A review of major application areas of Harmony Search Algorithm

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Abstract

Harmony Search (HS) a meta heuristic algorithm inspired by music improvisation process in which the musician searches for the best harmony and continues to polish the harmony in order to improve its aesthetics. The HS algorithm was introduced in the year 2001 and has found applications in diverse fields.

This manuscript reviews the recent significant applications of this simple yet powerful algorithm. As evidenced by a number of studies, this algorithm features several innovative aspects in its operational procedure that foster its utilization in diverse fields such as engineering, construction, telecommunications, robotics, health and energy.

Keywords:
Evolutionary Algorithms, metaheuristic Optimization, Harmony Search, Nature inspired Optimization

1. Introduction

Optimization is defined as the process of selecting the best option from a set of available alternatives. Every pro-cess has the potential to be optimized and many challenging problems in business, economics, science and engineering can be formulated as an optimization process. For example, the objective of formulated optimization problems can be the maximization of profit and/or quality, or minimization of time, cost and risk etc.

The application of optimization algorithms to real world problems has gained momentum in the last decade. Dat-ing back to the early 1940s, diverse traditional mathematical methods such as linear programming (LP), nonlinear programming (NLP) or dynamic programming (DP) were first employed for solving complex optimization problems by resorting to di erent relaxation methods of the underlying formulation. These techniques are capable of consistently obtaining a global optimal solution in problem models subject to certain particularities (e.g. optimal sub structurability and subproblem overlap for dynamic programming), but unfortunately their application range does not cover the whole class of NP-complete problems, where an exact solution cannot be found in polynomial time. In fact, the solution space (and hence, the solving time) of the problem increases exponentially with the number of inputs, which makes them unfeasible for practical applications.

Many real life optimization problems are complex and thus di cult to solve in an exact manner within reasonable amount of time. The classical optimization methods have the limitation of being highly sensitive to the starting point and frequently converge to a local optimum. Classical optimization techniques can be broadly classified into two categories: direct search method and gradient based search method. In the direct search method, only the objective function and constraints are utilized for the search process, whereas in the gradient based search method, the first order and/or second order derivatives are utilized in the search process. Direct search methods have the limitation of slow convergence whereas gradient based search methods are faster however have the limitation of being not applicable to discontinuous and non di erentiable functions. Furthermore, both methods seek local optima, thus starting the search in the vicinity of a local optima causes them to miss the global optima.

Metaheuristic algorithms eradicate some of the afore mentioned difficulties and are quickly replacing the classical methods in solving complex non linear optimization problems. Metaheuristic algorithms typically intend to find a reasonably good solution close to optimization in reasonable amount of computational time. During the last few decades, several metaheuristic algorithms have been proposed including Genetic Algorithms, Genetic Programming, Evolutionary Programming, Evolutionary Strategies (ES), Differential Evolution, Ant Colony Optimization and Particle Swarm Optimization to name a few.

The Harmony Search (HS) algorithm is the musicians inspired metaheuristic algorithm developed by Geem et.al. in 2001 [1] and has found applications in diverse fields. Weyland [2] raised an issue regarding the novelty of Harmony Search algorithm by declaring it a special case of (ES, however the pitch adjustment operator used in HS is entirely di erent than the mutation operator used in ES further HS utilizes the pitch adjustment operator (local search) probabilistically determined by PAR and thus the two cannot be considered same. Ample evidence has been provided by Saka et.al. in [3] to show HS is not a special case of ES even though superficially they seem to be identical.

2. Harmony Search

Harmony Search is a musicians behavior inspired evolutionary algorithm developed in 2001 by Geem et al.[1], though it is a relatively new meta heuristic algorithm, its e ectiveness and advantages have been demonstrated in various applications like design of municipal water distribution networks [4], structural design [5], tra c routing [6], load dispatch problem in electrical engineering [7], multi objective optimization [8], rostering problems [9], clustering [10], classification and feature selection [11, 12] to name a few. A detailed survey on applications of HS can be found in [13, 14]. In order to explain the Harmony Search in detail, let us first idealize the improvisation process by a skilled musician. When a musician is improvising there are three possible choices:

1. Play any piece of music exactly from his memory.
2. Play something similar to a known piece.
3. Compose new or random notes.

Geem et al. [1] formalized these three options into quantitative optimization process and the three corresponding components become usage of harmony memory (HM), pitch adjusting, and randomization. The usage of HM is similar to the choice of the best fit individuals in genetic algorithms. In order to use this memory e ectively, it is typically assigned a parameter called harmony memory considering rate (HMCR 2 [0, 1]). If this rate is low (near 0), only few best harmonies are utilized and thus convergence of algorithm is slow. If this rate is very high (near 1), it results in exploitation of the harmonies in the HM, thus the solution space is not explored properly leading to potentially ine cient solutions. Typically HMCR $\in$ [.7, .95] is used. The second component is pitch adjustment determined by a pitch bandwidth (BW) (also referred as fret width [15]) and a pitch adjusting rate (PAR), it corresponds to generating a slightly di erent solution in the HS algorithm. Pitch can be adjusted linearly or nonlinearly however most often linear adjustment is used. So we have

$$H_i^{new} = H_i^{old} + BW \times r_i \quad \text{where } r_i \in [\ 1, 1] \text{ and } 1 \le i \le D \quad (1)$$

Where H_i^{old} is the i^{th} component of the existing harmony or solution and H_i^{new} is the i^{th} component of new harmony after the pitch adjusting action and BW is the bandwidth. The Equation (1) essentially produces a new solution around the existing solution by altering it slightly by a very small random amount. Here r_i is a random number generated in the range of [-1, 1] and D is total number of components in the harmony. The pitch adjusting rate (PAR) controls the degree of adjustment. A low pitch adjusting rate with a narrow bandwidth can slow down the convergence of HS because of limitation in exploration of only a small subspace of the whole search space. On the other extreme a very high PAR with a wide bandwidth may cause the algorithm to swing around some optimal solution. Thus the recommended value of PAR ∈ [.1, .5]. The third component of the HS is the randomization, which is used to increase the exploration of the search space. Although pitch adjustment plays a some what similar role, but it is confined to close neighborhood of harmony and thus corresponds to local search. The use of randomization pushes the algorithm further to explore diverse search areas to find the global optima. The pseudo code of harmony search is shown as Algorithm 1. In the pseudo code H represents a potential solution or harmony, rand ∈ [0, 1] is a uniformly distributed random number generator, rand int(1,HMS) generates a uniformly distributed integer random number between 1 and HMS, size of harmony memory is represented as HMS and D is the dimension of problem.

Algorithm 1 HARMONY SEARCH (HS) ALGORITHM

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Define Objective function f(H).
Define harmony memory consideration rate (HMCR).
Define pitch adjustment rate (PAR) and bandwidth(BW).
Define Harmony Memory Size (HMS).
Initialize Harmony Memory (HM).
while (Stopping Criteria Not Reached) do
  Find current Worst and Best harmony in HM.
  for i = 1 to D do
    if (rand ≤ HMCR) then
      Hi = H Mi^j where j=rand_ int(1,HMS)
      if (rand ≤ PAR) then
        Hi = Hi ± rand BW
      end if
    else
      Generate Hi randomly within the allowed bounds.
    end if
  end for
  if (H is better than worst Harmony in HM) then
    Update HM by replacing WORST harmony by H.
  end if
    end while
    print Best Harmony as obtained solution.
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3. Overview of HS applications

In real life applications of wireless sensor networks (WSNs) optimization of the network operation is required to extend its lifetime. A framework is proposed in [10] that enables practical development of centralized cluster based protocols supported by optimization methods for the wireless sensor networks. Based on this framework, a protocol using harmony search algorithm is designed and implemented in real time for the WSNs. It is expected to minimize the intracluster distances between the cluster members and their cluster heads and optimize the energy distribution of the wireless sensor networks. The study of HS cluster based protocol is carried out in a real case where the WSNs equipped with the proposed protocol are deployed in an indoor environment to monitor the ambient temperature for fire detection. A comparison is made with the well-known clusterbased protocols developed for WSNs such as low-energy adaptive clustering hierarchy centralized (LEACH-C) and a cluster-based protocol using Fuzzy C-Means (FCM) clustering algorithm. Experimental results demonstrate that the HS based protocol can be realized in centralized cluster-based WSNs for safety and surveillance applications in building environments. From the obtained experimental test results, it can be seen that the WSNs lifetime has been extended using the proposed HS protocol in comparison with that of LEACH-C and FCM protocols.

A micro grid includes various types of smart distributed generators, renewable generators, storage devices and controllable load. A micro grid must satisfy its local needs and should be under the hierarchical control of management system. Due to this combination of conventional and renewable sources, the unit commitment becomes more crucial and more complicated in the management of a micro grid. In [29] a harmony algorithm based method is proposed for unit commitment in a micro grid. The objective is to minimize micro grids operational cost when it is isolated and maximize its revenue when it is connected to networks.

Economic load dispatch (ELD) problem is one of the basic and important optimization problems in a power system. However, considering practical constraints of real world power systems such as ramp rate limits, prohibited operating zones, valve loading effects, multi fuel options, spinning reserve and transmission system losses in ELD problem makes it a non convex optimization problem, which is a challenging one and cannot be solved by traditional methods. Moreover, considering environmental issues, results in combined economic and emission load dispatch (CEELD) problem that is a multiobjective optimization model with two non commensurable and contradictory objectives. In [30] a modified harmony search algorithm has been applied to solve Economic load dispatch problem. Performance of the algorithm is investigated by applying it to solve various test systems having non convex solution spaces. The numerical results demonstrate the e ectiveness of the proposed method.

Harmony Search algorithm has been used to find sustainable designs of post tensioned concrete box girder pedestrian bridges in [31]. The algorithm finds the geometry and the materials for which the sum of the costs or the emissions are the lowest, yet satisfying the requirements for structural safety and durability.

The parameters of Deep Belief Networks are fine tuned by means of Harmony Search algorithm in [32]. The HS algorithm was able to obtain state-of-the-art results when compared with several of its variants. The experimental results were carried out in two public datasets considering the task of binary image reconstruction, three DBN learning algorithms and three layers.

Hybrid bio inspired solver which combines elements from the recently proposed Coral Reefs Optimization (CRO) algorithm with operators from the Harmony Search approach is utilized in the context of short term wind speed prediction as a means to obtain the best set of meteorological variables to be input to a neural Extreme Learning Machine (ELM) network [33].The paper evaluates the performance of the algorithm when predicting the wind speed based on the measures of two meteorological towers located in USA and Spain.

Software remodularization is always a key task in the field of software reengineering. In recent years, search based optimization techniques have been considered as an e ective method to handle software remodularization problems. In [34] a Harmony Search Based Remodularization Algorithm (HSBRA) is proposed to solve the software remodularization problem for object-oriented software systems. Several key improvements have been put forward like an e cient encoding of harmony memory, initialization of harmony memory, an e ective strategy for improvisation of a new harmony. In addition, a new fitness function that considers coupling, cohesion, package count index and package size index is developed. Four di erent variants of HSBRA (i.e., HSBRA1, HSBRA2, HSBRA3, and HSBRA4) based on linear and exponential changes in Harmony Memory Consideration Rate (HMCR) and Pitch Adjusting Rate (PAR) have been formulated. The proposed approach is tested over 8 problem instances and results are compared with both the population based (Genetic Algorithm - GA, Dierential Evolution DE, and Artificial Bee Colony - ABC) and single-solution based (Simulated Annealing - SA and Hill-Climbing - HC) algorithms. A Wilcoxon test is performed to assess the pair wise statistical performance of the algorithms. The results show that HSBRA outperforms SA, HC, and GA algorithms and performs better than ABC algorithms. Out of four variants of HSBRA, exponential change based variants of HSBRA perform better than linear change based variants.

Discrete sizing optimization attempts to find the optimal cross-section of system elements in order to minimize struc-tural weight. However, the minimum design must also satisfy inequality constraints that limit design variable sizes and structural responses. In [35] Harmony Search algorithm is used for optimization of truss structure problems under multiple loading conditions.

HS is typically implemented on a software platform, which restrict its applications in time critical applications. In order to accelerate the algorithm, one can proceed with the parallelization of the algorithm and/or map it directly onto hardware to achieve faster execution time. An e cient architecture for parallel HS algorithm in FPGA platform in order to improve HS performance in terms of execution time, resource utilization and power consumption while searching several solution candidates for a problem is presented in [36]. The implementation is tested using a suite of well known benchmark functions. Analysis of the experimental results show that the proposed concurrent implemen-tation has a promising performance up to 175x and no less than 16x as compared with software implementation.

Image reconstruction from projections is an important problem in the areas of microscopy, geophysics, astrophysics, satellite and medical imaging. The problem of image reconstruction from projections is considered as an optimization problem where a meta-heuristic technique can be used to solve it. Harmony search has been utilized for image reconstruction from projections in [37]. The HS method is combined then with a local search method (LS) to improve the quality of reconstructed images in tomography. The proposed methods are validated on some images and compared with both the filtered back-projection

(FBP) and the simultaneous iterative reconstruction technique (SIRT) methods. The numerical results are encouraging and demonstrate the benefits of the proposed methods for image reconstruction in tomography.

The permutation flow shop scheduling (PFFSP) an NP-hard combinatorial optimization problem, is one of the most widely studied production scheduling problems. In [38] a hybrid harmony search algorithm with e cient job sequence mapping scheme and variable neighborhood search (VNS), named HHS, is proposed to solve the PFFSP with the objective to minimize the makespan. First of all, to extend the HHS algorithm to solve the PFSSP electively, an efficient smallest order value (SOV) rule based on random key is introduced to convert continuous harmony vector into a discrete job permutation after fully investigating the effect of different job sequence mapping schemes. Secondly, an effective initialization scheme, which is based on NEH heuristic mechanism combining with chaotic sequence, is employed with the aim of improving the solutions quality of the initial harmony memory. Thirdly, an opposition based learning technique in the selection process and the best harmony in the pitch adjustment process are made full use of to accelerate convergence performances and improve solution accuracy. Meanwhile, the parameter sensitivity is studied to investigate the properties of HHS, and the recommended values of parameters adopted in HHS are presented. Finally, by making use of a novel variable neighborhood search, the e cient insert and swap structures are incorporated into the HHS to adequately emphasize local exploitation ability. Experimental simulations and comparisons on both continuous and combinatorial benchmark problems demonstrate that the HHS algorithm outperforms the standard HS algorithm and other recently proposed e cient algorithms in terms of solution quality and stability.

An unequal area facility layout problem (UAFLP) is a typical optimization problem that occurs when constructing an e cient layout within given areas. In [39] a harmony search based heuristic algorithm is presented to solve UAFLPs. In the manuscript the facility layout is represented as an allocation of blocks with restrictions in terms of an unequal area and rectangular shape and an e ective facility layout representation is proposed. This is done via a slicing tree representation as a form of layout structure, and via the HS based algorithm, which generates a quality solution. Once the basic HS solution is generated, modifications are introduced to facilitate improvements. Specifically, the structure of the slicing tree representation is modified, and a readjustment operation is added to diversify the possible range of solutions. A penalty scheme is also proposed to improve the feasible region searching capabilities. The e ects of the alterations are evaluated by testing well known problems from previous studies. The proposed algorithm generates the solutions as proficiently as the best results provided by previous research. The proposed method is robust in terms of process, and it determines a favorable solution within a short amount of time.

To optimize the design of aircraft panels a modified version of harmony search algorithm is proposed in [40] In order to reduce the amount of calculation, response surface method is employed, and second order polynomial with cross terms is used to construct the model. To demonstrate the advantage of the proposed algorithm, typical aircraft panels under buckling constraint are established, and several existing HS algorithms are compared. The e ects of the number of improvisation (NI) and harmony memory size (HMS) are investigated and discussed in detail. Results indicate that the proposed algorithm can provide an optimum design in a robust manner. Finally, several useful information is obtained for the design of sti ened panels with cutouts.

Misclassification costs of minority class data in real world applications can be very high. This is a challenging problem especially when the data is also high in dimensionality because of the increase in overfitting and lower model interpretability. Feature selection is a popular way to address this problem by identifying features that best predict a minority class. A novel feature selection method call SYMON which uses symmetrical uncertainty and harmony search is proposed in [41]. Unlike existing methods, SYMON uses symmetrical uncertainty to weigh features with respect to their dependency to class labels. This helps to identify powerful features in retrieving the least frequent class labels. SYMON also uses harmony search to formulate the feature selection phase as an optimization problem to select the best possible combination of features. The proposed algorithm is able to deal with situations where a set of features have the same weight, by incorporating two vector tuning operations embedded in the harmony search process. SYMON is compared against various benchmark feature selection algorithms that were developed to address the same issue. Empirical evaluation on di erent microarray data sets using G-Mean and AUC measures confirm that SYMON is a comparable or a better solution to current benchmarks.

4. Conclusion

This article introduced the recent significant developments in the structure of Harmony Search algorithm and also describes its recent state-of-the-art applications. As evidenced by a number of studies, this algorithm features several innovative aspects in its operational procedure that foster its utilization in diverse fields such as engineering, construction, telecommunications, robotics, health and energy.

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