Navigation of Mini Unmanned Aerial Vehicle in Unknown Environment

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Abstract. In this paper, two algorithms are proposed to navigate the mini unmanned aerial vehicle (MUAV) in unknown environment. The first algorithm is path planning algorithm, it proposed to force the MUAV to track a specific trajectory. The second algorithm is obstacle avoidance algorithm, it proposed to avoid the collision between the MUAV and borrower when the MUAV is maneuvering in unknown environment. The pure pursuit algorithm (PPA) is used to force the MUAV to follow the desired trajectory depends on the given waypoints. While the vector field histogram algorithm (VFHA) is used to avoid collision of the MUAV with obstacles block in the desired path. To keep the flight of MUAV without collision, the 3D laser sensors are used to collect the information from the surrounding environment. The GPS sensor is used to keep the MUAV on the specific path. The collected information from the two sensors are analysed by the controller of the MUAV to improve its performance. The Matlab program is used to implement the proposed algorithms and plot the trajectories of MUAV in the unknown algorithm. The Matlab program is connected with the gazebo program via robotic operating system (ROS) to simulate the visual movement of the MUAV in any unknown environment. The obtained results show the effectiveness of the proposed algorithm to flight the MUAV in different environments.

1. Introduction
The mini unmanned aerial vehicle (it is sometime called Quadcopter) is widely used in the academic researches, commercial areas and civil operations for both known and unknown environments. In recent two decades, the technologies of implement of MUAVs are rapidly developed, for this reason the MUAV are applied in many important applications to help humans in their daily missions such as military applications, rescue missions, surveillance of disaster areas and media applications [1]. The dynamical model of MUAV is very complex, so that it needs accurate algorithms for navigating safely in any kind of environments. Four propellers power the MUAV in order to manoeuvre it in the three-dimensional unexpected environment. It is combined with multi types of sensors to help it in the navigation mission autonomously without hitting the obstacles and tracking the specific trajectory in a proper way. The obtained data from those sensors are fed to control unit which is attached with the MUAV. The control unit has two algorithms; path planning algorithm and obstacle avoidance algorithm that are used to navigate the MUAV safely in an unexpected environment. The output of the control unit is applied to the four motors of the MUAV and by changing the relative speed of each motor the MUAV can reach the targets without hitting the barriers. The ultrasonic sensors (US) and infrared sensors (IRS) are used in many applications for MUAVs [1-4]. Unfortunately, both IRS and US have many disadvantages in some applications. For example, US fail to detect sound absorbing surfaces such as clothes or curtains. The IRS cannot detect obstacles in smoky or foggy environments because those environments have poor lighting conditions. Some authors used camera vision and image processing to detect the obstacles in any environmental conditions [5-7], but the camera is heavy and it needs a motor to cover all the surrounding views, so that it is not suitable to use with mini unmanned aerial vehicle. The global positioning system (GPS) is used to estimate the position of UAVs during an autonomous navigation mission. In this work, 3D laser sensor and GPS are used to navigate the MUAV autonomously in different environments.
Many methods are proposed by the authors for collision avoidance and path planning of unmanned aerial vehicle in unknown environment. An intelligent fuzzy logic approach integrates a set of decision making strategies and several aviation traffic regulations for avoiding collision with hazardous obstacles blocking the desired path [8]. A different algorithms such as Bug1, Bug2 and DistBug are considered to perform the planning of trajectories in an unmanned aerial vehicle, where the times and distances traveled from one point to another are evaluated autonomously avoiding obstacles to define the effectiveness and efficiency of the algorithms [9]. The problem of positioning control of an unmanned aerial vehicle with obstacle avoidance is solved by proposing a model predictive controller (MPC) for minimizing the tracking error and avoiding the obstacles with a flexible trajectory [10].

In this paper, two algorithms are proposed for navigation of MUAV in unknown environment. The first algorithm is path planning algorithm, it proposed to force the MUAV to track a specific trajectory. The second algorithm is obstacle avoidance algorithm, it proposed to avoid the collision between the MUAV and borrower when the MUAV is maneuvering in unknown environment. In this work, the pure pursuit algorithm (PPA) is used to force the MUAV to follow the desired trajectory depends on the given waypoints. The vector field histogram algorithm (VFHA) is used to avoid collision of the MUAV with obstacles blocking the desired path. To keep the flight of MUAV without collision, the 3D laser sensors are used to collect the information from the surrounding environment. The GPS sensor is used to keep the MUAV on the specific path. The collected information from the two sensors are analyzed by the controller of the MUAV to improve its performance. The Matlab program is used to implement the proposed algorithms and plot the trajectories of MUAV in the unknown algorithm. The Matlab program is connected with the gazebo program via robotic operating system (ROS) to simulate the visual movement of the MUAV in any unknown environment. The obtained results show the effectiveness of the proposed algorithm to fly the MUAV in different environments.

2. The Basic Concept of Flight Mechanism of MUAV

Basically, the quadrotor is very convenient in many applications because its low cost, simplicity of its structure, its ability of vertical take-off and landing (VTOL), with advance of using senses and actuators. It has four propellers that are actuated by four independent motors, each two non consecutive propellers rotate in the same direction to guarantee the stable flight of the quadrotor as show in Figure 1.

Figure 1 Schematic diagram showing the rotation of four propellers

By changing the relative speed of each motor, the altitude and orientation can be changed. Therefore, the MUAV can be maneuvered in any direction and altitude to avoid the obstacles to track the desired trajectories. Below, the basic concept of the four movements of the MUAV has described:

- Vertical movement along the z-axis (ά shown in Figure 1): this type of movement is achieved by increasing or decreasing the speed of the four propellers simultaneously. By increasing
the speed of the four motors, the MUAV goes up. But, the MUAV goes down when the speed of the motors is decreased.

- **Yaw movement** (shown in Figure1): the MUAV can be turned left or right by changing the speed of clockwise rotating pair and counter clockwise rotating pair.
- **Rolling movement** (shown in Figure1): the MUAV can be tilting left (or right) by increasing the speed of left (or right) motor and decreasing the speed of the right (or left) motor.
- **Pitching movement** (shown in Figure1): moving front (or back) of the MUAV can be achieved by increasing the speed of the front (or back) motor and decreasing the speed of the back (or front) motor.

3. **Collision Avoidance System**

In general, the unmanned aerial vehicle can be controlled manually by special joystick, or navigated autonomously depending on the information collected by the sensors to avoid collision with hazardous obstacles blocking the desired path [11,12]. The capabilities of safe navigation mission still an interested research challenge until now. This mission can be established by a combination of three functions: path planning strategies, obstacle avoidance capabilities and online environment sensing information. The system that integrates those three functions is called collision avoidance system (CAS). The CAS is applied in many robotics problems such as: autonomous underwater vehicles (AUVs), mobile robot system, arm manipulators as well as in unmanned aerial vehicle. The structure of CAS for MUAVs is quite complex than the other robotics problems because of the limitations in onboard processing power, capability of objects carrying, their maneuverability in unknown environments [13]. In this work, the path planning algorithm and the obstacle avoidance algorithm are simulated in Matlab simulation environment by using state flow toolbox. The MUAV and different environments are simulated in the Gazebo simulator. The robot operating system (ROS) toolbox is used to connect and transfer the data from Matlab simulation environment to Gazebo environment and vice versa. ROS Toolbox provides an interface connecting MATLAB and Simulink with other simulators such as Gazebo, Rviz and Argos. The ROS has two main blocks: subscriber block and publisher block. The subscriber block receives the data (which are collected from the simulated sensors in Gazebo simulator) and fed them to the navigation algorithms (path planning algorithm and the obstacle avoidance algorithm) that located in Matlab Simulink. According to the data received, the navigation algorithms generate a suitable navigation signals for maneuvering in unknown environment. The navigation signals are transferred from Matlab Simulink program to Gazebo simulator via publisher block. To control the altitude of the MUAV, a simple PID controller is used in this work. Figure2 shown the Matlab Simulink block to simulate the CAS.

![Figure2 Simulation of collision avoidance system (CAS) in Matlab Simulink](image)
4. Navigation algorithms

Navigation term combines the ability obstacles avoidance and path planning of the desired trajectory to reach the targets. In this work, the pure pursuit algorithm is used to force the MUAV to follow the desired trajectory depends on the given waypoints. The vector field histogram algorithm is used to avoid collision of the MUAV with obstacles blocking the desired path.

4.1. Pure Pursuit Algorithm (PPA):

The pure pursuit algorithm is widely applied to solve the problem of path planning in the robotics field. It is a geometrical method depends on calculating the curvature that followed by the vehicle to the desired path point [14]. The curvature that connects the current position of the vehicle and the next point on the desired trajectory is constructed. Figure 3 shows the geometry of the pure pursuit algorithm.

As shown in Figure 3, the point $(0,0)$ is the current position of the MUAV, while, the point $(x,y)$ is the next point located on the arc. The curvature of the arc joint the current point to the next point should be calculated. From Figure 3 the following Equations can be written:

\[ x^2 + y^2 = L^2 \]  \hspace{1cm} (1)

\[ x + d = r \]  \hspace{1cm} (2)

Eq. (2) can be rewritten as

\[ d = r - x \]

From Figure 5 the following equation can be written

\[ d^2 + y^2 = r^2 \]  \hspace{1cm} (3)

\[ (r - x)^2 + y^2 = r^2 \]
By substituting Equation (1) in (4) yield:

$$2rx = l^2$$

$$r = \frac{l^2}{2x}$$

As shown in Figure 2, the proposed CAS has an altitude controller to keep the altitude of the MUAV constant, so that the PPA just control the x-position and y-position of the MUAV. The pure pursuit algorithm works inefficiently when the deviation of the orientation of the MUAV to the next point is too large (larger than the threshold angle $\delta_1$). So that, the MUAV should stop at the current position and turn its direction toward the next point then the arc $r$ should be computed. If the angle between the current position and the next point is too small (smaller than the threshold angle $\delta_2$), the MUVA should turn slow toward the next point then the arc $r$ should be computed. The following flow chart describes the PPA as shown in Figure 4.

4.2. Vector Field Histogram Algorithm (VFHA):

The vector field histogram algorithm is used to detect and avoid the obstacles in the path of the vehicle based on the sensor readings. The polar density histograms to detect barrier location and proximity are computed depends on the range of the sensor readings. The size of the radius of the vehicle $R$, the minimum turning radius of the vehicle $S$ and safety distance $D$ are the initial parameters that should be fed to the VFHA for safely avoiding of the obstacles blocking the desired path [15]. Figure 5 shows all of those parameters.
The cost function is computed to determine the final orientation of the vehicle. The following equation is used to compute the cost function:

$$CostFun = a * T_d + b * W_o + c * P_d$$  \hspace{1cm} (6)

where $a$, $b$ and $c$ are constants,

- $T_d$ is the target direction (alignment of vehicle path to the goal),
- $W_o$ is the wheel orientation (difference between next direction and current vehicle orientation),
- $P_d$ is previous direction (difference between previously selected direction and new direction of the vehicle).

The VFH algorithm considers multiple steering directions based on vehicle current, previous, and target directions. Those parameters are computed depending on the sensor readings. By setting those parameters, the orientation of the vehicle is updated to avoid the obstacles.

5. Simulation and Results

In this work, the navigation problem is introduced to the mini unmanned aerial vehicle. Two algorithms are used, one for path planning and the other for obstacle avoidance. The 3D laser sensor is used to detect the presence of the obstacles blocking the desired path, while the GPS is used for finding the target positions. The Gazebo simulator is used to show the 3D view of the moving of the MUAV. For testing the effectiveness of those algorithms, two different scenarios are studied as shown below:
5.1. Maze problem with one target

Figure 6 shows the environment that is used to test the performance of the navigation algorithms. The initial position of the MUAV is (-8,8). The mission is reaching the target point at (27.5,-8) without hitting the barriers. Figures 7, 8, 9 and 10 show the ability of the MUAV to avoid the barriers. Figure 11 shows the selection path by the MUAV to reach the target.

**Figure 6** the environment of the first scenario

**Figure 7** Avoiding the first barrier
Figure 8 Avoiding the second barrier

Figure 9 Avoiding the third barrier
Figure 10 Reaching the goal

Figure 11 The path from initial point to target for first scenario
5.2. Maze problem with multi targets

Another scenario is introduced to test the effectiveness of navigation algorithms. In this scenario, different environment was built in gazebo simulator with multi targets. The initial point of the MUAV (−8.5,8), while Table 2 shows the location of all targets. Figure 12 shows the second scenario proposed in this work. Figure 13, 14, 15 and 16 show the reaching the MUAV the desired targets without hitting the barriers. Figure 17 shows the trajectory of the MUAV in the second scenario.

Table 1 the waupoint for second scenario

| The points      | Location   |
|-----------------|------------|
| Initial point   | (−8.5,8)   |
| First point     | (2,2)      |
| Second point    | (12, −5)   |
| Third point     | (22,6)     |
| Final point     | (27, −8)   |

![Figure 12](image-url) the environment of the second scenario
**Figure 13** Reaching the first target

**Figure 14** Reaching the second target
Figure 15 Reaching the third target

Figure 16 Reaching the final target
6. Conclusion

The navigation problem of mini unmanned aerial vehicle has been introduced in this work. The pure pursuit algorithm was used to force the MUAV to reach the desired targets. The vector field histogram algorithm was used to avoid the collision with the barriers blocking the desired path. The Matlab Simulink was used to simulate the navigation algorithms to drive the MUAV in the unknown environment. The Gazebo simulator is used to show the 3D view of the moving MUAV. Two scenarios are studied to test the performance of the navigation algorithms. The results show that the proposed algorithms have driven the MUAV in different environments without hitting the obstacles.

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