NOVEL META-HEURISTIC BALD EAGLE SEARCH ALGORITHM FOR SINGLE OBJECTIVE UNCONSTRAINT FUNCTIONS IN GLOBAL OPTIMIZATION PROBLEM

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SULTAN IDRIS EDUCATION UNIVERSITY

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ABSTRACT

Approaches inspired by natural processes have been developed due to their effectiveness in addressing different challenges encountered by Swarm algorithms, such as struggling with local optima, and evolutionary algorithms, such as encountering slow convergence. By integrating evolutionary and swarm intelligence approaches, which is nature-inspired approach, a solution can be achieved that combines the exploration capacity of swarms with the exploitation ability of evolutionary algorithms. This has the potential to enhance overall optimization performance. Therefore, proposing techniques such as bald eagle search (BES), a nature-inspired approach that tackles optimization problems by mimicking the hunting behavior of bald eagles, appears to be beneficial. To our knowledge, there are presently no algorithm that mimic the hunting behavior of bald eagles, which is characterized by group hunting. The BES algorithm involves three stages: selection space, search, and swoop. The evaluation of the results has done in three parts. Initially, it defines a benchmark optimization problem to evaluate the algorithm's performance. Additionally, it evaluates the algorithm's performance by comparing it to other intelligent computation techniques and varying parameter values. Finally, the method is assessed using statistical measures including the mean, standard deviation, optimal point, and the Wilcoxon signed rank test statistic for function values. The examination of the optimization results and accompanying discussion clearly demonstrate that the BES algorithm surpasses its competitors, namely GWO, DE/best/1, DE/rand/1, EPSO, FDR-PSO, and CLPSO, in both sessions of CEC 2005 with 25 function and CEC 2014 with 30 function benchmark suite. The findings indicate that BES outperforms other algorithms in the specified scenarios: It surpasses DE/best/1 in 37 out of 55 functions, DE/rand/1 in 40 out of 55 functions, GWO in 44 out of 55 functions, EPSO in 32 out of 55 functions, CLPSO in 42 out of 55 functions, and FDR-PSO in 30 out of 55 functions.

ALGORITMA PENCARIAN HELANG BOTAK META-HEURISTIC NOVEL UNTUK FUNGSI TANPA KEKANGAN OBJEKTIF TUNGGAL DALAM MASALAH PENGOPTIMUMAN GLOBAL

ABSTRAK

Pendekatan yang diilhamkan oleh proses semula jadi telah dibangunkan kerana keberkesanannya dalam menangani cabaran berbeza yang dihadapi oleh algoritma Swarm, seperti bergelut dengan optima tempatan, dan algoritma evolusi, seperti menghadapi penumpuan yang perlahan. Dengan menyepadukan pendekatan kecerdasan evolusi dan kawanan, yang kedua-duanya diilhamkan oleh alam semula jadi, penyelesaian boleh dicapai melalui penggabungan kapasiti penerokaan kawanan dengan keupayaan eksploitasi algoritma evolusi. Ini berpotensi untuk meningkatkan prestasi pengoptimuman keseluruhan. Oleh itu, cadangan teknik seperti pencarian helang botak (BES), pendekatan yang diilhamkan oleh alam semula jadi yang menangani masalah pengoptimuman dengan meniru tingkah laku memburu helang botak, adalah bermanfaat. Dalam pengetahuan kajian, pada masa ini tiada algoritma yang meniru tingkah laku memburu helang botak, yang dicirikan oleh pemburuan berkumpulan. Algoritma BES melibatkan tiga peringkat: ruang pemilihan, carian dan melayah. Penilaian keputusan telah dilakukan dalam tiga bahagian. Pada mulanya, ia mentakrifkan masalah pengoptimuman penanda aras untuk menilai prestasi algoritma. Selain itu, ia menilai prestasi algoritma dengan membandingkannya dengan teknik pengiraan pintar lain dan nilai parameter yang berbeza-beza. Akhir sekali, kaedah ini dinilai menggunakan ukuran statistik termasuk min, sisihan piawai, titik optimum, dan statistik ujian pangkat bertanda Wilcoxon untuk nilai fungsi. Pemeriksaan keputusan pengoptimuman dan perbincangan yang disertakan dengan jelas menunjukkan bahawa algoritma BES mengatasi pesaingnya, iaitu GWO, DE/best/1, DE/rand/1, EPSO, FDR-PSO, dan CLPSO, dalam kedua-dua sesi CEC 2005 dengan 25 fungsi dan CEC 2014 dengan suite penanda aras 30 fungsi. Penemuan menunjukkan bahawa BES mengatasi algoritma lain dalam senario yang ditentukan: Ia mengatasi DE/terbaik/1 dalam 37 daripada 55 fungsi, DE/rand/1 dalam 40 daripada 55 fungsi, GWO dalam 44 daripada 55 fungsi, EPSO dalam 32 daripada 55 fungsi, CLPSO dalam 42 daripada 55 fungsi, dan FDR-PSO dalam 30 daripada 55 fungsi.

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LIST OF ABBREVIATIONS

BES	Bald Eagle Search
CLPSO	Comprehensive Learning Particle Swarm Optimizer
DA	Differential Evolution
EAs	Evolutionary Algorithms
EPSO	Ensemble Particle Swarm Optimizer
FDR-PSO	Fitness-Distance-Ratio-Based Particle Swarm Optimization
GA	Genetic Algorithm
GWO	Grey Wolf Optimizer
IRRO	Improved Raven Roosting Optimization
MBO	Monarch Butterfly Optimization
PSO	Particle Swarm Optimization
RRO	Raven Roosting Optimization
SI	Swarm Intelligence

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TERMINOLOGY OPERATIONAL DEFINITION

Variables	Operational definition	Value
$F(x)$	Objective function for evaluation problem	$[-\infty, \infty]$
x	Decision Variables	$[Lb, Ub]$
α	parameter for controlling the changes in position	[1.5,2]
r	Random number based on uniform distribution	[0,1]
a	Cycle parameter for generation solution in search space stage	[5,10]
R	Line parameter in search space stage	[0.5,2]
$\theta(i)$	Angle parameter for generation number in search space stage	[0,1]
$r(i)$	Radius parameter for generation number in search space stage	[0,1]
c_1, c_2	Control parameters in swooping stage	[1,2]

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the research topic, the statement of the problem, and research objectives. This chapter also presents the scope of this research where the experimental and technical scopes are explained. A brief background of the research components is presented in Section 1.2. The statement of the problem, on which the direction of the research is based, is identified and introduced in Section 1.3. Research questions are listed in Section 1.4. This is followed by the objectives of the research, which are described in Section 1.5. The connection between the research objectives and research equations are shown in Section 1.6. The scope of the study is discussed in Section 1.7 followed by Section 1.8 which is the significant of the study. The main structure of the thesis is briefly outlined in Section 1.9. Finally, a summary of the chapter is presented in Section 1.10.

1.2 Research Background

Operations research seeks to create a framework for modeling complex decision-making problems that arise in business, engineering, and analytics, as well as the mathematical sciences, and develops methods for evaluating and solving them. The most popular solution strategies include mathematical optimization, simulation, and data analysis, which all utilize mathematical models to explain the system (Anjos & Vieira, 2017).

Optimization is the process of selecting the optimum solution from a pool of alternative (feasible) solutions. Alternative solutions are those that meet all of the optimization problem's constraints. A function in an optimization problem is known as an objective function that must be maximized or minimized in order to solve real-world problems (Steczek, Jefimowski, & Szeląg, 2020). The optimization encompasses a wide range of techniques drawn from artificial intelligence, operations research, machine learning, and computer science that are used to enhance business processes in almost all industries and human endeavour. An example of optimization is the diet problem, where several food kinds with varying nutritional contents are available at different prices. The objective is to estimate different quantities of food in order to meet an individual's nutritional requirements at the lowest possible cost (Parouha & Verma, 2022). The classification, or determining the type of the optimization problems, is a very essential step. The optimization problem can be expressed as a combinatorial or as a continuous design search space (Neve, Kakandikar, & Kulkarni, 2017).

Combinatorial optimization is the process of searching for the optimal solution to problems that have a discrete set of alternative solutions and searching for the maximum (or minimum) value of an objective function f with a domain of a discrete search/solution space. It can be stated mathematically as a tuple (S, f, Ω), where S is commonly referred to the search space with $x = \{x_1, x_2, \cdots, x_n\}$ set of variables, f is the objective function to be maximized/minimized which is defined over the mapping $f: \Omega_1 \times \Omega_2 \times \cdots \times \Omega_n \mapsto R^+$, where Ω represent the set of constraints that must be met in order to get alternative solutions. To solve this type of problem, it is necessary to find the solution $s* \in S$ with minimum objective function value such that $f\ (s^*) \leq f\ (s) \forall s\ \in\ S$. where s^* represent globally optimal solution of the tuple (S, f, Ω), and $s* \subset\ S$ represent globally optimal solutions set (Vesselinova, Steinert, Perez-Ramirez, & Boman, 2020). In the continuous optimization, the process also involves searching for maximum/minimum of a function $f(x), x = \{x_1, x_2, \dots, x_D\} \in R^D$ subject to $g_i(x) \leq 0, (i = 1,2, \dots, M), h_j(x) = 0,, (j = 1,2, \dots, N), x_{kL} \leq x_k \leq x_{kU}, (k = 1,2, \dots, N)$, where L and U represent the lower and upper bounds on optimization variables, respectively. g_i and h_j represent inequality and equality constraints, respectively, in a continuous search space (Z. Li, Lin, Zhang, & Liu, 2020).

Meta-heuristic are (roughly) high-level strategies that combining lower-level techniques for exploration and exploitation of the search space to solve global optimization Problem (M. Sharma & Kaur, 2021). Global optimization is aimed at finding the best solution of constrained and unconstrained optimization problem which (may) also have various local optima (Zhao & Li, 2020). They rely on randomness for exploration, so every time you run them you may get a different result. No-free-lunch theorem, no single algorithm can do well on all problems - If an algorithm is improved for one problem, it will suffer for others (McDermott, 2020; Serafino, 2021).

Nature-inspired computation has attracted wide interest amongst researchers, given that nature is an important source of concepts, mechanisms and ideas for designing artificial computing systems that solve many complex mathematical problems (Ezugwu et al., 2021). Individuals must accommodate to their surrounding environments to ensure the survival and long-term preservation of their breed (Hussain, Mohd Salleh, Cheng, & Shi, 2019). This process is known as evolution. Maintaining the time of reproduction can also sustain the features that foster the competitiveness of individuals and remove their weak features. Only those good individuals from the surviving species can transmit genetically modified genes to their descendants. This procedure, which is known as natural selection, has inspired 'evolutionary algorithms' (EAs), which are amongst the most widespread and successful algorithms being applied in research. Several types of EAs have been employed in the literature, including genetic algorithms, genetic programming, evolutionary programming and evolutionary strategies (Corne & Lones, 2018). In this thesis, there is a need to propose a novel metaheuristic algorithm inspired from nature population to computer address the challenges associated with the global optimization problem.

1.3 Research Problem

Optimisation remains a significant challenge in artificial computation (Sameer, Abu Bakar, Zaidan, & Zaidan, 2019; Zaidan, Atiya, Abu Bakar, & Zaidan, 2019).

Accordingly, many algorithms have been developed to solve such a problem. However, two issues should be addressed to guarantee a successful solution to this problem: how to identify the global and local optimisation and how to preserve such optimisation until the end of the search (Qu, Liang, & Suganthan, 2012).

Evolutionary optimisation techniques are the most widely used intelligent computing techniques to solve many problems, such as the combinatorial and nonlinear optimisation problems. These techniques easily address different types of issues by using and integrating prior information into an evolutionary search yielding process to efficiently explore a state space of possible solutions. However, EAs are unable to find the optimal solution for numerous issues despite the aforementioned advantages; therefore, many researchers have merged these algorithms with extant technologies to improve their solutions (Whitley, 2001). In addition, In EAs, population diversity is essential for enabling global exploration and preventing poor performance owing to premature convergence. Therefore, there is a need to investigate how EAs enhance the diversity of a population in which every individual must exceed a set fitness threshold (Sudholt, 2020). In addition, EAs exhibit unstable convergence in the last period and are easy to fall to regional optimum (Y.-C. Wu, Lee, & Chien, 2011).

Swarm intelligence (SI) is another form of intelligent computing technique that includes particle swarm optimisation (PSO) (Birge, 2003; Kennedy & Eberhart, 1995; Shi & Eberhart, 1998), which mimics the swarm behaviour of birds or fish fish (X. Li, 2003); ant colony optimisation (Dorigo, Birattari, & Stutzle, 2006), which mimics the foraging and schooling behaviour of ants and other algorithms, such as gravitational search (Rashedi, Nezamabadi-Pour, & Saryazdi, 2009), grey wolf optimiser (GWO)

(Mirjalili, Mirjalili, & Lewis, 2014), artificial bee colony (Karaboga & Basturk, 2007), moth–flame optimisation (Mirjalili, 2015b), whale optimisation (Mirjalili & Lewis, 2016), group search optimiser (He, Wu, & Saunders, 2006; He, Wu, & Saunders, 2009) and ant lion optimiser algorithms (Mirjalili, 2015a), as well as many algorithms modified on the PSO algorithms, such as comprehensive learning particle swarm optimiser (CLPSO) (Liang, Qin, Suganthan, & Baskar, 2006) and fitness–distance–ratio-based particle swarm optimisation (FDR-PSO) (Peram, Veeramachaneni, & Mohan, 2003) and ensemble particle swarm optimiser (EPSO) (Lynn & Suganthan, 2017). SI solves many problems by simulating the normal behaviour of some animals when moving from one place to another in search of food. This technique is generally influenced by the size and nonlinearity of the problem. Despite obtaining the optimal solution to computational and combinatorial problems, the majority of the existent analytical methods are unable to converge such problems (Ezugwu et al., 2021).

SI offers many advantages. For example, each individual can improve his/her search efficiency by moving from one position to another, whilst all individuals within a swarm can improve their respective positions. In EAs, the weak and inefficient individuals are neglected and situated by highly competent individuals. A swarm continuously explores new areas within the search space to rapidly reach global optimisation areas. However, SI also has its own disadvantages. For particular instances, collective movement may induce a state of mass decline in the local optimum and the continued failure of individuals to escape from this area can lead to the early suspension of the exploration (Del Valle, Venayagamoorthy, Mohagheghi, Hernandez, & Harley, 2008; Ezugwu et al., 2021).

Therefore, an integrated and comprehensive Nature-inspired techniques should be developed to address various issues and the possibility of integrating evolutionary techniques with swarm techniques to create new technologies that can solve these problems. Such technologies can maximise the advantages offered by SI in terms of searching within the best position in the swarm and capitalise on the capability of evolutionary techniques to explore the search space frequently and avoid the local optimum.

1.4 Research Questions

1. What existing studies have used nature-inspired for solving optimization problem?

2. What are the issues should be considered when propose novel metaheuristic algorithm for solving single objective problems?
3. What is technique can be used to maximize the diversity of a population?
4. What is the technique can be Prevent the deterioration of search ability?
5. How can be combine two behaviours for solving single objective problems?
6. How can be develop the metaheuristic algorithm for improving the search section and get more acceptable results?
7. How can be evaluate the proposed algorithms and comparative with other algorithms?

1.5 Research Objectives

The objectives of this research are listed as follows:

1. To investigate the existing nature-inspired technique used for solving optimization problem and highlight the weaknesses.
2. To identify a new nature inspired that mimics the hunting strategy, social hierarchy and behaviour of bald eagles.
3. To formulate new mathematical model based on identified the behaviour of bald eagle.
4. To develop new nature inspired algorithm based on the formulated mathematical model for behaviour of bald eagle.
5. To evaluates the performance of the proposed BES algorithm based on computational experiment.

1.6 Connections between Research Objectives and Questions

In this section, all research questions have been answered by the research objectives. Each objective is linked to one or two questions. Table 1.1 below presents the connection amongst research objectives and research questions.

Table 1.1

Connection amongst Research Objectives and Questions

Research questions	Research objectives
1) What existing studies have used nature-inspired for solving optimization problem?	1) To investigate the existing nature-inspired technique used for solving optimization problem and highlight the weaknesses.
2) What are the issues should be considered when propose novel metaheuristic algorithm for solving single objective problems?	
3) What is the technique can be used to maximize the diversity of a population?	2) To identify a new nature inspired that mimics the hunting strategy, social hierarchy and behavior of bald eagles.
4) What is the technique can be Prevent the deterioration of search ability?	
5) How can be combine two behaviours for solving single objective problems?	3) To formulate new mathematical model based on identified the behaviour of bald eagle.
6) How can be develop the metaheuristic algorithm for improving the search section and get more acceptable results?	4) To develop new nature inspired algorithm based on the formulated mathematical model for behavior of bald eagle.
7) How can be evaluate the proposed algorithms and comparative with other algorithms?	5) To evaluates the performance of the proposed BES algorithm based on computational experiment.

1.7 Research Scope

Since the use of nature-inspired techniques based on meta-heuristic have been attracted many researchers in the literature, It decided to take advantage of SI and EA concepts to design a single objective unconstraint function in global optimization problem that could be more efficient (in terms of maximizing diversity in population).

SI is a search technique that can simulate the movements of an animal which aim to find food. This heuristic has been found to be very effective in a wide variety of applications, being able to produce very good results at a very low computational cost. The success of the SI algorithm as a single-objective optimizer (mainly when dealing with continuous search spaces) and its relative simplicity have motivated researchers to extend the use of this bio-inspired technique to other areas.

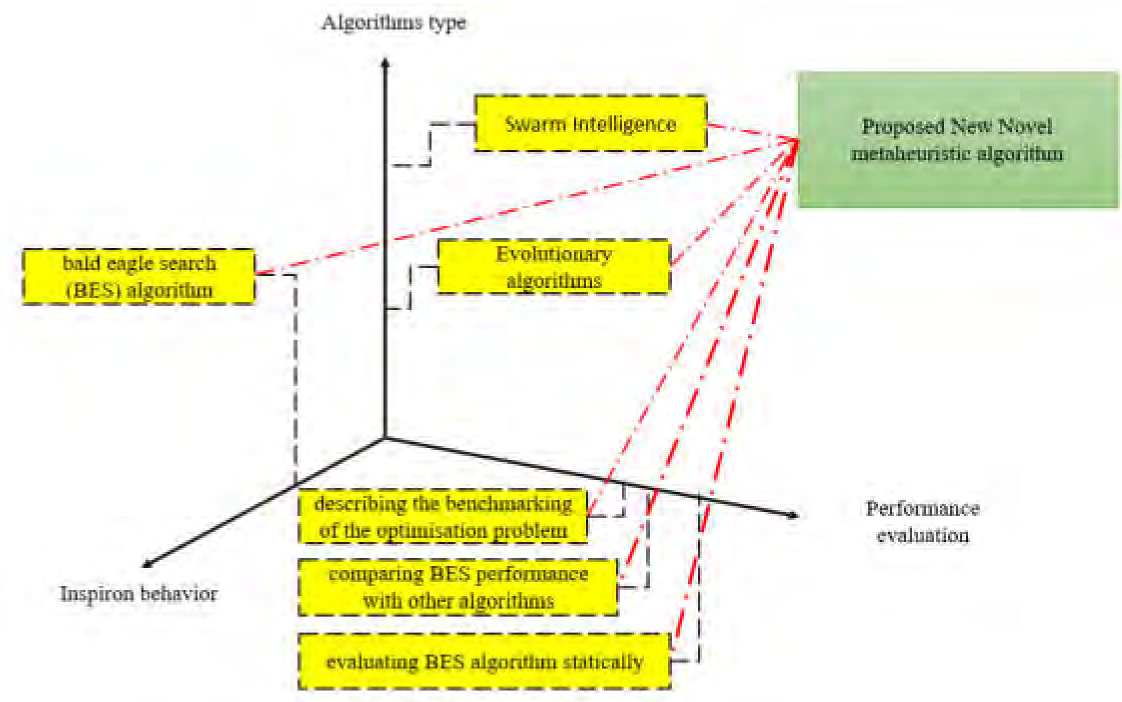
In the EAs, the solutions represent individual organisms in a population. There are inspired by natural optimization processes such as natural selection, species migration, bird swarms, human civilization, and ant colonies. EAs efficiently explore a state space of potential solutions by utilizing and integrating historical data into an evolutionary search producing process.

The outcomes of the research indicate the inspiration behavior of a bald eagle search (BES) algorithm performed via several steps to mimic the hunting strategy or intelligent social behavior of bald eagles as they search for fish.

BES has been evaluated by (1) describing the benchmarking of the optimisation problem to evaluate the algorithm performance, (2) comparing the algorithm performance with that of other intelligent computation techniques and parameter settings and (3) evaluating the algorithm based on mean, standard deviation, best point and Wilcoxon signed-rank test statistic of the function values. The general scheme for our research and the view that represents the meta-heuristic algorithm type, inspiration behavior, and performance evaluation are presented in Figure 1.1.

Figure 1.1

General Scheme and Scope of the Study



1.8 Significance of the study

The main significant of this research is to propose new nature inspired algorithm that mimics the hunting strategy, social hierarchy and behavior of bald eagles. This algorithm can solve the complex optimization problem and support decision making. Furthermore, it can provide and assist the optimization community and industrial (researchers and developers) by introducing more complex mechanisms and combining powerful operators with other heuristics. Researchers and developers may investigate the possibility of leveraging the prey identification process of bald eagles to reduce energy consumption by taking advantage of multiple elements, including wind and gravity, among others.

1.9 Organisation of Thesis

This research is composed of five chapters. These chapters are briefly reviewed as follow:

Chapter 1 illustrates the study context and problem statement. In addition, this chapter illustrates the research questions and objectives, as well as the interconnections between research objectives, research questions, and specific and general problems. This chapter also describes the study's research scope.

Chapter 2 reviews the literature on swarm intelligent and evolutionary algorithms. It begins by an overview and theoretical background on optimization models, follows by the deterministic optimization. Furthermore, continues optimization and unconstrained optimization are discussed, respectively. After that, global optimization techniques, meta-heuristic techniques, and nature inspired population based algorithms are explained, respectively.

Chapter 3 gives an overview and explanation methodology proposed algorithms for solving single objective optimization problem. The discussion comprises three phases: preliminary study to identify and describe the research problem, the development phase involves the development BES algorithm, and the evaluation phase evaluates the performance of the proposed algorithms and comparative with some of state of art algorithms.

Chapter 4 presents the results based on the proposed methods, and comparative study with other stat of art algorithms and discussion result of the proposed method.

Chapter 5 presents the conclusion and contributions. Areas to be pursued in future work are also suggested.