Study and Simulation of Autonomous Quadrotor Tracking a Pre-Defined Trajectory Using Matlab

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Abstract. The automated airborne vehicle (UAV) is an airplane that is worked without a human pilot. It was controlled either by the controller of a pilot or self-governingly by locally available PCs on the ground or in another vehicle. Modern Quadrotors are evolving than the old designs into a small agile vehicle. The quadrotor is increasingly becoming more and more popular, there is an increasing need for making this vehicle autonomous. The Methods for developing autonomous unmanned aerial vehicles has been an active area of research under the mobile platform. There are many commercially available drone platforms but all of them are required user interaction through a controller. In this work, we have created a control algorithm and trajectory generation for a smooth minimum snap trajectory through the given waypoints. Each waypoint specifies the desired position velocity, yaw, pitch, and roll angles. Such waypoints generated by our algorithm generate a smooth minimum snap trajectory between these waypoints. A PID controller is used to control the motions of the quadrotor in all planes.

Keywords: Autonomous, Controller, Minimum snap, PID, Quadrotors, Trajectory.
1. Introduction

We have seen several exciting developments in an uncrewed aerial vehicle since the last decades. Specifically, the work has been done on the multi-rotor aircraft and management of quadrotor. In this paper, a mechanical event following controller for quadrotor is created to decouple the 2 issues. By tolerating as data sources, a way of waypoints and wanted speeds, the Control input is refreshed regularly to precisely follow the necessary way, while the way planning happens as a different strategy.

The resulting directions are in simple mathematical terms of lines and interfacing bends identified with wanted speeds on each stage. At that point, a potential arrangement of data sources and travel speeds is registered, upheld the bend of the track, given speed and quickening limitations on the vehicles. The adaptability to drift permits turning with an unusual span of shape, in this way potential directions will undoubtedly exist [1-4].

Every direction following calculation is space-filed rather than time-filed, implementing the need that the obstacle-free planned path be tracked without deviation. The algorithm is used in the form of various structures to various problems to obtain optimal solutions. A nonlinear program is formulated to resolve the minimum time space-indexed optimization, which requires a mixed whole number program by using the exponential time complexity within the range of waypoints can resolve the time-indexed optimization, the methodology given here needs system time that is straight inside the scope of waypoints and should not to repeat.

The study on advanced engineering and technology, Quadrotor development is done in many excellent ways. The military of several countries used drones in a war to spectate the enemy camps and battlefields. And the military of Austrian first developed drones for these purposes. In 1849, the Austrians assaulted Venice, in Italy, with automated air inflatables topped off with explosives. These are worked effectively, and the un-utilized air inflatables get once more into Austrian domain. Not as innovatively as productive as the present Unmanned Air Vehicles, it made expectation on the improvement of UAVs later on. From that activity Planes without any pilots were showed up after World War 1. The Hewitt Sperry Automated Airplane, as evolved by Elmer Sperry at Sperry Gyroscope Company, it was the early form of the present flying vehicles advancement in a virtual area [5-7].

The algorithm for generating the optimal trajectory for the quadrotor using keyframes and waypoints. And this control algorithm for trajectories of three-dimensional trajectories for quadrotor that can fulfill requirements on positions, speeds, increasing velocities, and data sources. The directions are ideal in the limit cost works that are gotten from the square of the standard of the snap (the fourth subordinate of position). These cost capacities are significant since the info factors are logarithmically identified with the snap for example fourth induction of the position. In this paper real-time experiments are done with ascend tech hummingbird quadrotor and the Vicon motion capture system is used for calculating the position, orientation, and velocities of quadrotors [8].

The differential equations of the quadrotor dynamics for the study of quadrotors are derived from the Newton-Euler equations and Euler-Lagrange equations. The numerical model of quadcopter elements was acquired with the assistance of these determined differential conditions. The model is confirmed by stimulating the quadcopter with MATLAB. Also, further Stabilization of disposition control of the quadcopter was finished with the assistance of a PD controller. A heuristic strategy (calculation) was created to control the direction of the quadcopter. The PD controller is coordinated with the heuristic technique for the reaction of the quadrotor flying in different conditions with unsettling influences. The recreation shows the introduced numerical model should be possible continuously demonstrating the position and attitude of the quadcopter. The simulation results additionally demonstrate that the PD controller was better in balancing out the quadcopter to
the ideal elevation and mentality. The PD controller didn't consider positions x and y in this test. Thus, the estimations of x and y are differed from their unique qualities during the stabilization process [9].

Andrew Gibiansky et al. has derived equations of motion for a quadcopter, starting with the voltage-torque relation for the brushless motors and working through the quadcopter kinematics and dynamics is derived. The aerodynamically effects such as blade-flapping and non-zero free stream velocity are ignored in this work. The air friction as a linear drag force in all directions is included. The equations of motion are used for creating a simulator for testing and visualizing the quadcopter control mechanisms. The PID controller was used over the PD controller for overcoming the significant steady-state error. To decrease the steady-state error, an integral term is added to create a PID controller. The PID controller is tested with minor modifications and the result shows it was good for preventing the steady-state error than the PD controller. It shows the PID controller was difficult and led to an unstable system of quadrotors for unknown reasons. To avoid the difficulty of PID tuning and find the optimal set of parameters, the gradient-descent based extreme seeking method is used. And from the result of their work, it has been founded that the resulting controller was significantly better than the manually turned parameters [10].

Gabriel M. Homann et al. has proposed a trajectory monitoring algorithm to follow the desired path. An algorithm is generated for the trajectories that are dynamically possible. Using the trajectory tracking algorithm, a real-time experiment is conducted to map a route with 10 cm precision indoors and 50 cm precision outdoors. The dynamically workable trajectory generation algorithm segregated the generation of strategy from the computation of dynamically workable travel speeds and control inputs to prevent dynamically workable travel speeds and control inputs from being computed. With a little computational burden, it is possible to follow a given direction and the time-optimal inputs. Simulations send the precise result of these control inputs' mathematical calculations and run on the computer faster [11].

From the study, the algorithm generation and quadrotor mathematical model is done with the help of Euler-Lagrange equations. The algorithm for generating the optimal trajectory for the quadrotor using keyframes and waypoints is obtained by the fourth derivative of the position (i.e. snap) to obtain the accuracy. Velocity, Acceleration, Jerk, and Snap are the first, second and third derivative of the positions.

2. Methodology and Design Development

The W world frame and the β body frame, as well as the quadrotor propeller numbering convention, are used in the coordinate system. To prevent singularities and to control attitudes that reflect deviations from hover, rotate matrixes that are used to reflect frame orientations. Z-X-Y Euler angles to describe the angles of roll, pitch, and yaw as the local coordinate scheme. WRB = WRC where WRC represents the rotation of the yaw to the intermediate frame C and CRB represents the impact of roll and pitch, this gives the rotation matrix from β to W. The angular velocity of the robot is denoted by ωBW, which denotes the angular velocity of the frame β in frame W, with the components p, q and r being the body frame.
2.1 Coordinate Systems

The inertial frame, A, is defined by the axes $a_1$, $a_2$ and $a_3$ of the origin (O). The body frame, B, is attached to the centre of the quadrotor mass with $b_1$ coinciding with the common forward position, and $b_3$ perpendicular to the rotor plane tells up vertically in the hover. The vectors represented are parallel to the main axes. C is the centre of mass. Rotor 1 is away from L with $b_1$, 2 is away from L with $b_2$, while 3 and 4 are away from L with negative $b_1$ and $b_2$ respectively. Since $b_i$ is the main axis, the diagonal matrix is the inertia matrix referred to as the centre of mass along with the $b_i$ reference triad.

2.2 Position Control

Roll and pitch angles are used as inputs to control the orientation of the quadrotor. In order to measure the desired speeds, the position control algorithm can decide the necessary roll and pitch angles, the values and the values, which can be used from. The first, the hover controller, is used to hold the station or to maintain the location at the target position vector, $r_0$. The second monitors the defined direction, $r_T(t)$, in three dimensions. In both cases, the optimal angle of yaw is defined separately. It may be either a constant, a 0 or a time-varying quantity, a $T(t)$ value. To determine the position vector trajectory and the yaw angle to be tracked, Euler's angle is given as the input vector.

2.3 Attitude Control

To track a trajectory that is defined in terms of the desired roll, pitch, and yaw angle, a proportional integral derivative (PID) attitude controller is developed. The development of the controller is based on linearized motion equations, where roll and pitch angles are minimal, the attitude must be similar to the nominal hover state. The regulations of proportional plus derivative control near the nominal hover state take the form.

2.4 Procedure

The initial state conditions initialize the basic parameters like roll, pitch, yaw values are transformed into a rotational matrix. The rotational matrix is converted into quadrotian matrix. It also initializes the positions of $x$, $y$, $z$, $xdot$, $ydot$, $zdot$, quadrotian thrust, quadrotian $x$, quadrotian $y$, quadrotian $z$. The controller equation uses the PID controller to actuate the quadrotor in the desired trajectory path in an optimal way by computing the polynomial coefficients, the coefficients are split into cell arrays and store the velocity and accelerations. In the run simulation, the trajectory is generated with waypoints for the snap trajectory using the trajectory handle and control handle functions.

3. Results and Discussions

3.1 Line Trajectory

The pictorial representation of the simulation of the line trajectory is obtained using the MATLAB. Where the quadrotor travels from (0,0,0) to (1,1,1). It takes 76 iterations where the timing represents the total timing of quadrotor from an initial position (0,0,0) to the final position (1,1,1). The motion comes under the Dynamics of linear motion. A linear path that traces the projectile of the quadrotor with a mass in motion follows through space as a function of time. Its response is linear.
Fig. 1. Line trajectory of quadrotor

Fig. 2. Positional graph of line trajectory
3.2 Helix Trajectory

The pictorial representation of the simulation of the helix trajectory is obtained using the MATLAB. Where the quadrotor travels from (5,0,0) to (5,0,2.5). It takes 251 iterations where the timing represents the total timing of quadrotor from an initial position (5,0,0) to the final position (5,0,2.5). The motion comes under the Dynamics of Non-linear motion. The Helical path which traces the projectile of the quadrotor with a mass in motion follows through space as a function of time. Its response is Non-linear or a curve.
Fig. 4. Helix trajectory of quadrotor

Fig. 5. Positional graph of Helix trajectory
The pictorial representation of the simulation of the snap trajectory is obtained using the Matlab. The quadrotor travels through the waypoints which would create the set of snaps.

\[
\text{Waypoints} = \begin{bmatrix}
0 & 0 & 0 \\
1 & 1 & 1 \\
2 & 0 & 2 \\
3 & -1 & 1 \\
4 & 0 & 0
\end{bmatrix}
\]

It takes 271 iterations where the timing represents the total timing of quadrotor for passing through the waypoints in snap trajectory. The motion comes under the Dynamics of Non-linear motion. A linear path that traces the projectile of the quadrotor with a mass in motion follows through space as a function of time. Its response is Non-linear. Projectile Motion of linear is often Non-linear

**Fig. 6. Velocity graph of Helix trajectory**
Fig. 7. Snap trajectory of quadrotor

Fig. 8. Positional graph of Snap trajectory
4. Conclusion

Autonomous quadrotors can make possible dominance like aerial photography, geographic mapping, and wildlife monitoring. By using this quadrotor, we can reduce manpower. We stimulated the autonomous quadrotor using the PID controller. Simulation validates the exact computation of these control inputs and shows the optimal way of lowering the control effort. The simulation also shows the total thrust, pitch, roll, yaw angles for the given constraints using linear differential equations. Snap trajectory has derived to minimize the control effort in an ideal way. In 3-d trajectory, the automated quadrotor satisfies constraints on position and velocity. The quadrotor on several trajectories like tracking a line, helical ring by giving waypoints during the simulation. The required minimum snap trajectory is obtained by deriving Euler’s Lagrange's equation. The control algorithm of the quadrotor for trajectories requiring large accelerations is derived.

The simulation results and graph show that the autonomous quadrotor could be controlled accurately with the given control inputs in this method. The derived equations, controller of autonomous quadrotor and control inputs were tested only with simulations. For the realistic and reliable results, the real experimental prototype of the quadrotor should need to be constructed. Quadrotors are widely used for various applications because of their high stability and small size. The autonomous quadrotor has an ability to concern the obstacle locations in determining velocity and make a controlled tracking motion. The results of the simulation also show that in stabilizing the quadrotor to the correct attitude and altitude, the PID controller is successful. The aim of deriving a quadrotor mathematical equation is to aid in the development of quadrotor controllers. In the case of noise and disturbances, PID is often ineffective for operating mechanical devices.
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