Optimization of Geometry, Processes, Signals and Systems in Real World Engineering Problems by Cuckoo Search - A Survey of Recent Literature

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Abstract - *Cuckoo Search (CS) algorithm is a metaheuristic optimization algorithm developed by Xing-she Yang and Suash Deb in 2009. This paper explores the various research work done in application of Cuckoo Search algorithm in optimization of geometry, processes, signals and systems in real world engineering problems. Various researchers have applied Cuckoo Search algorithm in the following broad domains of computational geometry and structural optimization, scheduling and parameter optimization problems in manufacturing processes, operating point optimization for photovoltaic cells, electrical material structures and controllers, distributed resource allocation and scheduling optimization for power systems and also in signal and pattern optimization and obtained results that are of great utility. This algorithm has been found to be highly efficient, robust and precise.*

Keywords*:* *Cuckoo Search, optimization, metaheuristic, Lévy flight, engineering problem, structural optimization, manufacturing process.*

I. INTRODUCTION

A. Metaheuristics and Optimization in General Engineering

Real world engineering problem comprises of numerous variables and complex constraints and are often highly nonlinear. These constraints can be written either as simple bounds such as the ranges of material properties or as nonlinear relationships including maximum stress, maximum deflection, minimum load capacity and geometrical configuration. The result often obtained for such nonlinearity is multimodal response landscape. In general optimization problems are classified as Linear Programming, Integer Programming, Quadratic Programming, Combinatorial Optimization and Metaheuristics.

If the derivative of the objective function cannot be calculated, it gets difficult to search the optimal solution via classical optimization means. Metaheuristic algorithms are used in solving non-differentiable nonlinear-objective functions, the solution of which is either impossible or extremely difficult by using the classical optimization techniques. Genetic algorithms (GA), particle swarm optimization (PSO) are examples of modern metaheuristic algorithms. The solutions obtained by means of these methods are referred to as sub-optimal solutions because researchers are yet to propose a method which can be used to prove that a solution obtained by metaheuristic algorithms is the optimum solution.

Intensification/ exploitation and diversification/ exploration are the key features of metaheuristic algorithm. Intensification/ exploitation intend to search around the current best solutions and select the best candidates or solutions. Diversification/ exploration make sure that the algorithm can explore the search space more efficiently. A metaheuristic algorithm must be able to rapidly converge to the global optimum solution of the related objective function.

B. Cuckoo Search Optimization Algorithm

Cuckoo search (CS), nature-inspired metaheuristic optimization algorithm originally proposed by Yang and Deb in 2009[1].CS, is inspired by the brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds. Each egg (nest or cuckoo) represents a solution. A cuckoo bird's egg represents a new solution.

For simplicity, the authors consider the following rules: Firstly, each cuckoo lays one egg at a time and dumps it in a randomly chosen nest. Secondly, the eggs represent the solutions of the given optimization problem. The best nests with high quality of eggs (solutions) will carry over to the next generations. Thirdly, the number of available host nests is fixed, and a host can discover an alien egg with a probability $p_a \in [0, 1]$.

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begin
    Objective function f(x), x = (x1,x2 ..., xd)^T;
    Generate initial population of
     n host nests xi (i = 1, 2, ..., n) ;

while (t <MaxGeneration) or (stop criterion) ;
    Get a cuckoo(say i) randomly by Lévy flights ;
    Evaluate its quality/fitness Fi ;
    Choose a nest among  n (say  j) randomly;
     if (Fi > Fj ),
    Replace j by the new solution;
     end
    A fraction (pa) of worse nests are abandoned
     and new ones are built using Lévy flight ;
    Keep the best solutions
    (or nests with quality solutions);
    Rank the solutions and find the current best ;
    end while
    Post process results and visualization ;
end
```

Fig.1 Cuckoo Search Algorithm [1]

Lévy flight is used for producing new solution represented by $x_i^{(t+1)}$ where i represents the cuckoo and t represents the generation number.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus \text{Lévy}(\lambda), \quad (1)$$

where $\alpha > 0$. α represents the step size. α value is changed according to the size of the problem. Generally α value is taken as 1. The symbol $\oplus$ represents entry-wise multiplications. Lévy flights produces random walk. Random step size are calculated from a Lévy distribution for large steps

$$\text{Lévy} \sim u = t^{-\lambda}, (1 < \lambda \leq 3), \quad (2)$$

Lévy distribution has infinite variance with an infinite mean. Power-law step-length distribution with a heavy tail is followed by random walk in Lévy flight.

Compared to PSO and genetic algorithms fewer parameters (population size n and parameter p_a) need to be fine-tuned in CS. The algorithm consists of three components: selection of the best, exploitation by local random walk and exploration by randomization via Lévy flights globally. Selection assures that the best solution is passed onto the next iteration. Local random walk ensures exploitation around the best solutions

$$x^{(t+1)} = x^{(t)} + \alpha\varepsilon_t \quad (3)$$

If ε_t obeys a Gaussian distribution, this becomes a standard random walk. If ε_t is drawn from a Lévy distribution, the step of move is larger and could be potentially more efficient. There is risk that the move is too far away if the step is too large. By keeping the best solutions it makes sure that the exploitation moves are within the neighborhood of the best solutions locally. On the other hand, in order to sample the search space effectively so that new solutions generated are diverse enough, the exploration step is carried out in terms of Lévy flights. In contrast, most metaheuristic algorithms use either uniform distributions or Gaussian to generate new explorative moves (Geem, Woo, Kim and Loganathan 2001 [2], Blum and Rilo 2003 [3]). Lévy flights are usually more efficient, if the search space is large. A good combination of the above three components can thus lead to an efficient algorithm such as Cuckoo Search. CS is more generic and robust for many optimization problems compared other metaheuristic algorithms.

II. SURVEY OF RECENT LITERATURE

A. Computational Geometry and Structural Optimization

Using CS algorithm, Gandomi et al. [4] solved structural engineering design optimization problem. Results found were much better compared to the existing methods. For the inverse design of aerofoils and their subsequent shape optimization Walton et al [5] utilized the gradient free optimization technique and cuckoo search. Kanagaraja et al. [6] introduced a combination of GA and CS for solving optimization problem pertaining to structural geometry. The proposed hybrid algorithm was tested on more than ten benchmark problems and also on three recent structural geometry problems. Results showed by hybrid of CS and genetic algorithm were better in performance compared to existing algorithms usually used for these kinds of optimization problems.

Design optimization and dimensional synthesis of mechanism parameters of six bar double dwell linkages was done efficiently using cuckoo search algorithm by Bultovica et al. [7]. Kaveh and Bakhshpoori [8] compared the results obtained by the cuckoo search technique to design the space trusses to achieve least weight in them with results obtained through standard metaheuristic problem. Results showed that CS is more efficient and satisfactory.

Mohamad et al. [9] utilized CS algorithm in predicting the surface roughness produced out of abrasive water jets. They found that the solutions obtained were near optimal in predicting when the initial solutions obtained were large in number. The paired sample t-test was performed. Results showed CS outperforming over the artificial neural network and support vector machine for this surface roughness prediction.

B. Scheduling and Parameter Optimization Problems in Manufacturing Processes

Burnwall and Deb [10] applied the cuckoo search algorithm to scheduling optimization problem in order to improve the utilization of machines in standard flexible manufacturing system (FMS) and ramp up the production by decreasing the delay. The algorithm has been tested on FMS scheduling problem containing 43 jobs and 16 machines taken from literature. The authors here have customized the Lévy operator of the CS algorithm due to the discrete nature of the problem. Application of CS resulted in lesser downtime and better solutions than the basic version of GA. In another manufacturing process comprising of milling operation, CS algorithm was applied by Yildiz [11] for collection of varying but related optimal milling operator. The results obtained were compared with ant colony algorithm, immune algorithm, hybrid immune algorithm, hybrid particle swarm algorithm, genetic algorithm, etc. The analysis showed CS to be superior then other techniques. Aly and Sheta [12] applied CS to industrial metal cutting process for studying parameter estimation of nonlinear manufacturing process. They derived the conclusion that CS is more robust, accurate and effective towards finding near optimal solution as compared to genetic algorithm and swarm algorithms.

In clothing, shoe making and sheet metal industry, the complexity of sheet nesting is a crucial factor for optimum material utilization, minimum wastage and reduced material requirement. Elkeran [13] applied CS along with guided local search optimization procedure to obtain improved results. Available performance data of other algorithms were unable to compete with CS. For solving the problem of parallel machine scheduling with step-deteriorating jobs and sequence-dependent setup times, Guo et al [14] used a hybrid discrete CS algorithm. Their aim was to minimize the total delay by determining the allocation and sequence of jobs on identical parallel machines. A modified heuristic is incorporated in their algorithm for the initialization of the population to generate a good initial swarm for the CS algorithm. In order to get better quality of elite solutions, several discrete operators are incorporated in the random walk of Lévy flights and the crossover search. A local search procedure based on variable neighborhood descent is also integrated into the algorithm. Syberfeldt [15] applied the CS algorithm to maximize the utilization of machines and at the same time minimize the tied-up capital which required setting of about 50 unique decision variables in real world manufacturing process.

Asadi et al. [16] applied CS algorithm in order to minimize the total annual cost of shell-and-tube heat exchangers. Experimental result shows that CS algorithm gives superior results compared to PSO & GA.

Ravichandran et al. [17] applied Hybrid PSO-CS in parallel job shop scheduling in order to minimize the makespan. In parallel job shop scheduling, every job is allocated to predefined process line where the job is completed. All jobs allocated to a line are processed in a predefined order. The objective is to find optimal distribution of jobs in these lines. Also the specific process time and setup time are determined for optimal job order in each line. Hybrid PSO-CS shows superior results than CS and PS for parallel line job shop scheduling.

C. Operating Point Optimization for Photovoltaic cells, Electrical material structures and Controllers

Ma et al. [18] applied CS algorithm to estimate the parameters of single-diode models of photovoltaic generators used commercially. Results obtained experimentally and through simulation provided highly accurate values of the relevant parameters which are also indicated by low Root-Mean-Squared-Error values. Ahmed and Salam [19] used CS algorithm for finding maximum power point in photovoltaic systems. Voltage samples are directed towards the best solution using the Lévy distribution. The best position is found on the basis of power comparison. With almost zero oscillatory behavior in steady state, the algorithm also exhibits faster convergence. When the photovoltaic system is subjected to rapid changes of atmospheric condition, then also it tracks the maximum power point perfectly. Jovanovich [20] applied CS for improving efficiency in multiple layer cells of photovoltaic system by finding the gradient and minimization of a multi-parameter functions. She specifically optimized the splits spectrum and multi-junction photovoltaic cells by hybridization of the Nelder-Mead Simplex algorithm (NMSA) with the CS algorithm. Results showed that this hybridization is more effective than previous other hybridizations of NMSA e.g. with particle swarm optimization.

Pani et al. [21] applied Cuckoo Search algorithm in design of planar electromagnetic band gap structures. They used two dimensional planar electromagnetic band gap structures in specific frequency bands for testing and found results to be adequate. For parameter estimation of Jiles-Artherton Vector Hysteresis model required for accurate hysterical material simulation, Coelho et al. [22] have used a modified version of the multi-objective Cuckoo Search algorithm, based on Duffing's Oscillator, for parameter estimation of the Jiles-Artherton Vector Hysteresis model needed for correct hysteretic material simulation. This model is a nonlinear system with a relatively large number of variables and so the parameter determination is of high complexity. Modified version of the Cuckoo Search algorithm was used in solving the problem. The algorithm showed excellent performance when tested using benchmark data for JA model from literature.

Dash et al. [23] applied CS algorithm to optimize secondary controller gains in automatic generation control of an unequal three area thermal system with single reheat turbine and generation rate constraints. The controls obtained were better and not susceptible to loading.

Shi et al. [24] have proposed improved cuckoo search (ICS) maximum power point tracking (MPPT) method which finds the global MPPT under partial shaded conditions for photovoltaic system. Because of presence of multiple local maximum in power voltage characteristic curve under partial shaded conditions, standard MPPT are inefficient. ICS proposes new concept of low power, high power, normal and marked zone. In order to reduce search time, large step in low power and marked zone are taken. In order to improve search accuracy, small step in high power zone is used. Experimental results show that ICS can precisely and instantly track global maximum under partially shaded conditions. Results obtained by ICS were also found to be superior to that obtained by PSO, CS and P&O (Perturb and Observe).

D. Distributed Resource Allocation and Scheduling Optimization for Power Systems

Economic Load Dispatch (ELD) is a method of scheduling the required load demand among available generation units such that the fuel cost of operation is minimized. The ELD problem is formulated as a nonlinear constrained optimization problem with both equality and inequality constraints. Keeping in mind the constraints of transmission losses, multiple fuels, valve point loading and prohibited operating zones

Basu and Chowdhury [25] have applied the CS algorithm for economic load dispatch of fossil fuel powered generators. The algorithm proved to be useful for micro grid power dispatch problem also. The test results were excellent when applied on test systems. Dieu et al. [26] applied the CS algorithm for the non-convex economic dispatch problem while considering generator and system characteristics. The system characteristics includes valve-point effects, multiple fuels, prohibited zones, spinning reserve and power loss and found the approach to be cost effective compared to other methods in literature. Serapiao [27] tested the CS algorithm and six other swarm intelligence algorithms on 2 test systems. One system consisted of three-generators and other consisted of six-generator. The swarm intelligence algorithms which were tested were particle swarm optimization, shuffled frog leaping algorithm, bacterial foraging optimization, artificial bee colony, harmony search and firefly algorithm. CS algorithm gave better performance as compared to others.

With an aim for improving voltage profile and reducing power loss in distribution networks, Moravej and Akhlagi [28] applied CS algorithm for optimal distributed generation (DG) and compared their algorithm with genetic algorithm (GA) and particle swarm optimization (PSO).The performance of CS algorithm was better than rest as fewer parameters required tuning. In order to minimize real power losses, by maintaining the fault level and the voltage variation within the acceptable limit Buaklee and Hongesombut [29] used CS algorithm in optimal allocation of sizing and siting/ location of distributed generation installations in a smart distribution power grid system.

El-Fergany et al. [30] used CS algorithm to minimize system operating cost at different loading condition and enhance the system voltage profile in radial distribution network by allocation of static shunt capacitors. The algorithm was applied on the distribution network with various loading levels to find the optimal location and values of the switched and fixed capacitors. The proposed methodology was tested on the various radial distribution systems with different sizes, complexity and topology. Results showed that the precision and reliability of the algorithm was found better than the existing algorithm in the literature.

Nguyen and Truong [31] used CS algorithm to reconfigure distribution network in order to minimize power loss & maximize voltage. CS algorithm was applied on 3 distribution network system and results show that CS algorithm is better than other state-of-the-art procedures in the literature.

CS algorithm was used by Teske et al. [32] for system-level fault diagnosis (SLFD). In parallel or distributed system network, all faulty nodes detection is done by SLFD. The damaged nodes can be recognized by allowing nodes to test each other under specified conditions and carefully checking the test outcomes. CS algorithm was applied in the search space induced by SLFD in presence of t-diagnosable system which is a class of distributed systems. Results show that CS algorithm performs better than other state-of-the-art procedures present in the literature based on quality of solution and space and time complexity.

Short term hydrothermal scheduling problem was solved by Nguyen and Vo [33] by modified cuckoo search algorithm (MCSA). The aim was to minimize total cost of thermal generators such that valve point loading effects, fulfill power balance constraint, generator operating limit and water availability. Authors have modified CS algorithm in order to improve its searching capability. MCSA was tested on different systems and results outperform other methodologies available in literature in terms of quality of the solution.

Mishra et al. [34] applied modified CS algorithm in order to get maximum power flow using wind power. Cost related to wind includes reserving cost and penalty cost for not using total available wind power .Tests performed on modified IEEE 30-bus and IEEE 57-bus systems shows that MCSA outperforms PSO.

Pham et al. [35] applied Adoptive cuckoo search algorithm (ACSA) for solving economic emission load dispatch problem. ACSA gives faster convergence and quality solution in comparison to basic CS algorithm due to inclusion of two adoptive updated step size parameter in standard CS algorithm. The aim was minimizing the pollution from thermal plants and to minimize electricity generation fuel cost. ACSA was tested in two systems. One system was with 3 unit system having one load case. Another system was with six unit system and 3 load cases. Results obtained from ACSA were found to be superior than other methods present in the literature.

E. Signal and Pattern Optimization

Dey et al. [36] applied CS algorithm for optimization of scaling factors for embedding logo of concerned hospital during electrocardiogram to act as biomedical content verification system for telemedicine application.

In order to check and scrutinize the quality of the white poppy seeds and perform segmentation of black seeds, Das [37] applied Cuckoo Search along with Particle Swarm Optimization (PSO). CS algorithm was applied in image preprocessing stage to improve the image quality of the seeds. For segmentation and final outcome, to sort out impurities in terms of black seeds within white seeds PSO was used.

To overcome the problem of particle impoverishment which is generated during resampling, Walia and Kapoor [38] embedded cuckoo algorithm into particle filter for Non-linear and Non-Gaussian state estimation. It showed better results as compared to algorithm with the particle filter and PSO Particle Filter (PSO-PF).

Anoop and Rao [39] applied CS algorithm to compute the optimal mask and then combining the filtered signal units to it in order to achieve improved and enhanced speech.

Bhandari et al. [40] applied a combination of CS algorithm and DWT-SV (Discrete Wavelength Transform-Singular Value Decomposition) for enhancement of quality of low contrast satellite images. DWT divided the input image into 4 frequency subbands. Next each subband is optimized with the help of CS algorithm and gets a singular value matrix of low threshold subband image. Then IDWT (Inverse DWT) is applied to get the reconstructed enhanced image. Intensity information of the image is used to get the singular value matrix. The intensity of the image changes with the change in the singular value. Results show that the algorithm outperforms other methods namely GHE (General Histogram Equalization), DCT-SVD (Discrete Cosine Transform-Singular Value Decomposition) and DWT-SV in terms of PSNR (Peak signal to noise ratio), MSE (Mean square error), mean and standard deviation.

Identifying brain tumor is extremely challenging due to brain’s complex structure. George et al. [41] applied CS algorithm for brain tumor segmentation from MRI (Magnetic Resonance Images). Generally the radiologist examines the MRI in order to detect brain tumor which takes major amount of the time. The main objective is to develop a diagnostic system which would help the radiologist to confirm the presence or absence of tumor. Experimental results show that CS algorithm is effective in detecting brain tumor.

Naik and Panda [42] has proposed an adoptive cuckoo search (ACS) algorithm which is faster than CS algorithm. In ACS, step size is modified based on current position in search space and fitness value. ACS is parameter free i.e. without Lévy step. ACS along with principal component analysis (PCA) and intrinsic discriminant analysis (IDA) are used for effective face recognition. Proposed algorithm is mainly divided into two parts i) PCA+IDA which provides dimension reduction ii) ACS+IDA which is used to find optimal feature vectors for grouping of facial images on the basis of basic IDA. Algorithm was tested on three standard face databases—YALE, ORL, and FERET. Results show that ACS outperforms other algorithm present in literature.

F. Other Application Areas

Gupta et al. [43] applied CS algorithm to detect the presence of groundwater in any area .CS algorithm was used to process the data on geographical attributes. Geographical attributes includes landform, soil, lineament, geology, land use and slope of any area. With the help of these attribute intensity of groundwater of an area is calculated and categorized as high, moderate and low.

With a view to identify the health and safety risk of individual, Khan and Sahai [44] proposed a neural-swarm cuckoo search (NSCS) algorithm and analyzed health and safety (HS) risk index. Employee HS risk severity can be of four types: low, moderate, high and extreme HS risk. HS risk severity is calculated with the help of nine HS dimensions: work organization, displays, input devices, furniture, work space, environment, software, health hazards and satisfaction.

Li and Yin [45] proposed PSCS algorithm which is a combination of PSO and CS algorithm. PSCS was tested on 30 benchmark functions and results show that PSCS is superior to basic CS algorithm, PSO and many evolution algorithms present in literature. PSCS inspired by PSO uses global best solution of the population. In PSO, global best solution of the population is used to decide the new location of the particle in each iteration .In CS algorithm, global best solutions is stored in each iteration which increases global and local search abilities of PSCS. The PSO increases the diversity in the algorithm and CS algorithm keeps the balance between exploitation and exploration with the help of random probability. PSCS solves real-world problems like spread spectrum radar poly-phase code design problem and the chaotic system very efficiently.

Grey theory is a multidisciplinary and generic theory. It deals with systems that have poor or insufficient information. Qu et al. [46] using CS algorithm, have proposed an adaptive multi-variable optimized grey model with the analysis of shortages of GM (1,1) model and on the basis of grey prediction modeling theory. GM (1,1) is a basic simple structured grey scale prediction model. Using interrelated features among many related reduction feature information, the proposed model recreates whitening background values and initial conditions. Experimental results shows that the proposed model have high accuracy and is very practical in use.

III. CONCLUSION

The applications of Cuckoo Search optimization algorithm in a range of engineering optimization problems have shown promising efficiency. CS algorithm is helpful in attaining improved, robust, efficient and effective solutions for a range of real life design and engineering problems. It has been observed that Cuckoo Search optimization algorithm is better when compared to other optimization algorithms. This powerful optimization algorithm can effortlessly be utilized in studying multi objective optimization applications with various constraints, including NP - hard problems. Future studies can be extended to the sensitivity and parameter studies and their possible relationships with the convergence rate of the algorithm.

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