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Trajectory Optimization of Quadrotor-UAV Drone Using Genetic Algorithm

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Abstract
Unmanned Aerial Vehicles (UAVs) Technology recently attracts attention of many researchers; this is due to its numerous potentialities in civil application. One of the key areas of interest by researches is how to achieve a total talent of "Sense and Avoid" in the UAV which will enhance safe and efficient trajectory of the vehicle. This is why this paper is going to use an optimization technique to optimize trajectory path of the UAV flight. The chosen optimization algorithm is Genetic algorithm (GA) which is going to be use to optimize the trajectory of UAV by determine the shortest path of flight as well as obstacle-free path in order to save energy and time during flight. MATLAB and Simulink are used to simulate as well as evaluate the algorithm. In the result from the experiment, it appeared that an optimized trajectory path is tremendously better than path from the first randomly generated population in term of distance covered as well as time taken before triumph the target point from the initial point.
Keywords: Trajectory, Genetic Algorithm, optimization, AUV, Simulation

1. Introduction

Quadrotor (Quadcopter) is a multi-rotor helicopter that is lifted and propelled by four rotors. "Drone" is a general term used to describe any form of Unmanned Aerial Vehicle (UAV). As such "Quadcopter" is a term used to refer to a drone that is controlled by four rotors. Unmanned Aerial Vehicle, is self-pilot aircraft that is to say the its piloted by a remote control at a ground station. So also it flees autonomously based on pre-programmed flight [1].

According to Rojas *et al,* [2]"Many researches about the quad-rotor helicopters focus on the controller design field, but the trajectory optimization process specifically aiming at the quad-rotor helicopters, is scarce". Merely path planning process and trajectory planning process are similar but in good sense, the UAVs trajectory planning process and UAVs path planning process are differed. "The path planning is a process in which the UAV finds a three-dimensional (3D) space path from the starting point to the destination. The 3D space path is a static geometry path. It does not include the concept of time" [2]. in the case of trajectory process the time varying flying paths. This is what makes trajectory planning problem look more complicated than that of path planning problem. This is why a lot of effort by researchers was made to ensure optimal UAVs automatic control. Numerous optimization techniques could be used for optimization of the trajectory, such as A^* algorithm, Greedy algorithms as well as Genetic algorithm. The Genetic algorithms were firstly introduced by John Holland in the 1970s, to explain the feasibility of natural systems to be used in designing an artificial system that mimic the robust mechanism of natural systems [3]. Originally goal was not to develop algorithms to solve a designated problems, "but rather to study the phenomenon of adaptation as it occurs in nature and to develop ways in which the mechanisms of natural adaptation might be imported into computer systems" [3]. Ideally, the concept of G.A is based on Darwin theory of evolution's principles; it works on the search space called population. Each element in the population is term as chromosome. The chromosomes are initially randomly selected and evaluated for fitness and this fitness defines the quality of solution [4]. The trajectory of Quadrotor UAV appears in many cases some for surveillance, search, rescue missions and other security application and geographic studies. All these were within dynamic environment; this is why a need for optimizing the trajectory arises. In this work, some of the important point to actualized as follows: 1. An effective Quadrotor trajectory into the real dynamic and kinematic constraints 2. The power and time of flight need to be optimized. This research is trying to answer the following Question; How Genetic algorithm could be used to optimize the trajectory of Quadrotor Unmanned Ariel Vehicle?

2. Literature Review

The study illustrated the prospective optimization technique used in addressing optimization of trajectory path of UAV, the algorithm determines the nearest and obstacle free path. Though numerous algorithms could be used to achieve that such as: Dijkstra algorithm, Greedy algorithm and A^* algorithm. Dijkstra algorithm can be used to optimize a trajectory by generating an apt path node that would be test against the objective goal, but the only hitches is when it comes to larger scale problem. Likewise "A^* can find and near to optimal solutions more efficiently by directing search towards the goal by means of heuristic functions, reducing the time complexity substantially" [5].

2.1 AUV Trajectory planning

Trajectory planning is a major area in robotics, it defines the moving from point A to point B while

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avoiding collisions over time (Mohsen, 2016). It is sometimes referred to as motion planning and sometime wrongly refers it to path planning. Trajectory planning varied from path planning as it encompasses time as parameter. Ideally deals with how to move based on velocity, time, and kinematics. *The word derived for a* Latin word "*trajectoria"* meaning "throw across." The prefix "*tra"* is a short form of the" *trans"* which means "across" and the "*ject"* comes from the word "*jacere"*, meaning "throw". Whereas the jet's trajectory describes the If the path of a jet through the sky.

2.2 Genetic Algorithm

Genetic algorithm is search algorithm, which is worked by the principles of evolution by natural selection; it involves iterative search procedures based on an analogy of Darwin theory of evolution (Darwinism) and evolutionary genetics [6]. Ideally the GAs produces recombinants successor hypotheses by mutation operation and lastly recombines the best-known hypotheses. In the operation, the current inhabitants used to be replaced by progeny of and apt hypotheses in each iteration [7].

There are three main operators in genetic algorithms viz; are mutation, crossover and selection. All these targeted to obtain an apt solution. Each solution is prearranged in a sequence (most of the time binary or decimal) called ***chromosome*** [6]. New off-springs are generated by shifting the position of some of the genes of the chromosomes. Ideally the most fit chromosomes are of higher chance to move to next generation while the weaker once has less chance to moving to next generation. The idea is based on the principle on Darwin theory of evolution. This process repeats until the chromosomes have best fit solution to the given problem [8].

2.3 Quadrotor UAV

The quadrotor also known as quadcopter is a type of Unmanned Aerial Vehicles (UAVs) that has Vertical Take Off and Landing ability [9]. The maneuverability and versatility of quadcopter make it popular in nature. It has simple construction, good motor performance, this make it appropriate in civilian and military applications [10]. In terms of control of a quadrotor vehemently relies on its four rotors as shown in fig1. The attainment of direction control of flight depends on variation in term of rotation speed of one or more of its rotors, attainment of positive throttle and negative throttle depend on uniform speed up of the rotor speed of the entire four rotor (2) positive and negative yaw is due to adjustment of pair rotors clockwise or anti-clock (3) rolling of the Quadrotor depend on the verifying speed of two adjacent rotor.

3. Genetic Algorithms for Trajectory Planning

This section discusses the potential path planning algorithm together with genetic representation, chromosome decoding, the choice of fitness function and GA operators. The process starts from the initial point (A) to the target point (B) in 3-D coordinates. In a possible routes, along coordinates of X_1, Y_1, Z_1 up to X_{nth} ,Y_{nth}, Z_{nth}. The XYZ coordinates serve as an input parameter to the proposed genetic algorithm. At the end, the obtained output (fit sequence of coordinates) will be the solution (shortest path to travel).

Figure 3.1: Conceptual Framework

3.1 Genetic Representation

The Genetic Algorithm flowchart is shown in Figure 3.2. Where the possible routes travel by the quadrotor along XYZ coordinates are the inputs which initially generated randomly. Then eventually they will evaluate its fitness. By the use of formulated equation as it is going to be shown in Evaluation section.

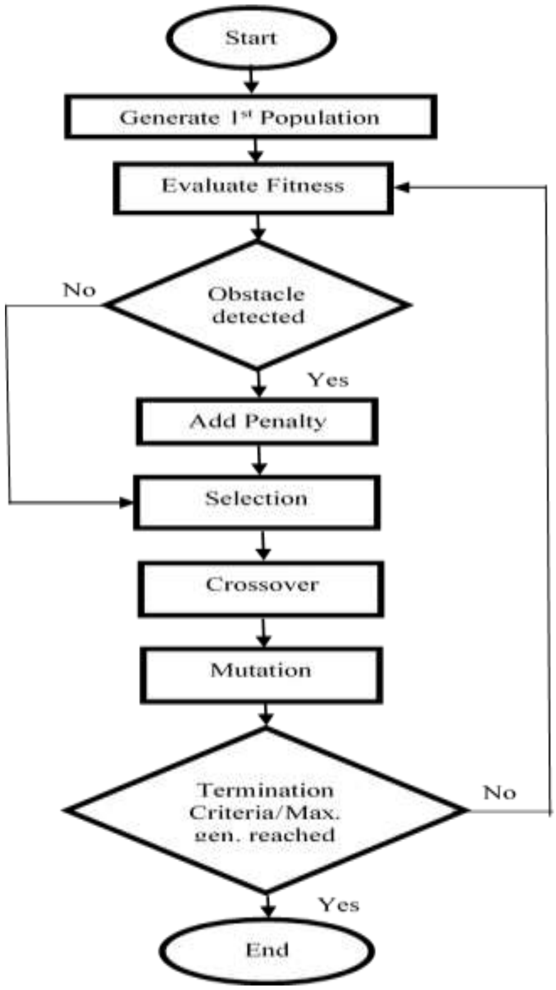

Figure3.2: GA flowchart

3.2 Chromosome Decoding

Given a sequence of the possible routes that quadrotor could travel along XYZ coordinates from an initial point (ip) to target point (tp), and then now it is necessary to generate a corresponding expected trajectory for the flight. Each possible route is decoded as chromosome as shows in Table 3.1.

Table 3.1: Initial Generation

Chrm	In. point	1st	2nd	3rd	4th	5th	6th	7th	target	distance
1	(0,6,0)	(0,4,0)	(0,6,3)	(2,6,1)	(1,5,6)	(4,1,6)	(2,6,0)	(5,3,9)	(9,6,10)	41.122
2	(0,6,0)	(3,7,5)	(0,7,2)	(4,7,2)	(8,9,2)	(5,2,3)	(6,5,5)	(8,9,6)	(9,6,10)	43.112
3	(0,6,0)	(4,5,6)	(0,3,7)	(7,3,5)	(4,3,4)	(5,3,5)	(6,6,4)	(9,9,6)	(9,6,10)	44.564
4	(0,6,0)	(7,6,3)	(5,4,3)	(7,2,6)	(6,3,10)	(7,6,10)	(7,6,5)	(5,7,1)	(9,6,10)	42.607

3.3 Fitness Function

The fitness function construes a chromosome and evaluates its fitness based on desired traits of the solution. The fitness function in the UAV trajectory evaluates the cost of a given path. This is defined as follows:

$$f(x) = \sum_{n=1} \sqrt{(x_{n+1} - x_n)^2 + (y_{n+1} - y_n)^2 + (z_{n+1} - z_n)^2 + p}$$

Where,
x, y and z are coordinates of possible routes n = total number of routes.
P is the Penalty function (If obstacle is detected) = 100

3.4 Genetic Operators

a. Selection

The selection operator is use to allow a chromosome of high-quality to get copied into the next generation.

Table 3.2: Selection

Chrm	In. point	1st	2nd	3rd	4th	5th	6th	7th	target	distance
1	(0,6,0)	(0,4,0)	(0,6,3)	(2,6,1)	(1,5,6)	(4,1,6)	(2,6,0)	(5,3,9)	(9,6,10)	41.122
2	(0,6,0)	(3,7,5)	(0,7,2)	(4,7,2)	(8,9,2)	(5,2,3)	(6,5,5)	(8,9,6)	(9,6,10)	43.112
3	(0,6,0)	(4,5,6)	(0,3,7)	(7,3,5)	(4,3,4)	(5,3,5)	(6,6,4)	(9,9,6)	(9,6,10)	44.564
4	(0,6,0)	(7,6,3)	(5,4,3)	(7,2,6)	(6,3,10)	(7,6,10)	(7,6,5)	(5,7,1)	(9,6,10)	42.607

b. Crossover

This mechanism is used to swap genes of two parent's chromosomes to form offspring. Table 3.3 shows the crossover of the generated population in Table 3.2

Table 3.3: Crossover

Chrm	In. point	1st	2nd	3rd	4th	5th	6th	7th	target	distance
1	(0,6,0)	(0,4,0)	(0,6,3)	(4,7,2)	(8,9,2)	(5,2,3)	(6,5,5)	(5,3,9)	(9,6,10)	40.122
2	(0,6,0)	(3,7,5)	(0,7,2)	(2,6,1)	(1,5,6)	(4,1,6)	(2,6,0)	(8,9,6)	(9,6,10)	45.112
3	(0,6,0)	(4,5,6)	(0,3,7)	(7,2,6)	(6,3,10)	(7,6,10)	(7,6,5)	(9,9,6)	(9,6,10)	43.564
4	(0,6,0)	(7,6,3)	(5,4,3)	(7,3,5)	(4,3,4)	(5,3,5)	(6,6,4)	(5,7,1)	(9,6,10)	41.607

c. Mutation

The population undergoes mutation by having alteration of allele of genes of some candidate chromosomes. In this study 0.2 mutation probability is going to be used by randomly alter the alleles. The process persists evaluation of fitness until the maximum number of generations exceeded. The Table 3.4 shows the chromosomes in the population after mutation occurred.

Table 3.4: Mutation

Chrm	In. point	1st	2nd	3rd	4th	5th	6th	7th	target	distance
1	(0,6,0)	(0,4,0)	(0,6,3)	(4,7,2)	(8,9,2)	(5,2,3)	(5,5,5)	(5,3,9)	(9,6,10)	40.022
2	(0,6,0)	(3,7,5)	(0,7,2)	(2,6,1)	(1,5,7)	(4,1,6)	(2,6,0)	(8,9,6)	(9,6,10)	44.112
3	(0,6,0)	(4,5,6)	(0,3,7)	(7,1,6)	(6,3,10)	(7,6,10)	(7,6,5)	(9,9,6)	(9,6,10)	42.564
4	(0,6,0)	(7,6,3)	(5,4,3)	(7,3,5)	(4,3,4)	(5,3,5)	(6,6,4)	(6,7,1)	(9,6,10)	40.607

4. Results and Discussions

MATLAB was used for simulation of the algorithm. A Random population was generated and assignation of Initial point and target point to each candidate chromosomes. Integer values were used to represent coordinates of possible routes for the quadrotor trajectory. The candidate chromosome inputs were process to generate the best possible solution. The boundary of 10x10x10 units in XYZ coordinates were adopted as dynamic environment. As it shown in Table3.1 randomly generated population were generated and at end 500 generations were evaluated and it capitulate that a candidate chromosome No. 1 has the shortest distance among the population of 500. The 3D plot of this chromosome was shown in Figure 4.1. The plot shows the route of that candidate chromosomes before been optimized.

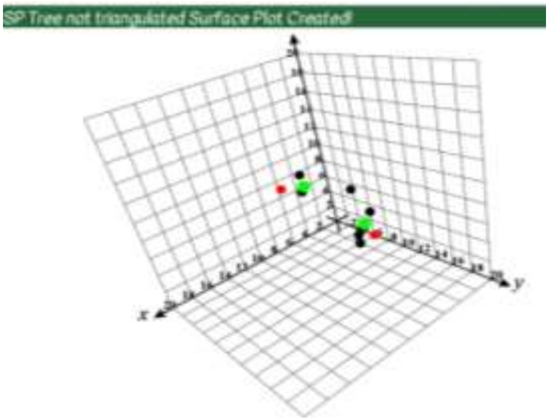

Figure 4.1: Trajectory graph

Looking at the plot above, it can be realized how inefficient the route was as its clumsy trajectory path uptight with some obstacles at (1, 2, 3) and (2, 3, 4) coordinate as indicated by different colors. Adopting the route as it was, there will be time consumption and wasteful energy in the trajectory.

Furthermore, Table 4.1 shows the fittest chromosomes after 500 generations while the plotted values were shown in the Figure 4.2.

Table 4.1: Chromosomes After 500 Generation

Chrm	In. point	1rt	2nd	3rd	4th	5th	6th	7th	target	distance
1	(0,6,0)	(0,3,0)	(0,7,2)	(1,1,1)	(2,0,2)	(5,0,6)	(6,0,7)	(4,0,4)	(9,6,10)	16.022
2	(0,6,0)	(0,3,0)	(0,7,2)	(1,1,1)	(2,0,2)	(5,0,6)	(6,0,7)	(4,0,4)	(9,6,10)	16.022
3	(0,6,0)	(0,3,0)	(0,7,2)	(1,1,1)	(2,0,2)	(5,0,6)	(6,0,7)	(4,0,4)	(9,6,10)	16.022
4	(0,6,0)	(0,3,0)	(0,7,2)	(1,1,1)	(2,0,2)	(5,0,6)	(6,0,7)	(4,0,4)	(9,6,10)	16.022

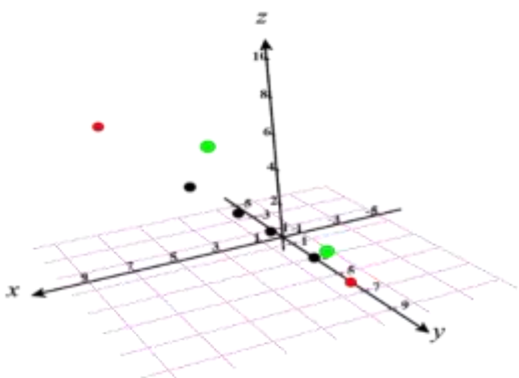

Figure 4.2: Plot of Fittest Chromosome After 500 Generations

From this Figure (4.2), it can be seen how the fittest trajectory path exhibited with obstacles avoidance, exhibiting a tremendous refinement of the trajectory before optimization.

5. Conclusions

In this work, an optimized genetic algorithm-based trajectory path was presented and the Simulation studies were performed with the aim of verifying the effectiveness of the proposed algorithm. The obtained, suggests that, the genetic algorithm is effective for the optimization. In addition, the route that quadrotor travel in order to minimize distance as well as energy was encouraging. Not only distance minimization, the algorithm put into cognizance how obstacles could be avoided by means of specified route at any point from the boundary. Also, the algorithm was able to perform searching for an optimal path among the possible trajectory routes in a given set of random points of possible route from initial to destination point.

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Appendix I

Listing1: GA pseudo code

Genetic Algorithm (GA) Psedocode
Algorithm: **GA** (n, f, m)
// Initialise generation by 0:
n: = 0;
pn: = a population of n randomly-generated individuals;
Compute fitness(i)
for each i ∈ Pn;
do {
// Create generation of p(n+1):
Select (1 − f) × k members of Pn, insert to Pn+1; // Copy
//Crossover
Select f × n members of Pn;
pair them up;
produce offspring;
insert the offspring into Pn+1;
//Mutate:
Select m × k members of Pn+1;
invert a randomly-selected bit in each;
// Evaluate Pk+1:
Compute fitness(i) for each i ∈ Pn;
n +=1; // Increment n
}
while fitness of fittest individual in Pn fitness reached;
return the fittest individual from Pn;