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Gravitational Search Optimization Algorithm: A Review

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ABSTRACT

Gravitational Search Algorithm is a nature inspired algorithm which is based on the Newton's law of gravity and the law of motion. The algorithm is intended to improve the performance in the exploration and exploitation capabilities of a population based algorithm, based on gravity rules. 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 . The GSA algorithm uses the theory of Newtonian physics and its searcher agents are the collection of masses. In GSA, we have an isolated system of masses. Using the gravitational force, every mass in the system can see the situation of other masses. The gravitational force is therefore a way of transferring information between different masses. GSA has been widely adapted due its ease of implementation and the ability to solve highly nonlinear optimization problems of complex engineering systems. An improved gravitational search algorithm (IGSA) is proposed and applied to the identification of dynamic neural network system.

Keywords : Gravitational Search Algorithm, Improved Gravitational Search Algorithm, Law of gravity

I. INTRODUCTION

Optimization means finding an alternative with most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones. Optimization finds most suitable value within the function. Optimization algorithm provides systematic and efficient ways of creating new design solutions. There is no single method available for solving all optimization problems efficiently. Hence, a number of optimization methods have been developed for solving different types of optimization problems.

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.

II. GRAVITATIONAL SEARCH ALGORITHM (GSA)

GSA was introduced by Rashedi et al. in 2009 and is intended to solve optimization problems. 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. GSA is grouped under the population based approach and is reported to be more intuitive. 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. 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. [2] 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. 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.

III. LAW OF GRAVITY

The gravitation is tendency of masses to accelerate toward search other. It is one of the four fundamental interactions in the nature. Every particle in the universe attracts every other particle. Gravity is everywhere. The inescapability of gravity makes it different from all other natural forces. [4]

The way the gravitational force behaves is called 'action at a distance'. This means gravity acts between separated particles without any intermediary and without any delay. In the Newton law of gravity, each particle attracts every other particle with a 'gravitational force'. The masses are actually obeying the law of gravity as shown in Equation (1) and the law of motion in Equation (2).

$$F = G\,(M_1 M_2 / R^2) \qquad (1)$$

$$a = F/M \qquad (2)$$

Based on Equation (1),

F- represents the magnitude of the gravitational force,

G-is gravitational constant,

M1 and M2- 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.

Based on (1) and (2), There is an attracting gravity among all particles of the universe where the effect of bigger and the closer particle is higher. As increase in the distance between two particles means decreasing the gravity force between them.

Active gravitational mass, M_a- It is measure of strength of the gravitational field due to the particular object. Gravitational field of an object with small object gravitational mass is weaker than the object with more active gravitational ma

Passive gravitational mass, M_p- It is measure of a strength of object's interaction with the gravitational field. Within the same gravity field, an object with a smaller passive gravitational mass experiences a smaller force than an object with a larger passive gravitational mass.

Inertial mass, M_i- It is a measure of object resistance to changing its state of motion when a force is applied. An object with large inertial mass changes its motion more slowly, and an object with small inertial mass changes it rapidly.

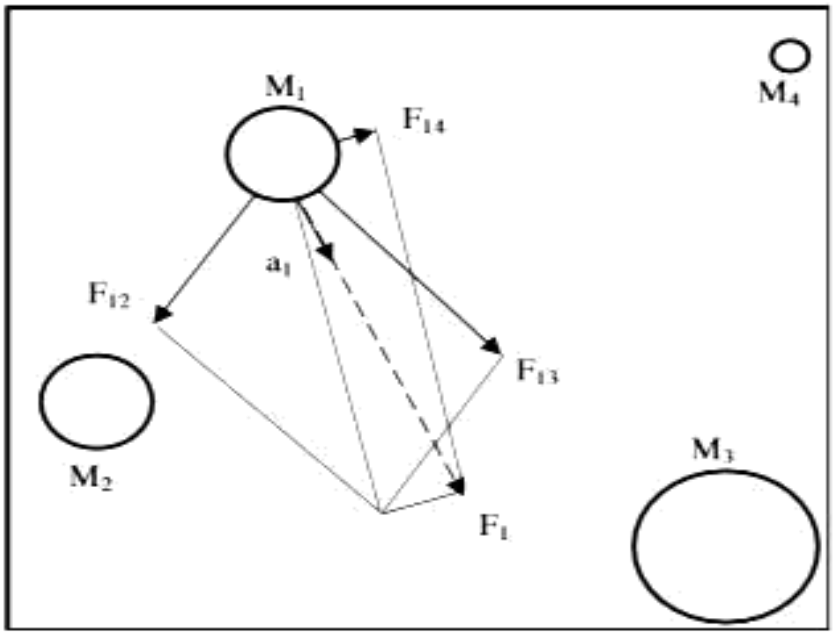

Fig.1 Every mass accelerated towards the result force that act it from the other masses

Although inertial mass, passive gravitational mass and active gravitational mass are conceptually distinct, no experiment has ever unambiguously demonstrated any difference between them. The theory of general relativity rests on the assumption that the inertial and passive gravitational mass is equivalent. This is known as weak equivalence principle. Standard general relativity also assumes the equivalence of inertial mass and active gravitational mass, this equivalence is sometimes called as strong equivalence principle.

IV. WORKING OF GSA

In GSA, the agent has four parameters which are position, inertial mass, active gravitational mass, and passive gravitational mass. 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.

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

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:

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

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

Maximization problems:

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

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

$fit_j(t)$ 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].

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

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.

$$M_{ai} = M_{pi} = M_{ii} = M_i, \quad i = 1, 2, ...,N. \quad (9)$$

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

Step 5: Accelerations of agents' calculation:

Acceleration of the i^{th} agents at iteration t is computed.

$$a_i^d(t) = F_i^d(t) / M_{ii}(t) \quad (10)$$

$F_i^d(t)$ is the total force acting on i^{th} agent calculated as:

$$F_i^d(t) = \Sigma rand_j F_{ij}^d(t) \quad (11)$$

jEkhest, j i

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:

$$F_{ij}^{d}(t) = G(t).(M_{pi}(t) \times M_{aj}(t) / R_{ij}(t) + \varepsilon).(x_j^{d}(t) - x_i^{d}(t)) \quad (12)$$

$F_{ij}^{d}(t)$ 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:

$$v_i^{d}(t+1) = rand_i \times v_i^{d}(t) + a_i^{d}(t) \quad (13)$$

$$x_i^{d}(t+1) = x_i^{d}(t) + v_i^{d}(t+1) \quad (14)$$

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.[2,11]

The gravitational search algorithm is outlined as follows:

1. Generate initial population of N agents at random
2. Compute G(t), Best Fitness and Worst Fitness
3. For each agent i, do:
3.3. Evaluate Force of Mass i
3.4. Evaluate Acceleration of Mass i
3.5. Update Velocity of Mass i
3.6. Find new Position of Agenti If (Probabilityi> Threshold)
{ If (Randi < Probabilityi) Then Pair Solutioni with the Best Fit Solutions Else Impose some minor change to Solutioni }
4. If Stopping Criteria Not Met, Go To 2 Else Stop. [5,9]

V.IMPROVED ALGORITHM OF GSA

GSA is a heuristic optimization algorithm based on the law of gravity among objects. In GSA, the search agents are a collection of masses, and their interactions are based on the Newtonian laws of gravity and motion. The gravity force is an acting force drawing objects closely. In the pre- luminary stage of the universe formation, various objects were disorderly distributed all around the universe. Due to the existence of the universal gravitation, the objects with higher gravitation gathered together and then evolved into the galaxy.[6]
In GSA, each agent has four variables: position, inertial mass, active gravitational mass and passive gravitational mass. Now consider a system with N agents in the search scope. We define the position of the i-th agent (agent i) by Xi =(x1 i,⋯,xdi ,⋯,xNi),i=1 ,2,⋯,N, wherexdi is the d-th dimension value of agent i. For the minimum problem, there are

$$best(t) = \min_{j\in\{1,\cdots,N\}} fitj(t)$$

$$worst(t) = \max_{j\in\{1,\cdots,N\}} fitj(t)$$

For the maximum problem, there are

$$best(t) = \max_{j\in\{1,\cdots,N\}} fitj(t)$$

$$worst(t) = \min_{j\in\{1,\cdots,N\}} fitj(t)$$

VI. STEPS OF IGSA ALGORITHM

The steps of IGSA algorithm are as follows:

• Step 1. Initialization of parameters.

• Step 2. Fitness evaluation of agents.

• Step 3. Update gravtational coefficient G(t), best value best(t) and worst value worst(t).

• Step 4. Update the optimal fitness Fbest(t) in the his- tory record group and its corresponding position Lbest(t), and the trial-and-error method is adopted for the updating of optimal agent.

• Step 5. Calculate the inertial mass, resultant force, ac- celeration and velocity of agents.

• Step 6. Update the position of agents.

• Step 7. If it has run 70% of the maximum iterative steps, the orbital change operation should be carried outfor those agents whose fitness values are bad.

• Step 8. If it has run 70% of the maximum iterative steps, the coordinate descent method should be carried out for the optimal agent.

• Step 9. Repeat Steps 2 to 8 until the stop criteria is reached

VII.CONCLUSION

Gravitational Search Algorithm is a nature inspired algorithm which is based on the Newton's law of gravity and the law of motion. The algorithm is developed to improve the performance in the exploration and exploitation capabilities of a population based algorithm, based on gravity rules. 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 . The GSA algorithm uses the theory of Newtonian physics and its searcher agents are the collection of masses. In GSA, we have an isolated system of masses. Using the gravitational force, every mass in the system can see the situation of other masses. The gravitational force is therefore a way of transferring information between different masses. GSA has been widely adapted due its ease of implementation and the ability to solve highly nonlinear optimization problems of complex engineering systems. An improved gravitational search algorithm (IGSA) is proposed and applied to the identification of dynamic neural network system.

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