Partially Optimistic UAV Route Planning & Formation Planning using Ant Colony Optimization Algorithm

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Abstract - Flight Plan depicts shortest course between two points either in identified/ unidentified route. The project emphasizes on identifying shortest possible traversal path having minimal distance along with minimum effort on the propulsion between identified points of reference. The minima of cumulative effort of distance traversed and motoring power consumption metrics are the identifiable characteristics, registering Flight Plan. Modified Ant Colony Optimization (mACO), is the design algorithm which envisages the route planning. Local maxima-minima are mapped to global values within constrained environment for route determination. The environment (constrained/ unconstrained) classified by the mission requirements keep abreast with objectives like territorial penetration, radar netting, no-fly zones etc. The pheromone level is directly proportional to the flight distance and evaporation level is proportional to battery discharge/ power consumption metric. The former metric provides multiple options for routes of which minima of later metric is considered as identified route path. Cooperative Maneuvering (Leader – follower) employing rigid geometric cohesion contour algorithm is being implemented for swarm optimization in traversal between source – destination.

Introduction

Unmanned systems had been the much researched topic during the past decade. Unmanned systems sowed its origins from space exploration & defense applications. The progress made had enabled the civilian usability of the ardent technologies. Many countries around the world are prying for commercial exploitation (specific emphasis on logistics support) of the unmanned systems. The research paper emphasizes on the route planning and formation for the UAV Swarms for proper usability. The Unmanned Aerial Vehicle (UAV) state estimation is represented by geo location mapping of the source and target/ destination (latitude, longitude, altitude). Several swarm optimization techniques are considered, of which Ant Colony Optimization Algorithm is selected owing to its minimum time & space complexities especially in indoor experimentation setup.

The UAV entity state is represented by 26 variables viz. latitude, longitude, altitude, heading, bearing, pitch, roll, yaw, velocity along (x, y, z) axis, acceleration (x, y, z) axis etc. The GPS co-ordinates represented by latitude, longitude, altitude are converted to Earth Centered Earth Fixed (ECEF) format, Geodethic format in lieu of World Geodethic Society (WGS 1984) framework. The UAV entity is moved in 3 dimensional space from one point of reference to another. The movement is accomplished by Direct Cosine Transformation (DCT), populated against North - East - Down (NED) axis or x-y-z axis. The y-axis usually represents the North, x-axis East and z-axis the Down. The Roll – Pitch – Yaw, are calculated from the DCT matrix and the UAV entity is guided by the Ground Control Station (GCS) for next possible movement towards the target.

The objective of ant colony algorithm is to find the shortest possible traversal path. The path is identified by the foraging ability of the individual ants and pheromone secretion level and pheromone evaporation level. The greater the pheromone scent level i.e. it is assumed that the more a particular path emanates fragrance the greater is the path being traversed. Owing, to the pheromone being deposited by ants while traversing, along the path. As the UAV are assumed to be working in constrained environment, hence they do not have luxury of recorded flight path in comparison to conventional aircrafts. The source and destination location addresses (latitude, longitude, altitude) are given. The source, destination locations are assumed as diagonal points of rectangle and a rectangle is constructed. Twelve different points are identified in the rectangle constructed, which are known as waypoints. The ant colony algorithm, is applied to find shortest path interconnecting source – destination location either using all/ some of the waypoints. In our case, the Optimization algorithm (ant colony optimization) is used in two different patterns viz. (a) to find the top two shortest distance routes from available routes and (b) to find the time of travel in each of two routes identified earlier. The shortest time taken is the outcome of the Ant Colony Optimization (ACO) Algorithm.

Problem Definition

An insight of traditional flight planning need to be understood prior to implementing similar pattern in Unmanned systems. The flight route/ plan is logged or recorded basing on the Aeronautical Navigation Charts available with the Controlling Agency like Director General of Civil Aviation (DGCA), Govt. of INDIA. The airplane must confirm to the flight plan recorded and it is the duty of the Air Traffic Controller (ATC) to advise the individual flight for correct flight plan, if any variance is observed. The flight plans are all along the air taxi ways quite similar to highways in terrestrial road network. Flights sharing same air ways are provided with separation distance co-operatively by the concerned ATC. If collision is sensed or detected, then evasive maneuvers are triggered and must be followed by the individual airplanes as suggested by the ATC concerned.

Unmanned Aerial Vehicles (UAVs) are being used in Dull – Dirty – Dangerous environments. Though, technological advancements have shaped the field of unmanned aviation in the current state. Unfortunately, fully autonomous unmanned vehicles are still being researched. The unmanned systems are being maneuvered either remotely (remotely piloted vehicles (RPV)) or semi autonomously. Autonomous maneuvering of the vehicle is the aim of the research project. In this context, route planning and control is the critical block of events, which dictate the outcome of the proposed capability of the system. A priori of environment, though is very important to plan the flight route; is often unavailable owing to the constrained conditions of operation. The Ground Control Station (GCS) through its array of sensors (both terrestrial and aerial) senses the environment and advises for qualitative route planning. The UAVs Route planner, identifies potential routes and logs in the flight plan log. The present problem rests in identifying the possible optimized flight plan/ route for traversal between the source – destination stations.

Proposed System

The UAV flight route planner employs Swarm optimization algorithm especially Ant Colony Optimization, Collision Detection & Avoidance algorithms, Optimized geometric Formation algorithms etc. The modified – ACO algorithm employs partially optimists i.e. identification of several potential route paths and optimistically selecting one route which is,

a. either full route from partial selected list or

b. making one route path from hybrid mix of two or more routes

The nature of m-ACO algorithm is dynamic i.e. if any congestion or constraint observed then alternate route must be opted from the available current point of reference to the destination. The very nature of ants moving around the obstacle is taken into consideration while deploying the dynamic route planning in the algorithm. The route paths, generally tends to move from North - South or East – West to assist in the Flight Approach Fix (FAF) while landing. The basis of this analogy depends on the direction of the runway/ landing platform at the destination. Conventional wisdom, suggests runways are from North – South in 80% cases and East – West in 15% while in certain special cases the runway X - runways exist.

Comparison of various Swarm Optimization Algorithms

Here comparison is made on various characteristics of different meta heuristic techniques like parameters whose value should be initiated before starting the implementation, convergence i.e. how the algorithms gets trapped in local optima. Exploitation & De – Centralization (E & D) component i.e. exploitation of search space and De - centralization means reaching the unexplored portion of the search space. CPU Time is the running time of the implementation of the algorithm. The last path length is the length of the path find by these for a common problem. The experimental sample is of 20 nodes for a tour.

Measures	ACO	GA	SA	PSO	Table Search
Parameters	Pheromone evaporation rate.	Crossover rate, mutation rate, population size	Annealing rate, initial temperature like parameter.	Population size, velocity of each particle	TL Length
Convergence	Slow due to pheromone evaporation.	Rapid	It avoid trapping by assigning probability to deteriorating moves.	Rapid but less than GA	By using TL, it avoid trapping in local search.
E & D Component	Pheromone update, probability of selecting next vertex	Crossover, mutation, natural selection	Cooling schedule, solution acceptance strategy	Local search, fitness	TL for neighbor selection, aspiration criteria.
CPU Time	250	200	101	220	140
Path Length	300	200	99	250	97

Hence, it could be inferred that Ant Colony Optimization (ACO) algorithm is extremely useful in comparison with others.

Route Planning using Ant Colony Optimization Algorithm

Input data to the algorithm include source and target location (indoor experimentation). The dimensions of the room/ experimental setup are specified as length, width and height in meters. The GCS does the computation in the route planner. The route planner performs the following functions,

a. Space Matrix & Way Point Generation

a. Constructs an imaginary rectangle in 3 dimensional space of the room i.e. between the source and targets.
b. The GCS prior to re-constructing the domain rectangle may try to pre-empt any obstacles or Raise flags prior to re-constructing the domain rectangle or
c. Randomly generate flags during run time in the domain rectangle
d. The least mobile UAV entity is selected as the test specimen for calculating the Safe zone. The average distance covered by the test specimen in one minute is calculated on a horizontal plane. Double the distance computed is considered as Safe distance along the vertical plane while double the turning radius of the UAV entity (biggest of the UAV in the swarm) is considered. A square is appropriated using Gaussian surface Rules for the vertical and horizontal planes just computed. Thus, the square computed is known as the safe zone.
e. The space matrix is divided into smaller cells or entities of dimensions equated to the safe zone. Thus, cell obtained is known as safe cell.
f. Multiple navigation way points (maximum of 12 no.) are generated randomly in the space matrix.
g. The spatial distribution is smoothened using Bresnel curves in the space matrix. The curve smoothening algorithm is triggered when the left/ right/ top/ bottom maneuvers are initiated. Moreover, the algorithm becomes renderable when angle of attack is more than 20^0. The prime logic in utilizing Bresnel curve, is to render the maneuvering of the UAV within its turning radius. The algorithm triggers the maneuvering just one waypoint prior to the actual referral point. The actual anchor points are computed and maneuvering is actuated. Point worth noting is that, the center point is inside the existing safe zone cell, if it falls outside then the next referral point is computed.

b. Route Identification

a. Distance Calculation

The spatial distance between two 3 dimensional points is computed using the following formula;

Distance = $\sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]}$ (1)
Pitch (θ) = $\tan^{-1}(\partial y/\partial x)$ (2)
Bearing(β) = $\tan^{-1}(\partial y/\partial x)$ (3)
Yaw = $-\tan^{-1}(((x_2 - x_1))/((z_1 - z_2)))$ (4)
Pitch = $\tan^{-1}((y_2 - y_1)/(\sqrt{((x_2 - x_1)^2 + (z_2 - z_1)^2)}))$ (5)
x (co-ordinate) = cos(yaw)*cos(pitch) (6)
y (co-ordinate) = sin(yaw)*cos(pitch) (7)
z (co-ordinate) = sin(pitch)
(8)

If the referral points are indicated in [latitude, longitude] format then;

Distance = $\sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]}$ (9)
Pitch (θ) = $\tan^{-1}(\partial y/\partial x)$ (10)
Bearing(β) = $\tan^{-1}(X, Y)$ (11)
X = cos(lat2) * sin (long2-long2)
Y = cos (lat1) * sin (lat2) – sin(lat1)*cos(lat2)*cos(lat2-lat1)

b. Interfacing with Database

The aeronautical charts/ satellite imagery are indicative of the altitude and terrain specifications of the referral way points. Conventional air passage ways for commercial applications have data pertaining to referral points; if its falls within its flight path. The following is the data recorded in the database i.e.

Parameters (P) = [routeid, name, latitude, longitude, altitude, wind, wing load]

Routeid : the identification no. of the referral point in the database

Name : name of the referral point
Latitude: mentioned in degrees. Must be converted to radians. North is Positive while south is negative
Longitude : mentioned in degrees. Must be converted to radians. East is Positive while West is negative
Altitude : mentioned in meters. The height above ground level. Care must Taken, because the height is in reference to ground level and Not center of earth.
Wind : the average wind velocity in specific month of the year over the Past 50 years. The data is maintained with defence organization For the last 100 years.
Wing load : the average load factor on the wing owing to the terrain Geometry and complexities e.g. ice formation, high winds etc.

Ms SQL Server 6.5 database is used owing to porting the application on Web Hosting Servers or using standalone application. For dynamic scripting Python is used as IronPython 3.3 which is supported both by Ms SQL Server and MySQL. While webpage loading for sake of simplicity is done using PHP which supports MySQL. Hence, in a tradeoff between Ms SQLserver and MySQL – MS Sql Server is selected. The necessary tools and libraries are added to the .NET environment for better workaround.

c. **Interpolating Elevation v/s Distance graph, Power v/s time graph**

Given a route path, a Elevation v/s distance graph is plotted in which for any given referral point x[distance, elevation] are considered. The elevation is plotted in meters while distance is generally considered in km. for indoor experimentation, both are assumed to be in meters.

Performance Curves or Thrust curves indicate the thrust v/s time for a given propulsion. But incidentally, power (W) v/s velocity (m/s) depict the minimum power condition, minimum thrust and maximum speed. The following formulae relate the conditions mentioned;
Power is defined as energy per unit time. Therefore, the power required for a level, unaccelerated flight at a given altitude and a given velocity is

$$P_R = T_R V\infty = \frac{W}{CL/Co)}$$

X = [N + H] cos ¢. cos £ (12)
Y = [N + H] cos ¢. sin £ (13)
Z = [(b 2 /a 2) N + h] sin ¢. (14)
Where:
¢ = latitude
£= longitude
h = height above ellipsoid (meters)
N = Prime Vertical of Curvature (meters) is defined as:

$$N = \frac{a^2}{[a^2 \cos^2 ¢. + b^2 \sin^2 £]^{½}} \qquad (15)$$

$$¢ = \arctan \left[\frac{Z + e'^2 b \sin^3 ¥}{p - e^2 a \cos^3 ¥} \right] \qquad (5)$$

$$£ = \arctan \left[\frac{Y}{X} \right] \qquad (6)$$

$$h = \left[\frac{p}{\text{Cos } ¢} \right] '' \qquad (7)$$

Where auxiliary values are:

$$¥ = \arctan \left[\frac{Z a}{p b} \right] \qquad (8)$$

$$p = [X^2 + Y^2]^{1/2} \qquad (9)$$

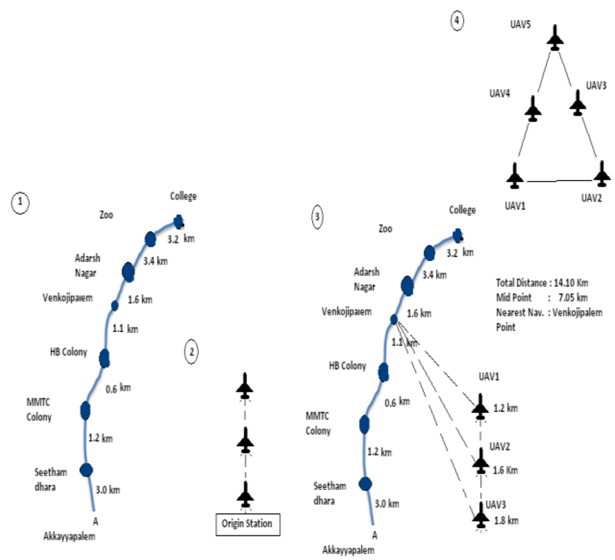
d. **Time Calculation**

The given data is as follows,

Launch GPS : [latitude1, longitude1, altitude1]
Target GPS : [latitude2, longitude2, altitude2]

A minimum of two and a maximum of twelve navigation points are identified between the Launch and Target GPS as follows;

WP1 : [latWP1, lonWP2, altWP1]
WP2 : [latWP2, lonWP3, altWP2]
WP3 : [latWP3, lonWP3, altWP3]
..
..
..
WP11 : [latWP11, lonWP11, altWP11]
WP12 : [latWP12, lonWP12, altWP12]



Force Vector:

$F_{thrust} - F_{gravity} - F_{airdrag} = mv$
$T = \rho g_0$

Climbing:

$T - mg_o - (\rho C_D A_{eff} V^2)/2 = mv$
Where,
ρ - air density (kg/m^3)
C_D - drag co-efficicent
A_{eff} - effective surface area of UAV
T - total motor thrust
g_0 - 9.81 m/s^2

Forward Flight

$Mv = \sqrt{} [1 - (mg_o/ T)^2 T] - [\rho C_D A_{eff} V^2)/2]$
Forward pitch angle (α) $= \sin^{-1}(mg_o/ T)$
Max. rate of Climb ($V_{vert.}$) $= \sqrt{2}((T - mg_o)/ \rho C_D A_{TopSurfaceArea})$
Thrust – Weight Ratio (TR) $= T/ mg_o$
Max. Speed (Forward Flight [$V_{hor.}$]) $= \sqrt{}[2T(\sqrt{}(1-(mg_o/ T)^2))]/ [\rho C_D A_{eff}]$
Area of the Quadcopter $= 0.5mT_m^2 + 3\pi r_{prop}^2$
Where mT_m is Motor to Motor Distance

With the velocity obtained. The time required to climb from one point of reference to another is computed and the total time taken in a particular path is computed. The timings are ranked with the least time taken route as rank 1 and the highest time taken route as last rank. The route identifying the Rank – 1 is the Partially optimistic route identified using Ant Colony Optimization Algorithm.

e. **Applying Ant Colony Algorithm**

Ant colony algorithm is a meta-heuristic search algorithm. The important aspects of an Ant Colony algorithm are pheromone trail, evaporation rate. UAV Swarm is an Multi Agent Ant Colony Algorithm. The outcome of the Ant Colony Algorithm is to identify the most traversed path, which is assumed to be the shortest path between the two reference points. The algorithm specifics is to identify shortest possible path from source/ ant pit to food source/ destination. As the ants, need to carry food to ant pit, hence they need to identify the shortest possible path. Multiple ants, randomly start from ant pit in search of food source. They leave a scent known as pheromone along their traversal path. For a frequently traversed path, the pheromone scent level would be more while for a sparsely travelled path, the scent level is low. As pheromone is a bio – marker, it evaporates or dissipates into the environment. Hence, evaporation rate need to be considered.

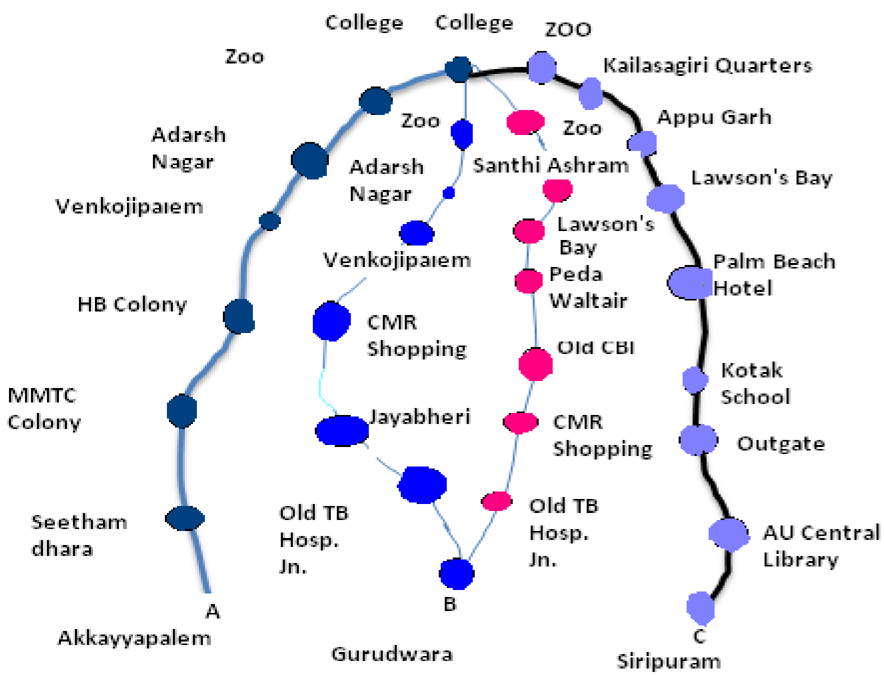
In our case of UAV swarm or multiple paths, owing to the constrained operational environment, the routes need to be identified prior to launch. Hence, a simulated Ant Colony Optimization Algorithm is undertaken. The pheromone level is equated to the distance of travel between two points of reference.

$$T_{distance} = \sum_{i=1}^{i=n} (distance_i - distance_{i-1})$$

Each Total route distance is ranked with least distance as rank 1 while highest distance as last ranked. The Ranked distance is an indicator of the pheromone scent level. The evaporation level is identified by the Time taken by the individual route in traversal from points of reference. The least time taken is the most frequently traversed while highest time taken is the least travelled.

c. Recording Flight path

The route path, thus computed is stored/ logged into the GCS in form of an array i.e. one waypoint after another. As shown in the figure ___, the route identified is A to C. The following is the schema of logging the path,



Mission ID No. : 171018001 **Date : ____________________**

Route ID	From station		To station		Time in seconds
	Name	ETA	Name	ETA	
101	A		WP1		
102	WP1		WP2		
103	WP2		WP3		
103	WP3		C		

Flight Log in array format : [A WP1 WP2 WP3 C]

Note : The array is limited to a maximum of 12 waypoints inclusive of source and destination.

Conclusion

Ant Colony Optimization Algorithm is effectively used in analyzing the complex route planning for UAV swarms in indoor experimental setup. In outdoor environment, the Particle Swarm Optimization Algorithm is efficient. A hybrid algorithm of Ant Colony Optimization and Particle Swarm Optimization could be studied for both indoor and outdoor experimentation. The Experimental data are being analyzed using Grossberg Neural Network (GNN) for finding efficient patterns of working within closed boundaries.

Future Work

Swarm Intelligence is gaining momentum, and many a problems in civilian applications it is being implemented. Still active research need to be performed in enabling the future technologies for commercial exploitation. The future directions, especially in our case should be to reduce computation time for route planning. Integrating sensor data for local – global environments must be memory optimized. Dynamic planning, collision avoidance & detection are the problem areas to be addressed. Wondering, how could our mythological stories depict the autonomous flying of pushapaka vimana as mentioned in Vimanika Sastra. Fully autonomous co-operative swarm flying must one day be a dream turned to reality.

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