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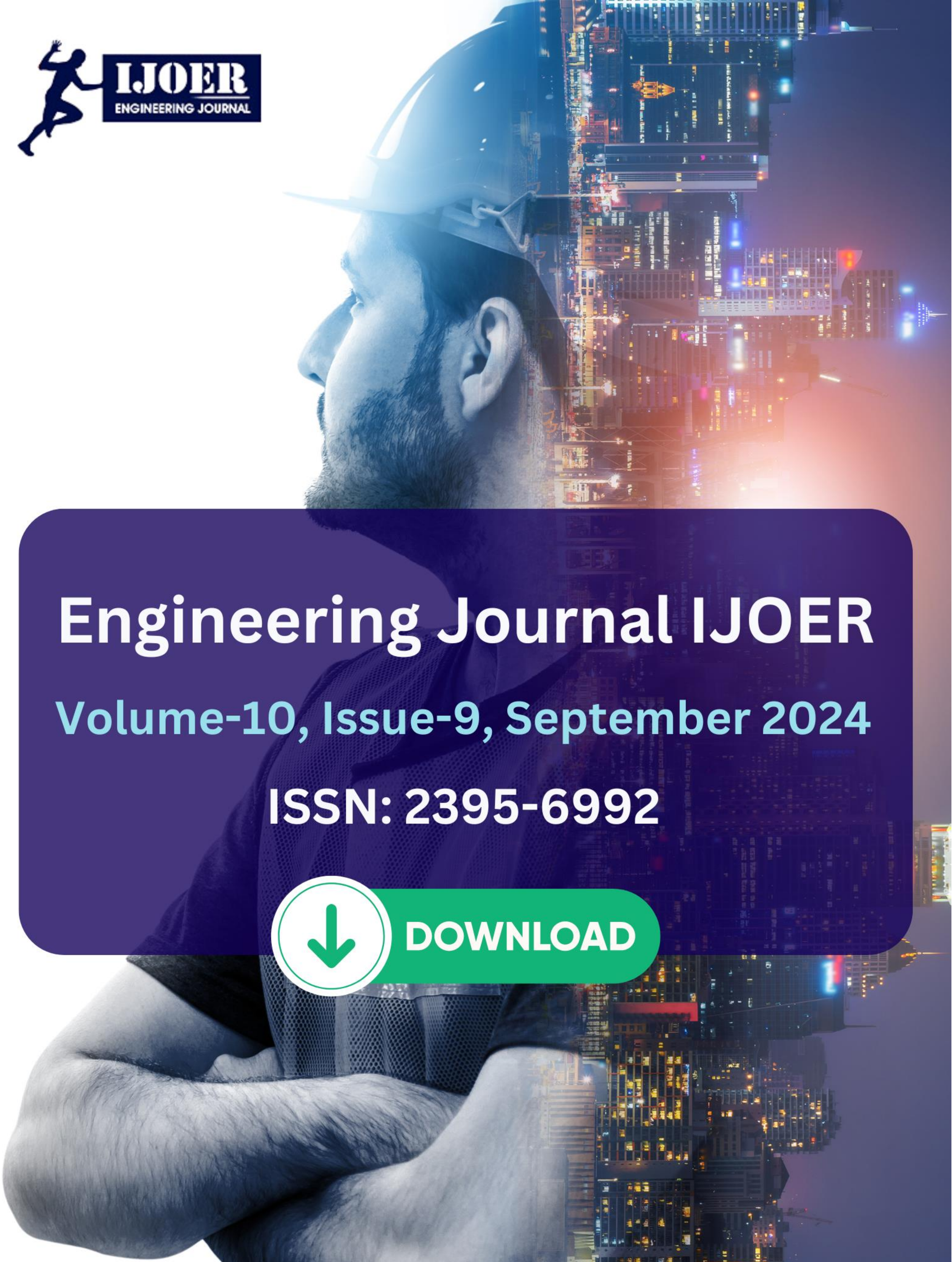

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Preface

We would like to present, with great pleasure, the inaugural volume-10, Issue-9, September 2024, of a scholarly journal, *International Journal of Engineering Research & Science*. This journal is part of the AD Publications series *in the field of Engineering, Mathematics, Physics, Chemistry and science Research Development*, and is devoted to the gamut of Engineering and Science issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Engineering and Science as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Engineering and Science community, addressing researchers and practitioners in below areas:

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Neural Networks	Plastic Engineering

Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with IJOER. We are certain that this issue will be followed by many others, reporting new developments in the Engineering and Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOER* readers and will stimulate further research into the vibrant area of Engineering and Science Research.

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A Cyber Security Case Study on eBay February 2014 Data Breach

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Abstract— *This report is an overview of some basic security associated services, that guard against risks to security of a system, using the ecommerce trading platform eBay February 2014 data breach, as case study. It covers some security policies, that not only detect the risks, but also outlines the conditions for a guaranteed protected system. Security procedures spot and stop incidents, therefore evaluating the security of a system demands an awareness of the procedures that implement the security policies. Correspondingly, basic knowledge of certain theories and trust, which lead to the risks and the extent to which they may likely be executed, is equally required. Human beings are the most vulnerable link in the security procedures of any system, and so should be taken into account while establishing policies (Matt Bishop, 2002).*

Keywords— E-commerce security, Data breach, eBay data breach, Cybersecurity vulnerabilities, User information security.

I. INTRODUCTION

Computer security deals with computer associated assets. it could simply be defined as mechanisms used to ensure confidentiality, Integrity, and availability of information system. This includes hardware, software, and information being communicated, managed and saved. Information is key which is why big organizations like Marriott, Google, Amazon, eBay and many more are often the major targets of cyberthieves. This report will be discussing the February 2014, eBay data breach; the methods used by the hackers to breach their system, their intentions, the vulnerabilities that may have led to the breach, and the countermeasures taken by eBay to reduce the damage. It will also reflect what eBay did right or wrong and how they were able to resolve the breach.

eBay is an American international e-commerce business established by Pierre Omidya, in September 1995, and has its headquarters in San Jose, California. The business arranges a client-to-client retail sales via online marketplace, and is used by organizations, individuals, and governments to trade and acquire items. In 2014, a group of hackers got access to the login identifications of three of eBay's employees, providing them entrance to the internal network of the company.

II. LITERATURE REVIEW

In recent years, the fundings in security changed from inessential to vital, organizations everywhere in the world now realize how important it is to constantly plough money into security (Yuri & Erdal, 2022). Every single data breach, cyberattack, vulnerability and exploit, deals with at least one component of the CIA triad; Confidentiality, Integrity, and Availability. The CIA triad is otherwise known as the three principles of Information Security or the CIA Model (Weissman, 2021). All cybersecurity process and mitigation practice, will also deal with one of the components on the minimum.

Whereas Confidentiality is concerned with restricting who can view a file or message, often achieved through encryption, Integrity is concerned with ensuring that the message or file has not been altered, either inadvertently or maliciously, and is often achieved through hashing. Availability is concerned with ensuring that networks and systems remain operational, so that approved users can have entrance to them, and it is often achieved through load balancing mechanisms and fault tolerance (Weissman, 2021).

In February/March 2014, ecommerce trading platform eBay, suffered a serious data breach which affected 145 million users, apparently their entire user base at the time. Customers' details like, email addresses, physical addresses, phone numbers, and encrypted passwords were exposed in the breach. eBay was compelled to ask all 145 million customers to change their passwords.

The organization was criticized for the vulnerability and also for the delays in communicating their customers. The breach was believed to have occurred more than a month before the organization made their first public announcement, requesting customers to change their passwords. Their employee log-in credential was compromised sometime in late February of 2014, enabling the thieves access to their user database. However, eBay established that they only discovered the compromised login roughly two weeks prior to their public announcement on May 21st ,2014.

The organization confirmed that the financial information of their customers, was however, not exposed during the incident as it could have worsened the whole situation. This does not dispute the fact that the stolen personal information of their customers, could still be sold to some criminals, who could in turn use them to commit crimes like impersonation, identity theft, and many more associated crimes. eBay's statement announcing the compromise, was first posted on their corporate website: eBayinc.com, which was believed to be a less trafficked medium, hence attracting an even bigger criticism, given that the affected customers are most likely not going to see the post. It is only a day later, that an announcement was made on behalf of the company, on their main website with very little information as just requesting customers to reset their password. This has left many in curiosity as to what exactly had happened.

The Commissioner of Information, UK, alongside the European data authorities, are working with a prospect to act against eBay concerning the breach. A few states in the US, are also investigating the theft of the personal information of up to 145 million clients. Meanwhile, several customers recounted troubles at the time of attempting to reset their passwords. eBay told BBC, that they are unaware of any technical troubles, associated with password reset malfunction on their site. However, they accepted that the site is engaged, and promised that the device for password reset is working. The company stated that they sent out millions of passwords reset emails to their clients, and also cautioned them that such emails do not contain any links. UK's Information Commissioner, speaking on BBC radio 5 live, said that the attack on eBay is very serious but the Office of the Information Commissioner cannot start an investigation immediately, because of some antiquated and intricate data protection laws. They would have to primarily interact with the data protection in Luxembourg, which is where eBay has its European headquarters. Millions of UK citizens were disclosed to be impacted by the breach.

Hugh Boyes from the institution of Engineering and Technology, queried why eBay kept that much data in the first place. UK Commissioner of Information, points out that companies ought to keep the smallest essential information. Thus, why do eBay require to store information such as addresses, and dates of birth of customers. As someone who uses eBay sporadically, he is worried that the company has lost his phone number, home address, and date of birth among other things like his email, username, and password. From an identity theft perspective, the breach is very serious as the thieves, have enough information to pose as an individual whom they are not, when trading with financial organizations.

Someone may ask, why should anyone be bothered about computer and network security? Compared to terrorism, risks of computers and networks may seem so light, however an average individual is most likely to be a target of cyberattack, than they are to be a victim of terrorism (Arthur et al., 2018). Organizations did not run businesses through the internet decades ago, as such ideas only existed as dreams in science fiction stories. Nowadays, millions of organizations run their daily businesses online. They depend on the internet to function, and handle their business. Huge sums of money are moved through networks, by means of bank transactions or credit card purchases. Anywhere there is huge sum of money, there are also individuals who will like to utilize that situation to steal or perform fraud.

Several years back, computer security was particularly concerned with basic components that form the computer. Many years ago, computers used to be the priceless items organizations could not bear losing. Currently, computer equipment is cheap in contrast with the information processed by the computer. The priceless item, went from the machine, to the information it keeps and processes. Extensive computer criminal actions many years back, was targeted towards obtaining illegal access to computer systems, not for the purpose of causing harm, but on a pursuit of academic inquisitiveness. The universal disposition of networks and computers, has reduced the supposed essence of breaching computers to acquire more knowledge about them. Therefore, it is normal today that malicious intents have substituted academic inquisitiveness.

For instance, sometime in 1995, Kevin Mitnick was detained over activities carried out in his computer in 1980s and 1990s. It involves unlawful access to about 20,000 credit card numbers, which included some belonging to Silicon Valley moguls, thereby causing serious millions of dollars damage to computer operations. He pled guilty to two counts of computer fraud, four counts of wire fraud, and one count of tapping wire communication illegally. He also acknowledged obtaining illegal entrance to computer systems of organizations like Sun Microsystems, Motorola, and Novell. He explained how he used diverse sets of tools and methods, which includes social engineering, replicated cellular telephones, and sniffers. However, there was no indication that he used the files he had stolen for financial gain, and would back his actions as inoffensive kind of play.

A second example is the slammer worm which was released to Microsoft by researcher David Litchfield in July 2002, and submitted with the consent of Microsoft at a Black Hat security conference held in October 2002. It is a 2003 computer worm that caused a denial of service on some internet hosts. It utilized a buffer-overflow weakness in computers running on Microsoft SQL Server. The worm had already infected 120,000 hosts on the minimum within the first 24 hours of its release. It caused network outages and interruptions of airline flights. It is projected that it took less than 10 minutes for the worm to corrupt up to 90 percent of the hosts, and doubled the number of affected hosts every 8 seconds. Ensuring that software is current with regards to release from seller, is one of the efficient methods security professionals can utilize to tackle incidents on their computer networks and systems. Impact of worms and virus outbreak would not have been acute if everyone had implemented security update patches just as soon as they were released.

On April 9 2009, San Jose area of California was hit by internet outage and widespread phone disconnection. The outage however, was not an outcome of cyberthieves bent on getting illegal access to computers and networks, rather, it was an outcome of numerous cuts in the fiber optic cables that transmit signals. The vandalization caused a loss of the entire telephone and internet service for thousands of people in the San Jose area. Now, when a computer is unable to do what it is expected to do, it is believed not to be secured. In like manner, Information Security is described by the information actually secured from illegal access or modification, and at the same time accessible to authorized individuals when needed. In the past, risks were relatively smaller and commonly irritant, but subsequently, more structured components of cybercrime have sufficed. The cyber threat prospect became more alarming with latest enemies out to execute operations like exploiting systems with aim to gain financially, steal intellectual property, or even financial information such as the PII (Personally Identifiable Information). The APIs (Advanced Persistent Threats) illustrate latest kind of attack models. Advanced signifies the adoption of complex methods such as spear phishing as a transmitter into a victim. Persistent signifies the enemy's aim of setting-up a continuing seclusion on a system. Threat signifies intention; exploitation. A lot of APIs can carry on for years in a system and remain undetected the entire period.

From an academic viewpoint, the first versions of ransomware date back to mid-1990s to late 1990s and so is not an unfamiliar threat. However, it was not until recently that it was utilized, so was practically hypothetical. Ransomware is rated as one of the highest threats nowadays as it has consistently developed since 2012. Remarkable number of recent ransomware attacks make use of a hybrid encrypting scheme, locking up records on the computer of the victim until a ransom is paid. In May 2017, WannaCry spanned as an encrypting worm, striking Systems that operate Microsoft Windows yet to be patched against SMB (Server Message Block).

III. DISCUSSION AND ANALYSIS

In 1991, a model framework used for creating and assessing information security programs, in what is known as McCumber Cube was created by John McCumber. The security model is portrayed as a three-dimensional cube-like grid which is comprised of:

- Information security properties: this is the first dimension of the model, and comprises of the three things that make up the Information security; Confidentiality, Integrity, Availability. For example, in the eBay 2014 February attack, the Confidentiality principle was violated as personal details of over 145 million clients, got exposed to unauthorized persons; the cyberthieves who managed to gain illegal access to the organization's network.
- Information states: the second dimension of the information security model, consisting of Processing, Storage and Transmission. Information can be conveyed through the internet or network and can also be saved on a hard drive. One may ask why eBay stored that much data of over 145 million clients including encrypted passwords, phone numbers, and home addresses on their database. They could easily have used any other storage means if they must keep such massive data.
- Safeguards: technology, is not necessarily what Information Technology Professionals consider when planning solutions to the information security problem. Rules and Methods offer the foundation for an organization.

How would one know how to configure their firewall without the appropriate rules and methods to direct them? It is a complete must, to teach employees to be security aware, so that whatever security measures executed in the organization will be successful. The operational model of a computer security, comprises of diverse technologies. Protection, is the entirety of prevention, and the measures used for detection and response (Ahmed, 2020). Controls need to be applied at diverse points before security can be effective. For instance, an organization may decide to get a security guard to watch the outside and at the same time may also require a biometric palm scan before accessing the server room. Access control describes the level of security structures that can be used to stop unapproved access to network or computer system. A lot of devices can be configured in a way that clearly specifies what kind of access or privileges a user has at a particular given time. For example, just because a particular employee, has access to log onto the organization's network, does not mean that such employee also has the permission to use maybe the printer. Authentication confirms that a user is actually whom they say they are; confirms the identity of a user. The user might need to generate a password, biometric like fingerprint or a card.

Communication security has various segments like:

- Emission security: comprises of actions taken to preclude unauthorized persons from interrupting or examining electronic waves a machine may generate.
- Transmission security: measures taken to ensure transmissions are protected from interception.
- Cryptosecurity: this makes sure that cryptosystems are secure and correctly used.
- Physical security: physical actions taken to protect confidential documents, data, and equipment.

Technology is not required for social engineering to take place; all the attacker needs to do is to convince their victim to provide their confidential information. Social engineering is one of the highly effective techniques cyberthieves use to gain access to networks and computer systems. In the attack on eBay, the cyberthieves might have used social engineering to deceive the employees into running their malicious file. Then again, there is also a possibility that they might have impersonated the employee by injecting undesired codes in their database. Social engineering collects what appears to be worthless bits of information, that when assembled disclose other sensitive information. Due care and Due diligence are the two terminologies that arise when examining steps taken to protect an organization's environment. Due Care examines all the measures an organization takes, in order to protect their company, their resources, and their employees. Due diligence demands that organization have recurrent actions to ensure that precautions are operational and sustained. Although eBay till date, has not disclosed how their employees' credentials were obtained by the cyberthieves, history has shown that most attacks start by web application vulnerability exploitation, or social engineering attack. The human side of computer security is secure system development and management.

Protection is not even automated in a reliable system; therefore, administrators require spelt out guidelines that distinctly defines what methods and actions to take earlier while working towards security. Security in this evolving world no longer depends on what our software or tools can do for us, rather in what we can do for ourselves. Setting security policies for our organization, and applying diligence in stating and sustaining them, is the first step in maintaining protection. This effort spans through all levels. While security Administrators are the ones in charge of implementing security polices with regards to protection, detection and enforcement, it is the responsibility of the user to ensure security is kept. The managers and proprietors must approve, sustain and penalize those who violate the process. For example, if the security policy of an organization requires that they regularly back up data, the administrator should make sure he trains users on how to do the backup and also severely punish them if they fail to comply.

Incident response is the most strategic area for all units to meet; what actions to take when there is a breach. In the eBay 2014 breach, one would say that the organization does not prove to have a good workable incident response. Considering the manner in which they handled the whole situation. It took over a month before the organization even noticed the breach. Even after they noticed, it took days before they reluctantly made a post on their less traffic site, simply requesting clients to change their password. eBay's response to losing control of over 145 million clients' information is said to be the worst form of response ever. Security policy is an existing record that needs to be efficient and regularly assessed. There are certain ways to interpret security policy into an actual defense: modifying and setting up intrusion detection systems and firewall, training users, administrating passwords, and assessing audit logs. Administrative security comes in 3 categories:

- Overall security administration and planning: this involves cooperating with management to establish a security policy for your organization, circulate it, get management approval for it, carryout risk analysis and disaster planning, educate users and supervise employees.

- Daily security administration: this category involves creating account and allocating security profiles to users. Some controls may include how often they are permitted to change their passwords, and at what hours they are free to log in.
- Daily system administration: involves making sure the system is running, performing backups on a daily basis, scanning for breaches, and assessing the state of both the software and hardware used in operation.

Computer security is a deal so once you are thinking of operating, developing or purchasing a security product, you have to contrast its cost to the risk of forgoing it. Great number of organizations normalize this practice and call it risk analysis. Risk analysis is a method used to assess possible deficits that may ensue from system weaknesses, and to measure the loss that may occur should any risk happen. The paramount objective of risk analysis is to choose an economical but efficient safety measures to cut risks to tolerable degree. Fundamentally, risk analysis is simply a means to fathom how valuable your system is, and the extent you are prepared to go with regards to people, tools, and finances to guard it (Lehtinen et al.,2006). A regular risk analysis requires observing all your physical resources such as buildings, tools, and computers and deciding how to safeguard them. The most valued resource one's organization has may be the data processed by their computers, consequently, one has to think of safest way to safeguard it. When assessing the data resources of your organization and reflecting if to safeguard it, and how to safeguard it, you would require to ask yourself these questions:

1. What data do you have and what is their importance?
2. How unprotected is it?
3. What will it cost to protect it?
4. What will it cost if it is lost or endangered?
5. Who will you call should there be an attack on your system?

Planning for disaster is one of the most essential things one can do to guard their organization from calamity. Disaster recovery plan is a preparation, that helps in maintaining the accessibility of your data and computer in occurrence of a disaster. The disaster plan may include actions such as backups and prearranging for other facilities. It could be formal or informal. Informal is when you make a mutual arrangement with another organization, branch or section to use one another's things in case an attack happens. Formal is when you prepare a distinct place for backup or outrightly outsource to organizations who handle disaster preparation.

Security specialists alerted that the clients' information that were stolen will most likely make eBay clients phishing targets effortlessly. The cyberthieves can send emails with malicious links and entice their targets into clicking such links. They can also lead them to fake login displays where they are requested to input more important information like their social security number or password. eBay communicated the Federal Bureau of Investigation's San Francisco office and also an external Computer Forensic Firm. Collaborating, they discovered that the cyberthieves had been in their corporate network since late February. eBay found through their computer logs, that the thieves had taken the identification of some of their employees and obtained illegal entry into their corporate network allowing them to duplicate a database which contained information of over 145 million clients. eBay informed their customers who use same passwords for their PayPal to get a new one straightaway. Although laws of notification vary by states, some states need organizations to inform customers of an attack only when their names, social security number, and credit cards are jointly compromised. However, encrypted information is exempted.

In eBay's case, the company encrypted the passwords of their clients, but left information such as their names, email, birth dates and physical addresses in plain text. A high number of states, would not have demanded eBay to reveal the breach. Some state like North Dakota, needs organizations to reveal an attack only in situations where a client's name is endangered together with their date of birth. Owing to the breach suffered by eBay in February 2014, a federal judge has dismissed the lawsuit filed against eBay. The lawsuit was filed by Collin Green sometime in July 2014, on behalf of American eBay users whose information were compromised during the breach. In the lawsuit, he alleged that the data breach caused financial harm for the clients but was unable to prove his claims. eBay maintained that there was no indication that payment card details had been compromised, or was there any actual damage suffered by any client and the ruling judge seemed to agree.

Information security is not restrained to wired systems, it is similarly crucial for wireless communications such as cellular and WIFI. Encryption is an essential technology in countless ways of communication. There is need to explore new improvements such as applications from algebraic formations like ECs (Elliptic Curves), rings and quantum physics. Over the years, standard cryptography has advanced to quantum cryptography, which is equally a branch of quantum information theory. Quantum cryptography is created on the quantum physics structure, and explains the difficulties of key distribution which is a critical section of cryptography that allows for data security. The key grants permission for coding of data, so that in order to decode the data, one should understand the key used in coding them. Encryption is coding a data using a key, and the reverse gradual decoding of the encrypted data is known as decryption. Encryption algorithm is in two phases; symmetric and asymmetric. Encryption of data makes data unusable and also stops the exposure of such data to unapproved access.

The three-dimensional approach required for data security includes: Detection, Prevention and Response. Information usually stays on storage medium that is often accessible across a network. The network is created with limits in it, such that each entry point gives a path for incoming and outgoing movement via the router, broadened by a firewall. Detection allows one to examine the actions of everyone using the network, offers a way to distinguish degrees of activities, and suggests likely evidence to network intrusions. Response is proportionately crucial, because a network intrusion should not be permitted to reoccur. The three-dimensional approach is progressional, thus, system investigation and policies should be considered when designing a secured information network. Cryptographic protocols will allow protected interaction by addressing nonrepudiation, authentication, confidentiality, and integrity.

IV. CONCLUSIONS AND RECOMMENDATIONS

One cannot assume a system is secured because it was created by them. Every man-made system is bound to have a flaw, and it doesn't take long before someone discovers it. Computers and the internets have changed virtually all outlook of our lives both professionally and personally. Safeguarding information is an essential issue for any organization; therefore, they should make computer security a priority. Why is computer security essential? It is essential because knowledge of computer security fundamentals can help prevent your information from getting into wrong hands. Delicate information is indispensable, and this has made computer systems bull's eye to cyberthieves and hackers. Computer security experts must make effort to incorporate best computer security approaches in their organization. This includes overseeing computer and network security, and designing a security-oriented values in their organization.

There are various kinds of computer security that effect different sections of an organization's digital and physical arrangement. Security experts should concentrate on these forms of security: Network security, Application security, Endpoint security and Information security. Every single one of these kinds of computer security comprises of various elements and can most likely be studied as their own expert fields. Network security concerns the physical elements of a network like the Servers, Routers and the software elements like the firewalls and security policies. Computer security professionals need to be well informed on extensive computer security issues, so as to safeguard their organizations from the progressing cyber threats they are faced with on a daily basis. Computer security safeguards people and organizations from loss of essential information and cyberthreats.

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Worker Ant Optimization: An Algorithm for Complex Problems

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Abstract— *The article introduces a novel metaheuristic algorithm called the Worker Ant Optimization (WAO) algorithm. This algorithm is mathematically modeled based on five natural behaviors of worker ants: avoiding danger, foraging, approaching food, decomposing food, and transporting food. The performance of WAO was evaluated using 23 classical test functions and compared with results from seven well-known metaheuristic algorithms. Simulation results demonstrate that the WAO algorithm exhibits significant advantages in terms of convergence speed, avoidance of local optima, and optimization accuracy. To assess the effectiveness of WAO in practical applications, the method was applied to three classical engineering design problems, validating the engineering applicability of the WAO optimization algorithm. WAO effectively explores the decision space and performs well across various evaluation metrics, demonstrating its capability to effectively address challenges in practical applications.*

Keywords— Classical test functions; Constrained optimization; Engineering constraint issues; Swarm optimization; WAO.

I. INTRODUCTION

The term "optimization problem" refers to a situation where the goal is to find feasible solutions under given constraints [1]. It involves the process of seeking optimal values for specific system parameters within existing solutions, aiming to meet a certain criterion at minimal cost [2]. Such criteria could include maximizing profit, minimizing costs, maximizing efficiency, or minimizing risks. Optimization problems find widespread applications in fields such as engineering, economics, management, and computer science.

Typically, an optimization problem comprises several elements: decision variables, constraints, and an objective function [3]. In practical applications, optimization problems can be highly complex, often involving conflicting objective functions and numerous constraints. To address these challenges, enhance system performance, and reduce computational costs, various optimization methods have been developed. These methods are generally categorized into two classes: mathematical methods and metaheuristic algorithms.

In academic and applied contexts, optimizing system parameters involves leveraging these methodologies to achieve desired outcomes efficiently and effectively.

In various real-world applications, particularly in fields like artificial intelligence and machine learning, optimization problems often exhibit discrete, unconstrained, or non-continuous characteristics [4]. Traditional mathematical programming methods rely on gradients, are sensitive to initial conditions, and struggle to solve such complex problems [5]. This limitation has spurred the development of metaheuristic algorithms [6].

Metaheuristic algorithms simulate the behavior of biological individuals or populations in nature to explore and optimize solution spaces. They are based on principles of simulation and natural inspiration for global optimization [7][8]. The optimization process begins by initializing a set of random feasible solutions in the problem space. Subsequently, these solutions are iteratively updated and improved according to algorithmic instructions. Upon completion, the algorithm identifies the optimal solution among the candidate solutions [9].

Due to their nature as stochastic searches, metaheuristic algorithms cannot guarantee finding the globally optimal solutions. However, they often converge near-optimal solutions that are accepted as quasi-optimal [10].

Metaheuristic algorithms draw inspiration from problem-solving methods observed in nature, such as cooperative behaviors among fish, birds, and ants. This intelligence emerges from interactions among simple individuals in a group, without the need for centralized control. Group members follow basic behavioral rules, exhibiting collective intelligent behavior through interaction. Algorithms based on simulating natural behaviors like population reproduction, hunting, and migration can solve complex optimization problems [11]. This research field is known as swarm intelligence [12]. In recent years, these algorithms have found wide applications in areas like image processing, path planning, and data mining, yielding significant research outcomes. Common swarm intelligence algorithms include Particle Swarm Optimization (PSO) [13], Sine Cosine Algorithm (SCA) [14], Raccoon Optimization Algorithm (ROA) [15], Genetic Algorithm (GA) [16], Harris Hawks Optimization (HHO) [17], Artificial Bee Colony (ABC) [18], Grey Wolf Optimizer (GWO) [19], and Whale Optimization Algorithm (WOA) [20].

This article proposes a novel metaheuristic algorithm—the Worker Ant Optimization (WAO), which simulates natural behaviors of worker ants. It evaluates WAO's performance in solving optimization problems using 23 classic test functions and compares its optimization results with seven well-known metaheuristic algorithms. The study tests WAO's performance in solving practical optimization problems in three engineering design scenarios.

The article introduces the WAO algorithm and models it in Section 2. Section 3 investigates the efficiency of WAO through simulation studies and analysis of practical applications. Section 4 examines WAO's efficiency in addressing real-world optimization problems. Finally, conclusions are drawn, and several future research directions are suggested.

II. WORKER ANT OPTIMIZATION ALGORITHM

2.1 Source of inspiration:

Worker ants in the black ant society undertake the crucial task of searching for and transporting food. The foraging behavior of worker ants demonstrates a high level of adaptability and intelligence. They are capable of adjusting their foraging strategies based on environmental changes, expanding their foraging range in times of food scarcity, and regulating the length and speed of foraging queues to meet different foraging needs.

During the food search process, worker ants release a chemical substance called pheromones to mark their foraging paths, which come in two types. When encountering natural enemies, worker ants release an alarm-type pheromone; when discovering food, they release a trail-type pheromone to guide other worker ants.

Other worker ants perceive these pheromones through their sense of smell and respond accordingly to their types. When receiving alarm-type pheromones, worker ants will avoid paths marked as dangerous; when receiving trail-type pheromones, worker ants will gather along the path indicated to locate the food. In addition to using pheromones to find paths, worker ants also observe the surrounding environment, memorize prominent landmarks, and use them to determine their position and direction, thereby adjusting their routes to find the optimal path.

After finding food, worker ants transport it back to the nest. If the food is too large, worker ants employ a decomposition strategy, cutting off and carrying back parts of the food until the task is completed.

Through this division of labor and pheromone communication system, worker ants in the black ant colony efficiently search for and transport food, ensuring the survival and reproduction of the entire ant colony. This behavioral strategy enables worker ants to cooperate to accomplish complex tasks and respond appropriately to different situations.

2.2 Algorithm initialization process:

The Ant Colony Optimization algorithm is based on the behavior of ants. In the WAO algorithm, ants are candidate solutions to the optimization problem, meaning that the position updates of each ant in the search space represent the values of decision variables. Therefore, each ant is represented as a vector, and the ant colony is mathematically characterized by a matrix. Similar to traditional optimization algorithms, the initialization stage of WAO involves generating random initial solutions. In this step, the following formula is used to generate vectors of decision variables:

$$x_{i,j} = lb_j + r * \left(ub_j - lb_j\right), \quad i = 1,2,\ldots,N, \quad j = 1,2,\ldots,m \tag{1}$$

In this context, $x_{i,j}$ represents the value of the j^{th} decision variable of the i^{th} candidate solution, r is a random number within the range of 0 to 1, and lb and ub denote the lower and upper bounds, respectively, of the j^{th} decision variable. The ant colony population can be mathematically represented by the matrix hh, referred to as the population matrix.

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{bmatrix}_{N*m} = \begin{bmatrix} X_{1,1} & \cdots & X_{1,j} & \cdots & X_{1,m} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ X_{i,1} & \cdots & X_{i,j} & \cdots & X_{i,m} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ X_{N,1} & \cdots & X_{N,j} & \cdots & X_{N,m} \end{bmatrix}_{N*m} \tag{2}$$

2.3 Mathematical model:

In WAO, the process of updating the position of worker ants (candidate solutions) is based on modeling four natural behaviors of the ants. These behaviors include:

a) Avoidance of danger behavior

b) Foraging behavior

c) Attraction to food behavior

d) Decomposition and transport of food behavior

2.3.1 Avoidance of danger behavior

This stage is modeled based on the danger avoidance behavior of worker ants. If a worker ant encounters a predator while searching for food, it releases an alarm pheromone. When other worker ants detect this alarm pheromone, they will avoid the route. The route where the predator is encountered is assumed to be the position of the best member. To simulate the behavior of the ants moving away in the opposite direction, an inverse learning update strategy based on the principle of convex lens imaging is used.

Inverse learning, proposed by Tizhoosh, is an optimization mechanism that expands the search range by calculating an inverse solution based on the current solution during the population optimization process. The current solution and the inverse solution's objective function values are compared, and the better solution is selected for the next iteration [21]. However, the inverse solution generated by the inverse learning strategy is at a fixed distance from the current solution, lacking randomness, and thus cannot effectively enhance the diversity of the population within the search space. Combining optimization algorithms with inverse learning can effectively improve the optimization performance of the algorithm. However, since the value generated by the inverse learning strategy is fixed, it cannot effectively help the algorithm escape local optima in the later stages of iteration and lacks randomness. Therefore, the lens imaging principle is introduced into the inverse learning strategy. As shown in the figure below, taking a two-dimensional space as an example, $[a, b]$ represents the search range of the solution, and the y axis represents the convex lens. Suppose there is an object p with height h and a projection on the $x$axis of x^*; this object is imaged by the convex lens on the other side as an inverted real image $p^*$with height $h^*$and a projection on the axis of x^*. According to the principle of convex lens imaging:

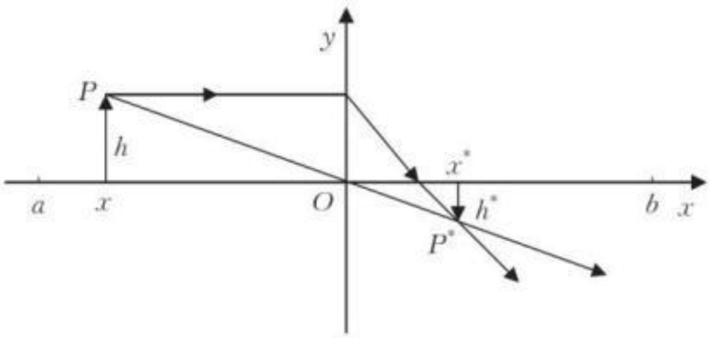

FIGURE 1: Schematic Diagram of the Reverse Learning Strategy for Lens Imaging

$$\frac{\frac{a+b}{2}-x}{x'-\frac{a+b}{2}} = \frac{h}{h'} \tag{3}$$

Let $n = \frac{h}{h'}$, then the equation can be rewritten as:

$$x' = \frac{a+b}{2} + \frac{a+b}{2n} - \frac{x}{n} \tag{4}$$

Further, the equation can be rewritten as the optimization algorithm update strategy:

$$n = \frac{5}{e^{-5.5*\frac{t}{t_{max}}}} \tag{5}$$

$$X_i^{t+1} = \frac{lb+ub}{2} + \frac{lb+ub}{2n} - \frac{X_{best}^t}{n} \quad (6)$$

2.3.2 Foraging behavior:

$$X_i^{t+1} = \begin{cases} r_1 * lb + r_2 * (ub - X_i^t), & p < 0.5 \\ X_i^t * e^{-\left(\frac{t}{r_3 * t_{max}}()^a\right)} \end{cases} \quad (7)$$

During foraging, worker ants adjust their strategies and intensity based on food availability. When food is scarce, they expand their foraging range and adjust their foraging intensity according to the length and speed of the foraging trail. The random walk strategy simulates the ants' behavior of randomly searching for food, while adaptive weights model the changes in foraging speed and intensity. The random walk strategy moves randomly within the search space to find the optimal solution. In each update, two random numbers within the interval [0,1] are generated to adjust the current solution's position, aiming to find better solutions. This randomness enhances the global search capability of the algorithm and helps avoid local optima. The adaptive weight strategy decreases exponentially with the number of iterations, allowing strong global search capabilities in the early stages and improving local search capabilities as the algorithm approaches the optimal solution. Here, t is the current iteration count, t_{max} is the maximum number of iterations, r_1, r_2, and $r_3$are random numbers within the range of 0 to 1, $lb$and $ub$are the bounds of the search space representing the ants' activity range, and $a$is a constant.

2.3.3 Approach behavior:

$$C_1 = \left(3 - e^{\left(\frac{t}{t_{max}}()^3\right)}()_4\right) \quad (8)$$

$$C_2 = \frac{X_{g\_best} + X_{best}^t}{2} \quad (9)$$

$$E = lb + r_5 * (ub - lb) \quad (10)$$

$$X_i^{t+1} = \begin{cases} X_i^t + C_1 * (C_2 - X_i^t), & p < 0.5 \\ X_i^t + r_6 * (X_i^t - E), & else \end{cases} \quad (11)$$

In this section, the behavior of worker ants approaching the food source is simulated. The ants use pheromones to follow and approach the food location denoted by C_2, and move with a step size determined by a nonlinear parameter $C_1$to get closer to the food source. The formula dynamically transitions the population from global search to local exploitation. In the early stages of the algorithm, a larger step size is maintained to enhance global search capability, while in the later stages, a smaller step size improves the precision of local development. In addition to using pheromones, ants also adjust their direction based on environmental observations and noticeable landmarks to find the best route to the food. Here, X_{best}^trepresents the position of the best individual in the population at the t^{th} iteration, $X_{g_best}$is the position of the globally best individual so far, $r_4$is a random number within the 2D [0,1] range, $r_5$is a random number between 0 and 1, and $r_6$is a random number following a standard normal distribution.

2.3.4 Food decomposition and transport:

$$D = 0.2 * \left(1 - e^{-5*(\frac{t}{t_{max}})^3}\right) \quad (12)$$

$$X_i^{t+1} = \begin{cases} D * X_i^t - r_7, & p < 0.5 \\ X_{best}^t + r_8 * (X_{best}^t - X_i^t), & else \end{cases} \quad (13)$$

When the food is large, worker ants choose to cut it into smaller pieces for easier transport. The parameter Drepresents the proportion of food cut by the ants relative to the current food volume. Initially, when the food is large, the cutting proportion is small. As the cutting progresses and the food volume decreases, the cutting proportion increases until the remaining food can be transported directly. The mathematical formula representing the ants' behavior in transporting food to the nest approaches the optimal value. Random perturbations, generated by a normal distribution, are applied to the current optimal solution, with the perturbation magnitude determined by the difference between the current optimal solution and the current solution. This strategy leverages information from the current optimal solution and introduces randomness to increase diversity in the search process, preventing convergence to local optima and enhancing global search convergence and robustness. Here, X_{best}^trepresents the position of the best individual in the population at the t^{th} iteration, $r_7$is a random number in the [0,1] interval, $r_8$is a random number following a standard normal distribution, $t$is the current iteration count, and $t_{max}$is the maximum number of iterations.

2.3.5 Repetition process and flowchart of WAO:

The specific optimization scheme is shown in Figure 2. After updating the positions of all the ants in the search space based on the first and second stages, the WAO iteration is completed. The population update process is repeated using equations (4), (5), (9) and (11) until the final iteration of the algorithm. Once a WAO run is completed, the best solutions obtained throughout all iterations of the algorithm are returned as output.

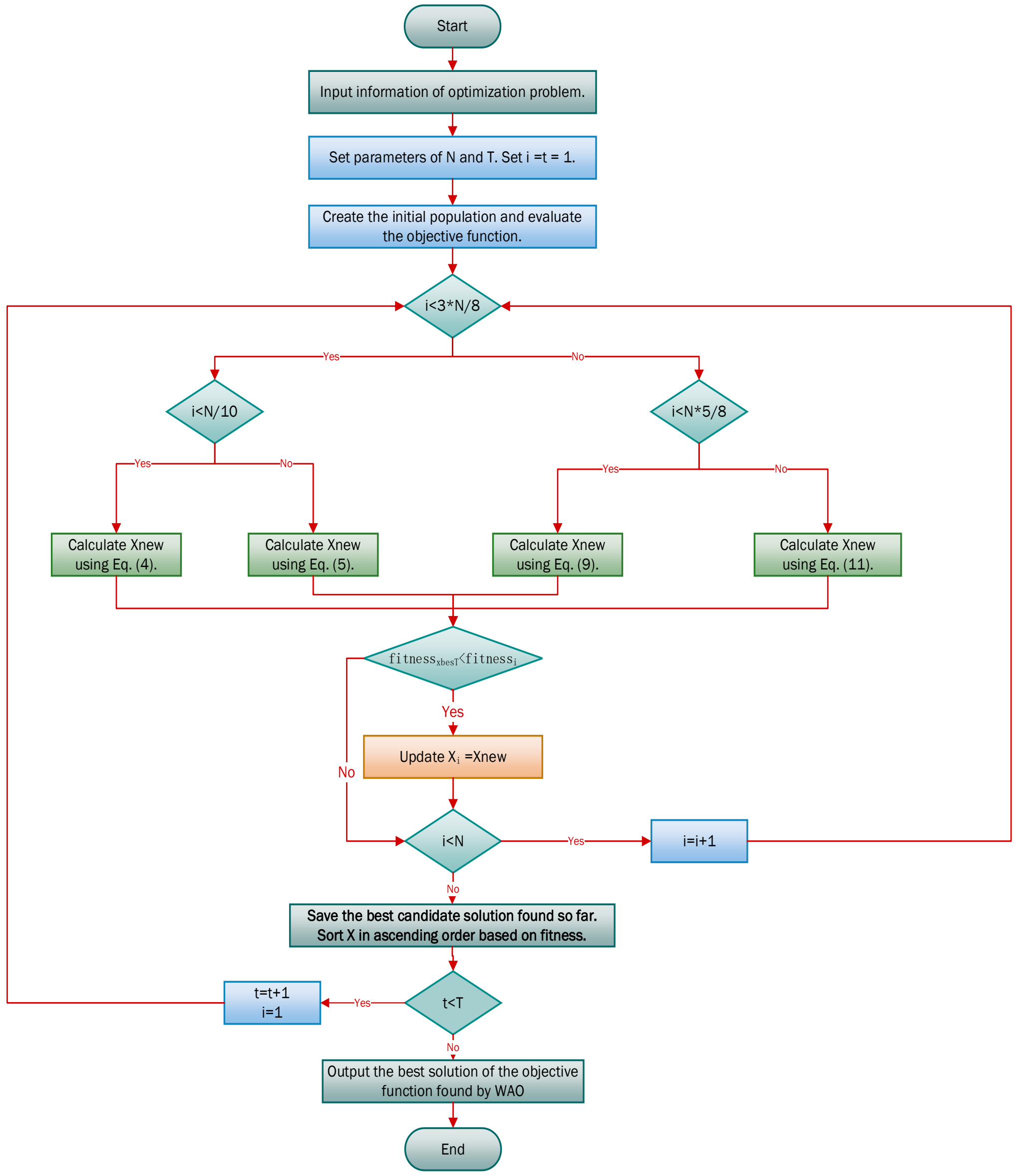

FIGURE 2: Flowchart of the worker ant optimization algorithm

III. EXPERIMENT SIMULATION AND ANALYSIS

To thoroughly validate the superiority of the WAO algorithm, this study tests it using 23 classical test functions, which effectively demonstrate the algorithm's optimization capability. Functions F1-F7 are unimodal test functions with a single theoretical optimal solution, used to assess the algorithm's convergence speed and accuracy. Functions F8-F23 are multimodal test functions with multiple local optima and one theoretical global optimum, used to evaluate the algorithm's global search capability and its ability to avoid local optima. Tables 1-3 provide the specific function forms, while Fig. 3 shows the function plots for F1-F23.

TABLE 1
UNIMODAL BENCHMARK FUNCTIONS

Function	Dim	Range	fmin
$F_1(x) = \sum_{i=1}^{n} x_i^2$	50	$[-100,100]$	0
$F_2(x) = \sum_{i=1}^{n} \lvert x_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$	50	$[-10,10]$	0
$F_3(x) = \sum_{i=1}^{n} \left(\sum_{j=1}^{i} x_i \right)^2$	50	$[-100,100]$	0
$F_4(x) = max\{\lvert x_i \rvert, 1 \leq i \leq n\}$	50	$[-100,100]$	0
$F_5(x) = \sum_{i=1}^{n-1} \left[100\left(x_{i+1} - x_i^2\right)^2 + (x_i - 1)^2\right]$	50	$[-30,30]$	0
$F_6(x) = \sum_{i=1}^{n} ([x_i + 0.5])^2$	50	$[-100,100]$	0
$F_7(x) = \sum_{i=1}^{n} ix_i^4 + random0,1)$	50	$[-1.28,1.28]$	0

TABLE 2
MULTIMODAL BENCHMARK FUNCTIONS

Function	Dim	Range	fmin
$F_8(x) = \sum_{i=1}^{n} -x_i sin\left(\sqrt{\lvert x_i \rvert}\right)$	50	$[-500,500]$	-20949
$F_9(x) = \sum_{i=1}^{n} \left[x_i^2 - 10cos(2\pi x_i) + 10\right]$	50	$[-5.12,5.12]$	0
$F_{10}(x) = -20exp\left(-0.2\sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}\right) - exp\left(\frac{1}{n}\sum_{i=1}^{n} cos(2\pi x_i)\right) + 20 + e$	50	$[-32,32]$	0
$F_{11}(x) = \frac{1}{4000}\sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} cos\left(\frac{x_i}{\sqrt{(i)}}\right) + 1$	50	$[-600,600]$	0
$F_{12}(x) = \frac{\pi}{n}\left\{10sin(\pi y_i) + \sum_{i=1}^{n-1} (y_i - 1)^2[1 + +10sin^2(\pi y_{i+1})] + (y_n - 1)^2\right\} + \sum_{i=1}^{n} \mu\,(x_i, 10,100,4)$ $y_i = 1 + \frac{x_i + 1}{4}$ $\mu(x_i, a, k, m) = \begin{cases} k(x_i - a)^m, x_i > a \\ 0, -a \leq x_i \leq a \\ k(-x_i - a)^m, x_i < -a \end{cases}$	50	$[-50,50]$	0
$F_{13}(x) = 0.1\left\{sin^2(3\pi x_i) + \sum_{i=1}^{n} (x_i - 1)^2[1 + sin^2(3\pi x_i + 1)] + (x_n - 1)^2[1 + sin^2(2\pi x_n)]\right\} + \sum_{i=1}^{n} \mu\,(x_i, 5,100,4)$	50	$[-50,50]$	0

To better assess the improved algorithm's performance, comparisons are made with currently mainstream and newly emerging optimization algorithms, including COA, GSA, WOA, GWO, GA, PSO, and HHO. For fairness, all algorithms are tested with the same dimensionality, a population size of 50, and each function is solved independently 30 times.

TABLE 3
FIXED-DIMENSION MULTIMODAL BENCHMARK FUNCTIONS

Function	Dim	Range	fmin
$F_{14}(x)=\left(\frac{1}{500}+\sum_{j=1}^{25}\frac{1}{j+\sum_{i=1}^{2}(x_i-a_{ij})^6}\right)^{-1}$	2	$[-65,65]$	1
$F_{15}(x)=\sum_{j=1}^{11}\left[a_i-\frac{x_1(b_i^2+b_ix_2)}{b_i^2+b_i^2x_3+x_4}\right]^2$	4	$[-5,5]$	0.0003075
$F_{16}(x)=4x_1^2-2.1x_1^4+\frac{1}{3}x_1^6+x_1x_2-4x_1^2+4x_1^4$	2	$[-5,5]$	-1.0316285
$F_{17}(x)=\left(x_2-\frac{5.1}{4\pi^2}x_1^2+\frac{5}{\pi}x_1-6\right)+10\left(1-\frac{1}{8\pi}\right)cos\,x_1+10$	2	$[-5,5]$	0.398
$F_{18}(x)=[1+(x_1+x_2+1)^2(19-14x_1+3x_1^2-14x_2+16x_1x_2+3_2^2)]*[30+(2x_1-3x_2)^2*(18-32x_1+12x_1^2+48x_2-36x_1x_2+27x_2^2)]$	2	$[-2,2]$	3
$F_{19}(x)=-\sum_{i=1}^{4}c_iexp\left(-\sum_{j3=1}^{3}a_{ij}(x_j-p_{ij})^2\right)$	3	$[1,3]$	-3.86
$F_{20}(x)=-\sum_{i=1}^{4}c_iexp\left(-\sum_{j3=1}^{6}a_{ij}(x_j-p_{ij})^2\right)$	6	$[0,1]$	-3.32
$F_{21}(x)=-\sum_{i=1}^{5}[(X-a_i)(X-a_i)^T+c_i]^{-1}$	4	$[0,10]$	-10.1532
$F_{22}(x)=-\sum_{i=1}^{7}[(X-a_i)(X-a_i)^T+c_i]^{-1}$	4	$[0,10]$	-10.4028

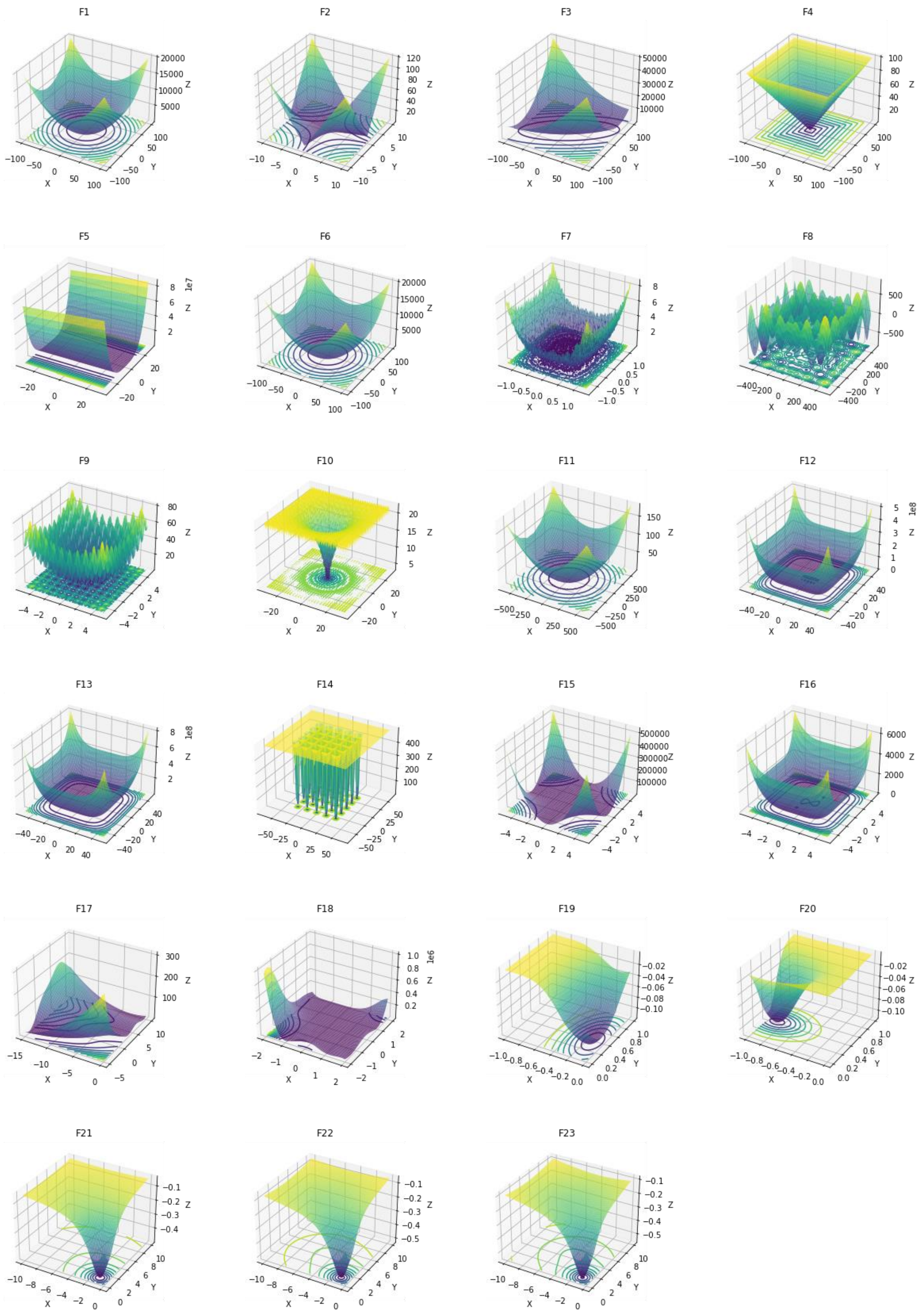

FIGURE 3: Classical function images

3.1 Comparison of different algorithms on classical test functions:

3.1.1 Analysis of solution accuracy:

The maximum iteration count is set to 300, and the test results are shown in Table 4, with the optimal results highlighted in bold. It is evident that WAO outperforms all comparison algorithms on unimodal test functions, indicating its superior development capability and fast convergence speed. For multimodal functions, WAO performs well on F12-F15 and F21-F23, demonstrating its ability to maintain good population diversity and avoid local optima. For functions F9-F12, F17, and F18, WAO's results are comparable to those of other algorithms. Overall, WAO shows better or comparable average optimization results across all 23 classic functions. However, it has slightly higher variance on F8, F16, F19, and F29 compared to other algorithms, and is slightly less effective than COA on F7, suggesting areas for further improvement.

TABLE 4
RESULT OF FIXED-DIMENSION MULTIMODAL BENCHMARK FUNCTIONS

Function	Item	COA	GSA	WOA	GWO	GA	PSO	HHO	WAO
F1	Mean	4.08E-227	5.99E-124	1.55E-54	9.71E-49	3.03E+02	4.93E+04	4.66E-142	**0.00E+00**
	STD	0.00E+00	3.28E-123	5.63E-54	2.15E-48	7.26E+01	2.02E+04	2.29E-141	**0.00E+00**
F2	Mean	3.15E-115	1.41E-79	5.87E-34	1.69E-31	6.77E+00	3.10E+19	5.00E-73	**0.00E+00**
	STD	1.01E-114	7.65E-79	2.76E-33	4.24E-31	9.38E-01	1.06E+20	2.57E-72	**0.00E+00**
F3	Mean	3.77E-228	1.06E-109	1.42E+05	3.68E+04	4.44E+04	1.35E+05	1.87E-85	**0.00E+00**
	STD	0.00E+00	5.83E-109	3.40E+04	1.24E+04	7.86E+03	6.03E+04	1.01E-84	**0.00E+00**
F4	Mean	1.38E-114	1.03E-82	8.78E+01	2.06E-10	2.44E+01	8.82E+01	3.98E-72	**0.00E+00**
	STD	6.20E-114	5.63E-82	4.02E+00	6.49E-10	2.64E+00	9.01E+00	1.42E-71	**0.00E+00**
F5	Mean	1.39E+00	1.02E-02	4.84E+01	4.86E+01	1.36E+04	3.40E+08	3.33E-04	**1.74E-07**
	STD	2.17E+00	2.28E-02	2.51E-01	4.88E-02	6.00E+03	1.70E+08	5.96E-04	**6.03E-07**
F6	Mean	7.49E-02	7.10E-04	1.61E+00	2.82E+00	3.02E+02	5.07E+04	2.85E-06	**1.22E-07**
	STD	4.72E-02	1.69E-03	5.57E-01	5.95E-01	7.51E+01	3.09E+04	3.68E-06	**2.51E-07**
F7	Mean	**1.31E-04**	1.46E-04	5.14E-03	8.41E-04	2.86E-01	1.74E+02	1.59E-04	1.93E-04
	STD	**1.05E-04**	1.13E-04	6.93E-03	5.39E-04	6.08E-02	1.29E+02	1.54E-04	1.58E-04
F8	Mean	-1.13E+04	**-2.09E+04**	-1.45E+04	-1.48E+04	-2.04E+04	-5.11E+03	-1.96E+04	**-2.09E+04**
	STD	1.63E+03	**4.19E-01**	5.24E+02	4.55E+02	1.00E+02	1.19E+03	2.72E+03	5.95E+01
F9	Mean	**0.00E+00**	**0.00E+00**	9.30E+01	**0.00E+00**	3.51E+01	6.53E+02	**0.00E+00**	**0.00E+00**
	STD	**0.00E+00**	**0.00E+00**	1.44E+02	**0.00E+00**	2.94E+00	8.14E+01	**0.00E+00**	**0.00E+00**
F10	Mean	**4.44E-16**	**4.44E-16**	4.00E-15	3.88E-15	4.51E+00	2.00E+01	**4.44E-16**	**4.44E-16**
	STD	**0.00E+00**	**0.00E+00**	2.59E-15	6.38E-16	3.67E-01	1.06E-03	**0.00E+00**	**0.00E+00**
F11	Mean	**0.00E+00**	**0.00E+00**	5.80E-03	**0.00E+00**	3.90E+00	5.14E+02	**0.00E+00**	**0.00E+00**
	STD	**0.00E+00**	**0.00E+00**	1.59E-02	**0.00E+00**	5.98E-01	2.57E+02	**0.00E+00**	**0.00E+00**
F12	Mean	1.83E-03	1.17E-05	9.54E-01	8.51E-02	2.22E+00	6.83E+08	2.91E-07	**1.11E-08**
	STD	1.48E-03	3.31E-05	3.48E+00	2.86E-02	6.86E-01	4.27E+08	3.02E-07	**1.97E-08**
F13	Mean	7.43E-02	7.34E-05	1.84E+00	1.32E+00	2.31E+01	1.40E+09	5.00E-06	**4.20E-07**
	STD	5.20E-02	1.07E-04	2.93E+00	2.87E-01	7.48E+00	7.74E+08	5.24E-06	**8.42E-07**
F14	Mean	1.03E+00	1.10E+00	2.70E+00	3.56E+00	1.04E+00	2.11E+00	3.16E+00	**9.98E-01**
	STD	1.82E-01	3.24E-01	2.92E+00	2.73E+00	1.91E-01	1.61E+00	2.69E+00	**1.25E-16**
F15	Mean	1.00E-03	3.74E-04	9.59E-04	6.57E-04	6.47E-03	1.13E-02	1.10E-03	**3.07E-04**
	STD	4.74E-04	6.53E-05	1.48E-03	4.20E-04	7.48E-03	9.41E-03	2.38E-03	**9.57E-19**
F16	Mean	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**	**-1.03E+00**
	STD	6.09E-07	7.95E-03	4.85E-16	2.25E-07	4.60E-03	5.26E-03	6.42E-16	**5.80E-16**
F17	Mean	**3.98E-01**	4.02E-01	**3.98E-01**	4.23E-01	4.17E-01	4.52E-01	**3.98E-01**	**3.98E-01**
	STD	9.77E-10	9.73E-03	9.03E-15	1.03E-01	3.90E-02	2.77E-01	2.34E-06	**0.00E+00**
F18	Mean	**3.00E+00**	**6.81E+00**	**3.00E+00**	6.60E+00	1.13E+01	**3.00E+00**	**3.00E+00**	**3.00E+00**
	STD	3.77E-06	9.69E+00	3.61E-15	9.18E+00	1.76E+01	5.49E-04	6.56E-15	**2.24E-15**
F19	Mean	**-3.86E+00**	-3.82E+00	**-3.86E+00**	**-3.86E+00**	**-3.86E+00**	-3.85E+00	**-3.86E+00**	**-3.86E+00**
	STD	3.67E-04	6.68E-02	1.91E-15	7.90E-04	6.04E-04	6.14E-02	1.44E-07	**2.44E-15**
F20	Mean	-3.25E+00	-3.06E+00	-3.27E+00	-3.25E+00	-3.29E+00	-2.85E+00	-3.25E+00	**-3.30E+00**
	STD	**4.73E-02**	1.00E-01	5.89E-02	7.38E-02	5.25E-02	2.87E-01	7.54E-02	4.76E-02
F21	Mean	-9.79E+00	-1.01E+01	-8.05E+00	-8.62E+00	-6.32E+00	-5.94E+00	-6.24E+00	**-1.02E+01**
	STD	3.48E-01	6.60E-03	3.06E+00	2.43E+00	3.50E+00	2.96E+00	2.16E+00	**5.39E-15**
F22	Mean	-1.01E+01	**-1.04E+01**	-8.53E+00	-8.01E+00	-5.01E+00	-5.17E+00	-6.51E+00	**-1.04E+01**
	STD	3.89E-01	8.25E-03	2.92E+00	2.96E+00	3.19E+00	3.58E+00	2.35E+00	**7.25E-16**
F23	Mean	-1.00E+01	**-1.05E+01**	-6.47E+00	-8.30E+00	-5.63E+00	-5.43E+00	-7.11E+00	**-1.05E+01**
	STD	7.92E-01	4.67E-03	3.68E+00	2.92E+00	3.62E+00	3.53E+00	2.61E+00	**2.00E-15**

3.1.2 Convergence analysis:

Comparing algorithm performance solely based on average values is not sufficient. To more intuitively demonstrate the performance of the WAO algorithm compared to other algorithms in terms of convergence accuracy and speed, Fig. 4 displays the convergence curves of each algorithm on the test functions. The horizontal axis represents the number of iterations, while the vertical axis reflects the convergence accuracy of the algorithm, i.e., the final fitness value. By comparing the evolutionary curves and convergence accuracy of seven algorithms on each test function, a detailed analysis of the experimental results was conducted. The results indicate that WAO outperforms other algorithms in most test functions. For single-peak functions F1-F6, WAO shows exceptional convergence speed and search capability compared to other optimization algorithms. For multi-peak functions, WAO exhibits better convergence accuracy and faster convergence speed on test functions F8-F13. On test functions F14-F23, WAO's convergence speed is comparable to that of other individual algorithms, quickly converging to global optima and demonstrating good capability in escaping local optima. However, WAO's convergence speed on test function F7 is slightly inferior to COA, indicating room for improvement. All algorithms achieved optimal or near-optimal solutions. Overall, compared to other established optimization algorithms, WAO performs well on both single-peak and multi-peak test functions, confirming its robustness across various function types and its applicability in solving complex optimization problems.

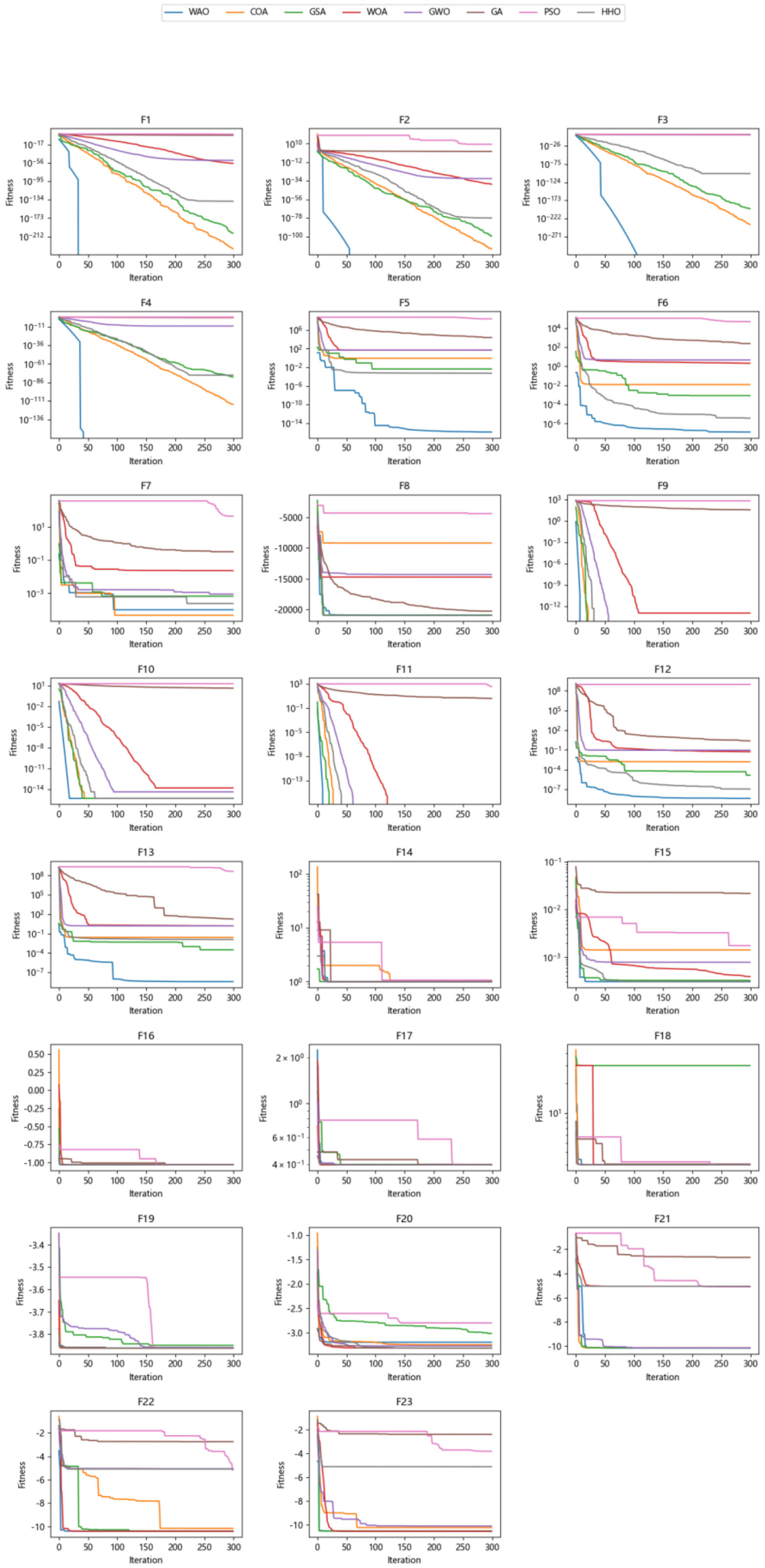

FIGURE 4: Comparison of convergence rates for different algorithms

3.2 Rank sum test:

This section employs the Wilcoxon signed-rank test to determine if there are statistically significant differences between the improved algorithm and the comparison algorithms, reducing the influence of chance in the tests. A significance level of 5% is set; if $p$is less than 5%, the null hypothesis is rejected, indicating a significant difference between the two algorithms; otherwise, the performance difference is not substantial. Results from 23 test functions are compared to assess WAO's statistical advantage. Table 5 displays the experimental results. Since the algorithm cannot be compared with itself, WAO's p are not included. Values in the table greater than 5% are bolded, and it is evident that most p are below 5%, indicating significant differences between WAO and the other seven comparison algorithms, suggesting that WAO has superior search capability.

TABLE 5
WILCOXON SIGNED-RANK TEST RESULTS

Function	COA	GSA	WOA	GWO	GA	PSO	HHO
F1	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F2	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F3	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F4	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F5	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F6	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	9.31323E-09
F7	**0.556113275**	**0.370740607**	3.72529E-09	8.32602E-07	1.86265E-09	1.86265E-09	**0.452164343**
F8	1.86265E-09	0.000152871	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	**0.164184082**
F9	**1**	**1**	0.00352902	**1**	1.86265E-09	1.86265E-09	**1**
F10	**1**	1.86265E-09	7.24259E-06	7.25244E-08	1.86265E-09	1.86265E-09	**1**
F11	**1**	**1**	0.022010526	**1**	1.86265E-09	1.86265E-09	**1**
F12	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	3.72529E-09
F13	1.86265E-09	5.58794E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	6.91041E-07
F14	1.82537E-06	1.86265E-09	5.99237E-05	1.86265E-09	1.86265E-09	1.86265E-09	6.71136E-06
F15	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F16	1.82537E-06	1.86265E-09	**0.202112635**	1.86265E-09	1.86265E-09	1.86265E-09	0.000499647
F17	1.86265E-09	1.86265E-09	0.000563755	1.86265E-09	1.86265E-09	1.86265E-09	0.000102642
F18	1.86265E-09	1.86265E-09	0.040256192	1.86265E-09	1.86265E-09	1.86265E-09	0.00041528
F19	1.86265E-09	1.86265E-09	0.000461595	1.86265E-09	1.86265E-09	1.86265E-09	1.82537E-06
F20	0.000283264	1.86265E-09	0.000460107	0.001232104	0.00256009	1.86265E-09	1.06096E-05
F21	1.86265E-09	1.86265E-09	2.73906E-06	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F22	1.86265E-09	1.86265E-09	3.65907E-05	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09
F23	1.86265E-09	1.86265E-09	3.43673E-06	1.86265E-09	1.86265E-09	1.86265E-09	1.86265E-09

IV. ENGINEERING DESIGN OPTIMIZATION PROBLEMS

The experimental parameter settings and test functions are the same. The engineering problems include the welding beam design optimization problem and the gearbox design problem, both using the same number of iterations (300) and population size (100) for optimization. The optimization results are compared with those obtained using COA, GSA, WOA, GWO, GA, PSO, and HHO algorithms.

4.1 Welded beam design problem:

The Welded beam design problem, as shown in Fig.5, is a minimization problem aimed at reducing manufacturing costs. The optimization algorithm focuses on minimizing the cost of manufacturing the welding beam by optimizing the beam's length l, height t, thickness b, and weld seam thickness h. Consequently, this problem is a classic nonlinear programming problem. Set $X = [x_1, x_2, x_3, x_4] = [h, l, t, b]$, the corresponding objective function f, constraints g, and the ranges of the design variables are as follows:

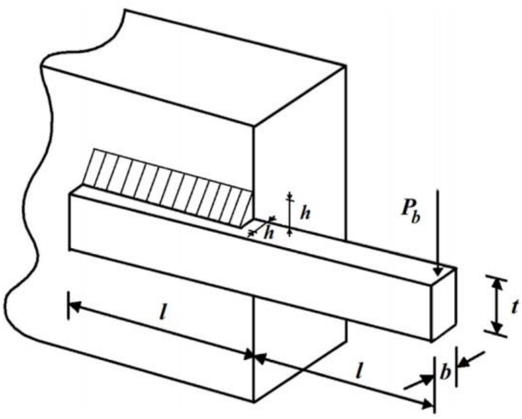

FIGURE 5: Schematic diagram of welded beam design

$$min\, f(x_1, x_2, x_3, x_4) = 1.1047x_1^2x_2 + 0.04811x_3x_4(14 + x_2) \tag{14}$$

Subject to

$$g_1(X) = \tau(X) - \tau_{max} \leq 0$$

$$g_2(X) = \sigma(X) - \sigma_{max} \leq 0$$

$$g_3(X) = \delta(X) - \delta_{max} \leq 0$$

$$g_4(X) = x_1 - x_4 \leq 0$$

$$g_5(X) = P - P_c(X) \leq 0$$

$$g_6(X) = 0.125 - x_1 \leq 0$$

$$g_7(X) = 1.10471x_1^2 + 0.04811x_4x_3(14.0 + x_2) - 5.0 \leq 0$$

$$0.1 < x_1 < 2$$

$$0.1 < x_2 < 10$$

$$0.1 < x_3 < 10$$

$$0.1 < x_4 < 2$$

In the constraints, the expressions for each function can be referenced using the following formulas:

$$\tau(X) = \sqrt{(\tau')^2 + 2\tau'\tau''\frac{x_2}{2R} + (\tau'')^2}$$

$$\tau' = \frac{P}{\sqrt{2}x_1x_2}$$

$$\tau'' = \frac{MR}{J}$$

$$M = P\left(L + \frac{x_2}{2}\right)$$

$$R = \sqrt{\frac{x_2^2}{4} + \left(\frac{x_1 + x_2}{2}\right)^2}$$

$$J = 2\left\{\sqrt{2}x_1x_2\left[\frac{x_2^2}{4} + \left(\frac{x_1 + x_2}{2}\right)^2\right]\right\}$$

$$\sigma(X) = \frac{6PL}{x_4x_3^2}$$

$$\delta(X) = \frac{6PL^3}{Ex_4x_3^2}$$

$$P_c(X) = \frac{4.013E\sqrt{\frac{x_3^2x_4^6}{36}}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right)$$

$$\sigma_{max} = 30000psi$$

$$P = 6000lb$$

$$\delta_{max} = 0.25in$$

$$L = 14i$$

$$E = 3 * 10^6psi$$

$$\tau_{max} = 136000psi$$

$$G = 1.2 * 10^7psi$$

Set the population size to 100 and the number of iterations to 300. The results of each algorithm are shown in Tables 6 and 7.

TABLE 6
PERFORMANCE OF OPTIMIZATION ALGORITHMS ON THE WELDED BEAM DESIGN PROBLEM

Algorithm	Optimum variables				Optimum cost
	X1	X2	X3	X4	
WAO	0.2057	3.2349	9.0366	0.2057	1.6928
COA	0.2019	3.3597	9.0366	0.2057	1.7041
GSA	0.2061	3.3923	9.0805	0.2065	1.7285
WOA	0.143	5.0461	9.4019	0.204	1.8713
GWO	0.2004	3.3447	9.0441	0.2059	1.7024
GA	0.2077	3.4654	8.4791	0.2404	1.8779
PSO	0.1722	4.1204	9.0456	0.2058	1.7577
HHO	0.1577	4.6585	9.0493	0.2057	1.7986

TABLE 7
STATISTICAL RESULTS OF OPTIMIZATION ALGORITHMS ON WELDED BEAM DESIGN PROBLEM.

Algorithm	Best	Worst	Mean	Std	Median
WAO	1.6928	2.3649	1.7512	0.1595	1.6935
COA	1.7041	1.8995	1.7814	0.047	1.7787
GSA	1.7285	3.7164	1.9276	0.3626	1.8221
WOA	1.8713	4.961	2.9542	0.8289	2.7298
GWO	1.7024	3.1509	1.9544	0.3537	1.8016
GA	1.8779	3.777	2.4613	0.4042	2.3894
PSO	1.7577	2.6159	2.1221	0.247	2.0264
HHO	1.7986	3.9132	2.4908	0.4976	2.338

4.2 Speed reducer design problem:

In a mechanical system, the reducer is a crucial component of the gearbox. The optimization problem involves minimizing the weight of the reducer while adhering to constraints related to gear root bending stress, surface stress, shaft lateral deflection, and shaft stress. The variables to be optimized include the gear face width b, gear module m, number of teeth in the small gear p, length of the first shaft between bearings l_1, length of the second shaft between bearings l_2, diameter of the first shaft d_1, and diameter of the second shaft d_2. The integer variable $p$is specified with $X = [x_1, x_2, x_3, x_4, x_5, x_6, x_7] = [b, m, p, l_1, l_2, d_1, d_2]$, while the remaining variables are continuous.

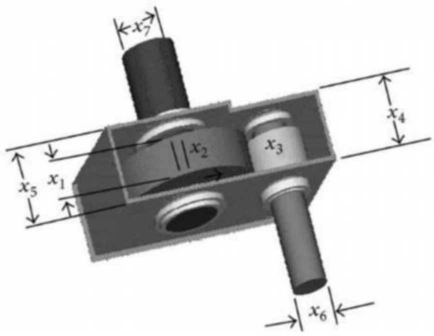

FIGURE 6: Schematic diagram of speed reducer design

The corresponding objective function f, constraints g, and variable ranges are as follows:

$min\, f(x_1, x_2, x_3, x_4, x_5, x_6, x_7) = 0.7854x_1x_2^2(3.3333x_3^2 + 14.9334x_3 - 43.0934) - 1.508x_1(x_6^2 + x_7^2) + 7.4777(x_6^3 + x_7^3) + 0.7854(x_4x_6^2 + x_5x_7^2)$ (15)

Subject to

$$g_1(X) = \frac{27}{x_1x_2^2x_3} - 1 \le 0$$

$$g_2(X) = \frac{397.5}{x_1x_2^2x_3^2} - 1 \le 0$$

$$g_3(X) = \frac{1.93x_4^3}{x_2x_3x_6^2} - 1 \le 0$$

$$g_4(X) = \frac{1.93x_5^3}{x_2x_3x_7^2} - 1 \le 0$$

$$g_5(X) = \frac{\sqrt{\left(\frac{754x_4}{x_2x_3}\right)^2 + 16.9e^6}}{110x_6^3} - 1 \le 0$$

$$g_6(X) = \frac{\sqrt{\left(\frac{754x_5}{x_2x_3}\right)^2 + 157.5e^6}}{85x_7^3} - 1 \le 0$$

$$g_7(X) = \frac{x_2x_3}{40} - 1 \le 0$$

$$g_8(X) = \frac{5x_2}{x_1} - 1 \le 0$$

$$g_9(X) = \frac{x_1}{12x_2} - 1 \le 0$$

$$g_{10}(X) = \frac{1.5x_6 + 1.9}{x_4} - 1 \le 0$$

$$g_{11}(X) = \frac{1.1x_6 + 1.9}{x_5} - 1 \le 0$$

$$2.6 < x_1 < 3.6$$

$0.7 < x_2 < 0.8$

$17 < x_3 < 28$

$7.3 < x_4 < 8.3$

$7.8 < x_5 < 8.3$

$2.9 < x_6 < 3.9$

$5.0 < x_7 < 5.5$

The optimization results for each algorithm are presented in the following table:

TABLE 8
PERFORMANCE OF OPTIMIZATION ALGORITHMS ON SPEED REDUCER DESIGN PROBLEM.

Algorithm	Optimum variables							Optimum cost
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	
WAO	3.5	0.7	17	7.3	7.7153	3.3502	5.2867	2994.4711
COA	3.506	0.7	17	7.3	7.8226	3.3542	5.2867	3000.22
GSA	3.5054	0.7	17	8.0664	8.0664	3.4445	5.2869	3036.2795
WOA	3.5	0.7	17	7.7858	7.7858	3.3512	5.2868	3000.66
GWO	3.5001	0.7	17	7.3	7.9708	3.3502	5.2911	3003.06
GA	3.5008	0.7001	17.0012	7.3036	7.7288	3.3504	5.2867	2996.0666
PSO	3.6	0.7	17	7.3	8.3	3.3535	5.2874	3047.89
HHO	3.5067	0.7	17	7.3	7.7521	3.3502	5.2868	2997.9701

TABLE 9
STATISTICAL RESULTS OF OPTIMIZATION ALGORITHMS ON SPEED REDUCER DESIGN PROBLEM

Algorithm	Best	Worst	Mean	Std	Median
WAO	2994.4711	3007.8428	2997.0406	4.4774	2994.4809
COA	3000.2235	3050.3287	3020.9087	12.102	3017.5886
GSA	3036.2795	5296.003	3312.7957	581.8437	3143.7067
WOA	3000.6616	5285.8882	3518.3961	594.6483	3241.1305
GWO	3003.0627	5278.9856	3337.8872	650.8056	3128.7551
GA	2996.0666	3549.0969	3018.3054	98.6448	2999.037
PSO	3047.8934	3222.3128	3096.4834	65.7039	3058.8795
HHO	2997.9701	5105.7952	3691.6963	703.4508	3503.2547

4.3 Pressure vessel design problem:

In the pressure vessel design problem, the goal is to minimize the cost while meeting production requirements. The pressure vessel has covers at both ends, with one end featuring a hemispherical head. The design involves four optimization variables: $L$is the length of the cylindrical section of the vessel, $R$is the internal diameter, $T_s$is the thickness of the vessel wall, and $T_h$is the thickness of the head. Let $X = [x_1, x_2, x_3, x_4] = [T_s, T_h, R, L]$. The objective function f, constraints g, and the range of the design variables are specified as follows:

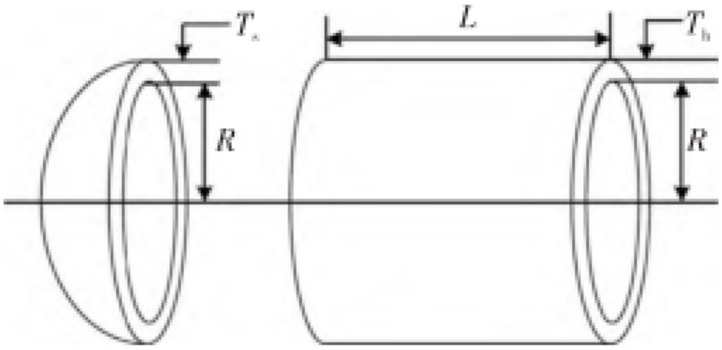

FIGURE 7: Schematic diagram of pressure vessel design

$$min\, f(x_1, x_2, x_3, x_4) = 0.6224x_1x_3x_4 + 1.7781x_2x_3^2 + 3.1661x_1^2x_4 + 19.84x_1^2x_3 \quad (16)$$

Subject to

$$g_1(X) = -x_1 + 0.0193x_3 \leq 0$$

$$g_2(X) = -x_2 + 0.00954x_3 \leq 0$$

$$g_3(X) = -\pi x_3^2 x_4 - \frac{4\pi x_3^3}{3} + 1296000 \leq 0$$

$$g_4(X) = x_4 - 240 \leq 0$$

$$0.0625 < x_1 < 99.999$$

$$0.0625 < x_2 < 99.999$$

$$10 < x_3 < 200$$

$$10 < x_4 < 200$$

The optimization results for each algorithm are presented in the following table:

TABLE 10
PERFORMANCE OF OPTIMIZATION ALGORITHMS ON THE PRESSURE VESSEL DESIGN PROBLEM

Algorithm	Optimum variables				Optimum cost
	x1	x2	x3	x4	
WAO	0.7782	0.3846	40.3196	200	5885.3379
COA	0.8274	0.4589	42.8696	167.3251	6138.5222
GSA	1.0935	0.5401	55.7566	58.7088	6758.2153
WOA	0.9177	0.4504	47.2075	122.1683	6193.3793
GWO	0.8598	0.425	44.4798	149.2101	6048.4539
GA	1.0668	0.5797	53.7254	71.5534	6998.602
PSO	1.4299	0.6468	65.3164	10	8201.8786
HHO	0.8533	0.4366	44.2053	152.201	6078.8689

TABLE 11
STATISTICAL RESULTS OF OPTIMIZATION ALGORITHMS ON THE PRESSURE VESSEL DESIGN PROBLEM.

Algorithm	Best	Worst	Mean	Std	Median
WAO	5885.3379	7319.007	6433.909	514.0014	6261.0542
COA	6138.5222	12346.614	7755.2197	1376.762	7317.44
GSA	6758.2153	26704.47	11746.118	6174.4435	9119.3473
WOA	6193.3793	437875.79	105923.96	131415.26	45444.839
GWO	6048.4539	10080.049	6788.6016	751.3376	6725.7667
GA	6998.602	13656.272	8624.9883	1344.316	8481.7794
PSO	8201.8786	68129.769	23515.66	15195.015	14875.789
HHO	6078.8689	138840.5	11210.103	23706.136	6805.7329

V. CONCLUSION AND FUTURE WORK

This paper presents a novel metaheuristic optimization algorithm called the Worker Ant Optimization (WAO) algorithm, designed to simulate various activities of worker ants in nature, including behaviors such as avoiding danger, foraging, approaching food, and decomposing and transporting food. The paper develops a mathematical optimization model based on these natural activities of worker ants and rigorously evaluates the convergence speed and search accuracy of WAO across 23 classic test functions. The quality of WAO optimization results is compared with the performance of seven well-known algorithms. Simulation results show that WAO exhibits excellent convergence speed, achieves a suitable balance between exploration in global search and exploitation in local search, and demonstrates a strong ability to escape local optima, providing effective solutions for optimization problems. Additionally, the WAO method is applied to three engineering design optimization problems, and its applicability to engineering optimization is validated. The comparisons with seven well-known optimization algorithms further demonstrate the advantages of the WAO algorithm in optimizing complex global optimization problems.

However, it is worth noting that there is still room for improvement in the convergence speed of WAO. While the algorithm shows strong performance in other aspects, optimizing its convergence rate could further enhance its overall efficiency and effectiveness in solving complex optimization problems. Future research could focus on refining the algorithm's parameters and exploring hybrid approaches to accelerate convergence without compromising its robustness and solution quality.

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Harnessing IoT for Enhanced Industrial Efficiency: A Review of IoT-Enabled Motor Monitoring and Control Systems

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Abstract— *The rapid evolution of technology and the growth of internet networking have established the Internet of Things (IoT) as a central communication method between devices. The number of internet-connected devices is rising, especially in industrial settings, where they enhance the control and monitoring of production processes. IoT plays a critical role in continuously monitoring key industrial parameters, ensuring consistent and high-quality production. Specifically, IoT-based systems are instrumental in ensuring the reliable performance of motors, thereby boosting productivity. These systems are highly beneficial for industrial applications, including solar power plants, where they contribute to efficient electricity usage.*

IoT's current capabilities extend beyond mere connectivity; they now link people and devices, paving the way for increased remote control via mobile applications. This development not only simplifies daily life but also empowers businesses by providing deeper insights into operations and customer preferences. Whether in home automation, healthcare, or industrial applications, IoT-enabled control and monitoring of motors significantly enhance operational productivity. By effectively tracking conditions based on predefined parameters, these systems can adjust motor speeds according to specific process requirements, thereby optimizing performance. Moreover, IoT's ability to collect and analyze vast amounts of data from motors allows for predictive maintenance, preventing issues such as motor overloading and improper handling. This leads to safer operations and extends the lifespan of the equipment. The integration of IoT in monitoring systems enables the storage, processing, and real-time analysis of data, providing actionable insights that reduce maintenance costs, improve reliability, optimize motor performance, and enhance the accuracy of failure predictions. Ultimately, the adoption of IoT in industrial environments not only ensures efficient and effective operations but also drives innovation and sustainability in various sectors.

Keywords— Internet of Things (IoT), Technology evolution, Control and monitoring, Motor performance, Mobile applications, Predictive maintenance, Failure prediction, Sustainability.

I. INTRODUCTION

Among the various AC motors, the three-phase induction motors are much more appreciated in the industry because of possessing comparatively higher degrees of performances. Remote drive inverters are one of the new fronts of enhancing efficiency and reliability of motors. Thus, Internet of Things is one of the most influential means of interacting with various devices due to the fast progress of technologies and the enlargement of the Internet network. The number of connections to the internet has increased and more so in industrial situations which lead to increased control of products.

The use of electrical motors connected to the IoT system is an enhancement that has a vast coverage in the market. Electrical motors form the center of many devices and installations, industrial and domestic and improving their performance and reliability by connecting them to IoT systems.

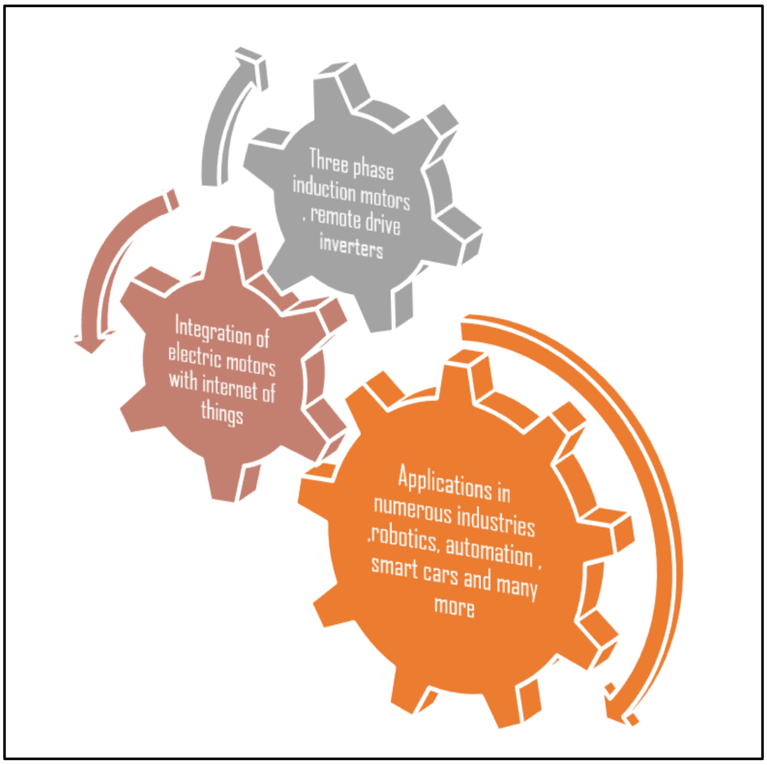

FIGURE 1: Representation of overall advancements by integration of IOT in electric motors

In other words, electric motors and IoT technologies combined empower machines and systems changing the approaches to their functioning by providing high levels of control, intellect, and integration. With IoT constantly growing and developing, the mission of electric motors as the core participants of the global industries' digitalization process will only strengthen in the future, opening up new opportunities for improvement, environmental responsibility, and market positioning.

II. RELATED WORK OF MOTOR AND APPLICATIONS

2.1 Real-Time Monitoring of Electric Motors for Detection of Operating Anomalies and Predictive Maintenance:

In this paper, we illustrate an IoT system to assess electric motors with the aim to identify operation abnormalities. Some of these include; The current architecture for this system will also support what will in future be a predictive maintenance system.

2.2 Low-cost real-time monitoring of electric motors for the Industry 4.0:

This paper reveals the idea, architecture, and evaluation of an IIoT system developed to track electric motors in real-time. This system will for detection of operating anomalies and in the future for a predictive maintenance system. The system has been designed with low-cost wireless multi-sensor modules and a low-cost single board computer as the gateway, and open source software for the data collection and control platform, actually using a free version of an IoT analytics service in the Cloud, where all the data is stored.

2.3 An IoT and Machine Learning-Based Predictive Maintenance System for Electrical Motors:

The current paper presents a conceptual work of integrated an intelligent health monitoring system for predicting equipment failures in industries. Industrial IoT, MQTT messaging and machine learning algorithms makes up the system. Sensors continuously measures vibrations, currents and temperature of electrical motors to analyze real-time data through five developed Machine Learning models for detection and forecasting of a possible failure.

The application of the IoT in the automotive industry is opening up boundless opportunities, revolutionizing the sector while reducing cost and improving quality. In the context of IoT applications in the automotive sector, vehicle manufacturers are engaged in the development of such innovative technologies as predictive maintenance solutions, ADAS, navigation & telematics solutions, in-vehicle infotainment systems, CV2X, and others. The application of IoT in control and monitoring of an electric motor creates smart drives.

III. TECHNOLOGY REFRAME

1. Robotics: Electric motors are part of the robots used in industries. In IoT-enabled robotics, these motors can easily be controlled and remotely monitored to achieve tasks, for example, automated material handling, operations on the assembly line, and even personal assistance robots.

2. Home Automation: Many devices within smart homes, like motorized blinds, curtains, and garage doors, are driven by electric motors. The IoT enables remote control of these motors by smartphones or voice commands and makes them part of more comprehensive home automation.

FIGURE 2: Home Automation System

3. HVAC systems: Electric motors drive fans, compressors, and dampers in the HVAC applications. In IoT-enabled HVAC systems, such motors will tune their speed and drive behavior to real-time data from temperature, humidity, and occupancy sensors to drive energy savings and comfort.

4. Industrial Automation: Electric motors drive industrial machinery in a huge number of applications—from conveyor belt operation to pumps and actuators. The performance of such motors may be optimized by IoT and AI technologies that monitor variables like speed, torque, and temperature to enhance efficiency and predictive maintenance.

5. Medical Devices: Electric motors drive a lot of medical devices, including drug delivery pumps, surgical robots, and diagnostic equipment. In such devices, IoT integration allows remote monitoring, which ensures that maintenance is done on time. This reduces hassles in patient care.

6. Consumer Electronics: Electric motors are embedded in many consumer electronics, from drones to cameras having motor-driven zooms and domestic appliances such as washing machines and dishwashers. IoT connectivity facilitates remote control and monitoring of these devices to enhance convenience and efficient energy usage.

7. Smart Agriculture: Electric motors drive agricultural equipment, such as irrigation systems, harvesters, and drones responsible for monitoring crops. IoT and AI technologies provide for precision agriculture, in that this motor drive could be made optimal for environmental conditions, soil moisture levels, and crop health data.

8. Wearable Devices: Miniature electric motors are applied in wearables, which power a great deal of haptic feedback, vibration alerts, and motorized adjustments. In its IoT connectivity, wearable devices are connected to a smartphone or any other device to track, analyze data for better user experience.

9. Energy Management Systems: Electric motors are integral parts of the energy management systems in industrial facilities, commercial buildings, and residential complexes, whose functions include speed control of pumps, valves, and fans. The IoT-enabled energy management systems adjust the motor operation to energy demand, occupancy patterns, and pricing signals, thereby supporting cost minimization and reducing an installation's environmental impact.

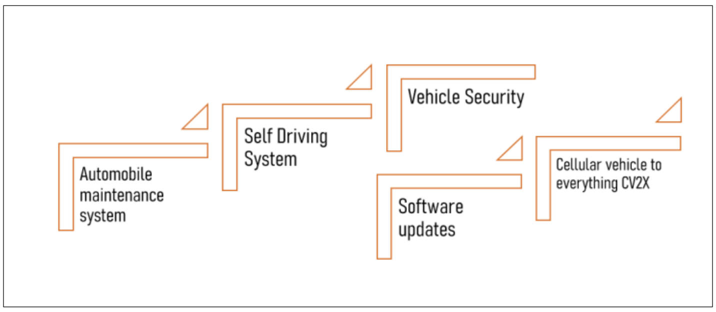

FIGURE 3: Technologically blooming applications

3.1 Automotive Maintenance System:

An automotive maintenance system would be a single software or platform systematizing all tasks and schedules in maintaining a vehicle. These systems are an integral part of fleet management, automobile repair shops, and individual vehicle owners who wish to maintain their vehicles properly. The sensors, which are located within various components of the car, can gather data and provide it to analysts, either through on-premise databases or on the cloud. All this data is going to be analyzed manually or by an algorithm working out future outcomes for that particular component, based on its performance. In this way, predictive maintenance can help the driver.

FIGURE 4: Automotive Maintenance System

A Vehicle Management System is a digital tool that helps businesses monitor, control, and manage their vehicles more effectively. It encompasses a range of functions such as tracking vehicle locations, scheduling maintenance, managing fuel consumption, and ensuring driver safety. The primary aim is to optimize the usage of vehicles, reduce costs, and enhance operational efficiency. It's inevitable that a vehicle's parts will begin to deteriorate and need replacing as they age. Spark plugs and filters need replacing, fluids need refilling, tires need rotating, and many more systems need to be checked on regularly. By staying on top of the little things with a good maintenance schedule, however, you can prevent costly reactive repairs down the line and greatly extend your vehicle's life span.

3.2 Self-Driving System:

Self-drive is slowly becoming a common feature across various vehicles. The one company that people culturally associate with this technology is Tesla. The autopilot feature lets drivers forgo active control over the steering and let the AI dictate how fast to go, when to break, park, change lanes, among others. This technology is yet to mature, with a number of sorry accidents reported, including a fatal one involving a Tesla Model S, killing a 22-year-old college student. However, autopilot-induced accidents for Tesla, for example, are reportedly one for every 978 000 miles. Hopefully, when the technology is fine-tuned, driving will be safer, seamless, and more comfortable than it's ever been.

It will bring safer driving if the positions of the nearby vehicles are collected and shared with other drivers in the vicinity, either through Bluetooth or 5G signal. Tesla itself uses 8 cameras, 12 ultrasonic sensors, and a forward-facing radar to read lane lines and identify nearby cars for autopilot driving. When completely implemented in other cars in the market, less dangerous roads will be realized. Tesla Autopilot is an ADAS developed at Tesla, amounting to partial vehicle automation. As defined by SAE International, Tesla offers "Base Autopilot" for all vehicles with lane centering and traffic-aware cruise control, providing Level 2 automation. FSD stands for Full Self-Driving, which is the name Tesla gives to the beta program that provides fully autonomous driving based on SAE Level 5. The name is disputable because vehicles running on FSD remain at Level 2 automation and, hence, are not "fully self-driving" while requiring active driver supervision. FSD allows semi-autonomous navigation of city streets and the ability to respond to visible traffic lights or a stop sign.

3.3 Vehicle security:

Vehicular telematics conveys the condition and status of the vehicle from external sensors and cameras to the owner's smartphone. This reduces theft auto since any forced entrance will trigger an alert, thus notifying the owner via his or her smartphone. Or, considering that almost all corners of cars are fitted with sensors and cameras, any minor accident—a scratch, a dent, or an accidental touch on someone's leg—will get captured and flashed on the car's screen in a jiffy. This will cut down a good chunk of hit-and-runs that go unreported and can also vindicate insurance claims.

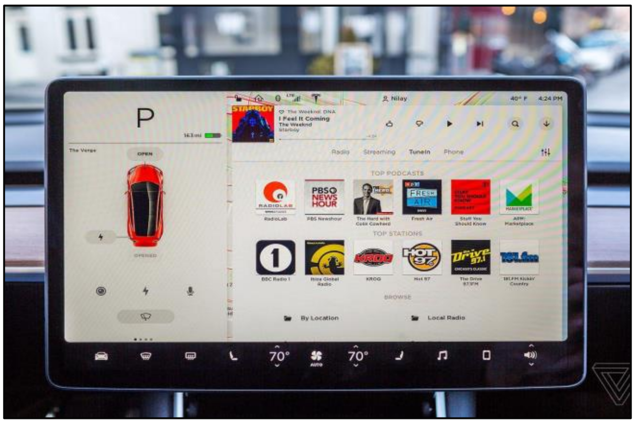

FIGURE 5: Tesla's telematics capabilities.
Source: The Verge

3.4 Software updates:

Like your smartphone, so can cars, using IoT, be remotely upgraded to better software. Some of the enhancements that may be put on these improvements include advanced locking mechanisms and stronger cyber security, in-car entertainment experience, navigation, among others. Besides the above, the majority of well-known car makers do not have any substantial over-the-air software update options. While Tesla has continued doing much more, which is in addition to "luxury"-related enhancements to significantly enhance the driving experience through software updates. For example, Tesla's software programmers were in a position to push an update containing hazard lights automatically flashing after a sudden break in speed. IoT-enabled vehicles receive software updates to improve locking mechanisms, enhance in-car entertainment, fortify cyber security, enhance navigation, and a lot more. One of the maximum IoT applications in the automobile business is the improvement of safety and performance of vehicles, which enhances the driving experience.

3.5 Cellular Vehicle to Everything (CV2X):

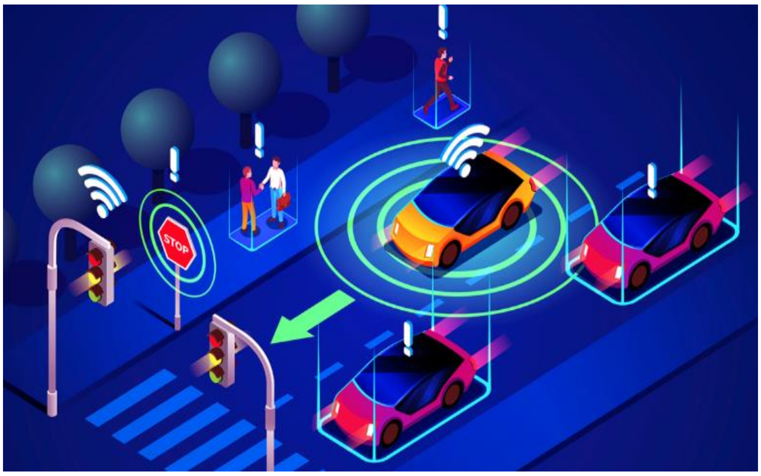

FIGURE 6: CV2X system by ADLINK

One of the most amazing cases of IoT applications in the automotive industry is cellular vehicle-to-everything, CV2X, which connects cars with one another. Connected cars allow faster data transmissions and improved vehicle communication. The CV2X can be further segmented into four sub-categories, depending on different connections the vehicle makes with an object.

A) Vehicle to Vehicle (V2V)-

V2V allows vehicles in proximity to share information about the position, velocity, and vehicle dynamics. V2V is substantially used in avoiding accidents and in facilitating smooth passage of traffic by emergency vehicles such as fire trucks, ambulances among others.

B) Vehicle to Infrastructure (V2I)-

V2I simply stands for the connection between vehicles and road infrastructures. It includes traffic lights, toll booths, lane markings, and so on. V2I facilitates the smooth flow of traffic, thus saving one from getting trapped at petrol pumps and toll booths in long queues.

C) Vehicle to Pedestrians (V2P)-

Using a mobile app, pedestrians can join the CV2X network and find nearby taxis, track how far away transit vehicles are. The pedestrians will also have the ability to associate with the application by using a walking system and modify traffic signals to cross a road without risk of an accident easily.

D) Vehicle to Network (V2N)-

Vehicle-to-network refers to the effective connection between the weather forecast department, Intelligent Transport System, and ITM for alerting the drivers regarding a change in weather condition or an accident on the road. Moreover, vehicle connectivity to smartphones allows the driver to use voice commands while driving for operating music systems and GPS.

IV. CONCLUSION

The integration of Internet of Things (IoT) technology into electric motors represents a significant advancement in both industrial and commercial sectors, revolutionizing their efficiency, productivity, and maintenance. IoT-enabled sensors allow electric motors to achieve unprecedented levels of precision and reliability by facilitating real-time data monitoring, predictive maintenance, and remote control. These capabilities lead to optimized energy consumption, reduced unscheduled downtime, and lower operational costs, all of which contribute to improved overall performance. Furthermore, the seamless integration of IoT with other smart systems fosters interconnected workflows, enhancing management efficiency and enabling higher levels of automation. As IoT technology continues to evolve, its application within electric motors is expected to drive substantial transformations in the industrial landscape, promoting sustainability and serving as a catalyst for innovation across various industries. The future of electric motor applications lies in embracing this technological synergy, which offers the potential to unlock unprecedented levels of performance and competitiveness. By adopting IoT-driven solutions, industries can position themselves at the forefront of a new era of operational excellence, where the benefits of enhanced precision, efficiency, and sustainability become the standard. As such, the adoption of IoT in electric motor systems is not merely an option but a critical step towards achieving long-term success and staying competitive in a rapidly evolving industrial environment. This technological infusion will undoubtedly pave the way for a more sustainable, innovative, and efficient future across all sectors that rely on electric motor applications.

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Improved Egret Swarm Optimization Algorithm with Multiple Strategies

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Abstract— *The Egrets Swarm Optimization Algorithm is a recently proposed heuristic algorithm that simulates the hunting behavior of egrets. To address the limitations of the original algorithm, such as insufficient development capability and decreased population diversity, a multi-strategy improved Egrets Swarm Optimization Algorithm is proposed. First, in the population initialization phase, Logistic chaotic mapping is introduced to generate chaotic sequences, enriching population diversity. Next, a dynamic perception factor is introduced to replace the step size factor in the idle strategy, which allows for more effective exploration and discovery of potential optimal solutions. Furthermore, to increase the breadth and depth of exploration, a crayfish foraging strategy is incorporated into the random walk strategy, and a roulette wheel strategy is added to the encircling mechanism to enhance the algorithm's search ability and avoid ineffective actions. Additionally, a distribution estimation strategy and a new exploration and exploitation strategy based on whale spiral ascent are introduced to improve the overall efficiency and functionality of the algorithm. Finally, testing on 20 classical functions shows that the improved algorithm enhances optimization performance. The algorithm is also applied to solve engineering constraint problems, demonstrating its practicality.*

Keywords— Egret Optimization Algorithm; Roulette Wheel Strategy; Distribution Estimation Strategy; Spiral Ascent Strategy; Crayfish Foraging Strategy.

I. INTRODUCTION

In recent years, with the increasing complexity of problems and the ambiguity of the final results, the demand for optimization algorithms has grown. Optimization problems can be represented as a continuous or combinatorial design search space, where the process involves finding the maximum or minimum of a function.

Metaheuristic algorithms are a class of heuristic methods based on natural phenomena or species behaviors [1], designed to solve optimization problems by simulating the behaviors of organisms or species in nature [2]. These algorithms typically exhibit some degree of randomness and adaptability, enabling them to search for optimal or near-optimal solutions within the search space [3]. Their inspiration comes from various biological phenomena, such as animal collective behavior, plant growth patterns, and microbial reproduction methods. According to the No Free Lunch theorem [4], many metaheuristic algorithms have emerged, including the Zunhai Qiao algorithm [5], Artificial Bee Colony algorithm [6], Butterfly Optimization Algorithm [7], Grasshopper Optimization Algorithm [8], Golden Sine Algorithm [9], Slime Mold Optimization Algorithm [10], Seagull Optimization Algorithm [11], Sparrow Search Algorithm [12], and Teaching-Learning-Based Optimization Algorithm [13]. Optimization problems are widespread across various fields, including engineering optimization, economics, logistics planning, machine learning, and artificial intelligence. Traditional optimization methods often face difficulties in solving complex high-dimensional, nonlinear, multimodal problems, whereas metaheuristic algorithms can effectively address various complex issues in the real world.

The Egret Swarm Intelligence Optimization Algorithm is an optimization algorithm designed based on the foraging behavior of egrets [14], simulating the collaborative and competitive behaviors of egret flocks during foraging to achieve optimization search. However, the Egret Swarm Intelligence Optimization Algorithm has some drawbacks, such as strong local convergence, sensitivity to parameters, and slow convergence speed. To address these issues, scholars have proposed improvements, such as the Sine-Cosine Egret Swarm Optimization Algorithm [15]. To enhance the ESOA algorithm, this paper combines strategies from the Whale Optimization Algorithm [16] and the Crawfish Optimization Algorithm [17], as well as strategies from the Hybrid Artificial Bee Colony Algorithm [18], to improve its search efficiency and optimization performance. The aim is to make the Egret Swarm Intelligence Optimization Algorithm more robust and efficient, thereby better applying it to practical engineering and scientific problems. This paper will present our improvement plan for the Egret Swarm Intelligence Optimization Algorithm and validate the effectiveness and performance advantages of the improved algorithm through a series of test functions [18][19][20] and experimental comparative analysis.

II. EGRETS SWARM OPTIMIZATION ALGORITHM

The Egrets Swarm Optimization Algorithm (ESOA) is an intelligent optimization algorithm introduced by Zuyan Chen and colleagues in 2022. It simulates the collective behavior of egrets during their hunting process. Egrets typically forage in groups, collaborating and competing in wetland environments to capture food, aiming to achieve the best foraging outcome. In the Egrets Swarm Optimization Algorithm, there are two main strategies: waiting and attacking. Suppose an egret team consists of three egrets: Egret A employs a guiding mechanism, Egret B uses random walk, and Egret C adopts an encircling mechanism. The behaviors of these egrets are quantified using corresponding mathematical models, as follows:

2.1 Waiting Strategy:

The observation equation for the i-th egret A can be described as: $y = f(x_i)$, where x_i represents the current position of the egret, and y denotes the assessment of potential prey at this position by Egret A. The parameterized assessment equation is given by Equation (1), where w_i is the weight of the assessment method, updated according to Equation (4). e_i represents the assessment error, and $\hat{g}_i$ is obtained by taking the partial derivative of e_i through Equation (2), representing the actual gradient of w_i.

$$\begin{aligned} \hat{y}_i &= \omega_i \cdot x_i \\ e_i &= \frac{\| \hat{y}_i - y_i \|^2}{2} \end{aligned} \tag{1}$$

$$\begin{aligned} \hat{g}_i &= \frac{\partial \hat{e}_i}{\partial w_i} = \frac{\partial \| \hat{y}_i - y_i \|^2 /2}{\partial w_i} = (\hat{y}_i - y_i) \cdot x_i \\ \hat{d}_i &= \hat{g}_i / | \hat{g}_i | \end{aligned} \tag{2}$$

$$\begin{aligned} \hat{g}_i &= \frac{\partial \hat{e}_i}{\partial w_i} = \frac{\partial \| \hat{y}_i - y_i \|^2 /2}{\partial w_i} = (\hat{y}_i - y_i) \cdot x_i \\ \hat{d}_i &= \hat{g}_i / | \hat{g}_i | \end{aligned} \tag{3}$$

$$\begin{aligned} \hat{g}_i &= \frac{\partial \hat{e}_i}{\partial w_i} = \frac{\partial \| \hat{y}_i - y_i \|^2 /2}{\partial w_i} = (\hat{y}_i - y_i) \cdot x_i \\ \hat{d}_i &= \hat{g}_i / | \hat{g}_i | \end{aligned} \tag{4}$$

Egret A achieves more stable rewards with lower energy consumption by constructing a pseudo-gradient estimator and updating its position based on historical experience. In Equation (3), d_{ibest} denotes the optimal direction within the team, d_{gbest} represents the optimal direction of all teams, while $d_{h,i}$ is the directional correction for the best position within the team, and $d_{h,i}$ is the directional correction for the best position among all teams. Subsequently, the pseudo-gradient of the observation equation weight is calculated using Equation (5), and finally, Egret A's position and fitness are updated based on Equation (6).

Here, t is the current iteration count, $t_{\max}$ is the maximum iteration count, hop is the range of the solution space (i.e., the difference between upper and lower bounds), $step_a$ is the step size factor for Egret A, set to 0.1, and $x_{a,i}$ is the expected next position of Egret B.

$$g_i = (1 - r_h - r_g) \cdot \hat{d}_i + r_h \cdot d_{h,r} + r_g \cdot d_{g,i} \tag{5}$$

$$x_{a,i} = x_i + step_a \cdot exp(- t/(0.1 \cdot ti_{max} \tag{6}$$

$$y_{a,i} = f(x_{a,i}) \tag{7}$$

2.2 Attacking Strategy:

Egret B uses a high-energy-consuming random search strategy, which results in higher potential rewards. Its position and fitness are updated according to Equation (9), where $r_{b,i}$ is a random number in $(-\frac{\pi}{2}, \frac{\pi}{2})$, $step_b$ is the step size factor for Egret B, and $x_{b,i}$ is the expected next position of Egret B. Egret C employs an encircling mechanism; once it locates prey, it will pursue it until captured. The position and fitness updates are given by Equation (12), where D_h is the difference matrix between the team's optimal position and the current position, D_g is the difference matrix between the optimal position of all teams and the current position, and r_h and r_h are random numbers in $[0,0.5)$, with $x_{c,i}$ being the expected next position of Egret B.

$$\begin{aligned} x_{b,i} &= x_i + step_b \cdot \tan(r_{b,i}) \cdot hop / (1+t) \\ y_{b.i} &= f(x_{b,i}) \end{aligned} \tag{8}$$

$$\begin{aligned} D_h &= x_{ibest} - x_i \\ D_g &= x_{gbest} - x_i \\ x_{c,i} &= (1 - r_h - r_g) \cdot x_i + r_h \cdot D_h + r_g \cdot D_g \\ y_{c,i} &= f(x_{c,i}) \end{aligned} \tag{9}$$

2.3 Discrimination Conditions:

After the egret team members compute their expected positions, they will determine the updated positions of the egret team based on the discrimination condition in Equation (10). Specifically, the expected positions and fitness of the four egrets are compared with their positions and fitness from the previous iteration. If any egret's expected position has better fitness than the previous iteration, it will be adopted for updating. Conversely, if all egrets' expected positions have worse fitness than before, a response is made based on a random number r. If r is less than 0.3, there is a 30% chance of accepting a worse solution for position updating.

$$\begin{aligned} x_{s,i} &= [x_{a,i}, x_{b,i}, x_{c,i}, x_{d,i}] \\ y_{s,i} &= [y_{a,i}, y_{b,i}, y_{c,i}, y_{d,i}] \\ c_i &= \arg\min(y_{s,i}) \\ x_i &= \begin{cases} x_{s,i} |_{c_i}, if \quad y_{s,i} < y_i \quad or \quad r < 0.3 \\ \qquad x_i, else \end{cases} \end{aligned} \tag{10}$$

III. IMPROVED EGRET SWARM OPTIMIZATION ALGORITHM

Through the analysis of the ESOA algorithm, it is evident that within an egret team comprising Egret A, Egret B, and Egret C, each egret employs a different strategy for hunting activities. Egret A uses a waiting strategy, where each position update depends on changes in fitness values and is largely influenced by the optimal values of the egret team and the egret population. Egret B, which employs a random walk, symbolizes the aggressive predatory behavior of egrets in nature. While it has a higher probability of achieving greater rewards, it also consumes a significant amount of energy. Egret C, which uses an encircling mechanism, is also prone to getting trapped in local optima.

Therefore, in the ESOA algorithm, the strategies of the egret team members exhibit a degree of blindness, which restricts the range of optimization results. The algorithm suffers from insufficient development capability, slow convergence speed, and a decline in population diversity.

To address these issues, this paper proposes multi-strategy improvements to the parallel framework of the ESOA algorithm, with the aim of enhancing the search capability of the improved Egret Swarm Optimization Algorithm (IESOA) and effectively balancing global and local search abilities.

3.1 Chaotic Local Search Strategy:

Logistic chaotic mapping is one of the simplest and most effective chaotic systems, easy to implement and apply. In this paper, Logistic chaotic mapping is introduced during the initialization of the population in the IESOA algorithm. The output of the Logistic chaotic mapping is used as a random factor to guide the search direction and strategy of the population, increasing the algorithm's randomness and diversity. As shown in Equation (11), where μ is a control parameter with a value of 3.9, the Logistic chaotic mapping exhibits high randomness and can generate high-quality random number sequences.

$$x(i+1) = \mu x(i)(1 - x(i)) \tag{11}$$

3.2 Dynamic Perception Factor:

The step size factor is crucial for finding the optimal solution. Therefore, this paper introduces a Dynamic Perception (DP) factor into the step size of the waiting strategy in the ESOA algorithm. The DP factor changes with each iteration of the algorithm, as described in Equation (12). It can enhance the global search capability of the algorithm in the early stages, expanding the search space, and improve the local search capability in the later stages, thereby enhancing the algorithm's ability to find the optimal solution.

$$DP = \begin{cases} a \cdot (1 - (\frac{t}{t_{\max}})^2), t > \frac{t_{\max}}{2}, \\ a \cdot (1 - \frac{t}{t_{\max}})^2, t \le \frac{t_{\max}}{2}. \end{cases} \tag{12}$$

3.3 Crayfish Foraging Strategy:

In the crayfish foraging strategy, the mathematical model is as follows: crayfish calculate the size of food q according to Equation (13) and choose different foraging methods. Food x_{best} represents the optimal solution. When the size of q is suitable for the crayfish, it will move closer to the food. Equation (15) uses a combination of sine and cosine functions to simulate the alternating process. When q is too large and there is a significant difference between the crayfish and the optimal solution, the size of x_{best} should be reduced to bring it closer to the food and control the crayfish's feeding amount. Given the asynchronous nature of the egret swarm, the crayfish foraging phase strategy is introduced into the random walk strategy of the ESOA algorithm with a probability of $\frac{1}{2}$. Specifically, the egret swarm selects different approaches based on the fitness of the optimal individual, as described in Equations (15) or (16), to approach the optimal solution, thereby updating the expected position and fitness of Egret B.

Including the crayfish foraging phase strategy in the random walk strategy of the ESOA algorithm ensures that during the search process, individuals randomly choose a new position to move with a certain probability. This preserves the randomness and exploratory nature of the search process, allowing individuals to escape from local optima and find better solutions. It also enables the IESOA algorithm to progressively approach the optimal solution, enhancing its development capability and convergence ability.

$$q = c_3 \times rand * (\frac{f_i}{f_{ibest}}) \tag{13}$$

$$x_{best} = \exp(-\frac{1}{q}) \times f_{ibest}$$
$$l = 0.2 \times (\frac{1}{3\sqrt{2\pi}}) \times e^{\frac{-(u-25)^2}{18}} \tag{14}$$

$$x_{b,i} = x_i + x_{best} \times l \times (cos(2 \times \pi \times rand) - sin(2 \times \pi \times rand)) \tag{15}$$

$$x_{b,i} = (x_i - x_{best}) \times l + p \times rand \times x_i \tag{16}$$

$$y_{b,i} = f(x_{b,i}) \tag{17}$$

3.4 Roulette Wheel Strategy:

The roulette wheel strategy, originating from genetic algorithms, essentially simulates the process of "survival of the fittest" in biological evolution. The fitness value of an individual serves as an indicator of how well the individual "adapts." Considering a population of np individuals, each with its own fitness function value, the probability of an individual being selected is defined by Equation (18). The higher the fitness value of an individual, the greater its probability of being selected, which is the principle behind the roulette wheel strategy. Compared to pure random search algorithms, this strategy has the advantage of more effectively utilizing the fitness information of individuals, thereby improving the algorithm's search efficiency and quality.

In the ESOA algorithm, for egret C when searching for prey, individuals adjust their speed and position based on the information of the global optimal position and their own optimal position to approach the optimal solution. This encircling mechanism helps the algorithm better balance exploration and the use of existing information during the search process, improving both global search capability and convergence speed. In the IESOA algorithm presented in this paper, the roulette wheel strategy with a stochastic element is introduced with a probability of $\frac{1}{2}$ during the position update process of egret C. This increases the likelihood of selecting individuals with higher fitness, making the IESOA algorithm more targeted, aiding in retaining high-quality individuals, enhancing the algorithm's convergence and global search capability, while also introducing some randomness to maintain population diversity and avoid local optima.

$$p_i = \frac{f_i}{\sum_{k=1}^{np} f_k} \tag{18}$$

3.5 Distribution Estimation Strategy:

The distribution estimation strategy is a random optimization algorithm based on experimental analysis, guiding population evolution through the construction of probabilistic models, sampling, and updating operations. Its main idea is to guide the search process by estimating the distribution of solutions in the problem space. Specifically, the strategy dynamically adjusts the search direction and strategy based on the known distribution of solutions to explore the solution space more effectively. This accelerates the algorithm's convergence speed, improves its global search capability, and enhances the algorithm's adaptability and robustness.

In the ESOA algorithm, the distribution estimation strategy is introduced with a probability of $\frac{1}{2}$ to simulate the position update process of egret D. During this process, the top $\frac{1}{2}$ individuals from the advantageous population are selected, avoiding the reduction in population diversity and the risk of falling into local optima caused by various strategies aimed at approaching the optimal solution. Additionally, a normal distribution estimate is incorporated into the distribution estimation strategy to further reduce the likelihood of the IESOA algorithm falling into local optima. Overall, introducing the distribution estimation strategy into the IESOA algorithm helps avoid local optima, enhances global search capability, and speeds up the convergence rate by facilitating quicker identification of regions close to the optimal solution, thus improving the algorithm's efficiency and performance and making it more suitable for complex optimization problems.

The mathematical model of this strategy is as follows: np represents the population size, and x_i denotes the top $\frac{np}{2}$ promising solutions ranked by fitness values from high to low. In Equation (19), ω_i represents the weight coefficients in descending order of fitness values in the advantageous population, with larger weights indicating higher ranks. In Equation (20), x_{mean} is the weighted average of the solutions from the top $\frac{np}{2}$ advantageous individuals. According to Equation (21), cov represents the weighted covariance matrix of the advantageous population, while Equation (22) y represents a random number that follows a normal distribution with mean $(0, \mathrm{cov})$. Finally, Equation (22) is used to update the expected position and fitness of egret D.

$$\omega_i = \frac{ln(np/2+0.5)-ln(i)}{\sum_{j=1}^{np/2}(ln(np/2+0.5)-ln(j))} \tag{19}$$

$$x_{mean} = \sum_{j=1}^{np/2}(\omega_j \cdot x_i) \tag{20}$$

$$\begin{aligned} mean &= (x_{ibest} + x_{mean} + x_i)/3 \\ cov &= \frac{1}{np/2}\sum_{j=1}^{np/2}((x_i - x_{mean})\cdot(x_j - x_{mean})^T) \end{aligned} \tag{21}$$

$$\begin{aligned} x_{d,i} &= \begin{cases} mean + y, & p < 0.5 \\ x_{mean} + rand(x_{mean} - x_i), & p \geq 0.5 \end{cases} \\ f_{d,i} &= f(x_{d,i}) \end{aligned} \tag{22}$$

3.6 Spiral Ascending Strategy:

The spiral ascending strategy is used in the whale optimization algorithm for spiral position updates during bubble-net attacks, where whales continuously approach the optimal position through spiral swimming. In the IESOA algorithm, the spiral ascending strategy is introduced with a probability of $\frac{1}{2}$ to simulate the position update process of egret D, enhancing the algorithm's global search capability and aiding in finding the global optimal solution. This strategy combines attraction and repulsion behavior patterns. In the attraction mode, the strategy aims to move towards the global optimal solution, while in the repulsion mode, it attempts to avoid local optima, balancing exploration and exploitation during the search process. This improves the algorithm's convergence speed, increases search diversity, and enhances its robustness and global search capability.

The mathematical model of this strategy is as follows: d' represents the distance between the whale's current position and the optimal value, b is a constant describing the logarithmic spiral shape, and b is a random number within the range of $[-1,1]$. Finally, Equation (23) is used to update the expected position and fitness of egret D.

$$\begin{aligned} d' &= | x_{gbest} - x_i | \\ x_{d,i} &= d' \times e^{bl} \times \cos(2\pi l) + x_{gbest} \end{aligned} \tag{23}$$

IV. FLOWCHART OF THE MULTI-STRATEGY IMPROVED EGRET SWARM OPTIMIZATION ALGORITHM

For the original ESOA algorithm, the improvements in the IESOA algorithm described in this paper mainly include:

1) In the ESOA algorithm, Egret A constructs a pseudo-gradient estimator to estimate the descending plane and searches based on the gradient of the cutting plane parameters. In the IESOA algorithm, a dynamic perception factor replaces the original step size factor of 0.1 in the waiting strategy of Egret A.

2) In the ESOA algorithm, Egret B performs global roaming. The IESOA algorithm introduces a shrimp foraging phase strategy with a certain probability to speed up convergence and efficiency.

3) In the ESOA algorithm, Egret C uses an enclosing mechanism for selective search based on better egret positions. The IESOA algorithm introduces a roulette strategy with a certain probability to avoid local optima.

4) The IESOA algorithm introduces distribution estimation and spiral ascent strategies with a probability of 1/2, simulating the position update process of Egret D to reduce the blindness in the actions of individual egrets in the original ESOA algorithm.

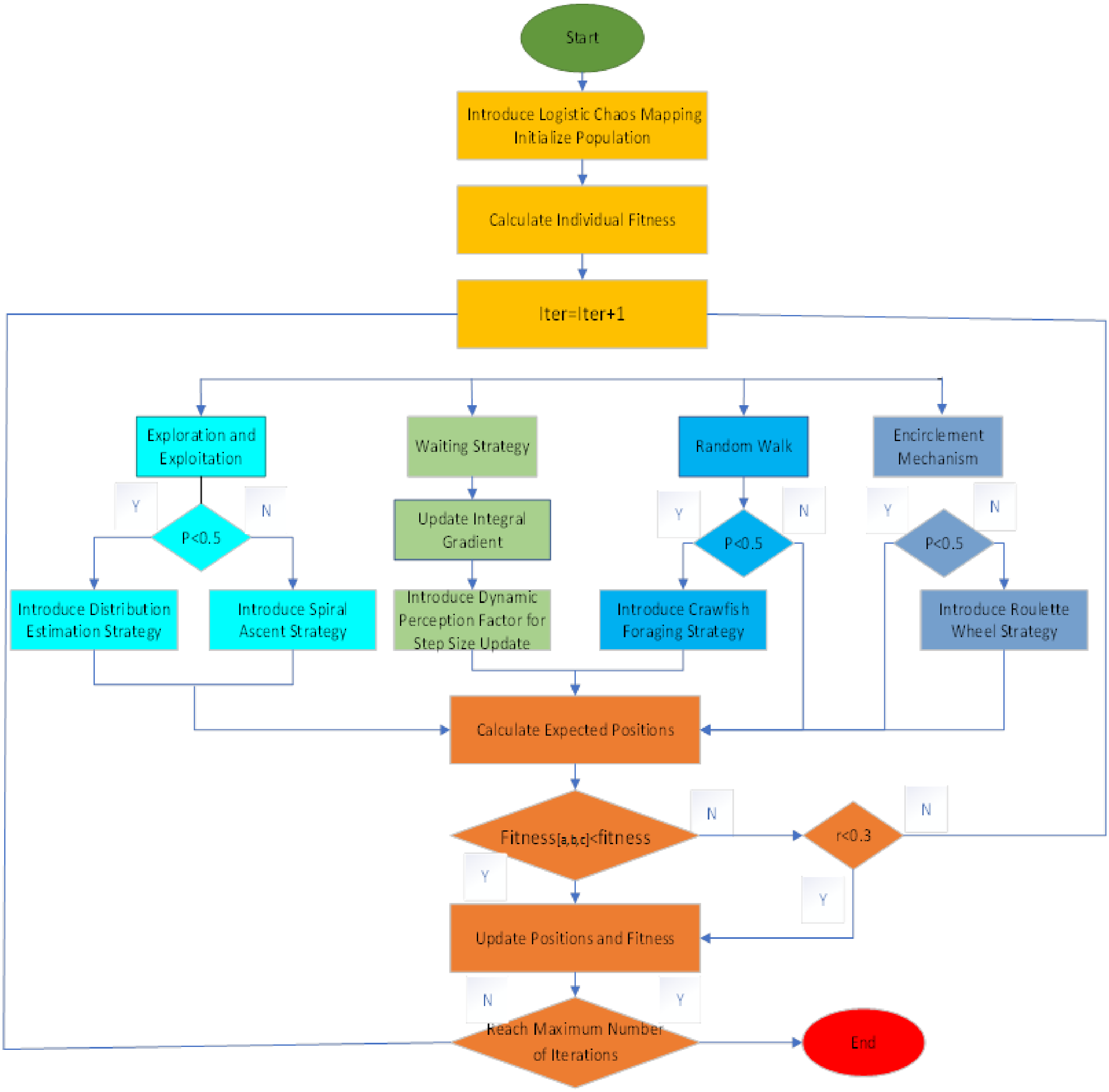

FIGURE 1: Flowchart of the IESOA Algorithm

V. SIMULATION EXPERIMENTS AND RESULTS ANALYSIS

This paper evaluates the convergence speed, solution accuracy, global search capability, and ability to avoid local optima of the multi-strategy improved Egret Swarm Optimization Algorithm (IESOA) using 20 classic test functions. Among these functions, F1 to F7 are single-peak functions used to assess convergence speed and solution accuracy; F8 to F19 and F21 are multi-peak functions containing multiple local optima and one theoretical optimum, used to evaluate global search capability and the ability to avoid local optima.

First, the IESOA algorithm was compared with the original ESOA algorithm using the 20 classic test functions, as shown in Figure 2. The results indicate that there is significant room for improvement in the original ESOA algorithm, with the IESOA algorithm demonstrating superior convergence speed and solution accuracy.

Next, the improved IESOA algorithm was independently tested 50 times on the 20 classic functions, alongside algorithms like BOA, GOA, GSA, and SOA. The average and standard deviation of 50 iterations for functions F1—F19 and F21 were calculated for each algorithm, and rankings for these 8 algorithms across the 20 functions were compared. As shown in Table-1, the IESOA algorithm achieved the best results for all 20 functions. For single-peak functions, the IESOA algorithm outperformed all other algorithms, showing strong development capability. For multi-peak functions, the IESOA algorithm maintained good population diversity and effectively avoided local optima, indicating its strong performance and potential for solving complex real-world problems.

Finally, to more intuitively demonstrate the performance or convergence of the IESOA algorithm, Figure 3 presents convergence curve plots of IESOA and nine other algorithms for the 20 classic test functions, analyzing convergence accuracy and efficiency. It can be seen that for single-peak functions F1-F7, the other nine algorithms prematurely fell into local optima, while the IESOA algorithm gradually converged to the global optimum. For multi-peak functions F8-F19 and F21, some functions showed multi-gradient descent trends, indicating the IESOA algorithm's excellent ability to escape local optima, and even exhibited unique local search or optimization performance in the early stages of iterations for some functions like F9. In summary, both in terms of convergence accuracy and speed, the IESOA algorithm demonstrates the best efficiency and performance.

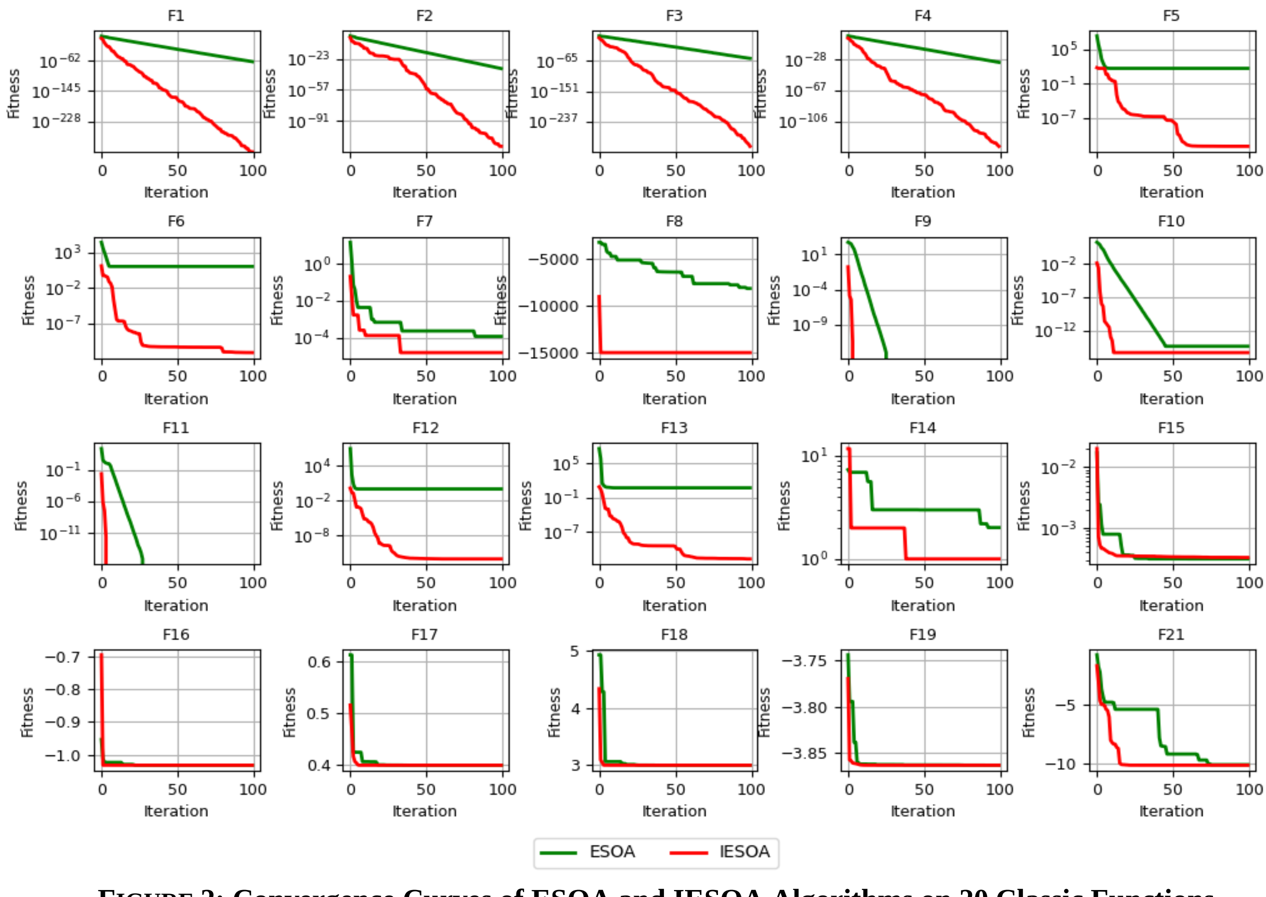

FIGURE 2: Convergence Curves of ESOA and IESOA Algorithms on 20 Classic Functions

TABLE 1
STATISTICAL RESULTS OF EIGHT ALGORITHMS ON 20 CLASSIC FUNCTIONS

		BOA	GOA	GSA	MFO	SOA	TLBO	WOA	IESOA
F1	Mean	0.000741	1910	2.46E-49	109000	2.91E-35	1910	0.0108	9.26E-200
	Std	0.0000529	649	1.28E-48	5900	1.97E-34	518	0.0245	0
F2	Mean	5.92E+23	42.8	8.75E-22	3.63E+19	2.09E-22	24	0.0101	3.47E-97
	Std	4.1E+24	28	6.11E-21	1.05E+20	1.3E-21	3.43	0.00712	2.43E-96
F3	Mean	0.000727	13600	3.48E-37	211000	245000	19600	2350	3.04E-177
	Std	0.000102	7850	2.44E-36	28600	81800	5070	2280	0
F4	Mean	0.0193	17.2	7.67E-23	88.5	0.915	21.8	4.26	5.97E-93
	Std	0.00136	2.93	4.96E-22	1.74	5.3	2.47	2.43	4.18E-92
F5	Mean	48.9	202000	0.204	410000000	18.3	276000	49.8	9.68
	Std	0.0309	119000	0.491	38700000	21.6	105000	1.67	19.4
F6	Mean	10.4	1730	0.00417	108000	0.635	2030	2.76	3.75E-12
	Std	0.715	679	0.00728	7740	0.561	495	0.647	9.79E-12
F7	Mean	0.000504	0.595	0.000525	327	0.000563	0.567	0.00638	0.0000672
	Std	0.000392	0.24	0.000496	32.9	0.000423	0.211	0.0049	0.0000626
F8	Mean	-3220	-10400	-20900	-6480	-20700	-6980	-11800	-19100
	Std	626	917	37.5	884	262	1010	515	3640
F9	Mean	191	270	0	721	0	174	16.8	0
	Std	174	50.3	0	24.1	0	40.5	15.2	0
F10	Mean	0.0136	9.17	4.44E-16	20.2	6.57E-16	9.59	0.196	4.44E-16
	Std	0.00076	1.17	9.86E-32	0.0993	8.44E-16	0.982	0.684	0
F11	Mean	0.00387	19	0	979	0.0195	19.3	0.0396	0
	Std	0.000452	5.47	0	67.1	0.136	4.25	0.0589	0
F12	Mean	0.906	21	0.000126	889000000	0.0176	30	0.19	0.000145
	Std	0.152	10.5	0.0002	129000000	0.0179	71.9	0.171	0.000946
F13	Mean	5.02	11200	0.000872	1770000000	0.281	50500	2.43	5.69E-12
	Std	0.158	22000	0.00144	198000000	0.189	83800	0.406	1.28E-11
F14	Mean	1.56	1.08	1.43	1.58	3.16	0.998	1	0.998
	Std	0.676	0.335	1.03	0.655	3.33	0.000116	0.0102	1.8E-14
F15	Mean	0.00058	0.00708	0.000448	0.00223	0.00149	0.000902	0.000645	0.000437
	Std	0.000319	0.011	0.00021	0.000707	0.00106	0.000318	0.000396	0.000179
F16	Mean	-0.609	-1.03	-1.02	-1.03	-1.03	-1.03	-1.03	-1.03
	Std	0.157	2.22E-16	0.0102	0.00494	0.0000237	0.000326	3.78E-08	2.93E-16
F17	Mean	0.403	0.398	0.404	0.403	0.402	0.398	0.398	0.398
	Std	0.0058	1.4E-09	0.0111	0.00974	0.0101	0.000362	0.00000428	0.000000095
F18	Mean	3.52	3	7.67	3.19	7.6	3	3	3
	Std	1.38	4.8E-09	10.1	0.432	10.6	0.0081	0.00000495	6.79E-15
F19	Mean	-3.42	-3.7	-3.77	-3.86	-3.75	-3.86	-3.86	-3.86
	Std	0.305	0.196	0.0791	0.00301	0.173	0.00086	0.00312	1.14E-09
F21	Mean	-0.588	-6.29	-10.1	-2.44	-6.85	-6.14	-5.35	-8.73
	Std	0.268	3.29	0.0364	0.988	3.04	2.4	1.12	2.29

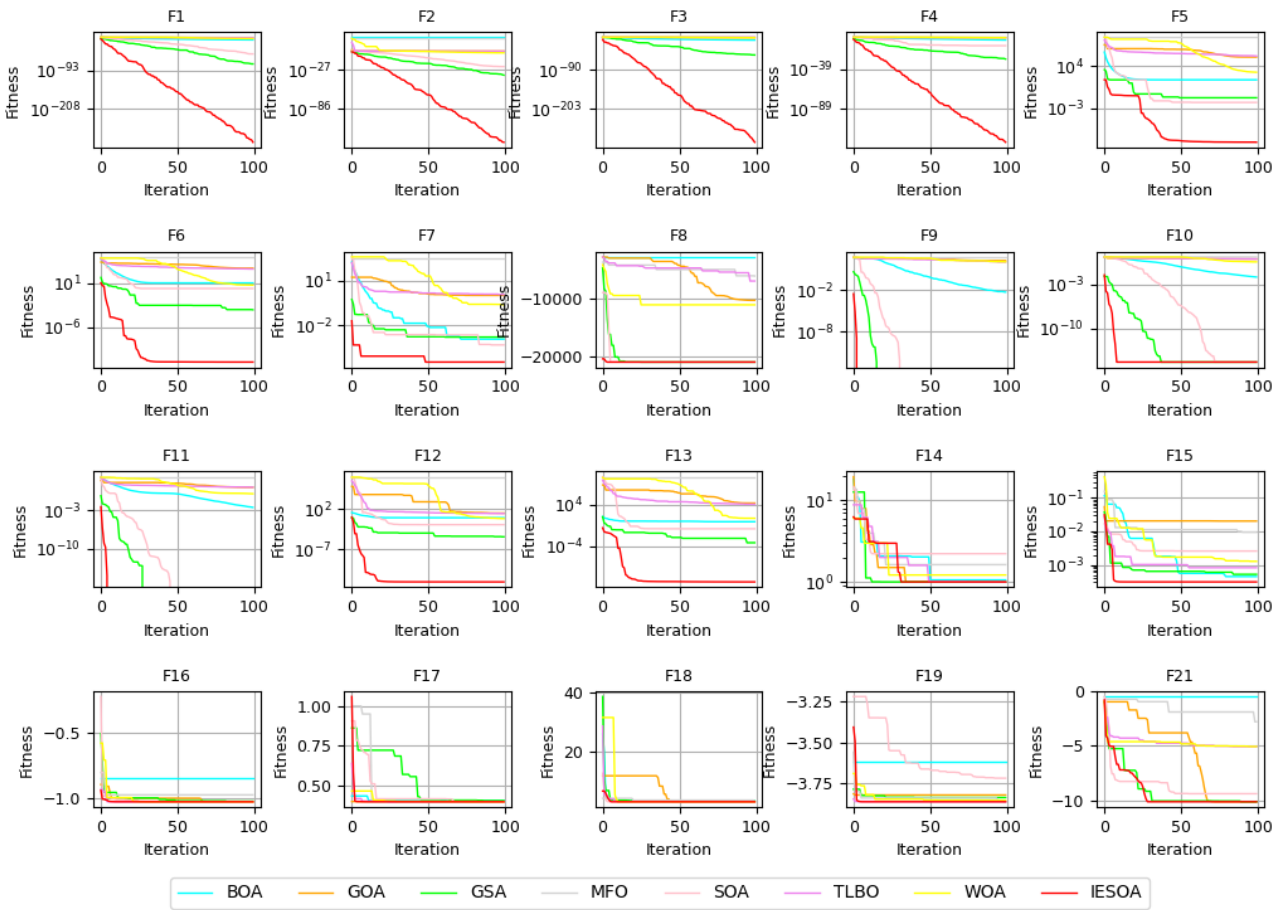

FIGURE 3: Convergence Curves of Eight Algorithms on 20 Classic

5.1 Engineering Constraint Problems:

5.1.1 Gearbox Design Problem:

In mechanical systems, a gearbox is one of the crucial components of a gear train and can be used in various applications. In this optimization problem, the goal is to minimize the weight of the gearbox under 11 constraints. This problem involves seven variables: face width $b=(x_1)$, gear module $m=(x_2)$, $z=(x_3)$, the length of the first shaft between bearings $l_1=(x_4)$, and the diameter of the bearings $l_1=(x_4)$ and the first shaft $d_1=x_6$, $d_2=x_7$. The mathematical model for this problem is expressed as follows:

a) Objective function:

$$f(X)=0.7854x_1x_2^2(3.3333x_3^2+14.9334x_3-43.0934)-1.508x_1(x_6^2+x_7^2)$$
$$+7.4777(x_6^3+x_7^3)+0.7854(x_4x_6^2+x_5x_7^2)$$

b) Constraints:

$$g_1(X)=\frac{27}{x_1x_2^2x_3}-1\le 0$$

$$g_2(X)=\frac{397.5}{x_1x_2^2x_3^2}-1\le 0$$

$$g_3(X)=\frac{1.93x_4^3}{x_2x_6^4x_3}-1\le 0$$

$$g_4(X) = \frac{1.93x_5^3}{x_2x_7^4x_3} - 1 \le 0$$

$$g_5(X) = \frac{\sqrt{(\frac{745x_4}{x_2x_3})^2 + 16.9 \times 10^6}}{110x_6^3} - 1 \le 0$$

$$g_6(X) = \frac{\sqrt{(\frac{745x_5}{x_2x_3})^2 + 157.5 \times 10^6}}{85x_7^3} - 1 \le 0$$

$$g_7(X) = \frac{x_2x_3}{40} - 1 \le 0$$

$$g_8(X) = \frac{5x_2}{x_1} - 1 \le 0$$

$$g_9(X) = \frac{x_1}{12x_2} - 1 \le 0$$

$$g_{10}(X) = \frac{1.1x_7 + 1.9}{x_5} - 1 \le 0$$

c) Range of Values:

$2.6 \le x_1 \le 3.6$

$0.7 \le x_2 \le 0.8$

$x_3 \in \{17,18,19,\dots,28\}$

$7.3 \le x_4$

$x_5 \le 8.3$

$2.9 \le x_6 \le 3.9$

$5 \le x_7 \le 5.5$

The optimization results of various algorithms are shown in Figure 4. It can be observed that, compared to the other seven optimization algorithms, the IESOA algorithm has the best accuracy and stability in solving the gearbox design problem. The optimal value obtained by the IESOA algorithm is approximately 2996.86, and the best solution provided by the IESOA algorithm is [3.500, 0.700, 17.000, 7.300, 7.800, 3.350, 5.287]. Therefore, IESOA achieves the best results in addressing this engineering problem.

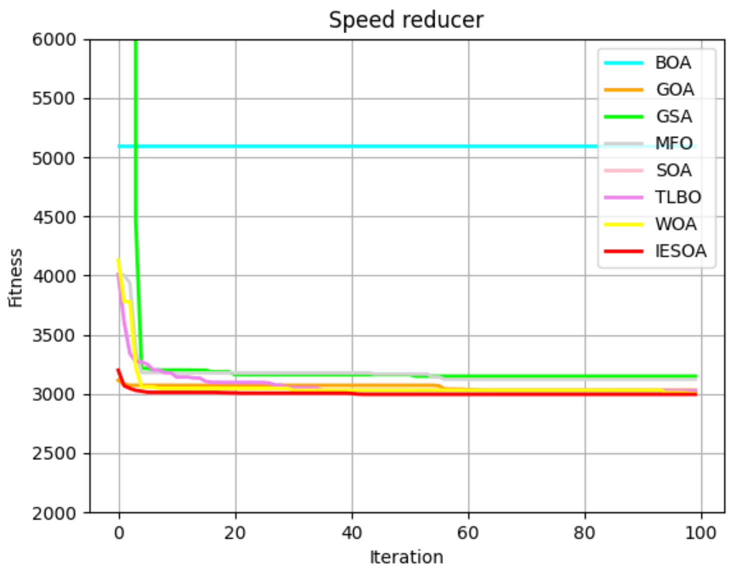

FIGURE 4: Comparison of Eight Optimization Algorithms in Solving the Gearbox Design Problem

TABLE 2
COMPARISON OF OPTIMAL SOLUTIONS FOR THE GEARBOX DESIGN PROBLEM

Algorithm	x1	x2	x3	x4	x5	x6	x7	Optimal weight
IESOA	3.5	0.7	17	7.3	7.8	3.35	5.287	2996.86
WOA	3.508	0.7	17	7.396	7.887	3.353	5.289	3004.73
TLBO	3.527	0.7	17	8.3	8.118	3.369	5.287	3027.89
SOA	3.501	0.7	17	7.398	7.864	3.565	5.299	3011
MFO	3.6	0.704	17.021	8.232	8.272	3.427	5.333	3124.31
GSA	3.502	0.7	17	8.125	7.8	3.794	5.311	3150.23
GOA	3.5	0.7	17	7.32	7.904	3.35	5.337	3031.02
BOA	3.54	0.701	25.862	7.931	7.916	3.744	5.354	5095.34

5.1.2 Tension/Compression Spring Design Problem:

In the tension/compression spring design problem, the optimization goal is to achieve the minimum spring mass using three variables and four constraints. The problem requires solving under constraints such as shear force, deflection, vibration frequency, and outer diameter. There are three design variables: coil diameter d , mean coil diameter D, and number of coils N . The variables in the design problem are coil diameter d , mean coil diameter D, and the number of effective coils N . The constraints include minimum deviation (g_1), shear stress (g_2), impact frequency (g_3), and outer diameter limits (g_4). By incorporating each variable into the constraints, the goal is to determine the minimum spring mass $f(x)$.The mathematical model for this problem is given by equations (27)–(29):

d) Objective function:

$$f(x) = (x_3 + 2)x_2x_1^2$$

e) Constraints:

$$g_1(x) = 1 - \frac{x_2^3x_3}{71785x_1^4} \leq 0$$

$$g_2(x) = \frac{4x_2^2 - x_1x_2}{12566(x_2x_1^3 - x_4)} + \frac{1}{5108x_1^2} - 1 \leq 0$$

$$g_3(x) = 1 - \frac{140.45x_1}{x_2^2x_3} \leq 0$$

$$g_4(x) = \frac{x_1 + x_2}{1.5} - 1 \leq 0$$

f) Range of Values:

$$0.05 \leq x_1 \leq 2, 0.25 \leq x_2 \leq 1.3, 2.0 \leq x_3 \leq 15$$

The optimization results of various algorithms are shown below in Figure 5. It can be observed that, compared to the other seven optimization algorithms, the IESOA algorithm has the best accuracy and stability when solving the tension/compression spring design problem. The best result obtained by the IESOA algorithm is approximately 0.0127, with the optimal solution being [0.050, 0.317, 14.087]. Therefore, IESOA achieves the best results in addressing this engineering problem.

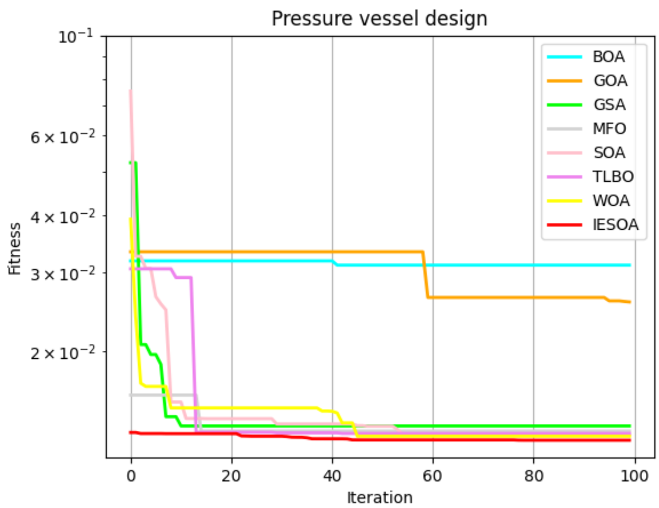

FIGURE 5: Comparison of Eight Optimization Algorithms in Solving the Tension Spring Design Problem

TABLE 3
COMPARISON OF OPTIMAL SOLUTIONS FOR THE TENSION SPRING DESIGN PROBLEM

Algorithm	x1	x2	x3	Optimal Cost
IESOA	0.05	0.317	14.087	0.0127
WOA	0.055	0.453	7.346	0.013
TLBO	0.05	0.31	15	0.0132
SOA	0.056	0.48	6.573	0.0131
MFO	0.05	0.314	15	0.0134
GSA	0.058	0.519	5.881	0.0137
GOA	0.064	0.738	6.481	0.0258
BOA	0.068	0.867	5.802	0.031

VI. CONCLUSION

The Egrets Swarm Optimization Algorithm (ESOA) is a new metaheuristic algorithm introduced in recent years. It features a straightforward and easy-to-understand principle, is user-friendly, and is suitable for integration with other metaheuristic algorithms to address complex problems involving high dimensions or multiple optima. To enhance the efficiency of this algorithm, this paper proposes an improved version of the Egrets Swarm Optimization Algorithm, known as the Improved Egrets Swarm Optimization Algorithm (IESOA).

This improvement incorporates a chaotic local search strategy to boost the performance of the original ESOA algorithm. To address the issue of single strategy blindness in parallel algorithms, it introduces the "lost phase" and "roulette wheel" strategies from the crayfish algorithm. Additionally, to increase population diversity, a new parallel strategy is added to the original ESOA algorithm, which includes distribution estimation algorithms and spiral ascent strategies. This new strategy helps better guide the population towards more optimal solutions.

Comparative experiments with 20 classic benchmark functions and nine other intelligent optimization algorithms demonstrate that the performance of the IESOA algorithm has significantly improved over the ESOA algorithm. It is hoped that the IESOA algorithm can be applied to more engineering problems in the future, providing a feasible solution approach for addressing various practical issues.

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Determination of the Effect of Steeping and Blanching Pretreatments and Drying Temperatures on the Proximate Properties of White-Fleshed Sweet Potato Variety

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Abstract— *Agricultural products require suitable preservation methods for retention of their nutritional qualities and attributes. Sweet potatoes are underutilized due to cost implications of their preservation using modern storage techniques. Enzymatic discoloration of freshly cut potato flesh surfaces from exposure to air affects processed potato qualities adversely. While steeping/blanching pretreatment is deployed in curbing this challenge, varying the steeping/blanching and drying treatments can assist in arriving at the optimum process conditions for white-fleshed sweet potatoes. 4 kg of similarly sized and healthy white-fleshed sweet potato tubers obtained from Eke Awka market (Latitude 6.210528 °N and Longitude 7.072277 °E) in Anambra state, Nigeria, was washed with clean tap water, peeled and cut into 4 mm by 10 mm by 10 mm slices. The experiment was designed using the Response Surface Methodology (RSM) software. The chipped potatoes were divided into 24 samples of 100g each for the analysis. 19 samples were pretreated in water at temperature range of 11ºC to 100ºC and 5 samples were not pretreated (served as control). All the pretreated samples were held in the fluid for period of 2 mins to 18 mins as contained in the design matrix. Both the pretreated and control samples were grouped and dried in convective oven at set temperatures of 53 °C, 60 °C, 70 °C, 80 °C and 87 °C and weighed every 30 mins until there was no further weight loss at three consecutive readings. The dried sweet potato chips were grated into flour, for the determination of the proximate composition of the chips. Optimized drying and pretreatment conditions were analyzed from the results using RSM software. Result of the analysis showed significant increase in proximate composition of the samples with increase in both the steeping and drying temperatures and indicated significance of the model terms. The error analysis showed a high degree of correlation between the observed and the predicted values. From this work the optimal conditions predicted by the RSM model were blanching temperature of 70 ºC, blanching time of 5 mins and drying temperature of 80 ºC for 4 mm-thick 100g of sliced white-fleshed sweet potato chips to yield 2.40% Crude protein, 73.95% Carbohydrate, 2.54% Fiber, 4.31% Ash, 3.24% Fat and 9.86% Moisture content which served as a guide for high quality sweet potato chips production from freshly harvested white-fleshed sweet potato tubers. The dried potato chips can be grated into flour and used as the major ingredient for bread, noodles and cake making. The application of the outcome of the work will help in reduction of post-harvest losses of the crop.*

Keywords*— *Sweet potato chips, Steeping/blanching pretreatment, Steeping temperature, Steeping time, Drying temperature.

I. INTRODUCTION

Sweet Potatoes (*Ipomea batatas*) are among the world's major food crops and most consumed herb belonging to the family of *Solanaceace* (Rahman *et al.*, 2015). It is rich in active ingredients such as Vitamins B_1, B_3, B_6 and C, minerals, antioxidants, fiber, carbohydrate (Kingsford, 2021; Saraiva and Rodrigues, 2011), with the leaves and tubers as the most vital parts of the plant. In some African countries such as Guinea, Liberia and Uganda, the young tips of the vine and young leaves are valuable as they are usually eaten as vegetable (Orhevba and Abimaje, 2019) and serve as good sources of Vitamins A, C, and B_2 as well as an admirable source of lutein (Carotenoid Pigment). It has variety of sizes and color which include orange, white, and purple fleshed with its origin believed to be Central/South America before it spread to other countries such as Mexico, China, Japan and continent of Africa (Orhevba and Abimaje, 2019). Today, Sweet potato is widely grown and consumed throughout the world and can be used for various purposes in the food industry and households (Arum *et al.,* 2022)

Huang *et al* (2018), Alam *et al*. (2020) and Omodamiro *et al*. (2022) revealed that orange-fleshed sweet potatoes are rich in nutrition including starch, protein, vitamins, polyphenols, and trace elements. Julson (2023) indicated that orange-fleshed sweet potatoes may help improve insulin sensitivity in diabetes and in maintaining healthy blood pressure levels Asadi *et al*. (2017) hinted on the efficacy of Anthocyanin-enriched sweet potatoes in cancer prevention. The perishable nature of the crop poses some challenges as majority of the produced crop is wasted as a result of high cost or unavailability of modern storage facilities to maintain their freshness and nutritional values. The high moisture content of sweet potatoes makes them to easily rot and sprout during storage (Delaplace *et al*., 2008). Enzymatic discoloration of the surface of freshly-cut potato on exposure to air also poses a challenge to quality of processed potato. Blanching pretreatment is applied to both fruits and vegetables to inactivate some natural food enzymes present in them and are usually carried out by immersion of the food products in heated water of 80 °C to 100 ℃ temperature range for 20 seconds to 20 minutes (Sun *et al.*, 2020). Blanching pretreatment are non-toxic and easier to apply compared to other chemical pretreatment and anti-browning methods like Sulfites deployment. Steeping pretreatment is carried out in unheated water mainly at or below room temperature. The blanched products can be dried in hot-air oven at 60 °C to 80 °C temperature ranges (Kingsford (2021).

Products drying reduce moisture content and help to minimize microbial activities and other sources of food spoilage during storage (Omodamiro *et al.*, 2022). Hii *et al.* (2021) indicated many drying methods in processing of fruits and vegetables which include hot-air oven drying, infrared drying, freeze drying, microwave drying, and hybrid drying technology. Murayama *et al.* (2015) showed that sweet potato chips can be produced from the starch-rich tubers with the process involving peeling, slicing, soaking, blanching, drying and packaging. This indicates that sweet potatoes can be utilized as raw material for flour production, and a major ingredient for bread, noodles and cake making (Daiki *et al*., 2015; Nemar *et al.*, 2015). By drying and processing the tubers into other useful end products such as sweet potato chips, the crop can be properly utilized and the post-harvest losses averted.

Higher blanching and drying temperatures may affect the rate of moisture release during drying (Orhevba and Abimaje, 2019). Pretreatment and drying of food materials such as orange-fleshed sweet potatoes and yam tubers help in retention of their nutritional qualities, color attributes and guarantee longer shelf life of the materials. Sun *et al.* (2020) studied the effect of blanching and drying on the Vitamin C content and the color and morphology of potato chips. Chhe *et al.* (2018) carried out blanching at only 96 °C and 5 minutes in studying the effects of pretreatment on the firmness, color, total dissolved solid and certain chemical properties of sweet potatoes from Japan. Orhevba and Abimaje (2019) studied the nutrient content for 55, 70 and 85 °C drying and blanching temperatures for sweet potatoes obtained from Gidan Kwano Niger State Nigeria. There is the need to investigate the effects of more varied steeping and blanching pretreatments on the proximate properties of sweet potato chips. This study therefore aims at finding the optimal treatments for steeping/blanching and drying of white-fleshed sweet potato at various temperatures and time intervals.

The Response Surface Methodology (RSM) is popularly used for experimental design. Statistical analysis indicates the level of significance of models and how valuable and accurate its response prediction can be. Abonyi *et al*. (2020) indicated that the larger the F-value and the smaller the p-value, the more significant the corresponding response model term will be. The lack of fit test measures the failure of the selected model in representing the predicted data within the experimental territory.

II. MATERIALS AND METHODS

2.1 Materials Used:

Freshly harvested and healthy white-fleshed variety sweet potato tubers were purchased from Eke Awka market (6.210528 °N and 7.072277 °E) in Anambra state of Nigeria), Metler analytical weighing balance of 0.01g accuracy, convective oven, vernier caliper, stainless knife, hot plate, desiccators, thermometer, stainless pot and stop watch.

2.2 Methods Used:

2.2.1 Preparation of samples:

The tubers were washed with clean tap water, peeled and cut into chips of 4mm thickness and 10mm length and10mm width as recommended by (Omodamiro *et al.*, 2022), using a stainless steel knife. The chips dimensions were measured using a Vernier Caliper and the weight measured for each run of the experiment using analytical weighing balance.

2.2.2 Steeping/blanching pretreatment:

Each of the weighed samples of approximately 100 g was placed in air-tight plastic container and labeled A to X for the pretreatment and drying (Table 1). Based on RSM design, Nineteen (19) of the samples were steeped in water at five different temperatures of 11 ºC, 32 ºC, 64 ºC, 95 ºC and 100 ºC for time duration of 2 mins to 18 mins as described by Sun *et al*. (2020). Five (5) control samples were not blanched at all before drying. The pretreated samples were spread on a wire mesh at the end of each process to allow draining of the surface water before convective oven drying.

2.2.3 Convective oven drying of samples:

The pretreated and control samples were dried at five (5) convective oven drying temperatures of 53 °C (T_1), 60 °C (T_2), 70 °C (T_3), 80 °C (T_4) and 87 °C (T_5) as recommended by Kingsford, (2021). The samples drying conditions are also shown in Table 1. All the drying samples were weighed every 30 mins until there was no weight loss at three consecutive readings. For nutrient properties determination, the dried sweet potato chips were grated using a milling machine sealed in air-tight polythene bags and placed in desiccators to prevent moisture gain in the samples. Proximate composition of the samples was determined according to the standard methods described by the Association of Official Analytical Chemists (AOAC, 2015).

2.2.4 Moisture Content Determination:

Moisture Content of the dry samples was determined by the gravimetric method described by the AOAC (2015). A measured weight of the sample (5.0 g) was weighed into a previously weighed moisture dish. The sample in the dish was dried in the oven at 105 ºC for 3 hours, and cooled in a desiccator and weighed. It was returned to the oven for further drying, cooling and repeated weighing at hourly interval until constant weight was obtained for 3 consecutive times. The weight of moisture lost was calculated and expressed as a percentage of the weight of sample analyzed. It was given by the expression below:

$$\text{Moisture Content (\% wb)} = \frac{M_2 - M_3}{M_2 - M_1} \times 100 \quad (1)$$

Where:

M_1 = Mass of empty moisture dish, (g)

M_2 = Mass of dish + Sample before drying, (g)

M_3 = Mass of dish + sample dried to constant weight, (g)

2.2.5 Crude protein (CP) determination:

This was done using Kjeldahl method according to AOAC (2015). 1 g of the sample was prepared into a micro Kjeldahl flask. 25 mL of Sulphuric acid (H_2SO_4), 1 g of Copper Sulphate ($CuSO_4$) and ten grams of Sodium Sulphate (Na_2SO_4) was added into the micro Kjeldahl flask containing the sample. The flask was heated at an inclined angle (60 ºC). The other steps of the method were duly followed, including the titration with 0.1N H_2SO_4 (titrant) against the content in the conical flask till a light pink color was obtained.

$$\text{\% Protein} = \text{\% Nitrogen} \times \text{Protein Factor} \quad (2)$$

Where

$$\text{\% Nitrogen} = \frac{Tv \times 0.0014}{M} \times 100 \quad (3)$$

Where:

Protein factor = 6.25

M = Weight of sample

Tv = Titrant volume (volume of H_2SO_4 used for the titration).

TABLE 1
PRETREATMENT AND DRYING CONDITIONS OF SAMPLES

SAMPLE	Steeping Pretreatments		Drying Temperature (°C)
	Temperature (° C)	Time (mins)	
P	100	10	70
K	32	5	60
Q	95	15	60
L	95	5	60
A	64	10	53
D	95	5	80
W	32	5	80
T*	64	10	70
O	64	18	70
S	64	2	70
V	95	15	80
R	11	10	70
X*	64	10	70
U	32	15	80
B	64	10	87
H*	64	10	70
G	32	15	60
M*	64	10	70
N*	64	10	70
F	0	0	53
I	0	0	60
J	0	0	70
C	0	0	80
E	0	0	87

***Samples T, X, H, M and N were replicated according to the RSM design.**

2.2.6 Ash content determination:

This was done by the furnace incineration gravimetric method according to AOAC (2015). Exactly 10 g of the sample was measured into a previously weighed porcelain crucible. The sample was burnt to ashes in a muffle furnace at 550 ºC for three hours. When it has become completely ash or turned grey, it was cooled in desiccator and weighed. The weight of ash obtained was determined by difference and the content calculated as a percentage of the weight of sample thus:

$$\% \text{ Ash} = \frac{M_2 - M_1}{M} \times 100 \quad (3)$$

Where:

M_1 = Mass of empty crucible, (g)

M_2 = Mass of crucible + Ash, (g)

M = mass of sample, (g)

2.2.7 Determination of crude fiber content (CF):

This was done using the method described by the AOAC (2015). 2 g of the defatted sample was weighed into a conical flask. 200 mL of 1.25% or 0.127N H_2SO_4 was added and the content boiled on a heating mantle at 80 ºC for 30 minutes. The other steps of the method were duly followed including burning the product inside a crucible in a muffle furnace at 600 ºC for 5 hours. After which it was cooled and weighed as M_5.

$$\% \text{ Fiber} = \frac{M_7}{M} \times 100 \quad (4)$$

Where:

$M_3 = M_2 - M_1$

$M_6 = M_5 - M_4$

$M_7 = M_3 - M_6$

Where:

M_1 = mass of filter paper, (g)

M_2 = mass of dry filter paper and its residue, (g)

M_4 = mass of washed, dried and cooled crucible, (g)

M_5 = mass of dried crucible burnt for 5hrs at 600ºC in a muffle furnace, (g)

2.2.8 Crude fat determination:

This was determined by Soxhlet extraction method described by AOAC (2015). Five (5) grams of sample was wrapped in a porous paper (Whatman filter paper) and put in a thimble. The thimble was put in a Soxhlet reflux flask and mounted into a weighed extraction flask containing 250ml of petroleum ether. The fat in the sample was extracted by Soxhlet extraction and was dried in the oven at 60 ºC for 30 mins to remove any residual solvent. It was cooled in a desiccator, weighed and recorded as M_2. The weight of oil (fat) extract was determined by difference and the weight percentage calculated as below.

$$\% \text{ Fat} = \frac{M_2 - M_1}{M} \times 100 \quad (5)$$

Where:

M_1 = Mass of empty extraction flask, (g)

M_2 = Mass of flask + oil (fat) extract, (g)

2.2.9 Carbohydrate content determination:

This was determined by difference method by deducting the mean values of other determined parameters from 100% composition calculation.

$$\% \text{ Carbohydrate} = 100 - (\% \text{ Mc} + \% \text{ Cp} + \% \text{ Fat} + \% \text{ Crude fiber} + \% \text{ Ash}) \quad (6)$$

Where

% Mc = Moisture content

% Cp = Crude Protein

% Fat = Fat

2.2.10 Analysis of Variance (ANOVA):

The RSM software was used to perform the ANOVA to ascertain the correctness or otherwise of the regression model. Statistical values such as probability value (p-value), F-value, coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}) as well as degree of freedom (Df) were useful in the valuation. The F-value and P-value were used in validating the significance of each of the model parameters. The F-value relates between the curvature variance and the residual variance and the p-value explains the probability of obtaining the observed F-value if the null hypothesis was valid. A confidence level of 95% ($\alpha = 0.05$) was adopted for determining the statistical significance in the analysis.

III. RESULTS AND DISCUSSION

3.1 Effect of the Treatments on Nutrient Content of Potato Chips:

Proximate values of both treated and untreated samples of the sweet potato chips dried under various conditions were determined in terms of percentage (%) Crude Protein content, Carbohydrate content, Ash content, Crude Fiber, Fat and oil and Moisture content as presented in Table 2. Changes in the nutritional properties of the potato chips were observed under different pretreatment and drying conditions.

Crude Protein content of the samples was observed to increase with increase in both blanching and drying temperatures (Fig. 1). Sample A (blanched in 64 ºC water for 10 mins and dried at 53 °C) had the highest protein content; 2.54%, which was more than that of sample R (steeped in water at 11 ºC for 10 mins and dried at 70 ºC) which had crude protein content of 2.13%. It was also observed that the control sample (E) dried at 87 ºC had the highest crude protein value of 2.40% among the control samples. This appears to corroborate the fact that protein is denatured at higher drying temperatures.

TABLE 2
PROXIMATE COMPOSITION OF THE SWEET POTATO CHIPS

Drying Temp (°C)	Steeping Pretreatment		Sample No	Sample Properties (% Content)					
	Temp. (°C)	Time (min)		Crude Protein	Carb.	Crude Fibre	Ash	Fat	Moisture
53	0	0	F	2.37	73.12	2.43	4.29	3.22	10.08
	64	10	A	2.54	72.99	2.58	4.26	3.55	10.32
60	0	0	I	2.31	73.43	2.41	4.23	3.24	10.06
	32	5	K	2.38	72.89	2.63	4.22	3.43	10.52
		15	G	2.41	73.09	2.57	4.27	3.46	10.49
	95	5	L	2.33	73.12	2.63	4.39	3.48	10.01
		15	Q	2.23	73.54	2.42	4.32	3.46	9.96
70	0	0	J	2.35	73.41	2.39	4.21	3.33	9.89
	11	10	R	2.13	72.71	2.6	4.59	3.48	10.23
	64	2	S	2.38	74.11	2.67	4.19	3.37	9.95
		10	H	2.37	73.79	2.75	4.31	3.36	10.13
			M	2.36	73.83	2.78	4.32	3.37	10.17
			N	2.37	74.05	2.79	4.4	3.36	10.18
			T	2.33	73.79	2.73	4.31	3.35	10.09
			X	2.36	73.79	2.73	4.31	3.35	10.09
		18	O	2.32	74.19	2.51	4.13	3.36	10.16
	100	10	P	2.2	73.52	2.51	4.36	3.27	9.97
80	0	0	C	2.38	73.49	2.31	4.28	3.34	9.68
	32	5	W	2.3	73.61	2.55	4.53	3.36	9.72
		15	U	2.31	73.41	2.71	4.52	3.35	9.98
	95	5	D	2.31	73.56	2.35	4.31	3.17	9.94
		15	V	2.27	74.01	2.24	4.21	3.09	10.18
87	0	0	E	2.4	74.01	2.3	4.31	3.37	9.45
	64	10	B	2.46	73.72	2.46	4.36	3.19	9.88

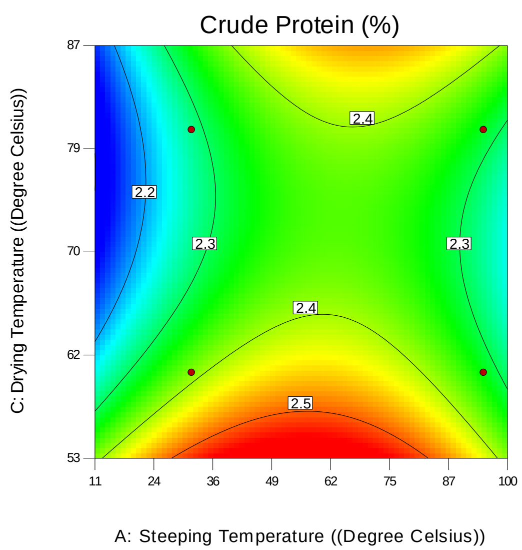

FIGURE 1: Contour model graph of steeping and drying temperatures effect on protein content of potato chip

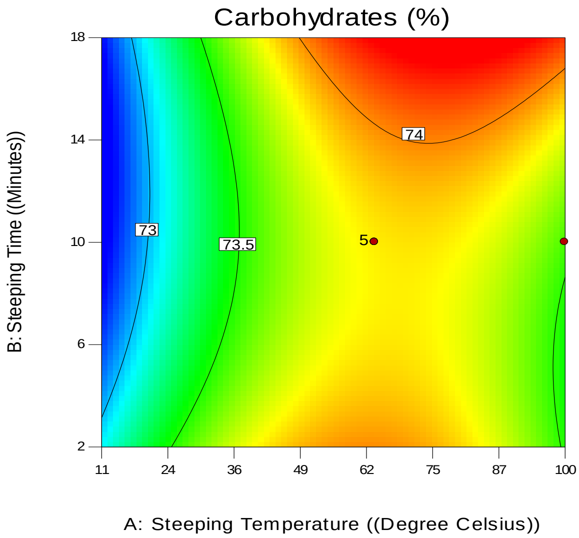

FIGURE 2: Contour graph of steeping temperature and time effect on sweet potato chips carbohydrate content

The Carbohydrate Content also showed significant increase with increased blanching time, and blanching and drying temperatures (Fig. 2). Sample O (blanched at 64 ºC for 18 mins and dried at 70 ºC) had the highest value of 74.19% while sample R (steeped in refrigerated water at 11 ºC for 10 mins and dried at 70 ºC) had the lowest value of 72.71%. The highest carbohydrate value of 74.01% for the control samples was observed in Sample E (at 87 ºC drying).

Crude Fiber Content was observed to be highest in sample N (blanched in 64 ºC water for 10 mins and dried at 70 ºC) with a value of 2.79% and sample V (blanched in heated water at 95 ºC for 15 mins and dried at temperature 80 ºC) having the lowest fiber content of 2.24%. Among the five control samples, F (dried at 53 ºC) had a higher value of 2.43% while E (dried at 87 ºC) had the lowest fiber content of 2.30%. Fig. 3 shows that crude fiber content increased slightly with increase in both steeping and drying temperatures with the value decreasing slightly with increase in drying temperature among the control samples. Sweet potato chips dried by microwave at 90 W; corresponding to their lowest drying temperature used gave highest crude fiber content (Nwajinka *et al.*, 2020).

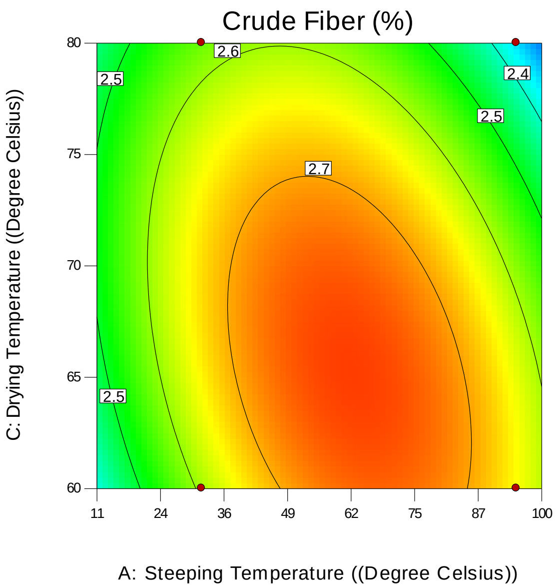

FIGURE 3: Plot of steeping and drying temperatures versus crude fiber content of sweet potato chips

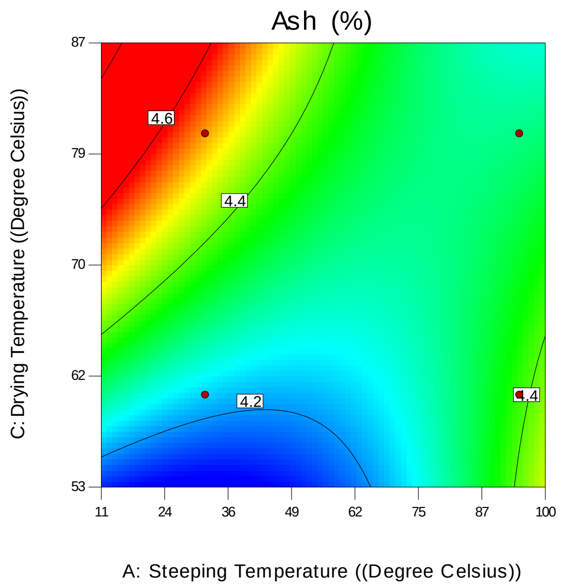

FIGURE 4: Effect of steeping and drying temperatures on ash content of sweet potato chips

The Ash Content of the samples was observed to decrease with increase in blanching temperature among the pretreated samples (Fig. 4). Sample E (dried at the highest temperature of 87 °C) had the highest ash content value of 4.31% among the control samples**.** Reduction in moisture content will increase the dry matter content, and therefore the ash content. The proximate values of the samples were in agreement with the recommendation reported by Olatunde *et al*. (2015) except for the Ash Content. The variation may be attributed to pretreatment and drying conditions of the samples as well as variety of sweet potato used for the experiment. Nwajinka *et al.* (2020) obtained highest value ash content in the un-blanched dried sweet potato chips for microwave drying at 90 W.

Fat and Oil content was observed to be highest in sample dried under the lowest drying temperature of T_1 (Fig. 5). Among the control samples, E (87 ºC drying) had the highest value of 3.37% followed by I (60 ºC drying) with 3.24% and F (dried at 53 ºC) with 3.22%, and. Samples D (95 ºC blanching for 5 mins and 80 ºC drying) had value of 3.17% and sample V (95 ºC blanching for 15 mins and 80 ºC drying) had 3.09%. It was generally noticed that the Fat content of the samples reduced with increase in both blanching and drying temperatures among the pretreated samples but increased with increase in drying temperature among the control samples. Fat becomes more mobile with increasing temperature as observed in cooking of foods.

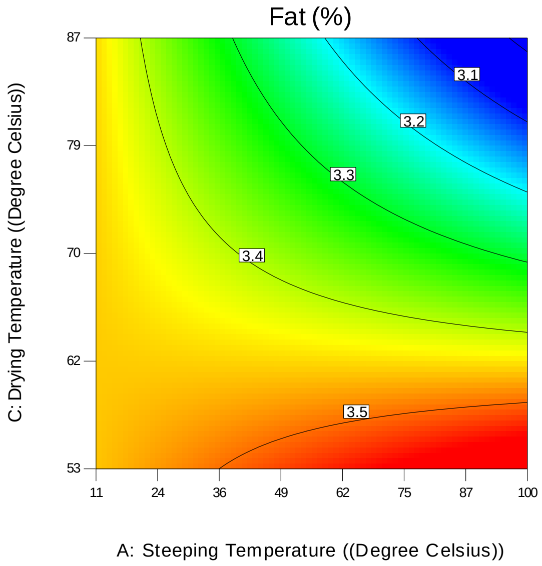

FIGURE 5: Contour graph of the effect of steeping and drying temperatures on fat content of sweet potato chips

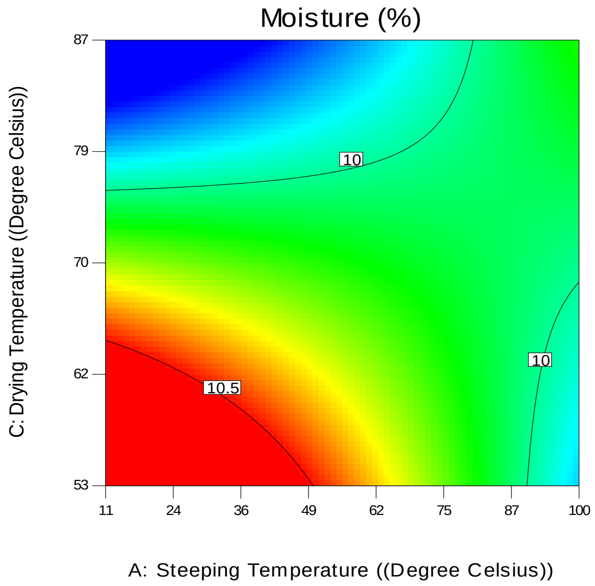

FIGURE 6: Contour graph of steeping and drying temperatures versus moisture content of sweet potato chips

The Moisture content of the samples decreased significantly with increase in drying temperatures. Higher moisture was obtained in many of the higher blanching temperatures. The trend was not same for all the blanching temperatures used. It was also observed that the control samples dried at the lower temperatures; F (53 °C) and "I" (60 °C) had higher moisture contents of 10.08% and 10.06% respectively than those dried at higher temperatures such as 87 °C for E with 9.45% and 80 °C for C with 9.68%. Samples A and F (dried at lowest temperature of 53 °C) showed higher values of moisture contents of 10.32% and 10.08% respectively. Higher drying temperatures gives higher temperature gradients and thus higher affinity for moisture removal. The highest moisture content in all the samples was observed in sample K; steeped at 32 °C for 5 mins and dried at 60 °C. Optimal moisture values were obtained between 11 ºC to 50 ºC steeping temperatures and 53 ºC to 65 ºC drying temperatures (Fig. 6). Steeping temperatures above 50 ºC and drying temperatures above 67 ºC showed reduced value of moisture content of the samples. Orhevba and Abimaje (2019) obtained higher moisture values for dried sweet potato chips with above 70 ºC blanching pretreatment, and argued that starch gelatinization inhibits easy release of moisture during drying.

3.2 ANOVA of Sample Results:

ANOVA on the samples showed significance of model F-values. The p-values for the samples indicated significant model terms. The "Lack-of-Fit F-value" for all the samples showed non-significance of the Lack of Fit relative to the pure error. The "Predicted R-Squared" values for all samples showed reasonable agreement with the "Adjusted R-Squared" values with the difference less than 0.2. The coefficient of determination (R^2) values also showed a high degree of correlation between the observed value and the predicted values. This implies that the variations in the convective oven drying process were explained by the independent variables of the models (steeping temperature, steeping time and drying temperature). The predicted R^2 values of the samples implied good predictability of the quadratic models. Optimization result of the variables showed the optimum treatment to be 70.45 ºC steeping temperature, 5 mins steeping time and 80 ºC drying temperature for desirable high quality sweet potato chips production. In response, the predictions showed the effects of the combinations of the treatments on the proximate composition of the samples as 2.40% for protein, 73.96% for carbohydrate, 2.54% crude fiber, 3.25% for ash content 9.86% for moisture content.

IV. CONCLUSION

The study, targeted at reducing the rate of post-harvest losses and underutilization of Sweet potato tubers in Nigeria, seeks to ascertain the possible pretreatment and drying conditions suitable for sweet potato chips production from the local white fleshed variety. The results of the experiment showed that steeping temperature, steeping time and drying temperature are essential factors in the production of high quality sweet potato chips. It was also observed that sweet potato chips contain lots of nutrients such as protein, carbohydrate and other essential vitamins and minerals which were noticed to be enhanced in the pretreatment and drying processes. In conclusion, the quadratic regression model successfully revealed the effects of the independent variables on the pretreatment and drying process with coefficient of determination (R^2) values as 0.9840, 0.9664, 0.9811, 0.9671, 0.9737, 0.9877.

The values of Protein, carbohydrate and crude fiber content of the samples were observed to be enhanced in pretreated samples than the control samples; especially samples blanched at temperatures above 32 ºC as the values were observed to gradually increase with increase in both the blanching and drying temperatures across the samples. The moisture content was observed to be generally higher in samples steeped in water of temperatures lower than 64 ºC. It increased with increasing blanching temperatures but gave peak values with blanching time variation in some temperatures. The dry samples moisture contents were within the recommended value for storage of sweet potato chips. The study has shown that steeping and drying temperatures of white-fleshed sweet potato for chips production should be above room temperature and less than 100ºC for good quality and nutritious sweet potato chips production. The optimal process conditions were predicted using the RSM as 70 ºC blanching temperature, 5 mins blanching time and drying temperature of 80 ºC; which yielded 2.39% Crude protein, 73.95% Carbohydrate, 2.54% Fiber, 4.31% Ash, 3.24% Fat and 9.86% Moisture content. Application of study findings will help to reduce postharvest crop losses and enhance sweet potato chips production.

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