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# Application of Intelligent Algorithms in the Optimization Design of Engineering Structures

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**ABSTRACT**
Engineering structure optimization design often requires a large amount of calculation and repetitive experiments. Traditional structural optimization takes a long time and is inefficient, making it difficult to meet the requirements of structural optimization. By using intelligent algorithms such as genetic algorithms, particle swarm optimization algorithms, and neural network algorithms, the efficiency and accuracy of engineering structure optimization can be significantly improved, and the experimental cost can be reduced.

**KEYWORDS**
Genetic algorithm; Particle swarm optimization algorithm; Neural network algorithm; Engineering structure; Optimized design

## 1 Introduction

Engineering structure optimization design is to seek an engineering structure form that is both economical and safe under specific constraints. The purpose of optimization is to solve for the minimum size or minimum weight of the engineering structure, while meeting certain constraints and obtaining the best mechanical properties. The current application fields of engineering structure optimization design cover a wide range of engineering areas such as aerospace, ships, buildings, Bridges, automobiles, water conservancy, machinery, high-speed trains, etc., addressing multiple issues including reducing stress levels, lightening weight, optimizing structural dimensions, and improving structural performance. However, the optimization design of engineering structures requires a large amount of calculation and repetitive experiments. Traditional structural optimization takes a long time and has low efficiency. With the development of computer technology and optimization methods, seeking more effective engineering structure optimization methods has become an important goal for designers.

## 2 Some Intelligent Algorithms and their Advantages and Disadvantages

### 2.1 Genetic Algorithm

Genetic algorithm is a method of searching for the optimal solution by simulating the biological evolution process in nature. This algorithm is a computational model that simulates the mechanism of genetics and the natural selection of biological evolution. It uses computers for simulation operations, transforming the problem-solving process into the crossover and mutation of chromosomes and genes in the biological evolution process. Genetic algorithms, based on the principle of "survival of the fittest", successively generate an approximately optimal solution among potential solutions. This process promotes the evolution of individuals in the population and leads to the acquisition of new individuals that are more adapted to the environment than the original ones. The most essential features of the standard genetic algorithm are simple genetic operators and population search strategies. It has a powerful ability to search for the global optimal solution, robustness in application, and simplicity in operation. It is a solution method with good adaptability and large-scale application. However, a large number of studies and practices have shown that the standard genetic algorithm has defects such as poor local search ability and "premature convergence", and cannot guarantee the convergence of the algorithm [1].

### 2.2 Particle Swarm Optimization Algorithm

Particle swarm optimization algorithm is an algorithm based on swarm intelligence. This algorithm is a global random search algorithm that simulates the behavior of a flock of birds in searching for food. This algorithm, like other biological evolutionary algorithms, is also based on the concepts of "evolution" and "population". Through competition and collaboration among individual organisms, it searches for the optimal solution in complex Spaces. This algorithm does not require evolutionary operator operations such as mutation, crossover and selection on individuals. Instead, it regards the individuals in the population as particles without volume and mass in the multi-dimensional search space. These particles move at a certain speed in the solution space and gather towards the best position. Particle swarm intelligence algorithm is easy to understand due to its good bio-social background and easy to implement because of its few parameters. This algorithm has a strong global search ability for nonlinear problems and has been widely applied in engineering practice and scientific research. The particle swarm optimization algorithm can converge to the optimal solution with a high probability. This algorithm is suitable for optimization in multi-objective and dynamic optimization environments and has good global search ability and computing speed. The particle swarm optimization algorithm also has some obvious drawbacks, which are manifested as follows: For functions with multiple local extreme point values, this algorithm is prone to getting stuck at local extreme points, that is, getting trapped in local optimal solutions and unable to obtain global optimal solutions; The convergence accuracy of this algorithm is low: The particle swarm optimization algorithm is mainly suitable for solving optimization problems in continuous space, but its effect on solving discrete and combinatorial optimization problems is not ideal [2].

### 2.3 Neural Network Algorithm

Artificial neural networks are information processing systems formed by the interconnection of processing units similar to neurons. They are a simplification, abstraction and simulation of the structure and operation mechanism of human brain tissue. They are a discipline that integrates engineering science and life science, and are a very representative machine learning algorithm. Currently, many neural network models and corresponding algorithms have emerged. Among them, the BP algorithm is a frequently used neural network algorithm. Artificial neural networks are systems with learning capabilities. By applying statistics, artificial neural networks can be endowed with the simple judgment and decision-making abilities that humans possess. Artificial neural networks have significant advantages: this algorithm has the ability to respond nonlinearly; This algorithm does not require precise mathematical models of various kinds. This algorithm is good at learning useful knowledge from data and is easy to implement parallel computing. It is easy to implement neural network algorithms with both software and hardware. At present, artificial neural networks have become powerful tools for solving many engineering problems, capable of deeply exploring various nonlinear complex phenomena, and have been widely applied in many engineering fields. Neural network algorithms possess powerful nonlinear fitting capabilities and automatic feature learning abilities, but they have disadvantages such as high training complexity [3].

## 3 Application of Intelligent Algorithms in the Optimization Design of Engineering Structures

### 3.1 Application of Genetic Algorithm in the Optimization Design of Engineering Structures

#### 3.1.1 Dimensional Optimization of Engineering Structures

Genetic algorithms have been successfully applied to the size optimization of truss structures. In the optimal design of steel truss structures, the size of each section can be determined through genetic algorithms, ensuring the maximum total stiffness under the condition of a constant total steel usage. During the process of optimizing the specific structural dimensions, the genetic algorithm will continuously adjust the cross-sectional dimensions of the truss structure members based on the force characteristics and constraints of the truss structure until an approximately optimal solution is found. This optimization method not only can improve the mechanical performance indicators of truss structures, but also can reduce the consumption of structural materials and lower costs.

#### 3.1.2 Shape Optimization of Engineering Structures

Shape optimization of engineering structures is an important issue that needs to be addressed in various mechanical design processes. Although traditional mathematical programming methods can solve topological and shape optimization problems of all kinds of engineering structures, they require continuous variables and constraint functions to be continuous and have good properties, and can only obtain local optimal solutions. Genetic algorithms can quickly find the optimal solution in a large space of design variables and have strong global optimization capabilities. The use of genetic algorithms to optimize the shape of engineering structures can enhance search efficiency and improve the performance and economy of engineering structures [4].

#### 3.1.3 Topological Optimization of Engineering structures

The application of genetic algorithms in the topology optimization of engineering structures is mainly reflected in several aspects: ① Problem modeling: Transform the topology optimization problem of engineering structures into a form that can be processed by genetic algorithms, including determining design variables (such as the connection mode, length, Angle, etc. of members), determining objective functions (such as maximizing stiffness, minimizing weight, etc.), and determining constraint conditions (such as stress, displacement, stability, etc.); ② Encoding and decoding: By using appropriate encoding methods, each design variable is represented as a chromosome in the algorithm, and through decoding, the chromosome is transformed into the specific form of the engineering structure. ③ Fitness function: Define the fitness function to evaluate the superiority or inferiority of each individual. The fitness function is closely related to the constraint conditions and the objective function. ④ Genetic manipulation: including selection, crossover and mutation operations, etc. The selection operation selects outstanding individuals for reproduction based on the evaluation results of the fitness function. Cross-operation generates new individuals by swapping certain genes of different individuals. Mutation operations increase the diversity of the population by randomly altering certain values of an individual's genes. ⑤ Iteration and optimization: Repeat the above genetic operations multiple times and continuously update the population until the optimal solution that meets the requirements is obtained. Genetic algorithms can be used to quickly optimize within a large space of design variables, find the optimal structural topological form, and improve the performance and economy of the structure [5].

### 3.2 Application of Particle Swarm Optimization Algorithm in Engineering Structure Optimization Design

#### 3.2.1 Engineering Structure Optimization

Particle swarm optimization algorithm is an emerging intelligent algorithm and also one of the current research hotspots in the field of engineering structure optimization. This algorithm has advantages such as strong global search ability and relatively fast convergence speed, and is suitable for various nonlinear optimization problems and high-dimensional problems. At present, the particle swarm optimization algorithm has been applied to the structural optimization of large-span structures, high-rise buildings, mechanical engineering and other fields. The main manifestations are as follows: ① Optimization of large-span engineering structures: The optimization of geometric parameters for large-span spatial structures has always been a difficult problem in engineering structure design. The computational load of force analysis for large-span spatial structures is large, and it is difficult to obtain the optimal solution through conventional calculation methods. At present, the optimization design of large-span spatial structures mainly relies on the years of design experience of structural engineers to solve. The application of particle swarm optimization algorithm for the optimization design of large-span engineering structures is an effective solution. The use of particle swarm optimization algorithm for the optimization design of large-span structures has the advantages of fast convergence speed and good robustness [6]. ② Optimization of high-rise building structures: The design of high-rise building structures needs to strike a balance among structural strength, structural stability and materials. The particle swarm optimization algorithm can be used to optimize the structure of high-rise buildings. By adjusting the positions and dimensions of each column, beam and shear wall, the seismic performance and material utilization rate of the engineering structure can be improved [7]. ③ Optimization of mechanical engineering structure design: In the design of mechanical structures such as truss structures and plate and shell structures, the particle swarm optimization algorithm can be used to find the optimal design scheme that meets performance indicators (such as strength, stiffness, stability, etc.). By optimizing the shape and size of engineering structures, it is possible to ensure the performance of engineering structures, reduce their weight, and lower their costs.

#### 3.2.2 Optimization of Engineering Structure Composite Materials

Composite materials applied in engineering structures, featuring high specific stiffness, high specific strength and excellent designability, have become key structural materials in certain engineering fields. The various mechanical properties of composite laminates are closely related to layup parameters (such as layup sequence, Angle, thickness, etc.), while the various mechanical properties of composite fiber materials are closely related to the direction of the fibers. Traditional design methods find it difficult to comprehensively consider the complex coupling relationships among various parameters and thus cannot obtain the optimal design scheme. The particle swarm optimization algorithm can be used to optimize the design of engineering structural composite materials, mainly manifested in the following aspects: ① Optimization of the stacking order of composite materials: In the design of composite laminated plates, the stacking order has a significant impact on various properties of the composite materials. The particle swarm optimization algorithm can be used to optimize the stacking sequence of composite laminated plates. By adjusting the arrangement and combination of each layer of the composite material, the strength, stiffness and fatigue resistance of the material can be improved. The layup thickness of composite laminates is directly related to the weight of the material and also has a significant impact on various mechanical properties of the laminates. On the basis of optimizing the layup sequence, further optimizing the thickness of each layer slab can effectively reduce the weight of engineering structural components. ② Optimization of fiber orientation in composite materials: The orientation of fibers is of great significance to the mechanical properties of fiber-reinforced composites. By using particle swarm optimization algorithms, the laying direction of fibers can be optimized to enhance various mechanical properties of fiber-reinforced materials, such as tensile strength and bending stiffness. ③ Multi-objective optimization: The optimization of composite material structures involves the optimization of multiple objectives, including strength, weight, cost and other indicators. The particle swarm optimization algorithm can be used to handle multi-objective optimization problems of composite materials and find the optimal balance point among multiple optimization objectives of composite materials.

### 3.3 Application of Neural Network Algorithms in the Optimization Design of Engineering Structures

Neural network algorithms process and optimize data by simulating the connection and signal transmission mechanisms of human neurons. In engineering structure optimization, artificial neural networks can learn and identify the relationship between key parameters and various performances in engineering structures, and achieve performance optimization of engineering structures by adjusting these parameters. Specifically, it is manifested in the following aspects: ① Optimization of engineering structure materials: Neural networks can predict the impact of various material combinations on the performance of engineering structures (such as stiffness, strength, and durability, etc.). By training neural network models, the optimal material combination for engineering structures can be quickly selected, thereby reducing the cost of material experiments and saving time. ② Engineering structure optimization: In the design of building structures, neural networks can analyze the impact of different structural design schemes on the safety and cost of engineering structures, and obtain the optimal scheme. In the aerospace field, neural networks can optimize the internal structure and aerodynamic shape of aircraft, enhance their flight efficiency and reduce their energy consumption. ③ Optimization of the manufacturing process of engineering structures: Neural networks can optimize the process parameters (such as pressure, temperature, time, etc.) in the manufacturing process of engineering structures, improving the manufacturing quality and production efficiency of engineering structures. Through the analysis and learning of engineering structure manufacturing data, neural networks can predict product performance under different process parameters and optimize manufacturing process parameters.

## 4 Conclusion

The application of intelligent algorithms in engineering structure optimization has achieved remarkable results and demonstrated its unique advantages in multiple fields. Intelligent algorithms can significantly enhance the efficiency and accuracy of engineering structure optimization, and reduce the costs of manual trial and error and experiments.

(1) Genetic algorithms, by simulating the ideas of natural selection and biological gene evolution, can efficiently solve complex engineering structure optimization problems. This algorithm has a strong ability to globally search for the optimal solution and is a solution method with good adaptability and large-scale application. However, a large number of engineering practices and studies have shown that the standard genetic algorithm has defects such as poor local search ability;

(2) Particle swarm optimization algorithm is essentially a random search intelligent algorithm. This algorithm can converge to the global optimal solution with a relatively high probability and is suitable for finding the optimal solution in dynamic and multi-objective optimization environments. The particle swarm optimization algorithm has some obvious drawbacks, which are manifested as follows: For functions with multiple local extremum points, it is prone to fall into local optimum; The convergence accuracy is relatively low: it cannot effectively solve discrete and combinatorial optimization problems. Particle swarm optimization algorithm is mainly applicable to optimization problems in continuous space. However, for discrete and combinatorial optimization problems, its effect is not ideal.

(3) Artificial neural networks can explore various nonlinear complex phenomena more deeply. This algorithm has strong automatic feature learning ability and nonlinear fitting ability, but artificial neural networks have disadvantages such as high training complexity and poor interpretability.

(4) In the future, intelligent algorithms will place greater emphasis on the integration of various algorithms, including genetic algorithms, particle swarm optimization algorithms, and neural network algorithms. These intelligent algorithms will be combined to form a collaborative optimization system, making full use of the advantages of various algorithms, overcoming their shortcomings, and achieving more efficient engineering structure optimization design.

## About the Author

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