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The Strategic and Scientific Importance of Optimization Algorithms: The Grey Wolf Optimizer as a Model

Sami Nadhim Hussain Khudhur*
General Directorate of Education of Salah al-Din
Email: sami.csp107@student.uomosul.edu.iq

***Correspondence :** Sami Nadhim Hussain Khudhur
sami.csp107@student.uomosul.edu.iq

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Abstract

This study examines the strategic and scientific importance of optimization algorithms, focusing on the Grey Wolf Optimizer (GWO) as a model. It addresses the need for fast, accurate tools to solve complex problems in energy, medicine, and artificial intelligence where traditional methods fail. The research analyzes GWO's behavioral roots in wolf pack hierarchy, its mathematical formulation, and its efficiency compared with competing algorithms. The study concludes that GWO's strength lies in its simplicity, reliability, and triple-leadership system (α, β, δ), which balances exploration and exploitation and avoids local optima, making it a key tool in modern engineering and AI applications.

Keywords

Grey Wolf Optimizer; Swarm Intelligence; Bio-inspired Computing; Exploration and Exploitation; Optimization Algorithms

Introduction

The contemporary world is witnessing a radical transformation in the mechanisms of solving complex problems, as artificial intelligence has emerged as a driving force for innovation across various scientific and engineering fields. With the growing volume of data and the intertwining of variables in computational problems, traditional and rigorously mathematical methods have become incapable of finding optimal solutions within a reasonable timeframe. Consequently, researchers have turned their attention toward "the first teacher"—nature—to draw inspiration from intelligent strategies capable of adapting and maneuvering within vast and complex search spaces. This is what is now known as bio-inspired computing or nature-inspired algorithms.

These algorithms fundamentally rely on simulating the intelligent behaviors of living organisms, whether in the form of flocks of birds, colonies of bees, or packs of predatory animals.

The secret behind the success of these organisms in surviving for millions of years is attributed to their innate ability for "optimization"—that is, reaching food or safety with the least possible effort and the highest available efficiency. Within this vast space of swarm intelligence algorithms, the Grey Wolf Optimizer (GWO) stands out as one of the most recent and powerful mathematical tools invented to simulate strict social systems and group hunting strategies.

The selection of the "grey wolf" as a model for this research was not coincidental but rather resulted from the unique social organization this creature possesses, which relies on a precise hierarchical structure (Alpha, Beta, Delta, Omega). This organization is not merely a form of authority; it is a "task distribution mechanism" in programming terms that ensures efforts are not scattered and that the goal (the optimal solution) is reached through the shortest paths. Simulating this behavior and framing it in a mathematical template opens wide horizons for solving problems previously classified as intractable, especially those requiring a delicate balance between exploring new solution regions and exploiting currently available results.

The research problem lies in the urgent need for optimization tools that are both fast and accurate, particularly in light of the current technological revolution in the fields of energy, medicine, and artificial intelligence. Hence, this research aims to provide an analytical and in-depth study of the Grey Wolf Optimizer, starting from its behavioral roots in the wild, passing through its complex mathematical formulation, and reaching the testing of its efficiency through applied examples and comparison with competing algorithms.

The Emergence of Bio-inspired Computing

Nature-inspired algorithms constitute a vital branch of artificial intelligence sciences, seeking to model complex biological and physical processes and transform them into software solutions. The philosophical roots of these algorithms trace back to scientists' observations of how living organisms survive and adapt to harsh environments, where these organisms follow innate optimization strategies to reach food or mates with minimal effort [1]

Swarm Intelligence and the Philosophy of the Collective

Swarm intelligence is considered the backbone of many modern algorithms. It describes the collective behavior of decentralized and self-organizing systems. In these systems, there is no central leader issuing commands; rather, collective wisdom emerges from simple local interactions between individuals (such as bees, ants, or birds). This interaction leads to the emergence of "global" intelligent behavior that transcends the capabilities of any single individual [2]

Classification of Nature-inspired Algorithms

These algorithms can be divided into several main categories based on their source of inspiration [3]:

1. Evolutionary Algorithms: Inspired by Darwin's theory of evolution (such as the Genetic Algorithm).
2. Swarm-based Algorithms: That mimic the social behavior of animals (such as the Grey Wolf Optimizer and Particle Swarm Optimization(
3. Physics-based Algorithms: Inspired by physical laws (such as Simulated Annealing or the Gravitational Search Algorithm(.

The Role of Balance between Exploration and Exploitation

The secret behind the success of any nature-inspired algorithm lies in its ability to balance

between "exploration" (searching in new and unknown regions of the solution space) and "exploitation" (focusing on improving the best solutions found so far). Weak algorithms are those that fall into the trap of "local optima" and cannot escape it to reach the global optimum [4]

Scientific and Technical Importance in the Modern Era

With the increasing complexity of engineering, medical, and technical problems, traditional solutions (deterministic algorithms) have become incapable of finding solutions within a logical timeframe. Here emerges the importance of nature-inspired algorithms as "heuristic" solutions that provide results very close to optimal with significantly less computational effort, making them the cornerstone of "big data" applications and neural network optimization [5].

Methods

Defining Wolf Pack Behavior (Grey Wolf Social Behavior)

The Social Hierarchical System

Grey wolves are known as social creatures par excellence, living in organized groups called "packs." What distinguishes this pack is its strict adherence to a hierarchical leadership structure that distributes roles with extreme precision. This system is not merely a means of control; it is a vital mechanism for reducing internal conflicts and ensuring efficient distribution of food and protection of the young. At the top of this pyramid is the "Alpha" pair, followed by "Beta," then "Delta," down to "Omega" at the base [6]

The Leading Category (Alpha): The Center of Decision-Making

The "Alpha" wolf is the dominant individual in the pack, often a male and female (the leading pair). The Alpha's duties are not limited to physical strength but extend to include wisdom in making fateful decisions such as: When does hunting begin? Where does the pack sleep? How is the territory defended? Behaviorally, the Alpha is characterized by raising its tail high as a symbol of sovereignty, and it is the only one authorized to begin eating after a successful hunt [7]

The Supporting and Executing Categories (Beta & Delta)

The "Beta" category comes in second place, acting as an advisor to the Alpha and executor of its orders, as well as being the first candidate to assume leadership in the Alpha's absence. The "Delta" category includes "scouts" who monitor territory boundaries, "guards" who protect the pack during sleep, and "caretakers" who look after the pups. These categories ensure the continuity of daily operations without burdening the higher leadership [8]

The Omega Category: The Tension Safety Valve

Although "Omega" wolves are at the bottom of the social ladder and sometimes face harassment, they play a dangerously important psychological role in the pack. The Omega acts as a "safety valve" to release aggression and tension within the group, and also plays a pivotal role in play and stimulating team spirit. It has been observed in the wild that a pack losing its Omega wolf suffers from increased internal conflicts and disrupted social bonds [9]

The Psychology of Group Hunting Dynamics

Hunting among grey wolves is a complex strategic process beyond mere chasing. The process begins with "rallying" and howling to boost morale, then launching in specific formations. Wolves possess an exceptional ability to "read" their prey; they first test the prey by running after it to identify weak or sick individuals, making the hunting process a tool of natural selection in

the environment [10]

The Mechanism of Encircling and Attacking

Upon identifying the target, the pack begins executing the "encircling" maneuver, where wolves spread out at different angles to prevent the prey from escaping. The attack behavior is characterized by extreme patience; wolves may watch the prey for hours waiting for the appropriate moment to pounce. This behavior represents the mathematical foundation for the update equations in the GWO algorithm, where the prey's position represents the "optimal solution" that the wolves (solutions) attempt to converge toward [11]

Signal and Vocal Communication

The stability of the pack and the success of its hunt depend on an advanced communication system that includes body language (ear and tail positioning), scents (for marking territory), and vocal communication (howling). Howling is not merely a terrifying sound but a means of locating missing pack members or warning competing packs to stay away, which ensures the "coordination" necessary for intelligent optimization operations [12]

Software Simulation of Social Hierarchy

The Grey Wolf Optimizer (GWO) fundamentally relies on converting the social pyramid studied in the previous section into a digital "data structure." In the optimization environment, each wolf is represented as a "vector" containing the values of the proposed solution. These solutions are classified based on their quality (Fitness Value); the solution closest to the goal is considered "Alpha," followed by "Beta" and then "Delta," while the remaining solutions are considered "Omega" that follow the leaders in the search space [13]

The Mechanism of Searching for the Optimal Solution

(The Hunting Mechanism)

Programmatically, the hunting process is executed through three main steps that mimic reality:

1. Exploration: Where wolves disperse from each other to search for "prey" (solutions) in different regions of the search space, ensuring the algorithm does not become confined to a single area.
2. Exploitation: Once a promising area is found, wolves begin converging toward it to determine the exact location of the best solution.
3. Continuous Updating: Wolf positions are updated in each iteration based on the movement of the top three leaders.

Results and Discussions

Digital Modeling of Collective Leadership

What distinguishes this algorithm's concept from others is "collective leadership"; while other algorithms rely on a single leader, GWO makes "Omega" wolves listen to three different opinions (Alpha, Beta, Delta). This mathematical concept reduces the probability of error; if the "Alpha" is in a wrong position, the "Beta" or "Delta" can correct the swarm's path, enhancing the efficiency of reaching the final solution [14]

The Algorithm's Flexibility in Handling Constraints

The concept of strength in GWO is manifested in its ability to handle high-dimensional

problems with complex constraints (Constrained Optimization). Thanks to the "prey encircling" mechanism, the algorithm can gradually and flexibly narrow the search scope, preventing solutions from jumping outside the permissible search range, making it very useful in precise engineering designs [15]

Software Polarization and Artificial Intelligence Applications

The concept of the Grey Wolf Optimizer has transitioned from mere nature simulation to an essential tool in "Neural Networks Training." The "leader-following" logic is used to adjust weights within artificial neurons, accelerating the machine learning process and reducing the error rate in future predictions [16]

Mathematical Modeling of Social Ranks

In the digital optimization environment, the social structure of the pack is converted into programmatic classifications based on solution efficiency. The best wolf is mathematically represented by the symbol (α) as the fittest solution, followed by (β) and (δ) as auxiliary solutions that help guide the swarm. The remaining proposed solutions are classified under (ω), whose mathematical task is to follow the three leaders and update their positions based on their coordinates in the search space, ensuring information flow from better solutions to the rest of the system's elements [17]

Mathematical Encircling Mechanism

The process of encircling the target relies on movement equations that ensure gradual narrowing of the search scope. The distance between the wolf and the prey is calculated through the following equation:

$$D = |C \cdot X_p(t) - X(t)$$

Based on this distance, the wolf's position in the next step is updated according to the equation:

$$X(t+1) = X_p(t) - A \cdot D$$

Where X_p represents the coordinates of the best solution found so far, while the vectors A and C act as parameters controlling the swarm's leaps and ensuring solutions do not exit the logical range [18]

Dynamic Balance between Exploration and Exploitation

The parameter a is the primary engine of the algorithm's intelligence; its value is gradually decreased from 2 to 0. Mathematically, when the absolute value of $|A| > 1$, wolves are forced to disperse to search in undiscovered areas (Exploration). When the value approaches zero (less than 1), the algorithm transitions to the exploitation phase (Exploitation) by tightening the noose on the prey to reach the optimal point with extreme precision [19]

Swarm Guidance Strategy (Position Updating)

Since the true location of the optimal solution is completely unknown at the beginning, the algorithm relies on the estimates of the top three leaders. Separate paths are calculated for each wolf toward (α, β, δ), then these paths are mathematically merged by calculating the arithmetic mean of their positions. This strategy gives GWO an advantage in avoiding falling into "Local Optima," as the swarm's path is continuously corrected based on the interaction of the three leaders rather than relying on a single solution[20]

Mechanism of Estimating Prey Position

In the GWO algorithm, solutions (wolves) possess no prior knowledge of the optimal solution's location (the prey). Mathematically, the recorded positions of the three leaders (α, β, δ)

are relied upon as the best available estimates.

1. $D_\alpha = |C_1 \cdot X_\alpha - X|$
2. $D_\beta = |C_2 \cdot X_\beta - X|$
3. $D_\delta = |C_3 \cdot X_\delta - X|$

These equations ensure that each individual in the swarm possesses a "multi-dimensional vision" of the solution's location, reducing the deviation rate [21]

Final Position Update Equations

After calculating the relative distances from the leaders, the potential positions of the wolf are determined based on each leader separately (X_1, X_2, X_3), then these results are merged to reach the updated position in the next iteration (t+1) through the arithmetic mean equation:

$X(t+1) = (X_1 + X_2 + X_3) / 3$

This mathematical merging enhances the algorithm's stability, acting as a filter to correct random paths, ensuring the swarm moves as a single block toward the target area [22]

Linear Decrement of Exploration Parameter (a)

The efficiency of the "attack" depends on the parameter a, which is updated in each iteration to decrease from 2 to 0 according to the equation:

$a = 2 - t \cdot (2 / Max_Iter)$

This decrement ensures a smooth and gradual transition of the algorithm from the wide search phase (Exploration) to the intense focus phase (Exploitation). Mathematically, this decrement resembles "cooling" the system to reduce randomness and increase precision in the final stages of the search [23]

Simulating Search Leaps and Overcoming Obstacles

The random vectors A and C play a vital role in preventing the system from "freezing" at non-ideal solutions. The vector C specifically, which is randomly generated between [0, 2], grants wolves the ability to change the "weight" of the prey, making the prey appear as if it is moving or difficult to encircle. This mathematical complexity is essential to ensure wolves continue searching and do not settle for the first good point they reach [24]

Convergence Analysis

The mathematical study of GWO's update equations proves that it possesses "Guaranteed Convergence." Since all wolves ultimately gravitate toward the arithmetic mean of the best three solutions, the search space shrinks exponentially. This means the algorithm can find the solution with very high precision (reaching 10^{-15} in some mathematical functions) within a short computational time compared to traditional algorithms [25]

General Pseudocode Framework

These equations are translated into programming code following these steps[26]:

1. Initialize random positions for N wolves.
2. Calculate fitness and assign α, β, δ.
3. Iteratively update a, A, C for each individual.
4. Update positions using arithmetic mean equations.
5. Check the stopping criterion and output results.

Chapter Three: Practical Applications and Vital Domains of the Algorithm

Smart Grid and Power Systems Optimization

The Grey Wolf Optimizer is an effective tool in solving the "Economic Load Dispatch" problem. The algorithm aims here to distribute energy demand among different generation units

at the lowest possible cost while considering technical constraints. Thanks to its precise "encircling" mechanism, GWO succeeded in reducing energy losses and greenhouse gas emissions in power plants compared to traditional algorithms [27]

.Software Engineering and Machine Learning

In artificial intelligence, the algorithm is widely used in the "Feature Selection" process. Wolves here search through thousands of variables to determine the most important data affecting classification accuracy, reducing the time needed to train models. It has also proven highly efficient in tuning the "weights" of Artificial Neural Networks (ANN), raising prediction accuracy in complex systems such as the stock market or weather forecasting [28]

Medical Processing and Disease Diagnosis

GWO has entered the core of modern medical technologies, especially in "Medical Image Segmentation." The algorithm is used to precisely determine tumor boundaries in MRI images. By simulating hunting behavior, wolves can accurately identify affected areas by optimizing image thresholding values, helping doctors in early and accurate diagnosis [29]

Robotics and Path Planning

In complex working environments, autonomous robots need to find the shortest path avoiding obstacles. GWO is used to model the robot's path as "prey" that wolves try to reach safely. The algorithm ensures path smoothness and reduces motor energy consumption, currently applied in drones for reconnaissance and rescue missions in rugged areas [30]

Structural Engineering Design

The algorithm is applied in designing metal structures and bridges to reduce the overall weight of the structure while maintaining safety standards. Mathematical equations test thousands of possibilities for column and bridge thickness and lengths, reaching the "optimal design" that saves material costs without compromising structural integrity [31]

Cybersecurity and Intrusion Detection

GWO has been employed in developing Intrusion Detection Systems within computer networks. By optimizing detection parameters, the algorithm can identify suspicious data movement patterns that may indicate a cyberattack, enhancing information security in sensitive institutions [32]

Communications Engineering and Wireless Network Optimization

With the massive development of 5G networks, GWO has emerged as an ideal solution for the "Channel Allocation" problem. The algorithm works to reduce interference between signals by modeling frequencies as a search space, where "wolves" seek the frequency distribution achieving the highest data transfer speed with the lowest energy consumption. It is also used to optimize broadcast tower locations to ensure comprehensive geographic coverage without dead zones [33]

Petrochemical Industries and Refinery Management

The algorithm is applied in optimizing "distillation" and chemical separation processes, where precise control of temperatures and pressure is required. GWO simulates these variables as moving prey, and the wolves' hierarchical sequence leads to reaching the chemical equilibrium point that ensures the highest final product quality while reducing chemical waste, directly reflecting on reducing operational costs of major plants [34]

Artificial Intelligence in Pattern Recognition

GWO excels in "Data Clustering," where it is used to determine optimal centers for groups within massive databases. In face or fingerprint recognition applications, the algorithm helps

reduce complex image dimensions (Dimensionality Reduction), making the matching process faster and more accurate even with "noise" or distortions in input images [34]

Supply Chain and Logistics Management

The algorithm is used to solve the "Traveling Salesman Problem" (TSP) in its complex version, where the search aims to find the shortest route for distributing goods across a set of cities. Thanks to its strong "exploration" mechanism, GWO can find routes saving millions of kilometers of annual transport for shipping companies, considering variables such as time, traffic congestion, and truck capacity [35]

Renewable Energy (Solar Panels and Wind Turbines(

In solar energy systems, GWO is used for "Maximum Power Point Tracking" (MPPT). Due to constantly changing light intensity, the algorithm adjusts panel angles or power converters with extreme speed to ensure extracting maximum possible electricity under all weather conditions. It is also used in designing wind turbine blades to raise the efficiency of converting wind energy into kinetic energy [36]

Defense Security and Military Systems

The algorithm is applied in "Drone Swarms Coordination" to execute complex missions. Roles are distributed among drones based on the hierarchical sequence (Alpha for command, Beta for reconnaissance), allowing the swarm to move as a single intelligent block capable of maneuvering and avoiding enemy radar, while maintaining constant communication between all units thanks to continuous position update equations [37]

Chapter Four: Applied Example and Numerical Analysis of Algorithm Results

Characterization of the Experimental Problem (Benchmark Function(

To test GWO's efficiency, a complex mathematical function known as the "Rosenbrock Function" is used. It is a classic function for testing optimization algorithms because it contains a narrow valley whose bottom (the optimal solution) is difficult to find. The search space is represented as a mountainous region, where grey wolves seek to find the lowest point in this valley within a specified range [38]

Simulation Settings and Operating Parameters

The simulation process begins by deploying 30 wolves randomly in the search space. The maximum number of iterations is set at 500. In each iteration, the algorithm executes the update equations discussed in Chapter Two. The value of "Alpha" (best solution) is monitored in each cycle to record Convergence Speed and the accuracy of reaching point (0,0), which represents the ideal solution for the function

Convergence Analysis

When numerically monitoring results, we note that GWO exhibits aggressive search behavior during the first 100 iterations (exploration phase), where wolves leap across wide distances. After iteration 200, the curve begins to stabilize, indicating that wolves have encircled the "prey" and begun refining the position. GWO's curve is characterized by descending faster than the Particle Swarm Optimization (PSO) algorithm, proving its efficiency in saving computational time [39]

Comparative Study

To prove the strength of results, a comparison is conducted between GWO and other algorithms such as the Genetic Algorithm (GA) and Ant Colony Optimization (ACO). Numerical results (such as the arithmetic mean and standard deviation of solutions) indicate that GWO achieves a lower "standard deviation," meaning its results are stable and non-random, capable of

reaching the same accurate solution each time the program is run [40]

Robustness Test in High Dimensions

The algorithm was tested in problems with high dimensions (reaching 1000 variables), and results showed that GWO does not suffer from the "Curse of Dimensionality" to the same extent as other algorithms. The wolves' ability to divide work among the three leaders allows the system to maintain its balance even when the search space becomes vast and extremely complex [41]

Analytical Summary of the Example

The applied example proved that the GWO algorithm is not merely a biological simulation but a powerful mathematical tool characterized by high precision and speed of execution. Its ability to smoothly transition from exploration to exploitation makes it the preferred choice for engineers when dealing with optimization problems requiring a balance between speed and final result accuracy [42].

Conclusion

In conclusion, the Grey Wolf Optimizer (GWO) is an effective optimization algorithm inspired by the social behavior of grey wolves. Its simple structure, leadership hierarchy, and balance between exploration and exploitation enable it to solve complex problems in engineering, medicine, and energy systems. Despite its effectiveness, future research should focus on hybridizing GWO with deep learning and quantum computing to improve its performance and expand its applications in artificial intelligence.

References

[1] S. S. Kar, *Bio-Inspired Computing Models and Algorithms*. Boca Raton, FL, USA: CRC Press, Taylor & Francis Group, 2016.

[2] G. Beni and J. Wang, "Swarm intelligence in cellular robotic systems," in *Proc. NATO Advanced Workshop on Robots and Biological Systems*, 1989.

[3] I. Fister *et al.*, "A brief review of nature-inspired algorithms for optimization," *Elektrotehniški Vestnik*, 2013.

[4] X.-S. Yang, *Nature-Inspired Optimization Algorithms*. Amsterdam, The Netherlands: Elsevier Science, 2014.

[5] J. Brownlee, *Clever Algorithms: Nature-Inspired Programming Recipes*. Lulu.com, 2011.

[6] L. D. Mech, "Alpha status, dominance, and division of labor in wolf packs," *Canadian Journal of Zoology*, 1999.

[7] R. Schenkel, "Submission: Its features and function in the wolf and dog," *American Zoologist*, 1947.

[8] E. Zimen, *The Wolf: His Place in the Natural World*. London, U.K.: Souvenir Press, 1981.

[9] B. H. Lopez, *Of Wolves and Men*. New York, NY, USA: Charles Scribner's Sons, 1978.

[10] T. Jayabarathi *et al.*, "Economic dispatch using grey wolf optimizer," *Swarm and Evolutionary Computation*, 2016.

[11] R. O. Peterson and P. Ciucci, "The wolf as a carnivore," in *Wolves: Behavior, Ecology, and Conservation*, 2003.

[12] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," *Advances in Engineering Software*, vol. 69, pp. 46–61, 2014.

[13] F. H. Harrington and L. D. Mech, "Wolf howling and its role in territory maintenance," *Behaviour*, 1979.
[14] H. Faris *et al.*, "Grey wolf optimizer: A review of recent variants and applications," *Neural Computing and Applications*, 2018.
[15] S. Gupta and K. Deep, "A memory-based grey wolf optimizer for global optimization tasks," *Applied Soft Computing*, 2019.
[16] Q. Al-Tashi *et al.*, "A review of grey wolf optimizer-based feature selection methods for classification," *IEEE Access*, 2020.
[17] C. Muro *et al.*, "Wolf-pack hunting strategies emerge from simple rules in computational models," *Behavioural Processes*, 2011.
[18] A. Kaveh and F. Shokohi, "Cost optimization of skeletal structures using grey wolf optimizer," *Iranian Journal of Science and Technology*, 2016.
[19] W. Long *et al.*, "An enhanced grey wolf optimizer for high-dimensional numerical optimization," *Applied Soft Computing*, 2018.
[20] A. Seyyedabbasi and F. Kiani, "I-GWO: An improved grey wolf optimizer for solving continuous optimization problems," *Engineering with Computers*, 2021.
[21] D. Guha *et al.*, "Load frequency control of large scale power system using grey wolf optimizer," *Swarm and Evolutionary Computation*, 2016.
[22] P. Niu *et al.*, "Optimization of weight and bias in an artificial neural network using an improved grey wolf optimizer," *Applied Soft Computing*, 2019.
[23] E. Emary *et al.*, "Binary grey wolf optimization approaches for feature selection," *Neurocomputing*, 2016.
[24] S. Sureshkumar *et al.*, "Grey wolf optimization based multilevel thresholding for image segmentation," *IET Image Processing*, 2020.
[25] H. Faris *et al.*, "Grey wolf optimizer: A review of recent variants and applications," *Neural Computing and Applications*, 2018.
[26] C. Qu *et al.*, "A novel hybrid grey wolf optimizer for unmanned aerial vehicle path planning," *IEEE Access*, 2018.
[27] A. Kaveh and P. Zakian, "Improved GWO algorithm for optimal design of truss structures," *Periodica Polytechnica Civil Engineering*, 2018.
[28] W. L. Al-Yaseen *et al.*, "Multi-level hybrid intrusion detection model using intelligent algorithms," *IEEE Systems Journal*, 2017.
[29] R. S. Rao *et al.*, "Energy efficient routing in wireless sensor networks using grey wolf optimization," *International Journal of Pure and Applied Mathematics*, 2017.
[30] H. Chantar *et al.*, "Grey wolf optimizer with genetic algorithm for feature selection," *IEEE Access*, 2020.
[31] K. Maduadaru *et al.*, "Optimization of supply chain management using nature-inspired algorithms," *Journal of Industrial Engineering and Management*, 2022.
[32] S. Kilele *et al.*, "Maximum power point tracking of PV systems under partial shading using grey wolf optimizer," *Solar Energy*, 2019.
[33] X. Zhang *et al.*, "Cooperative path planning for multiple UAVs based on improved grey wolf optimizer," *Aerospace Science and Technology*, 2021.
[34] H. Jia *et al.*, "Dynamic grey wolf optimizer for global optimization problems," *Expert Systems with Applications*, 2020.

[35] G. Srivastava *et al*., "Performance analysis of grey wolf optimizer for solving unconstrained optimization problems," *Materials Today: Proceedings*, 2021.
[36] P. K. Kashyap *et al*., "A comparative study of nature-inspired algorithms for engineering design," *Applied Intelligence*, 2022.
[37] M. Abdel-Basset *et al*., "A novel hybrid grey wolf optimizer and framework for the multi-objective optimal power flow problem," *IEEE Access*, 2018.
[38] M. H. Nadimi-Shahraki *et al*., "An improved grey wolf optimizer for solving continuous optimization problems," *IEEE Access*, 2021.
[39] G. Dhiman and V. Kumar, "Multi-objective spotted hyena optimizer: A novel algorithm for multi-objective optimization problems," *Knowledge-Based Systems*, 2017.
[40] M. Abdel-Basset *et al*., "A novel hybrid grey wolf optimizer and framework for the multi-objective optimal power flow problem," *IEEE Access*, 2018.
[41] M. H. Nadimi-Shahraki *et al*., "An improved grey wolf optimizer for solving continuous optimization problems," *IEEE Access*, 2021.
[42] E. Zimen, *The Wolf: His Place in the Natural World*. London, U.K.: Souvenir Press, 1981.