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A Review on Applications of Optimization Using Bat Algorithm

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ABSTRACT

Bat algorithm is introduced by Xin-She Yang. This article describes an overview of Bat algorithm, which is inspired by the life of a bat family, as well as an overview of bat algorithm applications in various categories for solving optimization problems. Optimization is a process of determining the best solution to make something as functional and effective as possible by minimizing or maximizing the parameters involved in the problems. The categories reviewed are engineering, scheduling, transportation/vehicle, and networking. The objective of this is to provide an overview and to summarize the review of applications on the bat algorithm.

Key words: Bat Algorithm, Optimization Problem, Applications.

1. INTRODUCTION

Bat algorithm is a bio inspired algorithm based on echo location method that uses sonar waves produce from bats. It was then introduced to optimization solution by Xin She Yang, a mathemathician through the article "A New Metaheuristic Bat-Inspired Algorithm" [1].

2. OVERVIEW OF BAT ALGORITHM

Bat algorithm is a simple optimization approach, yet at the same time very efficient [2, 3].This algorithm is inspired from microbat echolocation species mechanism since microbat utilizes extensive echolocation methods to detect their prey such as small insects, locate barriers in dark areas as well as identifying its habitat between stone cracks.

The global solution search mechanism is represented by the position and velocity of virtual microbats movement at random. Position xi represents the current solution value and velocity vi represents the movement from the current solution value to other potentially better solution values. The best current solution is represented by x∗ at every iteration. Solution exploration is performed by adjusting the frequency or wavelength fi, pulse emission rate r and Ai loudness for each iteration. The effectiveness of obtaining global solving solutions depends on the frequency or wavelength tuning technique to control the behavior of virtual microbats as well as the optimized balance between good exploration and exploitation [1, 3, 4].

The mathematical equations for updating the location and velocity values for each microbat in the group are as below.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (1)$$
$$V_i^t = V_i^{t-1} + (X_i^{t-1} - X_*)f_i \quad (2)$$
$$X_i^t = X_i^{t-1} + V_i^t \quad (3)$$

Here, β ∈ [0, 1] is a random vector obtained from uniform distribution. Frequency (or wavelength) f_i is used to control the rhythm and distance movement (position and velocity) virtual bat to get local solution x * on every iteration and global solution best when the target or objective is reached.

In addition, loudness and pulse emission rate also play a role in the effectiveness of Bat Algorithm and the similarities of mathematical equations for sound value changes and pulse emission rate are presented as below:

$$A_i^{t+1} = \alpha A_i^t \quad (4)$$
$$r_i^{t+1} = r_i^0 [1 - exp(-\gamma t)] \quad (5)$$

where $0 < \alpha < 1$ dan $\gamma > 0$.

Bat Algorithm is conducted on the condition of 3 main assumptions i.e.

i. All the bats in the swarm of bats are detecting the distance and to distinguish the difference between food and other objects using echolocation method.
ii. The bats fly at random and adjust frequency (or wavelength) f_i and pulse emission rate (r) of sonar signal to determine the next position and velocity. Although the value of A_i loudness can vary and but random value that is obtained needs to be between large positive value A_0 until its minimum value of A_{min}.

iii. To better understand Bat Algorithm more clearly, the optimization approach of Bat Algorithm is summarized in pseudo code below.

```
Initialize the bat population x_i and v_i (i = 1,2,...,n)
Initialize frequencies f_i, pulse rates r_i and the loudness A_i
while (t < maxvalue) do
    Generate new solutions by adjusting frequency
    f_i = f_min + (f_max - f_min)β
    Update velocities and locations/solutions
    V_i^t = V_i^{t-1} + (X_i^{t-1} - X_*) f_i
    X_i^t = X_i^{t-1} + V_i^t
    if (rand > r_i) then
        Select a solution among the best solutions
        Generate a local solution around the selected best solution (x_*)
    end if
    Generate a new solution by flying randomly
    if (rand < A_i & f(x_i) < f(x_*)) then
        Accept the new solutions
        Increase r_i and reduce A_i
    end if
    Rank the bats and find the current best x_*
end while
```

Original Bat Algorithm [1]

2.1 Advantages of Bat Algorithm

Bat Algorithm is very simple, easy to apply and very flexible to solve various types of optimization problem. According to [1, 3, 4] there are three reasons why Bat Algorithm can be very effective in solving optimisation problem namely:

A. Frequency Tuning

Bat Algorithm uses frequency-tuning approach to obtain global solution in optimization problem. Although frequency tuning in Bat Algorithm does not necessarily be exactly similar to real echolocation but this freedom allows researchers and developers to utilize a variety of different frequency tuning methods that is suitable to the optimization problem being resolved or as an alternative to the currently available existing frequency tuning.

B. Automatic Zooming

The main advantages of Bat Algorithms when compared to other metaheuristic algorithms is Bat Algorithm's ability to perform automatic zooming in highly potential areas to obtain a solution. Automatic zooming is performed during the transition between exploration mode to exploitation mode and this mechanism enables quick convergence rate to be achieved or at least during the initial stages when searching for a solution.

C.Parameter Control

Most other metaheuristic algorithms require prior parameters setup as initial value. However, Bat Algorithm instead uses parameter control to change signal loudness Ai and pulse emission rate ri on each iteration. The control parameter allows the transition from exploration mode to exploitation mode to be conducted automatically without any manual manipulation (the setting of inflexible target).

Furthermore, Bat Algorithm has big potential to be implemented in various optimization problems through the use of suitable random function or data distribution, according to the optimisation problem that needs to be solved [3,5].

2.2 Varieties of Bat Algorithm

Bat Algorithm is proven to be effective despite its simple algorithm design. However, should the parameters used are not set correctly (as I understand, you said no need to setup prior), Bat Algorithm will consequent imbalance problems between exploration and exploitation to obtain the real global solution. Therefore, many researches have introduced many new types of Bat Algorithms to increase the effectiveness of Bat Algorithm in order to achieve global solutions in optimization problem. There are various varieties of Bat Algorithm that exist as an improvement and modification for different problem nature after the original Bat Algorithm was first introduced in [1] it became the popular choice for metaheuristic optimization solution [3,5]. For example, among others are (i) Fuzzy Logic Bat Algorithm (FLBA), (ii) Multi-Objective Bat Algorithm (MOBA), (iii) K-Means Bat Algorithm (KMBA), (iv) Chaotic Bat Algorithm (CBA), (v) Improved Bat Algorithm (IBA), and (vi) Modified Bat Algorithm (MBA).

A. Fuzzy Logic Bat Algorithm (FLBA)

Authors in [6] introduced and suggested the use of Fuzzy Logic approach inside Bat Algorithm.

B. Multi-Objective Bat Algorithm (MOBA)

From the standard Bat Algorithm, [7] it develops the potential of Bat Algorithms into multi-objective optimization solutions and it is evidently proven in demonstrations conducted to efficiently solve engineering optimization problems.

C. K-Means Bat Algorithm (KMBA)

Authors in [8] on the other hand, introduced the KMBA, a combination of K-means approach and Bat Algorithm to effectively solve clustering problems.

D. Chaotic Bat Algorithm (CBA)

There are several different chaotic bat algorithm based modifications as introduced by [9, 10, 11]. The chaotic mechanism in use differs from one another. For example [9] using Lévy flights and chaotic maps to represent a dynamic biological system, [10] make comparisons of different chaotic map functions such as Chebyshev map, Circle map, Gauss map and a few other chaotic maps. Authors in [11] also compares several different chaotic map functions to determine the best chaotic approach to be used in the Chaotic Bat algorithm and Iterative chaotic map with infinite collapses (ICMIC) to produce the best results.

E. Binary Bat Algorithm (BBA)

The original Bat Algorithm design is to solve a problem with continuous nature. However, for discrete and combinatorial type of problems, modification is needed using Binary Bat Algorithm (BBA) method. There are some literature that introduces the Binary Bat Algorithm for different discrete and combinatorial problems such as [12] using BBA to tackle classification and feature choice problems. Authors in [13] on the other hand uses BBA to complete binary discrete optimization and compared it with Binary Partical Swarn Optimization and Genetic Algorithm. Further, author in [14] uses BBA to resolve load dispatch problem and compared it with other approaches such as lamda iteration, Genetic Algorithm (GA), Partical Swarn Optimization (PSO) and Artificial Bee Colony (ABC) algorithm.

F. Improved Bat Algorithm (IBA)

The Improved Bat Algorithm (IBA) has several different versions according to researchers such as [15] that improves solution exploration and exploitation from being trapped in local minimum by using inertia weigh factor modification, adaptive frequency modification and combining Bat Algorithm with Scout Bee algorithm. Authors in [16] improves Bat Algorithm with the addition of differential evolution to provide a balance between intensification and diversification when solution exploration is performed. While author in [17] introduces a four step velocity updating strategies to improve Bat Algorithm to make it self-adaptive and provide a needed balance in terms of solution exploration and exploitation.

G. Modified Bat Algorithm (MBA)

Modified Bat Algorithm (MBA) is a Bat Algorithm with some modification of algorithm structure as to improvement and to give focus on a more narrow and specific optimization problem. The MBA is developed by author in [19] specifically to address record deduplication problems by combining Bat Algorithm with Genetic Programming to enable duplicate detection to be conducted more efficiently. Authors in [20] additionally modify the equation of pulse emission rate and loudness of bats inside Bat Algorithm to improve solution quality when compared to the original Bat Algorithm. Authors in [21] modifies the virtual bat movement by utilizing the bacterial foraging strategies method in which opposite direction of negative velocity is allowed. This modification is used specifically for wireless sensor network localization.

There are also several other improvements that combine Bat Algorithm with other metaheuristic optimisation approaches such as combination of Harmony Search with Bat Algorithm introduced by author in [22] and hybrid self-adaptive Bat Algorithm introduced by author in [23] by using differential evolution as local search mechanism in Bat Algorithm to create an adaptive approach in Bat Algorithm local optimization.

2.3 Application and Potential of Bat Algorithm

With the existence of various variants of Bat Algorithm, various applications can be created using Bat Algorithm method and it is not only limited to continuous optimization problems [3]. Bat Algorithms has not only been tested in common mathematical problems but also has been included in engineering, computer networks, data/information processing, finance, transportation and so on.

Because Bat Algorithm is a metaheuristic optimization solution that is simple flexible, efficient and provide fast convergent speed, it is used successfully in various areas. Authors in [3] identifies Bat Algorithm applications within the perspective of general mathematical optimization, such as data mining, clustering, classification, scheduling, parameter estimation, inverse problem, combinatorial optimization and continuous optimization. However, we are more keen to observe the application and Bat Algorithm's potential in the form of horizontal classification to monitor applied Bat Algorithm in existing literatures.

A. General Engineering Optimisation Solution

Since its introduction, [1], Bat Algorithm receives much attention particularly towards solving various optimization problems in engineering especially in civil engineering and electrical/electronic engineering. In [24], Yang and Gandomi use Bat Algorithm with several other different modifications to solve eight examples of engineering optimization problem namely (1) nonlinear mathematical benchmark problem; (2) Himmelblau's problem; (3) three-bar truss design; (4) speed reducer design; (5) parameter identification of structures; (6) cantilever stepped beam; (7) heater exchanger design; and (8) car side problem. In the experiment, Bat Algorithm proved to be effective in solving all the problems in the selected case studies thus demonstrating Bat Algorithm's potential solving general engineering optimization problem.

B. Engineering

There are also several researches that uses Bat Algorithms as specific civil engineering optimization solutions as ones conducted by [25] that uses structural optimization for benchmark problem to test the effectiveness of Bat Algorithm in structural engineering. This is in contrast to [26] that exploits the potential of Bat Algorithm for steel space frames optimal design to obtain the most cost effective steel space frame structure while maintaining the reliability and stability of the structure based on Allowable Stress Design-American Institute of Steel Construction's (ASD-AISC) specification. Authors in [27] performs similar applications as [26] but give focus on discrete size of steel frames to determine the most ideal steel frame size in terms of cost and the load that the steel frame can bear according to ASD-AISC specification. Authors in [28] use improved Bat Algorithm that is dedicated for conducting several structural reliability analysis namely, reinforced concrete beam test, a conical structure test, parallel and serial systems test, a cantilever beam test and lastly, a steel joint test. Author in [29] using Bat Algorithm for other different problem that is, to optimize ergonomic criteria in office workspace layout to obtain the best possible result.

Bat Algorithm is also used to solve optimization problem that exists in electrical and electronic engineering field. To obtain the most efficient DC wheel motor design, author in [30] uses Bat Algorithm to perform mono and multi-objective optimization solution based on several different optimization parameters. Optimization of the design needs also to take into account several other constraints for the design of the DC wheel motor such as total mass of the DC motor, inner diameter and so on.

Bat Algorithm application is also found in the field of power grid and power generator engineering. Author in [31, 32, 33, 34] uses Bat Algorithm for the purpose of optimal schedule tuning of Proportional and Integral (PI) controller to enable power generator to provide optimal supply of electricity. Authors in [35] uses the Bat Algorithm to determine optimal exergy model for gas turbine generator in the form of fuzzy logic that is generated through locally linear model tree algorithm. This Exergy analysis is used for fault detection and diagnosis in gas turbine generators based on actual data. Authors in [36] further exploits Bat Algorithm to obtain the most optimal thermal power plant operating cost through the use of economic load dispatch (ELD) optimization approach. Authors in [37] recommends the use of Bat Algorithm that has been modified to tackle dynamic environment and economic optimization in dispatch problem as this type problem is a complex nonlinear non-smooth and nonconvex multi-objective optimization problem.

C. Scheduling

Scheduling is one of the popular optimization problem to be tested using metaheuristic algorithms that includes Bat Algorithm. Among researches that use Bat Algorithm in their investigation to solve scheduling optimization problems done by author in [38, 39] that tries to optimize realistic hybrid flow shop (HFS) scheduling that is NP-hard in nature. HFS is a special case flow shop problem because different operations and different machines operate simultaneously. The probability for several operations and machines to operate in parallel should also be taken into consideration and this increases the complexity to obtain the most optimum HFS. An almost similar investigation is carried out by author in [40] and uses Bat Algorithm to complete multi-stage multi-machine multi-product scheduling problems.

Other than operational schedule optimization problem, Bat Algorithm is also used for cloud computing's resources scheduling such as studies done by author in [41], [42] and [43]. Research conducted by author in [41] investigates Bat Algorithm's ability at optimizing workflow scheduling in cloud computing facilities, with main focus given towards task and resource mapping to produce the lowest workflow cost in term of resources and time. Author in [42] on the other hand is keen to compare several different metaheuristic algorithms to solve resource scheduling in cloud computing facilities that include Bat Algorithm. While authors in [43] tends to compare several different metaheuristic algorithms that include Bat Algorithm to perform resource allocation in distributed computing environment within cloud computing facilities.

D. Transportation/Vehicle

Besides scheduling, vehicle's routing or path planning is also among the optimization problems that is used as a case study to be solved using metaheuristic algorithm that include Bat Algorithm. Author in [44, 45] apply Bat Algorithm as optimisation solution in path planning to seek the most cost effective uninhabited combat air vehicle (UCAV) flight route as well as routes that is safe from any enemy threats. Author in [46] uses a modified Bat Algorithm called the Weibull Coded Binary Bat Algorithm (WCBBA) to obtain the most optimal travel route and load balanced of road traffic at the same time. Further, authors in [47] uses Bat Algorithm to solve multivariable optimization of travel plan for integrated group of caravan to know cost and benefit of the selected route based on speed, storage and other related resources. [48] introduced a hybrid Bat Algorithm with path relinking (HBA-PR), a modified Bat Algorithm that combined with greedy randomized adaptive search procedure (GRASP) and path relinking to solve NP-Hard optimization problem of capacitated vehicle routing problem (CVRP) from literature [49]. Authors in [50] solves optimization problems quite differently as it uses Bat Algorithm to solve NP-Hard aircraft landing problem (ALP) to reduce the cost of landing process in a predefined target time while maintaining safety.

E. Networking

Bat Algorithm is also used in networking field especially in wireless ad hoc network environment. Authors in [51] improve Bloom filter optimization with Bat Algorithm for spam filtering application. Like other probabilistic hash tables, Bloom filter allows a small percentage of false positives and [51] seek to compare between Bat Algorithm and Cuckoo search as to improve the level of accuracy in

Bloom filter because accuracy in information matching is critical for spam filtering. For author in [52] on the other hand, Bat Algorithm is used to detect anomaly and mitigation in software defined networking (SDN) environment efficiently and quickly.

Further, we now look at how Bat Algorithm is used to tackle different optimization problems in the wireless ad-hoc network from existing related literatures. Authors in [53] uses Bat Algorithm to solve optimisation problem to determine dynamic router node placement (dynRNP) in MANET where each node has a different priority that is based on weight value. This investigation is extended in [54] with dynamic placement of router and gateway simultaneously in the most optimum condition in term of network connectivity and client coverage based on relay load, QOS constraints of delay for every hops and capacity of gateway. Authors in [55] further uses a combination of Bat Algorithm and Distance-based Termite (D-Termite) algorithm [56] as hybrid algorithm Bat-termite Algorithm to create an adaptive and robust router mechanisms.

The Bat Algorithm also gain attention in the Wireless Sensor Network (WSN) as applied in author in [57] where it is used as a routing optimization solution to tackle security management, energy conservation requirement and QOS in WSN. Authors in [58] uses Bat Algorithm in WSN for another different purposes that is, to produce energy efficient routing technique for energy aware WSN based on radially optimized zone-divided approach. Author in [21], Bat Algorithm is used for wireless sensor node's localization by setting geographic location of sensor node with unknown location. Bat Algorithm is combined with bacterial foraging optimization algorithm and this is proven to result a more precise and robust localization. Author in [59] uses Bat Algorithm to create optimized routing protocols for Cognitive Radio Ad Hoc Network (CRAHN) to improve efficiency of CRAHN communications.

F. Other Applications

In addition to the above mentioned applications, Bat Algorithm applications also exists in several other areas but the number of existing literature still insufficient to be placed in independent category. Authors in [60] developed a decision support system for financial trust of temporary project with limited funds. Bat Algorithm is used to perform complex financial decision making with a numbers of constraints such as regulations, policies and government ideology to meet the diverse budget requirements within limited financial resources. Authors in [9] additionally uses Bat Algorithm as a tool to perform estimation parameters for the reconstruction of nonlinear biological system dynamics.

There are also several other researches that use Bat Algorithm for image processing applications such as the ones conducted by author in [61] and [62]. Authors in [61] uses Bat Algorithm that is combined with mutation process of Genetic Algorithm (GA) as a fast and robust solution for pixel by pixel image matching and it is evident to make image matching faster with higher accuracy than the original Bat Algorithm, differential evolution (DE) [63] and study genetic algorithm (SGA) [64]. In contrast to study done by author in [62], Bat Algorithm is applied as an optimization solution of multilevel image thresholding, a process required for image segmentation and pre-processing before higher level processing is performed. The experiments indicate that an improved Bat Algorithm combined with differential evolution (DE) from artificial bee colony algorithm proved to be much more effective when compared with five other metaheuristic algorithms.

Table 1 summarizes the review on applications of the bat algorithm in tabular form for ease of understanding and provide a quick glimpse on their use for the certain field.

Table 1: Summary of Review on Applications of the Bat Algorithm

Fields	References
General Engineering Optimisation Solution	[24]
Engineering	[25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37]
Scheduling	[38], [39], [40], [41], [42], [43]
Transportation/ Vehicle	[44], [45], [46], [47], [48], [49], [50]
Networking	[21], [51], [52], [53], [54], [55], [56], [57], [58]
Other Application	[9], [60], [61], [62], [63]

3. CONCLUSION

This article consolidate existing bat algorithm literatures for a review. The objective of this review is to summarize the overview and the application of bat algorithm in all categories that were reviewed. Additionally, from the reviews, we also obtained a knowledge on Bat algorithm application that is widely used in engineering, scheduling, transportation/ vehicle and networking.

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