ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20240809124430

Subject review
Received: 2024-08-09, Accepted: 2025-09-30

Transient Applications and Insights to Whale Optimization Algorithm

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Abstract: Whale Optimization Algorithm (WOA) is meta-heuristic nature-based optimization algorithm inspired from bubble-net hunting strategy behavior worn by humpback whales. The algorithm has been used to resolve problems in many categories. An insight to the available datasets, tools, comparison techniques and recent trends has not been elaborated comprehensively. Therefore, this work is conducted to get more updated and insightful information on how different problems are getting solved with applications, modifications, enhancement and hybridization of WOA with others. The work presents an insight to the recent publication trends, along with details of all the datasets used for testing various WOA applications. In addition, the tools used and the probable comparison techniques have all been listed along with the WOA version used to solve the problem. This would help the researchers in using the appropriate form of WOA for solving their problems. As per the findings, Whale Optimization Algorithm has been successfully employed in many areas of engineering to find optimal solutions.

Keywords: Applications of Whale Optimization Algorithm; Improved Whale Optimization Algorithm; Modified Whale Optimization Algorithm; Survey/Review; Whale Optimization Algorithm

1 INTRODUCTION

Whale Optimization Algorithm (WOA) [1] is a search-based nature-inspired optimization algorithm adopted from bubble-net chasing strategy worn by humpback whales. It was developed in 2016 by Mirjalili & Lewis [1]. WOA is basically a clustering-based clever calculation put forward for sustained optimization issues. It has demonstrated to show prevalent execution besides other meta-heuristic methods. It is simple in execution and powerful so that it persists comparable to diverse nature-inspired algorithms. The calculation requires lesser control parameters nearly, as it has been a solitary parameter (time interval) must be fine-tuned. In WOA, the populace of humpback whales appears via a multi-dimensional exploration region for nourishment as regarded within Fig. 1. The regions owned by humpback whales are explored to diverse factors, whereas the take away amongst the humpback whale entities and the nourishment compares to esteem of goal fetched.

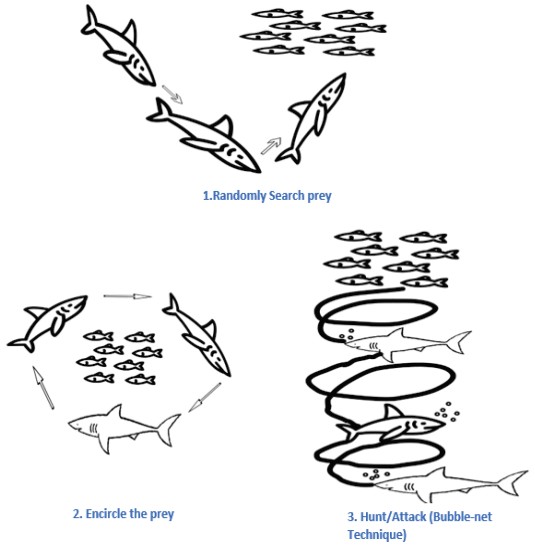


Figure 1 Visuals showing WOA

The time-based region of a whale is computed via the operational procedures: Encircling the prey, Bubble-net attacking stage and Search for the prey (Fig. 2).

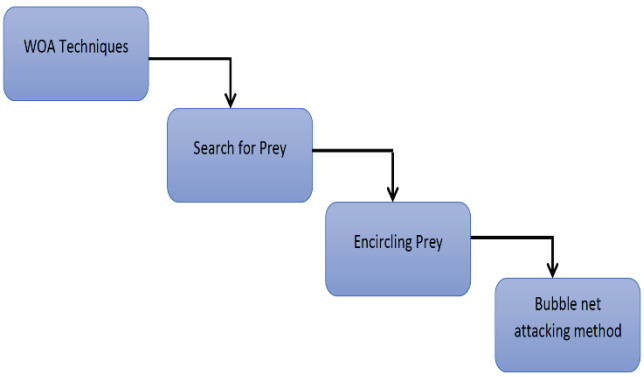


Figure 2 WOA Techniques

1.1 WOA Techniques

This section elaborates the technique used in WOA.

1.1.1 Encircling the Prey

Humpback whales are able to understand specified area of prey and then encircle those. Because location of ideal plan within the look area isn't recognized inferably, WOA supposes that present finest nominee arrangement is goal prey otherwise nearest of ideal. Then exertion is used in order of recognizing finest look operator, whereas alternative look operators will replace their positions close to the leading look operator. The conduct is communicated via the taking after conditions as expressed through equation below.

$$D = \left| \vec{C} \times \vec{X}'(t) - \vec{X}(t) \right| \quad (1)$$

$$\vec{X}(t+1) = \vec{X}'(t) - \vec{A} \times \vec{D} \quad (2)$$

$$\vec{A} = 2 \times \vec{a} \times \vec{r} - \vec{a} \quad (3)$$

$$\vec{C} = 2 \times \vec{r} \tag{4}$$

Here X is common best location X^* presenting whale location, t indicates the later cycle, a speaks to linearly decreased inside run of two to over the course of iterations, and the r may be an irregular number consistently allotted in the run of [0, 1]. The sign | | speaks to the utter value.

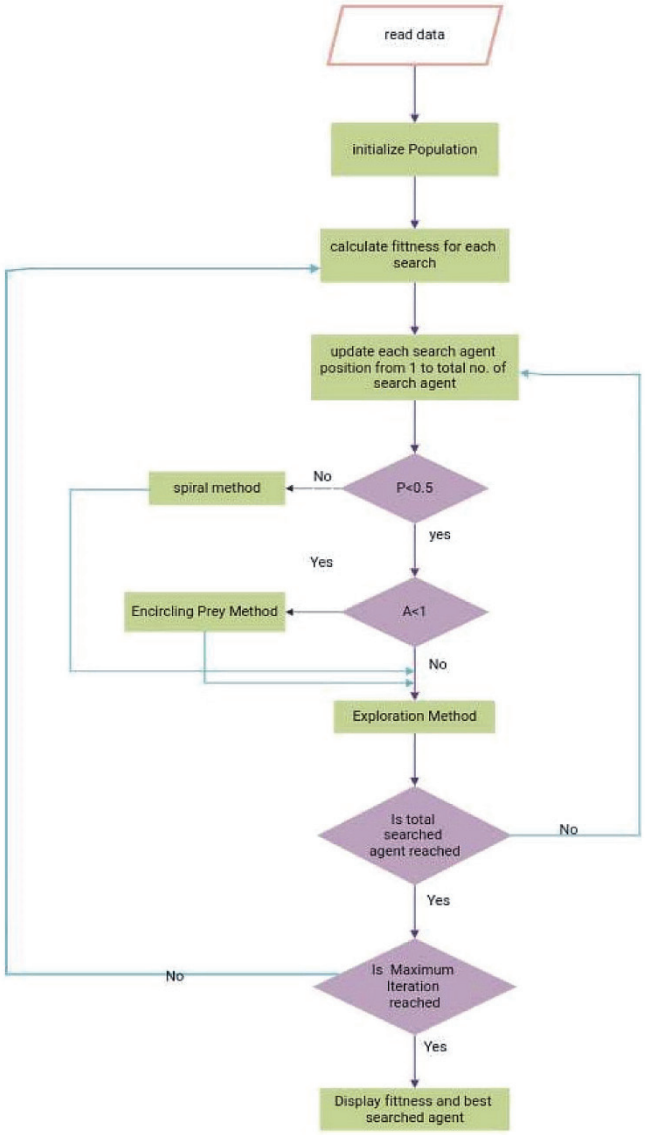


Figure 3 Flowchart for WOA

1.1.2 Bubble-net Attacking Technique (Manipulation Section)

Towards defining the bubble-net conduct about humpback whale, winding scientific definition remains connected among location of prey and whale in-order of mimicking the twirl-formed motion of humpback whale, within which p speaks to a steady for clarifying the form of the exponential winding and the k is self-assertive value uniformly distributed within extend of [–1, 1].

$$\vec{X}(t+1) = \vec{D}^n \times e^{bl} \times \cos(2\pi l) + \vec{X}' \tag{5}$$

$$\vec{X}(T+1) = \begin{cases} \vec{X}'(t) - \vec{A} \times \vec{D} \text{ if } p \geq 0.5 \\ \vec{D}'' \times e^{bl} \times \cos(2\pi l) + \vec{X}' \text{ if } p \geq 0.5 \end{cases} \tag{6}$$

1.1.3 Search for the Prey (Exploration Section)

To get worldwide optimizers, on the off chance that $A < -1$ or $A > 1$, search agent gets upgraded like expressed by a haphazardly selected search agent within the posit of leading look operator (Fig. 3). Where X is designated subjectively from whales in the current cycle.

$$\vec{D} = \left| \vec{C} \times \vec{X}_{\text{rand}} - \vec{X} \right| \tag{7}$$

$$\vec{X}(t+1) = \vec{X}_{\text{rand}} - \vec{A} \times \vec{D} \tag{8}$$

1.2 Time Complexity

The very interest in the WOA approach is driven by the fact that it is a search -based approach using random inputs. The same is observed for real whales also. Due to this, the result generated by the WOA approach may differ every time the algorithm is run. The WOA is thus a randomized-approximation algorithm used to solve NP-complete combinatorial optimization problems (problems whose optimal solution cannot be found in polynomial time due to the vastness in probable search space). Hence, the result generated is not guaranteed to be the best, yet is much better than any other random result. The justification for using an approximation approach comes from the time taken by the algorithm.

1.3 Whale Optimization – The Approach

1. Initialization – Wi digital whales are created ($1 \leq i \leq n$)
2. Compute fitness for every whale on food search
   Let W* be the best search Whale
   While (i < Total_no_of_iterations)
   For each Wi: update the parameters l, L, M, N and P
      If ($p < 0.5$)
      Then if ($|L| < 1$) then Compute Position of Wi using Eq. (2)
      else if($|L| \geq 1$)
         Choose random Wi
         Compute Position of Wi using Eq. (8)
         Else if ($p \geq 0.5$)
         Compute Position of Wi using Eq. (5)
   If any Wi goes outside the searched space, then correct its path
   Compute fitness for every Wi.
   Recompute W* for whale with best fitness (if better than before)
   $I = i + 1$
   End While loop
   Return optimum answer (W*)

There are only 2 loops in the WOA approach as given in the previous section. Hence the complexity is clearly a

product of '*N*', the number of whales, and total number of iterations (*NI*). Henceforth the complexity of WOA approach is ***O*(*N.NI*)**, which is polynomial time and very quick as compared to other approaches.

This work contributes in the following ways:

- Comprehensively providing insight to the available datasets, tools, comparison techniques and recent trends of employing WOA to various engineering problems.
- Providing a taxonomy of various kinds of applications to which WOA has been applied.
- Assessing and analyzing the results of applying WOA to various optimization problems.

Outline: Section II discusses the related work. Section III explains the transient applications of WOA. Section IV and V investigate the results and conclusion respectively.

2 RELATED WORK

WOA has been adopted for solving problems in various fields. Although, there exists some other survey papers as well. Some of them are Comprehensive survey [2], Meta-analysis survey [3] [4]. These survey papers have also, included many applications of WOA in various fields. In Addition, this paper gives more relevant information based on the type of methods used (New, Modified, Improved); Year of Publish; Method Problem; Dataset Used; Tool used; Compared with.

2.1 Research Procedure

A complete inquiry about technique was espoused for investigating articles present on WOA which had been distributed in famous logical records. The articles ensued elected by backward sifting prepare as per characterized set of measures, which navigate through four phases appeared in Fig. 7. At last, significant articles were concluded based on exclusion and consideration measures for the audit reason

2.1.1 Keyword-Based Article Search

Watch word aspect handle was exhausted two steps. In the initial step, greatest number of reports were recovered from the foremost important records utilizing the succeeding keyword: 'Whale Optimization Algorithm', 'WOA', 'Reduction encompassing prey', 'modified WOA' [2], 'enhancement of WOA', 'hybrid plus WOA', etc. Within next moment walk, a record sifting handle was executed to avoid insignificant reports. Subtle elements of categorizing prepare can be found in Orders. 4.4 and 4.5 'Assortment criteria' and 'extraction of the data' individually**.**

2.1.2 Search Strategies

The order to search to closely all spaces, anywhere WOA was performed. The article from all present trustworthy online records were looked, and after that thorough handle of confirmation for references and citations within the papers confirmed the determination as it was high characteristic peer-assessed articles. Besides, proximity of articles within diverse fields former building and computer discipline were also reserved into thought for the consider.

2.1.3 Database Selection for Research

Examination deliberates utmost of true publisher's records accessible online like on: ACM, ScienceDirect, IEEE Explorer, Springer. Tab. 1 keeps up sum of records reverted as of the over said databases. In order to supply substantial evidence of the fast development to investigate on the WOA, Fig. 4 comprises the total of articles distributed every year through the related publishers. Fig. 5 underpins the equivalent with graphic illustration of percent of articles grounded on publishers. IEEE, Elsevier and Springer were the databases in which maximum chosen articles on WOA were found to be published. Fig. 6 increases the confirmation by showing publisher-based percentage of the significant articles. Also around 30% of the papers were found to be published in databases other than the IEEE or Springer or Wiley or ACM. Surge in other publication houses other than the traditional ones could be one major reason behind this.

Table 1 WOA in general Academic Records

Online Databases	Article Returned
IEEE	151
Springer	145
Elsevier	143
Wiley	39
ACM	21
Others	208

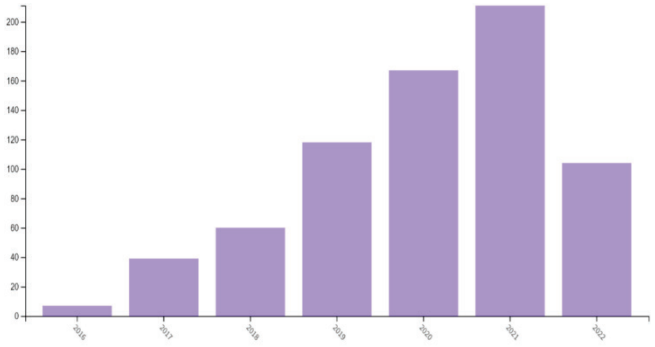


Figure 4 Number of Publications/Year

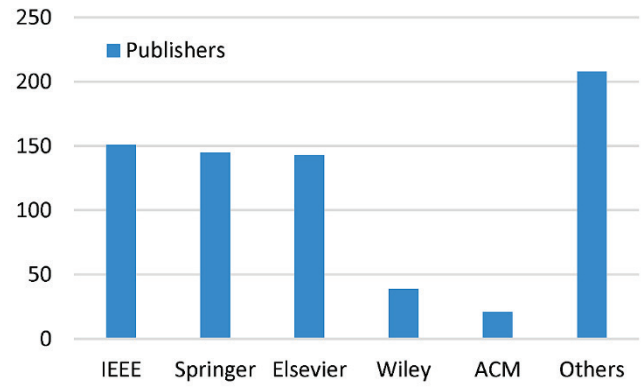


Figure 5 Sum of Articles by Publishers

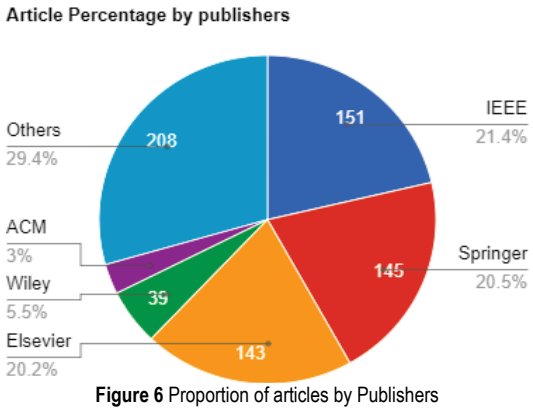


Figure 6 Proportion of articles by Publishers

2.1.4 Article Assortment Criteria

Article assortment criteria was set to integrate foremost appropriate documents and dispose of insignificant amongst them. A scrupulous way of examination was taken after to categorize related articles coordinating towards the goal were seen. At that point a careful perusing investigation was executed on titles, abstracts and conclusions in order for casting the chosen articles for additional processing (Fig. 7). In expansion, sifted articles were systematically reviewed to authenticate the suitability of articles for the purposes of this assessment. At last, foremost pertinent articles stood encompassed for this survey.

2.1.5 Mining of Data

Thorough information mining prepare was accomplished upon articles headed for dodge repetition in data. A complete record of information hence recovered from databases was sustained into a exceed expectations spreadsheet (woasurvey.xlsx). Formerly, numerous classification forms were executed upon data like application allied classification (areas and sub parts of areas), method allied classification (Alteration, Hybridizing and Multi-impartial, etc.), year allied classification.

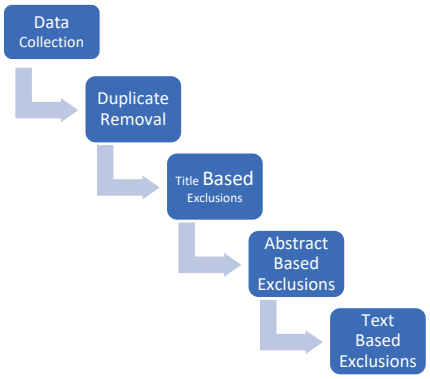


Figure 7 Inclusion Criteria

3 APPLICATIONS OF WOA

Scholarly works has appeared a few regions of the application of WOA to cope with actual-world issues. Maximum of the studies examined its execution with different standard meta-heuristic besides unique old-style optimization strategies. Also, applications of WOA are rising speedily in numerous orders owing to its proficiency and simply versatile highlights. Here, we portray the pertinency of WOA within totally diverse extents, and sub extents of building areas by means of the most purpose of this review. Mainly, applications of WOA are categorized in five key areas and numerous subfields and display scientific categorization within Fig. 8.

WOA has majorly been applied to 5 broad categories including Electrical Engineering, Computer Engineering, Applied Mathematics, Aeronautical Engineering and Construction Engineering. Out of these the major applications can be found for applying WOA in solving various computational problems.

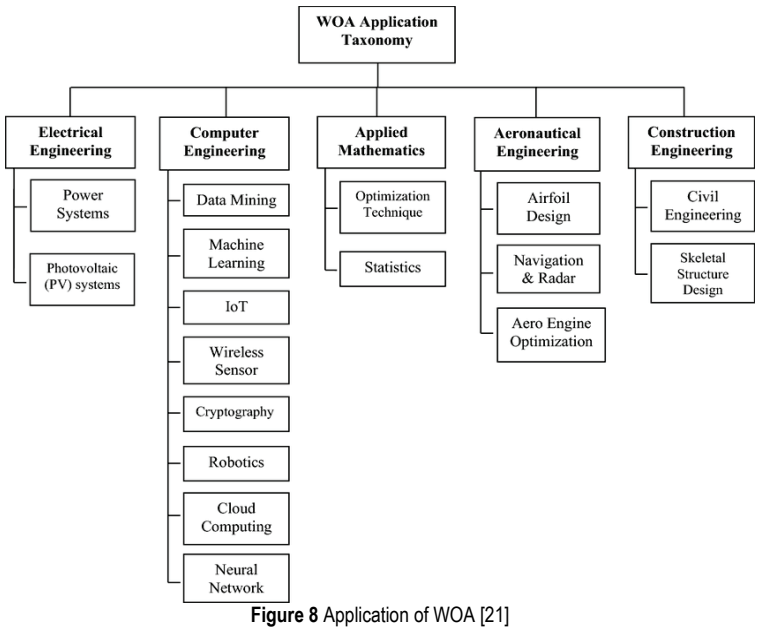


Figure 8 Application of WOA [21]

Table 2 Application Analysis of WOA

Link	Technique	YOP	Application Area	Problem	Proposed Method	Dataset Used	Tool Used	Comparison
[6]	Improved	2019	Computational Engineering	0/1 Knapsack problem	Opposition-based Whale Optimization Algorithm (OWOA)	Twenty cases of Knapsack problem,	MATLAB R2016a	OBL with WOA, (CGMA) and HS-Jaya
[7]	Proposed	2022	Cloud Computing	Privacy-protected data publishing in cloud computing	Brain storm-based Whale Optimization Algorithm	Chess T10I4D100 K, and the retail databases	-	-
[8]	Proposed	2021	Neural Networks	Enhancing Neural Networks	A New Harris Hawk Whale Optimization Algorithm	Cancer datasets and other datasets like fraud, banking note authentication.	-	-
[9]	Improved	2018	Machine Learning	Feature Selection of Network Intrusion Detection	Improved Binary Whale Optimization Algorithm	UCI database, KDD CUP 99 data set	-	Genetic Algorithm (GA), PSO and WOA,
[10]	Improved	2020	Neural Networks	multi-layer perceptron neural network training	Teaching learning-based whale optimization algorithm	Fifteen UCI benchmark datasets	-	GOA, GSO, SSO, FPA, GA and WOA
[11]	Modified	2020	Machine Learning	Feature Selection in Micro Array Cancer Dataset	Modified Whale Optimization Algorithm	Microarray datasets (Leukamia, Lymphoma, Prostate)	-	Classification models using SVM, NB and KNN with PSO algorithm
[5]	Proposed	2017	Machine Learning	Wrapper feature selection	WOA approaches for wrapper feature selection	Eighteen UCI benchmark datasets	MATLAB	Particle Swarm Optimization (PSO), Genetic Algorithm (GA), the Ant Lion Optimizer (ALO), and five standard filter feature selection methods
[12]	Proposed	2020	Computational Engineering	Enhance Software Project Effort Estimation	Exploring WOA to Enhance Software Project Effort Estimation	NASA 93	-	-
[13]	Improved	2021	Applied Mathematics	Constrained Optimization Problems	Improved Whale Optimization Algorithm	Single-modal functions and complex nonlinear multimodal functions	-	Comparision with Basic WOA
[14]	Proposed	2021	Machine Learning	Efficient high-dimensional feature selection approach	Spatial bound whale optimization algorithm	16 high-dimensional datasets gathered from Arizona State University (TOX_171, Colon, and Prostate_GE)	-	Eight state-of-the-art feature selection methods
[15]	Proposed	2018	Applied Mathematics	Maximum flow problem	WOA for solving Maximum flow Problem	-	MATLAB	Average run time and the accuracy of the results with ford-fulkerson Algorithm
[16]	Proposed	2017	Machine Learning	Feature Selection	Feature Selection approach based on WOA	Sixteen UCI benchmark datasets		particle swarm optimization (PSO) and genetic algorithm (GA)
[17]	Modified	2020	IoT	Control of switched reluctance motor	Cosine adapted modified whale optimization algorithm (CamWOA)	Unimodal benchmark functions	MATLAB/SIMULINK	WOA, WCMFOA, ABCA, GA, PSA, GS, CS, GSA, Hybrid PSOGSA, WCA, MFOA, DA
[18]	Improved	2021	Power Systems	Optimize the cascade reservoir power generation	Adaptive weights and differential mutation perturbation factors (APWOA)	Sphere, Griewank, Rastrigin, Ackley	-	WOA performance testing, APWOA, PSO, linearly decreasing weight PSO
[19]	Proposed	2019	Wireless Sensor Networks	Discover communities in networks	Whale optimization based community detection algorithm (WOCDA)	Karate, Dolphins, Polbooks, Football, Jazz, Elegans, Email, Facebook Networks	-	DPSO, iMeme-net, BA, AFSA
[20]	Proposed	2021	Computational Engineering	Enhance Apache Spark's computational performance	Spark-based parallel processing whale optimization algorithm	Alpine, Ackley, Sphere, and Schwefel Benchmark functions	AmazonWeb Services Elastic MapReduce (EMR)	MapReduce WOA (MR-WOA), and serial implementation of WOA; Nonparametric Wilcoxon's signed rank sum test

Tab. 2 summarize the gathered details about various studies analyzed for using WOA. As represented in Fig.8, many applications of WOA were used for solving computational engineering problems [5, 7-13, 15, 17, 21].

Few applied mathematics problems were also solved using WOA [14, 16].

It can also be observed that 12 different versions of WOA have been utilized (as listed in Tab. 2) based on the improving the existing WOA algorithms or utilizing a hybrid version by combining with some other technique. All of the applications have been tested on different datasets (Tab. 2) due to the difference in the very problem statement being solved using WOA. As per the tools used, majorly MATLAB has been utilized for the coding and analysis purposes as mentioned in the reviewed studies.

4 RESULT AND DISCUSSION

The current research led to the observation that WOA is already utilized within nearly every general field of building space aimed at measuring complex optimization issues. The prejudice of the search-based WOA like swarm insights optimization method is speedily expanding amid the scholarly community and businesses meanwhile its beginning. By means of the results gathered from the current research, the application of WOA is anticipated to be more developed in assorted other pertinent areas of designing further stated within this study (electrical as well as control system, computer building, aircraft building, and construction coaxing). A few adaptations of WOA grounded techniques are created via analysts throughout the globe in far along former to address various engineering optimization issues like binary-based technique, feature selection, and disapproval-based learning means.

Amid studied work, feature selection-based and disapproval-based learning strategies were foremost predominant methods attained within writing aimed at understanding advanced optimization issues.

WOA is used in the field of Neural Network to enhance masses and the prejudice of a neural network. Also, proposed algorithm is used in diverse kind of datasets like cancer, deception, investment memo authentication [8].

Proposed protection conservation demonstration was implemented particularly for cloud segment [7]. The projected prototypical intricate two fundamental phases: information decontamination then renovation through an ideal key creation. The ideal key remained augmented by means of proposed J-SSO calculation via determining a multi-intentional role amongst the constraints just as degree for adjustment, data conservation proportion. Whereas bearing in mind the level of expansion, search-based calculations for resolving privacy conservancy issue with taking care of various information, PSV-GWO faces bad neighborhood-looking capacity and moderate merging.

5 CONCLUSION

Transformation-based calculations were broadly examined search-based calculations in designing spaces to espouse optimization issues. Fast development of intelligent search-based calculations in later years enthused the analysts towards investigating pertinence within multidisciplinary areas. Within the similar vein, our survey attempts to sightsee the possibilities within recently created search-based WOA over an orderly prose review. Research is based on WOA: applications within diverse disciplines, alterations, and crossings, to confront different combinations for optimization issues. In spite of the reality that outset of this calculation is very current, its overpowering development completely diverse regions is rather self-evident. The larger part of articles checked on in this contemplate is focused on, the applications of calculation, modification-based tactic to an arrangement, cross breed strategy of a solution thru combining other strategies or calculations, and constraint enhancements. Be that as it may, there's chamber for change in calculation to unravel multi-dimensional and multimodal difficulties. Additionally, binary-based, feature selection based, choice-based require a part of effort hours within upcoming research to illuminate multifaceted optimization issues over WOA. An update of multi-intentional strategy by means of alternating the single-intentional constraint to multi-intentional constraints through same calculation may be additional exhilarating range of enhancements worth investigating.

A key parcel of works examined within this survey is towards resolving the worldwide optimization issue in excessive dimensional region. However, supplementary multifaceted perspectives, like ideal switch problem utilizing parallel mathematical strategy, disordered sequence issue, different backpack issue, multi-class SVM issue, stage stream shop issue, obligation issue, repetition assignment issue, and many additional, can be occupied into consideration for encouraging research track. This audit examines the applications of WOA within different areas and sub parts of engineering fields aimed at tackling optimization issues. This paper unlocks way for investigating additional intriguing and multi-disciplinary arenas that can be tattered by the smoothness of WOA.

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