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Calculation Of The Optimum Number Of Unmanned Air Vehicles Required For Surveillance Missions

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Abstract

The aim of this study is to determine minimum quantity of unmanned aerial vehicles (UAVs) that should be used in an area where an aerial reconnaissance/observation activity will be carried out. In order to make this kind of calculation, firstly, the energy consumption of a UAV while flying with a constant speed was examined and then % energy level consumed by the UAV while passing each meter was obtained approximately. In this study, by considering the length of the trajectory which a UAV will navigate, required % energy level of a UAV to complete a single tour is calculated. If it is determined that one UAV can not complete its assigned trajectory, the number of UAVs are increased until each UAV complete its trajectory. In this study, the vehicle routing problem approach was used to calculate the UAV trajectories. Genetic algorithm method that is one of the metaheuristic optimization methods, was used obtain the solution of the vehicle routing problem (VRP). The developed algorithm has been run in Matlab environment. By changing the parameters of crossing rate and the population number in the genetic algorithm (GA) method, the lowest number of UAVs that is enough to carry out aerial observation over a target area and the shortest UAV trajectories were obtained. Results were presented in table form.

Keywords: unmanned aerial vehicles, vehicle routing problem, genetic algorithm

1. INTRODUCTION

Today, systems made with a single robot dominate robotic fields such as path planning and controller design. There are fewer studies on multiple robots and multi-target/task sharing [1]. Unmanned aerial vehicle (UAV) is an aircraft that can be controlled remotely [2]. With today's technology, unmanned aerial vehicles are widely preferred for many activities as stand-alone and robot clusters [3]. Unmanned aerial vehicles are used in many fields such as military, scientific research, imaging, fire fighting, camera shooting [4]. Vehicle routing problem (VRP) is based on calculating optimum routes that start from depots and include target waypoints [5, 6]. VRP has been used frequently in UAV trajectory planning in recent years [7, 8, 9].

In recent years, many studies have been carried out on VRP [10]. For example, a study was made to determine the shortest route for the waste collection truck in the city. In Matlab environment, ant colony optimization was developed and the shortest route was obtained [11]. In another study, a solution was sought with a genetic algorithm for the vehicle routing problem that emerged in line with the customer requests of the bread distribution company. The least costly route was determined [12]. In another study, the electric vehicle routing problem with time windows was discussed. A solution to the problem was sought with a combination of genetic algorithm and simulated annealing algorithms. It has been obtained that the developed algorithm gives better results than the genetic algorithm in terms of both optimum result and problem solving time [13].

In this study, the minimum number of unmanned aerial vehicles (UAVs) to be used in an area where aerial observation activity will be carried out is calculated with an approach based on UAV trajectory planning with VRP. A solution to the vehicle routing problem was sought in Matlab/Simulink environment with Genetic Algorithm (GA) [14, 15]. Genetic algorithm, which is a metaheuristic algorithm, has been used for many years to solve many engineering problems [16]. The genetic algorithm aims to give optimum results in less time. By changing the parameters of the genetic algorithm, the solution is prevented from repeating itself. The difference of this study from the studies in the literature is that it does not only include an algorithm that makes path planning, but is a study in which the required number of UAVs is determined with the method of genetic algorithms. Within the scope of the study, an algorithm that reaches the most accurate solution in the shortest time was developed by changing various parameters in the genetic algorithms method, and the optimum number

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of UAVs required for aerial observation in a region was determined.

By calculation of the optimum number of unmanned aerial vehicles required for observation activity in a region, the cost required for aerial observation activity can decrease, and control and tracking of unmanned vehicles will be easier. In addition, the number of personnel who will view the images to be transferred from unmanned vehicles will decrease in direct proportion to the decrease in the number of vehicles.

2. MATERIALS AND METHODS

2.1. Materials

In the experimental stages of this study, quadcopter type VTOL UAV was used. Figure 1 shows the UAV that was used in the experiments. The total weight of the UAV is 0.83 kg and the arm lengths of UAV are 22 cm from the body center to brushless DC motors. UAV has F450 type chassis, an external UBlox GPS+Compass module, an analog camera with transmitter. APM 2.6 was used as the flight control board of experimental UAV [17].

Figure 1. UAV that was used in experiments

Mission Planner program was used to monitor the flight data of the UAV used in this study. Mission Planner, an open source interface program, is widely used in the control of autonomous vehicles. It provides the instant location of unmanned vehicles on the world via Google Maps connection. In addition, the Mission Planner has been used to send some commands to unmanned vehicles via computer.

In order to make UAV that was used in this study fly about 5 minutes in windless weather conditions, a 2200 mAh, 11.1 Volt battery with a lithuim-polymer was preferred. The flight control card used in the UAV structure is the ArduPilot Mega 2.6. The control card includes barometer, accelerometer, 3-axis gyroscope.

2.2. Methods

In this study, first of all, the amount of energy consumed by a UAV per meter was obtained through experimental studies. Approximately the energy that a UAV will consume per meter while moving at a constant speed has been obtained. Then, it was determined what percentage of the energy level of the UAV's battery would be consumed by making a tour in its trajectory obtained by the VRP path planning algorithm. In experimental studies, the UAV was moved at a speed of 4 m/sec horizontally. There is a 2200 mAh battery placed on the UAV. It has been determined that a UAV with a 2200 mAh battery consumes approximately 0.38% of its battery in 1 second if it travels at the speed of 4 m/sec. In this case, it has been determined that a UAV consumes approximately 0.095% of its battery in order to move 1 meter horizontally. It has been concluded that the UAV can travel approximately 1052 meters. This value was taken as 1000 meters in the calculation of the number of UAVs.

Energy level that each UAV will consume as a result of completing a tour in its trajectory represents the navigation cost. If the energy level of a UAV battery is greater than its trajectory cost, it means that a single UAV is sufficient for aerial observation activity. However, if the energy capacity of the UAV is insufficient for its trajectory, it will not be able to complete its trajectory. In this case, the number of UAVs is increased by one and the VRP algorithm is run again. This process continues until the proper UAV quantity for the area that will be observed is obtained. If the energy capacity of each UAV is higher than its trajectory cost, it is determined that the number of UAVs is sufficient to perform the observation activity.

In this study, the minimum number of unmanned aerial vehicles sufficient to carry out observation activity in a specified area was calculated. For this, the UAV trajectories must be created in a balanced manner. There are studies in the literature on obtaining balanced trajectories. In the literature, there are two objective functions, the first MinSum and the second MinMax, to produce balanced trajectories. MinMax aims to minimize the longest one of the UAV trajectories. Minsum aims to make the total length of the trajectories as minimum [18].

In this study, a single objective function containing these two objective functions was created. The purpose function created is given in Equation 1.

$$\text{Totalcost} = a * \text{lng\_trj} + b * \text{sum\_trj} \quad (1)$$

In Eq 1, Totalcost is the objective function, lng_trj denotes the longest trajectory and sum_trj denotes the total length of the trajectories. Coefficients of a and b were determined as 10 and 4 respectivelly by experimantal process explained in Results section.

The solution of the VRP model used in this study was carried out with the GA method in Matlab environment. Since Matlab has a rich library, it is preferred in codding stage in this study. The reason for choosing the GA method is that its structure is simple and it has been successfully used in solving VRP in the literature. GA flow chart is shown in Figure 2 and shows the general procedure of GA and the main components of GA. The operation of the GA starts with determining an initial population randomly. The objective function is used to evaluate the members of the population. When all the members of the population have been evaluated, the lower rank chromosomes are removed and the remaining members are used for reproduction. In cross-over operation two members of the remaining population are randomly selected for gene exchange. The last step of GA procedure is mutation and the mutation operator randomly mutates on a gene of a chromosome.

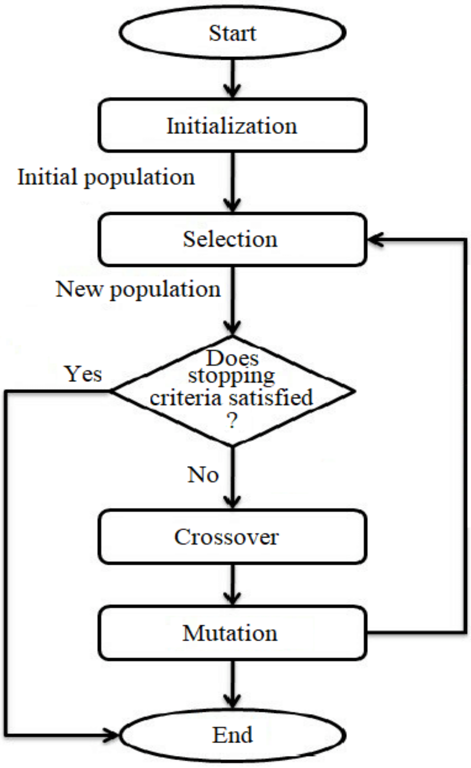

Figure 2. GA flow chart [19]

3. RESULTS

For the experiments in this study, 40x2 matrices containing the coordinates of the UAV visit points on the horizontal plane were produced in the Matlab environment. The randomly generated 40 visiting points are given in Figure 3. Tests were carried out by using 40 waypoints illustrated in Figure 3. In order to explain the contribution of the developed algorithm a sample test was illustrated by using 1,2,3,4,5 and 6 UAVs respectively for 40 waypoints. In Figure 4a, 2 UAV trajectories were given. In this situation, since the longest UAV trajectory was calculated as 1345 meters which is higher than UAV flight capacity, 2 UAVs are not enough to to carry out aerial observation over a target area. When the algorithm run with 3, 4 and 5 UAVs, it was observed that the longest UAV trajectory was calculated higher than UAV flight capacity. However, when 6 UAVs were used as shown in Figure 4b, the longest UAV trajectory was calculated as 939 meters which is lower than UAV flight capacity. This shows that the sample area can be observed by 6 UAVs at least.

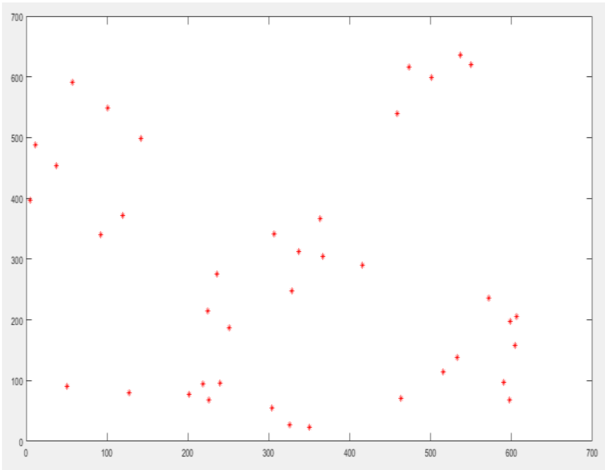

Figure 3. Randomly generated 40 waypoints

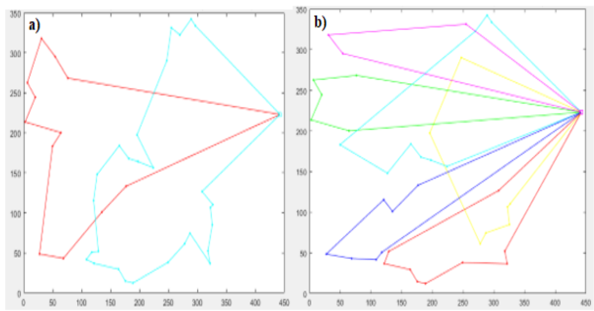

Figure 4. a) Trajectories for 2 UAVs b) Trajectories for 6 UAVs

In this study, the vehicle routing problem approach was used to calculate the UAV trajectories. By changing the parameters of crossing rate and the population number in the genetic algorithm (GA) method, the lowest number of UAVs that is enough to carry out aerial observation over a target area and the shortest UAV trajectories were obtained. Results were obtained by Tests that were carried out by using 40 waypoints illustrated in Figure 3 and as given in Table 1.

Table 1. Experiment table for 40 waypoints

Population size	Crossover rate	Iteration number	Longest trajectory length	Total length of all trajectories	UAV quantity
16	pmx(0.1)	4 438	955	4 490	5
16	pmx(0.5)	5 147	975	4 223	5
16	pmx(0.9)	4 437	954	5 179	6
48	pmx(0.1)	2 919	951.69	5 038.32	6
48	pmx(0.5)	3 719	994.05	4 675.54	5
48	pmx(0.9)	4 740	946.72	4 449.77	5
80	pmx(0.1)	1 044	972.10	4 537.58	5
80	pmx(0.5)	1 704	975.43	4 583.88	5
80	pmx(0.9)	3 890	985.71	4 261.95	5

4. DISCUSSION AND CONCLUSION

In literature there are lots of VRP approaches used in UAV routing [20]. Main subjects discussed in UAV based VRP studies can be grouped as: minimizing the sum of travel time among waypoints, minimizing the required UAV number and minimizing the total travel time of UAVs. The differences of this study from other studies in literature are including experimental data of battery consumption and including changing crossover ratio and population size parameters of GA procedure. It can be said that this study has a new approach within UAV based VRP studies.

In this study, an approach based on genetic algorithm method has been developed in Matlab environment to calculate the optimum number of drones required for air observation activities. In order to calculate the optimum number of UAVs, it is primarily aimed to create balanced orbits for UAVs. The closed-end vehicle routing problem is used to calculate the UAV trajectories. UAV trajectories start from the designated warehouse to carry out their activities and end in the same depot.

A solution to the scenario VRP was sought with a genetic algorithm. Partial planned crossover was chosen for crossover, which is one of the genetic algorithm parameters. In this study, the partial planned crossing rate was determined as 0.1, 0.5, 0.9 randomly. For the population size parameter, 16, 48 and 80 values were determined randomly. In this study, elitism method was used as the selection criteria. In this study, by changing the crossover ratio and population size input parameters, GA and closed-end VRP were solved and exit parameters such as number of iterations, total orbit length, longest orbit length and required number of UAVs were obtained.

The results of the experiments performed in Table 1, by selecting the coefficient a 10 in Equation 1, coefficient b 4, population size 16, 48, 80, and pmx crossing rate 0.1, 0.5, 0.9 and the number of visiting points 40, respectively, are as follows.

- It was determined that the number of iterations decreased while the population number was increasing and the crossing rate was constant. As a result, it has been determined that the number of populations should be increased if the solution time is an important criterion in the scenario problem.
- While the population number is increasing and the crossing rate is constant, it has been determined that there is not a regular increase or decrease in the length of the longest trajectory.
- While the population number is increasing and the crossing rate is constant, it has been determined that there is not a regular increase or decrease in the total orbit length.
- While the population number was increasing and the crossing rate was constant, it was determined that there is not a regular increase or decrease in the calculated number of UAVs.
- It was determined that there is not a regular increase or decrease in the number of iterations when the population number was constant and the crossing rate was increasing.
- It was found that there is not a regular increase or decrease in the longest orbit length when the population number was constant and the crossing rate was increasing.
- When the population number is constant and the crossing rate is increasing, it has been determined that there is not a regular increase or decrease in the total orbit length.
- When the population number was constant and the crossing rate was increasing, it was determined that there is not a regular increase or decrease in the calculated number of UAVs.

In this study, the optimum number of unmanned aerial vehicles required in a region for observation activity was calculated. As a result of the calculation of the optimum number of unmanned aerial vehicles, the cost required for observation activities in a region will be reduced and the control and tracking of unmanned vehicles will be easier. Since the number of vehicles is determined in the minimum number required, the number of personnel who will watch the images to be transferred from unmanned vehicles will be the least, which will reduce the cost.

Considering the changes caused by different parameter values in the results of the genetic algorithms method used in this study, it is possible that changing the selection criteria and testing various mutation operators will cause changes in the output parameters.

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