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Review: Binary Bat Algorithm, Applications and Modifications

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Abstract. The Bat algorithm, inspired by microbat foraging behavior, has been utilized to solve optimization issues in continuous and discrete spaces. This algorithm can stagnate after some initial stage. Many methods and tactics have been tried to improve performance by increasing the diversity of the solution and therefore increasing the performance. A variant of the bat algorithm is the binary bat algorithm, in which the new bat position is limited to binary numbers only. The binary bat technique is now widely used to address issues in practically every area of optimization, feature selection, classification, and engineering procedures. Because there have been few reviews of the binary bat algorithm, the proposed study conducted a review of recent applications and modifications.

Keywords: Bat Algorithm, Binary Bat Algorithm, Optimization, Feature Selection, Classification.

INTRODUCTION

Nature-inspired algorithms have appeared to be viable for resolving exceedingly challenging optimization problems in science and engineering. In recent decades, numerous nature-inspired algorithms have been produced. Nature's chemical, physical, and biological processes are commonly employed to develop nature-inspired algorithms. Furthermore, several algorithms were developed based on sports, sociology, or history [1].

The binary bat algorithm (BBA) is a swarm intelligence method inspired by nature. BBA was proposed by [2] in 2012, and remarkable progress has been made in recent years. The researchers in [3-8] published reviews on the original bat algorithm (BA) that was proposed in 2010 by [9], but no one focused on the binary bat algorithm applications and modifications. As a result, this review focuses on current applications and changes to the BBA algorithm. The study is organized as follows: initially, the fundamentals of the bat algorithm and binary bat algorithm are described, and then examples of the most recent BBA applications are provided. The different BBA modifications are also described then the conclusion, and future works are presented.

BAT ALGORITHM

Yang created the bat algorithm in 2010 [9], inspired by bat echolocation. Figure 1 shows how echolocation works as a type of sonar: As the obstacle or prey gets near, these microbats make a loud sound pulse and vary their pulse rate. In this way, the bat receives and detects the location of prey. Furthermore, Bats can distinguish between obstruction and prey using this remarkable orienting technique, allowing them to forage entirely in the dark. To emulate the foraging behavior of bats, the biological process of BA follows the following ideal assumptions:

1. Echolocation is used by all bats. To estimate distance, they can determine the difference between prey and surrounding barriers in some mysterious way.
2. To search for prey, A bat flies in a random direction with velocity vi at position xi with a fixed frequency $f_{\min}$, varying wavelength λ, and loudness A_0. Depending on the proximity of their targets, they may automatically modify the wavelength (or frequency) of their generated pulses as well as the rate of pulse emission $r\in(0,1)$.
3. Although loudness can vary in various ways, Yang thinks that it ranges from a large positive A_0 to a small fixed value $A_{\min}$.

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BA generates a collection of solutions at random based on the three idealized assumptions and then cycles through them in search of the optimal answer, strengthening the local search in the process. BA can identify the global optimal solution by using random flying to produce a local solution near the optimal solution. The steps of the BA are presented in Algorithm 1.

Algorithm 1: Bat Algorithm

Objective function $f(x)$, $x = (x^1,...,x^n)$.
Set the bat population x_i and v_i, $i = 1,2,...,m$.
Define pulse frequency f_i at x_i, $\forall i = 1,2,...,m$.
Set pulse rates r_i and the loudness A_i, $i = 1,2,...,m$.

1. While $t<T$
2. For bat bi, do
3. produce new solutions through Equations (1),
4. (2) and (3).
5. If $rand > r_i$, then
6. Choose a solution among the best solutions.
7. Produce a local solution around the
8. best solution.
9. If $rand < A_i$ and $f(x_i) < f(\hat{x})$, then
10. Admit the new solutions.
11. Raise r_i and reduce A_i.
12. Rank the bats and find the current best $\hat{x}$.

Firstly, the initial position x_i, velocity v_i, and frequency f_i are initialized for each bat bi. For each time step t, being T the maximum number of iterations, The virtual motion bat is determined by updating its velocity and position using Equations 1, 2, and 3, as shown below:

$$f_i = f_{min} + (f_{min} - f_{max})\beta, \tag{1}$$

$$v_i^j(t) = v_i^j(t-1) + \left[\hat{x}^j - x_i^j(t-1)\right]f_i, \tag{2}$$

$$x_i^j(t) = x_i^j(t-1) + v_i^j(t), \tag{3}$$

Where β represents a number generated randomly from the range [0,1]. Calling that $x_i^j\ (t)$ indicates the value of the variable of choice j for bat i at time step t. The resulted value of f_i (equation 1) is employed to regulate the speed of the bat and range of motion. The variable $\hat{x}^j$ indicates the current global best solution for the variable of choice j, which is accomplished by comparing all the solutions provided by the m bats.

Yang [9] has advocated using random walks to increase the variety of the available solutions. First, one of the existing best solutions is chosen; after that, for each bat that meets the criteria in algorithm 1(step 5), the random walk is employed to establish a new solution:

$$x_{new} = x_{old} + \epsilon\bar{A}(t), \tag{4}$$

Where $\bar{A}(t)$ is the average loudness of all the bats at time t, and $\epsilon \in [-1,1]$ attempts to the direction and strength of the random walk. The loudness A_i and the emission pulse rate r_i are changed for each iteration of the algorithm as follows:

$$A_i(t+1) = \alpha A_i(t) \tag{5}$$

$$r_i(t+1) = r_i(0)[1 - \exp(-\gamma t)], \tag{6}$$

In which α and γ are ad-hoc constants. At the beginning of the algorithm, the emission rate $r_i(0)$ and the loudness $A_i(0)$ are often randomly chosen. In general, $A_i(0) \in [1,2]$ and $r_i(0) \in [0,1]$.

The merit and demerit of the BA are:

- **Merit:**

    1. By shifting from exploration to exploitation, BA can offer rapid convergence at a very early stage.
    2. BA is receiving greater attention because of its simplicity, having fewer parameters, strong robustness, and being straightforward to implement.

- **Demerit:**

    1. After an early stage, BA may become stagnant if it moves too quickly from the preliminary stages to the exploitation stage by adjusting A and r.
    2. BA has some shortcomings in solving feature selection problems.

Several techniques have been developed to maximize the solution's variability and enhance performance, resulting in a few suitable BA modifications. The BBA is a discrete variant of the bat method used to tackle several tasks, including classification and feature selection.

BINARY BAT ALGORITHM

The researchers in [2] suggested the BBA, observing that while selecting features, the search space is depicted as a Boolean lattice with an n-dimension where the bat walks through the corners of a hypercube. The location of the bat is represented by vectors of binary values since the issue is to choose or not to choose a certain attribute. They suggested a binary version of the BA that uses a sigmoid function (Equation 7) to limit the new location of bat binary values:

$$S(v_i^j) = \frac{1}{1+e^{-v_i^j}}. \tag{7}$$

Equation 3 was replaced with the following:

$$x_i^j = \begin{cases} 1 \; if \; S(v_i^j) > \sigma, \\ 0 \; otherwise \end{cases} \tag{8}$$

Where $\sigma \sim U$ (0,1). As a result, Equation 8 can only yield binary values for coordinates of each bat in the Boolean lattice, which indicate whether the features are present or not.

The following are the merit and demerit of the BBA:

- **Merit:**

    1. Better Convergence: Bat and its derivatives have a higher convergence rate than the other algorithms.
    2. Auto-zooming: The capability of the bat to auto-zoom allows it to arrive at a promising solution zone faster.
    3. Auto-switching: Zooming is constantly accompanied by auto-switching, in which the digital bats switch from explorative movements to local-focused search space exploitation. The higher the convergence rate, the more efficient auto-switching is.
    4. Parameter control: Parameter control is a system in which the parameters are not static but instead change with the number of iterations. The bat algorithm regulates parameters that change with each iteration. Other meta algorithms, on the other hand, usually have defined parameters. Auto switching is aided by parameter control.

5. Frequency-tuning: Frequency-tuning mimics the echolocation behavior of bats. PSO, and Cuckoo Search have the frequency tuning property. As a result, frequency tuning can be used to give functionality comparable to that of other swarm intelligence algorithms.

- **Demerit:**

1. BBA can deliver competitive performance but occasionally risks getting stuck to local minima.
2. BBA has the disadvantage that the particles can only take values of 0 or 1. Therefore, even when the particles' velocities grow, their locations don't change.

APPLICATIONS OF BINARY BAT ALGORITHM

Since 2012, several new uses of the bat algorithm have developed in conjunction with the development of further BBA modifications and improvements. Indeed, advancements have been made in various applications, including classification, monitoring, feature selection, topology optimization, and others.

Classification and Feature Selection

The study in [10] used the concepts of the BBA and binary Particle Swarm Optimization (PSO) algorithms for feature selection. The vectors of the velocity for each particle are independently updated based on the velocity of the bats is estimated in real-time using a weighted combination of local and global best solutions. Moreover, the researchers in [11] utilized an unsupervised technique to determine the optimum feature subset. They suggested a modified BBA that wrapped the clustering technique. Also, the work in [12] presented a modified approach for feature selection using updated BBA. The updated BBA incorporates one mutation mechanism while locked in local optima to improve its ability to escape from local optima.

The study in [13] explained a method for anticipating spammers on Facebook. Different features of a Facebook profile are analyzed to predict spam. Then, using a BBA, 18 significant features for spam classification are chosen. Furthermore, a study in [14] proposed a two-stage strategy for gene selection: in the first, the fuzzy mutual information method is utilized to choose the most essential genes from a fuzzy model. Then, the BBA is utilized in the second step to decrease and determine a fixed number of genes that affect the classification process.

In [15] a blind image steganalysis technique is presented to use a BBA for feature selection to identify stego pictures from cover images. Meanwhile, SPAM and a variety of classifiers have been used to improve detection. On the other hand, the research in [16] provided a feature selection strategy for identifying the appropriate set of features for the machine learning job. The BBA technique is used to pick the set of features and the one-pass generalized classifier neural network is used to evaluate the selected features using a unique fitness function.

Additionally, the work in [17] provides an optimized BBA for leukocyte classification. A series of features are retrieved from White Blood Cell (WBC) pictures, and then the optimal technique is used to extract a subset of those features from the high-dimensional dataset. Meanwhile, the study in [18] focused on the importance of feature selection and suggested a hybrid model for credit score classification that combined feature selection with a novel fitness function and was aggregated with a radial basis function neural network. Also, a Hadoop-based parallel BBA in [19] is presented for effective feature selection and classification to attain an optimum detection rate using a nature-inspired feature selection technique and a parallel computing architecture.

Monitoring Systems

The researchers in [20] developed an improved BBA approach for optimal Phasor Measuring Unit (PMU) allocation in a power system network with complete observability. To measure the entire observability performance of the network, the bus redundancy index at each bus is taken into account. Upgraded BBA was created in such a way that the total observability of the system can be achieved at a low cost. Also, A new objective function for decreasing the number of voltage dip measuring devices was introduced in [21]. The optimization problem is solved using the BBA. The BBA reduces the number of measuring devices and finds the best position for them. Additionally, To discover the ideal number and deployment locations of PMU such that the power system is entirely visible, a technique based on Taguchi BBA is proposed in [22]. The suggested algorithm combines the systematic

reasoning ability of the Taguchi method with the classic BBA to improve the initial population and, as a result, the computational efficacy of the solution.

Topology Optimization

The study in [23] presented a new filtering technique that allows BBA to discover designs with no separated objects, no checkerboard patterns, minimum unusable material, and better constitutional performance. To speed up convergence to the best design, a topology optimization with a volition penalty function is given. This algorithm found better designs than other methods but had a higher computational cost because of the global search nature of the metaheuristic algorithm. Also, for high-dimensional binary optimization, the authors in [24] proposed a phase angle-modulated BBA. The goal was to lower the optimization dimensions while reducing the optimization time by applying angle modulation technology. The trigonometric generating function cosine wave is adjusted by adding additional parameters**.**

Applications in Other Areas

The researchers in [25] introduced a BBA for video tracking, assuming that the task of monitoring a target on each frame may be inferred as an optimization problem. In a binary bat algorithm-based tracker, a random set of target candidates is formed. This algorithm tracks a single target and does not have the ability to track multiple targets.

On the other hand, the study in [26] constructed an Anomaly-based intrusion detection system by utilizing the benefits of a BBA to improve the Support Vector Machine (SVM) classifier. For function optimization problems, researchers in [27] discovered that parameter initialization of the BBA significantly impacts the speed of the convergence, precision, and ability of the global search. Six standard test functions are used to carry out simulation trials. They proved when the rate of bat sent pulse is increased alone, the convergence precision decreases, and when the convergence speed is increased alone, the launch loudness increases.

In addition, the work in [28] identified the best attributes in diagnosing breast cancer. Using data mining algorithms, relevant attributes were extracted from a vast amount of data relating to the sickness of people and medical records. This method resulted in early diagnoses and the avoidance of death. Clump thickness, cell size uniformity, cell shape uniformity, marginal adhesion, and single epithelial cell size are the significant qualities discovered by the BBA and SVM categorization, according to the findings of this study. On the other hand, the authors in [29] suggested a hybrid algorithm to address the targeted marketing maximization. They proposed combining the BBA with the Genetic Algorithm (GA), which produces better populations from good parents, to profit from convergence in advanced iterations. These numbers are quite near to the global optimum.

Additionally, to solve the Quality of Service (QoS) multicast routing problem, the study in [30] developed an enhanced chaotic BBA. In the BBA, two modification approaches are added. First, the logistic map and the tent map are employed, two of the most representative chaotic maps. Second, they used a dynamic formulation to update the parameter α of the loudness A_i.

Furthermore, utilizing an SVM, the study in [31] used a multi-objective Pareto-based bat method to mine association rules. The multi-objective BBA has good convergence and can develop a collection of non-dominated solutions with M association rules by running it once. Also, The study in [32] presented a BBA algorithm for handling binary space optimization problems. The suggested algorithm is based on Kennedy and Eberhart's binary PSO algorithm, which utilized a sigmoid function in 1997. The BBA was put to the test on difficult multi-dimensional knapsack problems. Additionally, The test suite reduction problem in [33] was reformulated as a multi-objective optimization problem, and the heuristic BBA was used to solve it. The BBA algorithm was tweaked to improve its exploration skills when looking for Pareto-optimal solutions.

MODIFICATIONS OF BINARY BAT ALGORITHM

There are numerous new modifications of the BBA according to current works. BBA can perform well compared to other methods, although it occasionally stagnates at local minima. The performance of this algorithm is enhanced by applying some modifications. A summarization of some of the latest modifications of BBA is presented in Table 1.

TABLE 1. Modifications of Binary Bat Algorithm

Reference	Data Type	Enhancement	Year of Publication	Comparison Criteria
[26]	NSL-KDD dataset (data on network attacks)	1. BBA applied with Le´vy flights to locate the better subset for SVM. 2. BBA is used to locate the best parameters for SVM. 3. SVM found network attacks using the best parameters in the previous step.	2014	Attack detection rate, false alarm rate, and accuracy.
[34]	Biology dataset(data on breast cancer)	1. The feed-forward neural network is trained using BBA. The incremental training method is used, in which the network is trained for several iterations before being evaluated. 2. The BBA is used to minimize the error of classification computed for a set of biases and weights created at random.	2016	Time efficiency and error minimization
[31]	UCI machine learning datasets include Foods, Books, grocery products, Balance, Cars, and Nursery.	1. The problem of association rules mining is tackled using several measurements, and a new evaluation approach known as the degree of similarity is applied to the forward multi-objective BBA without a minimum of support or confidence.	2016	Computational time, quality of rules
[30]	Real-time multimedia data.	1. Two adjustment methods are introduced into the BBA. 2. The logistic map and the tent map are employed to determine the parameter β of the pulse frequency f_i. 3. A dynamic formula is used to update the parameter α of the loudness A_i.	2016	Tree cost, convergence time, delay, delay-jitter, and packet loss rate
[12]	UCI machine learning repository including WBCD1, Australian, Zoo, Vehicle, German, WBCD2, Ionosphere, Lung, Sonar, Hillvalley and Musk1.	1. A random bat and the global best bat are combined to guide the exploration of bats to increase the variety. 2. To improve the ability to avoid local optimization, this algorithm makes one mutation mechanism while the algorithm is trapped into local optima.	2017	Computational time
[10]	Biology, Politics, Electromagnetic, Game, Physics, Chemistry, Artificial	1. A unique formulation is obtained by separating the velocity vectors of the bats in BBA and the particles in PSO. The velocity vectors for both particles are updated independently based on a weighted combination of personal and global best solutions, and the bats' velocity arrives instantly. 2.	2018	Testing the stability, robustness and the repeatability of convergence

TABLE 1. Modifications of Binary Bat Algorithm (Continued)

Reference	Data Type	Enhancement	Year of Publication	Comparison Criteria
[25]	Self-made video	3. BBA used the tracking detection rate, object tracking error, absolute error, root mean square error and time cost as parameters.	2018	Average time cost
[11]	Eight datasets available in the UCI machine learning repository	1. The modified BBA with a k-means clustering algorithm is used to present a wrapper-based unsupervised feature selection approach. In addition, the mutation operator is used to ensure that the search space is diverse.	2018	Classification accuracy and number of selected features.
[23]	Structural topology problems.	1. To avoid the production of isolated elements and checkerboard patterns and increase the convergence rate toward minimum compliance, the BBA was updated with a new filtering algorithm and penalty function.	2020	Compliance subjected to a maximum volume constraint
[29]	Database marketing Scotiabank	1. Building initial solution using GA. 2. Sequential and parallel hybridization are used. The sequential one concern using GA in the initialization of a feasible solution. The parallel hybridization is used for perfecting the solution found in each BBA iteration by an application of the GA limited in terms of the number of iterations.	2020	Convergence of fitness function

CONCLUSION AND FUTURE WORK

In the last few years, the literature on the binary bat algorithm and its variants has grown significantly; we have presented a brief but timely summary of the most recent developments. The works reviewed above illustrated that the BBA is efficient in extracting important features and then improving the classification process. BBA's performance has been improved by incorporating other algorithms such as clustering algorithms, GA, and SVM classifier. There are several essential open research topics related to the BBA, which are as follows:

- More comparison studies on feature selection and optimization issues are needed for various modifications of the BBA in the literature.
- For tackling various issues, several swarm intelligence algorithms such as cuckoo search and shuffling frog leap algorithms can be combined with the BBA.
- Using the BBA to solve problems involving multi-dimensional structural topology optimization.
- Looking into the effects of different transfer functions on BBA performance.

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