Int. J. Advance. Soft Comput. Appl., Vol. 5, No. 3, November 2013
ISSN 2074-8523; Copyright © SCRG Publication, 2013

A Review of Gravitational Search Algorithm

Norlina Mohd Sabri, Mazidah Puteh, and Mohamad Rusop Mahmood

Faculty of Computer and Mathematical Sciences
Universiti Teknologi MARA (Terengganu), Dungun, Terengganu, Malaysia
e-mail: norli097@tganu.uitm.edu.my

Faculty of Computer and Mathematical Sciences
Universiti Teknologi MARA (Terengganu), Dungun, Terengganu, Malaysia
e-mail: mazidahputeh@tganu.uitm.edu.my

NANO-ElecTronic Centre, Faculty of Electrical Engineering
Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia
e-mail: rusop@salam.uitm.edu.my

Abstract

Gravitational Search Algorithm (GSA) is a recent algorithm that has been inspired by the Newtonian's law of gravity and motion. Since its introduction in 2009, GSA has undergone a lot of changes to the algorithm itself and has been applied in various applications. At present, there are various variants of GSA which have been developed to enhance and improve the original version. The algorithm has also been explored in many areas. Nevertheless, it is still unknown how much the algorithm has evolved and how far the research and development has been done since its introduction. Hence, this paper is intended to dig out the algorithm's current state of publications, advances, its applications and discover its future possibilities. This review is expected to provide an outlook on GSA especially for those researchers who are keen to explore the algorithm's capabilities and performances.

Keywords: *Applications, Gravitational Search Algorithm, Hybridization, Modifications, Review.*

1 Introduction

GSA is a heuristic optimization algorithm which has been gaining interest among the scientific community recently. GSA is a nature inspired algorithm which is based on the Newton's law of gravity and the law of motion [1]. GSA is grouped under the population based approach and is reported to be more intuitive [2]. The algorithm is intended to improve the performance in the exploration and exploitation capabilities of a population based algorithm, based on gravity rules. However, recently GSA has been criticized for not genuinely based on the law of gravity [3]. GSA is reported to exclude the distance between masses in its formula, whereas mass and distance are both integral parts of the law of gravity. Despite the criticism, the algorithm is still being explored and accepted by the scientific community.

This paper is intended to explore GSA in order to determine how much the algorithm has evolved and how far the research and development has been done since the introduction of the algorithm. The objectives of the paper are to analyzed the works related to GSA, to review GSA advances and its performances, to review the applications and finally to bring out the future challenges and possibilities.

The paper is organized as follows. Section 2 presents a brief review on GSA while section 3 provides the review methodology for carrying out the literature study. Section 4 summarizes GSA advancements and section 5 presents the algorithm's applications. Finally, section 6 presents the discussion and the possible path for future research in GSA.

2 GSA: A Brief Review

GSA was introduced by Rashedi et al. in 2009 and is intended to solve optimization problems. The population-based heuristic algorithm is based on the law of gravity and mass interactions. The algorithm is comprised of collection of searcher agents that interact with each other through the gravity force [1]. The agents are considered as objects and their performance is measured by their masses. The gravity force causes a global movement where all objects move towards other objects with heavier masses. The slow movement of heavier masses guarantees the exploitation step of the algorithm and corresponds to good solutions. The masses are actually obeying the law of gravity as shown in Equation (1) and the law of motion in Equation (2).

$$F = G\,(M_1 M_2 / R^2) \tag{1}$$

$$a = F/M \tag{2}$$

Based on Equation (1), F represents the magnitude of the gravitational force, G is gravitational constant, M_1 and M_2 are the mass of the first and second objects and R is the distance between the two objects. Equation (1) shows that in the Newton law of gravity, the gravitational force between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between the objects. While for Equation (2), Newton's second law shows that when a force, F, is applied to an object, its acceleration, a, depends on the force and its mass, M.

In GSA, the agent has four parameters which are position, inertial mass, active gravitational mass, and passive gravitational mass [1]. The position of the mass represents the solution of the problem, where the gravitational and inertial masses are determined using a fitness function. The algorithm is navigated by adjusting the gravitational and inertia masses, whereas each mass presents a solution. Masses are attracted by the heaviest mass. Hence, the heaviest mass presents an optimum solution in the search space. The steps of GSA are as follows:

Step 1: Agents initialization:

The positions of the N number of agents are initialized randomly.

$$X_i = (x_i^1, \ldots x_i^d, \ldots, x_i^n), \text{ for } i = 1,2,..,N. \tag{3}$$

x_i^d represents the positions of the i^{th} agent in the d^{th} dimension, while n is the space dimension.

Step 2: Fitness evolution and best fitness computation:

For minimization or maximization problems, the fitness evolution is performed by evaluating the best and worst fitness for all agents at each iteration.

Minimization problems:

$$best(t) = \min_{j \in \{1,\ldots,N\}} fit_j(t) \tag{4}$$

$$worst(t) = \max_{j \in \{1,\ldots,N\}} fit_j(t) \tag{5}$$

Maximization problems:

$$best(t) = \max_{j \in \{1,\ldots,N\}} fit_j(t) \tag{6}$$

$$worst(t) = \min_{j \in \{1,\ldots,N\}} fit_j(t) \tag{7}$$

$fit_j(t)$ represents the fitness value of the j^{th} agent at iteration t, $best(t)$ and $worst(t)$ represents the best and worst fitness at iteration t.

Step 3: Gravitational constant (*G*) computation:

Gravitational constant G is computed at iteration t [4].

$$G(t) = G_0 e^{(-\alpha t/T)} \tag{8}$$

G_0 and α are initialized at the beginning and will be reduced with time to control the search accuracy. T is the total number of iterations.

Step 4: Masses of the agents' calculation:

Gravitational and inertia masses for each agent are calculated at iteration t.

$$M_{ai} = M_{pi} = M_{ii} = M_i, \quad i = l, 2, \ldots, N. \tag{9}$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \tag{10}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{11}$$

M_{ai} and M_{pi} are the active and passive gravitational masses respectively, while M_{ii} is the inertia mass of the ith agent.

Step 5: Accelerations of agents' calculation:

Acceleration of the ith agents at iteration t is computed.

$$a_i^d(t) = F_i^d(t) \,/\, M_{ii}(t) \tag{12}$$

$F_i^d(t)$ is the total force acting on ith agent calculated as:

$$F_i^d(t) = \sum_{j \in Kbest,\, j \neq i} rand_j \, F_{ij}^d(t) \tag{13}$$

Kbest is the set of first K agents with the best fitness value and biggest mass. *Kbest* will decrease linearly with time and at the end there will be only one agent applying force to the others.

$F_{ij}^d(t)$ is computed as the following equation:

$$F_{ij}^d(t) = G(t).(M_{pi}(t) \times M_{aj}(t) \,/\, R_{ij}(t) + \varepsilon).(x_j^d(t) - x_i^d(t)) \tag{14}$$

$F_{ij}^d(t)$ is the force acting on agent i from agent j at d^{th} dimension and t^{th} iteration. $R_{ij}(t)$ is the Euclidian distance between two agents i and j at iteration t. $G(t)$ is the computed gravitational constant at the same iteration while ε is a small constant.

Step 6: Velocity and positions of agents:

Velocity and the position of the agents at next iteration (t+1) are computed based on the following equations:

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \tag{15}$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{16}$$

Step 7: Repeat steps 2 to 6

Steps 2 to 6 are repeated until the iterations reach their maximum limit. The best fitness value at the final iteration is computed as the global fitness while the position of the corresponding agent at specified dimensions is computed as the global solution of that particular problem. Fig. 1 shows the flowchart of GSA.

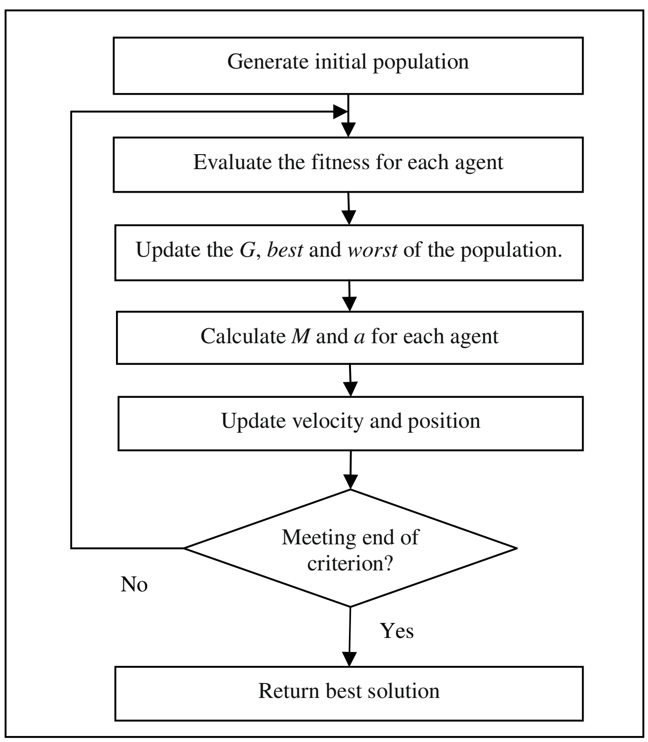

Fig. 1 Flowchart of GSA

3 Review Methodology and Analysis

This section presents the methodology for the review and analysis on the publication papers. A total number of 128 GSA related papers had been collected and analyzed to acquire information on the number of publications according to year, which journals and also which countries' institutions that have been contributed to the development of GSA.

3.1 The methodological approach

The publication papers, which involved journal papers and conference proceedings in this review, were gathered from several scientific journals and conferences. The papers were collected from selected online databases which were Compendex, IEEE Explore, ScienceDirect-Elsevier, Scientific.Net, SciVerse Hub and Springer Online Journal Collection.

The keyword used in the search was limited to 'gravitational search algorithm'. The first collection of papers had gathered over hundreds of publication papers. After eliminating few unrelated and redundant papers, only 128 of them which were specifically related to GSA were kept for this review. Out of these 128 publications, around 56 of them are related to modifications or hybridizations of GSA, while the remaining papers can be classified as applications of GSA. All of the selected papers were collected between the years 2009 until 2013 following the introduction of the algorithm in 2009. Fig. 2 shows the flow of the review process.

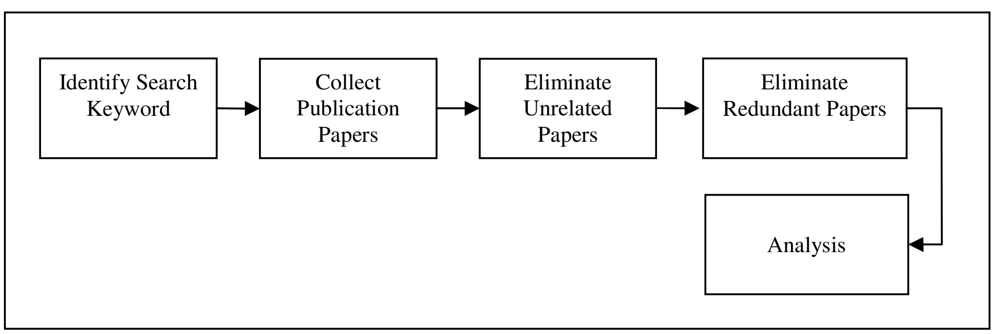

Fig. 2 Flow of the review process

3.2 Current State of Publication

In this section, the publication papers were analyzed in order to provide an outlook into the current state of GSA related publications. Fig. 3 shows the number of publication papers according to years starting from 2009 to 2012.

Based on Fig. 3, it could be seen that the undergoing research in GSA is still in its early stage. However, the number of GSA related publications had been increasing since 2009 until 2012.

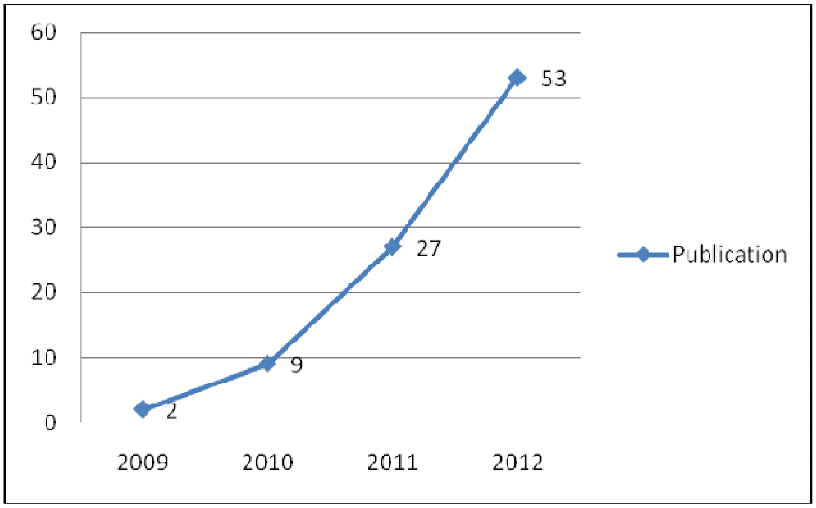

Fig. 3 Number of publication papers from 2009 to 2012

Out of 91 publication papers from 2009 to 2012, 55 of the papers were collected from journals while the remaining 36 papers were from conference proceedings. Table 1 shows the journals that had contributed to GSA publications up to year 2012. It could be seen that GSA research had been published in various scientific journals. Engineering Applications of Artificial Intelligence, Energy Conversion and Management, Scientia Iranica and Neural Computing & Application are among the journals that had contributed most to GSA publications.

Table 1. Contribution from journals to GSA research

No	Journals/Proceedings	No. of Paper
1	Energy Conversion and Management	3
2	Electrical Review	1
3	Applied Soft Computing	2
4	Electric Power Components and Systems	1
5	Engineering Applications of Artificial Intelligence	4
6	Scientia Iranica	3
7	International Review of Electrical Engineering	2
8	Neural Computing & Application	2
9	Information Sciences	3
10	Procedia Technology	1
11	IEEE Transactions On Fuzzy Systems	1

12	Applied Energy	1
13	Swarm and Evolutionary Computation	1
14	Simulated Evolution and Learning	1
15	IET Generation, Transmission & Distribution	2
16	Science China Technological Sciences	1
17	Journal of Central South University	1
18	Energy	2
19	IEEE Transactions On Industrial Informatics	1
20	International Journal of Computer Applications	1
21	Advances in Intelligent and Soft Computing	1
22	Knowledge-Based Systems	1
23	International Journal of Bio-Inspired Computation	1
24	Electrical Power and Energy Systems	2
25	Advances in Computational Intelligence	1
26	Applications of Evolutionary Computation	1
27	Mathematical and Computer Modelling	1
28	Engineering and Technology, Issue 49, January 2011	1
29	Expert Systems with Applications	1
30	Rough Sets and Knowledge Technology	1
31	Advanced in Control Engineering and Information Science	1
32	Energy Procedia	1
33	International Journal of Machine Learning and Cybernetics	1
34	Progress In Electromagnetics Research B	1
35	Natural Computing	2
36	Applied Mathematics and Computation	1
37	International Journal of Digital Content Technology and its Applications	1
38	Chaos, Solitons & Fractal	1
39	IEEE Computing in Science & Engineering	1
	Total	**55**

Another part of the analysis is to obtain the number of publications from countries of the institutions that have contributed to the research of GSA from 2009 until 2012. In this analysis, the institutions of the authors were traced in order to obtain the necessary data. Table 2 shows the countries, number of publications and the percentage of publications according to the countries.

Table 2 Number of GSA publications from countries of institutions

No.	Countries of Institutions	No. of Publication	Percentage
1	Iran	27	28.72
2	India	15	15.96
3	China	14	14.89
4	Malaysia	11	11.70

5	Turkey	11	11.70
6	Romania	5	5.32
7	Brazil	2	2.13
8	Spain	2	2.13
9	Estonia	1	1.06
10	United Kingdom	1	1.06
11	Netherland	1	1.06
12	Indonesia	1	1.06

Based on Table 2, GSA research is dominated by Iran which has contributed nearly 29% of total publications. This is followed by China, India, Malaysia and Turkey which have contributed more than 10% from overall publications. Other contributions are from Romania, Brazil, Spain, Estonia, United Kingdom, Netherland and Indonesia.

4 GSA Advancement

4.1 Modifications

GSA has widely been improved since its introduction in 2009. Various techniques have been adapted in order to enhance GSA performance ever since. Table 3 illustrates all of the modifications that have been done since then. The various versions of GSA that have been developed among others are chaotic, binary, multi-objective, quantum and constrained GSA. The performance of the enhanced GSA was also compared with the original GSA and with other well known algorithm such as PSO and GA.

Table 3. Modifications of GSA

Author	Technique	Modification	Problem	Result	Ref.
Yazdani, Nezamabadi-pour, Kamyab	Niche GSA (NGSA)	Divide main swarm of masses into smaller sub-swarms. Introduce 3 strategies; K-nearest neighbors (K-NN), an elitism strategy and modification of active gravitational mass formulation to preserve sub swarms.	Finding multiple solutions in multimodal problems.	Efficient and effective in finding multiple optima of unconstrained and constrained standard benchmark functions.	[5]

Pei et al.	Modified GSA (MGSA)	Introduce encoding correction strategy, three types of local search operators and batching mechanism.	Solving products and vehicles scheduling problem in a two-stage supply chain environment.	More robust and outperformed PSO and GA.	[6]
Doraghinejad et al.	Improved GSA	A discrete local search operator is combined with GSA.	Minimize the interference and increase the network throughput while ensuring network connectivity.	Better performance than DPSO-CA	[7]
Niknam et al.	Opposition-based self adaptive modified GSA (OSAMGSA)	Parameter tuning is accomplished through random generation and self-adaptive parameter tuning scheme.	Finding optimal reactive power dispatch and voltage control in power system Operation.	Better results than GSA and it is also suitable for solving multi objective problems	[8]
Pal et al.	Offspring Repair based GSA	Track changes in the environment separately and relocates the population all over the modified feasible region whenever environment is restructured.	Solving Dynamic Constrained Optimization Problems (DCOP)	Does not get trapped by disconnected feasible regions such as the penalty function and perform better in handling constraints.	[9]
Hosseinabadi et al.	Modified GSA (MGSA) and Baum-Welch algorithm (BW)	Combine MGSA and BW.	Improve the teaching of Hidden Markov Model (HMM).	MGSABW algorithm operates better than BW, PSOBW, and Ant Colony BW algorithms.	[10]
Li et al.	Piecewise function based GSA (PFGSA)	A piecewise function is designed as the gravitational constant function to replace the traditional exponential equation.	Parameter identification of automatic voltage regulator (AVR) system.	Compared with GA and PSO, PFGSA achieve better parameter identification accuracy	[11]

Shafigh et al.	Gravitation Based Classification (GBC)	Find the equilibrium condition of the classifier, which is modeled as a classifier line between two groups of fixed particles.	Two-class classification problem was modeled as a classifier line between two groups of fixed particles in order to find equilibrium condition of the classifier.	GBC model can obtain high classification performances in many cases.	[12]
Ibrahim et al.	Adaptive Quantum-Inspired Binary GSA	Combine concepts of quantum behavior, binary GSA and artificial immune system	Solving optimal power quality monitor (PQM) placement for voltage sag assessment	Better optimal PQM placement in terms of computational speed and good quality of the solution.	[13]
Doraghinejad et al.	Hybrid GSA	A black hole operator is inserted in GSA and assuming some of the heavy objects are stars in a gravitational system.	Solving unimodal optimization.	Better performance than original GSA and the GSA with the disruption operator	[14]
Soleimanpour-moghadam & Nezamabadi-pour	Improved Quantum Behaved GSA (IQGSA)	State of a mass is presented by wave function instead of position and velocity.	Finding the optimum result for unimodal and multimodal functions.	Easier to escape the sub-optima. Better performance than QGSA and GSA.	[15]
Li et al.	Chaotic GSA (CGSA)	Utilize the chaotic search based on logistic mapping function as a local search procedure of GSA.	Identifying the parameters of Lorenz chaotic system	Better performance compared to GSA, GA and PSO in terms of parameter accuracy and computation time.	[16]
Rashedi et al.	Stochastic feature based gravitational image segmentation algorithm (SGISA)	Introduce 3 operators called traveling, merging and escaping. Inspired by the concept of escape velocity in physics.	Partitioning image based on color, texture, and spatial information into homogenous and semi-compact segments.	SGISA has good ability to segment color images. Robust against multi-runs and noisy condition.	[17]

Han & Chang	Modified GSA (MGSA)	Chaotic operator is inserted into the standard GSA based on chaotic dynamic.	Parameters estimation of nonlinear filter modeling to reduce channel noise.	Minimized premature convergence of GSA. Estimate parameters more accurately compared to GSA and PSO.	[18]
Shamsudin et al.	Fast Discrete GSA (FDGSA)	Agent's position is updated based on its direction and velocity.	Proposed agent's position updating technique based on the velocity value and polarity for the existing GSA.	Converged faster compared to BGSA.	[19]
Li et al.	GSA-based hyperplane clustering algorithm (GSHPC)	Iteration process of GSA is applied to optimize the objective function of a hyperplane clustering model.	Improving the performance of the fuzzy clustering algorithm in fuzzy space partition in the identification of the Takagi–Sugeno (T–S) fuzzy model.	Effective in describing a complicated nonlinear system with high accuracies compared to other approaches in the literature.	[20]
Naji et al.	GSA	Implement a single agent in each operation or group of operations.	Replacing GSA sequential approach with a multiagent system to improve GSA speed while maintaining the high performance level.	Multiagent based GSA is faster than the sequential system.	[21]
Zhang et al.	Immunity-based GSA (IGSA)	Use memory antibody as vaccine to improve convergence speed and antibody diversity to raise diversity of agents.	Improving GSA slow convergence speed in order to avoid falling into local optimum solution.	IGSA showed competitive results with improved diversity and convergence speed compared to GSA and PSO.	[22]

Davarynejad et al.	Mass-dispersed GSA (mdGSA)	A mass bounded to the range of [LM,UM] is assigned to every particle.	Identifying a solution to inverse problem of GRN parameter identification.	Superior than the standard GSA due to its reduced center-seeking bias.	[23]
Kazak & Duysak	Member-Satellite algorithm (based on GSA)	A certain amount of satellites are assigned around the members and fitness values are calculated according to the fitness function of members and their satellites.	Satellites have been appointed to all the agents in GSA which are called as members. Members and their satellites are used to find a near optimal solution.	Solving various nonlinear functions with high performance.	[24]
Li & Duan	Improved GSA	A weighted value is assigned to inertia mass of every agent in each iteration process to accelerate the convergence speed of the search.	Solving the path planning of Uninhabited Aerial Vehicle (UAV) problem.	Feasibility and effectiveness of the improved GSA approach was verified by comparison with PSO, basic GSA and two other GSA models.	[25]
David et al.	adaptive GSA (aGSA)	Adaptation is ensured by a simple single input-two output fuzzy block in the algorithm structure.	Determining the optimal tuning of Takagi- Sugeno PI-fuzzy controllers (T-S PI-FCs)	Achieved optimal tuning of a T-S PI-FC for the position control of a laboratory servo system	[26]
Niknam et al.	Self-Adaptive GSA	A self-adaptive mutation technique is introduced to enhance the convergence characteristics of GSA.	Determining the optimal energy management of microgrids.	Robust, reliable and high quality solutions in a satisfactory simulation time.	[27]
Precup et al.	adaptive GSA	Reduce number of evaluations for the objective functions.	Determining optimal tuning of fuzzy controlled servo systems.	Resulting in a new generation of integral fuzzy controllers with a reduced time constant sensitivity.	[28]

Khajehzade et al.	Modified GSA	Use an adaptive maximum velocity constraint to control the global exploration ability.	Proposing an effective modification for GSA.	Has the potential to converge faster, while improving the quality of solution.	[29]
Ibrahim et al.	Vector Evaluated GSA (VEGSA)	Multi-objective optimization is achieved by exchanging a variable between populations.	Introducing vegsa for Multi-Objective Optimization Problems.	VEGSA requires enhancements in order to solve more challenging multi-objective optimization problems.	[30]
Chatterjee et al.	GSA with wavelet mutation (WM) (GSAWM)	Utilize the wavelet theory to enhance GSA exploration in solution space.	Determining the optimal solutions of different economic load dispatch (ELD) problems of power systems.	Both the optimality of the solution and the convergence speed of the algorithm are promising.	[31]
González-Álvarez et al.	Multiobjective GSA (MO-GSA)	The positions to update are the cells of the corresponding path vector associated to an individual.	Discovering common patterns, motifs, in a set of deoxyribonucleic acid (DNA) sequences	Outperformed other approaches published in the literature.	[32]
Nobahari et al.	Non-dominated Sorting GSA (NSGSA)	Propose sign and reordering mutations to promote the diversity within the swarm.	Utilizing the non-dominated sorting concept to update the gravitational acceleration of the particles	Better performance in convergence rate and spread of solutions compared to GSA and other multi-objective optimization algorithms.	[33]
Largo et al.	Multiobjective context (MO-GSA).	The positions to update are the cells of the corresponding path vector associated to an individual.	Solving static routing and Wavelength assignment problem.	Outperformed the results obtained by other approaches published in the literature.	[34]

Shaw et al.	Opposition-based GSA (OGSA)	Employs opposition-based learning for population initialization and also for generation jumping.	Solving combined economic and emission dispatch problems of power systems.	Effective and robust compared to those in the recent literature.	[35]
Papa et al.	Optimum-Path Forest (OPF) GSA (OPFGSA)	Combines the optimization behavior of GSA together with the speed of Optimum-Path Forest (OPF) classifier.	Provide a fast and accurate framework for feature selection.	Performed better than OPF-PSO, OPF with Principal Component Analysis (OPF-PCA), and OPF with Linear Discriminant Analysis (OPF-LDA) in the given tasks.	[36]
Askari & Zahiri	Intelligent GSA based classifier (IGSA-classifier)	Fuzzy system is designed for intelligently updating the parameters of GSA.	Intelligent GSA is applied to construct a decision function estimation algorithm from feature space.	Performance of IGSA-classifier was comparable to or better than the performance of other swarm intelligence based and evolutionary classifiers.	[37]
Sarafrazi et al.	Improved GSA (IGSA)	An operator called 'disruption', originating from astrophysics is introduced. A mass should be disrupted if it is smaller than a specific threshold.	Improving the exploration and exploitation abilities of GSA.	High performance in solving various nonlinear functions compared to Genetic Algorithm (GA) and PSO.	[38]
Wang & Li	Improved GSA (IGSA)	3 boundary conditions are introduced; absorbing walls, reflecting walls, invisible walls.	Study of boundary conditions is presented for unconstrained optimization	Boundary condition is more effective in obtaining better quality solution.	[39]

Hassanzadeh & Rouhani	Multi-Objective GSA	Incorporate uniform mutation operator and elitist policy to multi objective GSA.	Proposing a new method for handing multi objective optimization problems.	More superior compared to MOPSO.	[34]
Rashedi et al.	Binary GSA (BGSA)	The velocity is defined in term of changes of probabilities that a bit will be in states 0 or 1.	Proposing a new technique to the field of optimization in binary search spaces.	Efficient in solving various nonlinear benchmark functions.	[40]

4.2 Hybridization

GSA has also been combined with other algorithms such as k-means, PSO, Artificial Bee Colony (ABC), Neural Network (NN), Fuzzy Logic (FL), Support Vector Machine (SVM) and Genetic Algorithm (GA). These hybrids of GSA have demonstrated powerful results when compared with other techniques such as the original GSA itself, PSO, GA and ABC. For instance, the PSOGSA hybrid has successfully resolved the problem of slow searching speed in the last iterations of GSA [41]. Table 4 illustrates the hybrids of GSA with their comparison results.

Table 4 Hybrids of GSA

Author	**Technique**	**Hybridization**	**Problem**	**Result**	**Ref.**
Jiang, Ji & Shen	Hybrid PSO and GSA (HPSO–GSA)	Position updates of particles are based on PSO velocity and GSA acceleration.	Economic emission load dispatch problems.	Better performance compared to PSO and GSA.	[42]
Han et al.	QBGSA–K-NN	Combine the quantum-inspired binary GSA (QBGSA) with K-nearest neighbor (K-NN) method with leave-one-out cross-validation (LOOCV).	Improving classification accuracy with an appropriate feature subset in binary problems.	Select the discriminating input features correctly and achieve high classification accuracy.	[43]
Sombra et al.	New GSA	Apply change in alpha parameter throughout the iterations.	Improving performance of GSA.	Help to achieve better convergence.	[44]

Gu & Pan	Modified GSA (GSA & PSO)	PSO features of saving previous local optimum and global optimum solutions is implemented into GSA.	The particle memory ability in GSA is modified to remember its own local optimum and global optimum solutions in the updating process.	Better performance than SVM and SGSA-SVM in classification accuracy and feature selection ability.	[45]
Liu & Ma	Improved GSA (IGSA). Hybrid of GSA and free search differential evolution (FSDE)	FSDE is introduced to GSA during each iteration and a new parameter, *pro*, is embedded.	Overcoming exploitation capability of GSA and avoiding being easily trapped in local optima.	Improve the performance of GSA	[46]
Sarafrazi & Nezamabadi-pour	GSA-SVM	Combine a real-valued GSA (RGSA) with binary GSA (BGSA). RGSA to optimize the value of SVM parameters and BGSA to optimize the input feature subset selection.	Proposing a new hybrid GSA-SVM system for binary classification.	Select the discriminating input features correctly and achieve high classification accuracy compared to PSO and GA-SVM.	[47]
Sun & Zhang	Hybrid GA and GSA (HGA-GSA)	Integrate GA's global optimization and GSA's fast convergence by combining GA crossover and mutation operator and the GSA speed-displacement formula.	Image segmentation using multilevel thresholding.	Superior result and are comparable to PSO and GSA.	[48]
Tsai et al.	Gravitational particle swarm (GSA and PSO)	Positions updated with PSO velocity and GSA acceleration (gravity attraction).	Improving GSA and PSO	Better performance than CPSO and GSA.	[49]

Kumar et al.	Fuzzy Adaptive GSA	Tune gravitational constant (G) using fuzzy "IF/THEN" rules.	Improving the appropriate selection of gravitational constant parameter (G) difficulty.	Better quality solution within shorter computational time and stable convergence characteristics compared to GSA, PSO and GA.	[50]
Guo	ABC - GSA	Combine the search mechanism of the three steps methods of ABC with the moving methods of GSA.	Proposing a new hybrid GSA-ABC	Superior results compared to GSA and ABC.	[51]
David et al.	PSO-GSA	Combine PSO's exploitation and GSA's exploration in the search process.	Optimal tuning of Takagi-Sugeno-Kang PI-fuzzy controllers (TS-K PI-FCs).	Improved performance.	[52]
Hatamlou et al.	GSA-KM (GSA and k-means)	Incorporating a k-means algorithm in generating the initial population for GSA.	GSA-KM algorithm helps the k-means algorithm to escape from local optima and also increases the convergence speed of the GSA algorithm.	Encouraging in terms of quality of solutions and the convergence speed when compared to k-means, GA, simulated annealing (SA), ACO, honey bee mating optimization (HBMO), PSO and GSA.	[53]
Seljanko	Hybrid genetic gravitational algorithm (GA and GSA)	Utilize the features of GSA with operators from the GA.	Generation of the gait for a hexapod robot.	Increased of fitness of transformed gaits compared to the fitness of the initial gait population.	[54]

Jajarmi at al.	GSA-FL	GSA is applied to search globally the optimal parameters of fuzzy logic.	Shunt active power filter control.	Better performance in reducing THD and reactive power and robustness for DC capacitor voltage.	[55]
Ghalambaz et al.	HNNGSA (NN and GSA)	GSA technique is applied to train a multi-layer perceptron neural network.	Obtaining approximation solution of the Wessinger's equation.	Could introduce a closer form to the analytic solution than other numerical methods.	[56]
Yin et al.	IGSAKHM (K-harmonic means and IGSA)	Integrate the improved version of GSA into KHM.	Proposing a hybrid algorithm for clustering.	IGSAKHM is superior to KHM and PSOKHM in most cases.	[57]
Mirjalili & Siti Zaiton	PSOGSA	Combine the ability for social thinking (gbest) in PSO with the local search capability of GSA.	Proposing a hybrid PSOGSA for function optimization.	Better capability to escape from local optimum with faster convergence compared to PSO and GSA.	[58]

5 GSA Applications

After 4 years of its introduction, currently GSA has been applied in various areas and applications. The rising number of GSA researches is due to the rising interest of the scientific community in exploring the algorithm capabilities. The range of applications of GSA is getting wider and GSA has been implemented among others in business, bioinformatics, software design and mostly in engineering areas. Table 5 shows the areas and applications of GSA. In most of the applications, GSA had been reported to perform better and superior compared to other optimization algorithm such as PSO and GA.

Table 5 Applications of GSA

Area	**Application**	**Author**	**Year**	**Ref.**
Neural Network (NN) Training	Training Feedforward NN	Ojugo et al.	2013	[59]
		Mirjalili et al.	2012	[41]
	Training parameters of a fuzzy ARTMAP NN	Sheikhan & Sharifi Rad	2012	[60]
	Training a multi-layer perceptron NN	Biglari et al.	2013	[61]
		Ghalambaz et al.	2011	[56]

	Training multi-layered feed-forward NN	Taghipour et al.	2010	[62]
Robotics	Generating the gait for a walking hexapod robot	Seljanko	2011	[54]
Optical	Designing photonic crystal cavities	Saucer & Sih	2013	[63]
	Embedding GSA in Convolutional Neural Networks (CNNs) for optical character recognition (OCR)	Fedorovici et al.	2012	[64]
Bioinformatics	Descriptor selection tool for anticancer potency modeling	Bababdani & Mousavi	2012	[65]
	Identifying a solution to the inverse problem of Gene Regulatory Network (GRN) parameter identification	Davarynejad et al.	2012	[23]
	Discovering common patterns or motifs in a set of DNA	Álvarez & Rodríguez	2011	[32]
		Xiao & Cheng	2011	[66]
Software Engineering	Solving web services selection for composition based on QoS	Zibanezhad et al.	2012	[67]
	Exploring the software design space automatically	Amoozegar & Nezamabadi-pour	2012	[68]
	Solving web service composition problem	Palanikkumar et al.	2009	[69]
Networking	Improving a chaotic secure communication scheme	Han and Chang	2012	[70]
	Routing and Wavelength Assignment (RWA) problem	Largo et al.	2011	[71]
	Parameter optimization of sensor monitoring in a point coverage network	Rostamy et al.	2011	[72]
Image Processing	Histogram-based image segmentation	Sun & Zhang	2013	[48]
	Presenting a new LSB matching method	Soleimanpour-moghadam et al.	2012	[73]
	Improving the precision of content-based image retrieval (CBIR) systems	Rashedi & Nezamabadi-pour	2012	[74]
	Improving color image segmentation	Rashedi & Nezamabadi-pour	2012	[17]
	Presenting a new approach for edge detection	Verma & Sharma	2012	[75]
	Gray level image adaptive enhancement	Zhao	2011	[76]
Classification	Improving classification accuracy	Han et al.	2013	[43]

	Introducing a new classification method based on GSA.	Shafigh et al.	2012	[12]
	Introducing GSA classifier	Bahrololoum et al.	2012	[77]
	Introducing a new hybrid GSA-SVM system for binary classification	Sarafrazi & Nezamabadi-pour	2011	[47]
	Proposing an intelligent GSA based classifier	Askari & Zahiri	2011	[37]
Clustering	Biclustering of web usage data	Prabha & Rathipriya	2013	[78]
	Adapting GSA and k-means (GSA-KM)	Hatamlou et al.	2012	[53]
	Solving the clustering objective function	Li et al.	2012	[20]
	Finding near optimal solution for clustering problem	Hatamlou et al.	2011	[79]
	Introducing a hybrid approach for solving clustering problems	Yin et al.	2011	[57]
	Solving data clustering problems	Hatamlou et al.	2011	[80]
Scheduling	Products and vehicles scheduling problem in a two-stage supply chain environment	Pei et al.	2013	[6]
Business	Optimal bidding strategy for a pool based electricity market	Vijaya et al.	2012	[50]
	Optimal strategy in managing supply chain demand	Ojha	2012	[81]
Computer Engineering	Solving cell placement problem in physical design process of VLSI circuits	Qasem & Eldos	2013	[82]
Civil Engineering	Deterministic and probabilistic of slope stability analysis	Khajehzadeh et al.	2012	[29]
	Optimum emission dispatch and optimum fuel cost	Mondal et al.	2012	[83]
	Optimizing synthesis gas production	Ganesan et al.	2012	[84]
	Forecasting the Iran's oil demand	Behrang et al.	2011	[85]
	Forecasting of turbine heat rate	Zhang et al.	2012	[86]
Control Engineering	Analyzing design of Proportional-Integral (PI) controller for Automatic Generation Control (AGC)	Rout, Sahu & Panda	2013	[87]

	Designing PID control structures	Oliveira, Pires & Novais	2013	[88]
	Identification of Switched Linear Systems	Sadeghi et al.	2012	[89]
	Optimal PID controller parameters	Duman & Yörükeren	2012	[90]
		Duman et al.	2011	[91]
	Proposing a novel Proportional-plus-Integral (PI) controller	Dutta et al.	2012	[92]
	Damping controller coordinated design	Eslami et al	2012	[93]
		Khadanga & Panda	2011	[2]
	Optimal tuning of proportional-integral (PI) fuzzy controllers	David et al.	2011	[52]
		David et al.	2012	[94]
		Precup et al.	2012	[28]
		Precup et al.	2011	[95]
Mechanical Engineering	Metallurgical performance optimization of an industrial flotation column	Massinaei, Falaghi & Izadi	2013	[96]
	Optimal capacity and location determination of distributed generation	Mistry et al.	2012	[97]
	Optimal design of an auto-thermal ammonia synthesis reactor	Borges et al.	2012	[98]
	Parameters identification problem of hydraulic turbine governing system	Li & Zhou	2011	[99]
Power Engineering	Support vector regression (SVR)-based electricity forecasting	Ju & Hong	2013	[100]
	Modeling of hydraulic turbine governing system (HTGS)	Li et al.	2013	[101]
	Solving the static State Estimation (SE) problem	Mallick et al.	2013	[102]
	Optimal sizing and suitable placement for distributed generation (DG) in distribution system	Abdul Kadir et al.	2013	[103]
	Solving thermal unit commitment (UC) problem	Provas Kumar	2013	[104]
	Optimal amount of hydro thermal generations	Barisal et al.	2012	[105]
		Bhattacharya et al.	2012	[106]
	Optimal parameters in load frequency control of a single area power system	Duman et al.	2012	[107]
	Reactive power dispatch problem	Duman et al.	2012	[108]
	Multi-objective	Niknam et al.	2013	[8]

	optimal reactive power dispatch problems	Roy et al.	2012	[109]
	Controlling shunt active power filter	Jajarmi et al.	2011	[55]
	Economic and emission dispatch problem of power systems	Jiang, Ji & Shen	2013	[42]
		Mondal et al.	2013	[83]
		Udgir, Dubey & Pandit	2013	[110]
		Güvenç et al.	2012	[111]
		Maskani et al.	2012	[112]
		Swain et al.	2012	[113]
		Shaw et al.	2012	[35]
		Chatterjee et al.	2012	[31]
		Duman at al.	2010	[114]
	Estimating parameters of nonlinear filter modeling	Han & Chang	2012	[18]
	Optimal power problem (OPF)	Sonmez et al.	2012	[115]
		Duman et al.	2012	[116]
	Solving different single and multi-objective OPF problems	Bhattacharya & Roy	2012	[117]
	Designing of power system stabilizer	Ghasemi, Shayeghi, Alkhatib	2013	[118]
		Eslami et al.	2012	[119]
		Ali & Mehdi	2012	[120]
	Optimal energy management of microgrids	Niknam et al.	2012	[27]
	Parameter estimation problem for Infinite Impulse Response (IIR) and nonlinear rational filters	Rashedi et al.	2011	[121]
	Minimizing power losses through voltage control	Purwoharjono et al.	2011	[122]
	Solving problem of post-outage bus voltage magnitude calculations	Ceylan & Dag	2010	[123]
Telecommunication Engineering	Clustering of formation and data routing for Wireless Sensor Network (WSN)	Parvin & Vasanthanayaki	2013	[124]
	Solving channel assignment (CA) problem in multi-radio mesh networks	Doraghinejad et al.	2013	[7]
	Designing of optimal linear phase finite impulse response band pass (BP) and band stop (BS) digital filters	Saha et al.	2013	[125]
	Solving the path planning	Li & Duan	2012	[25]

	problem of Uninhabited Aerial Vehicle (UAV)			
	Finding optimum set parameter in the generation of phase-only pencil-beam pair from concentric ring array antenna	Chatterjee	2011	[4]
	Solving problem in the synthesis of thinned scanned concentric ring array antenna	Chatterjee & Mahanti	2010	[126]

5 Conclusion and Future Research

In this paper, the evolutions and applications of GSA have been presented. Based on the review, the core work on GSA has been focusing on the algorithm and the application aspects. Despite the fact that GSA is still a recent algorithm, the growth of the GSA related researches has been promising. At the time of writing, there are various variants of GSA which have been developed and the algorithm has been applied in solving various problems such as in neural network training, image processing, classification, clustering, multi objective optimization, networking, filter modeling, controller design and so on. Based on the review, it is observed that GSA was widely applied in solving engineering problems especially in power systems problems and controller design.

The various GSA variants have been proposed to overcome the weaknesses of GSA. Based on the literature, the original GSA has some weaknesses such as using complex operators and long computational time [127]. GSA also suffers from slow searching speed in the last iterations [41]. Another problem is the difficulty for the appropriate selection of gravitational constant parameter, G. The parameter controls the search accuracy and does not guarantee a global solution at all time [50].

Despite the weaknesses, GSA has been widely adapted due its ease of implementation and the ability to solve highly nonlinear optimization problems of complex engineering systems [2]. It has been reported that GSA could perform efficiently in terms of CPU time and could produce result more consistently with higher precision [121]. GSA has been proven to outperform other optimization algorithms such as PSO and ACO in terms of converging speed and local minima avoidance [41] and could generate better quality solution within shorter computational time and stable convergence characteristics compared to PSO and GA [50].

Nevertheless, modifications to the original GSA are still needed to be done in order to continuously improve the algorithm performance. Although a lot of researches have been done on GSA, the algorithm still has a lot of potential for improvements. There are still more enhancements could be done to the structure of GSA and there are a lot of possible hybrid techniques could be explored. Future research should combine GSA with other optimization algorithms such as ACO, Artificial Fish School Algorithm (AFSA), Artificial Immune System (AIS) and Differential Evolution (DE). Since improving the algorithm is always an open problem, future research is expected to produce new techniques with better performance [128].

In terms of range of applications, there are still many areas could be explored by using GSA. It is observed that GSA application has not yet penetrating in certain areas such as in finance, economics, military and medical areas. More studies should be done by the scientific community in order to test GSA capabilities in those areas. Hence, in years to come, it is expected that many more interesting topics are to be investigated based on GSA in more diverse areas.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Teknologi MARA (Terengganu) and NANO-ElecTronic Centre for the continuous support given in this research.

References

[1] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: A Gravitational Search Algorithm," *Information Sciences*, vol. 179, no. 13, (2009), pp. 2232–2248.

[2] R. K. Khadanga and S. Panda, "Gravitational search algorithm for Unified Power Flow Controller based damping controller design," *2011 International Conference on Energy, Automation and Signal*, (2011), pp. 1–6.

[3] M. Gauci, T. J. Dodd, and R. Groß, "Why 'GSA: a gravitational search algorithm' is not genuinely based on the law of gravity," *Natural Computing*, (2012), pp. 1–2.

[4] A. Chatterjee, G. K. Mahanti, and P. R. S. Mahapatra, "Generation of phase-only pencil-beam pair from concentric ring array antenna using gravitational search algorithm," in *2011 International Conference on Communications and Signal Processing*, (2011), pp. 384–388.

[5] S. Yazdani, H. Nezamabadi-pour, and S. Kamyab, “A Gravitational Search Algorithm for Multimodal Optimization,” *Swarm and Evolutionary Computation*, (2013), pp. 1–14.

[6] J. Pei, X. Liu, P. M. Pardalos, W. Fan, S. Yang, and L. Wang, “Application of an Effective Modified Gravitational Search Algorithm for the Coordinated Scheduling Problem in a Two-stage Supply Chain,” *The International Journal of Advanced Manufacturing Technology*, (2013).

[7] M. Doraghinejad, H. Nezamabadi-pour, and A. Mahani, “Channel Assignment in Multi-Radio Wireless Mesh Networks Using an Improved Gravitational Search Algorithm,” *Journal of Network and Computer Applications*, (2013), pp. 1–9.

[8] T. Niknam, M. R. Narimani, R. Azizipanah-abarghooee, and B. Bahmani-firouzi, “Multiobjective Optimal Reactive Power Dispatch and Voltage Control: A New Opposition-Based Self-Adaptive Modified Gravitational,” *IEEE SYSTEMS JOURNAL*, (2013), pp. 1–12.

[9] K. Pal, C. Saha, S. Das, and C. A. C. Coello, “Dynamic Constrained Optimization with Offspring Repair based Gravitational Search Algorithm,” in *2013 IEEE Congress on Evolutionary Computation*, (2013), pp. 2414–2421.

[10] A. Asghar, R. Hosseinabadi, M. R. Ghaleh, S. E. Hashemi, and B. Branch, “Application of Modified Gravitational Search Algorithm to Solve the Problem of Teaching Hidden Markov Model,” *International Journal of Computer Science Issues*, vol. 10, no. 3, (2013), pp. 1–8.

[11] C. Li, H. Li, and P. Kou, “Piecewise function based gravitational search algorithm and its application on parameter identification of AVR system,” *Neurocomputing*, vol. 124, (2013), pp. 139–148.

[12] P. Shafigh, S. Y. Hadi, and E. Sohrab, “Gravitation based classification,” *Information Sciences*, vol. 220, (2013), pp. 319–330.

[13] A. A. Ibrahim, A. Mohamed, and H. Shareef, “Power Quality Monitor Placement Method Using Adaptive Quantum-Inspired Binary Gravitational Search Algorithm,” in *2012 Conference on Power & Energy*, vol. 3, (2012), pp. 363–368.

[14] M. Doraghinejad, H. Nezamabadi-pour, A. Hashempoursadeghian, and M. Maghfoori, “A Hybrid Algorithm Based on Gravitational Search Algorithm

for Unimodal Optimization," in *2012 2nd International eConference on Computer and Knowledge Engineering (ICCKE)*, (2012), pp. 129–132.

[15] M. Soleimanpour-moghadam and H. Nezamabadi-pour, "An improved quantum behaved gravitational search algorithm," in *20th Iranian Conference on Electrical Engineering, (ICEE2012), (* 2012), pp. 711-714.

[16] C. Li, J. Zhou, J. Xiao, and H. Xiao, "Parameters identification of chaotic system by chaotic gravitational search algorithm," *Chaos, Solitons & Fractals*, vol. 45, no. 4, (2012), pp. 539–547.

[17] E. Rashedi and H. Nezamabadi-pour, "A stochastic gravitational approach to feature based color image segmentation," *Engineering Applications of Artificial Intelligence*, (2012), pp. 1–11.

[18] X. Han and X. Chang, "A chaotic digital secure communication based on a modified gravitational search algorithm filter," *Information Sciences*, vol. 208, (2012), pp. 14–27.

[19] H. C. Shamsudin, A. Irawan, Z. Ibrahim, A. F. Z. Abidin, S. Wahyudi, M. A. A. Rahim, and K. Khalil, "A Fast Discrete Gravitational Search Algorithm," *2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation*, (2012), pp. 24–28.

[20] C. Li, J. Zhou, B. Fu, P. Kou, and J. Xiao, "T - S Fuzzy Model Identification With a Gravitational Search-Based Hyperplane Clustering Algorithm," *IEEE Transactions On Fuzzy Systems*, vol. 20, no. 2, (2012), pp. 305–317.

[21] H. R. Naji, M. Sohrabi, and E. Rashedi, "A High-Speed, Performance-Optimization Algorithm Based on a Gravitational Approach," *Computing in Science & Engineering*, vol. 14, no. 5, (2012), pp. 56–62.

[22] Z. Zhang, Y. , Li, Y., Xia, F., Luo, "Immunity-based gravitational search algorithm," in *3rd International Conference on Information Computing and Applications (ICICA 2012)*, (2012), pp. 754–761.

[23] M. Davarynejad, Z. Forghany, and J. Van Den Berg, "Mass-Dispersed Gravitational Search Algorithm for Gene Regulatory Network Model Parameter Identification," *Simulated Evolution and Learning*, (2012), pp. 1–12.

[24] N. Kazak and A. Duysak, "Modified gravitational search algorithm," *2012 International Symposium on Innovations in Intelligent Systems and Applications*, (2012), pp. 1–4.

[25] P. Li and H. Duan, "Path planning of unmanned aerial vehicle based on improved gravitational search algorithm," *Science China Technological Sciences*, vol. 55, no. 10, (2012), pp. 2712–2719.

[26] R.-C. David, R.-E. Precup, E. . Petriu, M.-B. Rădac, C. Purcaru, C.-A. Dragoş, and S. Preitl, "Adaptive gravitational search algorithm for PI-fuzzy controller tuning," in *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics*, (2012), pp. 136–141.

[27] T. Niknam, F. Golestaneh, and A. Malekpour, "Probabilistic energy and operation management of a microgrid containing wind/photovoltaic/fuel cell generation and energy storage devices based on point estimate method and self-adaptive gravitational search algorithm," *Energy*, vol. 43, no. 1, (2012), pp. 427–437.

[28] R. Precup, S. Member, R. David, E. M. Petriu, S. Preitl, and M. Radac, "Novel Adaptive Gravitational Search Algorithm for Fuzzy Controlled Servo Systems," *IEEE Transactions on Industrial Informatics*, vol. 8, no. 4, (2012), pp. 791–800.

[29] M. Khajehzadeh, M. R. Taha, A. El-Shafie, and M. Eslami, "A modified gravitational search algorithm for slope stability analysis," *Engineering Applications of Artificial Intelligence*, vol. 25, no. 8, (2012), pp. 1589–1597.

[30] Z. Ibrahim, B. Muhammad, K. H. Ghazali, K. S. Lim, S. W. Nawawi, and Z. M. Yusof, "Vector Evaluated Gravitational Search Algorithm (VEGSA) for Multi-objective Optimization Problems," *2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation*, (2012), pp. 13–17.

[31] A. Chatterjee, S. . Ghoshal, and V. Mukherjee, "A maiden application of gravitational search algorithm with wavelet mutation for the solution of economic load dispatch problems," *International Journal of Bio-Inspired Computation*, vol. 4, no. 1, (2012), pp. 33–46.

[32] D. L. González-Álvarez, M. A. Vega-Rodríguez, J. A. Gómez-Pulido, and J. M. Sánchez-Pérez, "Applying a Multiobjective Gravitational Search Algorithm (MO-GSA) to Discover Motifs," *Advances in Computational Intelligence*, vol. 6692, (2011), pp. 372–379.

[33] H. Nobahari, M. Nikusokhan, and P. Siarry, "Non-dominated Sorting Gravitational Search Algorithm," in *International Conference on Swarm Intelligence (ICSI 2011)*, (2011), pp. 1-10.

[34] H. R. Hassanzadeh and M. Rouhani, "A Multi-objective Gravitational Search Algorithm," *2010 2nd International Conference on Computational Intelligence, Communication Systems and Networks*, vol. 1, (2010), pp. 7–12.

[35] B. Shaw, V. Mukherjee, and S. P. Ghoshal, "A novel opposition-based gravitational search algorithm for combined economic and emission dispatch problems of power systems," *International Journal of Electrical Power & Energy Systems*, vol. 35, no. 1, (2012), pp. 21–33.

[36] J. P. Papa, A. Pagnin, S. A. Schellini, A. Spadotto, R. C. Guido, M. Ponti, G. Chiachia, and A. X. Falcao, "Feature selection through gravitational search algorithm," in *2011 IEEE International Conference on Acoustics, Speech and Signal Processing*, no. 1, (2011), pp. 2052–2055.

[37] H. Askari and S.-H. Zahiri, "Decision function estimation using intelligent gravitational search algorithm," *International Journal of Machine Learning and Cybernetics*, vol. 3, no. 2, (2011), pp. 163–172.

[38] S. Sarafrazi, H. Nezamabadi-pour, and S. Saryazdi, "Disruption: A new operator in gravitational search algorithm," *Scientia Iranica*, vol. 18, no. 3, (2011), pp. 539–548.

[39] W. JiaNan and L. XiangTao, "An Improved Gravitation Search Algorithm for Unconstrained Optimization," *Advanced Materials Research*, vol. 143–144, (2010), pp. 409–413.

[40] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "BGSA: binary gravitational search algorithm," *Natural Computing*, vol. 9, no. 3, (2009), pp. 727–745.

[41] S. Mirjalili, S. Z. Mohd Hashim, and H. Moradian Sardroudi, "Training feedforward neural networks using hybrid particle swarm optimization and gravitational search algorithm," *Applied Mathematics and Computation*, vol. 218, no. 22, (2012), pp. 11125–11137.

[42] S. Jiang, Z. Ji, and Y. Shen, "A novel hybrid Particle Swarm Optimization and Gravitational Search Algorithm for Solving Economic Emission Load Dispatch Problems with Various Practical Constraints," *International*

Journal of Electrical Power & Energy Systems, vol. 55, (2014), pp. 628–644.

[43] X. Han, L. Quan, X. Xiong, and B. Wu, "Facing the Classification of Binary Problems with a Hybrid System Based on Quantum-Inspired Binary Gravitational Search Algorithm and K-NN Method," *Engineering Applications of Artificial Intelligence*, vol. 26, no. 10, (2013), pp. 2424–2430.

[44] A. Sombra, F. Valdez, P. Melin, and O. Castillo, "A New Gravitational Search Algorithm using Fuzzy Logic to Parameter Adaptation," in *2013 IEEE Congress on Evolutionary Computation*, no. 3, (2013), pp. 1068–1074.

[45] Binjie Gu and Feng Pan, "Modified Gravitational Search Algorithm with Particle Memory Ability and its Application," *International Journal of Innovative Computing, Information and Control*, vol. 9, no. 11, (2013), pp. 4531–4544.

[46] Y. Liu and L. Ma, "Improved Gravitational Search Algorithm based on Free Search Differential Evolution," *Journal of Systems Engineering and Electronics*, vol. 24, no. 4, (2013), pp. 690–698.

[47] S. Sarafrazi and H. Nezamabadi-pour, "Facing the classification of binary problems with a GSA-SVM hybrid system," *Mathematical and Computer Modelling*, vol. 57, no. 1–2, (2013), pp. 270–278.

[48] G. Sun and A. Zhang, "A Hybrid Genetic Algorithm and Gravitational Using Multilevel Thresholding," *Pattern Recognition and Image Analysis*, vol. 7887, (2013), pp. 707–714.

[49] H.-C. Tsai, Y.-Y. Tyan, Y.-W. Wu, and Y.-H. Lin, "Gravitational Particle Swarm," *Applied Mathematics and Computation*, vol. 219, no. 17, (2013), pp. 9106–9117.

[50] J. Vijaya Kumar, D. M. Vinod Kumar, and K. Edukondalu, "Strategic bidding using fuzzy adaptive gravitational search algorithm in a pool based electricity market," *Applied Soft Computing*, vol. 13, (2012), pp. 2445-2455.

[51] Z. Guo, "A Hybrid Optimization Algorithm Based on Artificial Bee Colony and Gravitational Search Algorithm," *International Journal of Digital Content Technology and its Applications*, vol. 6, no. 17, (2012), pp. 620–626.

[52] R. David, R. Precup, S. Member, E. M. Petriu, C. Purcaru, and S. Preitl, “PSO and GSA Algorithms for Fuzzy Controller Tuning with Reduced Process Small Time Constant Sensitivity *,” in *2012 16th International Conference on System Theory, Control and Computing*, (2012), pp.1-6.

[53] A. Hatamlou, S. Abdullah, and H. Nezamabadi-pour, “A combined approach for clustering based on K-means and gravitational search algorithms,” *Swarm and Evolutionary Computation*, vol. 6, (2012), pp. 47–52.

[54] F. Seljanko, “Hexapod Walking Robot Gait Generation Using Genetic-Gravitational Hybrid Algorithm,” in *The 15th International Conference on Advanced Robotics*, (2011), pp. 253-258.

[55] H. R. I. Jajarmi, A. Mohamed, and H. Shareef, “GSA-FL Controller for Three Phase Active Power Filter to Improve Power Quality,” in *2011 2nd International Conference on Control, Instrumentation and Automation*, (2011), pp. 417–422.

[56] M. Ghalambaz, A. R. Noghrehabadi, M. A. Behrang, E. Assareh, A. Ghanbarzadeh, and N. Hedayat, “A Hybrid Neural Network and Gravitational Search Algorithm (HNNGSA) Method to Solve well known Wessinger ' s Equation,” *World Academy of Science, Engineering and Technology*, (2011), pp. 803–807.

[57] M. Yin, Y. Hu, F. Yang, X. Li, and W. Gu, “A novel hybrid K-harmonic means and gravitational search algorithm approach for clustering,” *Expert Systems with Applications*, vol. 38, no. 8, (2011), pp. 9319–9324.

[58] S. Mirjalili and S. Z. M. Hashim, “A New Hybrid PSOGSA Algorithm for Function Optimization,” in *2010 International Conference on Computer and Information Application*, no. 1, (2010), pp. 374–377.

[59] A. A. Ojugo, R. E. Yoro, E. O. Okonta, and A. O. Eboka, “A Hybrid Artificial Neural Network Gravitational Search Algorithm for Rainfall Runoffs Modeling and Simulation in Hydrology,” *Progress in Intelligent Computing and Applications*, vol. 2, (2013), pp. 22–33.

[60] M. Sheikhan and M. Sharifi Rad, “Gravitational search algorithm–optimized neural misuse detector with selected features by fuzzy grids–based association rules mining,” *Neural Computing and Applications*, vol. 23, no.7-8, (2012), pp. 2451-2463.

[61] M. Biglari, E. Assareh, I. Poultangari, and M. Nedaei, “Solving Blasius Differential Equation by Using Hybrid Neural Network and Gravitational Search Algorithm (HNNGSA),” *Global Journal of Science, Engineering and Technology*, no. 11, (2013), pp. 29–36.

[62] M. Taghipour, a R. Moradi, and M. Yazdani-Asrami, “Identification of magnetizing inrush current in power transformers using GSA trained ANN for educational purposes,” in *2010 IEEE Conference on Open Systems (ICOS 2010)*, (2010), pp. 23–27.

[63] T. W. Saucer and V. Sih, “Optimizing Nanophotonic Cavity Designs with the Gravitational Search Algorithm,” *Optics Express*, vol. 21, no. 18, (2013), pp. 20831–20836.

[64] L.-O. Fedorovici, R.-E. Precup, F. Dragan, R.-C. David, and C. Purcaru, “Embedding Gravitational Search Algorithms in Convolutional Neural Networks for OCR applications,” in *2012 7th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI)*, (2012), pp. 125–130.

[65] B. M. Bababdani and M. Mousavi, “Gravitational Search Algorithm : A New Feature Selection Method for QSAR Study of Anticancer Potency of imidazo[4,5-b]pyridine Derivatives,” *Chemometrics and Intelligent Laboratory Systems*, vol. 122, (2013), pp. 1–11.

[66] J. Xiao and Z. Cheng, “DNA Sequences Optimization Based on Gravitational Search Algorithm for Reliable DNA Computing,” *2011 Sixth International Conference on Bio-Inspired Computing: Theories and Applications*, (2011), pp. 103–107.

[67] D. Palanikkumar, P. Anbuselvan, and B. Rithu, “A Gravitational Search Algorithm for effective Web Service Selection for Composition with enhanced QoS in SOA,” *International Journal of Computer Applications*, vol. 42, no. 8, (2012), pp. 12–15.

[68] M. Amoozegar and H. Nezamabadi-pour, “Software performance optimization based on constrained GSA,” *The 16th CSI International Symposium on Artificial Intelligence and Signal Processing (AISP 2012)*, (2012), pp. 134–139.

[69] B. Zibanezhad, K. Zamanifar, N. Nematbakhsh, and F. Mardukhi, “An Approach for Web Services Composition Based on QoS and Gravitational Search Algorithm,” in *2009 International Conference on Innovations in Information Technology*, (2009), pp. 340–344.

[70] X. Han and X. Chang, "Chaotic secure communication based on a gravitational search algorithm filter," *Engineering Applications of Artificial Intelligence*, vol. 25, no. 4, (2012), pp. 766–774.

[71] Á. Rubio-Largo, M. A. Vega-Rodríguez, J. A. Gómez-Pulido, and J. M. Sánchez-Pérez, "A Multiobjective Gravitational Search Algorithm Applied to the Static Routing and Wavelength Assignment Problem," *Applications of Evolutionary Computation*, vol. 6625, (2011), pp. 41–50.

[72] A. S. Rostamy, H. M. Bernety, and A. R. Hosseinabadi, "A Novel and Optimized Algorithm to Select Monitoring Senses by GSA," in *2nd International Conference on Control, Instrumentation and Automation*, (2011), pp. 829–834.

[73] M. Soleimanpourmoghadam, H. Nezamabadi-pour, M. M. Farsangi, and M. Mahyabadi, "A more secure steganography method based on pair-wise LSB matching via a quantum gravitational search algorithm," *The 16th CSI International Symposium on Artificial Intelligence and Signal Processing (AISP 2012)*,(2012), pp. 034–038.

[74] E. Rashedi and H. Nezamabadi-pour, "Improving the precision of CBIR systems by feature selection using binary gravitational search algorithm," *The 16th CSI International Symposium on Artificial Intelligence and Signal Processing (AISP 2012)*,(2012), pp. 039–042.

[75] O. P. Verma and R. Sharma, "Newtonian Gravitational Edge Detection Using Gravitational Search Algorithm," *2012 International Conference on Communication Systems and Network Technologies*, (2012), pp. 184–188.

[76] W. Zhao, "Adaptive Image Enhancement Based on Gravitational Search Algorithm," *Procedia Engineering*, vol. 15, (2011), pp. 3288–3292.

[77] A. Bahrololoum, H. Nezamabadi-pour, H. Bahrololoum, and M. Saeed, "A prototype classifier based on gravitational search algorithm," *Applied Soft Computing*, vol. 12, no. 2, (2012), pp. 819–825.

[78] V. D. Prabha, "Biclustering of Web Usage Data Using Gravitational Search Algorithm," in *2013 International Conference on Pattern Recognition, Informatics and Mobile Engineering*, (2013), pp. 500 - 505.

[79] A. Hatamlou, S. Abdullah, and Z. Othman, "Gravitational Search Algorithm with Heuristic Search for Clustering Problems," in *2011 3rd Conference on Data Mining and Optimization*, (2011), pp. 28–29.

[80] A. Hatamlou, S. Abdullah, and H. Nezamabadi-pour, “Application of Gravitational Search Algorithm on Data Clustering,” *Rough Sets and Knowledge Technology*, vol. 6954, (2011), pp. 337–346.

[81] Ojha M, “Optimizing supply chain management using gravitational search algorithm and multi agent system,” *Advances in Intelligent and Soft Computing*, vol. 1, (2012), pp. 481–491.

[82] R. Al Qasem and T. Eldos, “An Efficient Cell Placement Using Gravitational Search Algorithms,” *Journal of Computer Science*, vol. 9, no. 8, (2013), pp. 943–948.

[83] S. Mondal, A. Bhattacharya, and S. H. nee Dey, “Multi-objective Economic Emission Load Dispatch Solution using Gravitational Search Algorithm and Considering Wind Power Penetration,” *International Journal of Electrical Power & Energy Systems*, vol. 44, no. 1, (2013), pp. 282–292.

[84] T. Ganesan, I. Elamvazuthi, K. Z. Ku Shaari, and P. Vasant, “Swarm intelligence and gravitational search algorithm for multi-objective optimization of synthesis gas production,” *Applied Energy*, vol. 103, (2013), pp. 368–374.

[85] M. a. Behrang, E. Assareh, M. Ghalambaz, M. R. Assari, and a. R. Noghrehabadi, “Forecasting future oil demand in Iran using GSA (Gravitational Search Algorithm),” *Energy*, vol. 36, no. 9, (2011), pp. 5649–5654.

[86] W. Zhang, P. Niu, G. Li, and P. Li, “Forecasting of turbine heat rate with online least squares support vector machine based on gravitational search algorithm,” *Knowledge-Based Systems*, vol. 39, (2013), pp. 34–44.

[87] U. K. Rout, R. K. Sahu, and S. Panda, “Gravitational Search Algorithm based Automatic Generation Control for Interconnected Power System,” in *2013 International Conference on Circuits,Power and Computing Technologies (ICCPCT-2013)*, (2013), pp. 558–563.

[88] P. B. D. M. Oliveira, E. J. S. Pires, and P. Novais, “Gravitational Search Algorithm Design of Posicast PID Control Systems,” *Soft Computing Models in Industrial and Environmental Applications Advances in Intelligent Systems and Computing*, vol. 188, (2013), pp. 191–199.

[89] H. Sadeghi, N. Eghbal, and R. K. Moghaddam, “Application Gravitational Search Algorithm in Identification of Switched Linear Systems,” *2012*

Third International Conference on Intelligent Systems Modelling and Simulation, (2012), pp. 89–95.

[90] S. Duman, "Automatic Generation Control of the Two Area Non-reheat Thermal Power System using Gravitational Search Algorithm," *Electrical Review*, no. 10, (2012), pp. 254–259.

[91] S. Duman, D. Maden, and U. Güvenç, "Determination of the PID Controller Parameters for Speed and Position Control of DC Motor using Gravitational Search Algorithm," in *2011 7th International Conference on Electrical and Electronics Engineering*, no. 1, (2011), pp. 225–229.

[92] S. Dutta, S. Paul, K. Bhattacharjee, A. Bhattacharya, and R. Sarkar, "Automatic Generation Control of an Interconnected Hydro-Thermal System with Thyristor Control Phase Shifter using Gravitational Search Algorithm," in *IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012)*, (2012), pp. 269–274.

[93] M. Eslami, H. Shareef, and A. Mohamed, "PSS and TCSC Damping Controller Coordinated Design Using GSA," *Energy Procedia*, vol. 14, (2012), pp. 763-769.

[94] R.-C. David, R.-E. Precup, E. . Petriu, M.-B. Rădac, C. Purcaru, C.-A. Dragoş, and S. Preitl, "Adaptive gravitational search algorithm for PI-fuzzy controller tuning," in *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics*, (2012), pp. 136–141.

[95] R. Precup, R. David, E. M. Petriu, S. Preitl, and M. Rădac, "Gravitational Search Algorithms in Fuzzy Control Systems Tuning," in *18th International Federation of Automatic Control World Congress*, (2011), pp. 13624–13629.

[96] H. Massinaei, M; Falaghi, H; Izadi, "Optimisation of Metallurgical Performance of Industrial Flotation Column using Neural Network and Gravitational Search Algorithm," *Canadian Metallurgical Quarterly*, vol. 52, (2013), pp. 115–122.

[97] K. Mistry, V. Bhavsar, and R. Roy, "GSA based optimal capacity and location determination of distributed generation in radial distribution system for loss minimization," *2012 11th International Conference on Environment and Electrical Engineering*, (2012), pp. 513–518.

[98] R. A. Borges, F. S. Lobato, and V. S. Jr, "Modeling and Optimization of an Auto-Thermal Ammonia Synthesis Reactor," in *3rd International Conference on Engineering Optimization*, (2012), pp. 1–5.

[99] C. Li and J. Zhou, "Parameters identification of hydraulic turbine governing system using improved gravitational search algorithm," *Energy Conversion and Management*, vol. 52, no. 1, (2011), pp. 374–381.

[100] F. Ju and W. Hong, "Application of Seasonal SVR with Chaotic Gravitational Search Algorithm in Electricity Forecasting," *Applied Mathematical Modelling*, vol. 37, no. 23, (2013), pp. 9643–9651.

[101] C. Li, J. Zhou, J. Xiao, and H. Xiao, "Engineering Applications of Artificial Intelligence Hydraulic Turbine Governing System Identification using T- S Fuzzy Model Optimized by Chaotic Gravitational Search Algorithm," *Engineering Applications of Artificial Intelligence*, vol. 26, no. 9, (2013), pp. 2073–2082.

[102] S. Mallick, S. P. Ghoshal, P. Acharjee, and S. S. Thakur, "Optimal Static State Estimation using Improved Particle Swarm Optimization and Gravitational Search Algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 52, (2013), pp. 254–265.

[103] A. Fazliana, A. Kadir, A. Mohamed, H. Shareef, M. Zamri, C. H. E. Wanik, and A. A. Ibrahim, "Optimal Sizing and Placement of Distributed Generation in Distribution System Considering Losses and THDv using Gravitational Search Algorithm," *Przegląd Elektrotechniczny*, no. 4, (2013), pp. 132–136.

[104] P. K. Roy, "Solution of Unit Commitment Problem Using Gravitational Search Algorithm," *Electrical Power and Energy Systems*, vol. 53, (2013), pp. 85–94.

[105] A. K. Barisal, N. C. Sahu, R. C. Prusty, and P. K. Hota, "Short-term Hydrothermal Scheduling using Gravitational Search Algorithm," in *2012 2nd International Conference on Power, Control and Embedded Systems*, (2012), pp. 2–7.

[106] A. Bhattacharya, S. Datta, and M. Basu, "Gravitational Search Algorithm Optimization for Short-term Hydrothermal Scheduling," in *2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM)*, (2012), pp. 216–221.

[107] S. Duman, N. Yorukeren, and I. H. Altas, "Load frequency control of a single area power system using Gravitational Search Algorithm," *2012 International Symposium on Innovations in Intelligent Systems and Applications*, (2012), pp. 1–5.

[108] S. Duman, Y. Sönmez, U. Güvenç, and N. Yörükeren, "Optimal reactive power dispatch using a gravitational search algorithm," *IET Generation, Transmission & Distribution*, vol. 6, no. 6, (2012), pp. 563-576.

[109] P. K. Roy, B. Mandal, and K. Bhattacharya, "Gravitational Search Algorithm Based Optimal Reactive Power Dispatch for Voltage Stability Enhancement," *Electric Power Components and Systems*, vol. 40, no. 9, (2012), pp. 956-976.

[110] M. Udgir, H. M. Dubey, and M. Pandit, "Gravitational Search Algorithm: A Novel Optimization Approach for Economic Load Dispatch," in *International Conference on Microelectronics, Communication and Renewable Energy (ICMiCR- 2013)*, (2013), pp. 1-6.

[111] U. Güvenç, Y. Sönmez, S. Duman, and N. Yörükeren, "Combined economic and emission dispatch solution using gravitational search algorithm," *Scientia Iranica*, vol. 19, no. 6, (2012), pp. 1754–1762.

[112] H. Maskani, M. Yazdani, S. Alishahi, and H. Falaghi, "Dynamic economic dispatch considering network power losses based on gravitational search algorithm," *International Review of Electrical Engineering*, vol. 7, no. 1, (2012), pp. 3426–3434.

[113] R. K. Swain, N. C. Sahu, and P. K. Hota, "Gravitational Search Algorithm for Optimal Economic Dispatch," *Procedia Technology*, vol. 6, (2012), pp. 411–419.

[114] S. Duman, U. Güvenç, and N. Yörükeren, "Gravitational Search Algorithm for Economic Dispatch with Valve-Point Effects," *International Review of Electrical Engineering (I.R.E.E.)*, vol. 5, (2010), pp. 2890–2895.

[115] Y. Sonmez, U. Guvenc, S. Duman, and N. Yorukeren, "Optimal power flow incorporating FACTS devices using Gravitational Search Algorithm," *2012 International Symposium on Innovations in Intelligent Systems and Applications*, (2012), pp. 1–5.

[116] S. Duman, U. Güvenç, Y. Sönmez, and N. Yörükeren, "Optimal power flow using gravitational search algorithm," *Energy Conversion and Management*, vol. 59, (2012), pp. 86–95.

[117] a. Bhattacharya and P. K. Roy, "Solution of multi-objective optimal power flow using gravitational search algorithm," *IET Generation, Transmission & Distribution*, vol. 6, no. 8, (2012), pp. 751-763.

[118] A. Ghasemi, H. Shayeghi, and H. Alkhatib, "Robust Design of Multimachine Power System Stabilizers using Fuzzy Gravitational Search Algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 51, (2013), pp. 190–200.

[119] M. Eslami, H. Shareef, A. Mohamed, and M. Khajehzadeh, "Gravitational search algorithm for coordinated design of PSS and TCSC as damping controller," *Journal of Central South University*, vol. 19, no. 4, (2012), pp. 923–932.

[120] A. Ali and A. Mehdi, "A Multi-Objective Gravitational Search Algorithm based Approach of Power System Stability Enhancement with UPFC," *Journal of Central South University*, vol. 20, no. 6, (2013), pp. 1536–1544.

[121] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "Filter modeling using gravitational search algorithm," *Engineering Applications of Artificial Intelligence*, vol. 24, no. 1, (2011), pp. 117–122.

[122] O. Penangsang, M. Abdillah, and A. Soeprijanto, "Voltage Control on 500kV Java-Bali Electrical Power System for Power Losses Minimization Using Gravitational Search Algorithm," in *2011 First International Conference on Informatics and Computational Intelligence*, (2011), pp. 11–17.

[123] O. Ceylan and H. Dag, "Gravitational Search Algorithm for Post-Outage Bus Voltage Magnitude Calculations," in *2010 Universities Power Engineering Conference (UPEC)*, (2010), pp. 1-6.

[124] J. R. Parvin and C. Vasanthanayaki, "Gravitational Search Algorithm Based Mobile Aggregator Sink Nodes for Energy Efficient Wireless Sensor Networks," in *2013 International Conference on Circuits, Power and Computing Technologies (ICCPCT-2013)*, (2013), pp. 1052–1058.

[125] S. K. Saha, R. Kar, D. Mandal, and S. P. Ghoshal, "Design and Simulation of FIR Band Pass and Band Stop Filters using Gravitational Search Algorithm," *Memetic Computing*, vol. 5, no. 4, (2013), pp. 311–321.

[126] A. C. and G. K. Mahanti, "Comparative Performance Of Gravitational Search Algorithm And Modified Particle Swarm Optimization Algorithm

For Synthesis Of Thinned Scanned Concentric Ring Array Antenna," *Progress In Electromagnetics Research B*, vol. 25, (2010), pp. 331–348.

[127] Z. Beheshti, S. M. Shamsuddin, "A Review of Population-based Meta-Heuristic Algorithm," *International Journal of Advance Soft Computing*, vol. 5, no. 1, (2013), pp. 1–35.

[128] A. A. Abarghouei, A. Ghanizadeh, and S. M. Shamsuddin, "Advances of Soft Computing Methods in Edge Detection," *International Journal of Advance Soft Computing*, vol. 1, no. 2, (2009), pp. 1–42.