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Solving Uav Path Problem Using Meta-heuristic Optimization Algorithms

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***Abstract*—In this study, the path planning problem for UAVs has been investigated. Out goal was finding a method to go from the source to the target point in the shortest time and the shortest route. A mathematical programming model that takes into account the environmental safety conditions has been developed and solved with the MBO algorithm. MBO algorithm [2] gives better results than simulated annealing, tabu search, genetic algorithm, scatter search, particle swarm optimization, differential evolution and guided evolutionary simulated annealing approaches, as stated in a previous study [2].**

***Keywords*—Unmanned Aerial Vehicles (UAV), meta-heuristic optimization, migrating birds optimization (MBO), drone control, trajectory planning.**

I. Introduction

The Federal Aviation Administration, estimated the market share of thev Military UAVs to be $10 billion, while UVS estimated private drone sales to be $82 billion in 2017(onlinemasters.ohio.edu/blog/the-benefits-and-challenges-of-uavs/). After all, we are dealing with a truly overgrown industry.

It is obvious that a lot of research has been done on UAV. The reason for this is naturally to produce UAVs with more skill and lower cost. Scientific researches carried out for this purpose have focused on the following areas:

-Knowledge fusion

-Communication management

-Best path planning

-Collision avoidance

-job scheduling

-trajectory motion and path tracking

-Goal identification and movement creation

-Engagement decision

-Weapon use

-Collaboration methods

-path optimization

-Immediate decision making and response generation

-Energy minimization[1]

The areas where UAVs are used are becoming more and more common. Weather forecasts, cargo distribution control, control of environmental systems, monitoring of agricultural systems, surveillance, etc. are for civil UAVs.

Also, they are used for various military purposes too. There are even rumors that UAVs will replace classical warplanes.

In this study, the path problem for the UAV was investigated. The issue of determining the optimal route from a source to a destination by detecting obstacles was investigated. As an optimization method, the most successful meta-heuristic optimization algorithm, the migration birds optimization algorithm [2], was used and very successful results have been obtained.

II. RELATED WORKS

H.Ergezer and K.Leblebicioğlu [3] worked on the online route planning algorithm for a large number of unmanned aerial vehicles(UAV). They carried out the simulations in the MATLAB environment. The planning algorithm was tested for various scenarios and the results were presented.

J.W.Choi etal.[4] studied two path planning algorithms based on Bezier curves for autonomous devices, and presented their results, given the waypoints and constraints.

It has been stated that Bezier curves are an excellent tool for the path generation problem. The simulation results related to the above mentioned path algorithms for autonomous vehicles are presented at the end of this study.

Z.You et al[5] developed a dynamic model based on Bezier curves for rapidly generation 3D trajectories for UAVs .Moreover, the developed model, with its high computational capability, can also be a solution to the problem of online collaborative trajectory generation.

S.Ragi and H.D.Mittelmann[6] produced a non-linear mixed-integer optimization model for UAV path optimization problem. However, the numerical solution of the model brings quite a computational cost for the first version.

J.J.Liang et al. [7] stated in their study that the most important task in path planning problems is to find a safe path that meets certain conditions. For this purpose, three different and commonly used curve shapes are compared and evaluated in terms of performance. In this study, it has also been suggested that Bezier curves give the best results in path planning problems.

S. Aggarwal and N. Kumar [8] conducted a literature survey related to UAV Path Problems. One of the most important results is that the most important issue in path planning problems is not only to find the optimal and shortest path, but also to create a safe environment free from collisions for UAVs.

A. Sönmez et al.[9] solved the optimal path planning problem in 3D environment with MATLAB using an improved genetic algorithm(GA). Also, the reason for using MATLAB was expressed as its high visual power.

B. Ingersoll et al.[10] modeled the UAV path planning problem as a single-objective optimization problem. Collision with obstacles and aerodynamic flight constraints were considered as problem constraints. A wide control range was used for obstacle constraints and flight dynamics parameters.

G. Szafranski and R. Czyba[11] conducted a study on different control strategies for UAVs. The control process was formulated as the angular stabilization of the quadrotor. The results obtained for various platform controls with PID control architectures were given and the effectiveness of the proposed method was suggested.

L. R. Howell and B. D. Allen[12] proposed a method for the calculation of spline control points in their study. With the help of these spline control points, the autopilot trajectory can be determined within the limits of vehicle dynamics. The control point finding algorithm created with the help of Bezier curves is extremely useful in determining the trajectory for the UAV. .

Z. Fu et al.[13], in their study, defined three separate cost functions to determine the optimal flight of the UAV: path safety cost, length cost and smoothness cost. Path safety cost is related to whether the path is suitable for flight; length and smoothness functions on the other hand, it is related to the energy consumption of the UAV flight. For the solution of the optimization problem, evolutionary algorithms are used effectively.

K. Danancier et al.[14] stated that many optimization algorithms have been proposed for the UAV's path planning problem, but in their study, they focused to a heuristic algorithm with the Dijkstra Algorithm and compared them in terms of various parameter values.

F. Ge et al.[15] In their study, proposed an improved gray wolf optimization algorithm to solve UAV path planning processes for oil fields. The authors claimed that the improved gray wolf algorithm was more effective than the others in solving the aforementioned problem.

Z. H. L. Zhao and L. Zhao[16] tested 4 different algorithms in path planning problems, based on geometric search. These are Dijkstra Algorithm Floyd algorithm, A* algorithm and Ant Colony algorithm. Considering the parameters such as processing time, complexity and path length, it has been determined that Dijkstra algorithm gives better results than A*, Floyd and Ant Colony algorithms.

III. MAIN CONTRIBUTION OF THIS STUDY

The most important contribution of this article to the research area is the application of the Migrating Birds Optimization (MBO) algorithm to the path planning optimization problem for the first time. The results obtained with MBO were compared with the very popular PSO algorithm and they were found to be better.

Already in an article published in 2012 [2], we proved that MBO gives better results than PSO for another problem.

IV. PATH PLANNING PROBLEM

Path planning is the process of producing a feasible, suitable, and safe road, from the starting point to the destination, taking into account the current environmental conditions.

Path planning for UAVs is very relevant to the following key terms:[8]

- Motion planning
- Trajectory planning
- Navigation

The two most important factors in path planning are:

a) Minimum cost

b) Minimum time used

An optimal path planning should be a route from destination to the target in the shortest time and at the least cost, and which minimizes the probability of collisions for each type .

V. PARAMETRIC BEZIER CURVES

Another method for path planning is to use Bezier curves.

Bezier curves can be expressed as below:

The parametric Bezier curve at parameter t can be defined as below:

$$P(t) = \sum_{i=0}^{n} B_i \quad J_{n,i}(t)$$

$0 \leq t \leq 1$

[16] where the n is degree of the curve, Jn,i(t) is the Bernstein polynomial basis function and t is the parameter.

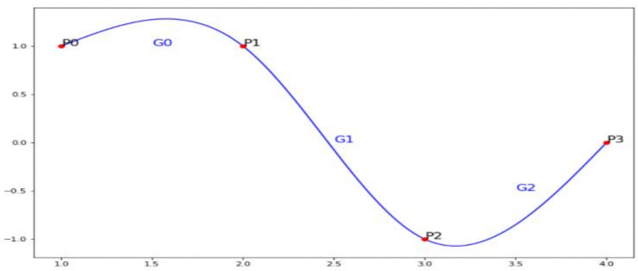

Figure 1-Bezier Curve

An example of a Bezier curve is shown in Figure 1. Here, G0, (P0, P1) control points, G1, (P1, P2) control points and G2, (P2, P3) are three different Bezier curves created by control points.

VI. BERNSTEIN BASIS FUNCTION

Bernstein Basis Function is defined as below:

$$J_{n,i}(t) = \binom{n}{i} t^i (1-t)^{n-i}$$

$J_{n,i}(t)$ is the nth-order Bernstein basis function. T is defined as below:

$$t_i = t_{i-1} + \frac{|x_i - x_{i-1}|}{\sum_{i=1}^{n} |x_i - x_{i-1}|}$$

i= 1,2,…n

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VII. BEZIER CURVE FITTING AND FITNESS FUNCTION OF THE OPTIMIZATION PROBLEM

Curve fitting problem focuses on two different case:

To find a set of control points that interpolates a sequence of data points

To find a set of control points that approximates a sequence of data points In this study our problem is the second case. To determine a set of control points that approximates a sequence of data points with minimum error. This last situation is an optimization problem.

VIII. FITNESS FUNCTION

Approximation of function can be done by minimizing the difference between the determined curve and the given sequence of way points:

$$F(p_0, p_1, \dots, p_n) = \sum_{k=1}^{m-1} |d_k - P(u_k)|^2$$

Where 0<k<m, n+1 is the number of control points and d is the sequence of points with m+1 elements. $|d_k - P(u_k)|$ is distance between one point d_k and Bezier curve. Points d_0 and d_m are not added in the sum because the first and last control points are always interpolated [16].

After the flight trajectories are determined by the Bezier method, the control variables of the trajectories can be solved. The flight trajectories should provide the dynamic constraints of the devices such as speed, acceleration and flight angle. It should also provide some constraints given about the UAV [5].

IX. GOAL FUNCTION

The objective function for the shortest path from the starting point to the target point for a safe and obstacle avoidance flight can be expressed as [17]:

$$\min F_{obj} = F_{lenght} + \lambda F_{obs}$$

Subject to:

$$g = \sqrt{(x_{uav} - x_{obs}^i)^2 + (y_{uav} - y_{obs}^i)^2} \le r_{obs}^i$$

Here F_{lenght} means the flight length, F_{obs} is the effect of obstacles. λ is a penalty coefficient and is determined by experience. In some studies, its value is taken as 10^3.

F_{lenght} , is given as

$$F_{lenght} = \sum_{j=1}^{M+1} \|S_j\|_2$$

Here S_j's are the arc lengths for M+1 path segments. F_{obs} can be written as below [17]:

$$F_{obs} = \sum_{i=1}^{N_{obs}} z_i$$

Where

$$z_i = \begin{cases} 1 & d_i <= 0 \\ 0 & otherwise \end{cases}$$

Where d_i is the distance between the current position of the UAV and the i^{th} obstacle [17]

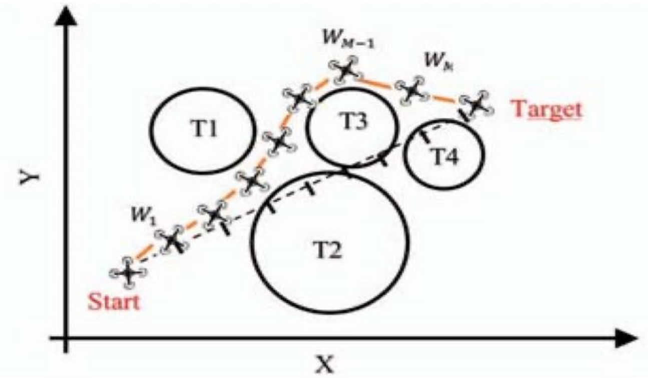

Figure 2- Path schema of UAV[17]

X. PROPOSED ALGORITHM

I. Waypoints on the trajectory are clear and can be expressed with a matrix. Waypoints are the points on the trajectory where the unmanned aerial vehicle will pass, and can be expressed as W=(w1,w2,…wn). Here it can be expressed as wi=(xi,yi,zi):

$$Trajectory = \begin{bmatrix} x1 & y1 & \cdots & z1 \\ \vdots & & \ddots & \vdots \\ xn & yn & \cdots & zn \end{bmatrix}$$

II. Danger zone coordinates are also given. Here di is the distance between the current position of the UAV and the ith obstacle:

$$danger\ zones = \begin{bmatrix} x1 & y1 & d1 \\ x2 & y2 & d2 \\ \cdots & \cdots & \cdots \\ xn & yn & dn \end{bmatrix}$$

III. By using the information (waypoints) in .I, trajectories consisting of Bezier curves are created. Here, II. Danger zone coordinates given with are also taken into account.

IV. The optimization problem given below is solved with the MBO algorithm.

$$\min F_{obj} = F_{lenght} + \lambda F_{obs}$$

Subject to:

$$g = \sqrt{(x_{uav} - x_{obs}^i)^2 + (y_{uav} - y_{obs}^i)^2} \le r_{obs}^i$$

V. Migrating Birds Optimization (MBO) Algorithm

MBO is a new nature inspired meta-heuristic approach based on the V flight formation of the migrating birds which is proven to be an effective formation in energy saving. Its performance is tested on quadratic assignment problem instances arising from a real life problem and very good results are obtained. The quality of the solutions are better than simulated annealing, tabu search, genetic algorithm, scatter search, particle swarm optimization, differential evolution and guided evolutionary simulated annealing approaches.[2] More details can be obtained from [2].

XI. NUMERICAL AND GRAPHICAL RESULTS

Figure 3 shows the applying the MBO algorithm to Bezier Curve Fitting problem. Until the required convergency is obtaines in each point, MBO algorithm continues. After completing the algorithm, optimal control points are produced.

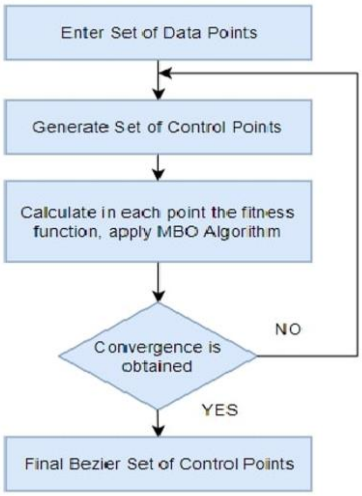

Figure 3-Bezier Curve Fitting Algorithm using MBO

In our study, 2D data points are used. A Java code is developed for the proposed model. Figure 4 shows the results of the proposed model in 2 dimensional spaces.

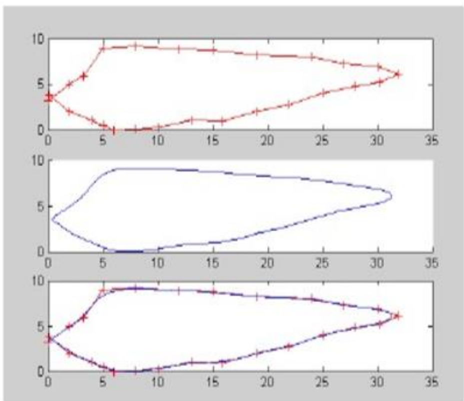

Figure 4: The result of Bezier Curve Fitting using MBO algorithm

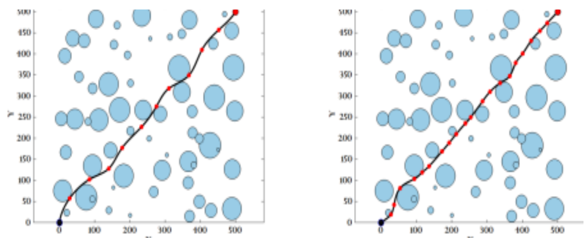

Figure 5- Path Planning under random obstacles[17]

The results obtained for PSO and MBO are presented in Table 1. In the simulation experiment, the starting and target points were taken the same. The number and arrangement of the waypoints are also the same. As a result, better results are obtained with MBO than PSO in all cases.

Table 1- Comparison of MBO and PSO—PSO=1.00 unit MBO=x*1.00 unit

PSO	MBO	Number of Obstacles
1.00	.0.95	20
1.25	1.11	30
1.32	1.28	40
1.53	1.32	50
2.45	2.09	100

XII. CONCLUSION AND FUTURE WORK

In this study, the path planning problem for unmanned aerial vehicles has been turned into a mathematical programming problem and numerical solutions have been realized with MBO and PSO algorithms. It has been seen that MBO gives better results than PSO in all cases.

The study has shown us that it is much more realistic to use software that will work online for unmanned aerial vehicles and will detect the environment well with sensitive sensors and create paths. Our goal in future studies is to realize this.

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