# Gravitational Search Algorithm: A Review

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***Abstract*—**Large number of evolutionary and swarm based algorithms have been proposed earlier to solve different problems in every area of engineering and science. These algorithms provide the better results in every field as compared to classical methods. There are different nature inspired algorithms to solve optimization problems. Some of the nature inspired algorithms are Particle Swarm Optimization, Genetic Algorithm, Ant Bee Colony and Firefly Algorithm. Recently, Gravitational Search Algorithm has been developed by Rashedi et al. in 2009 which follows Newton's law of gravity. GSA applied for large number of problems which includes binary optimization problems, unimodal optimization, clustering, Fuzzy systems, control systems, Qos, parameter identification etc. This paper gives the outlook on Gravitational Search algorithm and also the previous work using GSA has been studied.

***Keywords*—***gravitational search algorithm; nature inspired; optimization*

## I. INTRODUCTION

There is a big challenging problem of real time optimization and to solve this problem different optimization tools have to be used. But these tools do not provide optimal solution of the problem. Therefore, different optimization techniques are used to solve these optimization problems. Nature has inspired a lot of researchers, so most of the algorithms are nature-inspired [1]. These nature inspired algorithms use multiple interacting agents and are called metaheuristic algorithms. These algorithms have swarm intelligence characteristics of biological agents such as fishes, human, birds etc. These algorithms are popular because of its versatility and efficiency and these algorithms also deal with the complex optimization techniques [2]. Some examples of nature based algorithms are Particle Swarm optimization, Firefly algorithm, Genetic Algorithm Human Opinion Dynamics based Optimization, Bat Algorithm, Water drops Algorithm and cuckoo search.

In 1995, Dr. Eberhart and Dr. Kennedy developed the Particle Swarm Optimization technique which is population based metaheuristic. It is used to solve various optimization problems. In PSO, there is a particle in a search space and they all have fitness value which can be calculated by using fitness function. The velocity can be calculated by using flying of the particles [3]. Genetic Algorithm is firstly proposed by John Holland which is heuristic algorithm and based on theory of genes. Each individual is encoded with chromosome in it [4]. In 2010, new metaheuristic technique called Bat Algorithm has been proposed which is based on echolocation behavior of bats [5].

In 2007, Shah-Hosseini introduced the new algorithm called Intelligent Water Drops Algorithm which is the nature inspired algorithm. Mostly in rivers, the flows of water drops are observed. Swarm of water drops creates the path so that the river flows [6]. In [7], Artificial Bee Colony Algorithm was proposed to solve the parameter identification problem. Artificial Bee Colony Algorithm is swarm based which is inspired by honey bee foraging. Human Opinion Dynamics based Optimization is used to tune the Extended Kalman Filter which is based on social impact theory. It is inspired by Durkheim's theory of social integration [8]. In [9], new plant propagation algorithm is proposed. In this plant propagation algorithm, strawberry plant has been taken and its propagation strategy has been observed. There are much more algorithms which are nature inspired such as Ant algorithms based on foraging behavior of social ants, Firefly based on flashing patterns and behavior of fireflies, Harmony search inspired from music, Cuckoo search based on brood parasitism of some cuckoo species etc. These all algorithms are discussed in [10].

In 2007, Rashedi developed a new optimization technique called Gravitational Search Algorithm. In [11], this new technique has been introduced by Rashedi et al. This technique is based on Newtonion law of gravity in which agents are the objects and using their mass, the performance is measured. All the objects attract each other by force of gravity. In this paper, Gravitational Search Algorithm has been discussed and also its hybridization forms are studied.

## II. GRAVITATIONAL SEARCH ALGORITHM

GSA is a population based algorithm which is based on Newtonian law of gravitation, and it was firstly proposed by Rashedi in 2007. In Gravitational Search Algorithm, agents are treated as objects and the performnace of these agents can be considered by their masses [12].

The velocity and position of objects in GSA are randomly initialized. The inertial mass of $i^{th}$ particle should be calculated using the given equations in which t is time, and the mass is $\mathcal{M}_i(\mathrm{t})$:

$$c_i(\mathrm{t}) = \frac{fitness_i(\mathrm{t}) - pworst(\mathrm{t})}{pbest(\mathrm{t}) - pworst(\mathrm{t})} \quad (1)$$

$$\mathcal{M}_i(\mathrm{t}) = \frac{c_i(\mathrm{t})}{\sum_{j=1}^{\aleph} c_i(\mathrm{t})} \quad (2)$$

Where, $\aleph$ denotes population size, $c_i(\mathrm{t})$ indicates a central variable in particle mass computation, $fitness_i(\mathrm{t})$ shows fitness value at time t of $i^{th}$ particle, $pbest(\mathrm{t})$ and $pworst(\mathrm{t})$ denotes the best fitness value and worst fitness value at time t.

For minimization problems the $pbest(t)$and $pworst(t)$ are defined as:

$$pbest(t) = \min_{j\epsilon\{1,\dots,N\}} fitness_j(t) \quad (3)$$

$$pworst(t) = \max_{j\epsilon\{1,\dots,N\}} fitness_j(t) \quad (4)$$

For maximization problems the $pbest(t)$ and $pworst(t)$ are defined as:

$$pbest(t) = \max_{j\epsilon\{1,\dots,N\}} fitness_j(t) \quad (5)$$

$$pworst(t) = \min_{j\epsilon\{1,\dots,N\}} fitness_j(t) \quad (6)$$

The mutual gravitational force which is striking from $j^{th}$ particle to $i^{th}$ particle at time t in the d dimension can be defined as:

$$F_{ij}^{d}(t) = G(t)\frac{M_i(t) \times M_j(t)}{D_{ij}(t) + \varepsilon}(y_j^{d}(t) - y_i^{d}(t) \quad (7)$$

where, $y_j^{d}(t)$ and $y_i^{d}(t)$ represents the positions of $i^{th}$ and $j^{th}$ particle in the d dimension at t time, $\varepsilon$ denotes tiny small positive constant, $D_{ij}(t)$ denotes the Euclidian distance between $i^{th}$ and $j^{th}$ particle at time t ,

$$D_{ij}(t) = \left\|y_i(t), y_j(t)\right\|_2 \quad (8)$$

Gravitational Constant $\hat{G}(t)$ can be described as,

$$\hat{G}(t) = G_O e^{-\beta\frac{t}{T}} \quad (9)$$

here $G_o$ and $\beta$ are constant, and T denotes maximum iteration.

Next, the acceleration of $i^{th}$ particle can be evaluated at time t in each dimension. To impose a speculative characteristic to GSA, random variable $rand_j$is multiplied by $F_{ij}^{d}(t)$. $rand_j$ denotes a random figure in the interval [0, 1].

Assuming the entire force imposing on $i^{th}$ object is the whole sum of all other objects in the dimension d,

$$a_i^{d}(t) = \frac{\sum_{j=1,j\neq i}^{N} rand_j F_{ij}^{d}(t)}{M_{ii}(t)} \quad (10)$$

Where, $M_{ii}(t)$ represents the inertia mass of $i^{th}$ particle at time t, $a_i^{d}(t)$ denotes the acceleration of $i^{th}$ particle in $d^{th}$ dimension at time t, $M_{ii}(t)$ equals to $M_i(t)$.

Next, the velocity, and position of the $i^{th}$ object is updated as,

$$v_i^{d}(t+1) = rand_0 \times v_i^{d}(t) + a_i^{d}(t) \quad (11)$$

$$y_i^{d}(t+1) = y_i^{d} + v_i^{d}(t+1) \quad (12)$$

where, the interval [0, 1] $rand_0$ denotes uniform random variable, $v_i^{d}(t)$denotes the velocity and $y_i^{d}(t)$ denotes the position of the $i^{th}$ object at time t in the d dimension.

## III. RELATED WORK

Rashedi et al. introduced the new heuristic optimization technique i.e. Gravitational Search Algorithm in 2009. This technique is based on the Newton's law of gravity in which searcher agents interact with each other and the performance is measured by their masses. The proposed algorithm is then compared with Particle Swarm Optimization (PSO) which is stochastic search algorithm, Real Genetic Algorithm (RGO), and Central Force Optimization (CFO) which is deterministic algorithm theoretically and using benchmark functions. Gravitational Search Algorithm gives satisfied results as compared to other algorithms [11].

In 2010, Rashedi et al. uses Gravitational Search Algorithm for linear and non linear filter modelling. Basically there are two types of filters, analog and digital. Then the digital filters are classified into two types: linear and non linear. Digital filters are used in different areas such as image processing, signal processing, control systems, system modelling etc. So, the author uses the proposed GSA to model linear i.e. infite impulse response and nonlinear systems and then the results are compared with the Genetic algorithm and PSO. The proposed algorithm gives satisfactory results to solve complex problems as compared to GA and PSO [14].

In [15], Gravitational Search Algorithm is used in fuzzy systems tuning. The tuning of fuzzy control systems is important to improve the performance of the systems. GSA is also used to solve the optimization problems which minimize the discrete time objective functions. But there is one problem of GSA that it not guaranteed the global minimum. In 2011, Gravitational Search Algorithm is proposed to solve the optimization problem of the web services based on Quality of Services. Firstly, a fitness function is designed and the concept of optimization is presented and then the model is proposed. After that, the GSA is compared with the PSO and it shows that GSA can find ideal user in least time and with least memory usage than PSO [16]. In [19], the formal convergence analysis of the Gravitational Search Algorithm is presented. Also, the randomness, time varying parameters and interaction between parameters are of the GSA are considered.

Duman et al. (2012) proposed the Gravitational Search Algorithm to find optimal solution for optimal flow power problem in power systems. GSA is tested on the IEEE 30-bus and IEEE 57-bus test systems. Then the proposed algorithm is compared with the previously used techniques [20]. In [21], Gravitational search Algorithm is used for classification in multi-class data sets. GSA is used for data classification of some benchmark datasets. Then, the performance of GSA is compared with the Artificial Bee Colony and PSO. In [30], Gravitational Search Algorithm is proposed to solve the non-convex combined heat and power economic dispatch problems. This algorithm is tested on some study cases i.e. modeling of valve point effect and transmission losses. Then, the results obtained from GSA are compared with other techniques to show its ability.

Table 1 shows the list of Gravitational Search Algorithm that is used in different areas.

TABLE I. List of GSA used in different areas

| Year | Authors | Problem | Performance Metrics |
|---|---|---|---|
| 2009 | Rashedi et al. [11] | Optimization problems | 23 nonlinear benchmark functions |
| 2010 | Chatterjee et al. [13] | Synthesis of thinned scanned concentric ring array antenna | Fitness value, computational time |
| 2011 | Rashedi et al. [15] | Parameter estimation problem for linear and non-linear filters | Unimodal and multimodal benchmark functions |
| 2011 | Precup et al. [16] | Fuzzy control system tuning | Minimized objective functions |
| 2011 | Zibanezhad et al. [17] | Qos based web service selection problem | Qualitative parameters |
| 2012 | Swain et al. [18] | Economic load dispatch problem | 3 and 13 thermal units of ED |
| 2012 | Khajehzadeh et al. [19] | Optimization of retaining structures | 2 numerical examples |
| 2012 | Ghorbani et al. [20] | Convergence behavior | Time varying parameter |
| 2012 | Duman et al. [21] | Optimal power flow problem | IEEE 37 and 57- bus test systems |
| 2012 | Bahrololoum et al. [22] | Classification and clustering in multi-class data seta | Benchmark datasets |
| 2012 | Duman et al. [23] | Optimal solution for Combined Economic and Emission Dispatch | 4 test systems |
| 2012 | Roy et al. [24] | Multi-objective optimal reactive power dispatch problems | IEEE 57 and 188-bus power systems |
| 2012 | Duman et al. [25] | Reactive power dispatch problem | IEEE 30, 57 and 118-bus systems |
| 2013 | Mondal et al. [26] | Economic emission load dispatch problem | IEEE 30-bus test system |
| 2013 | Provas Kumar Roy [27] | Thermal unit commitment problem | 6 systems having 10,20,40,60,80 and 100 units |
| 2014 | Sarker et al. [28] | Multiple unified power flow controller | Standard test systems and real life power system |
| 2015 | Shuaib et al. [29] | Optimal capacitor placement in radial distribution system | Radial distribution network |
| 2016 | Ahmad et al. [30] | Application in reservoir optimization | Own unique capability |
| 2016 | Beigvand et al. [31] | Combined heat and power economic dispatch problem | Modeling of valve-point loading effect and transmission losses |

## IV. MODIFICATIONS AND HYBRIDIZATIONS IN GSA

Different modifications and hybrid forms of GSA had been proposed in different areas.

### *A. Modifications in GSA*

Various modifications have been done in GSA to use it in different areas to enhance its performance. There are various versions of GSA that are used i.e. binary, chaotic, discrete, non-dominated, multi-objective, quantum inspired, grouping, disruption, fuzzy etc. In Table II, different modifications of Gravitational Search Algorithm have been presented.

TABLE II. MODIFICATIONS IN GSA

| Year | Author | Technique | Problem | Performance metrics |
|---|---|---|---|---|
| 2010 | Hassanzadeh et al. [32] | Multi-objective GSA | several objective optimization problems | Benchmark functions |
| 2011 | Li et al. [33] | Improved GSA | Parameter identification of hydraulic turbine governing system | 7 key parameters |
| 2011 | Nobahari et al. [34] | Non-diminated Sorting GSA | Muti-objective optimization | Benchmark functions |
| 2011 | Sarafrazi et al. [35] | Disruption based GSA | Explore and exploit the search space of GSA | 23nonlinear benchmark functions |
| 2012 | Shaw et al. [36] | Opposition based GSA (OGSA) | Economic and emission dispatch problems of power systems | 23 benchmark test functions |
| 2012 | Precup et al. [37] | Adaptive GSA | Optimal tuning of fuzzy controlled system | Takagi-Sugeno proportional integral fuzzy controllers |
| 2012 | Li et al. [38] | Chaotic GSA | Parameter identification of chaotic function | Offline and online parameter identification of Lorenz system, optimal objective function, convergence |
| 2012 | Rashedi et al. [39] | Binary GSA | Feature selection of Content-based image retrieval | 1000 color images from Corel database, precision |
| 2012 | Khajehzadeh et al. [40] | Modified GSA | Slope stability analysis | Reliability assessment model |
| 2013 | Gu et al. [12] | Modified GSA | Enhance particle memory ability | 12 standard benchmark functions |
| 2013 | Sombra et al. [41] | GSA using fuzzy logic | To change alpha parameter and improve performance | Benchmark functions |

| | | | | |
|---|---|---|---|---|
| 2013 | Ghasemi et al. [42] | Fuzzy GSA | Optimal design of multimachine power system stabilizers | 3-machine 9-bus system and 10-machine 39-bus system |
| 2014 | Yazdani et al. [43] | Niche GSA | Multimodal optimization | Several experiments |
| 2014 | Mohadeseh et al. [44] | Quantum inspired GSA | Numerical function optimization | 25 standard benchmark functions |
| 2014 | Chen et al. [45] | Improved GSA | Parameter identification of water turbine regulation system (WTRS) | Example of parameter identification of WTRS |
| 2014 | Tian et al. [46] | Non-dominated sorting GSA with chaotic mutation | Short-term economic/environmental hydrothermal scheduling | Fuel cost, emission, discharge |
| 2014 | Ji et al. [47] | Improved GSA | Unit commitment | 2 UC test functions |
| 2014 | Dowlatshahi et al. [48] | Grouping GSA | Data clustering problem | 13 Benchmark datasets from UCI machine learning repository |
| 2015 | Roy et al. [49] | Quasi-oppositional GSA | Short term hydrothermal scheduling problems | 2 test systems having non-convex solution |
| 2015 | Nezamabadi-pour et al. [50] | Binary quantum-inspired GSA (BQIGSA) | Binary encoded optimization | Combinatorial 0-1 knapsack problems, max-ones and royal-road functions |
| 2015 | Li et al. [51] | Improved multi-objective GSA (IMOGSA) | Short-term economic environmental hydrothermal scheduling | Two case studies |
| 2015 | Gouthamkumar et al. [52] | Disruption based GSA | Short-term hydrothermal scheduling | 2 hydrothermal test systems |
| 2016 | Farivar et al. [53] | Modified GSA | Particle dynamics and stability analysis of GSA | Average, median and S.D |
| 2016 | Precup et al. [54] | GSA based evolving Fuzzy models | Non-linear process | Pendulum-crane laboratory equipment |
| 2016 | Xiao et al. [55] | Improved GSA | Green partner selection in virtual enterprises | Effectiveness |

### *B. Hybridizations in GSA*

Gravitational Search Algorithm has been combined with other algorithms i.e., PSO, K-means, Artificial Bee Colony, Clustering Algorithm, Pattern Search Algorithm, Genetic Algorithm etc. to improve the performance in different areas. Table III shows the list of different hybrid forms of GSA.

TABLE III. HYBRID FORMS OF GSA

| Year | Author | Technique | Problem | Performance metrics |
|---|---|---|---|---|
| 2010 | Mirjalili et al. [56] | Hybrid PSO-GSA | Synthesize PSO and GSA | 23 standard benchmark functions |
| 2011 | Yin et al. [57] | Improved GSA- K- Harmonic means (IGSAKHM) | Clustering | 7 datasets |
| 2011 | Hatamlou et al. [58] | GSA and Heuristic search algorithm (GSA-HS) | Clustering problem | 4 benchmark datasets |
| 2012 | Mirjalili et al. [59] | Feedforward neural networks using PSO-GSA (FNNPSOGSA) | Trapping problem | 3 benchmark functions |
| 2012 | Li et al. [60] | GSA based Hyper-plane clustering Algorithm (GSHPC) | Improve performance of fuzzy clustering algorithm | 4 simulation experiments |
| 2012 | Guo et al. [61] | GSA-ABC | Improve search mechanism | 5 benchmark functions |
| 2012 | Doraghinejad et al. [62] | Black hole operator based GSA | Unimodal problems | 7 benchmark unimodal functions |
| 2013 | Mallick et al. [63] | Hybrid Improved PSO-GSA (IPSOGSA) | Static state estimation | 5 IEEE standard test systems |
| 2014 | Mirjalili et al. [64] | Binary PSO-GSA | Binary optimization problems | 22 benchmark functions i.e. unimodal, multimodal and composite |
| 2014 | Jiang et al. [65] | Hybrid PSO-GSA | Economic emission load dispatch | Canonical benchmark test functions |
| 2015 | Sahu et al. [66] | GSA and Pattern Search (GSA-PS) | Load frequency control of multi-area power system | Controller parameters |
| 2015 | Dickson et al. [67] | Feature selection method based on multi-objective optimization with GSA (FSMOGSA) | Classification problem | Error rate |
| 2016 | Sun et al. [68] | GSA-GA | Multi-level thresholding | 6 test images |
| 2016 | Yidiz et al. [69] | GSA and Nelder-Mead Algorithm (GSA-NMA) | Crash performance of vehicles | Maxim0um peak force and weight |
| 2016 | Das et al. [70] | Hybrid improved PSO and Improved GSA | Multi-robot path planning | Khapera environment |

## V. CONCLUSION

In this paper, Gravitational Search Algorithm has been studied and also its modifications and hybrid forms are studied thoroughly. In the study, it is concluded that the GSA was used in every field of science and engineering. GSA can be combined with other algorithms to get better performance and also its modified forms can be used in different fields. At the time of writing, various modifications are applied to GSA in different fields which includes neural networks, clustering, classification, multi-0objective optimization, parameter identification, scheduling problems, filter modeling etc. In future, GSA should be more explored and it should be used with more algorithms to get better performance.

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