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# Trajectory Routing of an Autonomous Aerial Vehicle with Parabolic Blending Method and BFS Algorithm

**Md. Nur a Shams[1], Md. Asaduzzaman Abrar[1], Md. Manirul Islam[1,*], M. R. I. Sheikh[2]**

[1]Department of Mechatronics Engineering
[2]Department of Electrical & Electronic Engineering
Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

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**ABSTRACT**

Unmanned Aerial Vehicle (UAV) has experienced enormous development over the past few years. However, UAV's path planning problem is still deemed critical in developing autonomous trajectory planning. For instance, the traditional node to node linear transitions in trajectory planning can cause a loss in dynamic behavior like velocity and acceleration. Blend in trajectory such as parabolic type can preserve dynamics with smoother transitions in a node connecting two linear paths. This paper presents the Breadth First Search (BFS) algorithm for routing setpoints (nodes) with a parabolic blend in trajectory between two linear path segments in each node for smooth steering with more excellent manoeuvrability. Specially, a decision-support tool is developed to guide UAVs in configuring a multi-rotor vehicle support autonomous routing capability and trajectory blending. The project also reports communication be implemented via PubNub, an online broker to update necessary geo-locations from remote systems. Finally, the solution for path planning in the UAV was tested in a real simulation scenario.

## 1.Introduction

UAV is a special class of the aircraft system that can be capable of sustained without an onboard human operator and controlled autonomously [1]. With the advances of technology, the current application of multi-rotor vehicles in surveillance, remote search and rescue operation, reconnaissance, product delivery, real-time asset positioning, and

*Corresponding authors: Department of Mechatronics Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh.
Email: mmaniruleee@gmail.com (Md. Manirul Islam)

remote medical items delivery, area mapping, spatial information acquisition, have been increased significantly across the world. Big companies like Amazon, Google investing in such autonomous system development for civilian uses, and small farms like Zipline who introduced autonomous medical delivery in the rural areas. These applications brought hope for people creating a huge room for improvement of UAVs technologies more sophisticated manner

Although UAVs have extensive range of applications, the key to operating UAVs safely is to develop reliable navigation [1] and control technologies for required UAV application.

In this era, the most widely used navigation technologies for the UAVs are differentiated into two classes: (i) The Global Positing System (GPS) Receiver, or (ii) Inertial Navigation System (INS) Devices [2]. INS is a self-contained device and on-board computational system for estimating position, velocity, acceleration, and altitude, solely depends on local sensors that works basis on the system local behaviour. The main drawback of INS when operated in a stand-alone mode is the rapid growth of systematic errors with time [3]. On the other hand, satellite-based GPS navigation [4] techniques can offer relatively consistent accuracy if sufficient GPS signals delivered from satellites can be tracked during the entire UAV global position in latitude and longitude, and other parameters. However, GPS itself does not provide accurate attitude measurements.

UAV has been massively used in the military deployment, and the integration of civilian grade features, and capability also pave the way for nonmilitary application with rapid increment of scopes in daily basis. A delivery drone kind of parcel copter, which is an UAV, used to transport packages to remote areas [5], food or other goods. The UAV can transport medicine, vaccines, and other medical items even in the remote areas. In July 2015, the FAA approved the first use of drone within the United States to deliver medicine to a rural virginal medicine clinic in a program called “Let’s fly wisely” [17], [18]. Another use is the taco-copter, is the concept to delivery taco utilizing smart phone application to order drone-delivery tacos in San Francisco. It was developed by MIT graduate star Simpson. “Amazon Prime Air” initiative is taken by the Amazon; a delivery network is developed where packages are delivered using drone. Google demonstrated its own drone-based delivery service, under a development project called “Project Wing” derived from “Google X”, being tested in rural side of Australia.

The drone is fully automated for routing to locating its destination, with a very small payload as testing purpose along with its positional information being loaded and extracted from the system via an open source online broker that makes possible of real-time localization and monitoring. For commercial uses a private owned broker or server will be better option for security and encapsulation of a full operational delivery network. The design configuration depends on payload and delivery application methodology, between fixed wing aircraft and vertical take-off and landing (VTOL) design, the second one is much more preferable to designers for vertical takeoff and landing capability that makes it possible operating any kind of location. A simple quadcopter is common VTOL design being used in this project.

Localization, trajectory mapping and routing of the system in-between locations autonomously is quite a bit intensive work. Each of those autonomous UAV by different developers so far uses different approaches to attain such capability. In this paper, BFS algorithm also known as A* algorithm is used for autonomous routing in between pre-defined nodes (coordinates in earth space) and parabolic trajectory blending is applied for smoothing two straight line trajectory and necessary decisions to design such trajectory is contributed. The solo purpose of the BFS algorithm is to help the UAV routing in between set points so that the trajectory blending can be implemented and tested practically in the real-world application in a sophisticated manner.

## 2. History of Drones/UAV

In the past decades small scale unmanned aerial vehicle are used in many applications. Greater manoeuvrability and hovering ability of aircraft has led to increase in UAV research. In 1918, Kettering Bug made aerial torpedoes, later in 1935 British made radio-controlled aircraft, even though first general development of unmanned system serving purpose of military application, later it finds the way for civilian purpose and other relevant fields. A lot of countries like USA, Israel, Turkey, China, Iran mastered the use of UAV in military to civilian and research areas for geographic assets. A lot of design iteration and variation of systems are introduced with different level of complexity in designing. Rotorcraft type design allows systems like quad copters to be relatively simple in structure as well as highly reliable, less complexity and ease of implementation. This research on UAVs is for increasing the capacity of quad copters by making advances in aircraft communication, environment exploration and reliability.

## 3. Methodology

This quadrotor system includes a flight control unit and a navigation unit as well as communication unit. Those units interact among themselves from sensor to controller.

- A raspberry pie 3B used as fight controller and necessary data processing unit.
- Invensense MPU-9250 (gyroscope + accelerometer + compass) sensor acts as a inertial navigation unit provides acceleration, orientation and directional information. A barometric altitude sensor also included to measure altitude.
- For Coordinate determination a Ublox GPS shield also been used with 6m accuracy.
- 25A current supported Hobbyking made Electronic Speed Controller being used with 1400KV brushless DC motor.
- Geographic coordination is passed from PC to raspberry pie via pubnub broker, an online message delivery platform for IOT development. The raspberry pie is connected to internet via portable WIFI router for indoor testing.

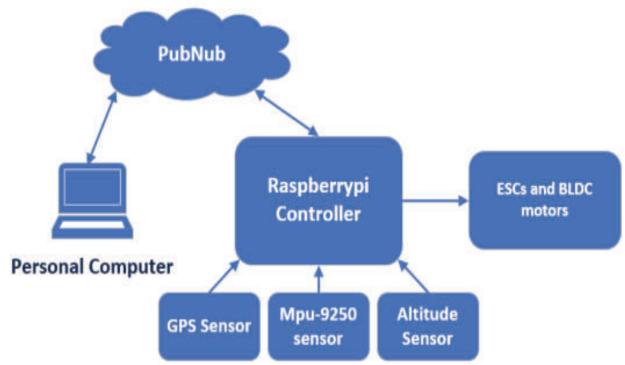


Figure 1. System block diagram.

### 3.1. Flight Control

In a quadcopter, each rotor produces both a thrust and torque about its center of rotation, as well as a drag force opposite to the vehicle's direction of flight. If all rotors are spinning at the same angular velocity, with rotor one and three rotating clockwise and rotor two and four counter clockwise, the regular acceleration about the yaw axis is exactly zero. Yaw is induced due to imbalance in aerodynamic torque. For controlling raspberry pie 3B is used as a flight controller along with necessary sensors (Invensense MPU-9250, BMP-180, Ublox Neo-6M) to control the flight mode. It works on the principle of PID controller with a low pass filter, a fusion with derivative section and together the whole PID compensates orientation errors as well as moments due to movement and rotation of propellers.

Figure 2. Conceptual CAD model of the quadcopter.

Figure 3. The UAV.

Necessary unidirectional (forward) movement and rotation along yaw for steering also controlled. It allows the system to translate into certain direction as controller decides based on GPS information and routing in-between positional nodes based on breath first search algorithm. The whole balancing and movement code are written in python running at single thread of the processor and other filters and data acquisition running at another thread.

### 3.2. Communication, Navigation and Routing

This proposed autonomous quad rotor system navigates using GPS (latitude, longitude) and Barometer (altitude) sensor, as it can fly from a location to another desired location, for this feature GPS is used. Using the latitude and longitude values provided by GPS, the spatial coordinate system quadcopter can be evaluated for calculating transitions and directions of different nodes. If a positional (a node) value is given in the controller, the controller can navigate to the location using an algorithm known as breath first search algorithm. A Ublox NEO-6M GPS module for this purpose.

To navigate to certain a location, its necessary to maintain hovering the quad rotor system automatically at certain altitude. For this automatic fixed hovering, the altitude value from barometric pressure sensor BMP-280 is used and fused with GPS provided altitude value in the algorithm. This module gives the altitude value measuring the pressure and temperature of the environment.

Figure 4. BMP280 Barometric pressure sensor [14].

Figure 5. Ublox NEO-6M GPS Module [15].

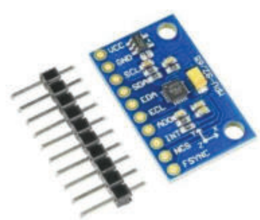

Figure 6. Invensense mpu9250 DOF sensor [13].

The GPS sensor integrated module was provided the latitude, longitude and altitude value from the system. Now an algorithm is necessary to attain such navigation of the quadcopter using this value. At first the quadcopter is hovered to a certain level from ground using the altitude value and holds the position. Then the controller collects the latitude and longitude value of current position. And then it receives the value of desired position. And now the algorithm starts working.

The Breadth First Search (BFS) algorithm in fig: 7 was used to navigate and route the quadcopter to desired position. This algorithm worked on the basis that it has a start position and then it searched for the next position to route to the desired location considering the shortest path. Each position was considered as a node, which is searched for next node. As it’s known that each geo-position in the earth has a corresponding latitude and longitude value, this system considers each geo-position as a node to implement this algorithm. All the latitude, longitude and altitude values are saved both in RAM and ROM memory. A parabolic blend on the trajectory is used for smooth transitions among nodes. The number of nodes being generated can be controlled but also the calculation is generic, that means the system can generate nodes adaptively in between positions

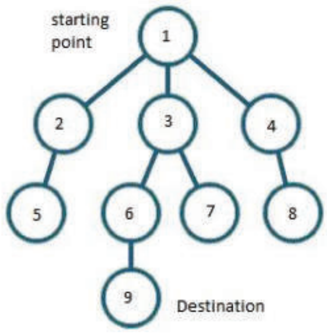


Figure **7.** Breadth First Search algorithm technique **.**

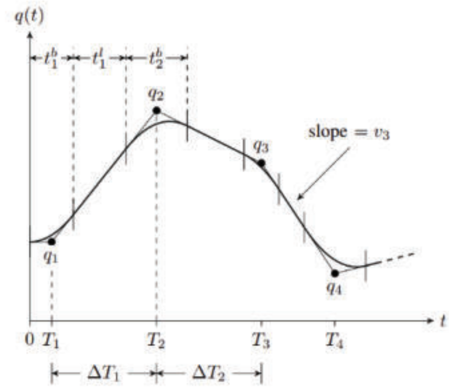


Figure **8.** Parabolic blending between two straights trajectories.

## 3.3. Trajectory Blending

Direct node to node routing is linear approach and, in every node, due to changing of direction it requires a steering that causes the system loses its dynamic behaviour with a very discontinuous response. For smoothing out its dynamics, velocity and acceleration constrains should be preserved thus replacing linear nodal approaches with a controlled blended trajectory in fig:8, is appreciated and parabolic blending is applied. In between two blends nodes a linear segment where velocity remains constant and for blended segment acceleration remains constant.

The resulting trajectory is given by, $s: [0, t_f] \rightarrow C$ , where $t_f$ is total time requires to reach final node, thus trajectories can be constrained as [17],[19]:

$$s(t) = \begin{cases} s_i + v_{i-1}(t - T_i) + .5a_i(t - T_i + .5t_i^b)^2 \\ if\ T_i - .5t_i^b \leq t \leq T_i + .5t_i^b \quad i \in \{1, \ldots, n\} \\ s_i + v_{i-1}(t - T_i) \\ if\ T_i + .5t_i^b \leq t \leq T_{i+1} - .5t_i^b \quad i \in \{1, \ldots, n\} \end{cases}$$

$$\dot{s}(t) = \begin{cases} v_{i-1} + .5a_i(t - T_i + .5t_i^b) \\ if\ T_i - .5t_i^b \leq t \leq T_i + .5t_i^b \quad i \in \{1, \ldots, n\} \\ v_i \\ if\ T_i + .5t_i^b \leq t \leq T_{i+1} - .5t_i^b \quad i \in \{1, \ldots, n\} \end{cases}$$

$$\ddot{s}(t) = \begin{cases} a_i \\ if\ T_i - .5t_i^b \leq t \leq T_i + .5t_i^b \quad i \in \{1, \ldots, n\} \\ 0 \\ if\ T_i + .5t_i^b \leq t \leq T_{i+1} - .5t_i^b \quad i \in \{1, \ldots, n\} \end{cases}$$

The time duration is designed for each blending to maximizing the acceleration rather than minimizing the deviation in between blended segment and nodes and possible overlapping of blended segments and linear phases are avoided.

## 4. Result

All the sample values were taken from a test flight of the quadcopter. The values were saved in a memory as CSV file which was connected to the controller board. The value of latitude and longitude of the starting point was 24.367268, and 88.627877 in degrees. Similarly, the latitude and longitude for the destination point was 24.367798, and 88.628552 in degrees, respectively.

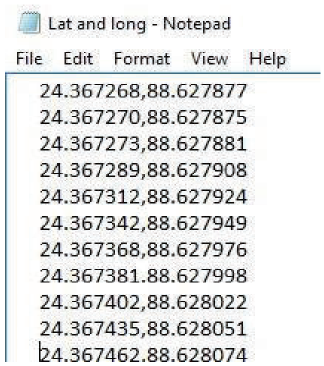


Figure 8. Sample value of latitude and longitude .

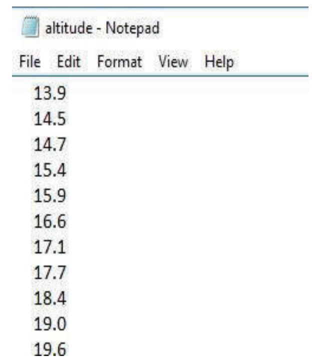


Figure 9. Sample value of altitude .

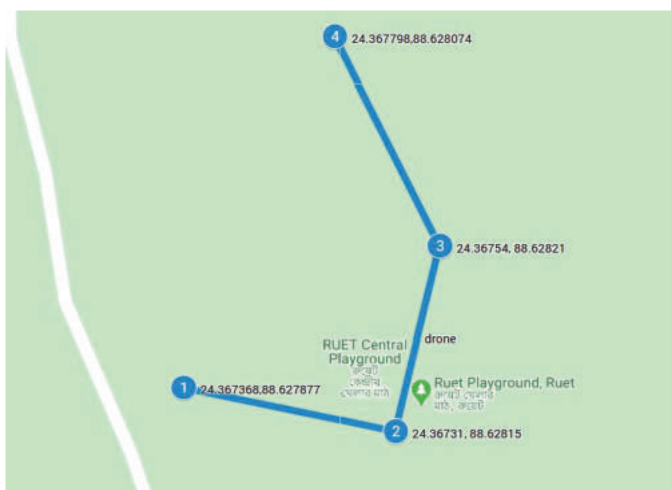


Figure 8. Google map location where the flying of quadcopter was tested and controlled.

The system was tested on those coordinates was able to calculate necessary trajectory blending information. At the same time this proposed system was able to obtain exact trajectory with promising accuracy of trajectory control. The fine tuning of PID controller was maintaining the flying in the exact trajectory with a certain period of time. The BFS algorithm was able to maintain the UAV routing in between set points so that the trajectory blending can be implemented and tested practically in the real-world application in a sophisticated manner.

## 5. Conclusion

The goal of the project was to develop an autonomous quad copter and its autonomous routing along with blended trajectory. New technologies have implemented on the field for different application purposes. Transforming straight trajectory into a blended trajectory with parabolic nature has introduced necessary smoothness in steering ability for such kind of systems. By using the blended trajectory, the velocity and acceleration, thus the dynamic behaviours of the system can be constrained without losing any agility. Necessary longitudes, latitudes coordinates were mapped. Besides, the altitude of the UAV was remained constrained in whole process. This technique made the navigation system of the quadcopter unchanged and consistent. The BFS algorithm was acted as a supportive implementation tool to attain trajectory generation and necessary testing data. By using the autonomous aircraft system, it can reduce the need of labours. With the help of GPS system, a payload can be delivered anywhere autonomously. Using android application, it will help to get the feedback from the aircraft to find the latitude, longitude and altitude of the UAV which can reduce the system error in run time. As a result, the navigation system of the quad copter will be smoother and more consistent while flying in the trajectory.

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