



A Review of Glowworm Swarm Optimization Meta-Heuristic Swarm Intelligence and its Fusion in Various Applications

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Abstract

Natural phenomena inspire the meta-heuristic algorithm to carry out the aim of reaching the optimal solution. Glowworm swarm optimization (GSO) is an original swarm intelligence algorithm for optimization, which mimic the glow behavior of glowworm that can effectively capture the maximum multimodal function. GSO is part of the meta-heuristic algorithm used to solve the optimization problem. This algorithm solves many problems in optimization, especially in science, engineering, and network. Therefore, this paper review exposes the GSO method in solving the problem in any industry area. This study focuses on the basic flow of GSO, the modification of GSO, and the hybridization of GSO by conducting the previous study of the researcher. Based on this study, the GSO application in the engineering industry gets the highest score of 15% among other sectors.

Keywords: Meta-heuristic; swarm intelligence; glowworm swarm optimization; multimodal function; optimization.

1. Introduction

Nowadays, many researchers implement the optimization problem with the meta-heuristics approach to find a solution. Optimization is a process of making the best effective result in solving problems. When constraints are enabled, any task, including discovering unknown parameter values, can be classified as an optimization problem [1]. Some fundamental issues, such as issues with apparent answers or no decision variables, do not require formal optimization. However, in most circumstances, a mathematical solution is required, and the goal is to get optimal results. The majority of problems in the technology are involved with some optimization technique [2]. The goal is to lower the expense and risk of a situation. It may also have many goals and involve making several choices to solve the problem.

Hence, the most common challenges in engineering design in large-scale constrained optimization problems, and meta-heuristic algorithms are used to resolve such challenging issues. The evolution of meta-heuristic algorithms demonstrated an impressive ability to solve various optimization problems in engineering systems and science [3]. Furthermore, meta-heuristic algorithms address issues by delivering near-optimal solutions in an acceptable time [4]. Meta-heuristics have exploded in popularity recently because of their efficiency and effectiveness in tackling large and complex optimization problems. Therefore, this review paper will introduce GSO and hybridize it with other meta-heuristic algorithms for solving the optimization problem.

Krishnanand and Ghose introduced glowworm swarm optimization (GSO) in 2005. The GSO algorithm is inspired by glowworm behavior. Glowworms' behavior pattern is the apparent capacity to change the intensity of luciferin emission and appear to light at various intensities. Hence, the higher the luciferin emitted by the glowworm, the

higher the attraction to another agent (glowworms that carry luminescence) in the glowworm for mate purposes. Also, luciferin attracts other insects for food and warns the predator. Glowworm commonly refers to the larvae of fireflies, also known as lightning bugs. GSO is a Swarm Intelligence (SI) technique for optimizing multimodal functions created by mimicking glowworm activity [5]. The SI algorithm is used to solve the complexity of optimization problems. Therefore, the GSO has been recently used in solving optimization problems in many areas, such as the engineering industry [6], the network industry [7], and science [8].

The GSO approach shares similarities with other well-known swarm intelligence-based optimization algorithms, such as ant colony optimization (ACO) and particle swarm optimization (PSO). Still, it also has some notable distinctions [9]. Lately, the GSO algorithm has been used to search for capturing the multiple optimal of a multimodal function with different values of objective function [10]. Oramus et al. [11] stated that to identify the multiple optimal solutions, the agents must be able to split into different subgroups, or else only one optimum result will be found. In practice, the agents will swap information locally with non-deterministic movements. For example, the GSO has been implemented in many areas to solve the optimization problem. Izzat et al. [25] carried out an experiment on GSO for cloud computing by using GSO. This study suggests a new task scheduling technique, and the proposed technique seeks the optimum mapping to reduce job execution time in cloud computing. At the end of the study, the GSO will be compared with the First come, first serve algorithm (FCFS). They found that GSO performs well in executing the time of cloud job. The GSO produces lower time consumption than the FCFS algorithm. Hence, the GSO performs well in reducing the time consumption in cloud computing.

On the other hand, Surender Reddy et al. [29] devised the project of the GSO for congestion management. The project uses multi-objective GSO (MO-GSO) to solve the problem of congestion management, where the issue contains more than two objective functions and need to be optimized. The researchers' main objective is to minimize the total cost of congestion rental in the system and minimize the total transmission losses in the system. As a result, the researchers concluded that MO-GSO congestion management had been solved with the MO-GSO algorithm.

Liang et al. [26] presented a study using GSO to investigate the mechanical servo system in LuGre friction. The researchers begin with an introduction to the mechanical servo system and the challenge in friction compensation systems. The article presents the experimental result of the proposed method with an adaptive controller (AC + GSO) and compares the result with an adaptive controller (AC). The result of the study shows the proposed method gives an effective solution in mechanical servo systems and has the potential for real-world application in industrial control systems.

Yunping Chen et al. [27] explored the GSO to identify air pollution sources using remotely sensed aerosol data. The authors use satellite technology to measure aerosol concentration and use the GSO algorithm to identify the air pollution many industries produce. This paper showed that the GSO algorithm could monitor and control air pollution more effectively in real-world environment management.

Pushpalatha k et al. [30] have presented an experimental clustering algorithm based on the GSO algorithm for multimedia documents. The article begins with the challenge of clustering multimedia documents and the need for an efficient clustering algorithm. Therefore, the authors proposed a GSO-based multimedia document clustering (GSOMDC) algorithm in this article. Overall, the researchers found that the GSOMDC can be used for clustering multimedia documents, and the proposed method has the potential to be applied in various multimedia applications. The authors also claim that the method can be improved the effectiveness and accuracy based on different applications of multimedia application for further study.

Shifei Ding et al. [33] performed a study using the GSO algorithm to overcome the wavelet twin support vector machine (WTWSVM) problem and optimize the parameters of WTWSVM using GSO. In this paper, the authors proposed GSO with WTWSVM (GSO-WTWSVM). In the article's introduction, the authors begin with the need for effective machine learning for classification problems and a brief overview of the SVM algorithm. However, the authors claim that the WTWSVM is ongoing, and GSO-WTWSVM is used to handle parameter selection problems in WTWSVM. The authors also claim that the GSO-WTWSVM are used to identify optimal solutions and in GSO have a drawback easily trapped into local optimum. Therefore, in this study, the authors will overcome the drawback of GSO, and for further work, the authors are going to implement the improved GSO with WTWSVM.

Therefore, this review paper focuses on identifying which sectors most implement the GSO and provide a comprehensive overview of GSO. This paper's contribution is to explain the GSO algorithm and its underlying principle, including its mathematical formulation and update rules. Second, this paper will highlight its strengths and weaknesses and discuss its potential application in various field industries, such as engineering, network, etc. Additionally, this paper provides insight into previous researchers in developing the hybridization and enhancing the GSO algorithm. This paper offers valuable resources for researchers interested in using GSO for optimization problems.

The general structure of this paper will be described in five sections. The first section explains the introduction to this paper and a remark section highlighting the significance of the GSO algorithm in solving an optimization problem, its drawbacks, and the strength of the GSO algorithm. The second section will be about the overview of the GSO algorithm. The third section will explain the modification and hybridization of the GSO algorithm based on previous research. The fourth section will highlight the remark on the empirical evidence from various researchers in using the GSO to solve the optimization problem. Finally, the results and findings will be explained in section 5, along with a conclusion of this study.

2. Glowworm Swarm Optimization

The GSO algorithm's mechanism is inspired by the natural glowworm features in which a glowworm is drawn to other brighter glowworms. The GSO method is a swarm intelligence-based (SI) technique for optimizing multimodal functions created by mimicking glowworm activity [5]. Swarm intelligence algorithms are used to solve complex optimization problems that are difficult or impossible for the traditional method to solve. Some SI algorithm has several advantages and disadvantages when applying SI. Walking across the meadows at night, we might see glowworms that light up the night with bright flashes and can be seen from a long distance. Each glowworm carries a luminescence quantity called luciferin along with them. Therefore, each glowworm releases a light during the night or inside the cave. Each glowworm will interact with one another in a changeable neighborhood bounded by a sensor range and decision range [12]. Because the nature of glowworms is to seek the brighter luciferin for a mate and prey purposes, therefore the glowworm will always move around their neighborhood.

Other than that, a glowworm will recognize another glowworm as a neighbor by employing a probabilistic technique placed within the current local decision domain. Therefore, the glowworm will decide based on the information available inside their neighborhood. The nature of glowworm inspires the GSO algorithm, which is divided into three key phases, luciferin-update phase, movement phase, and neighborhood range update phase [13].

This section will explain the detail of every phase in GSO. Figure 1 shows the GSO flow process, which consists of three significant phases: the luciferin-update phase, movement phase, and neighborhood range update phase.

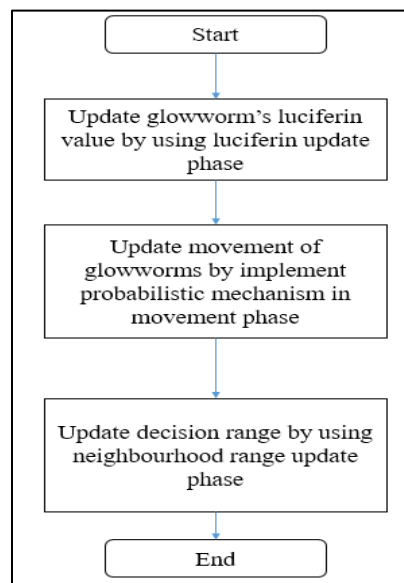


Figure 1: The flowchart of the GSO algorithm [13].

The function value based on glowworm location affected the luciferin update phase. To update its luciferin level, each glowworm adds the previous luciferin value to the luciferin quantity, which is proportional to its current location's fitness. To imitate the decay of luciferin over time, a fraction of the luciferin value is deducted. The luciferin of glowworm is updated by following equation (1), and the rules are given by [12-17].

$$l_i(t + 1) = (1 - \rho)l_i(t) + yJ(x_i(x + 1)) \quad (1)$$

Where $l_i(t)$ represents the luciferin level associated with glowworm i at time t , p is the luciferin decay constant ($0 < p < 1$), γ is the luciferin enhancement constant, and $J(x_i(t))$ represents the value of the objective function at agent i 's location at time t .

Based on the concept of GSO, the glowworm or the agent will attract their neighbor by moving around or toward their neighbor by finding a higher luciferin level compared to it. Furthermore, during this phase, the glowworm used the probabilistic mechanism to move toward their neighbor, who had higher intensity of luciferin.

$$N_1(t) = \{j : d_{ij}(t) < r_d^i(t); l_j(t) < l_i\} \tag{2}$$

Equation (2) is the set of neighbors of glowworm i at time t . $d_{ij}(t)$ represents the Euclidean distance between glowworms i and j at time t , and $r_d^i(t)$ represents the variable neighborhood range associated with glowworms i at time t . The variable is bounded by a radial sensor range ($0 < r_d < r_s$).

For each glowworm i , the probability of movement toward neighbor $j \in N_i(t)$ is given by equation (3).

$$P_{ij} = \frac{l_j(t) - l_i(t)}{\sum_{k \in N_i(t)} l_k(t) - l_i(t)} \tag{3}$$

Then, the discrete-time model of the glowworm movement can be stated as equation (4),

$$x_i(t + 1) = x_i(t) + s \left[\frac{x_j(t) - x_i(t)}{\|x_j(t) - x_i(t)\|} \right] \tag{4}$$

Where $s (> 0)$ represents the step size, $\| \cdot \|$ is the Euclidean norm operator. Then, $x_i(t) \in R^m$ represents the location of the glowworm i at time t in the m -dimensional real space R^m .

Equation (5) shows a neighbor range update phase used to detect the multiple peaks in a multimodal function landscape. Next, let r_0 be the initial neighborhood range value of each glowworm (i.e., $r_d^i(0) = r_0$, for all i). The following rule is used to update the neighborhood range update rule of each glowworm adaptively:

$$r_d^i(t + 1) = \min\{r_s, \max\{0, r_d^i(t) + \beta(n_t - |N_i(t)|)\}\} \tag{5}$$

Where β is a constant parameter and n_t represents a parameter being used to control the number of neighbors. Figure 2 shows the sensory radius and decision radius of glowworm i .

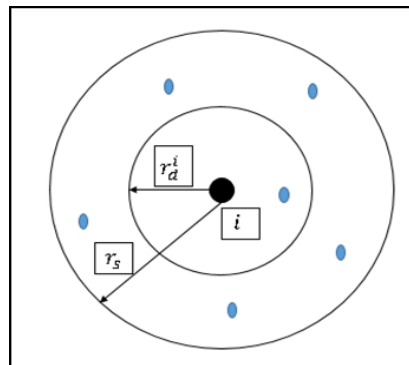


Figure 2: Sensory and decision radius of glowworm i [13].

Figure 2 shows the glowworm and r_s is the sensor radius. r_d^i is the initial neighborhood range that can be calculated at the neighborhood range phase. When the position of the glowworm i is updated, the neighborhood range phase is repeated to locate other glowworms in their range.

3. Modification and hybridization of GSO

3.1 Modified GSO

The modification technique of the meta-heuristic leads to minor changes in the algorithm's structure for solving any optimization problem. Therefore, the modification of GSO is used to adjust the process of standard GSO to achieve a better study result. Previous researchers were not just applying the basic algorithm but used to modify the basic algorithm to get better performance. Therefore, this section will discuss the modified GSO based on the researcher's previous work.

Li et al. [28] discussed the step size of GSO oscillating when the distance between a glowworm and its best neighbor is less than the real-time step size in (4). Therefore, the dynamic step size strategy in equation (6) is proposed to speed up the convergence speed in the early stages while improving calculation accuracy in the later stages of the search.

$$s(t) = \mu e^{-\psi t} + \xi \quad (6)$$

Where ψ and μ are positive factors, and ξ is a step minimum threshold.

If the initial step size in (6) is equal to or slightly more significant than the fixed step size in (4), the real-time step size (6) would be smaller than that in (4) at the end. Hence, the probability and amplitude of oscillation of the agent MGSO near the optimal solution would be much smaller than those of the standard GSO. When the parameter value in (6) is appropriately chosen, it can be ignored. Hence, the researchers got an excellent result in optimizing blind signal separation (BSS) by deploying MGSO. Other than that, the researchers strongly agree that the experiment result shows that the new modified GSO and Blind Signal Separation (M-GSO-BSS) has a more potent global search ability and faster convergence speed rate than Particle Swarm Optimization and Blind Signal Separation (PSO-BSS) and (GSO-BSS).

Other than that, another modified GSO was presented by Shukla et al. [37]. This paper proposed a modified GSO (M-GSO) to get better performance of the 3D unmanned aerial vehicle (UAV) path planning. The problem is identifying the most viable path between a source and destination while avoiding collisions in the underlying environment for mobile robotics. The authors have mentioned that the original GSO is only fit to be applied to an optimization function related to a continuous function. The researchers modified the luciferin update equation of GSO by using a hybrid genetic operator for reproduction and mutation to improve the basic GSO. As a result, the output of the researcher's studies successfully gives a better result by optimizing the route between the source and destination.

In recent days, there are still many researchers who are working on modifying and enhancing the standard GSO algorithm. Based on the articles reviewed, most researchers have modified the update phase of standard GSO and the step size of GSO to achieve convergence speed rate and performance. It is found that most researchers are modified by applying various types of techniques to achieve the objective study of researchers. Therefore, modifying the GSO algorithm is necessary to solve the optimization problem to produce a good performance and increase the algorithm's efficiency.

3.2 Hybridization Glowworm swarm algorithm

This section will discuss hybrid GSO applications in solving the optimization problem. The definition of the hybridization method in metaheuristic algorithms combines two algorithms. Besides that, the hybridization process in machine learning is the process of an algorithm or machine learning breeding with an individual of another machine learning [51]. Hence, the hybridization approach changes the entire individual algorithm with another algorithm. Therefore, the GSO will use other meta-heuristic algorithms or machine learning to solve the optimization problem.

Reddy et al. [51] used the hybridization of GSO and Ant Colony Optimization (ACI-GSO) to find the optimal cluster head (CH) for energy-efficient routing protocol in a wireless sensor network (WSN). The problem is to find a better network performance of WSN and prevent the WSN performance from network failure and energy depletion. Besides that, the hybridization process of this study is to solve the problem of selecting an optimal CH in each cluster. Furthermore, the authors used ACI-GSO to find a better global search and local search process of ACI-GSO. The hybridization process of the ACI-GSO model is during the range update phase of GSO, and the ACO update phase will be executed.

$$T(ij) \leftarrow (1 - p).T(ij) + p.\Delta T(ij) \quad (7)$$

Equation (7) is the pheromone update phase from the ACO model. Equation (7) will execute from the range update phase of the GSO model equation (5). The proposed algorithm of the studies is named ACI-GSO for the updating evaluation of ACO integrated with GSO. After the initialization of the glowworm, the luciferin value and location will be updated in the luciferin update phase in equation (1). After that, the second phase of GSO equation (2) will be executed. During the neighborhood range update phase, GSO will be changed into a pheromone update from the ACO model. The result found that the hybridization of ACI-GSO gives optimal CH energy-efficient routing protocol in WSN and gives a better result than GSO, ACO, and Particle Swarm Optimization (PSO) in terms of convergence speed.

Another hybridization GSO was produced by Chen et al. [32]. The GSO algorithm hybridization with a 2-opt algorithm was proposed to solve the three-dimensional traveling sales problem (TSP). The 2-opt was embedded into GSO to speed up the convergence speed rate of GSO. Moreover, the authors also make some improvements on basic GSO by transforming the carriers of the luciferin from the glowworm and modifying the probabilistic formula and luciferin update of the glowworm. As a result, the hybridization of GSO and the completed 2-opt algorithm perform well in finding optimal routes for solving three-dimensional TSP. Hence, based on the numerical result from researchers, the hybridization of GSO and completed 2-opt give a good performance and outperforms state-of-the-art algorithms for solving spherical TSP. The complete 2-opt algorithm overcomes the weakness of GSO, which is a low convergence speed rate.

Besides, D.Deepakraj et al. [54] proposed a hybrid GSO in wireless sensor networks. Harmony search (HS) and Tabu search (TS) were proposed to enhance the performance of standard GSO in solving the issue in wireless sensor networks (WSN). Moreover, the researchers implemented two-hybrid approaches: HSGSO and TSGSO. At the end of the study, the researchers will compare the value of HSGSO and TSGSO in a numerical cluster framed by the researchers. The study is to solve the network's lifespan in the WSN by reducing the energy consumption of the sensor nodes and, at the same time, reducing the data traffic of the sensor network. Hence, the hybrid GSO reduces energy consumption and data traffic among the sensor nodes. The hybrid approach is used to overcome the standard GSO drawback: reduced precision in later iterations, decreased convergence speed, and easy trapping in the optimal local solution. Consequently, the hybridization approach for HSGSO gives a superior value of cluster evaded by 64.15% and for TSGSO by 13.19%. Hence, the study shows HSGSO gives a good performance and achieves the objective of the researcher's study.

Until today, the standard GSO was hybridized by many researchers. Some researchers integrate more than one algorithm to produce a desirable outcome. Most researchers are hybrid the GSO with another swarm algorithm with the highest ability of convergence speed to overcome the drawback of GSO. Moreover, some researchers hybrid the GSO to get better performance in searching ability and global searching in their study. Hence, the hybridization technique can improve the standard GSO and give a good result in solving optimization problems.

4. Analysis and Discussion

This section will discuss the critical remark on the research works of previous researchers on using the GSO algorithm to solve optimization problems. Other than that, it has been discovered that most researchers integrate GSO into the new technique to obtain better results in terms of convergence speed and optimal solution. Figure 3 shows the application of the GSO algorithm in the industry from 2013 to 2022. It can be observed that the GSO algorithm has been widely used in the engineering area to solve optimization problems by as much as 15%. The optimization problems in engineering include determining the optimal cutting rate and machine performance to avoid major defects in the output while minimizing the cost and energy consumption. Most researchers are focused on determining the optimal dependent machining parameters. Aside from that, the GSO application in the network industry scores the second highest, by 13%. The researchers in the network industry are primarily concerned with determining router convergence speed rates and reducing data traffic of sensor nodes to achieve better wireless network performance. Meanwhile, the robotic industry has also used the GSO algorithm to solve the optimization problem by as much as 4%. The optimization problem in robotics is identifying multiple objective variables to overcome the robot path planning problem, such as avoiding collision in the underlying environment.

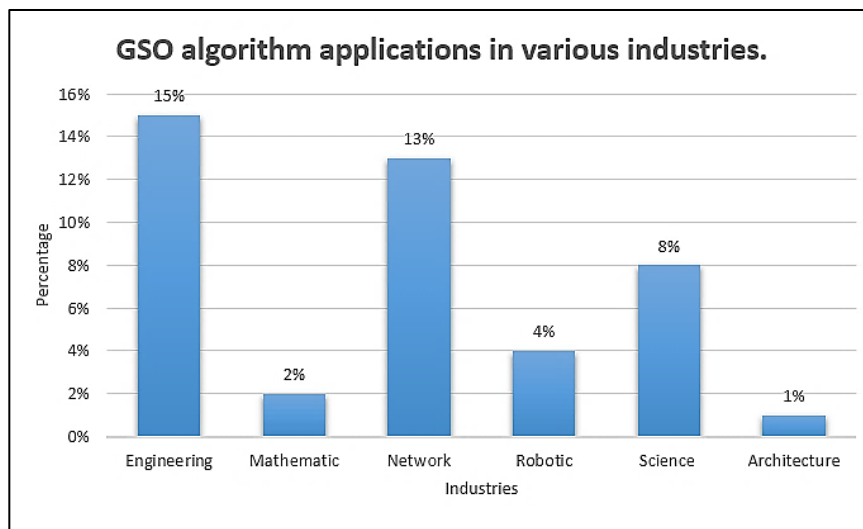


Figure 3: The GSO algorithm application in various industries.

Most researchers modified standard GSO into the new technique to obtain better results and hybrid the GSO algorithm. In addition, some researchers also implement standard GSO into the new application to optimize the problem and find multiple optimal multimodal functions [15]. Many areas have been applied in numerous types of industries, such as photovoltaic [35], cloud computing [18], image processing [31], etc. In addition, some researchers also implement standard GSO into the new application to optimize the problem and find multiple optimal multimodal functions [15]. Some researchers try to overcome the drawback of standard GSO by integrating with other meta-heuristics algorithms to get an optimal solution and increase convergence speed [56,57]. Therefore, some critical remarks on the GSO drawbacks and advantages are highlighted based on this review work:

- The GSO has a few drawbacks: low convergence and falling into the local optimum. However, hybridized, modified, and enhanced methods cope with the drawback of standard GSO.
- The GSO algorithm was developed for numerical optimization problem that involves computing various optimal multimodal functions as opposed to other swarm intelligence algorithm to locate the global optimum.
- The GSO can apply in many fields of industry to solve optimization problems, especially in engineering and network security.

5. Conclusions

In this paper, a detailed review of previous studies on GSO from 2013 to 2022 revealed that the GSO helped solve many optimization problems and improve GSO performance using hybridization and modification methods. Many industries implement GSO to optimize their problem, and it was found that GSO is improving the efficiency and effectiveness of their study. However, the basic GSO and other swarm intelligence algorithms always give the best results when finding the best solution to solving optimization problems. Despite GSO's promising results in various optimization problems, some areas still need further investigation. Future research could look into the potential of GSO for solving complex multi-objective optimization problems by extending the algorithm to handle multiple objectives simultaneously. Furthermore, the use of GSO in real-world problems such as engineering design, machining processes, and manufacturing has been limited and needs to be expanded. Finally, developing hybrid GSO algorithms that combine GSO with other metaheuristics or machine learning techniques could be an interesting future research direction.

Funding: This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2021/ICT02/UTHM/03/1).

Conflicts of Interest: “The authors declare no conflict of interest.”

Appendix:

Table 1: GOS method used for an optimization problem.

Year	Ref.	Method	Application area	Remarks
2013	[18]	Enhance GSO	Cloud computing.	The study uses the GSO method with the cloud model to overcome basic GSO's local optimum result and convergence speed rate.
2014	[19]	GSO algorithm & combination of TOPSIS with GSO (GSO-T)	Environmental economic dispatch (MOEED)	The purpose of the study is to use the GSO algorithm combined with the TOPSIS approach to solve the multiple objective environmental and economic dispatch (MOEED) problems. Other than that, the step size of TOPSIS is implemented into the GSO step size to enhance the performance of the GSO algorithm.
	[20]	Modified GSO algorithm & MapReduce (MRGSO)	Clustering large data.	The GSO used for scalable design and implementation of GSO clustering (MRCGSO) using MapReduce is introduced to handle big data.
	[21]	Binary GSO (BGSO)	Power system.	The BGSO algorithm is used to optimize the unit's on/off state, and the Lambda-iteration approach is used to solve the economic dispatch problem.
	[22]	GSO	Polar metric MIMO radar target detection.	In this study, GSO algorithms are implemented into MIMO radar to enhance the detection performance of MIMO radar.
2015	[23]	Hybrid GSO.	Greenhouse gas (GHG).	The studies used hybrid GSO to optimize precast-prestressed concrete U-beam road bridges' cost and CO2 emission optimization.
	[24]	Improved GSO and PSO (PGSO).	Uninhabited combat air vehicle (UCAV).	The PGSO is used to optimize the flight path planning of UCAV.
	[25]	GSO	Cloud computing.	Using GSO, this study suggests a new task scheduling technique and suggested technique seeks the optimum mapping to reduce job execution time.
	[26]	Adaptive control based on GSO	Mechanical servo system.	This study uses adaptive control of mechanical servo systems for friction identification of the GSO algorithm.
	[27]	GSO	Air pollution system.	This research aims to provide a new method (GSO) for identifying air pollution sources that do not require emission inventories or in-situ sampling.
2016	[28]	Modified GSO	Blind signal separation (digital signal processing).	The studies use MGSO and BSS to enhance the convergence speed and accuracy of standard GSO for optimization solutions, after comparing the result of PSO and BSS. The author concludes that the results of MGSO and BSS (MGSO-BSS) give impressive global search ability, faster convergence speed, and high accuracy.

	[29]	Multi-objective GSO (MO-GSO)	Congestion management.	The studies use MO-GSO for solving the multi-objective CM problem. The multi-objective optimization of a problem must contain two or more objective functions that must be optimized concurrently.
	[30]	GSO Based Multimedia Documents Clustering Algorithm (GSOMDC)	Document clustering.	The studies were motivated by the dynamic nature of GSO, a clustering algorithm is proposed to cluster the multimedia documents.
	[31]	Improved GSO (IGSO)	Image processing.	The IGSO is used in this study to find the optimal multilevel thresholds of color images based on between-class variance and minimum cross entropy (MCE).
2017	[32]	Hybrid GSO	Traveling sales problem (TSP).	The results of the hybrid GSO algorithm and completed 2-opt algorithm give a good performance and 2-opt gives a better result and speeds up the convergence rate by increasing the population GSOC.
	[33]	Wavelet twin support vector machine based on GSO algorithm (GSO-WTWSVM)	Machine learning algorithm.	The studies used the GSO algorithm to overcome the wavelet twin support vector machine (WTWSVM) problem and optimize the parameters of WTWSVM.
	[34]	Improved GSO	Air pollution source identification.	The improved GSO method is used to optimize the quantity of air pollution based on sensed imagery.
	[35]	GSO	The output power of a photovoltaic (PV) system.	The GSO algorithm is used to identify the maximum power point of PV.
	[36]	GSO	Photovoltaic panel.	The GSO algorithm can locate with precision both the global optimum point and the multiple global optimum, independently of the initial conditions of the photovoltaic panel.
2018	[37]	Modified GSO	3D Unmanned aerial vehicle (UAV) path planning.	Applying MGSO, the algorithm overcomes the problem in the robot path planning to avoid collision in the underlying environment. The result successfully gives a better result by optimizing the route between the source and destination.
	[38]	Hybrid GSO	Cloud computing.	The hybrid GSO (HGSO) is used for an evolutionary computation technique, a quantum behavior approach based on the principle of a neighborhood, offspring production, and random walk to produce more efficient scheduling in cloud computing.
	[39]	GSO	Plastic manufacturing part.	The GSO algorithm is used to identify optimal processing parameters to avoid the major defect of output, which is shrinkage and warpage.
	[40]	Variable step size optimized GSO	Mobiles robotics.	The study uses GSO on multi-robot chemical source positioning and establishes a simulation environment of chemical source positioning to perform simulation experiments to verify the method's effectiveness.

2019	[41]	Hybrid GSO	Wireless sensor network (WSN).	The GSO is hybridized with the Pareto optimal method to stabilize the output of security and reliable routing in WSN.
	[42]	Improved adaptive step-size GSO algorithm (IASGSO)	Three-dimensional elliptical vibration cutting (3D EVC).	The method of IASGSO is used to identify and optimize the nonlinear Wiener System model parameter of 3D EVC. The general GSO improved the step size of the GSO algorithm to get a better result.
	[43]	Uneven clustering routing algorithm based on GSO (UCRA-GSO)	Wireless sensor network (WSN).	The UCRA-GSO proposed in this study is to solve the energy balance problem in WSN.
	[44]	Combination of GSO with support vector machine (GSO-SVM)	Demand side management (DSM) of a power system.	The GSO-SVM is used for decision-making of battery storage to reduce the electricity tariff.
	[45]	Multi-objective GSO (MO-GSO)	Wind-thermal power system.	The MO-GSO is used to solve the problem of multi-objective power flow (MO-OPF), which minimizes the total generation cost and transmission loss and enhances voltage stability.
2020	[46]	GSO	Satellite image.	The logic of the GSO algorithm is used to determine the amount of population, the total area, and the total amount of electricity based on the selected area in a satellite image.
	[47]	Multi-objective GSO (MOGSO).	Thin-walled ring part (machining).	The MOGSO uses to analyze the prediction of thin-walled rings part during the pre-cutting process as well as find the optimum cutting parameter of the thin-walled ring.
	[48]	Glowworm swarm mechanism with improved the grid-interactive NZEB optimization design.	Architecture.	The methods used to reduce the building energy consumption and negative impact on the atmosphere.
	[49]	Movement Score based Limited Grid-mobility & Reverse GSO (MSLG-RGSO) algorithm for mobile	Mobile wireless sensor.	Movement Score-based Limited Grid-mobility approach using Reverse GSO (MSLG-RGSO) algorithm for mobile wireless sensor networks to achieve minimum energy consumption by the sensors through their optimum movements.
2021	[50]	GSO.	Mobile wireless sensor network.	The GSO approach is used in this study to find the optimal position of wireless sensor nodes in a randomly deployed dynamic network.
	[51]	Hybrid GSO & Ant-colony optimization (ACI-GSO).	Wireless sensor network.	To find the optimal cluster head for energy routing protocol in WSN the hybridization approach of ACI-GSO is implemented in this study.
	[52]	Quantum GSO with secure routing protocol (QGSOC-SRP).	Mobile ad-hoc network (MANETs).	The QGSOC-SRP was implemented in this study to find optimal selection routes to a base station (BS).

	[53]	Hybrid GSO and adaptive dimensionality.	Robotics.	The hybridization method is implemented in studies to develop a new method in robot path planning to enhance performance.
	[54]	Hybrid GSO.	Wireless sensor network.	The hybrid GSO algorithm optimized with Harmony search (HS) and Tabu search (TS) to reduce data traffic and energy consumption between the sensor nodes with this method can achieve better performance.
2022	[55]	Hybridization of pigeon inspired with GSO algorithm (HPISGSO).	Wireless networking.	The proposed method found that the ability of HPISGSO to achieve an optimal cluster head and network lifetime can be maximized by using the HPIGSO method compared to another method.
	[56]	Tournament selected GSO-based selective harmonic elimination (TSGWSO-SHE).	Electric power industry.	The TSGWSO-SHE method improves output voltage and current in a multilevel inverter.

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