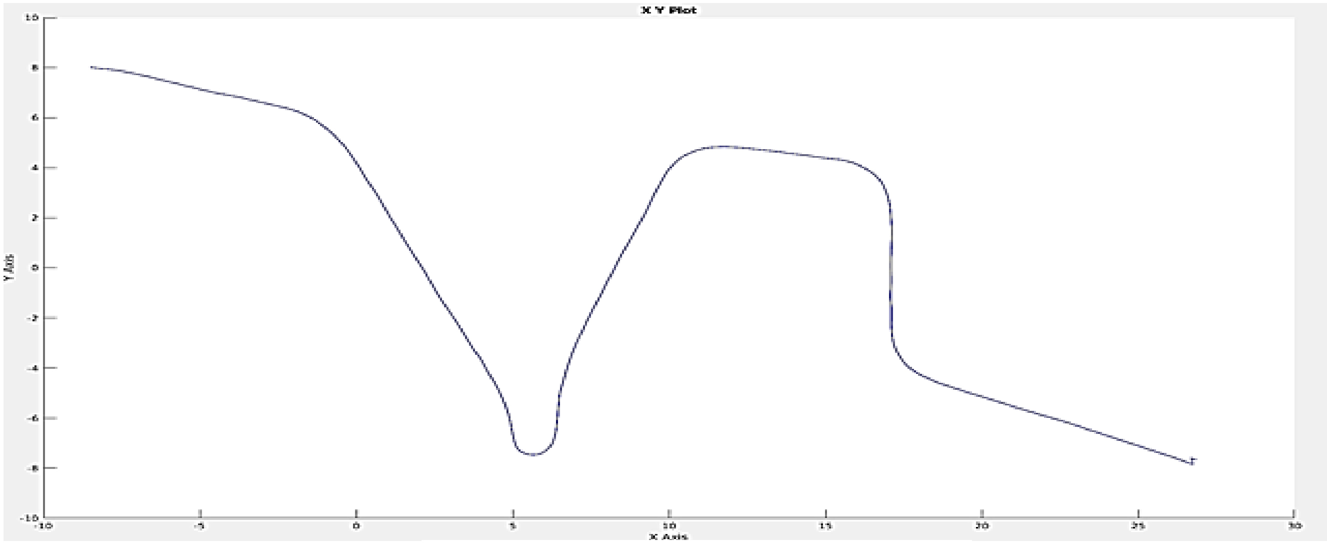

Figure (19) PFLOA path

Figure 20 shows the VFH path

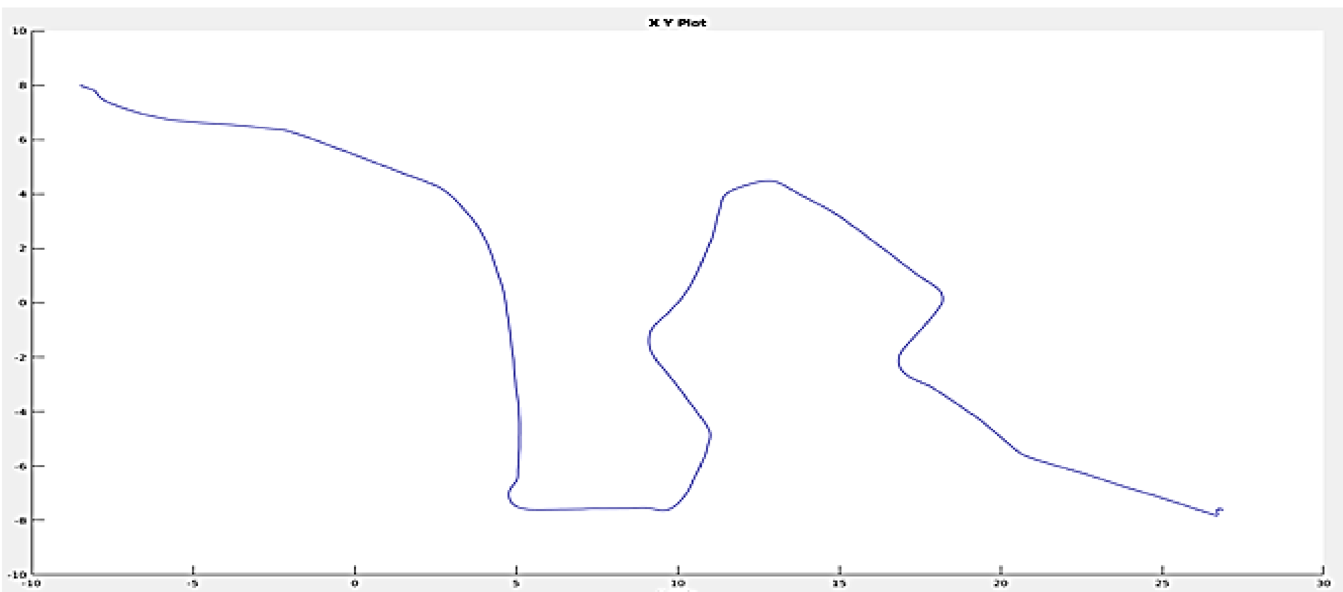

Figure (20) VFH path

The table (1) below showing the comparison between VFH and the new strategy (PFLOA) in terms of time, speed, distance and arrival safety

Algorithm	**Time**	**Distance**	**speed**	**Safety**
VFH	large	long	Same	Same
PFLOA	less	short		

Table (1) algorithm comparison

CONCLUSION

Quadrotor used widely last few years because of simple stricture and suitable for many applications, it is now a very successful market. quadrotor movements need an algorithm for path following and obstacle avoidance. Many paths following and obstacle avoidance algorithms has been suggested and submitted in the field of robotics. In this work Pure pursuit algorithm PPA introduced to map the quadrotor between a start point and the goal point in desired path .Two scenarios have been suggested , and implemented using MATLAB with the aid of 3D gazebo simulator via ROS.The first one was quadrotor outdoor reaching different goals mission in a simulated city by reaching multi targets successfully. The second one was a new strategy of using only path following like obstacle avoidance algorithm in well-known environment with obstacles. In well-known interment it can be calculate the position of obstacles , then you can choose the best path to reach the target This strategy based on an idea of using only a pure pursuit algorithm (PPA) without using any known obstacle avoidance algorithm by following a waypoint to guide the quadrotor to the final destination. The simulation results showed for the first scenario that the quadrotor complete the task and arrive to different target accurately. For the second one the result showed that the suggested strategy faster and reach goal with short distance compared to VFH this is because of no extra weight for sensors to avoid obstacle also less processing time to get information to fed to the Simulink

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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