Harris Hawks Optimization: A Formal Analysis of Its Variants and Applications

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Abstract: The Harris Hawks Optimization (HHO) is a recent meta-heuristic algorithm developed by Hideri in 2019. HHO algorithm has been widely utilized to solve many optimization problems in different fields. The primary objective of HHO is to define a fitness function that can successfully optimize a specific problem by finding the minimum or maximum value. This survey presents a thorough study of the algorithm, including its variants such as binary, hybridization, multi-objective and modifications. It highlights the main applications such as medical, engineering, machine learning, and network applications. Finally, the conclusion summarizes the current works on HHO and suggests possible future directions.

1 INTRODUCTION

Harris Hawks Optimization (HHO) is a new swarm-based algorithm developed by Heidari in 2019 (Heidari et al., 2019). HHO mimics the hunting strategy of Harris hawks in nature. HHO has two phases of exploration and four phases of exploitation.

The main motivation of this survey is to provide a full review of the HHO algorithm including its usage to address different optimization problems in different applications. Moreover, this survey focuses on the main modifications applied in the literature to enhance the performance of the HHO algorithm and to tackle its shortcomings. Besides, the survey uses references from various well-known publishers (e.g, IEEE, Springer, Elsevier, Hindawi, Taylor & Francis, and other publishers). Fig 1 shows the number of published papers that are classified based on the publisher of the HHO algorithm publications. Fig 2 shows the classification of these papers based on the applications.

This survey presents and discusses the HHO algorithm based on two major considerations:

- Theoretical aspects of HHO algorithm including the HHO modifications, hybridization, and multi-objective.
- Applications of HHO algorithm including environment, manufacturing, energy, power system, features selection, medical applications, network applications, engineering, image processing, and other applications.

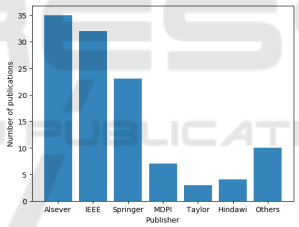

Figure 1: Number of publications of HHO algorithm per publisher.

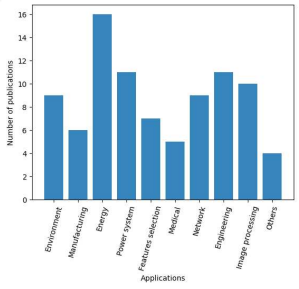

Figure 2: Number of publications of HHO algorithm per applications.

The rest of this survey is organized as follows: in Sect. 2, the theoretical aspects of the HHO algorithm and its

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variants are summarized. In Sect. 3, applications of HHO algorithm is outlined and highlighted. Assessment and evaluation of HHO algorithm are shown in Sect. 4. Finally, in Sect. 5, the conclusion and possible future works are presented.

2 VARIANTS OF HHO

2.1 Binary HHO Algorithm

A new binary variant of the HHO is proposed in (Beşkirli and Dağ, 2020) for the binary wind turbine micrositing problem. The new algorithm is named as HHO_{bin}. The HHO_{bin} algorithm proposed for converting the continuous version of the HHO algorithm into binary version is equipped with ceil (T1), ceilRound (T2), ceilFloor (T3), Roundfloor (T4), moduleBase A (T5), moduleBase B (T6), T7 and T8 transfer functions. Thus, the original HHO algorithm is converted to the HHO_{bin} algorithm to solve any binary problems. In this study, the HHO_{bin} algorithm is developed for solving binary wind turbines. In (Thaher et al., 2020), the HHO is converted into binary using transfer function to work in the features binary search space. The main target is to select the best features from a dataset and enhance the classification process. The used datasets are challenging as they consist of high dimensionality and a small number of instances.

2.2 Modified HHO Algorithm

In (Gölcük and Ozsoydan, 2020), the HHO algorithm is proposed to deal with dynamic optimization problems (DOPs). It is modified as a multi-population based algorithm to deal with multiple optima and to search in different parts of the search space. In (Fan et al., 2020), a novel quasi-reflected Harris hawks algorithm (QRHHO) is proposed, which combines the HHO algorithm and quasi-reflection-based learning mechanism (QRBL). The QRBL mechanism is proposed to increase the population diversity in the initial stage, and then, QRBL is added in each population position update to improve the convergence rate. In (Qu et al., 2020), the HHO based on information exchange is proposed. An individual obtains information from the shared area of cooperative foraging and the location area of collaborators. A nonlinear escaping energy factor with chaos disturbance is used to better balance the local search and the global search. In (Zhang et al., 2020b), the study focuses on the escaping energy (E) of prey. For E, six different update strategies are used to model the real situation. In (Al-Betar et al., 2020), the survival-of-the-fittest principle of evolutionary algorithms is incorporated in the HHO algorithm. Three selection strategies (i.e., tournament, proportional and linear rank-based methods) are used in the exploration phase of HHO.

2.3 Hybridizations of HHO Algorithm

In (Abdel-Basset et al., 2020a), the HHO algorithm, Bitwise operations, and Simulated Annealing are integrated. The new model is called HHOBSA. The main purpose is to solve the feature selection problem. The objective of using the (AND and OR) is to transfer the best features from the best solution to other low-quality solutions to raise their fitness. The SA algorithm helps to jump from the local minima. Another study that integrated SA algorithm with HHO algorithm is in (Elgamal et al., 2020) to enhance the exploitation of the HHO algorithm. In (Attiya et al., 2020), the HHO is also integrated with SA. In this paper, the authors use SA to perform the local search. The proposed method is applied for scheduling jobs in the cloud environment. In (Dhawale and Kamboj, 2020), the HHO algorithm is integrated with Improved Grey wolf optimization. The model is called hHHO-IGWO. In (Zhao and Gao, 2020), the HHO algorithm is integrated with the slime mould algorithm to allow the individuals to take more ways to update their positions. In (Xie et al., 2020b), the HHO algorithm is used to support the Henry Gas Solubility Optimization Algorithm (HGSO). Because the search strategy of HGSO is simple and it is weak in exploitation, the HHO is proposed.

2.4 Multi-objective HHO Algorithm

In (Du et al., 2020), a multi-objective HHO algorithm called MOHHO is proposed to estimate the parameters of the extreme learning machine (ELM) with high accuracy and stability in the predication of air pollution series. In (Yüzgeç and Kusoglu, 2020), in the MOHHO algorithm, the HHO algorithm structure is preserved and an archive repository is added to store and get the Pareto optimal results. The roulette wheel is used to select the archive member from the least populated area. The unconstrained test functions known as ZDT is used to assess the performance of the proposed model. In (Fu and Lu, 2020), MOHHO is proposed for the changeable operating conditions of the hydraulic turbine governing system (HTGS). Other modification strategies are embedded into the MOHHO including Latin hypercube sampling initialization, modified differential evolution operator, mutation operator, and nonlinear rabbit energy are applied in MOHHO (HMOHHO) to enhance the global

search performance. In (Islam et al., 2020), a new version of the HHO algorithm is proposed to solve single and multi-objective Optimal Power Flow (OPF) problems for controlling the emissions from thermal generating sources. Fuel cost, power loss, and environmental emissions are used as single and multi-objective functions for an optimal update of power system variables.

3 APPLICATIONS OF HHO

3.1 Environment

Malik (Malik et al., 2020), HHO algorithm is used to optimizes the parameters of support vector regression (SVR) to accurately and reliably predict the streamflow. This helps to manage water resources and predict reservoir flood. In (Yu et al., 2020), the HHO algorithm, the random forest (RF), and Monte Carlo simulation are used to predict, analyze and control the blast-induced ground vibration. Based on the performance indices, the proposed HHO-RF model can provide higher prediction performance. The HHO algorithm is used in (Sammen et al., 2020) to predict scour depth (SD) downstream of the ski-jump spillway. The HHO algorithm is applied to improve the performance of an artificial neural network (ANN) to predict the SD. The performance of the ANN-HHO method is compared with two-hybrid methods, namely, the particle swarm optimization with ANN (ANN-PSO) and the genetic algorithm with ANN (ANN-GA). In (Fu et al., 2020), a new model that integrates two-layer decomposition, improved hybrid differential evolution-HHO (IHDEHHO), phase space reconstruction (PSR) and kernel extreme learning machine (KELM) is proposed for the prediction of the short-term wind speed.

3.2 Manufacturing

In (Saravanakumar and Mohan, 2020), the HHO algorithm is proposed to solve the assembly line balance problem. The use of the HHO multipoint crossover method optimizes and improves the performance of a network-based line balancing problem. The HHO algorithm is proposed in (Jouhari et al., 2020) as a solution to the scheduling problem. In specific it is used to solve unrelated parallel machine scheduling problems (UPMSPs). The new method, called MHHO, uses the salp swarm algorithm (SSA) to perform a local search for HHO. This improves its performance and decreases its computation time. The MHHO shows better performance in both small and large problem cases. In (Golilarz et al., 2019), the HHO algorithm is proposed in the tuning stage to adjust the convolutional neural network (ConvNet) parameters. This method is used to enhance the production quality in the manufacturing industry. The least-squares support vector machine (LSSVM) is used as a soft-sensor model to predict key production indicators in complex grinding processes (Xie et al., 2020a).

3.3 Energy

A Boosted HHO is proposed in (Ridha et al., 2020) to estimate the parameters of the single diode PV model. The BHHO algorithm integrates random exploratory steps of the flower pollination algorithm (FPA) and a mutation operator of the differential evolution (DE) with 2-Opt algorithms. In (Mouassa et al., 2020), the HHO algorithm and other optimizers are used for energy scheduling in the smart home. A load prediction tool is developed in (Tayab et al., 2020) for efficient power management in the microgrid. The paper proposes a hybrid method that compromises the best-basis stationary wavelet packet transform and HHO-based feed-forward neural network. The HHO is used as a training algorithm for optimizing the weight and basis of neurons of the feed-forward neural network. Yousri (Yousri et al., 2020), the HHO algorithm is used to evaluate the best parameters of the Proportional-Integral (PI) controller simulating load frequency control (LFC) incorporated in a multi-interconnected system with renewable energy sources (RESs). The integral time absolute error (ITAE) of the frequency and tie-line power is selected as the objective function. In this study two systems are considered for testing: the first one has two interconnected areas of thermal and photovoltaic (PV) plants and the second system compromises four plants of PV, wind turbine (WT), and two thermal plants considering governor dead-band (GDB) and generation rate constraint (GRC).

3.4 Power Systems

The HHO is proposed as a solution to the optimum power flow (OPF) in (Akdag et al., 2020). This is an important problem for power system engineering. The proposed modified HHO is used to minimize the fuel cost of the power system when it is applied to IEEE 30-bus test system. In (Birogul, 2019), the HHO algorithm is integrated with the mutation operators of Differential Evolution (DE) in a new model called (HHODE). The HHODE algorithm is proposed to solve the OPF problem. The effectiveness of the HHODE hybrid algorithm is tested on a modified

IEEE 30-bus test system. The HHO algorithm in (HA et al., 2019) is used for tuning of integral classical controllers to design the appropriate load frequency controllers. The optimized controller parameters and the enhanced system performance are investigated. It has a two-area interconnected power system with different participation of DFIG based wind turbine at the first area only. In (Sobhy et al., 2019), the HHO algorithm is used to determine the gains of the proportional integral derivative (PID) controllers used in the load frequency control of power systems. The automatic generation control (AGC) problem is formulated as an objective function using the integral square of errors (ISE) criterion. The proposed algorithm is used with a two-area power system that consists of non reheat thermal generating units that consider the generation rate constraints (GRC).

3.5 Feature Selection

Feature selection is a datamining technique to select the most informative features in a dataset (Alazab et al., 2012). In (Sihwail et al., 2020), the HHO algorithm is modified and introduced as a search algorithm for feature selection. The HHO algorithm is modified and improved for feature selection in (Elgamal et al., 2020). Using different evaluation criteria, it was compared and analyzed. In (Thaher and Arman, 2020), the HHO algorithm is used as a search strategy to find a near-optimal solution for the feature selection problem. Different classifiers are used to assess the found solutions: K-nearest neighbors (kNN), Decision Trees (DT), and Linear Discriminant Analysis (LDA). The standard continuous HHO algorithm is converted into binary in (Too et al., 2019) using S and V transfer functions and another variant of HHO called quadratic HHO is generated. In (Ismael et al., 2020), the HHO is applied for optimizing the hyperparameter of v-support vector regression (v-SVR) and simultaneously performs feature selection. The HHO algorithm is modified and hybridized in (Abdel-Basset et al., 2020a) to enhance its performance for the feature selection problem. In (Zhang et al., 2020a), the HHO algorithm in this paper is enhanced to get high-quality solutions for solving the feature selection problem.

3.6 Medical Applications

The segmentation of medical images is presented in (Rodríguez-Esparza et al., 2020). Authors in this paper, propose the HHO algorithm to identify the regions of interests (ROIs) that contain malignant masses. In the applied multilevel threshold segmentation technique, the minimum cross-entropy thresholding (MCET) is used to select the optimal threshold values for the segmentation. (Rammurthy and Mahesh, 2020). The model is based on using cellular automata and rough set theory to make segmentation for the MR images. A deep convolutional neural network (DeepCNN) is used for brain tumor detection. The training is carried out using the integrating of Whale Optimization and HHO algorithms (WHHO). A variant of the HHO algorithm is used for collecting the most informative features regarding the mammography in (Hans et al., 2020). The HHO algorithm is integrated with Support Vector Machines (SVM) and the k-Nearest Neighbors (k-NN) in (Houssein et al., 2020a). The two methods HHOSVM and HHO-kNN are used for chemical descriptor selection and chemical compound activities. A hybrid HHO algorithm in (Houssein et al., 2020b) is used with two operators: cuckoo search (CS) and chaotic maps. The support vector machines (SVMs) are then used by the proposed CHHO–CS as an objective function for the classification process. The CHHO–CS-SVM is tested in the selection of appropriate chemical descriptors and compound activities.

3.7 Network Applications

A new model based on hybrid HHO and salp swarm (HH-SS) optimization algorithm is proposed in (Srinivas and Amgoth, 2020). The main motivation is to increase the lifetime of the wireless sensor network (WSN) using energy-efficient optimization methods. The hybrid HH-SS algorithm is utilized to select a single cluster head after dividing the WSN into a set of clusters using the K-medoid clustering approach. In (Houssein et al., 2020c), the HHO algorithm is used to determine the location of the sink node in the large-scale wireless sensor network (LSWSN). The sink node is responsible to collect and process the information from the sensor node and control the entire network. Hence, determining the position of the sink node will affect the lifetime of the network. The HHO algorithm in (Diaaeldin et al., 2020) is used to solve the mixed-integer nonlinear programming problem (MINLP). The proposed method reduced the total active losses by 21.428%. In (Abdel-Basset et al., 2020b), the HHO algorithm is used with the local search (HHOLS) as an energy-aware method for task scheduling in fog computing (TSFC) to enhance the service provided to users in the industrial internet of things (IIOT) applications. The HHO algorithm is used for the first time to solve Intelligent Reflecting Surface (IRS) network optimization problem in (Huaqiang et al., 2020). In (Bhat

and Venkata, 2020), the HHO algorithm is used to solve the localization problem with area minimization (HHO-AM). The HHO algorithm in (Singh and Prakash, 2020) is used in the hybrid fiber-wireless (FiWi) access network to determine the optimal placement of Optical Network Units (ONUs) in FiWi network. The results show the superiority of the HHO algorithm over other algorithms.

3.8 Engineering

A new method based on the HHO algorithm and first-order reliability method (FORM) is proposed in (Zhong et al., 2020). HHO-FORM is used to solve the high-dimensional reliability problem. The HHO-FORM is evaluated based on three numerical high-dimensional problems and two high-dimensional engineering problems to test its performance. In (Barshandeh et al., 2020), the HHO and artificial ecosystem-based optimization (AEO) algorithms are hybridized. The performance of the proposed method is studied on constrained/unconstrained real-life engineering problems. A fault diagnosis method for the rolling bearing is proposed in (Shao et al., 2020). The new method is based on integrating variational mode decomposition (VMD), time-shift multiscale dispersion entropy (TSMDE), and support vector machine (SVM) optimized by vibrational Harris hawks optimization algorithm (VHHO). The HHO algorithm has been proposed to achieve optimal parameters of a PID controller for aircraft pitch control system in (Izci et al., 2020). In (Nalcaci et al., 2020), the HHO is used for harmonic elimination in a traction motor drive based voltage source inverter. It is applied to a two-level, three-phase inverter to solve the equations. The proposed method has higher accuracy and convergence than the grey wolf optimizer (GWO). The authors in (Ekinci et al., 2020) applied the HHO algorithm to tune a PID controller for the regulation of the speed of a DC motor. The proposed method is used to minimize the integral of time multiplied absolute error (ITAE) and obtain optimal parameters of the PID controller.

3.9 Image Processing

In (Jia et al., 2020), pulse coupled neural network (PCNN) is used for image segmentation. HHO is used to search simplified PCNN parameters to reduce the number of parameters without affecting the segmentation effect. Then, image entropy (H) and mutual information entropy (MI) are used as fitness functions. In (Wunnava et al., 2020), a modified HHO algorithm is used as a maximization search algorithm for the segmentation of images. It is used to obtain the optimal threshold values when the 2D grey gradient (I2DGG) multilevel thresholding method is applied. In (Shahid et al., 2019), the HHO algorithm is used in combination with the thresholding function to obtain the best parameters of the thresholding function for image denoising in the wavelet domain. In (Golilarz et al., 2020), an improved version of the HHO algorithm called (CMDHHO) is used. HHO is assisted with differential evolution, chaos, and multi-population for satellite image denoising in the wavelet domain.

4 DISCUSSION

As reviewed earlier, the HHO algorithm has been adopted to address many optimization problems since it was proposed.The source codes of HHO and related supplementary materials are publicly available at http://www.aliasgharheidari.com/HHO.html, http://www.alimirjalili.com/HHO.html and http://www.evo-ml.com/2019/03/02/hho. The simple structure, few parameters, and adaptive and time varying search are the essential issues for the wide-spread usage of this algorithm. However, it has several limitations and suffers from some shortcomings. The advantages of the HHO algorithm include:

- There is a single control energy parameter E which plays a vital role in balancing the exploitation and exploration of the algorithm
- Solves a variety of complex problems
- Simple structure
- Easy to implement
- The adaptive and time-varying parameters allows HHO to overcome difficulties of a search space such as local minima

The disadvantages of the HHO algorithm include:

- Immature balance between exploitation and exploration
- Can't guarantee that it will not fall into the local minima trough the process of searching.
- The performance of the HHO decreases when increasing the dimensions of the problem
- Slow convergence
- Low diversity
- Exploration ability (single search method) is weaker than its exploitation ability

5 CONCLUSION

In this survey, over 100 research papers are collected about the HHO algorithm. The main goal is to study, analyze, and discuss the main features, advantages, disadvantages of the HHO optimizer as a new meta-heuristic optimization algorithm. This review summarizes references published after the development of the HHO algorithm in 2019 until the beginning of 2020 (December- 2020). Most of these papers described the variants of the HHO algorithm to tackle different optimization problems. Furthermore, discusses the applications of the HHO algorithm in various domains. The HHO algorithm has been widely adopted to solve various optimization problems. However, there is still room for improvement to enhance its performance. The HHO could be further hybridized, modified, and improved. In future work, we will cover the following perspectives:

- Using the HHO to solve optimization problems, especially multi-objective optimization problems.
- Hybridizing the HHO with other algorithm trajectory and population-based algorithms.

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