THE APPLICATION OF ASEXUAL DNA ALGORITHM TO AIRFOIL DESIGN

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Abstract

With the development of genetic engineering, many kinds of algorithms based on it have been applied to engineering design fields. Among those, Genetic algorithms are based on Darwin's Naturalistic evolutionism of which the main idea is natural selection and survival of the fittest, and Genetic algorithms simulate the evolutionary mechanism of sexual reproduction. Since Genetic algorithms have global convergence and wide feasibility, they have been applied maturely to aerodynamic design. Whereas, in the practical use of Genetic algorithms, there are problems such as they are incapable of representing the bidirectional evolution and the effects of mutation and crossover are not equal. In order to solve the problems, in this paper, an Asexual DNA (Deoxyribonucleic Acid) algorithm, which simulates the evolutionary mechanism of asexual reproduction, is applied to airfoil design. Compared with Genetic algorithms, Asexual DNA algorithm has faster global convergence and better optimal effect.

1 Introduction

In the last few decades, with the development of gene engineering, many kinds of methods handling DNA (Deoxyribonucleic Acid) have been built. The field of DNA computing in its present form started with Adleman's celebrated experiment, which solved a Hamiltonian Path Problem. Lipton demonstrated DNA computing could be applied to the satisfiability problem [1,2]. So far, research on DNA has involved in many fields, and through the simulation of heredity behavior and the process of evolution, many important research and application fields have been set up. Genetic algorithms, an example of evolution algorithms, are based on Darwin's Naturalistic evolutionism of which the main idea is natural selection and survival of the fittest, and simulate the evolutionary mechanism of sexual reproduction. Since Genetic algorithms have global convergence, robustness, excellent implicit parallelism and mathematic simplicity, they have been applied maturely to many kinds of design problems and pattern recognition problems.

Furthermore, by Genetic algorithms, the search for the optimal solution is executed by the mutation and crossover of individuals in form of chromosome to generate new individuals. The biology chromosome is a part of double helix DNA strands. So, Genetic algorithms adapt well to DNA computing [2].

For aerodynamic design, the application of optimization algorithms combined with CFD (Computational Fluid Dynamics) codes has improved the design efficiency a lot. Whereas, since the complexity and high nonlinearity of aerodynamic design, more and more attention has turned from traditional deterministic optimization algorithms such as gradient and second derivative methods to stochastic global algorithms such as Genetic algorithms. Consequentially, there are many satisfied aerodynamic shapes obtained by Genetic algorithms [3].

However, in the practical use of Genetic algorithms there are many problems. From the view of biology evolution, the process is from the simple to the complex and from the low level to the high. The characteristics of such bidirectional evolution process are complexity and diversity. Genetic algorithms are incapable of representing such bidirectional evolution and the mutation operator is just a minor fact of evolution [4,5]. Consequentially, for Genetic algorithms, the global search ability is not equal to the local.

Genetic algorithms focus on simulating the evolutionary mechanism of sexual reproduction while many kinds of natural reproduction are asexual. Although the asexual reproduction is unlike the recombination of sexual reproduction, as the basis of biology multiplication, it includes such basic biologic properties as heredity and mutation. In order to solve the problems appeared in the practical application of Genetic algorithms, in this paper, an Asexual DNA algorithm, which simulates the evolutionary mechanism of asexual reproduction and represents bidirectional evolution process [4,5], is applied to airfoil design. Compared with Genetic algorithms, Asexual DNA algorithm has faster global convergence and better optimal effect.

2 Biology Background

Cell is the smallest structural unit of an organism that is capable of independent functioning, consisting of one or more nuclei, cytoplasm, and various organelles, all surrounded by a semipermeable cell membrane. Cells contain the body's hereditary material and can make copies of themselves. In the nucleus of each cell, there are thread-like structures called chromosomes, which contain all the inheritance information. Each chromosome is made up of DNA tightly coiled many times around proteins called histones that support its structure. A chromosome is a singular piece of DNA, which contains many genes, regulatory elements and other nucleotide sequences. Chromosomes also contain DNA-bound proteins, which serve to package the DNA and control its functions [6~8].

DNA is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms and some viruses. The main role of DNA molecules is the long-term storage of information. The DNA segments that carry this genetic information are called genes, but other DNA sequences have structural purposes, or are involved in regulating the use of this genetic information. Chemically, DNA is a long polymer of simple units called nucleotides, with a backbone made of sugars and phosphate groups joined by ester bonds. Attached to each sugar is one of four types of molecules called bases. The information in DNA is stored as a code made up of these four chemical bases: adenine (A), guanine (G), cytosine (C), and thymine (T). This information is read using the genetic code, which specifies the sequence of the amino acids within proteins. The code is read by copying stretches of DNA into the related nucleic acid RNA, in a process called transcription. DNA bases pair up with each other, A with T and C with G, to form units called base pairs. Each base is also attached to a sugar molecule and a phosphate molecule. Together, a base, sugar, and phosphate are called a nucleotide. Nucleotides are arranged in two long strands that form a spiral called a double helix. The structure of the double helix is somewhat like a ladder, with the base pairs forming the ladder's rungs and the sugar and phosphate molecules forming the vertical sidepieces of the ladder [6~8].

An important property of DNA is that it can replicate, or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell [6~8].

When sexual reproduction happens, two chromosomes are recombined through cross. While when asexual reproduction happens, the DNA is copied by cell division. In addition, during cell reproduction, though the probability is little, some accident may happen to mutate the DNA and generate new chromosomes. These chromosomes represent new character. So, during the heredity process, heredity genes or chromosomes are changing for various reasons [6~8].

3 Genetic Algorithms

Genetic algorithms first formalized as an optimization method by Holland, are search tools modeled after the genetic evolution of natural species. Genetic algorithms utilize an iterative approach to problem solving. A Genetic algorithms consist of a group, called a population, of individuals, where each individual is a finite string of symbols encoding a possible solution in a given design space. The optimum process of Genetic algorithms is as follows: an initial population of individuals is generated at random. In each generation the individuals are decoded and evaluated according to some predefined fitness function. To form a new population, individuals are selected according to their fitness (so good solutions have a better chance of continuing than poor solutions) and then "mated" with other individuals via a crossover operation to generate children. The crossover operator tends to enable the process to move toward promising regions of the search space. After crossover, a mutation is performed where a small number of bits are randomly changed. The mutation operator is used to prevent premature convergence to local optima [7~10]. The architecture of Genetic algorithms is showed in fig.1.

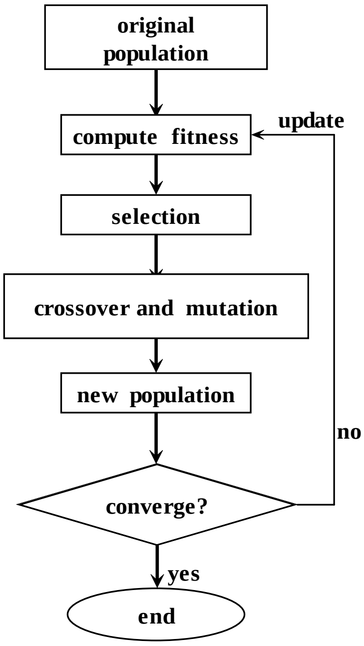

Fig. 1 Architecture of Genetic Algorithms

Genetic algorithms basically involves five components: a chromosomal representation of solution, an evaluation function mimicking the role of the environment, rating solutions in terms of their current fitness, genetic operators that alter the composition of children during reproduction and values of the algorithmic parameters (population size, probabilities of applying genetic operators etc) [7~10].

Standard Genetic algorithm is a typical scheme among the Genetic algorithms. SGA implements the evolution of population through the operations of reproduction, crossover and mutation based on binary encoding and decoding. In this paper, the selection strategy is the elitist strategy based on the roulette wheel selection, the one-point crossover is taken as the crossover operator and the one-point mutation is adopted as mutation operator.

4 Asexual DNA Algorithm

There are many kinds of biology of which the reproduction are asexual in the nature, such as protozoa, bacteria and many plants. The reproduction base of these biology is cell division. The essential character of cell division is that the hereditary material in the cell (DNA molecules) can be replicated.

Genetic algorithms focus on simulating the evolutionary mechanism of sexual reproduction while Asexual DNA algorithm simulates the reproduction, mutation and natural evolution progress of asexual biology. It introduces a division operator that simulates the self-inheritance of asexual cells, instead of crossover operator that simulate the inheritance of sexual cells in Genetic algorithms. Since the division can help to reproduce congener individuals, it could be regarded as a kind of extended replication operators, which cannot change the germ plasm of the individual but can change the phenotype. Therefore, the division provides the individual a non-mutation adaptive ability from heredity [4,5].

Furthermore, the evolution among different congener individuals is implemented by mutation operator. The iterative search progress of Asexual DNA algorithm includes division, horizontal selection, mutation, and vertical selection. The division and the horizontal selection compose horizontal evolution while the mutation and the vertical selection compose vertical evolution. The horizontal evolution and the vertical evolution implement alternately to make individuals progress [4,5]. The architecture of Asexual DNA algorithm is showed in fig.2.

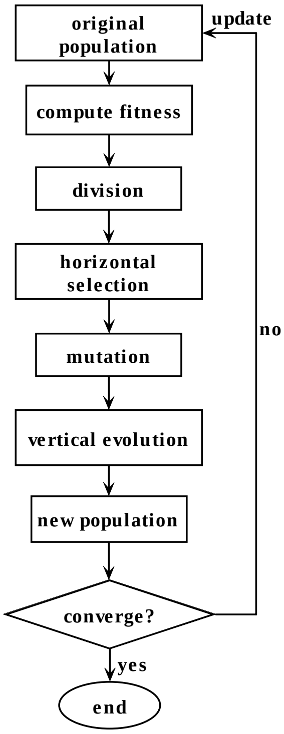

Fig. 2 Architecture of Asexual DNA Algorithm

After division, the division set of individual DNA single strand is obtained. The division set includes the DNA single strand, the complementary strand and their reverse strands. For binary coding, 0 and 1 are complementary while for DNA molecule, the complementary strand should be reverse. For example, the division set of an individual DNA single strand coding as 001101, is {001101， 101100， 110010，010011}. After mutation, the mutation set of individual’s DNA single strand is obtained. The mutation set includes the DNA single strand and the transfer region no more than once mutation [4,5].

The principle and the architecture of the algorithm show that there is a complementary relation between mutation and division and the effects of them are equal. There is horizontal selection after division and vertical selection after mutation, which makes individuals bidirectional evolved. The selection is limited in specified individuals, so the algorithm is suitable for parallel or distributed computation and is hard to prematurely converge. Furthermore, the convergence of Asexual DNA algorithm need not depend on the size of population and so the size could be small, even 1[5].

5 Function Test

In this paper, for test the perform of Asexual DNA algorithm, Genetic algorithms and Asexual DNA algorithm mentioned above are applied to optimize a function. The convergence strategies of two algorithms are both the maximum generation limited to 100. The chromosomal representation of solution is based on binary encoding and decoding. The population size of Asexual DNA algorithm is 1 while those of Genetic algorithms are 34 and 100. For Genetic algorithms, the probability of one-point crossover is 0.8 and the probability of one-point mutation is 0.1.

The optimal problem is:

$$\begin{aligned} \min: \quad & f = x_1^2 + 2x_2^2 - 0.3\cos 3\pi x_1 \\ & \quad - 0.4\cos 4\pi x_2 + 0.7 \\ & -100 \le x_{1,2} \le 100 \end{aligned} \tag{1}$$

This is a multipolar function. The optimal solution is $f(0,0)=0$. Fig.3 shows the optimization progress where ADNA refers to Asexual DNA algorithm while GA1 and GA2 refer to Genetic algorithms with different population size 34 and 100. Table.1 shows the call number of fitness computing and the generation number at which the optimal solution is obtained. Compared with Genetic algorithms, Asexual DNA algorithm has better global search ability, faster convergence.

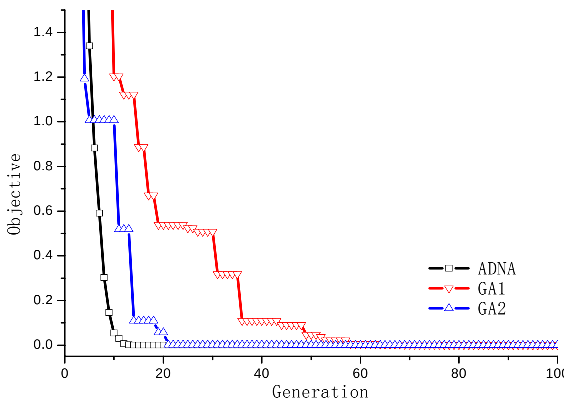

Fig.3 Progress of Function Optimization

Algorithm	ADNA	GA1	GA2
Number of calls	3400	3400	10000
Generation	14	95	45

Table.1 Performance of Algorithms

6 Airfoil Design

There are three basic factors of optimization model: design variables, objective functions and constrains. For airfoil design, after define the design condition, generally the aerodynamic coefficients which represent the lift, drag or moment feature are chosen to be objective functions, the thickness of the airfoil and etc are chosen to be constrains, and parameters which describe the airfoil shape are chosen to be design variables. Airfoils have been represented in many different ways such as analytical representations using few functions or airfoil shape fitting using Bezier curves, B-spline, NURBS, etc [11,12].

6.1 Optimization Model

The initial airfoil shape is a supercritical airfoil. The parameterization method for the airfoil shape is based on Hicks-Henne functions. There are 14 design variables including 7 variables define the thickness distribution and the other 7 variables define the camber distribution. The objective function is maximizing the lift-to-drag ratio at the flow speed Mach number of 0.8, angle of attack of $2°$ and Reynolds number of 30 million. The aerodynamic analysis is N-S equations solver. The constrains are that the lift coefficient cannot less than 0.5, the pitching moment cannot decrease and the maximum thickness of the airfoil remains unchanged. The optimization model is as follow:

$$\max: \quad f(x) = C_L / C_D \qquad (2)$$

$$\begin{aligned} s.t. \quad & g_1(x): \; C_L \geq 0.5 \\ & g_2(x): \; C_m \geq C_{m0} \\ & g_3(x): \; t_{\max} = 0.9 \end{aligned}$$

6.2 Search Algorithms

Genetic algorithms and Asexual DNA algorithm mentioned above are applied. The convergence strategies of two algorithms are both the maximum generation limited to 40. The chromosomal representation of solution for both algorithms is based on binary encoding and decoding. The population size of Asexual DNA algorithm is 1 while those of Genetic algorithms are 144 which could guarantee the same computing workload for both algorithms. For Genetic algorithms, the probability of one-point crossover is 0.8 and the probability of one-point mutation is 0.1.

6.3 Results and Discussion

Fig.4 shows the optimization progress, Fig.5 and Fig.6 show the compare of airfoil shape and pressure distribution before and after optimization, and Table.2 shows the performance of initial airfoil and optimal airfoils, where GA refer to optimal solution obtained by Genetic algorithms while ADNA refers to optimal solution obtained by Asexual DNA algorithm. The results show the shapes of optimal airfoils obtained by two algorithms are similar: the upper crest position and the maximum thickness position move backward. The aerodynamic performances at the design point of both optimal airfoils are improved and the constraints are satisfied. With the same computing workload, using Genetic algorithms, lift-to-drag ratio increases 74.6%, the pitching moment increases 48.6% while using Asexual DNA algorithm, lift-to-drag ratio increases 75.3%, and the pitching moment increases 72.2%. The actual CPU times are approximately 30 hours on a Pentium IV 3.0GHz PC. Compared with Genetic algorithms, Asexual DNA algorithm has better global search ability, faster convergence and much satisfying result.

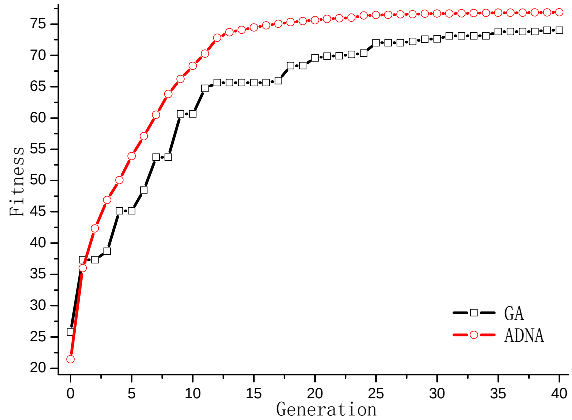

Fig.4 Progress of Airfoil Optimization

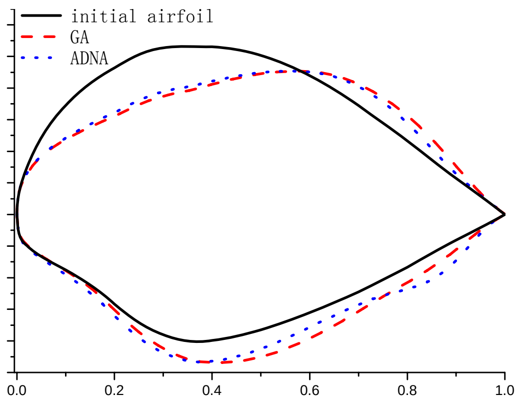

Fig.5 Comparison of Airfoil Shape

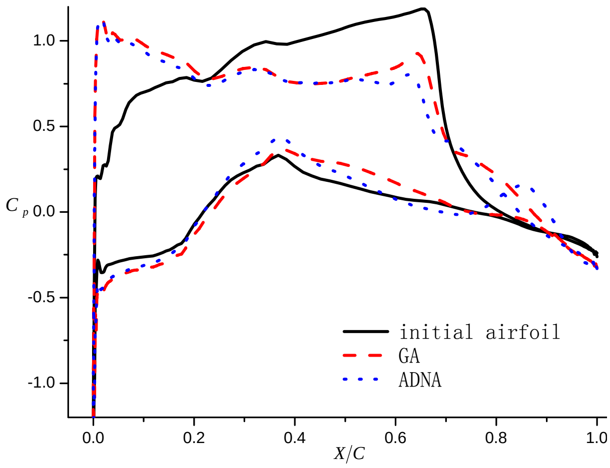

Fig.6 Comparison of Pressure Distribution

Aerodynamic performance	initial airfoil	GA	ADNA
Lift coefficient C_L	0.61	0.60	0.54
Drag coefficient C_D	0.032	0.008	0.007
Pitching moment coefficient C_m	-0.072	-0.037	-0.020
Lift-to-drag ratio L/D	19	75	77
maximum thickness t_{max}	0.09	0.09	0.09

Table.2 Comparison of Performance

7 Conclusions

With the progress in the fields of biology evolution and inheritance research, inspired from which, many kinds of algorithms are built and applied to design field. Among them, Genetic algorithms are based on Darwin's Naturalistic evolutionism of which the main idea is natural selection and survival of the fittest, and Genetic algorithms simulate the evolutionary mechanism of sexual reproduction. Since Genetic algorithms have global convergence and wide feasibility, they have been applied maturely to aerodynamic design. Whereas, in the practical use of Genetic algorithms, there are problems such as they are incapable of representing the bidirectional evolution and the effects of mutation and cross are not equal. The Asexual DNA algorithm is also based on Darwin's Naturalistic evolutionism but simulates the evolutionary mechanism of asexual reproduction. The function test results in this paper show that Asexual DNA algorithm has better global search ability and faster convergence. The airfoil design results could lead to the same conclusion but the predominance of Asexual DNA algorithm is not so notable as function test. In fact, applying such algorithm to high complex and nonlinear design problem as aerodynamic design, there are still many problems to be solved to improve the performance of Asexual DNA algorithm, such as the division operator, mutation operator and selection strategy, etc.

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