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Random Way Point Generation In Constrained Environment

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ABSTRACT

Integrating Unmanned Aerial Vehicles (UAV) into National Airspace is the need of the hour. Operational environment of UAV is primarily in Non – Towered sectors. Though, UAV flight plans need not be logged with the Director General Civil Aviation (DGCA), Govt. of INDIA. Efficient route planning can be performed with known Navigation Points along the path. The constrained Non – Towered Environment; do not have the luxury of known navigation points. Square Unit distribution of the route with minimum separation distance or cells is employed in generating random navigation points. The algorithm proposed employs exponential distribution scattered along with modified visibility graphs in the operable domain.

Keywords :— Put your keywords here, keywords are separated by comma.

I. INTRODUCTION

Employing Multi Agent UAVs is rather economical in comparison to single UAV e.g. autonomous agents being used in Rescue Operations [1], and a team of UAV for military operations such as target intercept [2], reconnaissance [3] and surveillance. However, dealing with multiple UAVs is far more challenging problem than dealing with single UAV owing to higher order of Search space, more constraints and higher chance of inter UAV collision. Following are three approaches to solve this problem viz. 1. Waypoint assignment, 2. Trajectory generation and 3. Additional smoothing of trajectory [2]. The goal of the trajectory generation stage is to generate feasible trajectories for UAVs, which in turn may require additional manipulation to satisfy various constraints.

a. Waypoint Assignment is a combinatorial optimization problem similar to multiple travelling salesman problem (MTSP). Given a fixed number of UAVs and waypoints, the goal of this step is to find the most efficient path for each UAV such that all waypoints are visited by at least one UAV. In this paper, the approach is mainly based on RNPG algorithm (RNPGA) because a fast determination is required for an algorithm to be used practically.

b. Trajectory Generation step aims to generate feasible trajectories for the UAVs based on the assigned waypoints. It has been extensively studied in robotics and automation [8, 9]. Constructing a roadmap based on cell decomposition (CD) is one of the most widely used approaches. This method is attractive in that the search space is reduced to a finite dimension, but generated paths are not smooth unless UAV dynamics is explicitly considered during CD. Usually incorporation of the dynamics during cell construction is not realistic, so often times an additional smoothing process is required to meet the constraints such as minimum turning radius of UAV. However, it is also difficult to obtain a smooth trajectory without additional smoothing [10]. There are a variety of algorithms based on a potential function (PF), where a UAV is guided by attractive force towards a goal and repulsive force from obstacles [11]. It is well known, that PF is fast but suffers from local minima. As an alternative, a navigation function without local minima can be constructed, but this requires heavy computation not suitable for online setting. Because, we consider a problem of efficiently finding safe trajectories for multiple UAVs with collision avoidance in a 2d environment with polygonal obstacles; the standard approaches mentioned above are not suitable for this problem due to kinematic constraints and the size of search space involved. In this paper, we adopt concepts from Visibility graphs (VG) to compute trajectories composed of straight lines and arcs obeying kinematic constraints, which is suitable to accelerate trajectory computation due to simplicity and the reduced search space.

c. Many trajectory planners first generate paths composed of lines without considering kinematic constraints, and then apply smoothing methods such as Bezier curves [15] or cubic spine [16] to them. However, this two step approach i.e. path generation and additional smoothing, may loose optimality and safety of the path after smoothing because the smoothing stage does not really consider the cost function or safety issues. On the other hand, sampling based approaches usually do not need additional smoothing. These approaches first discretize time and permit UAVs move which satisfies kinematic differential constraints [17]. In this paper, we propose an alternative approach that uses a variant of VG, which considers kinematic constraints at the time of construction, such that the achievable trajectories can be obtained without an additional smoothing process. We propose innovative methods that result in significant improvement.

We propose a strategy that does not need the problematic additional smoothing stage at all. It is based on the modified visibility graph (MVG), a variant of VG. The original VG contains line links only and does not consider allowable distance from static obstacles, therefore it might not satisfy the collision free criterion. However, the MVG contains arc links with radius of minimum turning limit which is one of the kinematic constraints of UAVs, and all links on MVG are farther from static obstacles than the allowable. Therefore, just by passing through links on MVG, a UAV does not collide with static obstacles and does not violate the minimum turning radius limit; thus, an additional smoothing is not required.

Secondly, we propose an efficient stochastic approach using Simulated Annealing (SA) that assigns waypoints to each UAV such that it minimizes the cost function which is based on real minimum length path on the constructed MVG. One of the most significant advantages of using (considering the kinematic constraints and static obstacles) between two points more accurately than the methods based on the Euclidean distance. Therefore, the cost functions of the waypoints assignment can become more optimal.

Third, we invent a method to detect collision between two UAV by iteratively comparing two UAVs path for any intersection of safe zone. If the safe zones intersect, then they are chances for collision. The Expected time for Collision is calculated, and necessary co-operative Collision Avoidance Maneuvers are employed [18].

II. PROBLEM FORMULATION

Our proposal is interested in generating trajectories for multi – UAV system under, non - holonomic constraints; avoiding obstacles and inter vehicle collision.

Waypoints, UAVs and Trajectories:

Let A_i (i=1, … , N_{uav}) denote the UAVs to be controlled. For simplicity, let us consider each UAV as a point mass so that the position of A_i at time t can be described by its (x, y) position $q_i(t) = (x_i(t), y_i(t))$. Similarly, let us define waypoint $w_j(j = 1, \dots, N_{wp})$, which should be passed through by a UAV at least once. We are interested in generating trajectories for $q_i(0) = q_i^{init}$, $q_i(T_i) = q_i^{init}$ which means that we want each UAV to visit the assigned waypoints and return to its initial position, where T_i denotes the time of completion of trajectory for A_i. Because, all waypoints should be visited at least once, the following equation holds where w_j represents the j^{th} waypoint.

$$\bigcup_{j=1}^{N_{wp}} w_j \; € \; \bigcup_{i=1}^{N_{uav}} \gamma_i$$

Also, the curve γ_i should satisfy kinematic constraints and collision avoidance which are described below The goal of this paper is to generate UAVs trajectories which minimizes T_{max} defined as the mission completion time.

$$T_{max} = \max_{i=1}^{Nuav} T_i \qquad (1)$$

In addition, we also define T_{tot} as the total flight time

$$T_{tot} = \sum_{i=1}^{Nuav} T_i \qquad (2)$$

Kinematic Constraints:

Many types of UAVs are limited in their maneuvers in terms of velocity and turning radius as shown in fig. 1. In this study, we consider two widely used kinematic constraints;

a) The velocity should be larger than V_{min}. And smaller than $V_{max.}$ Corresponding to the maximum available power, and
b) Turning radius should be larger than $r_{min.}$ Considering the mechanical limits like heading angle

Let us consider a trajectory generation problem for multiple

UAVs where the trajectory γ_i for each UAV A_i should satisfy the two kinematic constraints described above i.e.

a) Velocity of the A_i : $V_i(t) = \| x_i(t), y_i(t)\|$ should satisfy (3)

$$V_{min} \le V_i(t) \le V_{max}, \forall t \in [0, T_i] \quad (3)$$

b) Radius of turning of the A_i should satisfy (4):

$$r_i(t) = \left\| \frac{\| x_i(t)y_i(t) - y_i(t)x_i(t) \|}{\| (x^2_i(t) + y^2_i(t))^{3/2} \|} \right\| r_{min}, \forall t \in [0, T_i] \quad (4)$$

Roadmap:

A roadmap is a graph G(V,L) consisting of a set of vertices V and a set of links L. Once a roadmap is constructed, trajectory generation is reduced to connecting vertices in the roadmap. Suppose that each link in G(V, L) is either line or an arc with the radius of curvature $r_{min.}$ And each vertex is a beginning or end point of each line or arc link. Then trajectories generated by connecting vertices on this G(V, L) will satisfy the constraint Eq. (4), without additional smoothing processes. The goal of this research is to construct such a roadmap based on the concept of visibility graph, and then extend it to multi UAV problems including waypoints assignment and collision avoidance. In our algorithm, we used a modified version of VG as a roadmap, which is described later in detail.

Collision Avoidance:

We consider two types of collisions:

a) Collision with static obstacles,
b) Collision among UAVs

Let D_{obs}. Denote the safe separation distance from obstacles, and D_{UAV}. between UAVs. Suppose that there are total of N_{obs}. Static obstacles. For (a) avoiding collision with obstacles, we define the distance between A_i and the obstacle $B_k\{k=1, …., N_{obs}.\}$ as;

$$d(q_i(t),B_k) = \min_{b \in B_k} \|b-q_i(t)\|$$

Then, the condition under which A_i does not collide with B_k is given by Eq. (5)

$$d(q_i(t),B_k) \ge D_{obs.}, \forall t \in [0, T_i] \quad (5)$$

for $\forall$ i $\in$ {1, …, N_{uav}} and $\forall$ k $\in$ {1, …, $N_{obs.}$}. For each obstacle, we will let CB_k denote the region that does not satisfy Eq. (5) and CB the collection of obstacle region, i.e.

$$CB = \bigcup_{k}^{N_{obs.}} CB_k$$

III. ALGORITHM

A navigation point (np) can be identified by three state variables i.e. [latitude, longitude, altitude] etc. The collision avoidance system (cas) employed for multi agent uavs with limited or near zero nps are self centric and individual in nature. There are chances for mid air collision or near miss situations, if agents are non cooperative in nature. Hence, it had been proposed to employ distributed and co-operative algorithms employing cas for better air space utilization.

The source (a) and destination (b) gps co-ordinates are sensed and operational domain is constructed in 2d co-ordinates (x, y co-ordinates). The x, y follow the ecef notation. A single temporary path line connects the a and b points. The imaginary path line is divided into four equal parts using mid point calculation algorithm. Each agent of the uav swarm is computed for its vmax. Climb, amax. Climb, heading max., radius turn, distance safe zone etc. Where;

$V_{MAX. CLIMB}$	MAX. VELOCITY DURING CLIMBING IN M/S
$A_{MAX. CLIMB}$,	MAX. ACCELERATION DURING CLIMBING IN M/S^2
$HEADING_{MAX.}$	MAX. HEADING ANGLE OR ANGLE OF ATTACK DURING ASCENT
$RADIUS_{TURN}$,	MAX. TURN RADIUS IN M
$DISTANCE_{SAFE ZONE}$	SAFE ZONE DISTANCE

The horizontal and vertical planes are divided into squares of dimensions (x distance safe zone , y distance safe zone). No. Of squares in the domain space are computed using the formula:

NO.OF SQUARES (S_N)= (AREA $_{(DOMAIN)}$)/(AREA $_{(SAFE DIST.)}$)

For battery powered uavs, the $v_{max. Climb}$

Is assumed to be = 22 m/s

$$Distance_{safezone} = 2[\Pi * length_{wingspan} + distance_{traversed}]$$

$$= 2[\Pi * length_{wingspan} + \delta time * v_{max. Climb}]$$

No. Of cells ($cells_n$) = $\delta x * \delta y / s_n$

Data matrix $= [cells_n]^{26}$

The penalty factor (m) is given by the formula:

$$M_{new} = \sum_{i=1}^{n_{cell}} (\sum m_{cell})_i$$

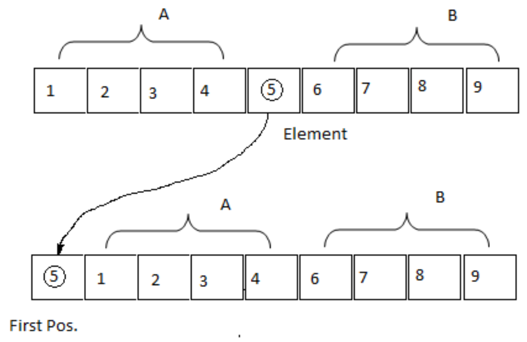
Reward function (r) = k x [m_{new}]

K – reward factor = 0.9

Converting the reward function to double format

$$Myvalues = \sum_{i=1}^{9} (r)_i$$

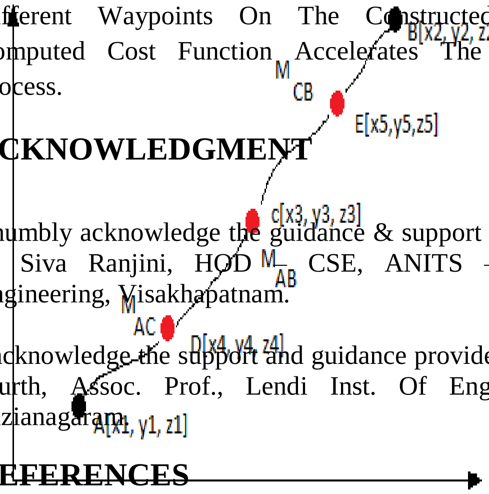
FINAL VALUE = MYVALUES % 26
NEW MATRIX FUNCTION = ROUND(0.27 * [M_{NEW}], 0)



New data matrix is interpolated as shown in figure.
Repeat procedure for four times with each new [x, y, z] position whilst the source co-ordinates remaining same.
Repeat the procedure for mab, mcb points also. Finally, populate the nps generated onto a graph sheet. Implementing the shortest optimal path using ant colony optimization algorithm; select the optimum path for traversal. The selected path is recorded for future use.

IV. CONCLUSIONS

This Paper Suggests A Method That Allocates And Generate Trajectories Along The Assigned Waypoints For A Co-Operative Multi – Uav Systems. First, We Modified A Visibility Graph (Mvg) To Consider Minimum Turning Radius And To Avoid Collision With Static Obstacles. Because Of The Nature Of The Visibility Graph, It Is Not Trivial To Extend This Method To A Full Three Dimensional Problems. However, The Proposed Approach Is Applicable To Various Convex Or Non – Convex Generated Polygons With Line Or Arc Edges. Second, We Used A Stochastic Approach Of Simulated Annealing To Efficiently Allocate Waypoints To Multiple Uavs. By Quickly And Accurately Calculating The Minimum Path Length Between Any Two Different Waypoints On The Constructed Mvg, The Computed Cost Function Accelerates The Optimization Process.



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