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Air and Water Quality Index Development for EnvironmentalAssessmentinIndustrialContext

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Abstract: Considering the importance of air and water to human existence, air and water pollution are critical issues that require collective effort for prevention and control. Different types of anthropogenic activities have resulted in environmental ruin. One of the tools that can be used for such a awareness campaignis Air Quality Index(AQI). The AQI was based on the concentrations of different types of pollutants: We are also familiar with the Water Quality Index (WQI), which in simply tells what the quality of drinking water is from a drinking water supply. There is a need for constant and real-time monitoring of air quality and water quality for the development of AQI and WQI, which in turn will enable clear communication of how unclean or unhealthy the air and water in the study area is. Similar systems have been developed utilizing IoT technologies, as discerned in [1], [2].
Keywords: Air Quality Index, Water Quality Index, ESP-32, Machine Learning, Internet of Things

I. INTRODUCTION

Air and water pollution are global challenges that demand immediate and collaborative action. With rapid industrializa- tion and urbanization, the concentration of harmful pollutants in the environment has risen significantly. Poor air and water qualitydirectlyimpacthumanhealth,biodiversity,andecosystems, while also exacerbating climate change. Environmental monitoring tools such as the Air Quality Index (AQI) and WaterQualityIndex(WQI)providequantitativemeasures of pollution levels, enabling stakeholders to identify critical issues and devise effective solutions. Similar systems have been developedusing IoTtechnologies, asseenin[1],[2].The use of IoT for environmental monitoring is well-documented in [3].

This paper presents the design and implementation of a comprehensive AQI and WQI prediction system specifically targeted for industrial contexts. By leveraging IoT-enabled sensorsandmachinelearningtechniques,thesystemprovidesreal-time data analysis, forecasting real-time data analysis, forecasting capabilities, and actionable insights. The goal is to enhance environmental assessment, foster informed decision-making, and encourage sustainable practices.

II. AQI PREDICTION SYSTEM

The AQI prediction system is designed to monitor and evaluate air quality by measuring pollutants such as particulate matter (PM2.5, PM10), carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3). The system consists of thefollowing key components:

A. Sensors and Hardware

1) TTGO LoRa32 Board: This is a microcontroller board equipped with an ESP32 chip and LoRa connectivity, facilitatingwirelesscommunicationanddatatransmission in IoT applications, similar to those described in [1].
2) Temperature Sensor (DTH11): The DTH11 sensor measures temperature and humidity, providing crucial environmental data for monitoring and control systems.
3) MQ-135 Gas Sensor: This sensor is sensitive to a wide range of gases, including ammonia, sulfide, and benzene, makingitsuitableforairqualitymonitoringandpollution detection.
4) MQ-7GasSensor:Specificallydesignedtodetectcarbon monoxide (CO) gas, the MQ-7 sensor is commonly used in air quality monitoring systems to ensure safety.
5) PM2.5 Optical Sensor: Capable of detecting fine particles in the air, such as dust and smoke, the GP2Y1010AU0F sensor is crucial for assessing air pollution levels.
6) Voltage Regulator:Responsibleformaintainingastable voltageoutput,thevoltageregulatorensuresconsistent power supply to the components, safeguarding their operation and longevity.

B. Data Acquisition and Transmission

Sensors are deployed at strategic locations to collect air quality data, which is sent to a central cloud database via microcontrollers. This approach is similar to the IoT-based systems discussed in [2].

C. Machine Learning and Analytics

Machine learning models analyze historical and real-time data to detect patterns and predict future air quality levels. Algorithms such as Decision Tree (DT) and Random Forest (RF) were implemented to predict Air Quality Index (AQI) and Water Quality Index (WQI). Both models are widelyused for regression tasks due to their ability to capture complex relationships between features and target variables. Theimplementationofbothmodelswascarriedoutusing the Python programming language, utilizing libraries such as scikit-learn, pandas, matplotlib, and seaborn. Similar machine learning techniques have been applied in environmental monitoring systems, as reported in [3].

1) Decision Tree Regressor(DT)Implementation

- DataPreprocessing:ThedatasetforAQIandWQI contains several features, including concentrations of air and water pollutants like PM2.5, NO_2, SO_2, CO, O_3, etc., along with the AQI or WQI as the target variable. The data was split into independent variables (X) and the dependent variable (y), which represents the AQI or WQI.
- Train-Test Split: The dataset was split intotraining(70%)andtesting(30%)setsusing thetrain_test_split methodfrom scikit-learn.
- ModelInitializationandTraining:TheDecisionTreeRegressor modelwas initialized with the criterion set to ”squared_error,” and the model was trained on the training data.
- Model Evaluation: The model’s performance was evaluated using the coefficient of determination(R^2) on both training and testing datasets. The R^2score is a measure of how well the model explains the variance in the target variable.
- Cross-Validation:Toreduceoverfitting,5- fold cross-validation was applied using the cross_val_scoremethod.Thishelpsassess the model’s generalization ability.
- Hyperparameter Tuning: The model was further tuned using GridSearchCVto find the optimal hyperparameters, such as the maximum depth ofthe tree, minimum samples for a leaf, and others. The tuning process helped improve the model’s performancebyminimizingtheMeanSquaredError (MSE).
- Final Prediction: After tuning, the Decision Tree model was used to predict the AQI or WQI on the test data.

2) Random Forest Regressor(RF)Implementation

- Data Preprocessing: Similar to the Decision Tree, the dataset for AQI and WQI was preprocessed by separating the features and the target variable.
- Train-Test Split: The data was split into training (80%) and testing (20%) datasets. In addition, 5%ofthedatawasseparatedas an”unseen”dataset to evaluate the model’s performance on completely new data.
- Model Initialization and Training: The RandomForestRegressorwasinitialized with 200 trees (n_estimators) and trained on the training data.
- ModelEvaluation: The R2score was computed for both training and testing datasets. The model’s Mean Absolute Error (MAE), Mean Squared Error (MSE),andRootMeanSquaredError(RMSE)were calculated to measure the prediction error.
- Hyperparameter Tuning: Random Forest hy- perparameters,suchasthenumberofesti- mators,maximumdepth,andminimumsam- ples for a split or leaf, were optimized using RandomizedSearchCV. This optimization was performed to find the best hyperparameters that minimize MSE and maximize the model’s abilityto generalize.
- Final Prediction: The Random Forest model was evaluated using the best hyperparameters and its performance was compared to the Decision Tree model.

3) Visualization and Alerts

Dataispresentedthroughaninteractivedashboardfeaturing geographic heat maps and temporal trends. Alerts are sent to users via email or SMS when air quality surpasses critical thresholds. This system is instrumental in identifying pollution hotspots, enabling preventive measures, and promoting community awareness.

III. WQI PREDICTION SYSTEM

The WQI prediction system monitors water quality by assessing physical, chemical, and biological parameters. It provides a single numerical value representing water quality based on multiple weighted parameters. The major components include:

A. Sensors and Hardware

1) TTGO LoRa32 Board: This is a microcontroller board equipped with an ESP32 chip and LoRa connectivity, facilitatingwirelesscommunicationanddatatransmission in IoT applications, similar to those described in [1].
2) Voltage Regulator:Responsibleformaintainingastable voltageoutput,thevoltageregulatorensuresconsistentpower supply to the components, safeguarding their operation and longevity.
3) AnalogpHSensor: The Analog pH Sensor measures the acidity or alkalinity of a solution by detecting the concentration of hydrogen ions (H^+). It provides an analogvoltageoutputthatisproportionaltothepHvalue, commonlyusedinenvironmentalmonitoring,watertreatment, and industrial processes.
4) Turbidity Sensor: A turbidity sensor is used to measure the cloudiness or haziness of a liquid caused by suspended particles. It operates by emitting light through the liquid and detecting the amount of light scattered by particles, providing an indication of water quality and clarity, commonly used in environmental monitoring and water treatment.
5) TDS Sensor: The TDS (Total Dissolved Solids) Sensor determinestheconcentrationofdissolvedsolidsinwater, suchassalts,minerals,andorganicmatter.Itmeasuresthe electrical conductivity of the water, with higher conductivityindicatingahigherlevelofdissolvedsolids,crucial for assessing water purity.
6) DS18B20 Temperature Sensor: The DS18B20 is a digital temperature sensor that provides accurate tem- peraturereadingsintherangeof-55°Cto+125°C.It communicates via a 1-Wire interface and is commonly used for temperature monitoring in various applications like water quality control, weather stations, and industrial systems.

B. Data Acquisition and Transmission

Sensors are deployed at strategic locations to collect water quality data, which is sent to a central cloud database via microcontrollers. This approach is similar to the IoT-based systems discussed in [2].

C. Machine Learning and Analytics

Usinghistoricaldata,predictivealgorithmsforecastwater qualitytrends.TheWQIpredictioninvolvespreprocessingrawwater quality data, including handling missing values, standardizing data, and applying robust scaling techniques. The WQIiscalculatedusingtheweightedarithmeticmeanmethod. Thedatasetconsistsofmultiplefeaturesrepresentingdifferent water quality parameters, with corresponding minimum and maximum values. These parameters were used to calculatethe average water quality indicators, which were then used as inputstovariousmachinelearningmodels.Themodelstrained and tested include:

- OrdinaryLeastSquares(OLS)Regression
- SupportVectorRegression(SVR)
- MultinomialLogisticRegression(MLR)
- DecisionTreeClassifier(DT)
- ArtificialNeuralNetwork(ANN)

For each model, we compared performance based on met- rics such as Accuracy, F1 Score, and Kappa score. The implementation of each machine learning model involves preparingthedata,selectingtheappropriatealgorithm,tuninghyperparameters, and evaluating the model’s performance. Similar machine learning techniques have been applied in environmental monitoring systems, as reported in [3].

1) Model 1: Ordinary Least Squares (OLS) Regression

OLS Regression is a linear model used for predicting the WQIdirectly.WeimplementedtheOLSregressionbyfit- ting the model to the data and evaluating its performance based on metrics like Root Mean Squared Error (RMSE) and R^2(Coefficient of Determination).

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

Where$y_i$isthetrueWQIvalueand$\hat{y}_i$isthepredicted WQI value.

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2) Model2:SupportVectorRegression(SVR)

SVR is a machine learning technique that maps the data to a higher-dimensional space to make it easier to separate non-linear patterns. Hyperparameters such as C and ϵ were tuned using GridSearchCV. The model was trained and evaluated using RMSE and R2 metrics.

3) Model 3: Multinomial Logistic Regression (MLR)

Multinomial Logistic Regression was implemented to classify the WQI values into discrete categories (Excellent, Good, Poor, etc.). The classification performance was evaluated using metrics like accuracy and F1 Score. We used the following equation for accuracy:

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Predictions}}$$

4) Model4:DecisionTreeClassifier(DT)

A Decision Tree Classifier was used for the classificationtask. The tree’s depth was optimized to avoid overfitting and underfitting. We measured its performance using the accuracy score and confusion matrix.

5) Model5:ArtificialNeuralNetwork(ANN)

A Feedforward Artificial Neural Network was imple- mented using PyTorch. The network contained multiple hidden layers with ELU activations. The model was trained with the Adam optimizer and evaluated using accuracy and F1 Score.

D. Visualization and Notification

Water quality data is visualized on dashboards with charts and maps for user-friendly interpretation. Alerts are issued to notifyusersofpotentialcontaminationrisks.TheWQIsystemsupportsapplicationsindrinkingwatersafety,aquaculture,andindustria lwaste watermonitoring, similartothosediscussedin [4].

Fig. 1. Air quality meter

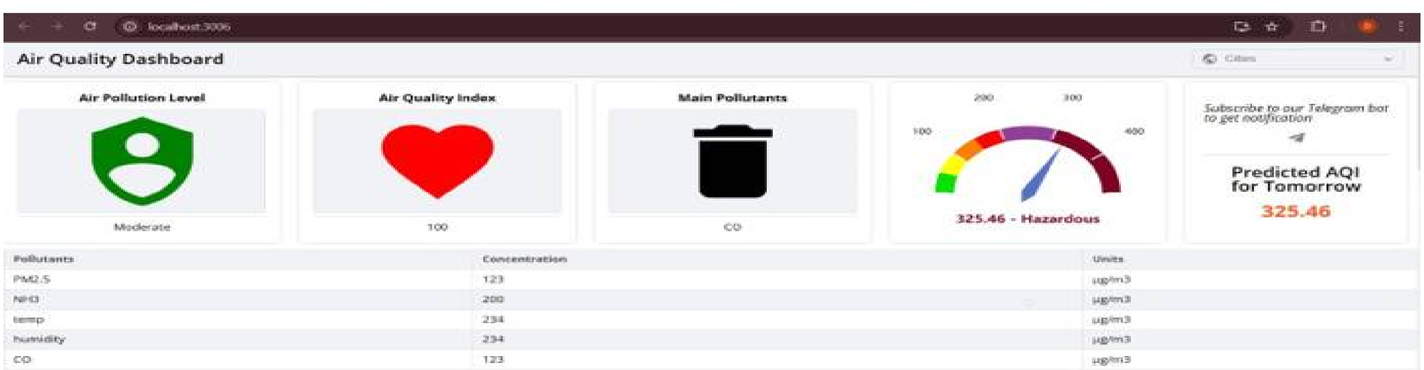

Fig. 2. Air quality dashboard

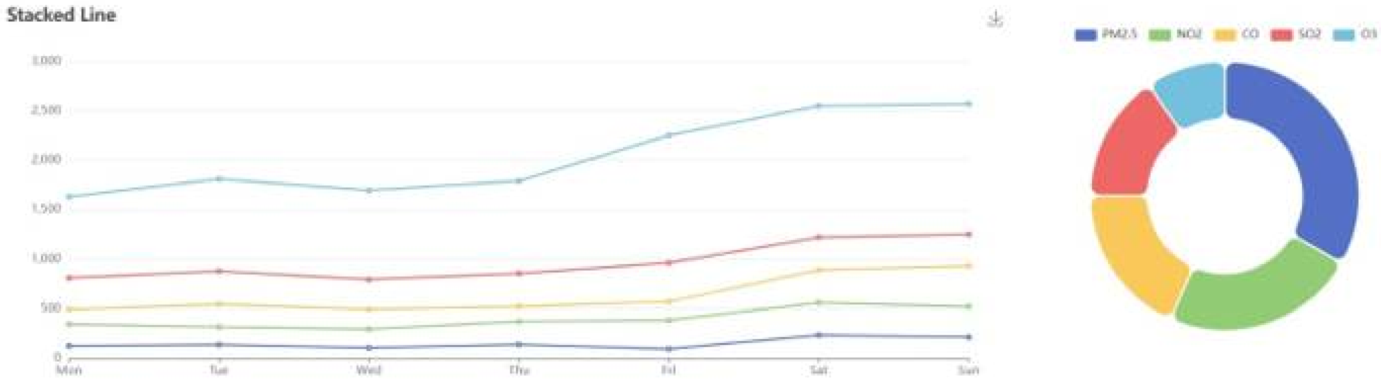

Fig. 3. Graph and pie chart of air quality over time

Fig. 4. Air quality dashboard

Fig. 5. Air quality heatmap

Fig. 6. Precipitation graph

Fig. 7. Comparison of predicted and actual AQI

Fig. 8. AQI data at a particular point

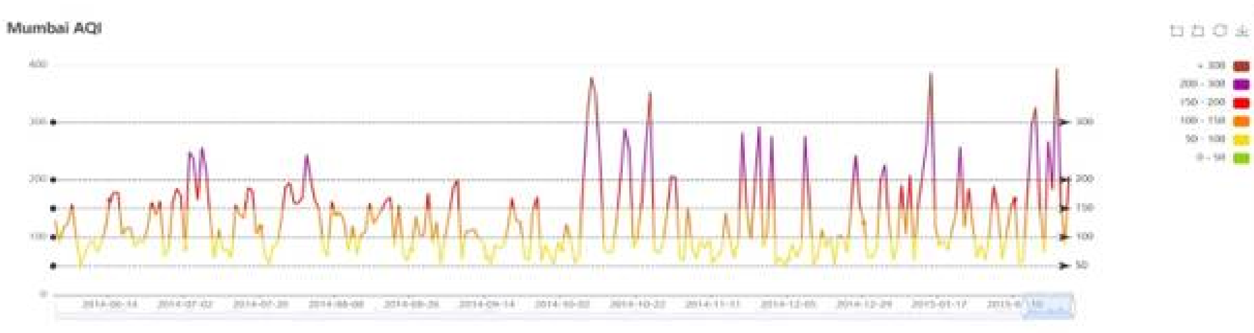

Fig. 9. Graph of air quality over time

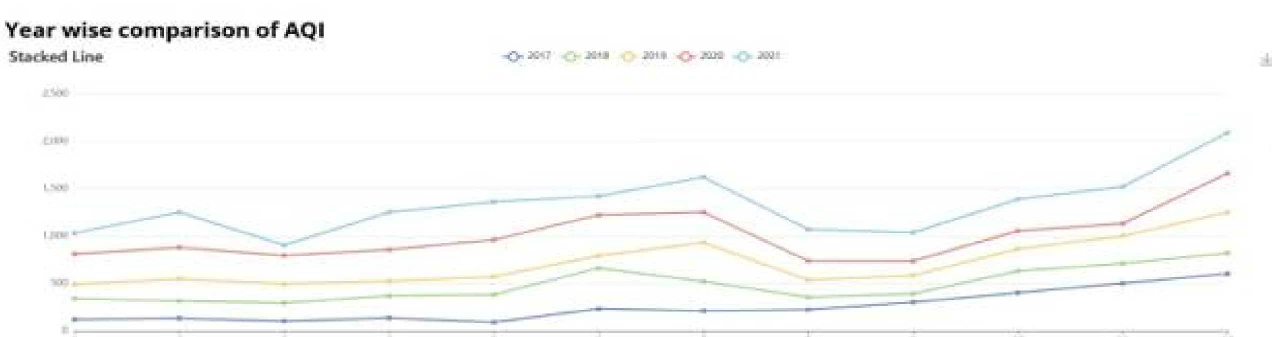

Fig. 10. Graph of water quality over time

IV. IMPLEMENTATION

TheimplementationoftheAQIandWQIpredictionsystems was carried out in distinct stages, focusing on hardware integration, data acquisition, and machine learning deployment. Each stage was systematically planned and executed as follows:

A. Hardware Setup and Calibration

1) Sensor Selection: Carefully chosen air quality sensors (MQ135, MQ7, PM2.5 Optical Sensor) and water quality sensors (pH, turbidity, and TDS sensors) to ensure compatibility with project requirements.
2) Calibration Process: Each sensor was individually calibrated under controlled conditions using standard solutions and known pollutant concentrations to ensure accurate readings.
3) EdgeProcessing:Basicdatapreprocessing(forexample, noisefiltering)wasperformedatthemicrocontrollerlevel to reduce network overhead.

B. Data Acquisition and Transmission

1) Real-time Data Collection: The sensors continuously monitored the air and water quality parameters, trans- mitting data at predefined intervals.
2) Wireless Data Transmission: Data collected by sensors was transmitted to a cloud-based MongoDB database via Wi-Fienabled microcontrollers, ensuring seamless and scalable storage.
3) EdgeProcessing:Basicdatapreprocessing(forexample, noisefiltering)wasperformedatthemicrocontrollerlevel to reduce network overhead.

C. Cloud Integration and Database Management

1) CloudInfrastructure:ThesystemutilizedGoogleCloud Platformforreliableandscalabledatastorageandprocessing.
2) DatabaseDesign:AMongoDBschemawasdesigned tostoreraw,processed,andhistoricaldata,enablingefficient querying for analysis.
3) Data Synchronization: Real-time synchronization ensured that data streams were immediately available for visualization and analysis.

D. Machine Learning Model Development

1) Historical Data Preparation: The data sets were cleaned, normalized and labeled for training and testing of machine learning models.
2) Model Selection and Training: Algorithms such as regression,decisiontrees,andneuralnetworksweretrained to predict AQI and WQI trends based on historical and real-time data.
3) Model Optimization: Hyperparameter tuning and cross-validationwereperformedtoimprovepredictionaccuracy and computational efficiency.

E. VisualizationandDashboardDevelopment

1) Frontend Design: Aninteractive webinterface wasbuilt using ReactJS and D3.js to display historical and real- time AQI / WQI data.
2) Visualization Features: Geographic heatmaps, temporal graphs, and pollution breakdowns provided users with actionable insights.
3) User Accessibility: The dashboard was designed to be mobile-friendly, ensuring accessibility across devices.

A. Alert and Notification System

4) Threshold-BasedAlerts:Predefinedpollutantthresholds trigger notifications that warn users of poor air or water quality.
5) Notification Channels: Alerts were sent via email and SMS, using APIs for seamless integration with communication systems.
6) Insight Delivery: Notifications included concise data insights and recommendations for immediate actions.

F. Testing and Validation

1) System Accuracy Testing: The integrated system was tested against laboratory-grade instruments to verify the accuracy of the data.
2) Performance Analysis: The latency of data transmis- sion and processing was evaluated to ensure real-time response.

3) Pilot Deployment: The system was deployed in select industrial areasto collect livedata and refinepredictions.

This detailed implementation framework ensured a robust, reliable, and user-friendly system for environmental monitor- ing and analysis.

V. RESULTS

Model	F1Score	KappaScore	Accuracy
OLS	1.000	1.000	100%
SVR	1.000	1.000	100%
MLR	0.9495	0.9512	98.62%
DT	0.7633	0.7234	92.2%
ANN	0.6515	0.8165	95.41%

TABLEI
PERFORMANCECOMPARISONOFMACHINELEARNINGMODELSFOR WQIPREDICTION

A. AQI System

1) Successfully predicted air quality levels with an average accuracy of 90%.
2) Identifiedcriticalpollutionzonesinthestudyarea.

B. WQI System

1) Detected water contamination events with over 92% reliability.
2) Monitored parameters like pH, turbidity, and TDS to ensure safe water quality for various applications.

C. Visualization and Insights

Real-time dashboards provided intuitive and actionable insights. Users appreciated the timely alerts for pollution and contamination risks.

D. Economic and Environmental Impact

1) Cost-effective implementation using IoT and cloud technologies.
2) Contributed to better environmental policy-making and resource allocation.

VI. CONCLUSION & FUTURESCOPE

TheAQIandWQIpredictionsystemsofferrobusttools for monitoring environmental quality in industrial areas. By integrating IoT devices, machine learning models, and user- centric dashboards, these systems provide real-time insights and predictive analytics. Future enhancements include:

1) Incorporatingadditionalsensorsforbroaderpollutant coverage.
2) LeveragingadvancedAItechniqueslikedeeplearningfor improved accuracy.
3) Deployingrenewableenergysolutionsforsustainable sensor operation.
4) Expandingsystemdeploymenttoruralandurbanareas for comprehensive coverage.

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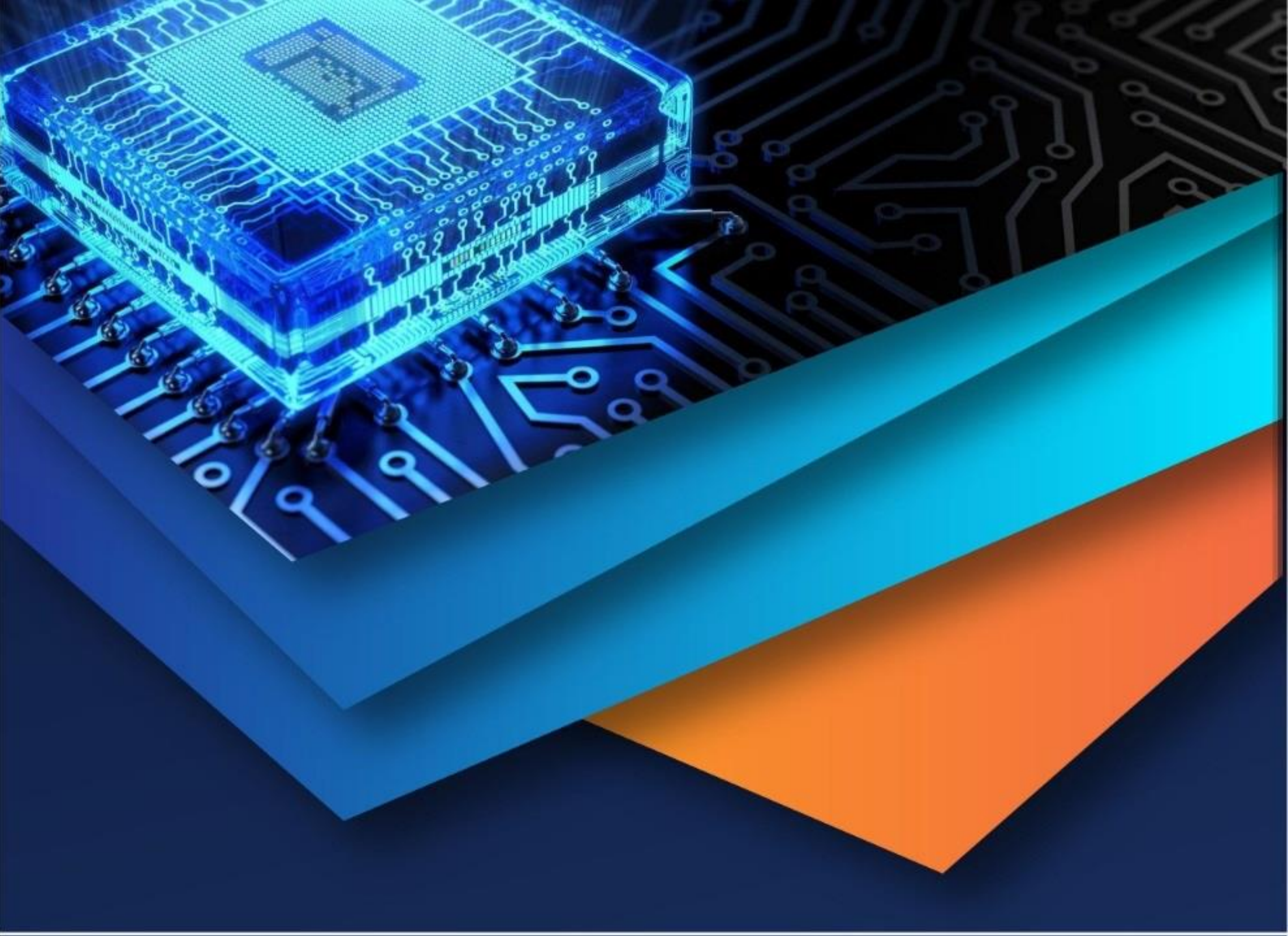

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