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Truss optimization with natural frequency bounds using improved symbiotic organisms search

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ABSTRACT

Many engineering structures are subjected to dynamic excitation, which may lead to undesirable vibrations. The multiple natural frequency bounds in truss optimization problems can improve dynamic behaviour of structures. However, shape and size variables with frequency bounds are challenging due to its characteristic, which is non-linear, non-convex, and implicit with respect to the design variables. As the main contribution, this work proposes an improved version of a recently proposed Symbiotic Organisms Search (SOS) called an Improved SOS (ISOS) to tackle the above-mentioned challenges. The main motivation is to improve the exploitative behaviour of SOS since this algorithm significantly promotes exploration which is a good mechanism to avoid local solution, yet it negatively impacts the accuracy of solutions (exploitation) as a consequence. The feasibility and effectiveness of ISOS is studied with six benchmark planar/space trusses and thirty functions extracted from the CEC2014 test suite, and the results are compared with other meta-heuristics. The experimental results show that ISOS is more reliable and efficient as compared to the basis SOS algorithm and other state-of-the-art algorithms.

1. Introduction

The optimal engineering truss subjected to dynamic behaviour is a challenging area of study that has been an active research area. Thus, optimal truss design subjected to frequency bounds has seen much consideration in the past decades. natural frequencies of a truss are really useful considerations to improve the dynamic behaviour of the truss [23,26]. Therefore, natural frequencies of the truss should be constrained to avoid resonance with an external excitation. In addition, engineering structures should be as light as possible. On the other hand, mass minimization conflicts with frequency bounds and increases complexity in truss optimization. As such, an efficient optimization method is required to design the trusses subjected to fundamental frequency constraints and continuous efforts are put by researchers in this aspect.

Size optimization, shape optimization, and topology optimization are fundament types of truss optimization. In size optimization, the final goal is to obtain the best bar sections, whereas shape optimization works to search the best nodal positions of predefine nodes of the truss structure. The effect of shape and sizing on objective function and constraints are in conflict. Therefore, simultaneous shape and sizing with natural frequency bounds adds further complexity and often lead to divergence. Several researchers have been using different optimization algorithms, yet this research area has not been fully investigated so far.

Truss optimization with frequency bound was firstly addressed by Bellagamba and Yang [1] since proposal many scholars have been investigating further into this research area. Lin et al. [19] presented a bi-factor algorithm. Grandhi and Venkayya [7] and Wang et al. [31] tested an optimality criterion (OC). Wei et al. [33] presented a niche genetic hybrid algorithm (NGHA). Particle swarm optimization (PSO; [18]) tested by Gomes [6]. Kaveh and Zolghadr [9] used a charged system search (CSS; [8]) and enhanced CSS. Wei et al. [32] applied a parallel genetic algorithm (GA). Kaveh and Zolghadr [10] addressed a hybridized CSS and a big bang-big crunch (CSS-BBBC). Miguel and Miguel [21] tested a harmony search (HS; [5]) and a firefly algorithm (FA). Kaveh and Zolghadr [12] utilized a democratic PSO (DPSO). Kaveh and Zolghadr [13] investigated nine recent optimization algorithms. Pholdee and Bureerat [23] investigated twenty-four advanced algorithms. Zuo et al. [37] applied a hybrid OC-GA. Kaveh and Mahdavi [16] studied a colliding-bodies optimization (CBO). Tejani et al. [29] suggested a modified sub-population teaching-learning-based optimization (MS-TLBO) and Farshchin et al. [4] used Multi-Class

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TLBO (MC-TLBO) for trusses subjected to frequency bounds. Kaveh and Zolghadr [14] used tug of war optimization (TWO), whereas Kaveh and Ilchi Ghazaan [15] used vibrating particles system (VPS). On the other hand, truss subjected to both static and dynamic bounds has been investigated by few scholars [11,25,26,34].

In the second test, thirty benchmark functions extracted from the CEC2014 test suite are solved using the proposed technique and the results are compared with state-of-the-art algorithms. The comparative algorithms are selected from different categories as follows: Invasive Weed Optimization (IWO) [20], Biogeography-Based Optimization (BBO) [27], GSA [24], Hunting Search (HuS) [22], Bat Algorithm (BA) [35], and Water Wave Optimization (WWO) [36].

All these studies proved the efficacy of stochastic optimization algorithms in handling a large number of difficulties when solving structure design problems. According to the No Free Lunch theorem in the field of optimization, however, there is no algorithm to solve all optimization problems. This means that a new adapted algorithm has potential to solve a group of problems (e.g. structures design) better than the current algorithms while they still perform equal considering all optimization problems. This motivated our attempts to improve the performance of the recently proposed symbiotic organisms search (SOS) algorithm and adapt it better for structure design problems.

Cheng and Prayogo [2] proposed the SOS algorithm works on cooperating behaviour among species in the society. SOS simulates symbiotic living behaviours. SOS is a population-based method, where species of the society is assumed to be a population. SOS has been equipped with a minimum number of controlling parameters: population size and number of generations. This makes this algorithm more convenient to use compare to GA which requires mutation, crossover, selection rate etc., PSO which needs inertia weight, social, and cognitive parameters, and HS which should be tested with setting harmony memory rate, pitch adjusting rate, and improvisation rate [3,28].

The SOS algorithm has been applied to a large number of constrained and unconstrained problems and proved to be a very competitive algorithm [2,3]. In 2015, Cheng et al. proposed a discrete version of SOS to optimize multiple-resources levelling problems. Capability of SOS in truss optimization is still under research, although Cheng and Prayogo [2] and Tejani et al. [28] have investigated SOS for some structural optimization problems. Another interesting work in the literature has been conducted by Tran et al. [30], in which a multi-objective SOS was proposed and applied to multiple work shifts problems in construction projects. As another improvement, Tejani et al. [28] introduced an adaptive search mechanism called Adaptive benefit factor (ABF) in the mutualism phase of SOS. Adaptive versions of SOS were called as a SOS-ABF1 incorporates ABF1 and BF2, a SOS-ABF2 incorporates BF1 and ABF2, and a SOS-ABF1&2 incorporates ABF1 and ABF2. These motivated our attempt to improve the performance of SOS.

Regardless of the successful application of SOS, this algorithm estimates the global optimum of a given problem in three phases: the mutualism phase, commensalism phase, and parasitism phase.

In the parasitism phase, parasite vector is produced by a fusion of host design variables and randomly generated variables, therefore this phase works mainly in order to improve exploitation capabilities of the search process. The highly heuristic nature of the phase leads solution to jump into non-visited regions (exploration) and permits local search of visited regions (exploitation) as well. However, the exploitation capability of this phase is considerably low as compared to exploratory capability. Thus, the acceptance rate of new solution obtained by the parasitism phase reduces rapidly with function evaluations (*FEs*) or number of generations. This action consumes a large number of unused *FEs* later in the parasitism phase. Moreover, it seems that the literature lacks efficient methods to improve exploration to improve the convergence speed and exploitation. Also, adaptive mechanisms are required to balance exploration and exploitation since either of these will not guarantee the success of SOS. In other works, a propose balance of these two phases is essential to avoid local solutions and find an accurate estimation of the global optimum for a given optimization problem. To alleviate these drawbacks, an improved SOS (ISOS) algorithm is equipped with an improved parasitism phase to boosts exploitation capability of the algorithm.

This study intends to devise a method to establish a good balance between exploration and exploitation of the search space using SOS. In addition, several considerations are made in the paper to solve structure design problems using ISOS.

2. The symbiotic organisms search algorithm

The SOS algorithm, proposed by Cheng and Prayogo [2], is a simple and powerful meta-heuristic. SOS works on the biological dependency seen among organisms in the nature. Some organisms live together because they are reliant on other species for survival and food. The reliance between two discrete organisms is known as symbiotic. In this context, mutualism, commensalism, and parasitism are the most common symbiotic relations found in the nature. An interdependency between two different species benefits to each other is called mutualism. A relationship between two different species benefits to one of them without affecting other is called commensalism. Whereas, a relationship between two different species benefits to one of them with aggressively harm another is called parasitism.

SOS starts with a randomly generated population, where the system has '*n*' number of organisms (population size) in the ecosystem. In the next stage, the population is updated in each generation '*g*' by 'the mutualism phase', 'the commensalism phase', and 'the parasitism phase' respectively. Moreover, updated solution in each phase is accepted only if it has better objective value. These steps are repeated until a termination criterion is satisfied. In this optimization method, the better solution can be achieved the symbiotic relations between the current solution and either of other random solution and the best solution from population.

The detailed description of all three phases and modification of SOS is explained in the subsequent sections:

2.1. The mutualism phase

A relationship between two organisms of different species results in individual benefits of the symbiotic interaction is called mutualism. The symbiotic interaction between bee and flower is a classic example of this phenomenon. Bees fly from one flower to another and collect nectar that is produced into honey. This activity also benefits to result in the formation of seeds as the bee acts as the vehicle to move pollen for plant. In this way, this symbiotic association benefits both individuals from the exchange. Therefore, this relationship is called a mutually beneficial symbiotic [2].

In the mutualism phase, the design vector (X_i) of the organism '*i*' (i.e. population) interacts with another design vector (X_k) of a randomly selected organism '*k*' of the ecosystem (where $k \neq i$). The interaction between these organisms results in a mutualistic relationship, which improves individual functional values of the organisms in the ecosystem. Therefore, new organisms are governed by a Mutual Vector (*MV*) and Benefit Factors (BF_1 and BF_2). The mutual vector (the average of two organisms) signifies the mutual connection between organisms 'X_i' and 'X_k' Eq. (3)). The benefit factors are decided by a heuristic step and so it is decided randomly with equal probability as either 1 or 2 (Eqs. (4) and ((5)). Therefore, the benefit factors signify two conditions where organisms 'X_i' and 'X_k' benefit partially or fully from the