iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67741

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

Next-Gen Hybrid Machine Learning for Bankruptcy Prediction: A Polish Market Analysis

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Abstract: ***Bankruptcy forecasting is crucial for financial stability and risk management. This study advances the accuracy of bankruptcy prediction using hybrid machine learning techniques on an imbalanced Polish dataset. The dataset presents challenges typical in real-world financial data, such as class imbalance and noisy features. Our approach combines the strengths of oversampling techniques, ensemble methods to enhance predictive performance. Experimental results demonstrate significant improvements in precision, recall, and F1-score metrics compared to traditional methods. Insights gained from feature importance analysis provide deeper understanding of financial indicators driving bankruptcy. This research contributes to the field by proposing a robust framework adaptable to imbalanced datasets, offering practical insights for financial institutions to mitigate bankruptcy risks effectively.***

Keywords: Bankruptcy forecasting, hybrid machine learning, imbalanced dataset, oversampling techniques, ensemble methods, financial risk management.

I. INTRODUCTION

Bankruptcy prediction is a crucial area of research in the financial sector, as business failures can lead to severe economic consequences such as job losses, supply chain disruptions, reduced tax revenues, and declining investor confidence. Machine learning techniques provide a promisingapproach for accurately predicting financial distress and enabling proactive interventions to prevent bankruptcy. By analyzing various financial indicators such as cash flow, debt ratios, profitability, and market trends, machine learning algorithms can effectively identify early warning signs of financial instability. These models can also predict bankruptcyrisks based on historical data, allowing businesses and investors to take preventive measures before a company reaches a critical point.

Mitigation strategies for bankruptcy using machine learning include personalized financial recommendations, risk assessment models, and optimized financial planning techniques. By leveraging predictive analytics, companies can implement strategic interventions such as debt restructuring, operational adjustments, and investment diversification to reduce bankruptcy risks. Additionally, machine learning models can assist in credit risk evaluation, helping financial institutions determine the creditworthiness of businesses and minimizing potential losses. Overall, utilizing machine learning for bankruptcy prediction and mitigation enhances financial decision-making, promotes economic stability, and demonstrates the potential for AI- driven solutions in financial risk management.

Implementing machine learning for bankruptcy prediction involves utilizing various techniques to analyze and identify patterns in financial data, including revenue trends, expenditure patterns, and liquidity ratios. By collecting data from financial reports, market conditions, and macroeconomic factors, machine learning algorithms can betrained to detect financial distress in real time. These algorithms can then provide timely recommendations and strategies to mitigate bankruptcy risks, such as optimizing cash flow management, reducing financial liabilities, or adjusting business strategies. Additionally, by continuously learning from new financial data and market fluctuations, machine learning models can improve their predictive accuracy over time. Ultimately, integrating machine learning into bankruptcy prediction not only aids in early intervention and risk mitigation but also strengthens financial resilience and ensures sustainable business growth.

Strategies for Enhancing Bankruptcy Prediction Using Machine Learning

1) Implement regular monitoring of financial health using machine learning algorithms that analyze patterns financial metrics and debt ratios to detect early signs of financial distress. By leveraging predictive models, businesses can receive timely insights into their financial stability, allowing them to take proactive measures to prevent bankruptcy.

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2) Provide personalized risk assessments and financial recommendations based on insights derived from machine learning models. These recommendations can include strategies for cost-cutting, revenue optimization, and investment diversification tailored to each company's financial condition. By offering data-driven guidance, businesses can make informed decisions to strengthen their financial position.
3) Utilize predictive modeling to identify high-risk financial periods or economic downturns and proactively allocate resources to support businesses during critical times. By forecasting financial challenges in advance, organizations can implement precautionary measures such as liquidity management, restructuring plans, or contingency funds to mitigate bankruptcy risks.
4) Enhance transparency and financial reporting by using machine learning to analyze financial statements, detect anomalies, and identify fraudulent activities. AI-powered systems can assist auditors and financial analysts in ensuring accurate reporting, thereby reducing the risk of financial mismanagement and insolvency.

II. LITERATURE REVIEW

1) Shetty, Musa, & Brédart (2022)

Shetty, Musa, and Brédart (2022) investigate the effectiveness of machine learning models in predicting corporate bankruptcies. Their study builds on previous research by Brédart (2014) that used a simple neural network with Belgian bankruptcy data. The authors explore advanced techniques, including deep neural networks, Random Forests, Support Vector Machines (SVM), and Extreme Gradient Boosting (XGBoost). Despite utilizing only three financial ratios, these methods show promising accuracy in predicting bankruptcy, demonstrating that even limited data can yield reliable forecasts. The study underscores the potential of sophisticated machine learning models in enhancing financial risk prediction, emphasizing that advanced algorithms can lead to more accurate forecasts than traditional methods. This research illustrates the growing role of artificial intelligence in corporate finance, where machine learning has the power to reshape financial stability assessment practices.

2) Shi & Li (2019)

Shi and Li's (2019) systematic literature review explores corporate bankruptcy prediction models from 1968 to 2017. Using Scopus data, the study identifies core academic contributions in this area, examining the key models and methodologies used for forecasting bankruptcy. The authors highlight how interest in bankruptcy prediction grew post-2008, following the global financial crisis, which underscored the importance of accurate financial forecasting. Their review also finds that there is limited co-authorship among researchers, indicating that the field has been more individually driven than collaborative. The paper provides an essential overview of bankruptcy prediction research, pointing out the evolution of predictive techniques and areas where future research collaboration is necessary to improve predictive accuracy.

3) Alam et al. (2019)

In their 2019 paper, Alam, Shaukat, Mushtaq, Ali, Khushi, Luo, and Wahab examine methods for predicting corporate bankruptcy to foster a healthier corporate environment. The authors aim to develop predictive models that assess the likelihood of bankruptcy using financial indicators and company health metrics. Their study underscores the necessity of accurate bankruptcy prediction, not only for financial stability but also to ensure better corporate governance and decision-making. By leveraging advanced machine learning techniques, the authors emphasize the importance of improving bankruptcy forecasting models to help businesses avoid financial distress. This research contributes to the broader goal of building a more stable corporate ecosystem by identifying potential financial crises early.

4) Perboli & Arabnezhad (2021)

Perboli and Arabnezhad (2021) present a machine learning-based Decision Support System (DSS) designed for mid- and long-term company crisis prediction. Their system analyzes various financial and operational indicators to assess a company's risk of entering a financial crisis. The study's key focus is to provide a proactive forecasting tool for stakeholders, enabling them to take preventive measures before a crisis occurs. By incorporating machine learning, the DSS enhances traditional financial risk assessment methods, providing more accurate and timely predictions. The authors highlight the value of integrating machine learning into corporate decision- making, as it offers more dynamic, adaptable, and reliable insights compared to traditional forecasting techniques. This system represents a step forward in utilizing advanced analytics to improve financial stability and business longevity.

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5) Boughaci & Alkhawaldeh (2020)

Boughaci and Alkhawaldeh (2020) compare various machine learning techniques for credit scoringand bankruptcy prediction within the banking and finance sectors. Their study evaluates models like Decision Trees, Random Forests, Neural Networks, and Support Vector Machines (SVM), assessing each technique's predictive accuracy for both credit risk andbankruptcy forecasting. By comparing different machine learning classifiers, the authors aim to identifythe most effective methods for these critical financial assessments. Their research highlights the importance of selecting appropriate models to enhance decision- making processes in banking and finance, providing insights that could lead to more reliable credit evaluation and bankruptcy predictions. This comparative study supports the integration of machinelearning into financial risk management practices, offering improved tools for financial institutions.

III. METHODOLOGY

In this project, we have designed two primary modules: User Module and System Module, incorporating various technologies for accuratebankruptcy prediction.

A. System Module

1) Dataset Creation

- The dataset consists of financial records, includingbankruptcy status and key financial ratios.
- Data is collected from marketdatabases and company filingsfor training the bankruptcy prediction model.

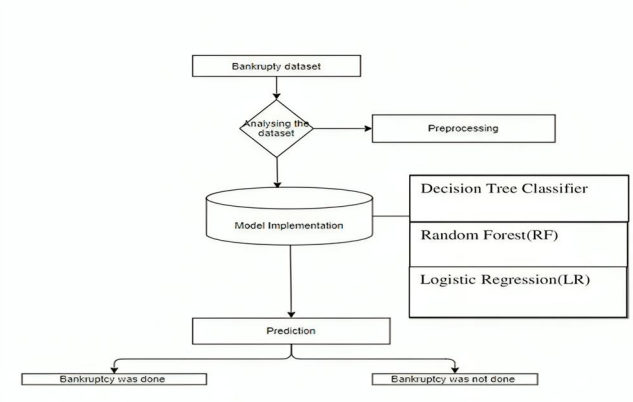
2) Pre-processing

- Handles missing values, normalizes numerical values, and removes redundant financial indicators.
- Feature selection using Genetic Algorithms (GA), and Praticle Swarm Optimization (POS) for balancing data are applied.

3) Training

- The pre-processed dataset is used to train machine learning models, including Random Forest, Decision Tree, Logistic Regression.
- Hyperparameter tuning is performed using Genetic Algorithms (GA) and Particle Swarm Optimization (PSO).

4) Classification



- The trained models classify companies into "Bankrupt" or "Non-Bankrupt" based on financial risk factors.
- The results provide bankruptcy probability scores and financial stability assessments.

B. User Module

1) Upload Financial Data

- Users (e.g., financial analysts,investors) upload company financial reports for bankruptcy risk assessment.

2) View Prediction Results:

- Users receive a bankruptcy risk score (High, Medium, Low) along with visual reportson financial stability.

3) User Login/Signup:

- Secure authenticationsystem for user access and personalized financial risk analysis.

C. Financial Data Processing

Financial data processing involves analyzing key financial ratios and economic indicators to identify bankruptcy risk patterns.

1) Feature Extraction:

- Extracts and processes financial ratios such as debt- to-equity, profitability, liquidity, and solvency metrics.
- Analyzes historical trends and market- based indicatorsto improve risk assessment.

2) Machine Learning & AI Models

- Logistic Regression: It Was Used as the primary classifier for predicting bankruptcy. It is trained twice: Once with features selected by the Genetic Al]orithm (GA). Once with hyperparameters optimized by ParticleSwarm Optimization (PSO).
- Random Forest: Classifies companiesbased on decision trees trained on financial attributes.
- Decision Tree : Used to predict bankruptcy by learning decision rules from financial data, helping to classify companies as bankrupt or not bankrupt based on key financial indicators. Additionally, it provides an interpretable model that can be visualized to understand which financial factorscontribute most to the prediction.

3) Algorithms Used

- Feature Selection with Genetic Algorithms (GA): Selects the most relevant financial indicators for improved model accuracy.
- Particle Swarm Optimization (PSO) : Hyperparameter tuning optimizes C and tol to improve Logistic Regression accuracy.
- Logistic Regression: Used to assess financial trends and determine risk factors affecting bankruptcy.

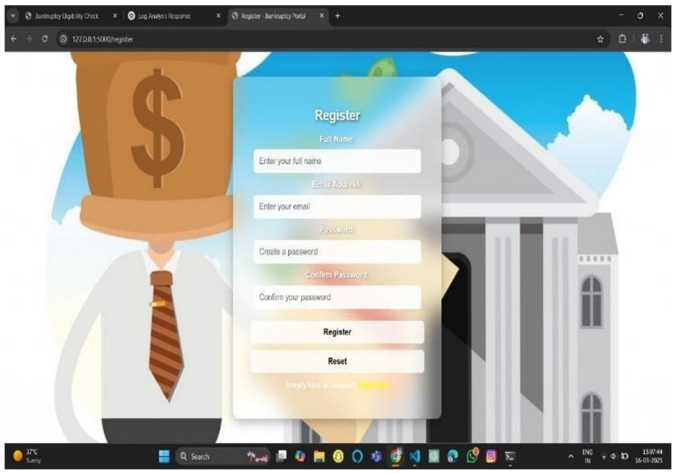
This methodology ensures a robust, scalable, andefficient bankruptcy prediction system, aiding financial institutions and investors in proactive risk management.

Test Case Model:

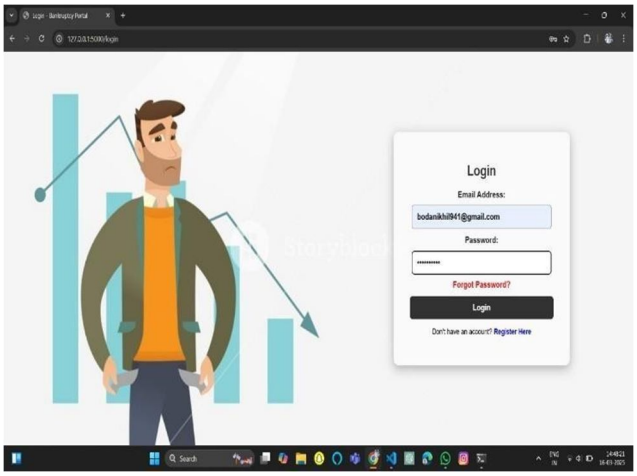
Input	Output	Result
Input text	Tested for the Detecting Stress	Success

S.NO	Test cases	I/O	Expected O/T	Actual O/T	P/F
1	Readthe dataset.	Dataset path.	Dataset need to read successfully.	Dataset fetched successfully.	P
2	Performing pre-processing on the dataset	Pre-processing part takes place	Pre-processing should be performed on dataset	Pre-processing successfully completed.	P
3	Model Building	Model Building for the clean data	Need to createmodel using	Model Created Successfully.	P
4	Detecting	Input data	Output	Model	P

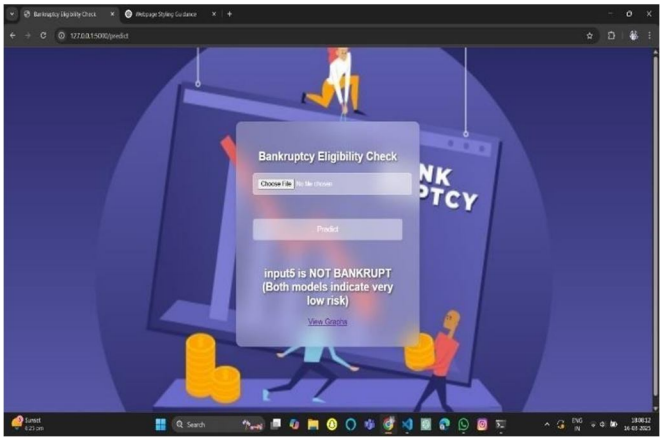
IV. RESULT AND OUTPUT



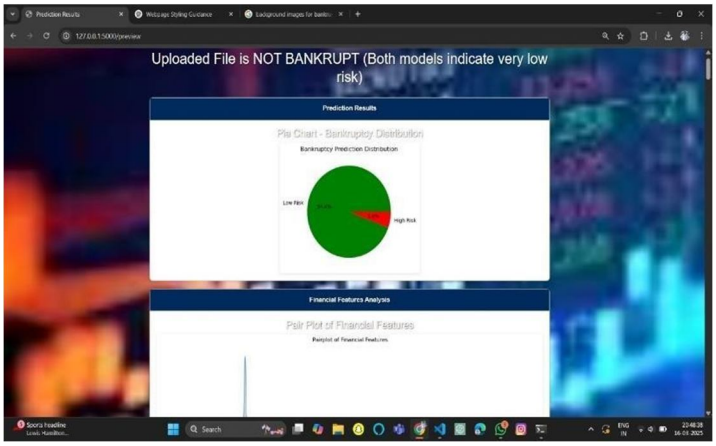
Registration Interface



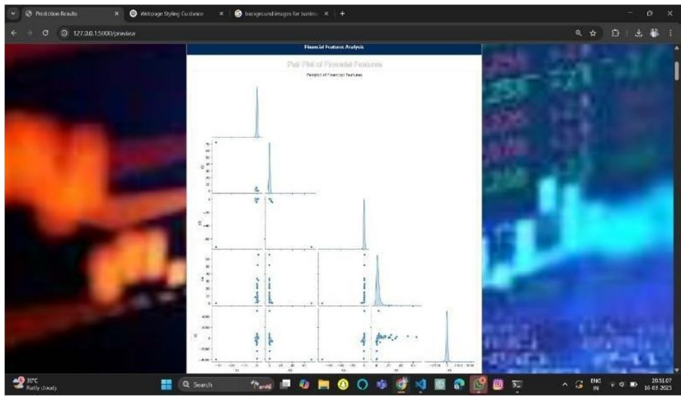
Login Module



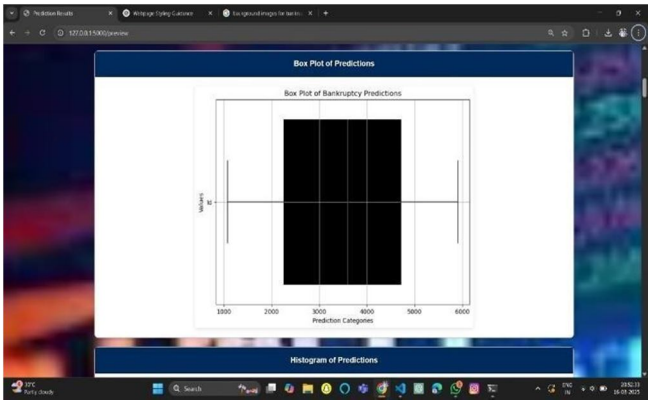
Dataset Upload Page



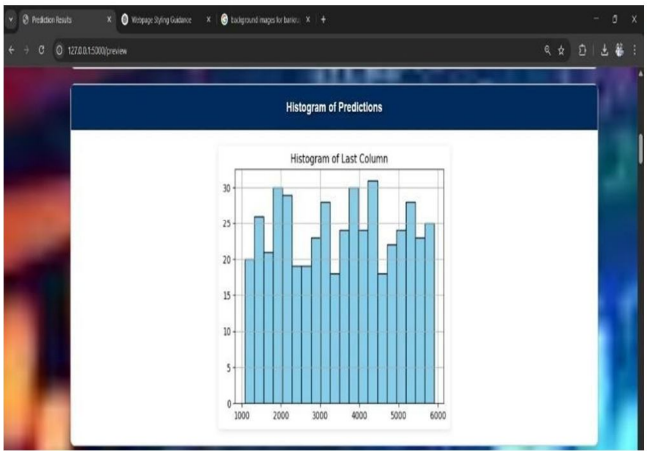
Prediction Page



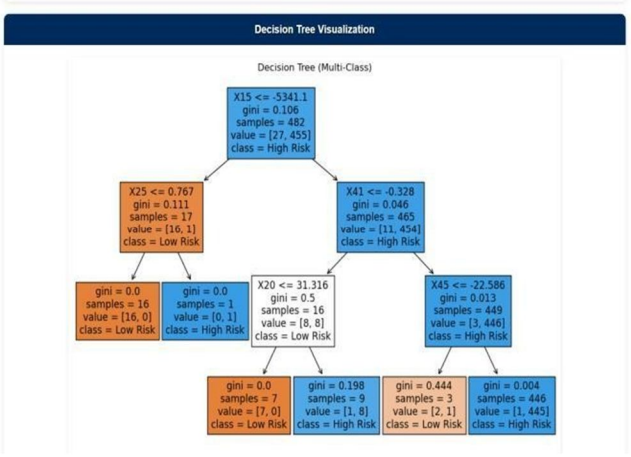
Graph Page



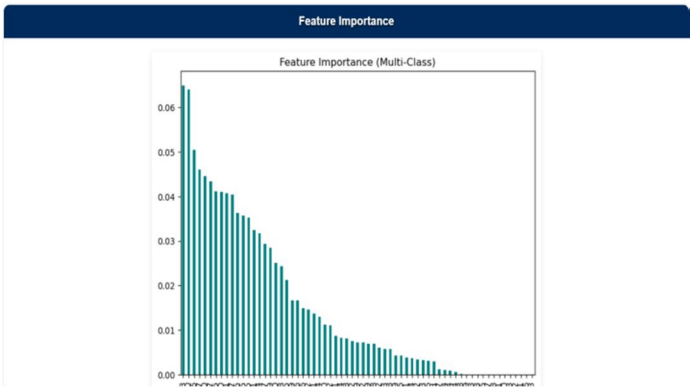
box plot visualization



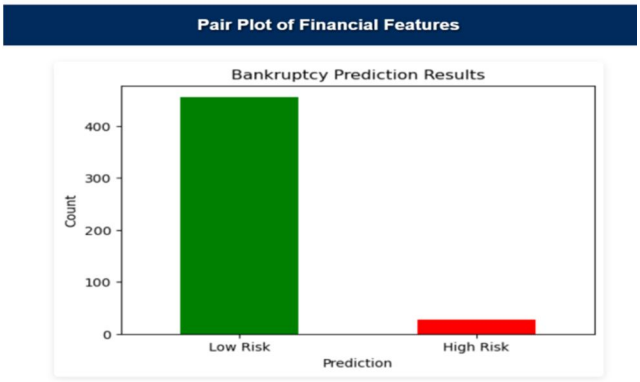
histogram visualization



histogram visualization



Feature Importance plot



bar chart (categorical count plot)

V. CONCLUSION AND FUTURE SCOPE

Predicting bankruptcy is vital for assessing the financialhealth and sustainability of companies. This researchexplores two powerful optimization techniques, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), integrated with Logistic Regression to enhance bankruptcy prediction accuracy. Through extensive model training, we focused on improving performance, especially when handling unbalanced datasets, which is a common challenge in financial prediction tasks. Our findings demonstrate the value of hybrid methods in this domain. The GA model, optimized for feature selection, achieved impressive accuracy with 64 features, while the PSO model, fine-tuned for hyperparameters, showed significant improvements in prediction precision with 24 selected features. Both models successfully predicted bankruptcy with high accuracy, confirming their potential for real-world application. Furthermore, the models were able to handle large datasets with missing values and imbalanced classes without needing complex resampling methods. The visual analytics through Flask-based web application also proved to be an essential tool for presenting the results, providing users with interactive plots and insights into bankruptcy risks. The combination of GA and PSO for feature selection and hyperparameter tuning marks a significant contribution to predictive analytics in finance.

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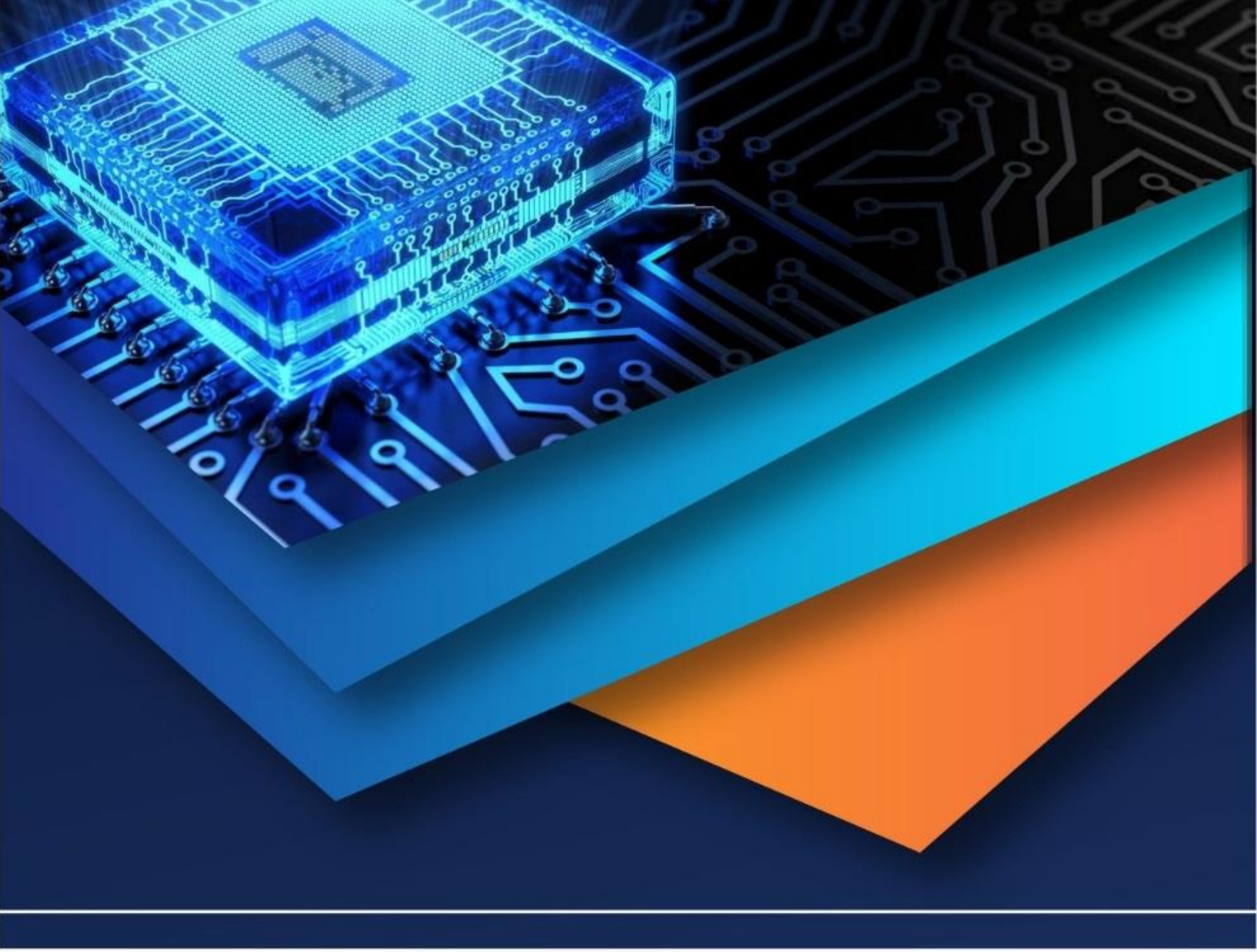
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