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Analysis of Evolutional Algorithms for and their Integration to Unmanned Aerial Vehicles

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Abstract:

The article discusses the basic concepts of a genetic algorithm and its components. Processes such as crossover selection and mutation are considered. In addition, a review of the works of scientists is provided, where the capabilities of genetic algorithms are actively used. The article discusses works that study image clustering using a genetic algorithm and the application of genetic algorithms to solve the problem of aircraft arrival scheduling in systems with multiple runways. The types of military unmanned aerial vehicles are also given and the advantages of using genetic algorithms in them are discussed.

Keywords: *Genetic algorithm, crossover, selection, mutation, chromosome, individual, population, unmanned aerial vehicles.*

1. Introduction

Research in the field of information and communication technologies is carried out all over the world, and the entire field is developing at a rapid pace due to this. It is no secret that in all countries all advanced technologies and knowledge are primarily introduced into the military field, since ensuring the security and integrity of the country is a priority. Based on the above, modern information technology is also no exception, and as a developing field, artificial intelligence has begun to be actively used in all areas of military defense around the world. The field of artificial intelligence itself is a fairly large area and includes many areas. Such as machine learning, deep learning, neural networks, genetic algorithms, etc. Scientists from all over the world are actively studying and developing new types of algorithms to improve the performance of artificial intelligence. In this article we will analyze the operation of a genetic algorithm and review existing algorithms, as well as their application in real problems.

Genetic algorithm is a searching method based on Darwin's theory of evolution that has gained enormous popularity around the world in recent years. In recent years, the international scientific community has shown growing interest in a new searching technique based on the theory of evolution, known as a genetic algorithm. This method is based on nature's selection mechanisms, according to which the fittest individuals in a population are those that survive by more easily adapting to changes occurring in their environment. Today we know that these changes occur in an individual's genes (the basic unit of codification of each of the characteristics of a living being) and that its most desirable traits (i.e., those that allow it to better adapt to its environment) are passed on to their descendants through crossover. University of Michigan researcher John Holland recognized the importance of natural selection and, in the late 1960s, developed a technique that allowed it to be included in the program. His goal was to make computers learn on their own. The technique Holland invented was originally called "reproductive plans" but became popular under the name "genetic algorithm" after the publication of his book in 1975 [1].

A fairly complete definition of a genetic algorithm is offered by John Koza: “It is a highly parallel mathematical algorithm that transforms a set of individual mathematical objects with respect to time using operations modeled after the Darwinian principle of reproduction and survival, each of these mathematical objects usually representing a string of characters (letters or numbers) of a fixed length, which corresponds to the model of chromosome chains, and they are associated with a certain mathematical function reflecting their fitness" [1].

Advantages of Genetic Algorithm. The algorithm is as follows:

- Optimization using continuous or discrete variables,
- Does not require derived information,
- Simultaneous search of an extensive sample on the cost surface,
- Given the large number of variables,
- Suitable for parallel computers,
- Optimization of variable surfaces with very complex costs (GA can jump from a local minimum),
- Provide a list of optimal variables, not just one solution,
- Can encode variables so that optimization is done by encoding variables,
- Works with generated numerical data, experimental data or analytical functions.

A genetic algorithm starts from a set of randomly generated solutions called populations. While each individual in the population is called a chromosome, which is a representation of the solution, and the fitness level of each is assessed using a predetermined function. Through the process of natural selection of genetic operators, the genes of the two chromosomes (called the parents) are expected to produce new chromosomes with higher levels of fitness as the next generation or offspring. Chromosomes will have an iteration called generation. In each generation, the chromosomes are evaluated according to the value of the fitness function. After several generations, the genetic algorithm will converge to the best chromosome, which is the optimal solution.

2. Population in genetic algorithm

In a genetic algorithm, the initial solution is called the initial population, and usually the population is generated randomly according to certain constraints. A population can be divided into independent individuals, also known as chromosomes, which is one solution to the problem, and all individuals constitute the space of understanding. Individuals are usually represented by code strings consisting of binary character sets {0, 1}, a set of individuals representing a population (Fig. 1.), which are used to describe various parameters in practical problems. In the iterative process of the algorithm, the evolution of each generation is called heredity. The genetic process consists of three operation operators, namely: selection operator, crossover operator and mutation operator. In addition, positives and negatives sides of an individual in the genetic process are assessed by fitness, and fitness is calculated by the adaptive function for each member of the population. The higher the individual's fitness, the closer the solution he presents to the optimal one, the higher the probability of being selected into the next generation. The probability of exclusion is greater, which is consistent with the idea of “survival of the fittest” in the theory of evolution [2].

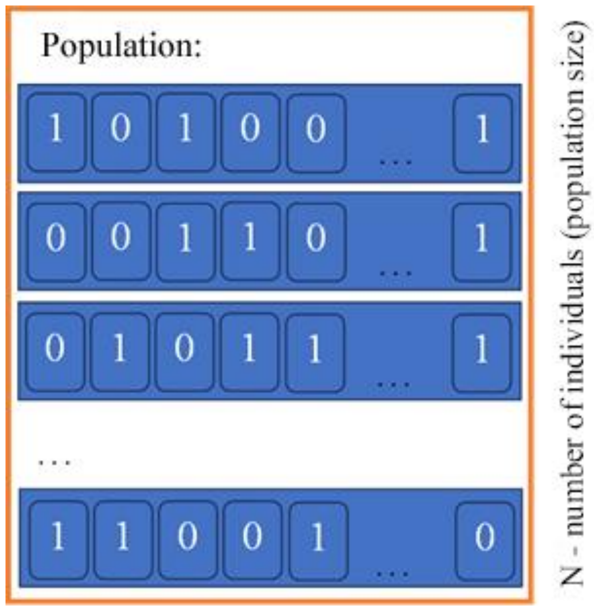

Figure 1. Population of individuals.

A genetic algorithm mainly consists of the following five steps: population initialization, fitness value estimation, selection, crossing and mutation [3].

- Selection is the random process of selecting a parent chromosome from a population based on the fitness value of each chromosome [4]. The selection process through tournament is more efficient than other selection methods and leads to optimal decisions [4]. Before the tournament selection process begins, the number of participants must be determined. Tournament selection then randomly selects a candidate from the population. The winner of the tournament is the chromosome with the highest fitness value. This selection process is repeated until 2 chromosomes are selected as the parent pair.

- Crossover is the process of combining the chromosomes of the parents to produce a new individual. Method - Uniform Crossover. This method defines a binary zero and one when the locus mask is 1, the first source has the same gene composition as the first parent, the second source has the same gene composition as the second parent. If the locus mask has a value of 0, the first source has the second parental gene compositions, and the second source has the first gene compositions [4].

- Mutation is a genetic operator used to maintain genetic diversity from one generation of a genetic algorithm chromosome population to the next generation. The mutation method used in this paper is random mutation. In random mutation, the mutated gene is determined by the mutation rate, and the mutated gene is selected randomly [5].

In the work of the authors Gevin Valerian, Tri Sutrisno and Dyah Erny Herwindiat [2]. The authors of the study were testing a genetic algorithm with tournament selection and uniform crossover for clustering complex images. The authors argue that a genetic algorithm can be used to find the optimal centroid for image clustering (Fig. 2). The study used images of the beach, city, traditional market images and garden images. Based on the research results, genetic algorithm with tournament selection and uniform crossover can be used to cluster images, but there is some outlier in the generated cluster. Based on testing, the best parameters for image clustering using genetic algorithm with tournament selection and uniform crossover are population = 200, iteration = 200 and number of clusters = 2. The fitness value of the genetic algorithm increases when the population and iteration value are higher. The result of this study can be used as a guide when developing image clustering.

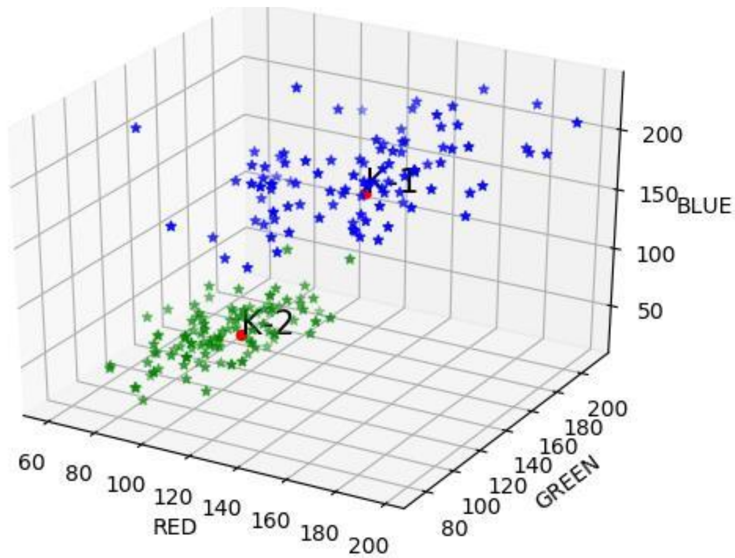

Figure 2. Three-dimensional plot of the formed cluster and the centroid between the beach and the garden.

Xiao-Bing Hu and Ezequiel Di Paolo conducted research and calculations on the efficient operation of uniform crossover genetic algorithms for air traffic control. In the study, the authors found that the sequencing and scheduling of aircraft arrivals is a major problem in the daily operations of air traffic control authorities. The paper reports the application of genetic algorithms to solve the ASS problem in multi-runway systems. Most existing genetic algorithms for aircraft arrival scheduling face feasibility and efficiency issues when developing their evolutionary operators, especially crossover. The new genetic algorithm described by author uses the following relationship between planes to construct chromosomes. The main advantage of the proposed by author universal crossover operator is efficiency and effectiveness in identifying, inheriting, and protecting common subtraffic sequences without compromising the ability to diversify chromosomes, as demonstrated in an extensive comparative modelling study. By adopting a receding horizon control strategy, the described genetic algorithm shows good real-time implementation potential for solving the aircraft arrival scheduling problem [6].

3. Genetic algorithms in unmanned aerial vehicle

In [7], the author develops a genetic algorithm for planning the trajectory of UAVs in a dynamic environment. The author first of all generated an initial set of path genotype strings randomly, and the elements of this set are chromosomes of variable length. The vehicle trajectory is modelled as a sequence of speed and heading changes occurring at discrete times, and the model specifically contains vehicle dynamic constraints when generating trial solutions. Subsequently, a new set of pathway genotype rows will be generated through genetic operations, some of which will replace the previous rows based on fitness selection. This process is repeated until some predefined stopping criteria are met.

Also, using the developed model, the author calculates the cost of the path length. The path length cost is used by the planner to discover shorter paths. The first and most obvious option is to try to limit the number of points along the path. More precisely, we can try to minimize J_{length}, which can be expressed as:

$$J_{length} = \sum_{k=0}^{n^j-1} u_k(t_{k+1} - t_k)$$

Where $\mathbf{u_k}$ is the speed of the UAV from time $\mathbf{t_k}$ to $\mathbf{t_{k+1}}$. $\mathbf{N^j}$ is the number of sampling intervals [7].

Based on the above, it should be noted that the use of genetic algorithms is feasible and, one might say, necessary in all areas of human activity. In particular, the introduction of artificial intelligence systems in combination with genetic algorithms in military aviation will allow unmanned aerial vehicles (UAVs) to improve as intelligent autonomous control systems. Naturally, in order for unmanned aerial vehicles to become autonomous, it is necessary to develop a genetic algorithm and then populations of individuals will be modeled on its basis. In this case, each individual has a corresponding chromosome. In our case, by individual we mean an unmanned aerial vehicle. When simulating real-life conditions for an unmanned aerial vehicle, with the development of a population of individuals, the intelligent system of the aircraft will be able to learn from scratch to autonomous control of the vehicle, taking into account various external conditions. Such as taking off in various weather conditions, as well as landing the aircraft and evading possible air attacks. While flying from point A to point B, unmanned aerial vehicles based on artificial intelligence must independently reach the target and complete assigned tasks. The advantage of evolutionary algorithms is that the process of system evolution can be carried out in a short time without significant expenditure on technology.

Unmanned aerial vehicles come in many different types, but military types are the focus. In the work of Rostopchin V.V. strike unmanned aerial vehicles (UAVs) and air defense are described in detail [8]. UAVs are a very dynamically developing class of unmanned aerial vehicles and, based on the history of their development, the following classification of attack unmanned aerial systems (UAS) can be applied according to the frequency of use and the principles for implementing the functional purpose of the UAV, which is shown in Figure 3 [8].

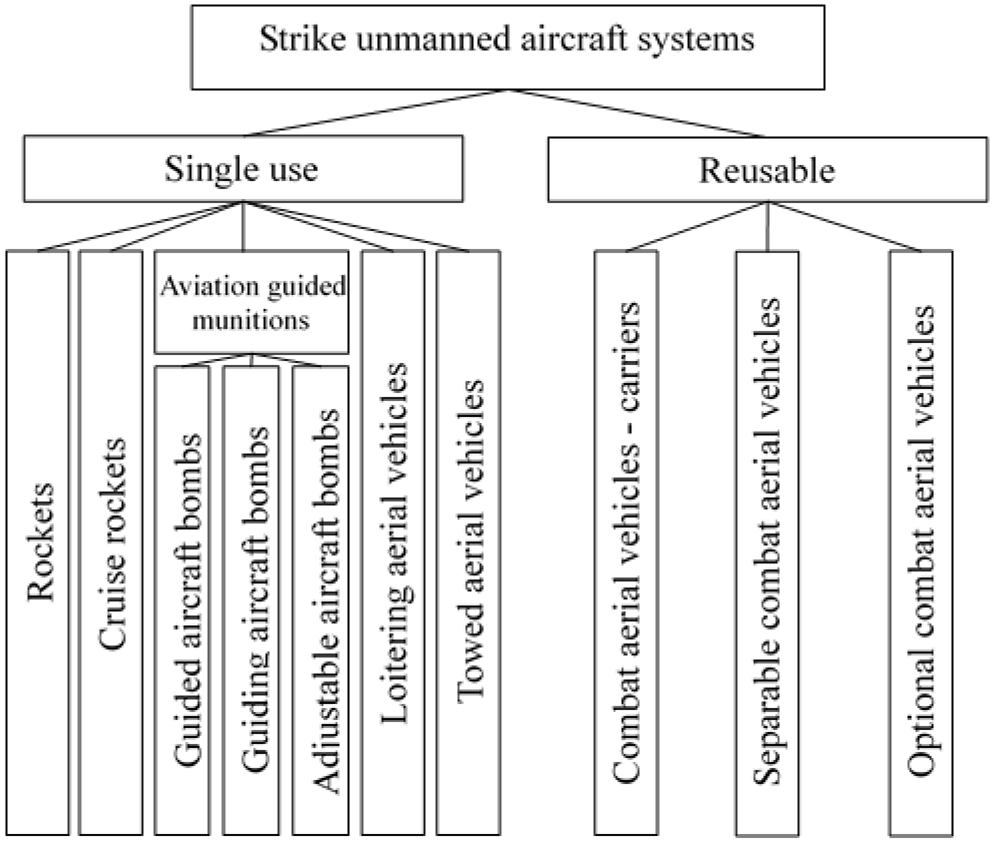

Figure 3. Modern classification of strike unmanned aerial vehicles [8]

There are many varieties of genetic algorithms developed to this day that are focused on solving specific problems. Below are a few of them:

1. Simple Genetic Algorithm (SGA). Description: The basic form of a genetic algorithm consisting of selection, crossover and mutation operators.
2. Stationary genetic algorithm. Description: Instead of replacing the entire population, only a few individuals are replaced in each generation [9].
3. Elite genetic algorithm. Description: ensures that the best individuals pass on to the next generation unchanged [10].
4. Parallel genetic algorithm. Description: several subpopulations develop in parallel, often periodically changing individuals [11].
5. Distributed genetic algorithm. Description: Similar to parallel GAs, but subpopulations evolve independently over longer periods of time before exchanging individuals [12].

Each of the above algorithms is designed for specific tasks. Depending on the task at hand, each of the algorithms has its own advantages and disadvantages. In particular, stationary genetic algorithm is more suitable for UAVs due to the reason that this algorithm can provide better solutions for dynamic or real-time applications. Since the algorithm does not change the entire population, but replaces only a few individuals and this increases the speed of work.

Conclusion

To summarize, genetic algorithms are the most effective for identifying the best solution in real-life problems. Since genetic algorithms make it possible to carry out processes of evolution and learning that take a long time in a short period of time by training programs or robots by trial and error.

The study and application of genetic algorithms in various fields, including military aviation, demonstrate significant potential for improving the efficiency and autonomy of control systems. Genetic algorithm, based on the principles of natural selection and evolution, provides powerful tools for optimizing and solving complex problems.

The example of unmanned aerial vehicles (UAVs) shows how the introduction of artificial intelligence systems, in combination with genetic algorithms, can contribute to the development of autonomous control systems capable of adapting to various external conditions. Genetic algorithms have been shown to significantly improve the capabilities of UAVs in tasks such as taking off and landing in various weather conditions, evading air attacks, and navigating complex routes.

In conclusion, genetic algorithms represent an important tool in the arsenal of artificial intelligence techniques that can significantly improve autonomous systems, including in military aviation. Further research and development in this area will help create more advanced and adaptive systems, which will ultimately improve the efficiency and safety of performing tasks in a variety of conditions.

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