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A new hybrid artificial bee colony algorithm for robust optimal design and manufacturing

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ABSTRACT

The purpose of this paper is to develop a novel hybrid optimization method (HRABC) based on artificial bee colony algorithm and Taguchi method. The proposed approach is applied to a structural design optimization of a vehicle component and a multi-tool milling optimization problem.

A comparison of state-of-the-art optimization techniques for the design and manufacturing optimization problems is presented. The results have demonstrated the superiority of the HRABC over the other techniques like differential evolution algorithm, harmony search algorithm, particle swarm optimization algorithm, artificial immune algorithm, ant colony algorithm, hybrid robust genetic algorithm, scatter search algorithm, genetic algorithm in terms of convergence speed and efficiency by measuring the number of function evaluations required.

1. Introduction

Designing and manufacturing new products possessing desired property are important in industry. With the advent of ever faster computing platforms, the computer aided design and optimization tools are becoming more attractive due to its great contribution to cost, material and time savings in the procedures of the engineering design. The application of these tools allows a more rapid design process and more detailed design studies.

Over the past decades, a number of optimization algorithms have been used extensively in structural and manufacturing optimization tasks. The early works on the topics mostly use various mathematical techniques. These methods may not be used efficiently in finding global optimum solutions. As an alternative to traditional techniques, population-based optimization approaches, such as, genetic algorithm, particle swarm optimization algorithm, artificial immune algorithm, cuckoo search algorithm and artificial bee colony algorithm have been developed by mimicking natural phenomena and widely applied in various fields of science [1–12]. Artificial bee colony algorithm (ABC) is one of the most recently introduced swarm-based algorithms based on the intelligent foraging behaviour of honey bee swarm [13]. The ABC has been found to be successful in a wide variety of optimization tasks [13–15].

On the other hand, researchers are paying more and more interest on hybrid algorithms to solve optimization problems. The hybrid algorithms have shown outstanding reliability and efficiency in application to the engineering optimization problems [16–20].

The main goal of the present research is to develop a robust optimization approach based on artificial bee colony algorithm and Taguchi method to solve design and manufacturing optimization problems. In the new hybrid approach, S/N values are calculated and ANOVA (analysis of variance) table for the objective function is formed using S/N ratios respectively. According to results of ANOVA table, appropriate interval levels of design variables are found and then, initial population of artificial bee colony algorithm is defined according to these interval levels. Then optimum results of the problem are obtained using artificial bee colony algorithm. Since the ABC has been found to be successful in a wide variety of optimization tasks, it is used in this paper.

The developed new hybrid optimization approach entitled hybrid robust artificial bee colony algorithm (HRABC) is applied to optimum design of a vehicle part taken from automotive industry and to optimization of the machining parameters in multi-tool milling operations. The results of the HRABC for each case study show that the proposed optimization method converges rapidly to the global optimum solution and provides reliable and accurate solutions.

The remaining contents of the paper are organized as follows. Literature review is given in Section 2. The standard ABC and Taguchi method are presented in Section 3. In Section 4, the proposed approach is used for optimization of a vehicle component.

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The results are discussed in Section 5. An application of the HRABC to optimization of the machining parameters in multi-tool milling operations is given in the Appendix A.

2. Literature review

Recently, new approaches in the area of optimization research are presented to further improve the solution of optimization problems with complex nature.

Over the past few years, the studies on evolutionary algorithms have shown that these methods can be efficiently used to eliminate most of the difficulties of classical methods. Evolutionary algorithms are widely used to solve engineering optimization problems with complex nature. Various research works are carried out to enhance the performance of evolutionary algorithm [1–23].

For instance, a novel approach for multi-component topology optimization of continuum structures using a multi-objective genetic algorithm is developed by Yildiz and Saitou [2]. The developed approach is applied to multi-component topology optimization of a vehicle floor frame.

Artificial bee colony (ABC) algorithm originally developed by Karaboga [13] is inspired with social behavior, such as bird flocking, fish schooling, which is used successfully in the solution of optimization problems. The ABC algorithm has been used in many areas of optimization studies. The use of the ABC algorithms in the optimum solution of problems resulted better solutions compared to classical methods [13–15,25–32].

The robustness issues have been used to solve optimization problems by researchers [33–37]. Robinson et al. [38] presents a review paper which focuses largely on the work done since 1992 and a historical perspective of parameter design is also given. Kunjur and Krishnamurty [39] presented a robust optimization approach that integrates optimization concepts with statistical robust design techniques. Although Taguchi's methods have been successfully applied to processes in the design and manufacturing, they are also criticized for their efficiency [36,40].

Hybrid methods are also used to enhance the performance of evolutionary algorithm. For instance, the artificial immune algorithm is hybridized with hill climbing local search algorithm by Yildiz [16] and applied to multi-objective disc brake and manufacturing optimization problems from literature. In another paper [18], the particle swarm optimization approach is hybridized with receptor editing property of immune system. The proposed approach is used to solve optimization problems in design and manufacturing areas.

Tsai et al. [41] proposed a hybrid algorithm which the Taguchi's method is inserted between crossover and mutation operations of a genetic algorithm. Taguchi method is incorporated in the crossover operations to select the better genes to achieve crossover, and consequently, enhance the performance of genetic algorithm.

It is known that the ABC algorithm is an efficient approach at exploring the solution space, but it does not guarantee the global optimum as other evolutionary methods. The introduction of hybrid methods comes from the need to tackle more and more complex real-world problems. Some of the hybrid approaches in literature have been made on hybrid ABC [28,42,43].

3. Hybrid bee colony optimization algorithm for structural optimization

Structural design optimization has always been a very interesting and creative segment in a large variety of engineering designs. Structures, of course, should be designed such that they can resist applied forces (stress constraints), and do not exceed certain deformations (displacement constraints). Moreover, structures should be economical. Theoretically, the best design is the one that satisfies the stress and displacement constraints, and results in the least cost of construction. Although there are many factors that may affect the design cost, the first and most important one is the amount of material used to design the structures. Therefore, minimizing the weight of the structure is usually the goal of structural optimization.

In this paper, a new hybrid optimization approach (HRABC) is developed to solve structural design and manufacturing optimization problems. In the proposed optimization approach, the refinement of the population space is introduced by Taguchi's method. The bounds selected on the design variables are first used for the initial population, then they apply throughout bee colony algorithm for finding optimal solutions. The aim is to overcome the limitations caused by larger population regarding computational cost and quality of solutions for global optimization. First, some brief explanations about bee colony optimization algorithm and Taguchi's method are given and, finally, the proposed hybrid approach is explained.

3.1. Bee colony algorithm

Artificial bee colony algorithm (ABC) developed by Karaboga [13] and further developed by Karaboga and Basturk [14,24–27] is a nature inspired algorithm based on the intelligent foraging behavior of honey bee swarm. The ABC algorithm describes the foraging behavior, learning, memorizing and information sharing characteristics of honeybees. A basic model of foraging behavior of honeybee swarms consists of two essential components and define two leading modes of the behavior.

The colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. The colony of the artificial bees is divided into two groups, first half of the colony consists of the employed artificial bees and the second half includes the onlooker bees. Scout bees are the employed bees whose food source has been abandoned. In ABC algorithm, the position of a food source represents a possible solution to the optimization problem (value of design variables) and the nectar amount of a food source corresponds to the quality of the associated solution (fitness value).

At the first step, the ABC generates a randomly distributed initial population $P_{initial}$ of N solutions, where N denotes the size of population. Each solution $x_i (i = 1, 3, \ldots, N)$ is a S-dimensional vector where S is the number of optimization parameters (design variables). After initialization, the population of the solutions is subjected to repeated cycles, $C = 1, 2, \ldots, G$, of the search processes of the employed bees, the onlooker bees and scout bees. An employed bee generates a modification in the solution in her memory depending on the local information. If the objective function value (fitness) of the new solution is better than that of the previous one, the bee memorizes the new position and forgets the old one. Otherwise, she keeps the position of the previous one in her memory. After all employed bees complete the search process; they share the nectar information of the food sources and their position information with the onlooker bees on the dance area. An onlooker bee evaluates the fitness information taken from all employed bees and chooses a food source with a probability related to its fitness value. An onlooker bee also produces a new solution and it memorizes the new position if its fitness value is better than the previous position. An artificial onlooker bee chooses a food source depending on the probability value associated with that food source, P_i, calculated by the following expression:

$$P_i = \frac{F_i}{\sum_{n=1}^{N_b} F_n} \quad (1)$$