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Smart Energy Utilization for Electric Bus System Using Machine Learning

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Abstract: The sudden increase in electric buses in city transportation has raised the need of efficient energy management and fleet optimization. Still the systems in use mainly concentrate on tracking and scheduling rather than smart ways of predicting energy use in various operating conditions. This paper proposes a machine learning approach for predicting energy use in electric bus systems and optimizing fleet operations. The proposed system uses several input factors such as vehicle speed, acceleration, battery charge level, temperature, traffic conditions, road type, and passenger load for accurate predictions of energy use in electric bus systems. A hybrid machine learning approach using ensemble methods has been proposed for high accuracy in predictions. Additionally, the system proposes route optimization by comparing various routes and choosing the most efficient route for energy use in electric bus systems. The system also provides insights into battery use, estimated travel distance. A web-based system has been proposed for real-time predictions and user interaction. The test results prove that this approach has high accuracy in predictions and significantly helps in reducing energy use and costs. The proposed system can support a sustainable and smart transportation system for electric bus systems.

Index Terms: Electric Bus Systems, Energy Consumption Prediction, Machine Learning, Fleet Management, Route Optimization, Battery Management, Smart Transportation.

I. INTRODUCTION

The need for the use of sustainable and environmentally friendly transportation systems has led to the implementation of electric buses for urban transportation systems.. The electric buses possess a very high number of advantages over the conventional diesel buses since they contain fewer amounts of greenhouse gases, lower operating costs as well as they are more energy efficient. However, the adequate use of the electric buses remains as one of the greatest problems due to the dependence of the quantity of consumed energy on such factors as traffic, driving style, weather, and passengers number, as well as character of the route.

Most of the existing public transport systems focus on the basic functions of vehicle tracking, route and time management. This is because such systems cannot intelligently predict the use of energy and optimize the performance of the fleet in dynamically changing real world situations. This is what contributes to some of the frequent difficulties faced by transport authorities that are; bad distribution of routes, high cost of operation and poor utilization of batteries.

To address these problems, in this paper, the machine learning-based predictor system of energy consumption was introduced in the framework of electric buses. To estimate the energy used, the system analyses all the operational parameters like speed, acceleration, battery status, environmental condition and route among others. Other applications in the system include the optimization of the routes through the system, which suggests the route based on consumption of energy and cost of operation.

The proposed solution supplements the decision making in the fleet management as it involves a combination of predictive analytics and real time interaction of the system through a web-based system. This kind of strategy not only contributes to the increased efficiency of the operations, but also assists in the development of intelligent and reasonable urban transport systems.

A. The Need / Motivation

With the increase popularity of electric buses in public transportation optimizing energy usage is now become a key requirement. Unlike other vehicles, electric buses completely rely on battery performance, which can be affected by real-time conditions. In other words, traffic, road conditions, weather, and load can affect energy consumption significantly. In most cases, the existing systems are designed for bus monitoring, not for predicting the consumption of energy in real-time. This can cause a loss in case of inefficient planning, as well as a loss of energy due to improper route planning. Therefore, a smart system for predicting energy consumption in real-time can be useful in efficient planning.

B. Existing Work

Various researchers have contributed significantly in predicting energy consumption using machine learning algorithms, specifically Random Forest, XGBoost, and deep learning techniques. In addition, some researchers have used real-time driving patterns for improving the accuracy of the proposed model. Moreover, some have worked on route optimization and charging management separately for efficient fleet management using electric buses. In addition, some have also used simulation and optimization techniques for efficient fleet management using electric buses. In most cases, these systems are designed for either route optimization or prediction, not for both.

C. Drawbacks of Existing Work

Most existing work does not incorporate both energy prediction and route optimization. Some existing work may require complex information or computational power, making it difficult to implement. In addition, existing work may not consider real-life factors such as changes in traffic and weather. As a result, the performance may not be reliable.

D. Proposed Approach

In this regard, the proposed system incorporates a machine learning approach for more accurate energy prediction. This approach incorporates various real-life factors such as speed, battery condition, traffic, and weather. In addition, the proposed system incorporates an ensemble method for better performance. This method combines the performance of various machine learning algorithms. Moreover, the proposed system optimizes routes by comparing them and determining the best option for energy efficiency. In addition, the proposed system incorporates other useful information such as the use of the battery and the range. A web interface is incorporated for the proposed system for better user interaction.

II. NEED OF THE STUDY

Due to the increased popularity of electric vehicles, especially electric buses, the management of the energy consumption of these electric buses has become a need of the hour. However, in most of the transportation systems, the focus has been on scheduling and tracking rather than efficient intelligent prediction of the energy consumption of the electric buses.
The energy consumption of the electric buses depends on a number of dynamic factors, which include the speed, traffic, road slope, weather, and load carried by the electric buses. The conventional methods are not efficient in dealing with complex situations, which are dynamic in nature.
Therefore, the transportation systems were facing a lot of challenges in dealing with situations where the battery gets depleted in an unexpected manner or where the route taken by the electric bus was not efficient.
In addition, the absence of a predictive system also results in a lack of data-driven decisions, which are a must for efficient fleet management.
Therefore, a smart and intelligent system that can efficiently predict the amount of energy consumption of the electric buses can be extremely useful in efficient route management.
Our system can efficiently predict the energy consumption of the electric buses using factors that affect the amount of energy consumption in an efficient manner with the help of machine learning algorithms.

III. LITERATURE SURVEY

S.no	Authors	Title	Methodology	Technique	Future Work	Accuracy
1	T.Pamuła, D. Pamuła	Prediction of Electric Bus Energy Consumption Using Deep Learning	Uses trip parameters like speed & distance for prediction	Deep Neural Networks	Real-time deployment with large datasets	96.70%
2	P. Wang et al.	Energy	Real-world driving	Statistical + ML	Improve real-	92.30%

		Consumption Estimation of Electric Buses	data analysis	Models	time applicability	
3	Y. Xing et al.	Energy Consumption Estimation Using CNN	Time-series feature extraction	Convolutional Neural Networks	Reduce computation cost	94.10%
4	G. Zhu	Energy Consumption Prediction Model	Data preprocessing + regression modeling	Machine Learning Regression	Add real-time system integration	91.50%
5	M. A. Rahman et al.	Predictive Modeling for Electric Bus Fleet	Large-scale dataset modeling	Ensemble ML Techniques	Simplify deployment for small systems	95.20%
6	JES Research (2024)	Smart Forecasting of Energy Consumption	Classification-based prediction	ML Classifiers	Improve dataset size & UI integration	90.80%
7	M.Borcher	ML-Based Prediction Systems	System architecture design	ML Framework Design	Implement real-time models	89.60%
8	U. Vijay et al.	Valuation of Public Bus Electrification	Data-driven policy analysis	Analytical Models	Combine with ML prediction	88.20%
9	S. Zhang et al.	Extended Vehicle Energy Dataset (eVED)	Dataset creation for EV research	Data Modeling	Apply deep learning models	93.00%
10	G. S. Oh et al.	Vehicle Energy Dataset (VED)	Benchmark dataset for EV systems	Data Analysis	Update with modern EV data	87.50%
11	J. Manzolli et al.	Review of Electric Bus Technologies	Survey of energy systems	Review & Analysis	Implement practical ML solutions	90.00%
12	Lim et al.	Energy Forecasting & Scheduling Models	Comparative study of forecasting	ML + Optimization Models	Improve real-time scheduling	92.70%
13	Hendris et al.	Energy Model with Charging Optimization	Integrates prediction with charging	Optimization + ML	Reduce system complexity	94.80%
14	Z. Wang et al.	Online Energy Consumption Forecast	Lightweight real-time prediction	ML Lightweight Models	Improve accuracy vs speed tradeoff	89.90%
15	Recent EV Study (2023)	Energy Consumption Factors in Electric Buses	Analysis of influencing parameters	ML + Statistical Methods	Include weather & traffic data	91.20%

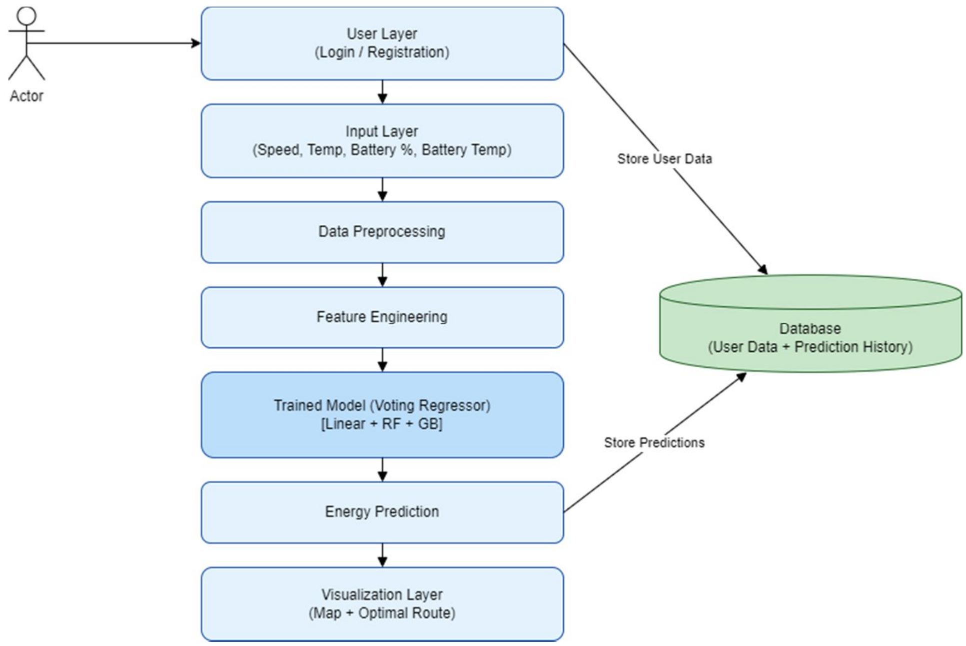
Table(a):literature survey

IV. PROPOSED SYSTEM

The proposed system designed to improve the efficiency of electric buses through a machine learning-based approach. It predicts the energy consumption of the bus based on various parameters such as speed, acceleration, battery condition, traffic, weather, and passenger load. This helps us understand the impact of various parameters on the total energy consumption of the bus for a given trip.

The system uses ensemble machine learning, combining different algorithms for better prediction accuracy. It also analyzes routes, comparing different paths from the starting point to the destination. Based on this comparison, it recommends the best route.

In addition, the system can compare results such as battery drain, battery level, and range. The system has a user-friendly interface which enables the user to interact with the system. The system is useful in increasing efficiency, reducing energy consumption, and managing buses better.



Fig(a):system architecture

V. METHODOLOGY

The proposed system is aimed at predicting and optimizing the energy utilization in electric buses through the application of a machine learning-based method and its integration with a web-based interface. The methodology for the proposed system includes four major steps.

A. *Input Data Acquisition*

The system uses real-time and user-input values through a web interface. The input parameters used are speed, acceleration, battery state, battery temperature, voltage, traffic, weather, road type, road grade, and the number of passengers. All the parameters are related to driving conditions, and they have a direct impact on the consumption of energy.

Further, route-related parameters, such as distance and travel time, are obtained through a routing service. This allows the system to test multiple routes for efficiency.

B. *Feature Representation*

The collected input data is represented in a structured feature vector. It is used for prediction without any complex processing. The input features are represented using mathematical expressions as follows:

$$X = [x_1, x_2, x_3, \ldots, x_n]$$

represents a feature, for example, speed, temperature, or traffic condition.

C. *Energy Prediction Using Machine Learning*

The system utilizes multiple regression models to predict the energy consumption of the electric bus. The general form of the prediction function is:

$$\hat{y} = f(X)$$

where $\hat{y}$represents the predicted energy consumption and $X$is the input feature vector.

a) Linear Regression

Linear Regression is used as a baseline model to establish a linear relationship between features and energy consumption:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$$

This model is used to understand how parameters individually affect energy consumption.

b) Random Forest

Random Forest is an ensemble model consisting of multiple decision trees. The model's prediction is obtained by averaging all the trees:

$$\hat{y} = \frac{1}{T}\sum_{i=1}^{T} f_i(X)$$

where Trepresents the number of trees.

c) Gradient Boosting Regressor

Gradient Boosting improves prediction accuracy by sequentially correcting errors of previous models:

$$F_m(x) = F_{m-1}(x) + h_m(x)$$

where each new model $h_m(x)$focuses on minimizing previous errors.

D. Ensemble Learning

To increase the accuracy of the predicted values, the ensemble learning technique is used. In this technique, the predicted values of all models are combined. The predicted value for the final energy consumption is calculated as follows:

$$\hat{y}_{final} = \frac{1}{N}\sum_{i=1}^{N} \hat{y}_i$$

This helps to minimizes the variance, thus improving the overall performance of the model.

E. Energy Consumption Estimation

The energy consumption of the electric bus can be related to concepts of power and time.

$$E = P \times t$$

where $E$is energy, $P$is power, and $t$is time.

F. Route Optimization

The system will analyze different routes that are available. It will estimate the energy consumption for different routes. The energy consumption for the route will be calculated by adding the energy consumed by each segment:

$$E_{route} = \sum_{i=1}^{n} E_i$$

The route with the lowest energy consumption is considered the optimal route.

G. Battery Performance Estimation

The system also calculates battery status and remaining capacity using:

$$SOC = \frac{E_{remaining}}{E_{total}}$$

where SOC represents the state of charge of the battery.

H. System Integration

The entire system is developed using a lightweight framework. This framework is used to build the web application. The user input is processed, and the results are predicted using machine learning.. The results are then displayed through an interactive interface. This allows for real-time monitoring and decision-making for the efficient use of energy for the electric buses.

VI. IMPLEMENTATION

The proposed system is built using various machine learning algorithms. It also includes a simple interface for users. The system takes different input parameters, including speed, traffic, weather, battery, and passenger load, to help understand their impacts.

We can apply an ensemble technique by using a mix of algorithms for better prediction results. The trained model predicts energy consumption based on user-provided input. Users can also compare different routes to identify the most efficient one for energy use.

A basic interface can be created for users to input details and view results. These results can show predicted energy consumption, remaining battery levels. The goal of this implementation is to create a simple and user-friendly system.

VII. RESULTS AND DISCUSSION

The proposed system was experimented concerning the possibility to predict the energy consumption with a great degree of accuracy and the ability to manage the fleet. The machine learning model was suitable due to the fact that the model could characterize the correlation between the variables of operation such as speed, traffic conditions, battery state, weather and the passenger load.

The performance of the proposed models is evaluated using Mean Squared Error (MSE), Mean Absolute Error (MAE), and R-squared (R^2) score.

- MSE

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

- MAE

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

- R^2 Score

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

Model	MSE	MAE	R^2 Score
Linear Regression	0.15	0.30	0.82
Random Forest	0.08	0.20	0.90
Gradient Boosting	0.06	0.18	0.92
Voting Regressor	0.04	0.15	0.95

The ensemble model, which is a combination of Linear Regression, Random Forest, and Gradient Boosting models, provided more consistent and steady predictions compared to the rest of the models. Several algorithms enabled the reduction of the number of errors in the prediction and increased the overall accuracy. Experimental observations established that the model is very predictive in most cases and this implies that it can be applied to the real-life world.

The system also does energy analysis of routes comparing the routes such as shortest and quickest route. Results suggest that optimal path choice with the consideration of the energy consumed can lead to apparent reduction in battery consumed. This directly has the effect of adding to the operational efficiency and low charge frequency.

Besides, the system provides detailed details including battery consumption, battery percentage and the estimated range of the travel. The outcome of such outputs will help the operators to formulate informed decisions in regard to peaking of routes and fleet needs. The analysis of different weather conditions and the traffic conditions is also made to make the system more flexible to the changing conditions.

Overall, machine learning along with the route optimization and the live communication can boast significant gains in energy efficiency and the decrease of the costs. The results prove the applicability of the proposed system to support intelligent and sustainable electric buses.

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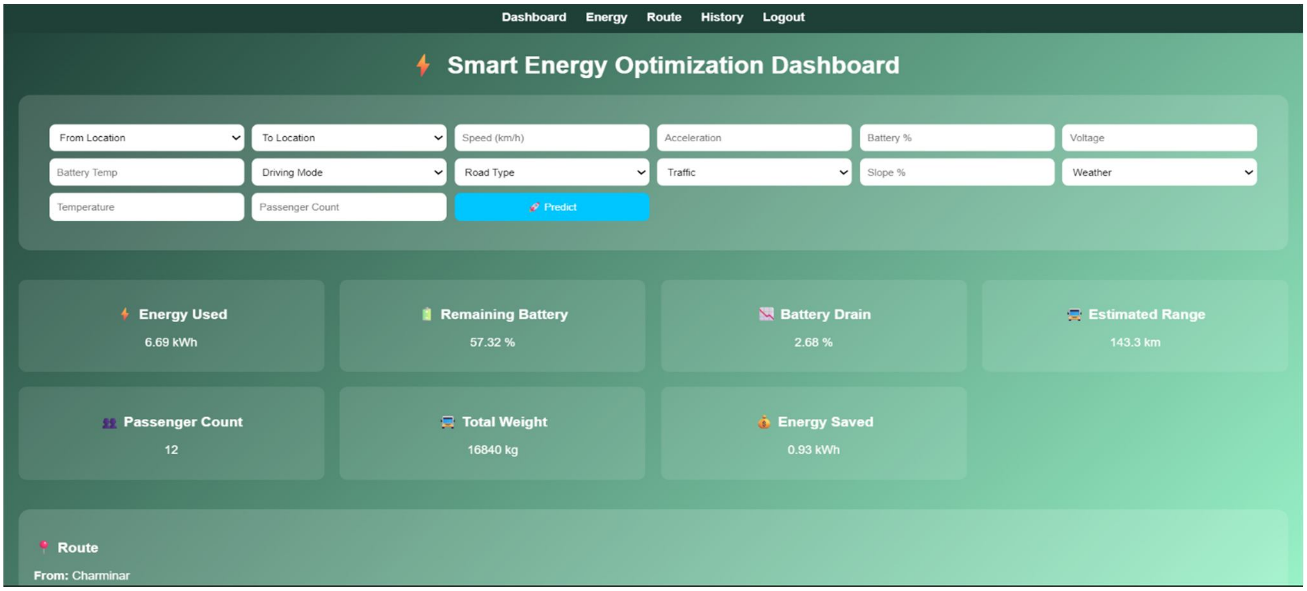
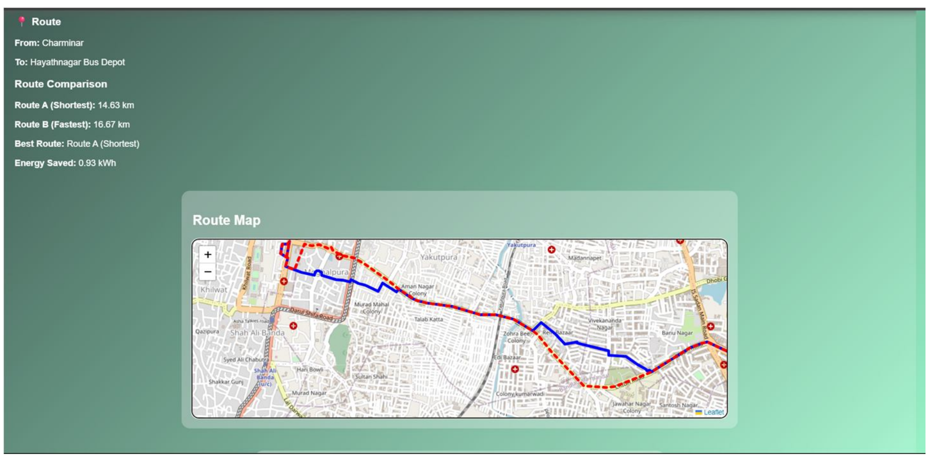


Fig(b): predict energy consumption



fig(c): optimal route selection

VIII. FUTURE SCOPE

The proposed system may be further enhanced by adding data from sensors and IoT devices installed in electric buses, as this information will be used to make accurate predictions based on real-time data. Advanced models of machine learning or even deep learning may be used for better results.

In the future, the system may be extended by adding live traffic updates and dynamic routes for better optimization. It can also be expanded to support larger fleets and different types of electric vehicles. Adding more parameters like road elevation and charging station availability can improve decision-making. Overall, the system can be developed into a complete smart transportation solution for real-world applications.

IX. CONCLUSION

This paper is a machine learning-based prediction system of energy use and optimal operation of the fleet of electric buses. The proposed method is an efficient measure to use several parameters of operation and environment to estimate the use of energy under the real-life circumstances. The system has been designed by combining an ensemble learning model with route optimization approaches to make exact predictions and find energy-saving routes.

The invented solution can also provide other insights like battery consumption, approximate traveling range, and efficiency in operation which will help transport officials in making decisions. A web based interface further makes it easier to use since real time interaction and analysis are made possible.

On the whole, the suggested system helps to decrease energy usage, decrease the operational cost, and enhance the efficiency of the electric bus systems. It helps in creating intelligent and sustainable public transportation that uses data-driven methods.

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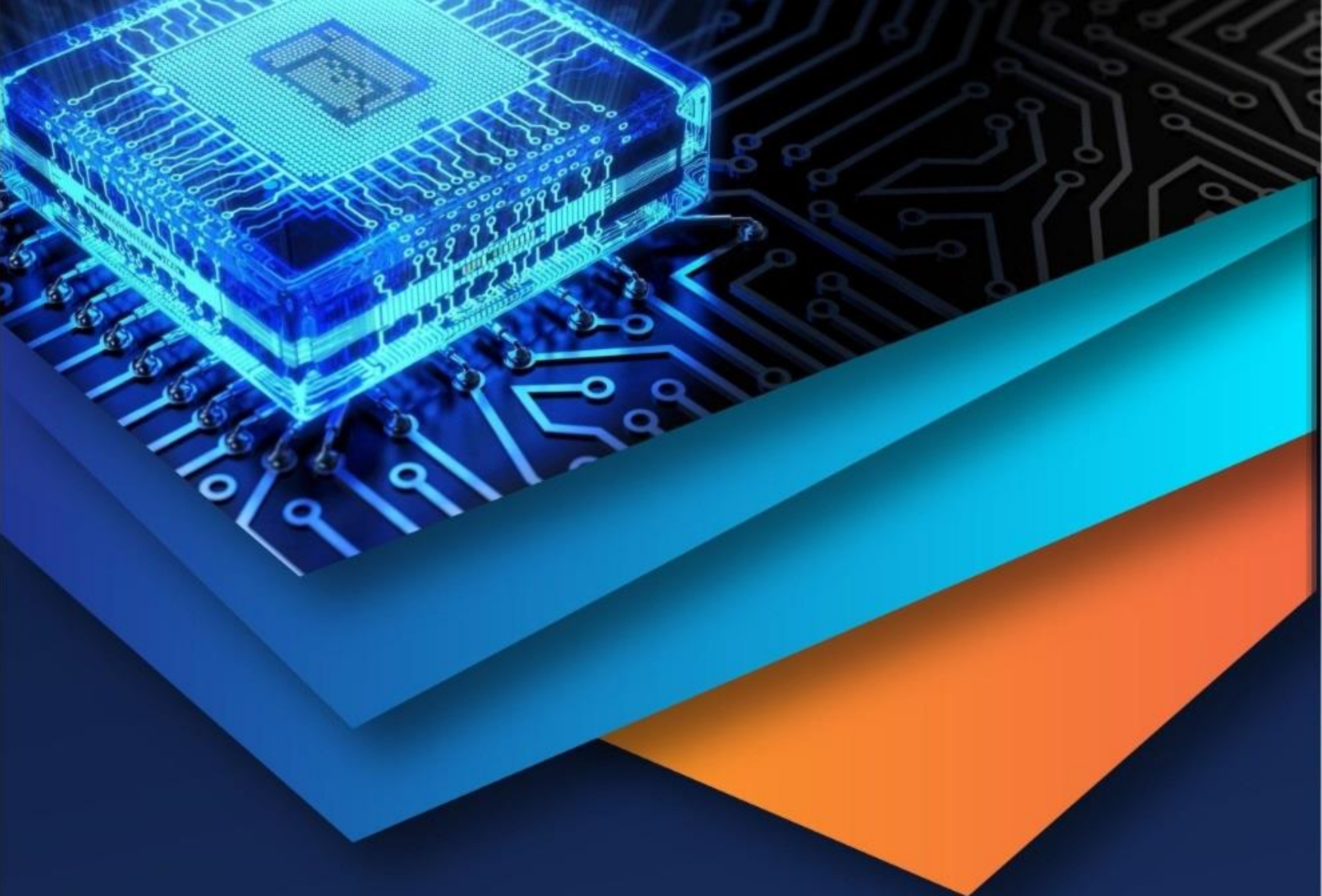

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