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The applications of Artificial Hummingbird Algorithm (AHA) in the optimization problems: A review of the state-of-the-art

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Abstract

Nature-inspired algorithms have been developed and applied to solve a wide range of real-world optimization problems. Artificial Hummingbird Algorithm (AHA) is one of the recently introduced ones. The foraging and flight behaviors of hummingbirds inspire the mechanisms of the AHA. It has a simple structure and operates exploitation and exploration processes based on the visitation of hummingbirds, to find optimal solutions effectively with a few parameter settings. To the best of our knowledge, there has been no comprehensive and systematic review of the AHA, which is the objective of this paper. Researchers have demonstrated AHA's effectiveness in various applications, including antenna design, biomedical, networking, optimization, prediction and forecasting, scheduling, and power generation and controlling. Many studies have reported that the efficiency of AHA can be increased by modifying and hybridizing it with other algorithms. The most well-known problem that AHA has solved is the renewable energy issue. The AHA is also classified as a bio-inspired algorithm frequently used to compare performance. Although the AHA has been published recently and applied to many problems, there are limitations to some application areas, such as scheduling problems and robotics, security, fuzzy systems, data mining, and other interesting optimization problems.

Keywords: **S**warm-based metaheuristics, Artificial intelligence, Soft computing, Comprehensive survey, Systematic literature review

1. Introduction

Real-world optimization problems come in a variety of sizes and complexity. Most are non-deterministic polynomial-time hard (NP-hard) problems, such as the traveling salesman problem, vehicle routing problems [1], and scheduling problems [2]. Conventional Optimization Algorithms (COA) such as global programming, linear programming, dynamic programming, linear and quadratic integer programming, and branch and bound seek the best solution for small and non-complex problems. Finding the solution may take a long time, especially for NP-hard problems [3].

Approximation Optimization Algorithm (AOA) can reduce the time spent searching for the best solution by estimating the near optimal solution. One of the subgroups of the AOA is constructive approaches, which are sometimes called heuristics. These are specific ways to solve a problem, like the critical path method, the project evaluation and review technique, and material requirement planning. Another subgroup is stochastic algorithms, called metaheuristics [3]. The main processes are to generate solutions randomly and improve them repeatedly, like Genetic Algorithm (GA) [4], Biogeography-based Optimization (BBO) [5], Grey Wolf Optimization (GWO) [6], and Artificial Hummingbird Algorithm (AHA) [7].

AHA is a swarm-based metaheuristic method for solving optimization problems inspired by hummingbird foraging and flight behaviors. It has been used to solve various engineering and optimization problems, such as antenna design, biomedical, networking, prediction and forecasting, scheduling, and power generation and control. The advantage of AHA is its parameter less algorithm with simple mechanisms. Hummingbirds share information with other birds in the population through a visitation memory to find better locations for their next visit, called a visit table. The table is updated for each improvement iteration until the end of the termination criteria.

The AHA was proposed on February 20, 2021, published online on November 9, 2021, and published in 2022 in Computer Methods in Applied Mechanics and Engineering. Figure 1 depicts the chronology of selected developments and applications of the AHA from 2021 to 2023. Wolpert and Macready [8] stated that no metaheuristic method effectively solves all optimization problems. Although they are used to solve many optimization problems, they often suffer from some issues of their own, such as slow convergence, long time, no precision, and inaccurate answers. Modification and hybridization of meta-heuristics are ways to enhance their efficiency.

In 2022 and 2023, the development of the AHA in Ramadan et al. [9] motivates AHA to adapt to and oppose photovoltaic issues. Sadoun et al. [10] combined AHA and random vector functional link algorithm to forecast material wear rates. Basavaraja and Ganesarathinam [11] used an AHA hybrid with a cat hunting optimization algorithm to detect osteoporosis using x-rays. Zhao et al. [12] developed AHA as MOAHA to solve multi-objective optimization problems. To solve the engineering problem, Yildiz et al. [13]

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used hybrid AHA with simulated annealing. Alamir et al. [14] combined the AHA and the point estimation method to solve the energy management problem. Elaziz et al. [15] have combined AHA and Aquila Optimization in medical image classification. For use in fundus imaging classification, Dhiravidachelvi et al. [16] hybrid AHA with the convolutional neural network-recurrent neural network was obtained. To solve the desalination problem from seawater, Essa et al. [17] have deployed a hybrid AHA with a machine-learning model. El-Sattar et al. [18] designed renewable energy systems using hybrid AHA and a Gradient-based optimizer. Li et al. [19] used Monte Carlo to help predict the life of energy equipment. Prem Jacob et al. [20] are collaborating with AHA to create a model to improve IoT in healthcare using convolutional neural networks. The first applications of AHA to solve these problems were pioneered by Shadman Abid et al. [21] for renewable energy, Ali et al. [22] for classification garbage, Singh et al. [23] designed the antenna, Mohseni et al. [24] applied it to the microgrid, Kansal and Dhillon [25] applied a renewable energy generation scheduling problem, Bhat and Santhosh [26] solved the positioning problem of the wireless sensor, and Zhou et al. [27] made the wrinkle model for the clothing industry.

AHA is an innovative metaheuristic approach. Based on the review analysis, no comprehensive and systematic review of the AHA has been conducted. Hence, this endeavor aims to fill the gap by conducting a thorough and systematic review of AHA. This paper discusses the application of AHA in various domains. This paper also includes a systematic analysis. The following are the main points of this paper:

- The theoretical basis of the AHA has been thoroughly examined.
- The AHA's working principles are applied to scheduling and the chronology of its development and application areas.
- The application of AHA in various problem areas demonstrates its efficacy and benefits.

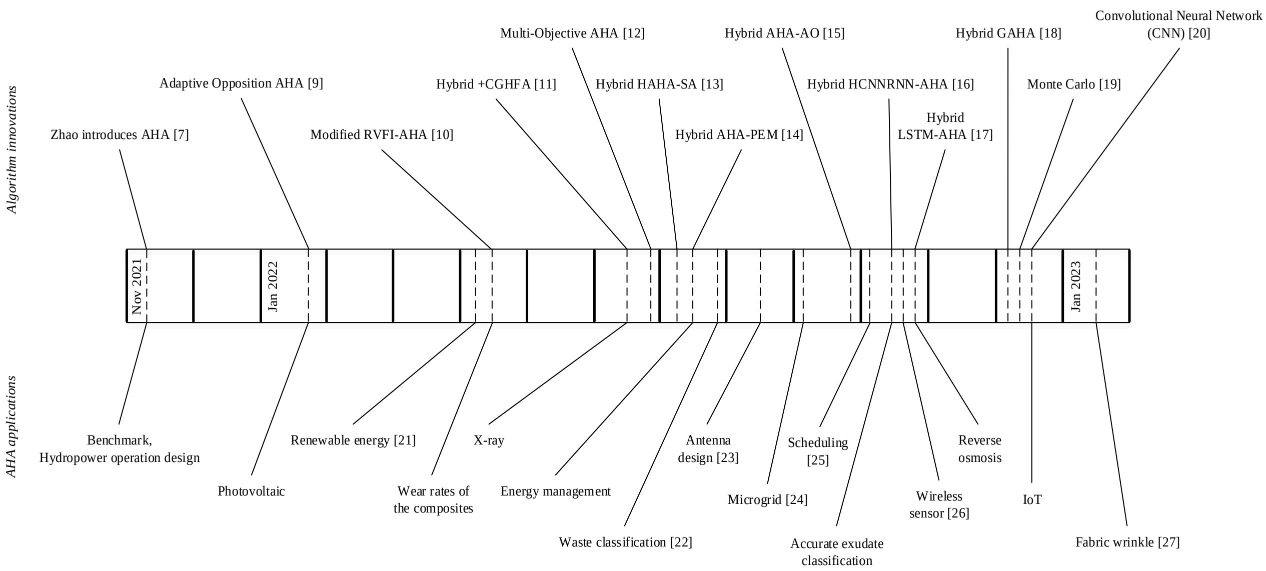

Figure 1 Chronology of selected developments and applications of the AHA from 2021 to 2023

The remainder of this paper is divided into sections. Section 2 describes the review process strategy for AHA articles. Section 3 summarizes the basic structure of the AHA and depicts a flow chart of the AHA's application to scheduling. Section 4 discusses how AHA can be applied to solve problems in various of areas. Section 5 explains the critical analysis of the AHA. Finally, Section 6 provides a summary of this paper as well as some future research guidelines. Figure 2 depicts the graphical structure of this paper.

2. Procedure of systematic literature review

A systematic and comprehensive literature review process. According to Liberati et al. [28] Preferred Reports List for Systematic Review and Meta-Analysis (PRISMA), the stages are as follows:

1. Identification
2. Pre-selection
3. Eligibility
4. Included

This paper focuses on the application of the Artificial Hummingbird Algorithm (AHA) to solve problems in various fields. The international academic database Scopus was searched for articles related to the AHA. The last search was on February 22, 2023, and the search interval was determined from the publication of the AHA in 2022 until the last search date. The PRISMA flow process was used with all the search results:

1. Selected 121 articles that cited the AHA.
2. Collected articles whose reference types were journal ones only; there were 105 related articles.
3. Read the titles and abstracts, looking for articles related to AHA; 36 were selected.
4. Only full articles were selected (36 articles).
5. The PRISMA review process was used to analyze the 36 articles.

PRISMA aims to improve the clarity and transparency of a systematic review report. It was created to aid in comprehension, implementation, and dissemination. The goal is to reduce the possibility of flaws in systematic reviews [28]. Figure 3 depicts the selection of paper for a systematic literature review using the PRISMA flow.

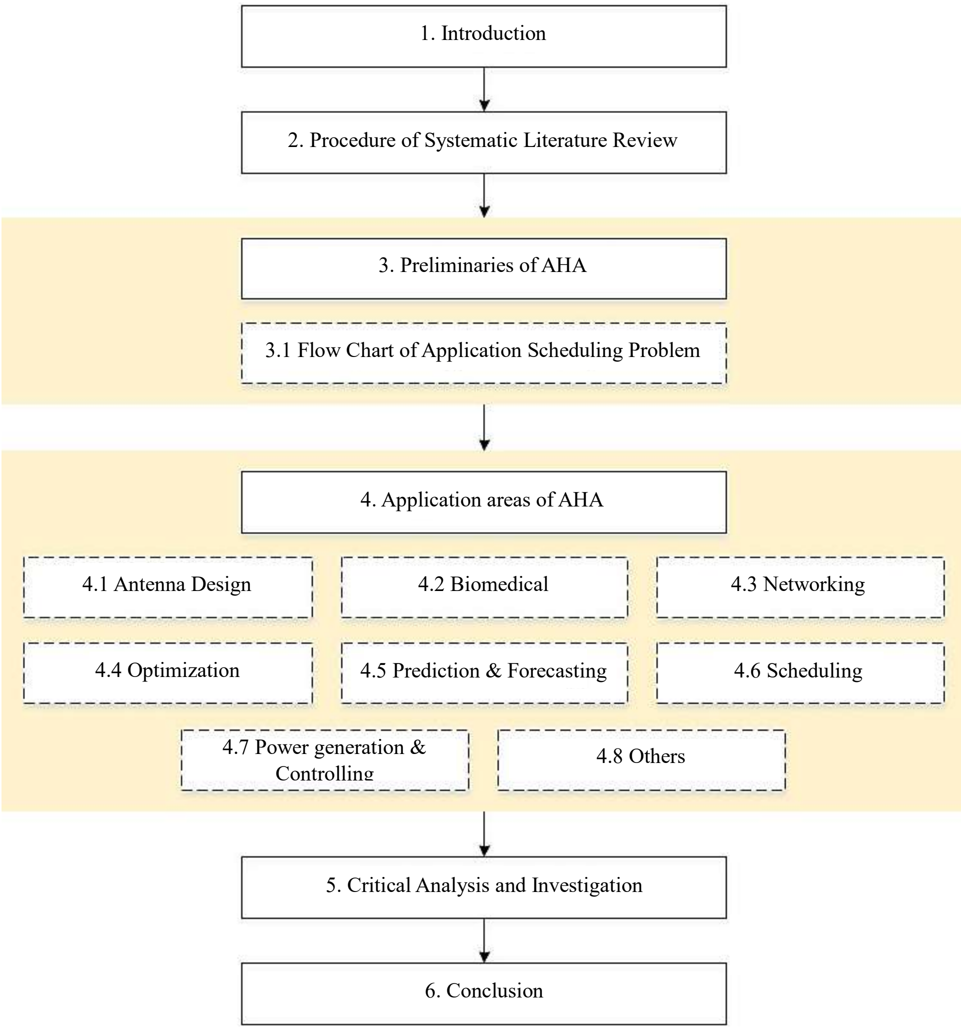

Figure 2 Structure of this paper

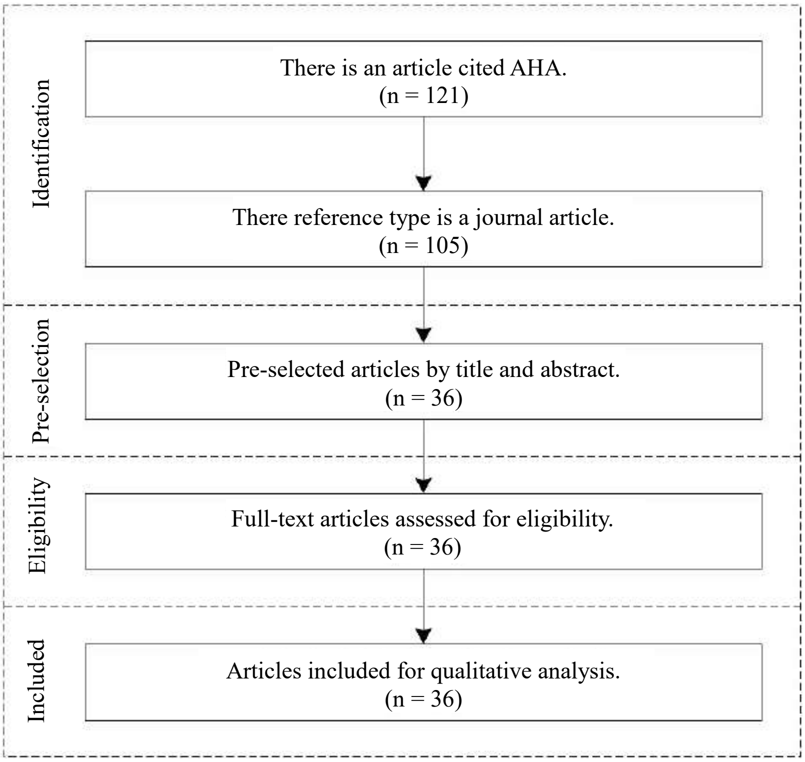

Figure 3 PRISMA flow for this study

3. Preliminaries of Artificial Hummingbird Algorithm

Zhao et al. [7] developed and published the Artificial Hummingbird Algorithm (AHA). The simulation of hummingbird behavior Figure 4 shows the foraging strategy behavior of hummingbirds, including guided foraging, territorial foraging, and migration foraging. Second, as shown in Figure 5, hummingbirds fly in three directions: axially, diagonally, and omnidirectionally. Figure 6 depicts the final hummingbird memories that are applied to the visit table.

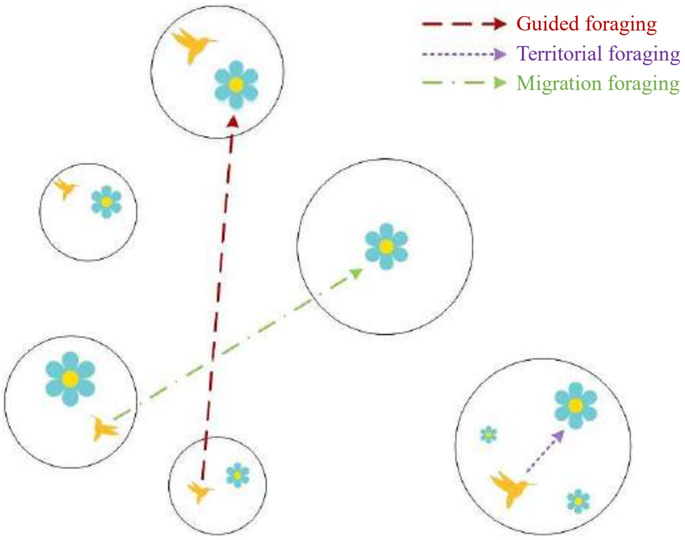

Figure 4 Three foraging behaviors of AHA

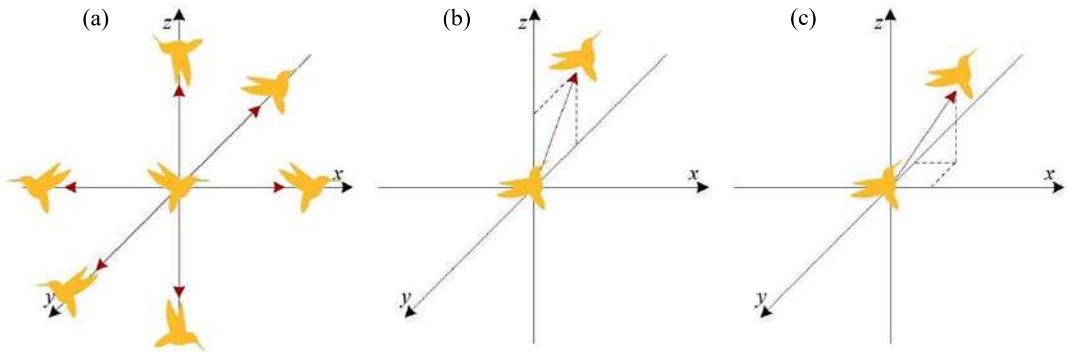

Figure 5 Three flight behaviors of hummingbirds, (a) axial flight, (b) diagonal flight, and (c) omnidirectional flight

Food source

Hummingbird	x_1	x_2	x_3	x_4	x_5
x_1	--	3	5	6	4
x_2	2	--	4	**9**	8
x_3	5	3	--	7	2
x_4	6	6	3	--	4
x_5	7	2	5	3	--

Figure 6 Visit table of a population of five hummingbirds

Hummingbirds select a foraging strategy and a flight method to reach their food source. The food source selection is based on the visitation table and the refilled rate of nectar. The level of visitation will be prioritized. Each hummingbird will go to the food source with the highest visit level on the visit table. However, if the visit level is the same the nectar-refilling rate is considered. When the minimizing problem is considered, hummingbirds will select food sources with the highest nectar-refilling rate. When the target food source is chosen, the solution value is calculated to see if the food source outperforms the initial solution value. The better food sources will receive a bonus at the visit level in order to attract more hummingbirds.

The guided foraging strategy is a method of exploitation and finding answers. The territorial foraging strategy is an exploration method. The migration foraging strategy, also known as perturbation, is to avoid becoming stuck in local optima. Hummingbirds choose exploitation and exploration with a probability of 0.5, while perturbation has a probability of 2n, where n is the population size. Table 1 summarizes the advantages and disadvantages of AHA, which has unique mechanisms embedded in it and thus owns properties.

Table 1 Advantages and disadvantages of AHA

Advantages	**Disadvantages**
- Very simple to implement and few parameters [7]. - Quick convergence [14], [31], [32]. - High performance of exploitation and exploration by the different flight behaviors of hummingbirds [21].	- May be trapped in the local optimum [22], [25], [29], [30]. - Premature convergence [25], [29].

3.1 Flowchart of application scheduling problem

Figure 7 depicts the application of AHA in scheduling. The tool should be created in a modular style using the computer programming language, and the workflow is as follows:

1) Started by inputting data from the user-related information.
   a) Identify parameter - AHA parameters (population size: *n* and iteration: *t*).
   b) The number of replications - an experiment was repeated using 30 different random seed numbers.
   c) Other information.
2) AHA parameters set by the user included:
   a) The number of hummingbirds (*n*).
   b) Number of iterations (*t*).
   c) Number of replications.
3) Problem encoding - a generated initial population of hummingbirds $(x_1, x_2, \dots, x_n)$ and generating a representation for an example of a single solution shown in Figure 8. There was a total of ten jobs (J_1, J_2, J_3, …, J_{10}), which were organized according to constraints.
4) A visit table was created to show the position of the hummingbirds to the food source, as shown in Figure 9.
5) Candidate solutions $(x_1, x_2, \dots, x_n)$ may be unfeasible. A repair process [33] satisfies constraints.
6) The evaluated value for all hummingbirds (solutions) in the initial population was computed.
7) Performs iterations from *t*: = 1 to t_{max}
8) Performs migration foraging from *m*: = $m * n/2n_{max}$
9) Started improving the solution for the first hummingbird.
10) A random vector (*rand*) in the range [0, 1] to choose a foraging strategy for each hummingbird.
11) and 12) A random number (*r*) in the range (0, 1] to choose a flight for each hummingbird.
13) Procedure for choosing a flight $r < 0.33$ select an axial flight, $0.66 \leq r \leq 0.33$ select an omnidirectional flight, and $r > 0.66$ select a diagonal flight.
14) Procedure for choosing a foraging strategy $rand \leq 0.5$ select guided foraging and $rand > 0.5$ select territorial foraging.
15) Apply the same repair procedure to all hummingbirds $(x_1, x_2, \dots, x_n)$.
16) The evaluated value for all hummingbirds (solutions) in the initial population was computed.
17) Food source with the highest visit level.
18) The hummingbird selects a target food source. The visit table for each hummingbird with the highest visit level is selected as a food source. But if the highest visit levels were equal, they would choose from the highest nectar-refilling rate as a food source.
19) Update the hummingbird's location.
20) The set target food source is set to 0.
21) Update the visit table.
22) Increased by 1 to food source neither was visited.
23) The current function fitness value ($f(v)$) is better than the initial function fitness value ($f(x)$), increasing the visit level value for a better food source.
24) Change the visit level of the food source to the highest visit level in all relevant rows and add 1.
25) If there are remaining hummingbirds go to step 9.
26) Recall and the hummingbirds are ranked.
27) Verify the migration foraging condition. In case $m * n/2n_{max}$ is not equal to the integer, skip to step 36. If the calculated is equal to an integer, go to step 28.
28) Migration foraging.
29) Select one of the worst foraging hummingbirds to improve.
30) Update the visit table.
31) Update the visit level with an increase of 1 to the hummingbird worst case.
32) Update the visit table.
33) Update the visit level for food sources with the position of the same worst hummingbird, by selecting the highest visit level value in each row and adding 1.
34) Apply the repair process for all hummingbirds $(x_1, x_2, \dots, x_n)$.
35) The evaluated value for all hummingbirds (solutions) in the initial population is computed.
36) If there are any more iterations, proceed to step 7.
37) Ranked the individuals and displayed the best position.
38) End.

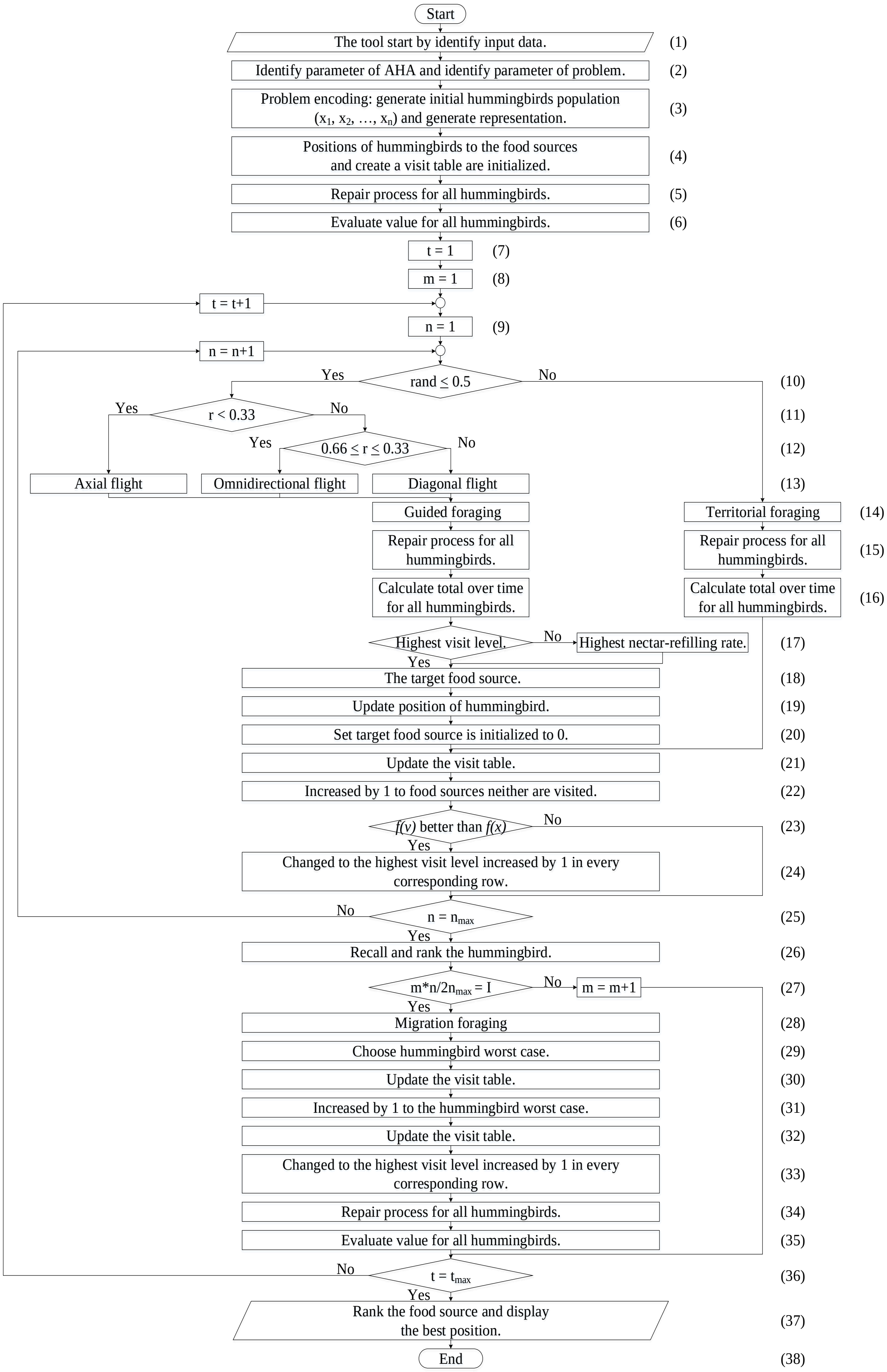

Figure 7 Flowchart of the AHA scheduling tool

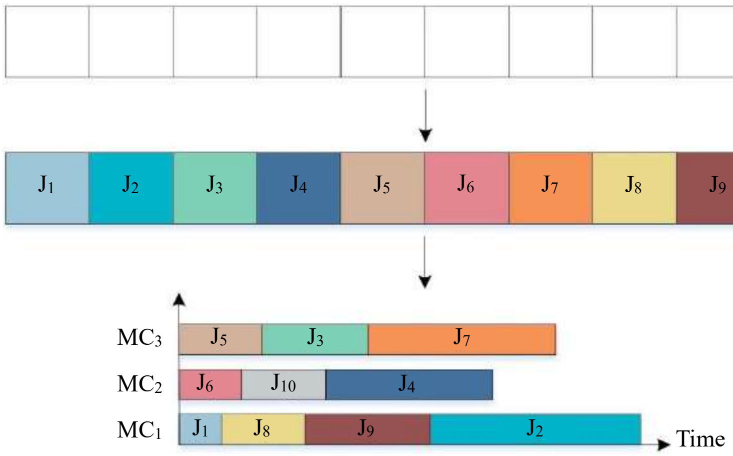

Figure 8 Example of a single solution

Food source

Hummingbird	x_1	x_2	x_3	…	x_n
x_1	--	0	0	0	0
x_2	0	--	0	0	0
x_3	0	0	--	0	0
…	0	0	0	--	0
x_n	0	0	0	0	--

Figure 9 Create initialized a visit table

4. Application areas of AHA

The AHA was recently introduced and has undergone modification and hybridization. Figure 10, which is adapted from Nayak et al. [34], depicts the areas where significant research was conducted using AHA. AHA has been used for multiple objectives in the areas of antenna design, biomedical, networking, optimization, prediction and forecasting, scheduling, and power generation control, as shown in Table 2.

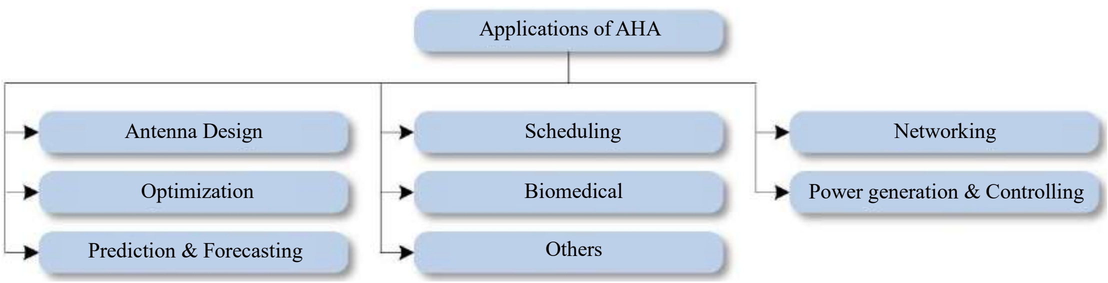

Figure 10 Application of AHA

4.1 Antenna design

An antenna is in charge of converting radio waves into electromagnetic waves. Multiple elements in an array antenna work together to increase gain and control radiation direction. An antenna is a Circular Antenna Array (CAA). The issue with CAA optimization is the presence of Side Lobe Levels (SLL). SLL is the ratio of the amplitude at the peak of the main lobe to the amplitude at the peak of the side lobe, expressed in decibels (dB). Existing algorithms have slow convergence problems that take a long time to solve; therefore, AHA is used to solve the problem by Singh et al. [23].

4.2 Biomedical

Osteoporosis is a bone disease caused by a lack or slow repair of new bone to replace old or injured bone. Bones become fragile and more prone to breaking therefore patients with osteoporosis are frequently misdiagnosed and treated late. The case study's osteoporosis detection procedure consists of four steps. As a result, developing +CGHFA, which is a combination of CHOA and AHA, is an optimal feature selection for early osteoporosis diagnosis by Basavaraja and Ganesarathinam [11].

Table 2 Application areas of AHA

Author	Application area	Problem name	Proposed approach	Compared approach	Result
Ramadan et al. [9]	Power generation & Controlling	Photovoltaic	Modified Adaptive Opposition AHA (AOAHA)	AHA, SDO, WHO, and TSA	This algorithm's performance is satisfied in terms of irradiance
Sadoun et al. [10]	Prediction & Forecasting	Predict the wear rates of the composites	Modified Random Vector Functional Link Algorithm using AHA (RVFl-AHA)	SSA, SCA, and ALO	The wear rates of composites were predicted using this method
Basavaraja and Ganesarathinam [11]	Biomedical	Osteoporosis detection from bone x-ray images	Hybrid Cat Guided Hummingbird Foraging Algorithm (+CGHFA)	CSOA, SSA, BOA, AHM, and CSA	The detection accuracy was higher than that of the existing models
Zhao et al. [12]	Optimization	Engineering Optimization Problems	Modified Multi-Objective AHA (MOAHA)	MOPSO, NSGA-II, MOEA/D, MOALO, MSSA, MOGWO, and SPEA2	In terms of convergence, diversity, and solution distribution, this method outperforms other algorithms
Yildiz et al. [13]*	Optimization	Engineering problems	Hybrid AHA and simulated annealing (HAHA-SA)	-	This algorithm is capable of efficiently solving complex multi-constrained design optimization problems
Alamir et al. [14]	Power generation & Controlling	Energy management	Hybrid AHA and Point Estimation Method (AHA-PEM)	PSO, JAYA, HBA, INFO, and AHA	The results of AHA in the case studies reduce energy consumption, and it is most likely using AHA-PEM solved EM
Elaziz et al. [15]	Biomedical	Medical image classification	Hybrid AHA based on Aquila Optimization (AHA-AO)	PSO, MFO, WOA, AO, and AHA	This algorithm outperformed the others
Dhiravidachelvi et al. [16]	Biomedical	Accurate Exudate Classification	Hybrid Convolutional Neural Network-Recurrent Neural Network along with the AHA (HCNNRNN-AHA)	FSVM, CNN, HIMLA, and Deep DR	The analytic results show that this algorithm approach improves prediction and classification accuracy
Essa et al. [17]	Prediction & Forecasting	Performance prediction of a reverse osmosis unit	Hybrid Long Short-Term Memory by AHA (LSTM-AHA)	LSTM	This method provides better permeation flow prediction and saves power
El-Sattar et al. [18]*	Power generation & Controlling	Design of standalone hybrid renewable energy systems	Hybrid Gradient-AHA (GAHA)	SDO, WHO, GWO, TSA, SCA, WOA, and AHA	The GAHA produced the best results
Li et al. [19]	Prediction & Forecasting	Determining the decommissioning life of energy equipment	Modified Monte Carlo-AHABi-Lifecycle Cost (MC-AHABi-LCC)	Bi-LSTM, GRU, and LSTM	This model's decommissioning life is closer to that of the actual equipment
Prem Jacob et al. [20]*	Biomedical	A secure IoT based healthcare framework	Modified AHA-based Convolutional Neural Network (AHB-CNN)	-	When compared to other state-of-the-art techniques this method demonstrated superior performance
Shadman Abid et al. [21]	Power generation & Controlling	Renewable energy-based distributed generation units	AHA	PPSOGSA and HHO-PSO	The AHA provides superior solutions
Ali et al. [22]	Others	Waste classification problem (Trash Net dataset)	Modified AHA-ROBL and AHA-OBL	AHA, HHO, SSA, AO, HGSO, PSO, GWO, AOA, MRFO, SCA, MPA, and SAR	The experimental results confirm that both algorithms outperform comparable algorithms
Singh et al. [23]	Antenna design	Design and synthesis of circular antenna array	AHA	GWO, SCA, SSA, and CSA	The AHA achieves side lobe levels and maintains directionality
Mohseni et al. [24]	Power generation & Controlling	Microgrid	AHA	PSO and GA	The total discounted costs of off-grid microgrids are being reduced by AHA
Kansal and Dhillon [25]	Scheduling	Coordinated wind-solar-thermal generation scheduling problem	Modified Ameliorated AHA (AAHA)	AHA	AAHA has lower minimum operating costs and an estimated improvement of up to 3%
Bhat and Santhosh [26]	Networking	The problem of localization wireless sensor networks	AHA	HHO and PSO	The reported AHAL's performance at a lower reference node ratio is comparable to other algorithms
Zhou et al. [27]	Optimization	Fabric wrinkles objective evaluation model	Modified DarkNet19-QGAHA-RVFL	SCA, WOA, MFO, MVO, SSA, and AHA	When compared to existing fabric wrinkle rating methods and results, this model by us has higher evaluation accuracy and robustness

**Only information from the title and abstracts was considered.*

Table 2 (continued) Application areas of AHA

Author	Application area	Problem name	Proposed approach	Compared approach	Result
Shaheen et al. [29]*	Power generation & Controlling	Parameter estimation of solar photovoltaic triple-diode models	AHA	AVOA, TSO, and TLBO	AHA is useful for estimating solar photovoltaic models
Fathy [30]	Power generation & Controlling	Biomass distributed generators	AHA and Modified MOAHA	GA, PSO, WOA, SSO, TSA, PFA, SOA, and SCA	When compared to the others, the AHA is superior
Haddad et al. [31]	Power generation & Controlling	Parameter adjustment problem of PV	AHA	GBO, RUN, and SEDE	The AHA can be used as a tool to optimize PV system design
Waleed et al. [32]	Optimization	Optimal reactive power dispatch	AHA	SFO, GWO, PSO, CBA, SCA, and BA	The AHA outperformed its rivals
Çelik and Soylu [35]*	Power generation & Controlling	Parameter estimation of PEMFC	AHA	ABC, SSO, PSO, GWO, GA, HHO, and WOA	In terms of computational speed and robustness AHA can compete
Duong et al. [36]*	Optimization	Optimal Power Flow (OPF) problem	AHA	SSA, PSO, TLBO, and DE	The AHA is a powerful solver
Franklin and Fathima [37]	Power generation & Controlling	Estimate the parameters of the controller	AHA	PSO, GSA, SOA, MFO, MVO, MPA, GNDO, and GTO	By increasing its performance AHA demonstrates that it is more feasible and acceptable
Hamida et al. [38]	Power generation & Controlling	Identify parameter unknown of Li-Ion batteries	AHA	AVO, JSO, TSO, GWO, AO, and HO	AHA outperforms other algorithms in terms of precision
Kıymaç and Kaya [39]	Biomedical	A novel automated CNN arrhythmia classifier	Modified Memory-enhanced AHA (MAHA)	PSO, BA, GWO, SCA, and WOA	In terms of accuracy rate, MAHA has the best performance, tied with PSO
Kotb et al. [40]	Power generation & Controlling	Estimation of electrical transformer parameters	AHA	PSO, ICA, GSA, GA, BHO, HOA, ISA, and COA	AHA yields the best transformer parameter values
Mohamed et al. [41]	Power generation & Controlling	Renewable energy power grids	AHA	PSO, ABC, BOA, and AEO	This controller can achieve improved frequency regulation performance
Navarro et al. [42]	Power generation & Controlling	Estimation of parameters in solar cell models	AHA	AO, AVOA, EO, GEO, SBLA, SNS, and RSA	In terms of performance and minor errors, AHA is the best algorithm for solving solar cell problems
Ramadan et al. [43]	Power generation & Controlling	Renewable distributed generators (RDGs)	AHA	PSO, ALO, WOA, and SCA	Costs, emissions, and voltage deviation are all reduced significantly
Raghavendra et al. [44]	Prediction & Forecasting	Data science enabled stability prediction model for smart grids	Modified AHA-based Feature Selection with Optimal DL enabled Stability Pre-diction (AHAFS-ODLSP)	-	This algorithm outperformed other prediction models by achieving its maximum performance with a F score of 99.02%
Sadoun et al. [45]	Prediction & Forecasting	Rates prediction of nanocomposites	Modified Dendritic Neural Model AHA (DNM-AHA)	SSA, SCA, and GWO	For nanocomposites this model has excellent predictability of wear rate and coefficient of friction
Wang et al. [46]	Optimization	Truss topology optimization	Modified AHA based on Golden Sine (DGSAHA)	AHA, AOA, BWO, GWO, MPA, PSO, MFO, SCA, SSA, TSA, and SOA	This algorithm performs better in terms of overall optimization
Wang et al. [47]	Optimization	Parameter identification of a governing system in a pumped storage unit	Modified Improved AHA (IAHA)	AHA, PSO, ALO, and GSA	When compared to other algorithms, the IAHA errors are only 2.04%, 1.82%, and 1.28%

**Only information from the title and abstracts was considered.*

Diabetes is a common chronic disease that is on the rise. Diabetes mellitus is the result of the body having high blood sugar levels for an extended period of time. Diabetes retinopathy is a complication of diabetes that can lead to vision loss. As a result, the HCNNRNN-AHA technique was developed to detect and classify organ images that are exudate or not exudate. It is possible to detect diabetic retinopathy aggression using fundus image analysis. Using AHA to appropriately adjust CNN and RNN parameters improves prediction precision by Dhiravidachelvi et al. [16].

Medical imaging is a technique and process for imaging internal organs and is used in disease diagnosis and treatment. AHA-AO is a current medical imaging diagnosis system that employs Transfer Learning (TL) and Feature Selection (FS). The FS technique employs a modified algorithm, which improves classification efficiency by Elaziz et al. [15].

Carcinoma is a form of cancer, a disease that affects people of all ages. The condition is manifested by defective cells that grow faster than normal, resulting in various forms of cancer in the body. Prem Jacob et al. [20] placed sensors on the bodies of humans to collect IoT datasets, and the classification of carcinoma types using IoT medical sensor datasets were analyzed with AHA-CNN.

Cardiovascular disease affects the cardiovascular system and is related to the heart or blood vessels. Although an electrocardiogram (ECG) can detect the disease, morphological variation makes the ECG a poor classification tool. As a result, the doctors must interpret using their expertise. Therefore, using AHA memory to improve the hyperparameters of the received optimal value. This method reduces calculation time as presented by Kıymaç and Kaya [39].

4.3 Networking

A Wireless Sensor Network (WSN) is the use of a large number of small sensor devices to measure and process data. However, the positioning of sensor nodes and the usability of reference nodes raises the cost and complexity of the network. WSN is made up of three components: a) sensor nodes that act as input receivers, b) router nodes that function similarly to sensor nodes but can find the data transmission path, and c) coordinator nodes that collect all information in the WSN. Anchor nodes and unknown nodes are the two types of WSN nodes. One of the major issues with WSN is estimating the position of unknown nodes. AHAL is a method for estimating the position of reference nodes developed by Bhat and Santhosh [26]. AHAL reduces the number of reference nodes while also saving costs.

4.4 Optimization

Renewable energy is obtained from a power source that is both continuous and sustainable, and it does not deplete over time. It primarily originates from natural sources, including solar, wind, water, geothermal, and biomass. Renewable energy is environmentally friendly, improving the country's economy and allowing people to live longer lives. However, renewable energy is only found in certain areas and cannot produce energy continuously. As a result, AHA is being used to solve optimal power flow with multi-objective functions by Duong et al. [36].

More recently, the demand for electricity has increased, making it imperative that electrical system planning remains efficient to minimize energy loss and voltage deviations within the system. The optimal reactive power dispatch problem is a multi-objective optimization problem that is part of the optimal power flow problem, this is solved using AHA to determine the optimal setting of the control variable by Waleed et al. [32].

Truss topology optimization is a structural optimization problem related to the truss design. The various shortcomings of AHA, have been improved with the development of the algorithm known as DGSAHA which has improved AHA by adding three improved steps. First, the initial population is created by using chaos mapping to increase the diversity of the population. Second, the number of foraging migrations or mutations increases after each iteration. Third, in territorial foraging, Wang et al. [46] used the golden sine factor. This enhancement according to Wang et al. [46] improves the balance of AHA exploration and exploitation.

When one encounters difficulty in determining the values of parameters, they are confronted with a parameter identification problem, which is classified as an optimization problem. An identified optimal parameter to the governing system of a control system of pumped storage units makes the system more efficient, and the storage unit operates safely and reliably. In this case, IAHA is used to solve the parameter identification problem by improving AHA's two strategies. First, the initial population was generated using Chebyshev's chaotic map to increase the size of the global search. Second, Levy flight can be used in guided foraging strategies to broaden the search area while avoiding convergence by Wang et al. [47].

AHA has been hybridized with SA, giving rise to the name HAHA-SA, in order to investigate the performance of the improved algorithms in solving engineering design problems by Yildiz et al. [13].

With AHA's efficiency in solving engineering problems and designing hydropower operations, there is a single objective problem in existing work. Zhao et al. [12] recognized a trend in the development and created the MOAHA to solve the multi-objective problem using DECO and Pareto.

Fabric wrinkles are undesirable properties because they detract from the beauty of clothing. The results of assessing existing fabric wrinkles are inaccurate, time-consuming, and biased. Zhou et al. [27] demonstrates the DarkNet19-QGAHA-RVFL method for assessing fabric wrinkles. To improve the initial population of AHA, they used quasi-reflection learning. In addition, the Gaussian mutation was used to improve territorial foraging and accelerate convergence.

4.5 Prediction and forecasting

LCC and EL methods have been used in various applications, most recently in the energy field. However, this method is inaccurate and unscientific. As a result, the MC-AHABi-LCC model was created to estimate the age of dismantling equipment. AHA can be used to include both short-term and long-term memory models. In addition, use these indices MAE, MAPE, and RMES to select the best model forecast by Li et al. [19].

A smart grid integrates various technologies to cover the entire chain of command of the electrical system, connecting renewable energy to the power grid. AHAFS-ODLSP is a model that has been developed to predict the stability of a smart grid system. Raghavendra et al. [44] used AHA to create feature selection modeling and has developed a method for predicting long-term and short-term memory stability known as MHSA-LSTM.

By improving the physical properties, nanocomposites are being designed and new material manufacturing has become more flexible. In this case, the nanocomposites Cu-Al_2O_3 study, employs the quantity and ratio difference of Al_2O_3 to predict the effect of Al_2O_3 on the wear rate of nanocomposites Cu-Al_2O_3. In addition, RVFI-AHA models for predicting composite material wear rate have been developed. Using AHA to determine the best value configuration for RVFI, by Sadoun et al. [10].

The amount of freshwater on Earth is only 3% of the total; the remaining 97% is saltwater in the seas and oceans. Water is used in various industries, agriculture, and daily life activities. With advancements in various fields, there may be a severe shortage of freshwater. Essa et al. [17] created the LSTM-AHA, a machine learning method that includes an LSTM that uses AHA to set the appropriate parameters to improve the efficiency of the LSTM. This algorithm was created to predict reverse osmosis (RO) seepage and energy savings. RO is a freshwater production method that employs a filter. The water is free of contaminants that are toxic to the body thanks to the efficiency of RO.

Cu-Al2O3 nanocomposite is widely used in electronics. Cu has good thermal and electrical conductivity but suffers from wear resistance and strength limitations. As a result, the DNM-AHA method was developed to predict the wear of Cu-Al2O3 nanocomposite by using AHA to set the optimal DN value. This method significantly lowers the cost of testing, according to Sadoun et al. [45].

4.6 Scheduling

Wind and solar energy are both sources of clean energy. A wind and solar heat generation schedule was developed to reduce the use of coal in electricity generation. However, due to the unpredictability of wind speed and direction, as well as the unpredictability of the rays of the sun due to seasonal changes and weather factors such as cloud formation, the AAHA method was developed, which introduced SSS to improve the AHA's guided foraging strategy of using previous answers as a guide to finding new answers Kansal and Dhillon [25].

4.7 Power generation and controlling

Energy management is the process of monitoring and optimizing energy use in order to control and reduce consumption. However, because renewable energy sources are uncertain, hybrid AHA-PEM is used to solve this problem. In addition, AHA is being used to solve the energy management problem of microgrids, as stated by Alamir et al. [14].

Polymer Electrolyte Membrane Fuel Cells (PEMFC) are fuel cells with continuous development that can be used as a power source while not polluting the environment. PEMFC parameters were estimated in order to determine the efficiency of AHA by Çelik and Soylu [35].

A standalone hybrid renewable energy system is less expensive and more reliable than a solar-wind system. GAHA was created to address the issue of energy costs and optimizing hybrid power generation system configurations by El-Sattar et al. [18].

Because customer demand for electricity has increased significantly, reducing voltage deviation and power loss leads to improved network efficiency. Distributed Generators (DG) in the network can solve both problems. DG is a smart grid system that uses multiple renewable energy sites to provide directionless power distribution. However, the use of DG in a network should be specified in the best possible location and size for network performance. This problem was solved using AHA and MOAHA by Fathy [30].

Because of the COVID-19 epidemic, many countries had policies requiring people to quarantine themselves at home. This resulted in increased electricity consumption and an impact on the industry, making renewable energy more appealing. Solar energy is clean energy, but the uncertainty and capacity of power generation are not equal to traditional methods. In order to improve PV accuracy and efficiency, Haddad et al. [31] employ AHA to optimize photovoltaic cell (PV) parameter estimation.

A lithium-ion battery is rechargeable and is commonly found in electronic devices and electric vehicles. However, the estimation cannot be accurate due to side effects such as noise, temperature, sensor sensitivity, parameters, etc., which causes the meter's state of charge (SOC) to be incorrect. Hamida et al. [38] used AHA to estimate the SOC and determine the parameters in the lithium-ion battery.

A transformer plays a critical role as it converts voltage into a standardized, readily utilized level. Voltage levels vary from one country to another, and the voltage used in households is typically different from that employed in industrial factories. Kotb et al. [40] wish to locate an unknown parameter in a single-phase transformer (SPT). Literature reviews of algorithms used to solve this problem have found various issues, including precision, incorrect answers, slow convergence, and getting stuck in local optima. Due to the fact that AHA is a new algorithm with few parameters, it was used by Kotb et al. [40] to define the parameters in SPT.

The use of a load frequency controller improved the stability of renewable energy power grids. Some existing optimizers are extremely sensitive to parameter changes and take a long time to complete. To reduce frequency deviation, Mohamed et al. [41] presents a TFOIDFF frequency controller suitable for AHA.

The microgrid system has two modes of operation: grid-connected mode and island mode. Another system, known as a stand-alone microgrid, operates in island mode. A standalone microgrid, which is used in electric vehicles, requires batteries to store energy. AHA is designed for self-contained microgrids in high-volume EV charging load areas (Mohseni et al. [24]).

Static photovoltaic using diodes has grown in popularity because increasing the number of diodes improves model accuracy, but also increases model complexity. Many works of literature use a three-diode model with approximately nine parameters. To obtain a valid model, Ramadan et al. [9] propose using AOAHA to evaluate the parameters. When compared to the original algorithm, this algorithm improves the balance between exploitation and exploration.

The optimal size and location of distributed generation placement were evaluated in order to increase the efficiency of renewable energy-based distributed generation units. To reduce costs, deviation, and energy waste, AHA was used to solve this problem as a multi-purpose optimization problem, by Shadman Abid et al. [21].

The generated model was incorrect due to the inaccuracy of the solar cell parameters. As a result, Shaheen et al. [29] used AHA to calculate solar photovoltaic parameters.

The state space model is used in modern control theory to analyze and control time-domain systems. Franklin and Fathima [37] used AHA to estimate the optimal controller parameters before using a 3DOF-FOPID controller to control the frequency of the microgrid system. The importance of frequency control is that it keeps the system constant and does not vary with load.

Alternative Energy (AE) is derived from sources other than fossil fuels. The vast majority of AE is clean energy that will never run out and will not pollute the environment. As a result, the parameters of the photovoltaic diode model were estimated using a new metaheuristic algorithm (Navarro et al. [42]).

AHA was used by Ramadan et al. [43] to determine the best location and size for renewable distributed generators. However, because it is a renewable energy source, it creates uncertainty and discontinuity. As a result, a Monte Carlo model was used in conjunction with a reverse reduction algorithm to predict uncertainty probabilities.

4.8 Others

Recycling reduces waste and the use of natural resources and lowers waste emissions. Waste classification enables proper waste treatment and the development of a better waste management system. As a result, Ali et al. [22] created two generations of AHA-based algorithms to solve the waste classification problem. Because the answer is stuck in local optimal and slow convergence, AHA's garbage classification performance is poor and unsatisfactory.

5. Critical analysis and investigation

A total of 36 articles related to the application of AHA were reviewed in this study. There is a review of the use of AHA in various fields. This section provides an analysis that can be summarized through the use of analytical visualizations.

5.1 Q1: Which "application areas" are popularly used in AHA to solve problems?

Figure 11 shows that AHA was used most in the domain of power generation and control in fifteen articles. Zhao et al. [7] used AHA to solve renewable energy problems, namely hydropower operation design. The authors believe that this is the reason for the widespread use of AHA in energy problems. The optimization problem application is the second most popular, with seven articles commonly used to solve engineering problems. The third most popular topics are biomedical, prediction, and forecasting, with five articles each. In medicine, photographs are often used to analyze and detect diseases, forecast equipment life, and wear rates of composite materials. Finally, one article in the application of AHA was used to solve antenna design, networking, scheduling, etc. Renewable energy challengers frequently used AHA to solve wind, solar, and water energy problems. This helped to cut back on the use of finite fossil fuels and reduced emissions being released into the environment.

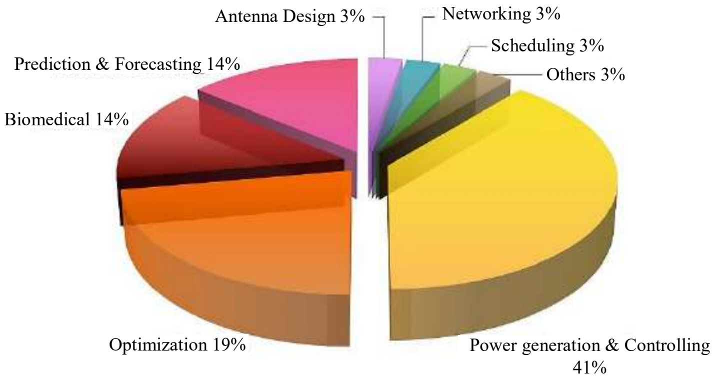

Figure 11 Application of AHA in various domains

The most well-liked optimal problem topic that AHA solved, according to an earlier statement, is the area of power generation and control. For example, Zhao et al. [7] applied AHA to solve hydropower operational design problems, which were classified as part of the power generation and control optimization problems which were considered as highly complex and of top priority. This problem relates to reservoir and hydropower systems determining how to operate a hydropower plant optimally. The results showed that AHA was effective and had a good convergence rate. It primarily demonstrates AHA's potential to tackle real-world problems with unknown and constrained variables. However, AHA has yet to be applied and tested to many problems, especially combinatorial optimization problems such as layout design, routing problems, scheduling, and timetabling.

5.2 Q2: Which type of AHA is frequently used to solve problems?

How do we solve problems in various areas? The studies on the applications of metaheuristics for solving optimization problems have normally started with their original mechanisms and basic or recommended parameters. However, there are many ways to improve the searching abilities of metaheuristics. In the case of AHA, it may focus on avoiding being trapped in the local optimum and premature convergence. Parameter tuning by Design of Experiment (DOE) and statistical analysis [48] is the first choice because there have been no optimal parameters, and the configuration of parameters depends on the specified problems. The second choice is modification, which is one of the trendy efficiency improvements [49]. It is the consideration and identification of AHA's potential mechanism(s) to improve the searching ability or adapt the balance of the exploration and exploitation processes. Hybridization is another improvement choice that relates to a combination of mechanism(s) between two or more metaheuristics. It focuses on their appropriate cooperation and strengths with each other [50].

The majority of the present 16 articles (43%) used the original AHA to solve problems and was commonly used to solve benchmark functions or engineering problems and compare the efficiency with existing algorithms. The second was the modification AHA, which had 14 articles (38%), that were used to solve problems. Finally, the hybridization AHA was used to solve the problems in 7 articles (19%). Hybridization and modification increased the AHA's effectiveness in problem-solving, as shown in Figure 12.

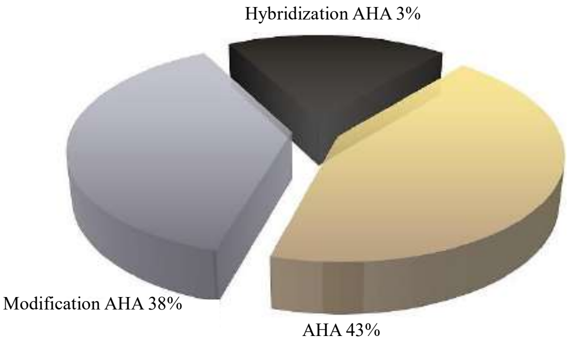

Figure 12 Type of AHA to solve problem

5.3 Q3: Which "algorithms" are popularly used to compare AHA performance?

The fourth column in Table 2 shows that various algorithms were used to compare the efficiency with AHA. The taxonomy of metaheuristics introduced by Kumar and Bawa [51] is divided into five categories: bio-stimulated algorithms, nature-inspired algorithms, physics-based algorithms, evolutionary algorithms, and swarm-based algorithms. And in the article, Kumar and Bawa [51] explained and justified each group.

According to Kumar and Bawa, Figure 13 depicts a clustering of algorithms that were compared to AHA. The number of algorithms in the groups of bio-stimulated algorithms and nature-inspired algorithms is equal. Figure 14 shows the number of times all 36 articles were used. It demonstrates that the bio-stimulated algorithm was the most popular group to have its efficiency compared with the AHA, which is also classified as a bio-stimulated algorithm.

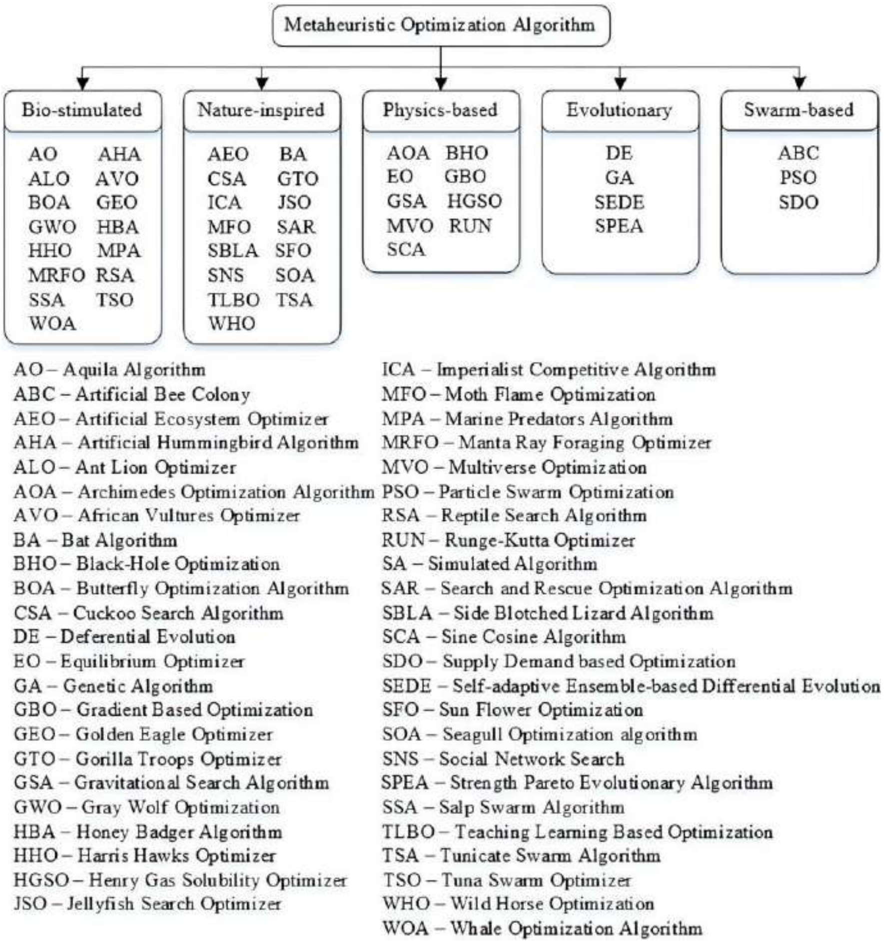

Figure 13 Taxonomy of metaheuristic

5.4 Q4: Which "publications" dominate in the area of AHA?

Table 3 lists the journals for each of the 36 articles reviewed in this paper. As can be seen, three Mathematics Journals had published the most AHA articles.

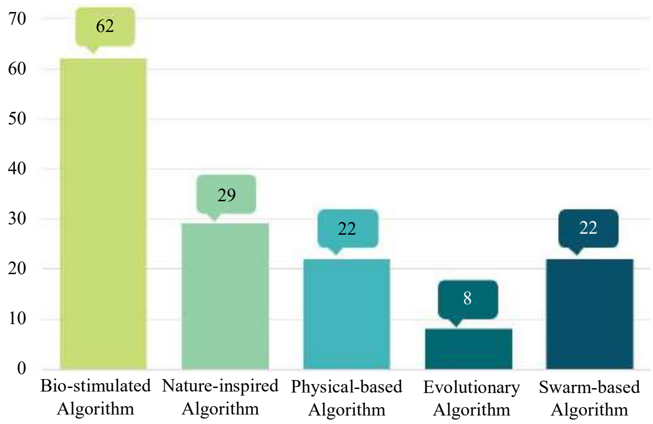

Figure 14 Number of times to compare

5.5 Q5: Which AHA research gap?

Based on a literature review on the use of AHA in various applications. Many domain areas, such as neural networks, robotics, security, signal processing, fuzzy systems, and data mining, etc., have yet to see the application of AHA. There are additional types of problems in these application areas. For example, in the scheduling problem, the review found only one article in this domain. However, scheduling issues can be classified into a variety of categories, which include the scheduling of physicians, nurses, examiners, call centers, etc. And these problems were not solved by AHA.

Table 3 Ranking of journals by the number of AHA publications

Rank	Journal	Num.	Rank	Journal	Num.
1	Mathematics	3	16	Expert Systems with Applications	1
2	Applied Energy	2	17	Frontiers in Energy Research	1
3	Energies	2	18	International Journal of Intelligent Engineering and Systems	1
4	IEEE Access	2	19	International Journal on Electrical Engineering and Informatics	1
5	Sustainability (Switzerland)	2	20	Journal of Computational Electronics	1
6	Advanced Engineering Informatics	1	21	Journal of Digital Imaging	1
7	Ain Shams Engineering Journal	1	22	Journal of Energy Storage	1
8	Alexandria Engineering Journal	1	23	Journal of Mechanical Engineering Science	1
9	Applied Sciences (Switzerland)	1	24	Journal of Natural Fibers	1
10	Computer Methods in Applied Mechanics and Engineering	1	25	Materialpruefung /Materials Testing	1
11	Electronics (Switzerland)	1	26	Physical Communication	1
12	Energy	1	27	Process Safety and Environmental Protection	1
13	Energy Conversion and Management	1	28	Scientific Reports	1
14	Energy Reports	1	29	Sustainable Computing: Informatics and Systems	1
15	Energy Sources, Part A: Recovery, Utilization and Environmental Effects	1	30	Transactions on Emerging Telecommunications Technologies	1

6. Conclusions

In this study, we provided a comprehensive and systematic literature review of the applications of AHA for optimization problems using the PRISMA flow to identify gaps in the literature and initiate future research activities. Our findings show that the domains of power generation and control are the most popular, and discrete optimization problems are also research gaps. In addition, to identify research gaps, a systematic and comprehensive review using appropriate tools, such as PRISMA, is required.

The majority of existing real-world optimization problems are classified as NP-hard, which is a large and complex problem because uncontrollable natural disturbances constrain real-world problems. Therefore, metaheuristics are appropriate to find optimal solutions. The natural behavior of animals, insects, nature, evolution, and natural phenomena inspire many metaheuristics. An optimization algorithm in the bio-stimulated algorithm group simulates wild and marine animals' foraging and hunting behavior [51]. On the other hand, AHA, drawing inspiration from hummingbirds' foraging behavior, exhibits limitations, including low convergence, a tendency to become trapped in local optima, and poor answers. As a result, the AHA was improved by modification, and the hybridization of its mechanisms with other algorithms to increase its efficiency.

A systematic review of AHA-related articles was conducted in this study by searching the Scopus international database for articles that cite Zhao et al. [7]. Antenna design, biomedical, networking, optimization, prediction and forecasting, scheduling, power generation and control, and others are the application areas of the AHA. The domain of power generation and control is a popular topic for problem-solving, and renewable energy is a problem that is receiving a lot of attention these days. The original AHA is the most widely used and is frequently used to solve engineering problems. Many bio-stimulated algorithms are often used to compare performance with AHA. Three Mathematics Journals published many AHA-related articles. The AHA has not yet been applied, especially to discrete optimization problems such as scheduling, timetabling, facility layout, vehicle routing, etc. These are interesting research gaps for future investigation.

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