

EXPERIMENTAL DESIGN OF BIO-INSPIRED ALGORITHMS FOR OPTIMIZATION PROBLEMS IN INDUSTRY 5.0



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Applied Machine Learning for IoT and Data Analytics

(Volume 1)

Experimental Design of Bio- Inspired Algorithms for Optimization Problems in Industry 5.0

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FOREWORD

Industry 5.0, which emphasizes the collaboration of intelligent systems and humans to create highly personalized, efficient, and sustainable manufacturing processes, represents a significant change in how industries function. Industry 5.0 aims to establish a cooperative environment where artificial intelligence and human creativity may coexist peacefully, in contrast to its predecessor, which was mainly concerned with automation and cyber-physical systems. In this new industrial age, optimization is essential for solving complicated problems, from energy efficiency and resource allocation to dynamic production planning and real-time decision-making.

To address these complex optimization problems, bio-inspired algorithms—which draw inspiration from natural processes like evolution, swarm intelligence, and brain adaptation—have become very effective. They are ideal for the dynamic and unpredictable situations seen in Industry 5.0 applications due to their innate flexibility, adaptability, and capacity to break free from local optima. Bio-inspired optimization approaches provide creative ways to increase productivity, resilience, and sustainability as businesses get increasingly linked through the Internet of Things, edge computing, and artificial intelligence.

This book, "Experimental Design of Bio-Inspired Algorithms for Optimization Problems in Industry 5.0," is published at a pivotal point in time when industry applications and scholarly research must come together to fully use these methods. It methodically investigates experimental approaches that guarantee the effective application of bio-inspired algorithms in commercial contexts. The book explores important topics, including algorithm selection, parameter tweaking, performance benchmarking, and real-world application scenarios, through several perceptive chapters written by top specialists.

The well-organized combination of theoretical underpinnings and real-world applications will provide readers with the skills they need to successfully develop, apply, and assess bio-inspired algorithms. This book provides a lot of material to help you in your endeavors, whether you are a researcher investigating new optimization techniques or an industry expert looking for workable ways to improve operational efficiency.

I have no doubt that this book will be a priceless tool for practitioners, researchers, and students alike, spurring more advancements in bio-inspired optimization for Industry 5.0. It is admirable that the editors and collaborators put together such an extensive and progressive work. I invite you to explore the insights contained within these pages and leverage the knowledge presented to address the pressing optimization challenges of Industry 5.0.

We sincerely hope that readers will find this book informative and inspiring, and we extend our gratitude to all contributors for their invaluable efforts in making this work possible.

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PREFACE

Advances in robots, artificial intelligence, and cyber-physical systems have accelerated the evolution of industrial systems, opening the door for the emergence of Industry 5.0, a paradigm change that prioritizes resilient, sustainable, and human-centric production. Robust optimization strategies become increasingly important as companies shift toward intelligent automation, energy efficiency, and individualized manufacturing. In this regard, bio-inspired algorithms have drawn a lot of interest because of their versatility, capacity for self-organization, and efficiency in resolving challenging optimization problems.

To close the gap between theoretical developments and real-world applications of bio-inspired optimization techniques in the changing industrial environment, this book, "Experimental Design of Bio-Inspired Algorithms for Optimization Problems in Industry 5.0," was developed. It offers a thorough manual for creating, putting into practice, and assessing these algorithms for practical uses in supply chain management, smart manufacturing, human-robot cooperation, predictive maintenance, and other fields.

Leading authorities in the domains of neural computation, swarm intelligence, evolutionary computing, and industrial engineering have contributed to the edited edition. With an emphasis on crucial elements, including parameter tweaking, performance assessment, benchmarking, and scalability, each chapter is thoughtfully written to provide insights into the experimental design features of bio-inspired algorithms. The integration of these algorithms with contemporary computational frameworks is also covered in the book, providing useful answers for both scholars and practitioners.

This book's salient characteristics include:

- A comprehensive examination of bio-inspired algorithms designed for industrial use, such as genetic algorithms, particle swarm optimization, ant colony optimization, and hybrid approaches.
- Recommendations for creating exacting experimental frameworks that guarantee robustness, repeatability, and dependability in optimization solutions.
- Real-world examples and case studies that show how bio-inspired approaches may be used to address Industry 5.0 issues.
- New developments and potential lines of inquiry, such as the application of AI-enhanced optimization in industrial systems.

Chapter 1 explains the way how Artificial Intelligence (AI) has rapidly advanced and changed many industries, ranging from healthcare and finance to manufacturing and entertainment, where people began to interact and process information with machines differently. However, despite the potential offered by AI, some challenges have also emerged. For instance, the black box issue, which is the aspect of AI where many systems, and especially those that rely on complex algorithms such as deep learning, are hard to understand by the human race. The difficulty in understanding how decisions are made and how models work brings worries about trust, fairness, responsibility, and openness in AI systems, especially in situations where they are of critical importance, for instance, in medical diagnosis, autonomous vehicles, or legal matters. This is where Explainable AI (XAI) comes in to remediate this problem and help make decisions more transparently without suppressing the functioning of the AI

systems. XAI not only improves the performance of AI systems in healthcare but also fosters trust between patients and providers in Industry 5.0, where human-AI collaboration is crucial.

Chapter 2 covers extending the techniques of ANOVA in optometric research to different experimental designs. In each case, the type of experimental design is described, a statistical model is given, and the advantages and limitations of the appropriate ANOVA are discussed. In addition, the problems of non-conformity to the statistical model and the determination of the number of replications are considered.

Chapter 3 investigates a power series nonlinear mathematical model based on an enhanced Elephant swarm water Search algorithm (ESWSA). The proposed ESWSA algorithm has been developed to predict the average localization error (ALE) of a wireless sensor network system. The performance of the proposed algorithm is evaluated from the effects of anchor ratio, transmission range, node density, and number of iterations. Experimental results demonstrate that higher localization precision with fewer iterations can be achieved. This chapter presents the suggested approach in real-world WSN applications as a foundation for optimizing node location, which is advantageous to lower computational consumption and thereby extend the lifetime of sensor nodes.

Chapter 4 provides a mathematical model of the grinding process based on the input parameters (*i.e.*, infeed, flow rate, and presence of scrapper board) using Regression Equations and ANOVA analysis. The model has been developed from the experimental data of the up-grinding mode with or without a scraperboard. The relationship between response and the grinding parameters has been illustrated graphically by contour plots and surface plots. The output variables are optimized to find the best suitable conditions for grinding using ANOVA. The aim is to find the optimal parametric conditions at which output variables will be minimized.

Chapter 5 analyzes a nonlinear optimization issue for powder injection molding (PIM) of Alumina feedstock, which is addressed by using the artificial neural network (ANN) algorithm. The Jaya algorithm is used to solve the problem of injection variables in a mold-filling optimization issue. The ANN model is implemented with the help of analysis of variance (ANOVA) based on input and response variables. In the last stage, the optimum process parameters are obtained, which show a satisfactory output. Future research may concentrate on creating a posteriori version of the Jaya method, which could then be used to tackle optimization issues for various conventional and contemporary machining processes while taking into account several goals at once.

Chapter 6 demonstrates that a micro-blind hole generation on silica by electrochemical deposition (ECDM) is a very promising method for micro-hole generation on glass. To achieve the target results of the work and to control the process parameters such as machining voltage, pulse frequency (fixed 50Hz), pulse on-time inter-electrode gap (IEG), duty ratio, electrolyte concentration, *etc.*, a series of experiments and analyses are performed to achieve the target results during the micro-ECDM process. The results show that applied voltage leads to a critical voltage that takes action mainly on diametric overcut (DOC) and tool wear rate (TWR).

Chapter 7 presents a micro-drilling of glass by the electrochemical discharge machining (ECDM) process, which is a challenging process due to its high material removal rate and radial overcut during the drilling process. The analysis of variance (ANOVA) is conducted to find out the significant process parameters for the above-mentioned responses of the ECDM process. A mathematical model for Material Removal Rate (MRR) and Radial Overcut (ROC) is developed using the factorial design method. The effects of two process parameters, applied

voltage and electrolyte conductivity, on respective machining criteria are justified through ANOVA results and experimental analyses.

Chapter 8 explains Gas Metal Arc (MIG) welding of austenitic stainless steel AISI 304 using ER 308L electrode and 99% pure Argon gas shielding at suitable combinations of input parameters that have been considered for research. A second-order model is developed to represent the responses in terms of the process variables, including welding current (I), gas flow rate (F), and welding speed (S). The relationship between the responses and welding parameters is depicted graphically using contour plots and surface plots. A total of twenty welded specimens are fabricated under varying parametric conditions using the Response Surface Methodology (RSM) with a face-centered central composite design (CCD). ANOVA and ESWA metaheuristics are applied for the optimization of the welding process, i.e., to find out the optimal welding condition for MIG welding.

Chapter 9 discusses speed control of a 4-phase, 8/6 switched reluctance motor (SRM) powered by photovoltaic. The high-gain converter is controlled by using a Maximum Power Point Tracking (MPPT) technique by implementing an Adaptive Neuro Fuzzy Inference System (ANFIS). The ANFIS-MPPT algorithm generates a control signal and maximizes the efficiency of PV systems using input voltage (VPV) and current (IPV). In addition, a PI and an optimization algorithm for fine-tuning the parameters of the PI result in regulating the speed of SRM.

Chapter 10 explores an experimental framework for bio-inspired algorithms in wireless communication at the physical layer, supporting various components throughout the system. The proposed wireless experimental environment can construct local, small- or medium-sized internal communication systems for factory scenes and provide better understanding and verification in high-definition and high-precision industrial case instruments. The paper focuses on the technical merit and potential of Biological Inheritance (BIA), which not only achieves the same performance as a parallel counterpart scheme for discrete signal data transmission, but also achieves point-to-point signal data communication. BIA's quick operability and the importance of the annealing process in ensuring correct behavior in complex future applications are highlighted.

Chapter 11 introduces Artificial Intelligence (AI) and Robotic Process Automation (RPA) in revolutionizing the Indian banking industry, offering significant improvements in efficiency, customer service, and risk management. However, AI and RPA have not been fully implemented in India. In this paper, the implementation strategies, applications, and benefits of AI, RPA, and AI in the Indian banking sector have been discussed. The paper concludes with the following. (1) AI is a powerful tool for enhancing operational efficiency, improving decision-making, and providing personalized customer experiences. (2) RPA has the potential to revolutionize the banking sector, enabling more efficient and streamlined processes, as well as improving customer experience. (3) RPA and AI are essential to the digital transformation of the banking industry. (4) RPA can allow banks to lessen guide efforts, provide higher compliance, reduce risks, and improve the general patron experience. (5) RPA is an important tool for improving the overall customer experience of banks. (6) AI is an effective approach for improving operational efficiency and reducing operational costs.

Chapter 12 suggests a 4.5 GHz rectangular patch antenna with a hexagonal slot cut in the copper patch, designed and simulated using CST Studio. The proposed antenna exhibits a remarkable return loss (S11) of -61.4 dB and a substantial bandwidth of 1.291916 GHz, significantly outperforming existing works in this frequency band. The antenna's near-ideal

VSWR of 1.00169, combined with these superior performance parameters, makes it highly suitable for high-speed data transmission applications.

Chapter 13 presents a hybrid optimization algorithm based on Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and hybrid HGAPSO for the nonlinear liquid flow control process model. In the first phase, a total of 117 datasets are used to design a nonlinear power model by ANOVA. In the second phase, two ordinary common metaheuristic optimizations, GA and PSO, along with this improved hybrid optimization technique HOAPSO, are also applied to test the model on 17 test datasets to find the coefficient of the nonlinear model analysis of variance (ANOVA) coefficient.

Chapter 14 introduces a new hybrid algorithm, HCSPSO, which is based on incorporating PSO with CSO algorithms. The proposed hybrid algorithm is applied to extract the parameters of single and double-diode RTC France silicon solar cells (S75), which have irradiance levels of 1000 W/m² and a temperature of 25 °C. The effectiveness of this technique in the single and double solar cell model problem with non-smooth cost functions, like diode current, in both cases can be improved using the hybrid algorithm.

Chapter 15 describes an experiment on a rectangular microstrip patch antenna with a triangular polygon at the right upper side of the patch designed in the environment of CST studio suite version 2023,. Twenty five different antennas are configured by changing three parameters, namely substrate height(h), width of the patch, and width of the feedline. A regression model with ANOVA for both bandwidth and resonant frequency is created in the Minitab (version 21) environment to design several antennas with variations in these four variables. The model is well-fitted and validates the target outcome of 2.5 GHz of bandwidth close to the desired frequency of 26 GHz, which is appropriate for applications on 5G and very useful for Industry 5.0.

For researchers, business executives, and graduate students eager to investigate and use bio-inspired algorithms to improve intricate industrial processes, we think this book will be an invaluable resource. The ideas presented in this book will contribute to the development of Industry 5.0 optimization as the globe transitions to a more intelligent and connected industrial environment.

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CHAPTER 1

Explainable AI in Industry 5.0: Principles, Mission, and Future Direction

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Abstract: Explainable AI (XAI) is a critical component of Industry 5.0, which focuses on human-centric, sustainable, and resilient manufacturing. Unlike Industry 4.0, which emphasizes automation and cyber-physical systems, Industry 5.0 integrates human intelligence with AI, ensuring that AI-driven decisions are transparent, interpretable, and aligned with human values. XAI enhances trust and collaboration between humans and AI systems by explaining AI decisions. This is particularly important in industries like manufacturing, healthcare, and finance, where AI-driven insights affect critical operations. With XAI, workers and decision-makers can validate AI recommendations, reduce bias, and ensure compliance with regulations like GDPR and AI ethics guidelines.

Keywords: AI-driven, Explainable AI (XAI), General Data Protection Regulation (GDPR), Industries, Industry 5.0.

INTRODUCTION

Artificial Intelligence (AI) has quickly advanced and changed many industries, ranging from healthcare and finance to manufacturing and entertainment, where people began to interact and process information with machines differently [1]. However, the extent of the promise offered by AI is matched by the magnitude of the challenges it presents. For instance, the ‘black box’ issue, which is the aspect of AI where many systems, especially those that rely on complex algorithms such as deep learning, are hard to be understood by the human race [2, 3]. The difficulty in understanding how decisions are made and how models work brings worries about trust, fairness, responsibility, and openness in AI systems, especially in situations where they are of critical importance, for instance, in medical diagnosis, autonomous vehicles, or legal matters [4]. This is where Explainable AI (XAI) comes in to remediate this problem and help in making

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decisions more transparently without suppressing the functioning of the AI systems. One such example that is explored in XAI is the need for justification, main principles, techniques, hurdles, and the development of the ethical AI of the future [5]. Fig. (1) represents industry evolution from Industry 1.0 to Industry 5.0 with its verticals.

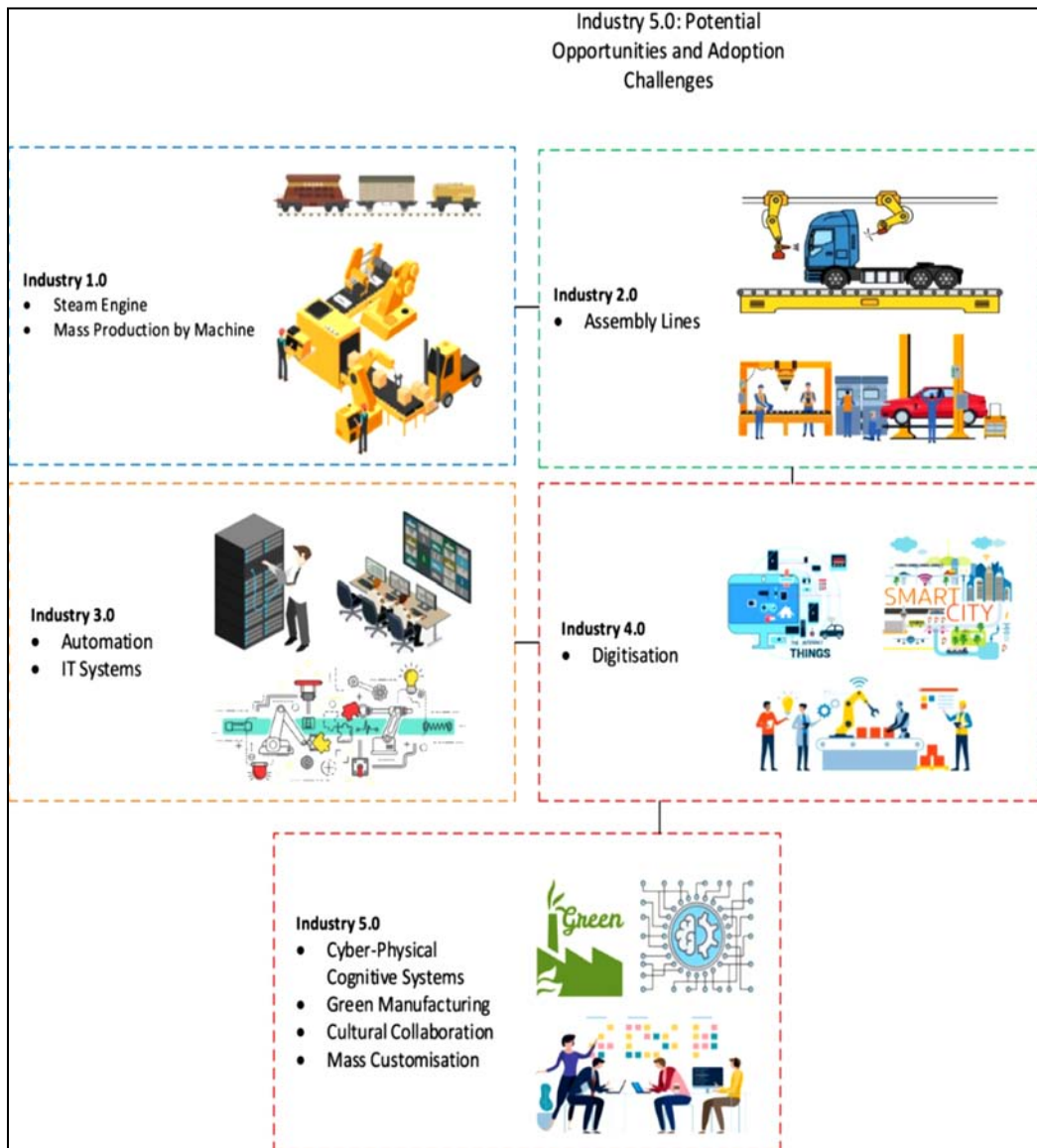


Fig. (1). Industrial Evolution.

The exponential growth of Explainable AI (XAI) is significantly attributable to the numerous application domains in which AI models are being increasingly used to make decisions. Today's AI models are predominantly designed using complex, deep neural networks, some with millions of parameters, to deal with big data to identify, classify, or recommend actions. Even though such models seem to be very accurate and efficient, the naked eye cannot decipher how they reach a defined outcome on a particular issue; hence, disregard is placed on ethics and reasoning [6]. This is quite problematic, especially in critical fields like healthcare, law, and others, where there are high consequences associated with the decision-making process and whose outputs are doled out to humans. For example, in the health sector, forecasting a disease's occurrence could be an AI application. However, if physicians do not grasp the reasoning discordant with that prediction, they may refuse to use that application within their diagnostic pattern. Similar conditions exist in the finance sector while evaluating customers' applications for credit [7]. In such and many more cases, a lack of apparent justification leads to dialogue paralysis concerning AI, especially its acceptance and use, thus inducing social problems. As the pressure mounts for more transparency in AI from policymakers and regulators, explainability becomes even more important. For example, the General Data Protection Regulation (GDPR) of the European Union also provides for an individual's right to explanation in instances when AI impacts his or her life a great deal, such as when a loan or job application is denied. Explainability as a concept cannot thus be polarized into it being merely an engineering requirement, but there are legal and moral reasons for ensuring AI embeds fairness and accountability in a socio-culturally relevant manner [8].

Explainable AI is a subset of AI that tries to provide human-understandable explanations for AI models. Hence, it is pertinent to first analyze the key terms of the definition of explainable AI. Explainability can be analyzed as the responsibility of the artificial intelligence (AI) system to justify its actions through evaluation of how well humans comprehend the reasons for the actions of AI systems [9]. However, explainability is not just a one-size-fits-all remedy. It can vary depending on the intended audience (*e.g.*, data scientist vs. a layperson), the setting (*e.g.*, simple recommendation system vs. recommendation affecting health), or the artificial intelligence model itself. There are two key types of explainability, namely global and local. Global explainability refers to the understanding of a model in its entirety—how it makes predictions given input in all instances. For example, in medicine, it may help to know the broad principles that the model employs to reach the diagnosis. While local explainability is concerned with the explanations for individual decisions, it explains why a particular output is a result of a particular input. For instance, in the case of a

Optimization of Process Parameters Using ANOVA: A Review

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Abstract: The process parameters in casting, welding, renewable energy, and machinability research are optimized using mobile analysis of variance (ANOVA). Experiments are frequently designed using analysis of variance, which reduces the number of experiments for a given number of components and their levels. Compared to the Taguchi approach to design, it has numerous advantages. Experiments are carried out under the experimental design, and output and other reactions are documented. To determine which factors have a major impact on the answer, an analysis of variance is utilized. The process parameters are optimized to achieve a particular goal function, and regression equations are created to forecast the response.

Keywords: Analysis of Variance (ANOVA), Experimental design, Factorial experimental design, Modeling.

INTRODUCTION

Analysis of variance (ANOVA) is the most efficient technique to perform data analysis, avoiding the multiple comparisons between groups [1]. ANOVA is a sophisticated and subtle technique with multiple variations, each of which is appropriate for a certain experimental setting [2]. A clinical experiment taken from optometric research was used to define and illustrate the analysis's most basic form, the one-way ANOVA, in a randomized design [3]. The many ways to compare certain group mean pairings were also taken into account. The objective of this paper is to apply these methods to various experimental setups. These

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ANOVA types will be discussed in this article under the following headings, which should cover a wide range of scenarios that arise in optometric research: (1) 1-way ANOVA, (2) 2-way ANOVA, (3) 3-way ANOVA, (4) factorial ANOVA, and (5) Split-plot factorial ANOVA. Each instance includes a description of the experimental design type, a statistical model, and a discussion of the benefits and drawbacks of the relevant ANOVA. The issues of determining the number of replications for the statistical model are also considered.

STATISTICAL MODELS

ANOVA is commonly described by the following notation: The subscript “i” indicates the group or class that ranges from “1 to x,” while the subscript “j” indicates the members of the class that range from “1 to n”. Any observation in a linear model can relate to the mean and variance and can be written as follows:

$$x_{ij} = \mu + a_i + e_{ij}$$

By adding additional terms x_{ij} to a simple model, it turns into complex types of ANOVA obtained from equation 1 (Table 1), so that an observed value reflects the combined effects of errors of measurement and natural variation between replications.

Table 1. Statistical models

Types of ANOVA	Y (Dependent Variable)	Constant elements	Additional Components
One-way, fixed	x_{ij}	$\mu + e_{ij}$	a_i
One-way, random	x_{ij}	$\mu + e_{ij}$	A_i
Two-way, randomized blocks	x_{ij}	$\mu + e_{ij}$	$a_i + b_j$
Three-way	x_{ijk}	$\mu + e_{ijk}$	$a_i + b_j + c_k + d_{ij}$
Two-factor, factorial	x_{ijk}	$\mu + e_{ijk}$	$a_i + b_j$
Two-factor, factorial split-plot	x_{ijk}	$\mu + e_{ijk}$	$M_i + B_j + T_k + D_{ij}$

TYPES OF ANOVA

One-way ANOVA

In a randomized design, a one-way ANOVA is used to examine the reading rates of three groups of people: patients with age-related macular degeneration, old normal participants, and young normal subjects [4]. To estimate the deviation between the subject groups that are regarded as “fixed,” a one-way ANOVA

model [5] is used. An alternative model aims to evaluate different causes of variation in time and space and, in many circumstances, to quantify the degree of variance [6].

Two-way ANOVA in randomized blocks

Each observation in the one-way ANOVA is categorized according to only one factor. Patients within a group are a random sample of a certain demographic and are allocated to treatment groups at random [7]. It is feasible to create more intricate experiment designs in several ways. Because of a constraint in the way subjects are randomized to treatments, it is sometimes called “randomized blocks design” that satisfies the following metrics: (1) subjects are first grouped into “Segments”, and (2) Individual participants within each segment receive treatments at random [8].

The three-way ANOVA

The “carry-over” effect may become ‘tired’ as the tests go on when they are administered in randomized blocks in a two-way ANOVA. The strategy is to provide each combination of treatments to an equal number of participants to avoid systematic effects [9]. Each treatment order would be $n/2$ participants if there were two treatments and n subjects [10].

Factorial ANOVA

A factorial design examines the effects of several distinct elements simultaneously, compared to analyzing each element separately in a single experiment. Additionally, the sums of squares (SS) across treatments or groups are separated into discrete comparisons [11, 12] that illustrate possible interactions between the variables, which is different from the three-way design. The interactions between the variables are sometimes the most intriguing data from a factorial experiment [13]. An illustration of the most basic kind of factorial experiment is when two medications (A and B) are administered to 24 randomly selected patients, six to each treatment combination, at two “levels” (given or not).

Factorial ANOVA, split-plot design

The experimental subjects were randomly allocated to every conceivable combination of the two components in the 2^2 factorial mentioned above [14]. However, in certain designs, the two elements are not interchangeable. When one component may be regarded as a major factor concerning the other as a minor factor, a typical situation known as a split-plot design occurs. In factorial

CHAPTER 3

Study on Intelligent WSN Localization Error Using Anova-based Optimization Technique**Sumanta Dey^{1,*}, Gour Gopal Jana¹ and Anubrata Mondal²**¹ *Department of Electronics and Communication Engineering, Greater Kolkata College of Engineering & Management, West Bengal 743387, India*² *Department of Electrical Engineering, Greater Kolkata College of Engineering & Management, West Bengal 743387, India*

Abstract: In the realm of wireless communication engineering, the localization of unidentified nodes in wireless sensor networks (WSN) is crucial. The localization of unknown nodes in wireless sensor networks (WSN) is an important problem in wireless communication engineering. Improving localization performance while extending the lifespan of energy-limited sensor nodes remains a key objective. The coordinates of unidentified nodes can typically be found using sensors that have the anchor nodes' known coordinates. However, it takes a lot of time to use bio-inspired algorithms. Therefore, it remains a difficult problem to find the best network configuration for node localization within a short period. This article describes an effective method for utilising an Elephant Swarm Water Search Algorithm (ESWSA) model to assess the ideal network parameters that lead to a low Average Localisation Error (ALE). The average localisation error (ALE) and the input variables' transmission range (TR), node density (ND), anchor ratio (AR), and iterations (IT) are nonlinearly related in this study using an ANOVA-based model. In the experimental section, a metaheuristic optimization technique was applied to predict the ALE for a given set of input variables, producing an accuracy of about 97.843% and 98.109% for cross-validation and testing the dataset.

Keywords: ALE, ANOVA, ESWSA, Metaheuristic optimization technique, WSNs.

INTRODUCTION

A WSN is made up of several small, low-cost sensors that are dispersed around an area to measure physical characteristics or monitor habitat conditions. It may also be used in various real-world applications, including target tracking and precision farming [1]. These sensors must be able to accurately estimate their locations with

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fewer resources in most applications. These sensors can quickly determine their positions using GPS. GPS is too large and expensive to be practically integrated into every sensor; thus, another strategy is required to be implemented using the concept of localization algorithms [2]. Several localization techniques have been developed to handle different localization problems. To function well in a variety of indoor and outdoor environments and topologies, these algorithms need to be adaptive. Range-based methods use the distance between the anchor and unknown sensor nodes to calculate the position of the unknown nodes. They employ range metrics such as Received Signal Strength Indication (RSSI), Angle of Arrival, and Time of Arrival [3, 4]. The range-free techniques, in contrast, employ straightforward connectivity-related operations to locate the unknown node, such as the centroid [5] and ad-hoc positioning system [6]. They simply require the anchor node's beacon signal to be present in the medium. Range-based algorithms are utilized more frequently and are favored over range-free algorithms among the two [7]. In an attempt to develop a simpler algorithm, several bio-inspired algorithms were used for range-based approaches [8]. The localization error was minimized with observable outcomes. This is mostly due to the CS algorithm's tuning settings, which facilitate computation. Recently, a modified form of CS was developed, which increased the typical CS algorithm's rate of convergence [9]. To enhance the search process, the mutation probability and the random walk step size were changed. ALE metrics assessed the accuracy of these localization methods. The algorithm with the lowest ALE value was chosen. After choosing a BIA for node localization, the main issue that arises is the computing time. To determine the appropriate network characteristics and optimize the ALE below the threshold for the best case, the algorithm must be repeated several times during the network creation. We selected and retrieved four features from the improved ESWSA algorithm: the number of iterations, node density, anchor ratio, and transmission range. Finally, we used these data to train the ANOVA model, from which we were able to derive the predicted value of ALE using ESWSA. This article is divided into six sections. Relevant works are discussed in Section II. The system model for the node localization problem is covered in Section III. Additionally, Section IV describes the settings and simulated scenarios for the updated ESWSA. We have covered the ALE prediction findings in Section V. Lastly, the discussion and conclusion are provided in Section VI.

REVIEW WORKS

We have covered several techniques for increasing the node localization accuracy in this section. According to a method provided by Ghargan *et al.* in their paper published in the journal Science, artificial neural networks (ANN) are individually hybridized with PSO, backtracking search algorithms (BSA), and gravitational search algorithms (GSA) to improve localization accuracy [10]. From the results,

it was observed that the GSA-ANN hybrid outperformed the other techniques. The Naive Bayes (NB) method, Decision Tree (DT), Support Vector Machine (SVM), and Artificial Neural Network (ANN) were among the methods whose cumulative localization error distribution curves were analyzed [10]. Based on cumulative localization error distributions, the experimental results showed that NB performed better than the other ML approaches [11].

SYSTEM MODEL

The proposed model mainly highlighted the node localization procedure that is covered initially in this part. Next, the method for figuring out how far the anchor is from unknown nodes is discussed. After that, how the improved ESWSA algorithm for node localization formed its goal functions and operated is elaborated in the latter part of this section.

System architecture

The sensor nodes were dispersed at random throughout an X-Y square unit area. There were M anchor nodes, and N was an unknown node in the system that needed to be localized. Within the given TR, sensors could transmit and receive the data. All of the localizable unknown nodes' coordinates were evaluated using the anchor's positional data as a guide.

Problem Formulation

The unknown nodes utilize the RSSI to determine how far away they are from the anchor nodes. Shadowing and multipath fading lead sensors to lose power while exchanging information. Eq. (1) illustrates how log-normal shadowing [12] is used to describe this path loss.

$$PL(d) = PL(0) + 10 \times \eta \times \log_{10} \frac{d}{d_0} + X_g \quad (1)$$

PL(d) and PL(0) are the path loss for the reference distance 0 and d. Several factors, including the propagation environment, antenna height, and signal frequency, affect the value of η . For an indoor environment, its values are greater than 4 and fall between 2 and 6 meters [13]. The attenuation brought on by fading is represented by the Gaussian random variable X_g . Equation (2) expresses its variance, σ^2 .

$$\sigma^2 = \gamma^2 D_{ij}^2 \quad (2)$$

Where, γ^2 represents the localization error

Modeling and Optimization of Process Parameters of Grinding Using ANOVA Analysis for Industry 5.0

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Abstract: Modeling and optimization of the corresponding parameters of grinding processes are fascinating tasks for mechanical engineers. This paper mainly investigates a suitable model of the grinding process using a very popular statistical analysis tool, ANOVA, and Regression Analysis to control the output parameters, such as tangential force and change in temperature during grinding, by controlling the coolant flow rate, infeed of wheel, and scraperboard positioning. The experiment is also conducted to examine the effect of using a scraperboard on changing the grinding temperature. A K-type thermocouple brazed beneath the workpiece surface and a force dynamometer are used for measuring the grinding temperature and tangential force during experimentation. Initially, a linear regression model is used to model force and change in temperature. Next, ANOVA is used for response optimization for the grinding process, where the objective is to minimize both output variables. From the optimization, it is found that the use of a scraper board is very effective in minimizing the tangential force and generated temperature during grinding.

Keywords: ANOVA, Grinding process, Industry 5.0, Modeling, Optimization, Scarper board.

INTRODUCTION

Grinding is a precise surface finishing process, performed on a final product, that faces the disadvantage of excessive heat production, which leads to the burning of the grinding contact surface, transformation in metallurgical phase, high residual

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stress, surface and sub-surface cracks, loss of surface integrity, *etc.* These consequently lead to the refusal of a final workpiece at the last stage of production. A significant amount of mechanical energy, primarily the force needed for grinding, transforms into thermal energy [1 - 3]. It happens due to the elevated friction coefficient between the tiny grits of the wheel and the workpiece. Hence, a liquid called coolant is utilized in the workpiece-wheel interface to lower the temperature. However, the surrounding air layer of the revolving grinding wheel hinders the effective penetration of the fluid jet into the grinding zone [4 - 7]. Because of this potential limitation, impingement of the fluid jet through the workpiece-wheel junction becomes challenging, and controlling the air pressure around the wheel becomes imperative. Considering the airflow effect along with the other prevailing parameters for better prediction accuracy, the modeling of the grinding process becomes much more complex and demanding. This modeling and optimization not only lower the expenses and duration of experiments, but they also enhance comprehension of the process.

Unlike other machining operations, heat production in grinding is a critical event that is obligatory to be controlled to achieve better surface integrity of finished products. To regulate heat generation, the requirement of force for machining is to be checked, since a major portion of the force applied in the course of grinding is converted to heat [8]. Hence, both the force applied and heat generation are closely interrelated and are two important characteristics that need to be addressed for better process performance. The unavoidable circumstances of heat generation due to the interaction between the workpiece and the abrasive grits of varying rake angles are usually controlled by applying a stream of fluid into the grinding area. Previous studies indicate that the existence of a rotating air-ring around the wheel restricts the suitable entrance of the coolant stream in the interface between wheel and workpiece, resulting in a higher friction coefficient and heat development [9, 10]. So, the impact of the air boundary on heat generation needs to be investigated. Further, a relationship is required to be established between five important parameters that can be used to decide the optimal input conditions of grinding. Hybrid modeling is therefore needed, which may help in better decision making, choosing the best input settings. This study aimed to determine the best input parameters to reduce the need for force and the production of heat during the process of grinding.

Different models have been generated based on numerous parameters of grinding, including the texture of the grinding wheel's surface, the wear on the wheel, the value of the surface of the workpiece, the forces and energy involved in grinding, and the relationship between the workpiece and the wheel [11 - 13]. To predict the results of the grinding process, different modeling techniques, including experiential, logical, regression, finite element method (FEM), and heuristics,

have been utilized. Cao *et al.* [14] developed a model for the topography of wheel-cutting-face based on various experiential correlations, demonstrating that this approach can greatly enhance the quality of the ground surface. Leonesio also utilized a z-buffer method to enhance the quality of the surface [15]. Salisbury [16] created a model of the wheel surface that can be combined with a model of the surface grinding process to simulate the texture of the workpiece's surface. Models [17] are developed to improve surface irregularity and metal removal rate by applying response surface methodology by controlling the depth of cut and the speed of the wheel and table. Mathematical models were developed by Janardhan *et al.* [18] to improve surface roughness and the rate of metal elimination. Temperature distribution was described using partial differential equations [19], and statistical or mathematical techniques like Laplace and Fourier transforms coupled with the Green's function method [20], as well as Finite Element Analysis [21], were employed.

However, very few researchers considered the airflow around the grinding wheel along with other parameters to forecast the alteration in workpiece temperature difference and the tangential grinding force. The influence of numerous factors, such as grinding cycles, force, wheel speed, cut-depth, and grinding fluid flow, on temperature was previously analyzed. Implementation of an air-deflector has been shown to enhance the grinding ratio, improve the quality of surface, also diminish the machining forces [22, 23]. Consequently, the modeling of various grinding parameters along with the scraper board, which authoritatively affects the grinding performance, is a new study. Further, the application of the ANOVA model equations to analyze the increase in the percentage of temperature and grinding force is based on experimental research, which accounts for the regulation of the rotating air. The remainder of the document is structured in the following way. Section II describes the experimental process and data of grinding. Next, the proposed methodology for modeling the grinding process has been described. The results are elaborated in Section IV, which is followed by the Conclusion and Reference Section. An ANOVA-based approach is used to develop mathematical models for grinding processes, which helps identify optimal grinding conditions, contributing to human-machine interaction crucial for Industry 5.0.

INVESTIGATION INTO GRINDING

The empirical section of this study was carried out on a surface grinding machine with a conventional alumina wheel (specification: AA46/54K5V8). Experiments were carried out in up-grinding mode at different flow rates and infeeds of the grinding wheel, at a speed of 29.3 m/s, *i.e.*, wheel surface velocity in the presence or absence of the scraper board. The tangential force was noted from the grinding

CHAPTER 5

An ANOVA-based Optimization Technique to Predict the Part Weight During Micro-powder Injection Molding of Alumina Feedstock**S. K. Tanbir Islam^{1,*}, Peeraj Mazumder², Pijush Dutta³ and Barun Haldar⁴**¹ *Department of Mechanical Engineering, Greater Kolkata College of Engineering and Management, Baruipur-743387, India*² *Department of Mechanical Engineering and Mining Machinery Engineering, Indian Institute of Technology, Jharkhand, Dhanbad, India*³ *Department of Computer Science and Engineering, Greater Kolkata College of Engineering and Management, Baruipur-743387, India*⁴ *Industrial Engineering Department, College of Engineering, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh-11432, Saudi Arabia*

Abstract: Micro-powder injection molding (μ -PIM) has significantly evolved as a technique for manufacturing micro-components. It is well established that injection parameters play a critical role in achieving proper mold filling. Injection molding parameters significantly affect performance in terms of cost, product quality, and sustainability. Choosing the most effective (optimal) combination of injection parameters is therefore essential for each PIM procedure. To address this optimization challenge, a novel algorithm is employed in this study. An optimization technique based on ANOVA is used to predict good mold filling utilizing part weights. The proposed model takes injection pressure, temperature, and actual injection shot size as input variables and predicts the weight of the injected sample. The model is validated using the experimental results. The ANOVA-based Jaya Algorithm achieved maximum accuracies of 95.73% and 96.04% for the training and testing datasets, respectively.

Keywords: ANOVA, Alumina feedstock, Micro-powder injection molding, Modeling, Optimization.

INTRODUCTION

Micro-parts are defined as components with a maximum size below 10 mm and features in the micron range. Powder injection molding (PIM) has emerged as a viable method for producing complex-shaped parts at a competitive cost since the

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early 1990s. The field of micro-powder injection molding (μ -PIM), which is only a miniature version of regular PIM, was explored by researchers after significant breakthroughs in conventional PIM [1, 2]. μ -PIM's high form intricacy and micron-level component dimension precision are two main benefits. Moreover, it becomes commercially viable when mass production is a primary requirement [3 - 5]. Using plastic injection molding technology and powder metallurgy, the PIM process creates net-shaped metal, ceramic, or hard material parts [1]. Additionally, a modified feedstock may be used for micro components (micro-PIM) using extremely tiny powders. The μ -PIM process consists of four steps, similar to conventional PIM. In the first step, a sigma-blade mixer is used to combine metal or ceramic powders with thermoplastic polymeric materials (binders) to create a uniform mixture called a feedstock. The required component's geometry is then created by feeding the feedstock in the form of pellets into the injection molding machine. According to the binder formulation, the binder is then extracted from the injection molded component using a solvent, catalyst, or heating technique. Finally, the debound specimens are sintered in a furnace with the temperature raised to a degree where the metal or ceramic powders fuse to create the component's shape [5]. The quality of the final product depends on efficient injection molding, as defects such as short shots, jetting, voids, weld lines, and powder-binder separation cannot be corrected in subsequent stages [5, 6]. Several commercial programs, including Moldflow, Moldex3D, PIMSolver, COMSOL, FLUENT, and others, are available to model mold-filling issues, mostly in plastic injection molding. Nonetheless, with some restrictions, researchers have previously employed these techniques for powder injection molding [7, 8]. High shear, the primary cause of powder-binder separation, is frequently observed in flow through micro-cavities, particularly during the micro-PIM process [9 - 11]. According to reports, powder-binder segregation may be detected more effectively using multiphase simulations than with a single-phase analysis [12]. The multiphase modeling technique has already been used by researchers [13 - 15], who have also noted that high temperatures and shear strain rates affect the alteration in drag force among phases, which causes powder-binder separation. The different types of defects lead to inappropriate mold filling that turns into a low part weight compared to the theoretical value. So, part weight can represent the quality of the injection molding component.

AN ARTIFICIAL NEURAL NETWORK'S (ANN) PRELIMINARY DETAILS

To solve the nonlinearity issue between data input and output, one AI model that draws inspiration from the structure of human neurons is the artificial neural network (ANN) [16]. This model is used to predict outcomes for unknown input parameters within a defined domain. This model builds a complicated structure.

Compared to conventional techniques, an ANN has a significant amount of potential to forecast and decide more useful outcomes. An ANN's only objective is to teach a computer anything so that its network can adjust to a certain dataset. Artificial neural networks (ANNs) are appropriate for pattern identification, speech detection, and data classification challenges because, like humans, they can learn by example and use this information for training [17]. A neural network typically uses a feed-forward architecture consisting of three layers, which is one of the most widely adopted designs. This network's input layer consists of a collection of input units that take in input feature vector items. Together with the hidden units, the input units (neurons) are completely linked to the hidden layer. Additionally, the output layer is entirely coupled to the hidden units or neurons. The output layer processes the activation signals propagated from the input layer. A neural network may use one or more hidden layers to transport the input layer's data to its final layer. The magnitude offset is the node's interval or threshold F . It has the following effects on node output O 's activation:

$$O = f(I) = f \left(\sum_{i=1}^n I_i w_i - \phi_k \right) \quad (1)$$

For the networks to generate the intended input-output mapping for the classification job, the ANN must be trained. A learning algorithm adjusts the connection weights, also known as synaptic weights. This adjustment occurs as the network is trained using a set of instances or data. The NN system's goal is to respond to certain input signals with the desired output. The system is set up to its standard or random values before NN training. The weights that establish the link between the nodes can be altered during training, and certain traditional learning methods, such as the backpropagation algorithm, can also alter the structure based on input data and hidden values [18]. This suggests that by altering the solution's structure and the weights' computation, the NNs may be made more efficient. Recently, several metaheuristic and evolutionary optimization approaches have been effectively used to learn an NN's weights [19 - 21].

JAYA ALGORITHM

Assume that the goal is to minimize (or maximize) a function $y(x)$. If there are “m” design variables and “n” candidate solutions ($k = 1, 2, \dots, n$) at any given iteration I , the best candidate solution is the one that offers the most favorable objective function value (*i.e.*, $y(x)$ best) within all the candidate solutions, and the worst candidate solution is the one that offers the most unsuccessful objective function value (*i.e.*, $y(x)$ worst) within all the candidate solutions [22]. In the i^{th} iteration, the j^{th} variable for the k^{th} candidate is changed following Eqn.

$$x_{new}^{j,k,i} = x^{j,k,i} + r_1^{j,i} (x^{j,best,i} - \text{abs}(x^{j,k,i})) - r_2^{j,i} (x^{j,worst,i} - \text{abs}(x^{j,k,i})) \quad (2)$$

ANOVA-based Analysis and Optimization of Micro-performances during Blend Hole Generation on Glass

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Abstract: Electrochemical discharge machining (ECDM) performance enhancement is challenging when applied in the industrial field. The book chapter shows the second-order correlating mathematical models with pulse on-time, electrolyte concentration, duty ratio, inter-electrode gap, and applied voltage for diametric over cut (DOC) and tool wear rate (TWR) when a mixture of potassium hydroxide (KOH) and sodium hydroxide (NaOH) is used as an electrolyte during blind hole generation on glass. ANOVA is used to analyze the fitness of models, as well as the effects of and process parameters. Desirability function analysis is performed in this chapter for the minimization of DOC and TWR for blind hole formation on glass and contour diagrams. Multi-objective optimization also represents the better results of micro-hole fabrication by the ECDM process. It is found that 50V/30mm IEG/20wt%/45 μ s/.50 duty ratio/50Hz pulse frequency provides a minimum TWR of tungsten carbide tool and DOC of micro-hole.

Keywords: DOC, Glass, Micro-ECDM, Micro-blind hole, NaOH+KOH, TWR.

INTRODUCTION

Fizeau (1819-1896) and Foucault (1819-1868) made the ECDM system, and Kurafuji and Suda (1968) applied it for machining performances. Some fundamentals and material removal aspects of the ECDM process have been propounded [1]. A better accuracy and quality improvement in ECDM performances are described [2]. Several applications of ECDM in the field of micro-drilling of advanced ceramics are also discussed [3, 4]. Mixed graphite dust is added to the electrolyte to increase conductivity in ECDM [5]. A certain

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application of glass in ECDM is described [6]. Mixed electrolytes and GRA are used for micro-machining analysis [7]. Different shapes of profiles and parameter effects are analyzed using PSO-RSM, GA-ANN, and ANOVA-RSM during micro-channeling on brittle materials [8 - 14]. Taguchi-GRA proposes to find better results of the ECDM process during the micro-fabrication of glass [15]. To fulfill the objectives of the book chapter, the lineup of experimentations and analysis is performed to achieve the target results during micro-hole generation on glass by micro-ECDM. This chapter aims to achieve the target results of the work and control the process parameters, such as machining voltage, pulse frequency (fixed 50Hz), pulse on-time inter-electrode gap (IEG), duty ratio, electrolyte concentration, etc. A tungsten micro-tool with a diameter of 250 μm is used, and a 1:1 mixture of NaOH and KOH is employed for micro-hole generation on glass. Fig. (1) shows the micro-ECDM system, which is used for the experimental work of micro-hole generation on glass.

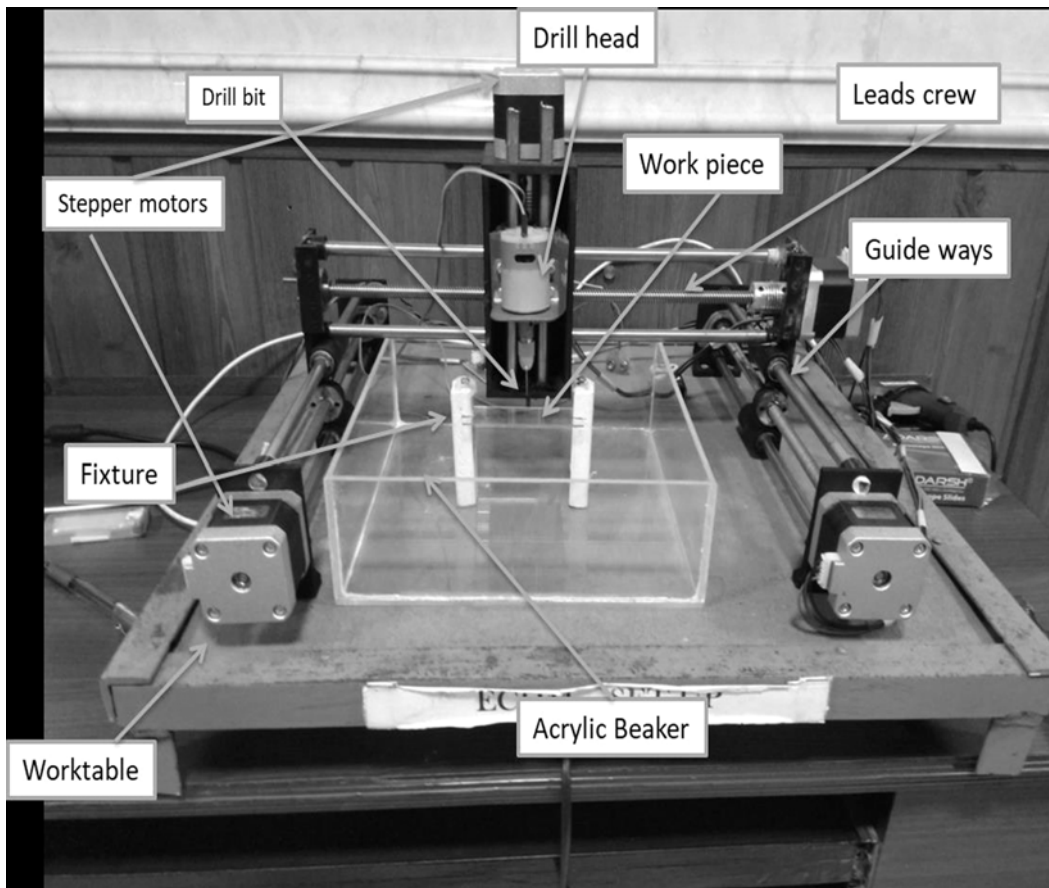


Fig. (1). The Micro-ECDM setup.

EXPERIMENTAL PLANNING AND RESULT ANALYSIS BASED ON ANOVA AND DESIRABILITY FUNCTION

Table 1 represents the levels and ranges of the process parameters. A face-centered design (-1 to +1) of experiments is chosen for experimentation. Every combination of parameters is set properly, and 1 tungsten carbide tool is used only once using a mixed electrolyte of 1:1 NaOH and KOH. Table 2 shows the experimental results for various parametric combinations. An optical microscope is used to measure diametric overcut, and a weighing machine is used to measure tool wear rate.

Table 1. Range of variables

Process Parameters (Variables)	Range		
	-1	0	+1
Voltage(V)	50	55	60
Pulse on-time(μ s)	45	50	55
IEG(mm)	30	35	40
Duty ratio	0.45	0.50	0.55
Electrolyte Con.(wt%)	20	25	30

Table 2. Experimental results.

StdOrder	VOLTAGE(V) (x1)	PULSE ON TIME(μ s) (x2)	IEG(mm) (x3)	DUTY RATIO(x4)	ELECTROLYTE CON.(wt%)(x5)	DOC(μ m)	TWR(mg/hr)
1	50	45	30	0.45	30	230	0.030
2	60	45	30	0.45	20	432	0.039
3	50	55	30	0.45	20	292	0.038
4	60	55	30	0.45	30	522	0.042
5	50	45	40	0.45	20	320	0.033
6	60	45	40	0.45	30	412	0.033
7	50	55	40	0.45	30	230	0.031
8	60	55	40	0.45	20	372	0.033
9	50	45	30	0.55	20	218	0.017
10	60	45	30	0.55	30	370	0.039
11	50	55	30	0.55	30	202	0.038
12	60	55	30	0.55	20	540	0.033
13	50	45	40	0.55	30	228	0.031
14	60	45	40	0.55	20	374	0.033

CHAPTER 7

Micro-ECDM Performance Analysis Based on ANOVA

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Abstract: The augmentation of the characteristics of micro-ECDM during micro-drilling on borosilicate glass is a challenging task. The book chapter indicates the ANOVA-based second-order mathematical models by correlating with voltage and conductivity of the electrolyte for radial over cut (ROC) and material removal rate (MRR) when NaOH is used as electrolyte during drilling on borosilicate glass. ANOVA is used to find the best fitness models for MRR and ROC. In this chapter, root mean square error (RMSE) for ROC and MRR is proposed during the drilling of glass by the ECDM process. It is found that optimized parametric combinations are 51 V/172 mmho-cm / 40mm, which achieve minimum ROC and MRR using stainless steel (SS) micro-tool.

Keywords: Drilling, Glass, Micro-ECDM, MRR, NaOH, ROC.

INTRODUCTION

According to modern developments, electrical, optical, and medical equipment must integrate and reduce the size of high-strength performance devices. Often, brittle materials are used to make these parts (non-conductive). Advanced materials, such as ceramics and composites, are used increasingly for applications in various advanced industries like automobile, aeronautics, and nuclear because of their exceptional qualities, which include high compressive strength, high hardness, high strength-to-weight ratio, high corrosion resistance, high-temperature resistance, high wear resistance, and good thermal shock resistance. Engineering ceramics are often processed using traditional powder metallurgy

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sintering and compacting processes. It is very difficult to generate complex shapes with a higher degree of accuracy than the conventional technique. Therefore, there is an urgent need for an alternative manufacturing process, which will be a resurgence of conventional machining processes for creating products with hard, brittle, and advanced materials such as glass, ceramics, *etc.* Some non-conventional machining processes have great potential to manufacture a product with the above-mentioned materials. Arndt and Probst (1922) examined the significance of the electrodes' wettability in the anode effect and noted that the development of "larger and larger growing" bubbles preceded the anode effect. However, since Kellogg's breakthrough in 1950, electrode effects have been the subject of more thorough research. Electrochemical discharges were extensively researched and applied in a wide range of fields, from wireless telegraphy to X-ray imaging, in the late 19th and early 20th centuries. These were frequently referred to as "anode or cathode effects" in the literature, depending on which electrode phenomenon occurred. The physical and chemical causes of the electrode effects, or the electrochemical discharge machining process, have been attempted to be explained by several writers in the past few decades. A brief discussion of previous research investigations is given below. It has been observed that a large number of bubbles would cover the tool surface area at a critical applied voltage, leading to isolation between the tool and electrolyte, and an insulating layer would be formed in the surroundings of the tool [1]. A semi-empirical model was developed to predict the material removal rate during an idealized electrochemical discharge machining operation [2]. A spark generation mechanism was experimented with in the electrochemical discharge machining (ECDM) process [3]. Gautam and Jain [4] investigated the spark electrochemical spark machining process for the enhancement of process capability with the help of various tool kinematics, such as machining with eccentricity, machining without eccentricity, and rotation of the tool. The effect of various predominant process parameters of the ECDM process was experimented on different machining criteria, such as material removal rate and the overcut phenomenon [5]. The machining of non-conducting zirconia was investigated with an electrochemical discharge machining process [6]. A 3D model developed for an unsteady state heat condition problem using the finite element method (FEM) to predict the material removal rate during electrochemical spark machining (ECSM) machining of non-conducting materials [7]. A 3D-micro structuring of glass machining characteristics was investigated by the spark-assisted chemical engraving (SACE) process [8]. The limitations of machining depth associated with the electrochemical spark machining process were studied [9]. A time-varying current during ECDM of non-conducting material was investigated to reveal the basic mechanism of temperature rise and material removal [10]. The machining operation of optical glass, quartz, and engineering ceramics was

studied with the traveling wire-ECDM process [11]. A spark-assisted chemical engraving process was investigated in the light of electrochemistry [12]. A reversible interconnection for a glass-based microfluidic system was developed using the ECDM process [13]. A theoretical model for electrode effects was established with the help of percolation theory in the spark-assisted chemical engraving process [14]. Different types of channels and parameter influences were experimented using RSM, GA, PSO, etc [15 - 21]. An optimized process parameter based on GRA-Taguchi analysis was determined during the micro-machining of glass [22].

This chapter mainly focuses on ANOVA-based modeling as well as multi-response optimization for the minimization of ROC as well as MRR. Fig. (1) represents the micro-ECDM setup for micro-drilling operation on glass.

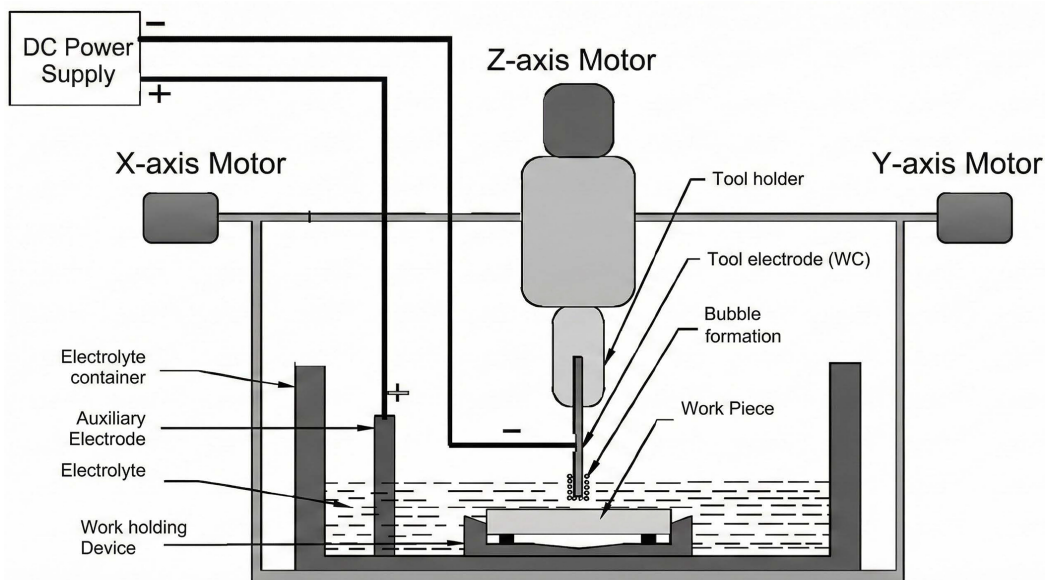


Fig. (1). The Micro-ECDM setup

EXPERIMENTAL DESIGN BASED ON THE FACTORIAL METHOD

A complete factorial design is one in which every setting of each component appears alongside every setting of every other factor. All input components are specified at two levels, each in a simple complete factorial experimental design. “High” and “low,” or “+1” and “-1,” are the names given to these levels, respectively. A two-level complete factorial design includes every conceivable high/low combination of all the input elements. A factorial experiment in which just a suitably selected percentage of the treatment combinations needed for the full factorial experiment is chosen to be conducted is known as a fractional

CHAPTER 8

Metaheuristics-based Parametric Optimization of Semi-automatic MIG Welded Austenitic AISI 304 Stainless Steel for Industry 5.0**Abhishek Ghosh¹ and Sudip Mandal^{2,*}**¹ *Department of Mechanical Engineering, SKFGI Mankundu, West Bengal, India*² *Department of Electronics and Communication Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, India*

Abstract: Austenitic stainless steels are readily weldable, but sensitization and solidification cracks are common defects in the welding of such steels. It is found that the problem of solidification cracking remains under control if the weld pool solidifies in FA mode. 6-8% delta ferrite in the fusion zone can promote the FA mode of solidification. The effects of different semi-automatic MIG welding parameters, like welding current, gas flow rate, and welding speed, on solidification behavior and microstructure of the weldment are not clear. In this present work, an attempt has been made to optimize MIG welding input parameters to achieve 7% delta ferrite in the fusion zone. Initially, ANOVA-based analysis and optimization was performed. A new metaheuristic, namely the Elephant Swarm Water Search Algorithm (ESWSA), was used for optimization purposes to get the optimal condition of grinding.

Keywords: AISI304 austenitic stainless steel, ANOVA, ESWSA, Industry 5.0, Metaheuristics optimization, Semi-automatic MIG welding.

INTRODUCTION

Gas Metal Arc Welding (MIG welding) creates a bond between metals by heating them with an arc formed between a continuous, consumable electrode and the workpiece in a protective gas-shielded environment [1]. MIG welding is frequently used to weld austenitic stainless steels when quality, cost, and productivity are areas of concern [2]. Austenitic stainless steels are interstitial solid solutions of carbon with an FCC crystal structure [3]. They are non-magnetic, cannot be treated with heat, and offer toughness, ductility, and corrosion resistance [4]. Their superior properties have made them an automatic

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choice to be used in nuclear, chemical, power, and aviation industries, as well as other critical areas [3]. The present work deals with the optimization of MIG welding parameters to achieve the FA mode of solidification during welding. RSM-based modeling and optimizations have already been successfully implemented by Ghosh *et al.* [5, 6] for TIG welding. Hence, in this work, ANOVA and metaheuristic-based parameters optimization of MIG welding have been considered for research. A machine learning-based approach for mathematical modeling of MIG welding and finding out optimal welding conditions helps in human-machine interaction, which can be used in Industry 5.0.

Sensitization and Solidification Cracking in Austenitic Stainless-steel Welds

Although austenitic stainless steels are weldable, sensitization and solidification cracking are common defects of their weldment [3, 4]. Solidification cracking is thought to occur because the solidifying weldment cannot withstand the strain during the freezing process [7]. Solidification cracking tendency in austenitic stainless steel is enhanced by impurities such as sulfur and phosphorus, forming low-melting sulfide and phosphide films, respectively, which segregate during solidification, causing more shrinkage stress [4].

Role of δ -ferrite on Solidification Mode and Weld Quality

Around 5 - 10% retained δ -ferrite in microstructure is beneficial to resistance against hot cracking and can minimize the detrimental effects of sulfur and phosphorus [4, 8]. Sulfur and phosphorus are not soluble in iron, chromium, and nickel, but their solubility is higher in δ -ferrite [9]. The ductility of ferrite at high temperatures is higher than that of austenite, which enables the relaxation of thermal stresses [10]. Additionally, the lower thermal expansion coefficient of δ -ferrite compared to austenite leads to reduced contraction stresses during solidification [10]. But the presence of too much δ -ferrite (>10 vol. %) in the weld zone tends to reduce the ductility, toughness, and corrosion resistance of the weldment, and extremely less quantity of δ -ferrite (<5 vol. %) cannot provide enough resistance to hot cracking [11]. But if the percentage volume of δ -ferrite reaches beyond 8-10%, a continuous network of δ -ferrite is formed, which can be beneficial for stress corrosion cracks (SCC) to propagate along the continuous path [12]. Kathak *et al.* [13] concluded that the corrosion rate at different atmospheres increased with an increase in δ -ferrite in microstructure from 3 vol. % to 8 vol. % and the corrosion rate increased rapidly beyond 8 vol. % δ -ferrite in weld microstructure [14 - 17]. Considering all the factors, it is concluded that 7% δ -ferrite in the as-welded condition in an austenitic stainless steel weld metal zone is suitable, and this value has been taken as a target during optimization.

EXPERIMENTAL PLAN AND PROCEDURE

An austenitic stainless-steel plate of type AISI 304 (100 mm length \times 50 mm width \times 3 mm thickness) is used as base metal (BM) for the present experiments. The chemical composition of the base metal is shown in Table 1.

Table 1. Chemical composition of base metal.

AISI 304	% C	% Mn	%Si	% S	% P	% Cr	% Ni	% Mo
	0.08	1.52	0.61	0.02	0.035	18.45	8.12	0.05

ER 308L MIG welding electrode is used in the present work. The chemical composition of the electrode wire is shown in Table 2.

Table 2. Chemical composition of electrode wire.

ER 304L	% C	% Mn	%Si	% S	% P	% Cr	% Ni	% Mo
	0.02	1.74	0.45	0.03	0.025	19.05	8.28	0.02

The CPT-400 semi-automatic MIG welding set-up was used for welding. 99% pure argon gas shielding was supplied for welding. Welding was completed in a single pass, square butt joint. The diameter of the electrode rod was taken as 1.2 mm. The XXQ-2005 (130 KV, 5 mA) radiographic testing machine was used for radiographic tests. Tensile test specimens were prepared according to the ASTM E8 standard, and the tests were conducted using a strong universal testing machine. The microstructural evaluation was performed with a Leica metallurgical microscope (model no. DMLM/11888605), adhering to the AWS D1.1 codes. After welding, the samples were cut transversely from the welds, followed by mechanical grinding, polishing, and etching with an aqua regia solution ($\text{HCl}:\text{HNO}_3 = 3:1$). The micro-hardness of the base metal, HAZ, and weld zone was measured using a LECO LM 248AT micro-hardness tester (Vickers scale). Ferrite content in the weld zone and HAZ was determined using a ferrite scope. The input parameters considered for the study were welding current (I), gas flow rate (F), and welding speed (S). The levels of these parameters are presented in Table 3. A total of twenty welded specimens were fabricated under varying parametric conditions using the Response Surface Methodology (RSM) with a face-centered central composite design (CCD). Six center runs were chosen, and the axial points were selected with $\alpha = 1.682$.

CHAPTER 9

Bio-Inspired Algorithm-based Performance Enhancement of Solar-powered SR Motor for Sustainable Marine Propulsion**G. Jegadeeswari^{1,*} and B. Kirubadurai²**¹ *Department of Electrical and Electronics Engineering, Saveetha Engineering College, Chennai, India*² *Aeronautical Engg, VelTech Dr. Rangarajan Dr. Sagunthala R&D Institute of Science and Tech, Chennai, India*

Abstract: Marine propulsion systems are evolving towards energy-efficient and environmentally friendly solutions, with solar-powered Switched Reluctance Motors (SRMs) emerging as a promising alternative. Despite SRM's inherent advantages, such as robust design, high efficiency, and fault tolerance, it suffers from torque ripples and non-linearity, which hinder its optimal performance in marine applications. This chapter investigates the performance enhancement of solar-fed SRMs in ship propulsion systems through the application of metaheuristic algorithms for intelligent control. Specifically, metaheuristic techniques such as Particle Swarm Optimization are employed to fine-tune controller parameters for minimizing torque ripple and improving speed control under varying load conditions. A solar-fed SEPIC converter is integrated into the system, providing a stable and renewable energy source while maintaining system's efficiency. The proposed approach leverages metaheuristic algorithms to optimize the performance of the SRM drive by adjusting the control gains, thus ensuring smooth and efficient propulsion. Simulation results demonstrate a significant reduction in torque ripples, enhanced speed response, and improved overall system efficiency compared to traditional PI controllers. The findings highlight the potential of metaheuristic algorithms to transform SRM technology into a viable solution for sustainable marine propulsion systems.

Keywords: Metaheuristic algorithms, Particle swarm optimization (PSO), Switched Reluctance Motor (SRM), Sustainable marine propulsion, Solar-powered propulsion, Torque ripple reduction.

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INTRODUCTION

As the maritime industry moves towards greener technologies, integrating solar power into ship propulsion systems is crucial for reducing carbon emissions and dependence on fossil fuels. The use of solar-fed Switched Reluctance Motors (SRMs), developed by *G. Jegadeeswari et al., in 2024*, aligns with global efforts to adopt renewable energy in transportation for reducing environmental impact while maintaining propulsion efficiency [1, 2].

SRMs, despite their advantages, face issues like torque ripple and non-linear control challenges. Metaheuristic algorithms, proposed by *G. Jegadeeswari et al., in 2023*, such as Particle Swarm Optimization, offer powerful solutions for tuning controller parameters [5, 3]. These algorithms can optimize motor performance, reduce torque ripple, and enhance speed control, which is critical for ensuring smooth and efficient marine propulsion. Ships operate in dynamic environments with varying load conditions, speed demands, and power fluctuations. *G. Jegadeeswari et al in 2020* [4] developed metaheuristic algorithms that are adaptive and can fine-tune controllers in real time, improving the SRM's ability to respond to these unpredictable conditions. This enhances the system's overall reliability, ensuring stable and efficient propulsion in both shallow and deep-water operations.

Harnessing solar energy and optimizing SRM performance, the system proposed by *M. Das et al., in 2015* can significantly lower operational costs related to fuel consumption and maintenance [6]. Solar-fed systems reduce the need for frequent refuelling and extend the ship's range, contributing to the economic sustainability of maritime operations. Furthermore, the robustness and fault tolerance of SRMs, combined with optimized control, can lower maintenance costs by minimizing wear and tear on mechanical components. *R. Errouissi et al., in 2018* [7] introduce advanced control methodologies through metaheuristic algorithms, which can be further expanded to other renewable energy-based propulsion systems. The success of this approach can inspire the development of more intelligent, adaptive, and eco-friendly propulsion technologies, making it a vital step toward the next generation of marine propulsion systems. *R. Prabhu et al., in 2019* [8] suggested that the solutions proposed in this chapter can be adapted not only to large commercial ships but also to smaller vessels such as autonomous underwater vehicles (AUVs) and drones, opening possibilities for wider applications in exploration, defense, and ocean research. The metaheuristic approach can also be extended to other motor types and renewable energy systems, demonstrating the scalability of the research. *H. Len et al., in 2015* [9] suggested a revolutionary high-performance converter among non-conventional energy sources. The Solar Photovoltaic (SPV) source has received a lot of interest

because of its low environmental impact and low installation and maintenance costs. *J.F. Hansen et al., in 2015* [10] discussed that the atmospheric conditions have an important role in the power conversion efficiency of SPV systems. *K. Kavitha et al., in 2012* [11] developed an innovative speed control design of a PI controller for AC motor drives, taking input saturation into account. *G. Jegadeeswari in 2017* [12], showcased the development of a Proportional-Integral (PI) controller using an innovative technique that enables the approximate restoration of nominal tracking performance while mitigating the adverse effects induced by input saturation that allowed the bridgeless SEPIC converter to employ connected inductors, resulting in a reduced overall component count and lower inductance demand when compared to the regular SEPIC converter. OCC is a nonlinear control method used to regulate the voltage loops and improve behavior and transient state reactivity. *R. Vinifa et al., in 2024 and 2022* [13, 14] suggested THD reduction for a three-phase power multilevel inverter.

METHODOLOGY

The proposed study explains how a 4-phase, 8/6 switched reluctance motor (SRM) powered by photovoltaic is used to power the ship's propeller. Chapters four, five, and six include specifics on the proposed method, including its behavior and working principles. Switched Reluctance Motors use a variety of metaheuristic optimization techniques and intelligent controllers to minimize torque ripples and smooth control operation. The sudden increase in the speed and torque observed in the conventional induction motors is effectively addressed in maritime propulsion systems by replacing them with SR motors. Because hysteresis current control technology is used, the motor's speed will not drop when a load is changed. Photovoltaic systems will produce a low-level DC voltage with fluctuations that can be boosted by the use of a high-gain Single-Ended Primary Inductance Converter. With the help of a high-gain converter, the output of the solar system has been effectively controlled. Additionally, the high-gain converter is controlled by using a Maximum Power Point Tracking technique by implementing an Adaptive Neuro-Fuzzy Inference System. By effectively removing errors, the ANFIS-MPPT algorithm generates a control signal and maximizes the efficiency of photovoltaic (PV) systems using input voltage (VPV) and current (IPV). The PWM generator is controlled by this control signal, which produces PWM pulses that regulate the operation of the SEPIC Converter by energizing the switching processes, thereby controlling the output voltage of the converter.

The BR converter is also called an (n+1) semiconductor, and the (n+1) diode converter powers the motor phase windings and sends the Sepic Converter output to the motor. In addition, a PI and an optimization algorithm for fine-tuning the

CHAPTER 10

Experimental Framework for Bio-inspired Algorithms in Wireless Communication: An Industry 5.0 Perspective.

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Abstract: Advancements in wireless networks are crucial for the transformative potential of Industry 5.0, particularly in smart manufacturing and industrial automation. However, this new era demands solutions for persistent challenges, such as limited communication range, real-time data processing, and privacy concerns. Bio-inspired algorithms provide a novel approach to addressing these challenges, leveraging patterns observed in nature to enhance optimization and efficiency in wireless communication systems. This paper proposes an experimental framework using bio-inspired techniques to address specific industrial wireless communication needs, with a focus on edge intelligence, ultra-reliable low-latency communication, and energy efficiency. By emulating message protocols found in social animals, bio-inspired algorithms can optimize aspects like dynamic channel allocation and energy-saving topologies. The framework facilitates real-world testing in small to medium-sized industrial network settings, enabling an enhanced understanding of Industry 5.0 scenarios. Case studies demonstrate the effectiveness of bio-inspired solutions in optimizing network topology and energy consumption across smart factory networks, achieving notable results in scenarios requiring efficient data handling and reliable connectivity. This research highlights the importance of interdisciplinary approaches in supporting Industry 5.0 goals, demonstrating bio-inspired algorithms as promising tools for scalable, adaptive, and human-centered industrial wireless systems. The findings point towards sustainable advancements in wireless technology, fostering a deeper integration of nature-inspired solutions within next-generation industrial communication networks.

Keywords: Bio-inspired algorithms, Industrial automation, Industry 5.0, Optimization, Real-time data processing, Smart manufacturing, Wireless networks.

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INTRODUCTION

Advancements in wireless networks have led to industrial revolutions, such as the Industrial Internet and intelligent manufacturing. However, challenges remain in the communication range, real-time communication, and privacy protection [1]. The evolution of Industry 5.0 will bring more sophisticated requirements, improving the performance and capability of next-generation communication systems. Key technologies and concepts, such as edge intelligence, cell-free massive MIMO, ultra-reliable low-latency communication, spectral sharing, communication separation, and fusion, will be essential components. Bio-inspired algorithms can optimize specific components in future wireless communication systems, enhance performance, and refine algorithmic structures. An experimental framework for bio-inspired algorithms in wireless communication at the physical layer is presented, supporting various components throughout the system [2]. The proposed wireless experimental environment can construct local, small to medium-sized internal communication systems for factory scenes, providing a better understanding and verification in high-definition and high-precision industrial case instruments.

Background and Motivation

The recent revolution is changing the paradigms of various sectors of the modern economy, leading to integrated cooperation among heterogeneous entities, which enables a more efficient standard of living and accelerates the challenges that society is facing. Wireless communication has had a prominent role in both small and large projects. Wireless communication is everywhere, and shortly, it is expected that billions of devices will be able to transmit and receive at different scales of communication [3]. As the fourth industrial revolution paves the way for the digitalization of all processes, concepts, and services, it becomes essential to communicate even better and be recognized in advance. Thus, bio-inspired algorithms play an important role in processing the information necessary to bring life to prediction theories.

Although Industry 5.0 brings promising results by aligning security, comfort, and low processing latency, it also reveals certain flaws. One key issue is that the current peak in data processing demand—driven by the economy and intelligent services—has outpaced the system's ability to effectively manage and control. Data transmission based on an increasing number of connected devices does not give such precedence, if we think of large numbers of users who, at distinct intervals, decide to send large volumes of data simultaneously [4]. Hence, the teachings and strategies discussed can benefit such services, thereby minimizing traffic.

Scope and Objectives

To integrate the vast amount of unexploited principles on distributed computing provided by the biologically inspired algorithms community, whose focus is entirely on problem-solving and not on specific communication networks, this paper describes the main challenges and possible applications of specially tailored bio-inspired algorithms in industrial wireless communication networks, which constitute the basis for the monitoring, control, and automation of Industry 5.0 systems [5]. More specifically, after a review of the basics of bio-inspired algorithms, message protocols in social animals, and herd behavior phenomena, we identify the key features of wireless networks that might be overcome by properly mimicking mainly the message protocols employed by social animals, with the hope of contributing to renewing the stimulus underpinning original interdisciplinary research—characterizing symbiosis with nature typical of the engineering domains [6]. The considered categories of message protocols—specifically, the algorithmic strategies that allow nodes to adapt their messaging based on received signals, inspired by animal communication—can be leveraged to enhance the spatial reuse of network resources. This approach supports the analysis, design, and optimization of protocols that enable crowded networks to dynamically select small subsets of peer energy sources for time-shared use. Such mobile-to-mobile recharging services represent a promising energy provisioning solution for mobile networks, offering benefits in both performance and environmental sustainability.

BIO-INSPIRED ALGORITHMS IN WIRELESS COMMUNICATION

The Biologically Inspired Approach (BIA) has gained importance in solving complex optimization problems in communication systems due to its real-world analogy in biological systems [7]. BIA models randomized problems based on parameters, potential values, limitations, and convergence processes. Metaheuristic algorithms play a significant role in discrete and population optimization problems, focusing on limits and problem-specific knowledge. BIA design problem-solving focuses on the given solution and its costs. BIA can use direct or antibody-based metaheuristic algorithms for modulation classification and error functions for transmitted signal parameters. BIA achieves considerable performance, complexity, and convergence gain compared to current signal detection solutions. It monitors covariance matrices, confirming the accuracy of the data model and the deterministic process of optimization. Compared to additional algorithms, BIA significantly reduces redundant training time and achievable gains [8]. The signal's nearest neighbor is processed using Békédy's trigger mechanism for improved accuracy. BIA effectively meets the competitive needs of the wireless industry, driven by its growing data requirements.

Artificial Intelligence and Robotic Process Automation in the Indian Banking Industry: Implementation Strategies, Applications, Benefits, and Sustainability

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Abstract: Recent developments in technology within the Indian banking sector, specifically the implementation of Artificial Intelligence (AI) and Robotic Process Automation (RPA), have significantly transformed banking operations and customer experience. This study examines the implementation strategies, applications, and benefits of AI and RPA in Indian banking by reviewing secondary data from government and private reports, publications, books, and journals. The findings indicate that AI is used for building knowledge graphs, recommending services, and detecting financial fraud, whereas RPA delivers AI insights in real time. Applications include customer service, risk management, fraud detection, and personalized financial advice. The benefits of integrating AI and RPA include operational cost reductions of 30-70%, improved accuracy, 24x7 operations, and enhanced customer experience. The challenges include data security, regulatory compliance, potential job shifting, and the requirement for staff training. The study concludes that the successful integration of AI and RPA requires a strategic approach that focuses on organizational readiness, stakeholder engagement, and ethical considerations. Future research should find the long-term effects, ethical implications, strategies for sustainable integration, and potential for promoting financial inclusion in India.

Keywords: Artificial intelligence, Indian banking industry, Machine learning techniques, Robotic process automation.

INTRODUCTION

The banking system forms the foundation of the economic and social development of a country. It is the most important pillar of the financial sector,

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which plays a pivotal role in economic development of a country [1]. It is also very important that the financial requirement of various sectors of the economy is fulfilled with a higher degree of commitment and responsibility. They play a crucial role in the mobilization of deposits and supply of credit to the industry, and perform a similar role to the heart of the human body. The primary component of a nation's economic strength is the financial system's ability to operate efficiently, which is the outcome of a stable and solvent banking system. The Indian banking industry has undergone significant technological development in recent years, with the adoption of digital technologies that transform the way banks function and serve their customers [2]. One of the key areas of technological development is mobile banking, with banks launching mobile apps that allow customers access to a variety of banking services on their smartphones. This has improved banking's accessibility and convenience, especially for clients in rural areas, who may not have easy access to physical bank branches.

Another important development in the Indian banking industry is the adoption of artificial intelligence and machine-learning technologies. These technologies are being used to improve fraud detection and prevention, as well as to enhance the level of customer service by providing personalized services and recommendations [3].

Regular tasks in the banking sector, such as handling customer data, detecting fraud, and processing transactions, can be automated with AI. However, repetitive operations like data entry, report generation, and onboard customer analysis can be automated with RPA. Banks may lower operating expenses, increase productivity, and improve customer happiness by utilizing AI and RPA [4]. One of the major advantages of AI in the banking industry is its ability to analyze large amounts of data quickly and accurately. Banks can use AI to identify patterns and trends in customer behavior, which can help them offer personalized services and improve their marketing strategies. Additionally, AI can be used to identify criminal behavior like identity theft and money laundering, which can help banks prevent financial losses and protect their customers' interests. RPA can also help banks automate their back-office operations, such as account opening, processing loans, and claims management. By automating these operations, banks can reduce the turnaround time and improve the precision of their processes. RPA can also be used to automate customer interactions, such as chatbots and virtual assistants, which can assist banks in offering their clients round-the-clock assistance. However, there are several obstacles to overcome when implementing AI and RPA in the banking sector. Banks must ensure that the data used for AI and RPA is accurate, secure, and compliant with the regulatory requirements [5, 6]. Banks also need to invest in the appropriate infrastructure and talent to support AI and RPA initiatives.

In conclusion, AI and RPA have the potential to completely change the Indian banking industry by increasing productivity, reducing costs, and improving the overall customer experience. Banks that embrace these technologies can gain competitive advantages and provide better services to their customers.

Objectives

The goals of the research are:

- To identify the need for the implementation of AI and RPA in the Indian banking industry.
- To study the benefits of adopting AI and RPA in the Indian banking industry, and
- To learn about the implementation strategies of AI and RPA in various Indian Banks.

METHODOLOGY

The foundation of this study is a thorough analysis of secondary data, which was gathered from a variety of public and private reports, websites, books, newspapers, journals, and magazines.

Information Technology in the Banking Industry

Around the world, information technology (IT) has altered how organizations operate. Offering cutting-edge goods and services through technology advancements has benefited the Indian banking industry as well [7]. Through the introduction of innovative delivery channels to consumers, such as ATMs and shared payment platforms, online banking, the deployment of core banking solutions, mobile banking, *etc.*, information technology has greatly benefited the banking industry.

The main advantages of technological adoptions in the banking industry are:

- Reduction of operational cost
- Encouraging customers to transact efficiently

The RBI has increased its emphasis on integrating modern technologies into banks' daily operations over time. As stated in the IT Vision Document, 2011–17, the Reserve Bank of India lays out a comprehensive plan for implementing important IT applications in banking, with a focus on ensuring that banking services are delivered flawlessly through the effective use of Business Continuity Management (BCM), Information Security Policy, and Business Process Re-

Artificial Neural Network-Based Modelling of Hexagonal Slotted Microstrip Patch Antenna Operating at 4.5 GHz for 5G Communication in Industry 5.0

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Abstract: In a very fast communication world, the technology is inclining towards the 5G & 6G communication techniques. Among the available frequency bands for 5G, the n79 band (4.5 GHz) is very popular. It can be applied for many purposes like mobile communication, radios, *etc.* Even this band is also tested and deployed for 4G communication. A microstrip patch antenna is very popular for high-speed communication due to compact size, light weight, and ease of application. In this research work, we used Rogers 92 mL substrate, a copper ground and a copper patch with a hexagonal slot utilizing the inset feeding technique with the help of Computer Simulation Technology (CST) Studio Suite 2024. After adjusting the radius of the hexagonal slot and after shifting its centre to the exact location, satisfactory results have been achieved. For the best result, S_{11} falls up to -61.33dB at the exact 4.5GHz frequency and the corresponding bandwidth is 1.2919 GHz, which is suitable for 5G communication in the n79 band. Additionally, a mathematical model for the proposed patch antenna is developed using Artificial Neural Network models to predict antenna parameters like S_{11} , bandwidth, and resonant frequency based on the radius of the hexagonal slot and the position of the centre of the slot. Predicted results show satisfactory accuracy in comparison with the CST Studio 2024 values.

Keywords: Artificial Neural Network (ANN), Industry 5.0, Microstrip patch antenna, Modelling, 5G communication.

INTRODUCTION

Following the development of 4G communication, the fifth generation, *i.e.*, 5G, becomes more efficient in IoT technology, mobile communication, remote surgery, autonomous driving, and other applications. Therefore, industries require

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small, portable, cost-efficient, and moderately priced antennas with good speed and communication capabilities. There are so many types of antennas, like parabolic antennas, horn antennas, Yagi-Uda antennas, *etc.*, among those, Microstrip Patch Antenna (MPA) [1] is preferable for being portable, durable, reliable, cost-efficient, and light-weight. An MPA is made up of a dielectric substrate element between the patch and the ground. Generally, the patch and the ground are made up of Gold or Copper with different shapes and sizes for better efficiency [2]. The patch is connected to the transmission line by the inset feeding technique. In our research for achieving 4.5 GHz frequency in the CST Studio Suite 2024, we selected Rogers 92 mL dielectric substrate, with Copper as the patch and the ground. To enhance the bandwidth, resonant frequency, and gain, we designed the patch with a hexagonal slot. After varying several parameters of the antenna, we observed that changing the radius of the hexagonal slot and the position along the transmission line axis gave the desired results. After designing the patch antenna, Surface fitting technique is applied through MATLAB software to predict the result with CTS values. After adjusting the layers and the nodes in the Artificial Neural Network, we observed the best output result compared with our designed antenna result in CST. Many authors have attempted to design a process of MPA process at this frequency band. Geetharaman *et al.* [3] have proposed A-shaped antenna of $40 \times 50 \times 1.6$ mm³ dimensions that operates at 4.5 GHz with -37.92 dB return loss, 4.14 dB gain, 1.024 VSWR, and 340 MHz bandwidth. Singh *et al.* [4] designed a symmetrical maze-shaped slots antenna of $15 \times 15 \times 1.6$ mm³ dimensions, resonating at 4.5 GHz with -43 dB return loss and 500 MHz bandwidth. Maheshwari *et al.* [5] designed an antenna that resonates at 4.6 GHz with -25.93 dB return loss, 7.944 dB gain, and 0.8781 VSWR. Werfelli *et al.* [6] designed an antenna operating at 4.3 GHz with -30 dB return loss, 3.488 dB gain, 1.6-1.7 VSWR. On the other hand, Maurya *et al.* [7] proposed a hexagonal ring microstrip patch antenna with asymmetrical feed and DGS. Ahmed *et al.* [8] proposed a rectangular microstrip antenna design with a multi-slotted patch and partial grounding for 5G communication. Moreover, Maity *et al.* [9] also designed a circular patch antenna with DGS working at 3GHz.

The use of the 4.5 GHz frequency band in our research on hexagonal slotted MPA design is strategically important for 5G communications [9, 10] due to several key factors. This frequency falls within FR1 (Frequency Range 1) and the mid-band spectrum (1-6 GHz) of 5G, offering an optimal balance between coverage and capacity while providing good signal penetration through buildings and reasonable coverage areas. It is part of the standardized n79 band (4.4-5.0 GHz) for 5G New Radio (NR) and has been allocated for 5G deployment [11, 12] in many countries, particularly in Asia and parts of Europe. From an antenna design perspective, 4.5 GHz provides practical advantages as it allows for reasonable physical dimensions in microstrip patch antennas while maintaining good

performance characteristics, making it suitable for mobile devices and advanced array implementations. This frequency represents an ideal choice for research as it enables the study of crucial 5G features [13] like beam forming, and the findings can apply to nearby frequencies within the mid-band spectrum, contributing valuable insights to the field of 5G antenna design and optimization.

METHODOLOGY

Fig. (1) represents a four-step process for optimizing antenna design using artificial intelligence. It starts with designing an antenna using CST software, followed by creating a database through systematic parameter variations. The third step involves developing and training an Artificial Neural Network (ANN) using this database. Finally, the trained ANN is used to predict antenna performance for new designs, with validation to ensure accuracy. This approach combines traditional electromagnetic simulation with machine learning to make antenna design more efficient and less time-consuming.

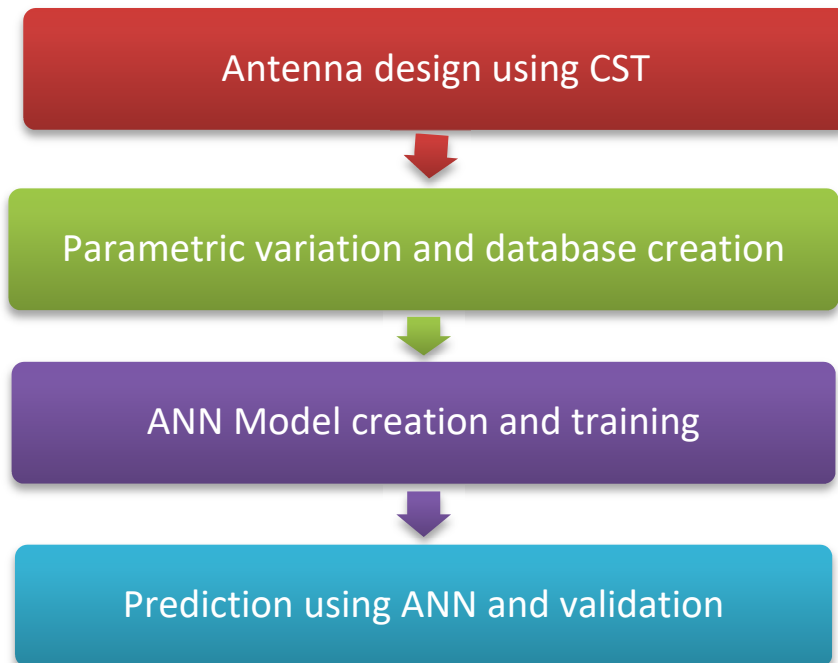


Fig. (1). Flowchart of our overall research.

Design of the Proposed Microstrip Patch

In the beginning, the width and the length of the antenna are calculated by the MPA calculator from the Pasternack [14] website. For making a Microstrip patch

Comparative Study of Hybrid GAPSO for Parametric Optimization of the Liquid Flow Model

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Abstract: This study focuses on optimizing a nonlinear liquid flow control process model using advanced techniques. A total of 134 datasets were collected, with 117 used for training and 17 for validation. To check the performance of the best algorithm, a comparative study has been conducted between GA, PSO, and the proposed hybrid GAPSO techniques. The performance was evaluated using MAE, MAPE, RMSE, and computational time. The results showed that the hybrid algorithm outperformed others in terms of convergence speed, computation time, and accuracy.

Keywords: ANOVA, Genetic algorithm (GA), Liquid flow, Particle swarm optimization (PSO).

INTRODUCTION

In the process industry, optimization has been crucial during the past few decades, and Artificial Intelligence approaches have taken the lead in creating process models [1]. The optimization technique is typically applied to any nonlinear model to determine the best response. The liquid flow process model is a restriction of traditional optimization techniques because of the complex relationship between multiple inputs, response, and significant delay time. Because computational optimization reduces the computing time and accurately forecasts the possible input, researchers use it in the majority of complicated nonlinear process models [2]. Computational optimization performance is typically divided into two categories. In the first stage, the majority of the dataset,

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comprising input and output variables, is used to help develop the model. The model, which accounts for the input and output process variables, is verified and evaluated against the test data set in the second phase. Neural network control models are among the various AI techniques employed in numerous studies, namely ANFIS [3, 4], FLC [5, 6], GA [7], hybrid GA-ANN model [8, 9], *etc.* Nonlinear process plant train datasets are often modeled using empirical approaches such as ANOVA, RSM, and ANN [10 - 12]. For the liquid flow process industry, several studies have been conducted to optimize empirical models parametrically using various metaheuristic optimization techniques. These include improved FPA and enhanced versions of the ESWSA-integrated ANOVA and RSM model [13]. In addition, a hybrid HPSOGWO was suggested to execute this complex model, aiming to increase convergence speed [14]. In addition to providing better solutions and running faster than other metaheuristic algorithms, PSO is a highly effective algorithm [15], however, its main drawback is that it cannot find the global optimum [16]. The global optimum solution is provided by the genetic algorithm, which takes a considerable amount of computing time because it improves outcomes by increasing the number of iterations and computational steps [17]. Therefore, in this study, we used both PSO and GA to develop a hybrid optimization technique called HGAPSO, which enables faster performance [18]. HGAPSO is used as an optimization tool used in several fields, including medical diagnosis and potential attribute selections [19, 20], as an estimation tool for wear in a milling process [21], in cluster-based routing in WSN [22], hierarchical problem-solving in GP algorithm [23], transformer fault diagnosis [24], *etc.* The HGAPSO assessment indicates that the suggested optimization methods are practical and efficient in fulfilling the real-time control needs of the liquid flow control process.

Overall, the article is organized into the following sections: introduction, followed by a mathematical explanation, suggested technique, findings and discussion, and finally, conclusions.

EXPERIMENTAL PROCEDURE

The Liquid Flow experimental setup [2], as shown in Fig. (1), is used for the experimental work. Four independent variables have been included in 134-sample data collected for this work.



Fig. (1). Experimental setup [3].

A well-known nonlinear power equation, Analysis of Variance (ANOVA) [25 - 27], is formulated to represent the input and output variables as shown in Eq. (1)

$$F = \mu_1 \cdot E^{\mu_2} \cdot D^{\mu_3} \cdot k^{\mu_4} \cdot n^{\mu_5} \quad (1)$$

The values of this coefficient can be obtained using computational intelligence techniques. Here, three distinct metaheuristic optimization strategies are used to fit the process with the experimental one and provide the optimal value of the process variable. We employed RMSE as an objective function in this study to minimize the metaheuristic. The error function for ANOVA-based modeling can be written as:

$$(E_i, D_i, X) = \mu_1 \cdot E^{\mu_2} \cdot D^{\mu_3} \cdot k^{\mu_4} \cdot n^{\mu_5} - F \quad (2)$$

$$X = \{\mu_1, \mu_2, \mu_3, \mu_4, \mu_5\} \quad (3)$$

PROPOSED METHODOLOGY

GA, PSO, and hybrid HGAPSO are explained first before the suggested methodology is further developed.

Photovoltaic Cell Performance Assessment Using the Hybrid CSPSO Algorithm

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Abstract: The conventional model is limited to obtaining the optimal solution from a nonlinear system objective function. An effective method for determining the optimal solution for nonlinear objective functions is the use of evolutionary algorithms (EA). In this study, we suggested three optimization techniques: Cuckoo Search Optimization (CSO), Particle Swarm Optimization (PSO), and a hybrid algorithm of CSO & PSO (HCSPSO) to determine the single and double-diode solar cells' optimal parameters. The proposed algorithm was compared with the CSO and PSO in terms of statistical metrics for a single-diode (SDM) and double-diode model (DDM). According to a comparison analysis, a more precise model for estimating a solar cell's optimal parameter with fewer iterations is offered by the upgraded CSO optimization. As a result, we suggested HCSPSO as the top optimization tool for delivering the most promising results.

Keywords: Improved cuckoo search optimization, Metaheuristics, Parametric optimization, Solar cell.

INTRODUCTION

In the current period, renewable energy sources such as solar energy are becoming increasingly appealing due to the energy crisis and the negative environmental impacts of pollution [1 - 3]. A solar cell must be modeled to forecast how it will behave under varying temperatures and sun intensity situations. Although there have been several research studies on solar cells, the most popular literature

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review compares the SDM with the DDM [4 - 7]. An effective optimization approach is necessary in a photovoltaic system to determine the best parameter and anticipate the performance of a solar cell [8, 9].

There are diverse characteristics of bio inspired optimization experimented on SDM & DDM of PV modules such as Genetic Algorithm [10, 11], Differential Evolution [12, 13], ABC calculation [14, 15], Chaotic JAYA Algorithm [16], TLBO [17], SFLA [18], Moth-Flame Optimization (MFO) [19], Sine-Cosine Algorithm [21], Ant lion optimization (ALO) [20], FPA [22, 23], elephant swarm water search (ESWS) [24], PSO [25] and so on. To study the performance of an SDM, three optimization techniques, Bat algorithm (BA), CSO & Firefly algorithm (FA) [26], were used. Moreover, wind-driven optimization was also used for the optimization of DDM [27]. Apart from this metaheuristic optimization, some researchers also applied a fuzzy logic controller [28] and genetic algorithms [29]. In the theory of the “No Free Lunch hypothesis,” [30] it is mentioned that no single metaheuristic is reasonable for taking care of a wide range of issues. Parametric optimization of a single diode, double diode and PV model was done by a hybrid teaching-learning and artificial bee colony (TLABC) [31, 32], improved version of whale optimization algorithm (IWOA) [33], ensemble differential evolution (EDE) [34], improved differential evolution (DE), and WOA [35], improved chaotic whale optimization algorithm (ICWOA) [36], improved ABC, and FPA [37], Hybrid PSO and SA (HPSOSA) [38], Hybrid FA and PSA (HFPSA) [39], Hybrid PSO & GWO algorithm [40]. There are still open challenges in achieving better computational time and convergence speed for optimizing mathematical models. PSO deals with only local search abilities in certain constraints [41 - 43]. Cuckoo Search Optimizer (CSO) is a powerful evolutionary algorithm [44, 45] that exhibits superior convergence ability. To improve the convergence speed and capability of searching the global optimum, we introduced a new hybrid algorithm, HCSPSO, constructed by incorporating PSO with CSO algorithms. The effectiveness of this technique lies in the single and double solar cell model problem with non-smooth cost functions like diode current in both cases. So far Hybrid HCSPSO has been applied to many problems such as for improving the convergence performance of electrical load forecasting [46], energy extraction from fuel cells [47], reconfiguration of electrical distribution network [48], multiobjective parametric optimization in hydropower station [49], self-adaptive knowledge learning in the education sector [50], identification of fault location in a distributed network [51], *etc.* The remaining part of this paper is presented as follows. SDM and DDM mathematical models are presented followed by a discussion on the objective function, the hybrid algorithm, and the analysis of results and conclusions.

MATHEMATICS MODEL OF SOLAR CELL

Single Diode Model (SDM)

Fig. (1) represents the equivalent circuit with a mathematical model for SDM [52].

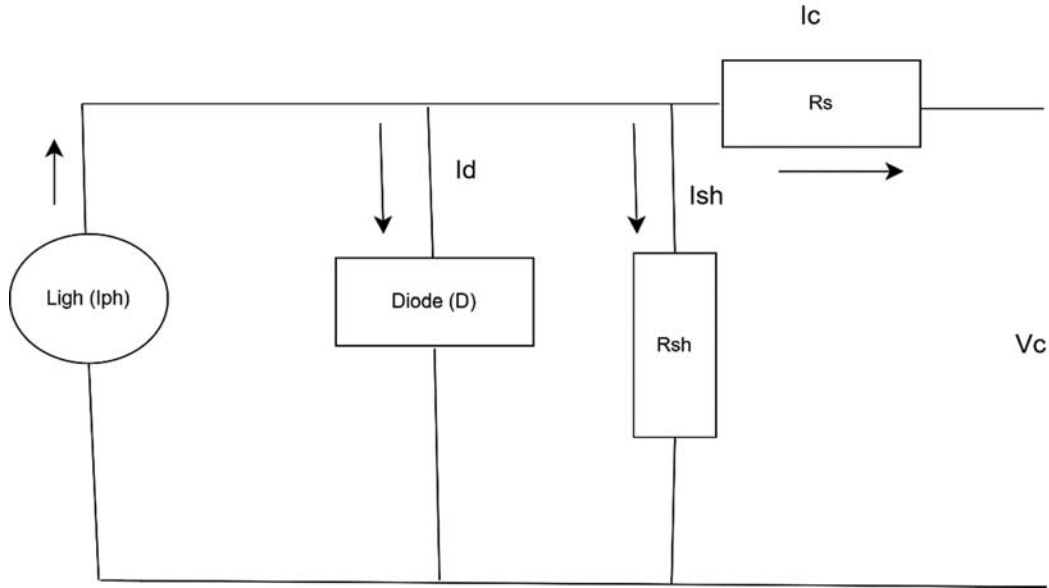


Fig. (1). Simplified model of SDM.

$$I_C = I_{ph} - I_{sh} - I_d \quad (1)$$

$$\text{Where, } I_d = I_{sd} \left[\exp \left(\frac{V_C + I_C R_s}{\eta V_t} \right) - 1 \right] \quad (2)$$

$$I_{sh} = \frac{V_C + I_C R_s}{R} \quad (3)$$

After combining the equations, the resulting current equation is presented in Eq. (4)

$$I_C = I_{ph} - I_{sd} \left[\exp \left(\frac{V_C + I_C R_s}{\eta V_t} \right) - 1 \right] - \frac{V_C + I_C R_s}{R_{sh}} \quad (4)$$

So, the equation contains five parameters (I_{ph} , I_{sd} , R_s , R_{sh} , η) that needs to be optimized.

Design of Rectangular Microstrip Patch Antenna Using ANOVA at 26 GHz for Industry 5.0

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Abstract: In this paper, a rectangular microstrip patch antenna with a triangular polygon at the top of the right side is designed. FR-4 is used as a substrate material with a relative permittivity of 4.3. The inset feeding technique is used to construct the proposed patch antenna. By changing three parameters, namely patch width (W_p), substrate height (h), and width of feedline (W_f), a dataset is created to achieve the resonant frequency of 26 GHz and a bandwidth of 2.5 GHz. ANOVA is employed to find out two equations for the resonant frequency (F_r) and bandwidth (BW) to obtain target outcomes. All the simulations and calculations of the dataset are made using the CST Studio Suite version 2023, and ANOVA is carried out in Minitab version 21.

Keywords: ANOVA, Bandwidth, CST microwave studio, Industry 5.0, Resonant frequency, Rectangular microstrip patch, Triangular polygon.

INTRODUCTION

An antenna is an essential device to communicate a message from the sender to the receiver. In today's fast-paced life, mobile phones have become an indispensable tool to connect with the world. The extensive use of mobile phones requires a miniaturized antenna. The most often searched topic in the communication system industry is wireless technology, which is a relatively new field that creates portable devices. Although there are many other types of antennas utilized in wireless applications today, microstrip antennas are highly regarded. Microstrip patch antennas' compact length, low cost, light weight, and ease of fabrication allow them to serve a vital role in a wide range of applications,

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including cellular communication, satellite communication, radar, and aircraft. The most commonly used microstrip patch antennas are rectangular, square, and circular. Despite this, microstrip patch antennas come in a variety of shapes, including hexagonal, triangular, elliptical, etc. The overcrowded spectrum of 4G technologies and the demand for higher data rates, good bandwidth, low latency, and high-resolution video streaming made the way for 5G technology. In order to improve coverage at a cheaper cost and with greater dependability, 5G delivers fast connections, strong throughput capabilities, large bandwidth, and low power consumption.

A typical microstrip patch antenna is made up of three parts: substrate, patch, and ground. The metallic patch is placed on the insulating material and supported by the ground plane. The substrate's relative permittivity (ϵ_r) can be anywhere between 2.2 and 12 when constructing a microstrip antenna. The quality of the substrate additionally determines the radiation, improves effectiveness, and ensures more extensive data transfer capacity and a greater size of the receiving wire. The feeding of a microstrip patch antenna can be taken care of through various procedures, including coaxial feed, inset feed, microstrip line, and others. A fringe field forms and radiates from the discontinuity side of the patch antenna. The microstrip patch antenna offers a narrow bandwidth and low gain. In order to address the inadequacies, the patch is designed with various slots, slits, and notches. Astuti *et al.* [1] demonstrated a bow-tie microstrip patch antenna that improved bandwidth at 3.67 GHz from 2.6% to 10.45%. Verma *et al.* proposed a T-shaped patch antenna that increased the bandwidth from 40.05 to 81.34% in the frequency range of 1.682–3.988 GHz [2] utilizing FR-4 substrate. Saha *et al.* [3] presented a rectangular slotted microstrip patch antenna at 27 GHz with a bandwidth of 1.51 GHz and a gain of 6.85 dBi. A rectangular patch antenna was reported by Darboe *et al.* [4] at 28 GHz using an inset feedline with 70.18% efficiency and 8.37 dBi directivity. A wearable microstrip antenna was reported by Ateeyah [5] at 28 GHz, which was found to enhance performance by modifying antenna dimensions. Djouimaa and Bencherif [6] introduced a circular patch antenna with a bandwidth of 1.76 GHz and a gain of 0.1573 dBi, operating at 28 GHz. Sadoon *et al.* [7] highlighted three slots in the patch side of the antenna and achieved -39 dB return loss and 753 MHz of bandwidth. There are various optimization methods that can be applied to boost bandwidth. A microstrip patch antenna with an inverted E-shape, PSO, and a 15% bandwidth increase was simplified, according to Islam *et al.* [8]. Dual-band and multiband applications can also be utilized in the design of microstrip patch antennas. Punith *et al.* proposed a microstrip patch antenna operating at 23.9 GHz, 35.5 GHz, and 70.9 GHz, suitable for 5G and space applications [9]. A rectangular patch antenna designed for dual-band 5G cellular communication (38 GHz and 54 GHz) was developed by Imran *et al.* [10]. Syahbana *et al.* [11] presented a rectangular

microstrip patch antenna at a frequency of 26-28 GHz with a centre frequency of 26 GHz and a gain of 6.846 dBi. Colaco *et al.* [12] proposed a multiband (26GHz,40 GHz,53.5GHz) rectangular microstrip patch antenna with a metamaterial structure to enhance the bandwidth from 5.368 GHz to 5.630 GHz. Kenari *et al.* [13] proposed a miniaturized composite right/left-handed UWB antenna using a metamaterial structure with a fractional bandwidth of 111% and a peak gain of 9.41 dBi. Nahas [14] demonstrated an antenna that incorporated two symmetric L-shaped slots and a centrally placed square slot into a single rectangular patch operating at 26 GHz and 28 GHz.

In this present research, a rectangular microstrip patch antenna with a triangular polygon at the right upper side of the patch is constructed using the CST Studio Suite version 2023, and three variables are used, namely substrate height(h), width of the patch (W_p) and width of the feedline (W_f), to increase the bandwidth close to the target resonant frequency. A regression model with ANOVA for both bandwidth and resonant frequency is created using Minitab (version 21) to design several antennas with variations in these four variables. From two equations for bandwidth and resonant frequency, the model is well-suited and validates the enhancement of bandwidth and achieves the desired resonant frequency of 26 GHz, which is appropriate for 5G applications and is very useful for Industry 5.0.

METHODOLOGY

Rectangular patch having dimensions of width (W_p), length (L_p), substrate thickness (h), and relative permittivity (ϵ_r) of the dielectric substrate are used to create the proposed rectangular microstrip patch antennas. A triangular polygon (1.2 mm x 1.2 mm x 1.7 mm) is created for better impedance matching. Utilizing FR-4 substrate with a relative permittivity of 4.3 and a loss tangent ($\tan\delta$) of 0.02 has allowed for the modeling of the proposed rectangular patch antenna. The inset feed technique is used to feed the suggested patch antenna. A ground layer of copper is designed with dimensions of 7.74 mm x 6.65 mm. The patch antenna's length and width can be calculated using the following formulas [15].

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where C is the speed of light, f_r is the resonant frequency, ϵ_r is the relative permittivity of the substrate

$$L = L_{eff} - 2\Delta L \quad (2)$$

Where L_{eff} the effective length of the patch, which can be expressed as

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