Faculty of Information and Communication Technology

IMPROVED BAT ALGORITHM FOR FASTER CONVERGENCE IN SOLVING OPTIMISATION PROBLEM

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Doctor of Philosophy

2021

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A thesis submitted
fulfillment of the requirements for the degree of Doctor of Philosophy
in Information and Communication Technology

Faculty of Information and Communication Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled "Improved Bat Algorithm for Faster Convergence in Solving Optimisation Problem" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Mohamad Raziff bin Ramli

Date : 16/04/2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature	:	…….
Supervisor Name	:	Associate Professor Dr. Zuraida Binti Abal Abas
Date	:	16/04/2021

DEDICATION

This research is dedicated to the Almighty Allah SWT for giving me a good health and strength to implement this research without a sense of hopelessness.

To my beloved parents and my wife, thank you for voluntarily providing support and encouragement for my studies. I am very grateful to have both of you in my life. Thank you for giving me the opportunity to improve and change myself to face all the tests and trials in life. Thanks to Allah in the presence of both of you.

To the family and other friends, thank you for always giving help, support and encouragement in this research. I really appreciate it.

To my both respected supervisor and co-supervisor, Associate Professor Dr. Zuraida bin Abal Abas and Professor Dr. Mohammad Ishak bin Desa, my deepest gratitude goes to both of you for providing me the guidance, understanding and giving great opinions and ideas in helping me to complete this research.

To my fellow friends and seniors, who offered earnest help in solving problems and always there to support all my bittersweet moments throughout this research. I owed all of you my highest appreciation. May Allah bless us all.

ABSTRACT

Optimisation is concerned with finding solutions to problems under certain constraints. One of the optimisation approaches is metaheuristic. Metaheuristic algorithms are inspired by nature and utilise intelligent mechanisms. In this study, one of the metaheuristic algorithms known as the Bat Algorithm (BA) has been discussed. Previous research has shown that BA is able to provide a good exploration and exploitation in finding solutions. However, this standard BA has the tendency to be trapped in a local minimum when applied to high dimensional search spaces besides experiencing slow convergence rate and low accuracy. The standard BA may be improved by integrating it with additional techniques which can increase its robustness through faster convergence and eventually producing more accurate results. Thus, this study proposed an Improved Bat Algorithm (IBA) by introducing some modifications to the standard BA. The additional techniques included are inertia weight factor, modified new bat position and adaptive boundary size. The IBA is evaluated and tested through a sequence of experiments conducted with ten benchmark functions. For comparison, three established algorithms namely Harmony Search (HS), Particle Swarm Optimisation (PSO) and Genetic Algorithm (GA) are analysed through the same set of experiments and compared with the IBA. The results show that the IBA performs better than Harmony Search (HS), Particle Swarm Optimisation (PSO) and Genetic Algorithm (GA). Despite the high dimensionality of the boundary size, the IBA is still able to produce significant results with the small number of iterations and fast convergence compared to other algorithms. Besides that, IBA was found comparable with existing variants of BA such as the IBA developed from the previous researcher in the year 2013 and the Hybrid Self-Adaptive Bat Algorithm (HSABA) developed in the year 2014. Finally, the developed IBA is found consistent with the exact method which is the simplex method when tested through fairness nurse scheduling problem. Therefore, this confirms the validity of the IBA as an alternative algorithm for solving optimisation problems.

PENAMBAHBAIKAN ALGORITMA KELAWAR BAGI PENUMPUAN YANG LEBIH CEPAT DALAM PENYELESAIAN MASALAH PENGOPTIMUMAN

ABSTRAK

Pengoptimuman adalah suatu usaha untuk menghasilkan penyelesaian terhadap masalah dalam kekangan tertentu. Salah satu pendekatan pengoptimuman adalah metaheuristik. Algoritma metaheuristik diilhamkan berdasarkan kepada alam semula jadi yang menggunakan mekanisme pencarian pintar. Dalam kajian ini, salah satu algoritma metaheuristik yang dikenali sebagai Bat Algorithm (BA) *telah dibincangkan. Penyelidikan sebelumnya menunjukkan bahawa Bat Algorithm dapat memberikan penerokaan dan eksploitasi penyelesaian yang baik. Walau bagaimanapun,* BA *berpeluang untuk terperangkap di dalam penyelesaian yang sama ketika digunakan di ruang carian dimensi yang tinggi. Disamping itu, algoritma ini mengalami kadar penumpuan perlahan dan ketepatan yang rendah. BA standard dapat ditingkatkan dengan manyatukannya dengan teknik tambahan yang dapat meningkatkan kekuatannya dari segi penumpuan yang lebih cepat dan akhirnya menghasilkan keputusan yang lebih tepat. Oleh itu, kajian ini mencadangkan* Improved Bat Algorithm (IBA) *dengan memperkenalkan beberapa pengubahsuaian kepada BA standard. Pengubahsuaian tersebut termasuklah faktor berat inersia, penyesuaian kedudukan baharu dan pengubahsuaian saiz sempadan.* IBA *ini dibincangkan dan diuji melalui urutan ujikaji yang dijalankan dengan 10 fungsi penanda aras. Sebagai perbandingan, tiga teknik terdahulu iaitu* Harmony Search (HS), Particle Swarm Optimisation (PSO) *dan* Genetic Algorithm (GA) *akan diguna pakai melalui set ujikaji yang sama dan akan dibandingkan dengan* IBA. *Keputusan uijkaji menunjukkan bahawa* IBA *berprestasi jauh lebih baik daripada ketiga-tiga teknik tersebut. Walaupun saiz sempadan dimensi diperbesarkan, namun,* IBA *masih mampu menghasilkan keputusan yang signifikan dimana hanya perlu bilangan pengulangan yang rendah dan pantas. Selain itu,* IBA *didapati setanding dengan variasi* BA *yang sedia ada seperti* Improve Bat Algorithm (IBA) *yang telah dibangunkan oleh penyelidik terdahulu pada tahun 2013 dan* Hybrid Self-Adaptive Bat Algorithm (HSABA) *yang telah dibangunkan pada 2014. Akhir sekali* IBA *yang dibangunkan didapati manghasilkan keputusan yang konsisten dengan kaedah tepat iaitu kaedah simplex apabila diuji dengan masalah penyelesaian penjadualan jururawat. Oleh itu,* IBA *telah diperakui sebagai algoritma alternatif untuk menyelesaikan masalah pengoptimuman.*

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah the Almighty, for his guidance, ideas and comfortable environment. I want to extend my appreciation to the Universiti Teknikal Malaysia Melaka and Ministry of Education Malaysia for their generosity for awarding me the scholarship during this study. Thank you to my supervisor, Associate Professor Dr. Zuraida Binti Abal Abas, and co-supervisors, Professor Dr. Mohammad Ishak Bin Desa, Department of Computer Systems and Communications, Faculty of Information and Communication Technology (FTMK), Universiti Teknikal Malaysia Melaka (UTeM). Without their sincere guidance, this work would not be possible. I not forget for their constructive discussions and helps with the analysis and in thesis writing during this study. An appreciation to Associate Professor Dr. Abdul Samad Shibghatullah for giving fruitful comments about my work and supports in completing my study. Last but not least, from the bottom of my heart, gratitude to my family for their love and caring. Special thanks to my wife, Sakinah Binti Abdul Razak, for his encouragements. Finally, I would like to thank my beloved parents who have been the pillar of strength in all my endeavours. I am always deeply indebted to them for all their endless love and prayers that they have given me. Thank you to the individual(s) who provided me with the inspiration to embark on my study.

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LIST OF ABBREVIATIONS

IBA	:	Improved Bat Algorithm
BA	:	Bat Algorithm
GA	:	Genetic Algorithm
HS	:	Harmony Search
PSO	:	Particle Swarm Optimisation
ACO	:	Ant Colony Optimisation
HSABA	:	Hybrid Self-Adaptive Bat Algorithm
FWER	:	Family-Wise Error Rate

LIST OF PUBLICATIONS

1 Ramli, M. R., Abas, Z. A., Desa, M. I., Abidin, Z. Z., and Alazzam, M. B., 2019. Enhanced convergence of Bat Algorithm based on dimensional and inertia weight factor. *Journal of King Saud University-Computer and Information Sciences*, *31*(4), pp. 452-458, Scopus and ISI indexed.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Optimisation has become increasingly important and well known in most the human activities, for example, finance, industries, sport, pharmacy, and so forth. The raise optimisation problem from human activities can be interpreted into complex nonlinear constraints (Yang, 2011) and known as optimisation model. Development of optimisation model give the opportunity to solve optimisation problem in term of minimum the cost and material use. Hence, increase the performance and lifetime services.

This design criterion is practically important (Deb 1995; Yang 2010) but at the same time poses difficulties in finding the correct and practical efficient algorithms. However, it is possible to come out with a solution. The truth is extensive experience and knowledge about solving the problem of interest is required to choose the appropriate algorithm. Even so, the algorithm does not guarantee finding the optimal or sub-optimal solution. Thus, the aim of finding the right solution that is not necessarily the optimal one in relation to the specific problem has led to various approximation development algorithms like the metaheuristic algorithm. Many severe issues have been solved by powerful methods like metaheuristic algorithms including evolutionary and swarm intelligence algorithms (Gandomi and Alavi 2011), and particularly real-world engineering problems (Gandomi et al. 2011; Alavi and Gandomi 2011).

Most heuristic and metaheuristic algorithms were inspired by natural living things in ecosystems, including biological and/or physical system behaviour. The current established approach is particle swarm optimisation, which is inspired by nature, based on the swarm behaviour of birds and fish (Kennedy and Eberhart 1995). There are now upcoming popular algorithms emerging, including bat algorithm and harmony search (Wang and Guo, 2013). Discrete cuckoo algorithm was inspired by bird breeding behaviour. This approach has been proved to be effective in solving continuous optimisation problems (Ouaarab et al., 2014), while the fireflies algorithm was formulated based on the flashing pattern and behaviour of fireflies (Yang, 2012). However, although these algorithms have advantages, they also have disadvantages. As an example is simulating annealing, which finds the optimal solution only if slow cooling is processed and the simulation is run for long enough. However, this weakness can be overcome by adjusting parameters to obtain the convergence rate for the optimisation process. The question is, what are the possibilities that this algorithm can combine with others method to form significant advantages and how an algorithm is needed to be developed that potentially produce a better solution?

Predefining optimal input parameters can develop a better algorithm optimisation according to a known outcome and known model. The model can represent a problem that needs to be solved, and input parameters represent a solution to obtain the output as a result. Basically, the quality of a solution is determined based on the evaluation of input parameters. Definitely, the quality of the objective function is described in the form of a mathematical function in which its value can be either minimised or maximised. As an example, the optimisation problem raised in health human resource planning (HHRP) needs to optimise the minimum and maximum gaps (as an objective function) between provider supply $\left(N^{st}\right)$ and requirement $\left(N^{rt}\right)$. Defined as Gap = Supply-Requirement = $\left(N^{st} - N^{rt}\right)$.

Negative Gap Means Shortage of Nurses, Positive Gap Means Surplus of Nurses. This situation is also known as a fitness function in the evolutionary computation community. The objective function in HHRP, both minimum and maximum, was assumed as a fitness function in this research. This fitness function can be optimised using the current famous bat algorithm (BA) approach. The BA is one of the fresh metaheuristic algorithms, and was introduced in the year 2010 by Yang (2010). The BA algorithm is inspired by the echolocation behaviour of bats. Echolocation is a type of sonar that guides bats' flying and hunting behaviour. Even in complete darkness bats can distinguish different types of insects. Thus, the advantages of the BA algorithm inspire the researcher to continue this study. The advantages are, at the initial stage, the BA algorithm can swap from exploration to exploitation to provide very fast convergence. Additionally, simple wide range of optimisation problem that formulated into function is flexible to be implemented into BA to generate the best solution.

As a matter of fact, the total number of publications on bat algorithms has rapidly grown. In 2015, Google Scholar recorded 1,130 searches for bat algorithm, including type the sentences in the quotation mark ("Bat Algorithm"). The same search showed about 1,960 results in 2017, whereas, by the end of 2018, the result was further increased to a number greater than 2,590. Some of the areas with the highest rate of requests for the BA to be put into practice are flow shop scheduling problem (Marichelvam et al., 2013), practical engineering applications (Jayabarathi et al., 2018), image matching (Marichelvam et al., 2013), Vehicle Routing Problem (Osaba et al., 2018), Optimal Power Dispatch (Reddy and Kumar, 2015) and Numerical Optimisation Problems (Tsai et al., 2012).

The BA has shown its capability as an approach that can construct a better solution while improving exploration and exploitation. The increasing BA's popularity encourages the research study on this algorithm keep continuing. At the end of these studies, a few

approaches will be added to the standard BA and known as Improve Bat Algorithm (ABA). This approach typically depends on the efficiency in exploitation and global diverse exploration. Previous research has shown that the Bat Algorithm could provide good exploration and exploitation of a solution. However, it can get trapped in a local minimum in some multi-dimensional functions (Lin et al., 2010; Wang et al., 2013). Thus, the phenomenon of slow convergence rate and low accuracy still exists.

It is important to avoid the exploration of the solution being trapped in local minima to obtain a high chance of a better solution and give faster convergence, to make it more effective and efficient. To improve the performance of the BA, researchers have come with various solutions. Yang (2011) presented a multi-objective bat algorithm (MOBA) for solving a few design benchmarks in engineering. Nakamura et al. (2012) introduced a binary bat algorithm (BBA) that developed a discrete version of the bat algorithm to solve classifications and feature selection problems. In addition, Yilmaz and Kucuksille (2013) introduced an improved bat algorithm (IBA) for achieving good performance in relation to the problem of interest.

In these studies, with the advent of new Improved Bat Algorithms, a kind of inertia factor has been added, and the generated solution was within the boundary searching space. In addition, the boundary dimension size is updated according to the current best solution, at once giving a faster convergence and becoming a decisive factor in obtaining the most optimal solution. In closing this section, it is noted that, in order to improve the standard BA without impacting its strong robustness, an additional method is needed that can help the global convergence rate become faster.

The remaining sections of the chapter are organised as follows. Section 1.2 discusses the challenges in the optimisation algorithm, while Section 1.3 presents the problem statement. In Section 1.4, the research objective is presented. Section 1.5 explains the

research scope, while Section 1.6 explains the significance of the study, Section 1.7 discusses the thesis layout and Section 1.8 summarises the whole chapter.

1.2 Challenges in optimisation algorithms

Today's highly capitalized societies require "maximum benefit with minimum cost." For achieving this goal, we usually depend on optimisation techniques. Many problems in various fields are formulated as optimisation problems and solved using various optimisation algorithms. Generally, optimisation problems, either single-objective or multi-objective, are difficult to solve. To solve real world optimisation problem is very complex. Even the optimisation algorithm can't solve the problem at a given time. The combination of the problem is extremely computationally expensive and unrealistic. Over the decades, the development and application of optimisation models have attracted growing attention among engineers. Traditional mathematical techniques, such as linear programming (LP), non-linear programming (NLP), and dynamic programming (DP), have been frequently used for solving the optimisation problems. All three techniques can guarantee global optima in simple and ideal models.

However, in real world problems, there are some drawbacks: in LP, considerable losses occur when a linear ideal model from a non-linear real world problem is developed; in DP, an increase in the number of variables would exponentially increase the number of evaluations of the recursive functions and tax the core-memory (the "curse of dimensionality"); in NLP, if the functions used in computation are not differentiable, the solving algorithm may not find the optimum. Careful attention is also required in selecting the initial values in order to guarantee convergence to the global optimum and not into local optima. In order to overcome the above deficiencies of mathematical techniques, heuristic optimisation techniques based on simulation have been introduced.