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Intelipole: IoT and ML-Powered Smart Pole for Advanced Home Security

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Abstract: Smart home is slowly but steadily becoming a part of our daily life in today's world. In this context, Intelipole, an IoT and Machine Learning (ML)-powered smart home system designed for advanced home security and automatic IoT device control, has been proposed. With the rise of IoT-connected devices, the integration of ML techniques is essential for enabling real-life predictions and automating device control. To achieve this, synthetic data along with a portion of real-time sensor data is collected to train the system's control models. Key features used include human presence count and environmental factors such as temperature, humidity, and luminosity. The system predicts appropriate control levels for devices like lights, fans, and ACs. The architecture includes real-time sensors, IP cameras for person counting, a microprocessor, cloud storage for historical data and ML models, and manual mobile control via Wi-Fi. The development process involves data collection, preprocessing, relevant feature selection, dataset splitting, and model implementation. Model performance, assessed using accuracy, precision, recall, and F1 score, shows strong potential for realworld application. Future work includes integrating user preferences and embedded systems to improve system adaptability and efficiency.
Keywords: CNN, Classification Algorithm, Home Automation, IOT, Machine Learning, Smart Home.

I. INTRODUCTION

IoT is defined as the network of physical objects "Things" integrated with numerous sensors, software, and other technologies to connect and exchange data with other devices and the system over the internet. Smart homes integrated with the Internet of Things (IoT), noting the greater number of connected devices than humans. It examines the current state of IoT-based smart home systems and introduces a novel machine learning (ML) approach for automatic and efficient IoT device management through real-time predictions. The proposed system trains control models using synthetic data and a portion of real-time sensor data, utilizing features like human presence, temperature, humidity, and luminosity, with Controlling Levels as class attributes. The Decision Tree algorithm is employed for classification, and the system's performance is evaluated using cross-validation techniques. With the rapid development in this domain, more electronic devices are included. The intelligence of the system is the current concern. Human activity and environmental databased prediction techniques can provide intelligence to the system. Decision-making capability depending upon the previously obtained real-life data, will entirely change the smart home experience. With the recent meteoric rise of new ML and hardware technology, more data can be sourced and applied in different fields of science previously unexplored.

As The proposed system, initially for a single room with expansion potential, includes real-time sensors, IP cameras for person counting, a microprocessor, cloud storage, and manual mobile control. Connected via Wi-Fi, it processes real-time sensor data and uses machine learning algorithms on stored cloud data to predict outcomes and generate control signals for lighting and cooling. A mobile app allows temporary overrides, with these manual choices saved for future reference. The development process involves raw data collection (including synthetic and real-time data), preprocessing, feature selection using ANOVA, dataset splitting, and the implementation of the Decision Tree classifier. The system's models for lighting, fan, and AC control were evaluated using metrics like accuracy, precision, recall, and F1 score, with both k-fold and stratified k-fold cross-validation indicating potential for real-world application and future improvements by incorporating user preferences and embedded system integration.

II. EXISTING WORKS

In the past decade, much research and development have been done in Smart Home Automation systems. Home automation is used to increase the comfort level of living conditions within a home. In 2025[2], A IoT-based sensing and monitoring platform was presented for smart home automation. EmonCMS platform is used for collecting and visualizing. This solar house monitoring system design includes typical monitoring parameters like humidity, luminosity, and air quality. Niek Tax described performance observation via various prediction techniques on human activity for the smart home environment.

Long Short-Term Memory (LSTM), an artificial Recurrent Neural Network (RNN), is implemented. Their study shows an outperform of LSTM over other prediction methods for predicting future activity.

A general functional architecture for the IoT Data Analytics system has been deployed by M. M. Ishaq et al. [4] on smart home services based on actual data. They proposed a generic way of applying machine learning and data mining techniques for controlling smart devices. Another exploratory study [5] describes an IoT-based home environment monitoring and controlling system. Naïve Bayes classifier algorithm is used for prediction strategy to discover any complications in any connected devices on the system. This system can also produce automatic fault detection and correction to the devices connected to that system.

Air conditioners, dehumidifiers, power curtains, and lights were controlled through the predicted output of the system. An Artificial Neural Network (ANN) was implemented to process the input data for machine learning.

An Eco-friendly home automation system can attain the proper usage of energy to global warming. IOT [8] is implemented to build a system for controlling the windows of a smart house. It aimed to reduce the energy consumption of heaters or air conditioners by predicting the suitable time to use it depending upon the weather condition. They claimed an 89% success rate of the system. In 2023, [10] the authors demonstrate the units and structure of an automated system for house control based on ANN. Their main concern was combining the existing ideas and including specialized tasks into one integrated system.

III. PROPOSED MODEL AND METHODOLOGY

In this section, the function and methodology of the proposed system are discussed. This system is designed for a single room, with the potential for adding other rooms as a subset. The proposed system utilizes different real-time sensors, IP cameras, a Microprocessor, Cloud-based data storage, and a manual mobile control operation feature. For real-time operation, the proposed system is connected to the cloud via the main home Wi-Fi network. Figure 1 illustrates a block representation of the system.

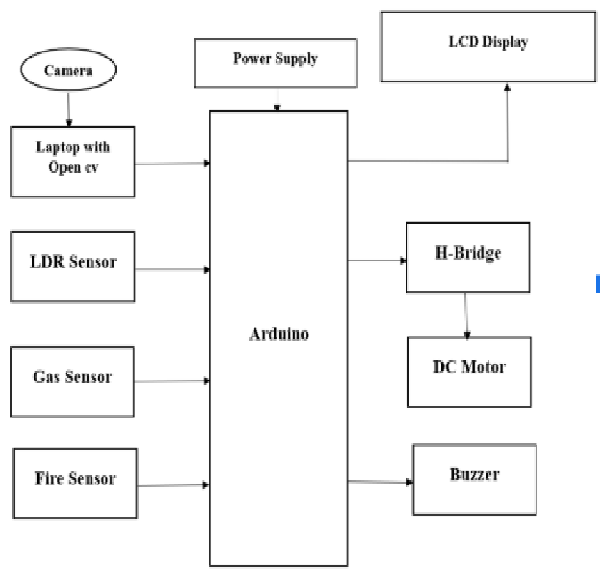

Fig. 1. Proposed system block diagram.

Fig. 1 illustrates the block diagram of a smart home security system, outlining the interaction between various hardware components managed by an Arduino microcontroller. Camera is the input device responsible for capturing visual information from the surroundings. It's likely used for surveillance, visitor identification, or monitoring specific areas of the home. The camera is connected to a laptop running OpenCV (Open-Source Computer Vision Library). OpenCV is a software library that provides tools for image processing, computer vision, and machine learning. In this context, the laptop with OpenCV is likely performing tasks. Facial Recognition for analyzing the video feed from the camera to identify known individuals. Object Detection will Identify specific objects of interest (e.g., people, vehicles). Motion Detection is involved in detecting any movement within the camera's field of view. The processed information or alerts from the laptop (based on OpenCV analysis) are then sent to the Arduino for further action. Sensor (Light Dependent Resistor) measures the intensity of light. In a smart home security system, it can be used for a sudden change in light level (e.g., when a door or window is opened at night) can trigger an alert. Turning lights on or off based on ambient light conditions.

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The LDR sensor sends its readings to the Arduino. Gas Sensor detects the presence and concentration of specific gases (e.g., LPG, CO). It's a crucial safety component for detecting gas leaks, which can be hazardous. When a gas leak is detected, the sensor sends a signal to Arduino.

Fire Sensor detects the presence of fire, typically by sensing smoke or a rapid increase in temperature. It's a vital safety component for early fire detection. When a fire is detected, the sensor sends a signal to the Arduino. Arduino is the central microcontroller board that acts as the "brain" of the smart home security system. It receives data from all the sensors (Laptop/OpenCV, LDR, Gas Sensor, Fire Sensor). It is programmed to process this data according to predefined logic. Based on the sensor inputs and the programmed rules, the Arduino controls the various output devices: LCD Display, H-Bridge, DC Motor, and Buzzer. The LCD display can show real-time information about the system status, sensor readings, alerts, or any other relevant data programmed by the Arduino. It provides a local visual interface for the user.

H-Bridge is an electronic circuit that allows the Arduino to control the direction and speed of a DC motor. In a smart home security context, the H-Bridge and DC Motor could be used for Automated door/gate locking mechanisms and controlling a motor to lock or unlock doors or gates. Pan-tilt control for a security camera will adjust the viewing angle of a connected camera (though a separate pan-tilt mechanism and motor would be needed). DC Motor is an electromechanical actuator that produces rotational motion when supplied with DC voltage. As mentioned above, controlled by the H-Bridge, it can be used for physical security mechanisms. Buzzer is an audio signaling device. In the security system, it would be used to generate an audible alarm in case of a detected threat (e.g., unauthorized entry, fire, gas leak).

This block diagram represents a basic yet functional smart home security system that integrates various sensing technologies, a central processing unit (Arduino), and output mechanisms for alerts and control. The inclusion of a laptop with OpenCV suggests the potential for more advanced security features like facial recognition, enhancing the system's intelligence and capabilities.

Temperature and humidity sensors collect data for both the room and the outside environment in real-time, while the luminosity sensors gather data only from outside. The IP camera functions as a person counting device. Real-time data is transmitted to the processing unit and the cloud. The processor predicts favorable outcomes based on previously stored data in the cloud using machine learning algorithms. Following the generation of outputs through machine learning, the processor activates lighting and cooling control signals. The system also incorporates five different cooling levels. Similar to the lighting control, the machine learning algorithms predict and activate one of these five levels to manage the temperature within the room. The cooling mechanism in this proposed system appears to be a combination of fan and air conditioning control, as indicated by the feature selection process where a single "Cooling control" model was developed. The five cooling levels likely represent different fan speeds and potentially different target temperatures or modes for the air conditioning unit. The choice of cooling level would be determined by factors such as room temperature, room humidity, and user preferences.

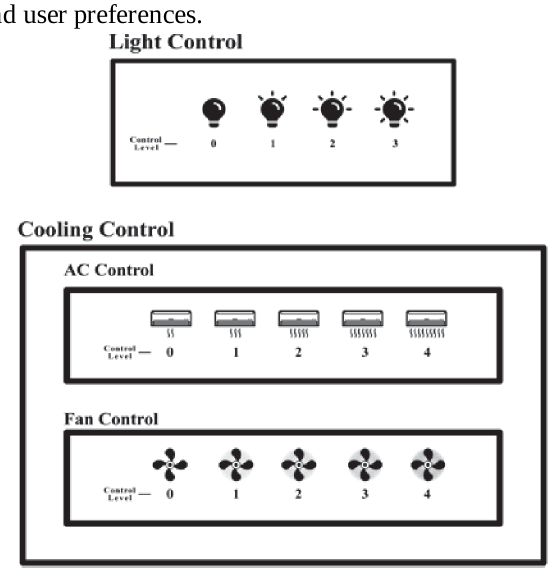

Fig. 2. Lighting and cooling level of the system.

The system also incorporates five different cooling levels as illustrated in Fig. 2. Similar to the lighting control, the machine learning algorithms predict and activate one of these five levels to manage the temperature within the room.

The cooling mechanism in this proposed system appears to be a combination of fan and air conditioning control, as indicated by the feature selection process where a single "Cooling control" model was developed. The five cooling levels likely represent different fan speeds and potentially different target temperatures or modes for the air conditioning unit. The choice of cooling level would be determined by factors such as room temperature, room humidity, and user preferences.

The presence of discrete control levels for both lighting and cooling suggests a practical and incremental approach to adjusting the indoor environment. Instead of continuous adjustments, the system operates within these predefined steps, making the control logic and the user's understanding of the system's actions more straightforward. The text also mentions that a mobile application allows users to manually override the automated settings. When a user makes a manual adjustment, the system will temporarily apply this setting for an hour before reverting to the automated mode, and the user's choice is stored for future reference, potentially influencing the machine learning model's future predictions.

The development of separate models for lighting control and cooling control (which encompasses fan and AC control) indicates a modular approach to managing different aspects of the indoor environment. Each model likely uses a subset of the available sensor data that is most relevant for predicting the appropriate control level for its respective function. For instance, outside luminosity is identified as a key feature for lighting control, while room temperature and humidity are crucial for fan and AC control, respectively. This structured approach, with defined control levels for lighting and cooling, forms a crucial part of the proposed IoT-based smart home system's functionality.

Different phases like Raw Data Collection, Data PreProcessing, Feature Selection, Dataset splitting, Classification Algorithm (Decision Tree) Implementation are involved in building the models, shown in Figure 4.

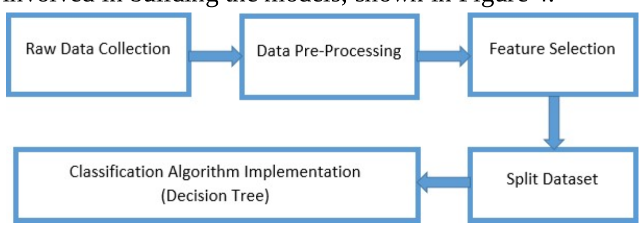

Fig. 3. A schematic representation of the proposed system for model control level prediction

The flow diagram shown in Fig. 3 illustrates the systematic process employed in the proposed system for model control level prediction. The pipeline begins with raw data collection, where relevant environmental and user-specific parameters are gathered. This data is then passed to the data preprocessing stage, where cleaning, normalization, or transformation techniques are applied to ensure data quality. Following this, feature selection is performed to identify the most influential variables that contribute to accurate model predictions. The selected features are then used to split the dataset into training and testing sets, which helps in evaluating the model's performance. Finally, a classification algorithm, specifically a decision tree, is implemented to predict the appropriate control levels for the system. This structured approach ensures efficient and accurate prediction of lighting and cooling levels based on contextual inputs.

A. Raw Data Collection

The dataset employed represents a comprehensive view of weather information and human preference for the proposed system, which was created and preprocessed. The generated dataset encompasses eight attributes: Time, Day & Month, Outside Temperature, Room Temperature, Outside Humidity, Room Humidity, Outside Luminosity, and Person Count. The primary focus is to analyze this dataset using machine learning techniques to enable the proposed system to make informed decisions for automatically controlling IoT devices to maximize user comfort.

Weather Temperature and Humidity data were obtained from a weather data provider website for Dhaka city between October 15, 2020, and April 15, 2021. Data representing Outside Luminosity was synthetically produced based on different weather parameters. Indoor person count data was generated based on the occupation patterns of family members from three observing families, considering weekends, weekdays, time, and certain weather conditions. Additionally, a specific portion of real-time indoor environment data (Temperature, Humidity, Luminosity) was obtained from different sensors for the dataset.

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B. Data Preprocessing
Following the collection of the raw dataset, it undergoes a preprocessing step. Datasets can contain missing data, duplicated values, or inconsistencies due to human errors. Therefore, data cleaning and smoothing of noisy data are performed at this stage, which is crucial for the ML approach.

C. Feature Selection
In this system, three separate models were designed for Lighting control, Fan control, and AC control to predict the controlling decisions for the respective devices. Given that the inputs are numerical and the predicted output is ordinal, *ANOVA was deemed more suitable for feature selection*. Utilizing the ANOVA feature selection method, it was found that Outside Luminosity is a less important feature for Cooling control, which combines Fan and AC control. Consequently, this cooling control model was built with seven attributes, excluding Outside Luminosity. Figure 5 and Figure 6 illustrate the labeled data visualization for cooling control, while Figure 7 represents the lighting control.

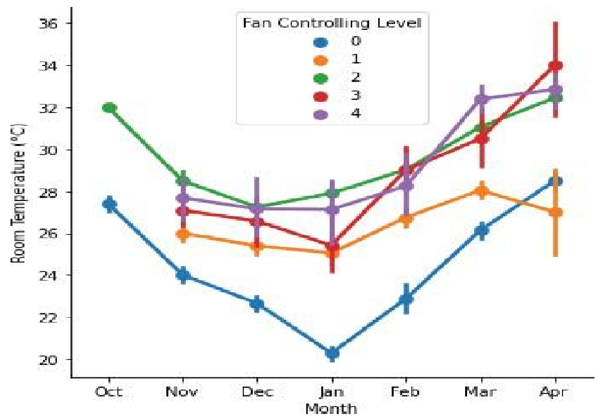

Fig. 4. Room temperature vs fan control.

For the Fan controlling model, Room Temperature emerged as the most important feature, whereas Room Humidity was identified as the top feature for AC Controlling. As illustrated in Fig. 4, the fan control levels are influenced by variations in room temperature controlling level (0,1,2,3,4) varies with Room Temperature across the entire data acquisition timeframe (October 2020 to April 2021). It is observed that for a specific temperature range of 20-26 °C, the control level consistently remains zero. Conversely, above approximately 32 °C, Fan control level 3 or 4 is used depending on other parameters.

IV. RESULT ANALYSIS
The experiments conducted and their corresponding results are discussed in detail in this section.

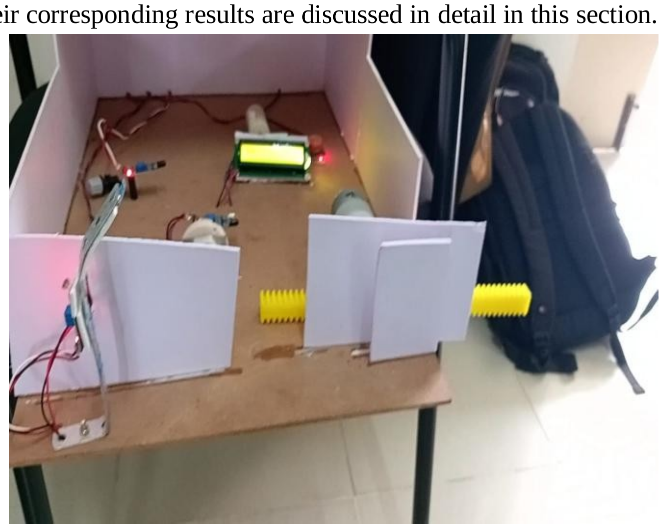
Fig. 5. Vehicle number plate recognition and gate opening

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As illustrated in Fig. 5, when a vehicle arrives at the gate, the camera captures the number plate, and the OpenCV software running on the laptop processes the image using OCR to recognize the plate number. If the vehicle is successfully verified against the stored database, a message saying "Vehicle Successfully Verified" is displayed on the LCD Display placed inside the home. After verification, a signal is sent from the Arduino to the H-Bridge, activating the DC motor to open the gate automatically. This ensures that only authorized vehicles are allowed entry without manual intervention.

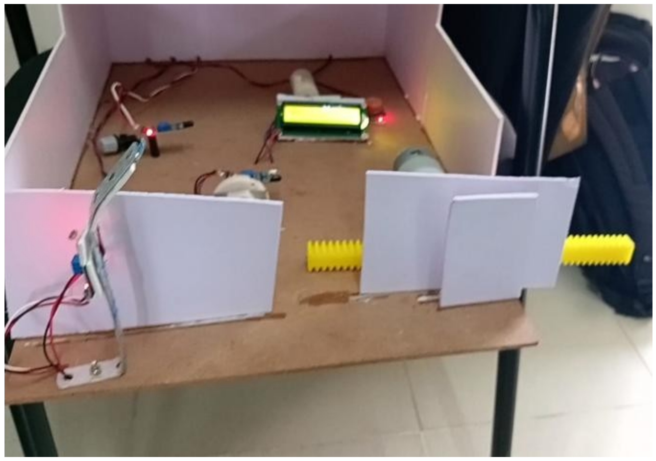

Fig. 6. Face recognition and gate opening for person

As illustrated in Fig. 6, when a person approaches the entrance, the camera captures the face and sends it to the laptop with OpenCV for face recognition processing. If the face is recognized as an authorized user, the LCD display inside the home shows the message "Person Successfully Verified" (similar to the vehicle message). Upon successful verification, the Arduino triggers the H-Bridge circuit to operate the DC motor, which opens the gate, allowing the person to enter securely.

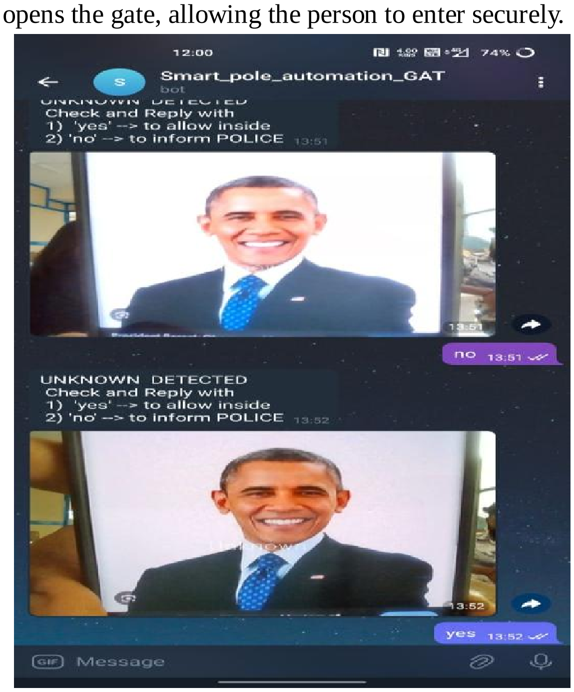

Fig. 7. Owner notification about face via telegram bot

As illustrated in Fig. 7, the owner receives a notification via a Telegram bot upon detection of a face by the camera system. The message includes an image of the detected individual for quick identification. This enables realtime security alerts and remote monitoring functionality.

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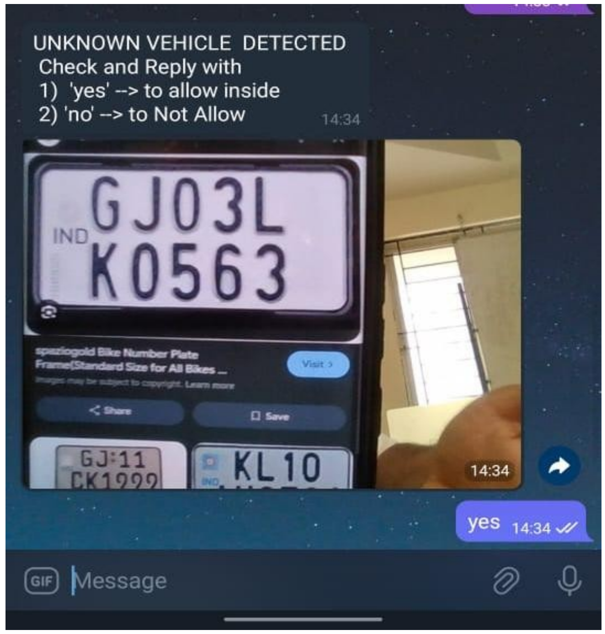

Fig. 8. Owner notification about number plate via telegram bot

As illustrated in Fig. 8, for every vehicle number plate and face recognition event, an instant notification is sent to the owner's mobile through the Telegram Bot API. The owner can either accept or deny access by clicking the respective option in the Telegram message. If the owner allows, Arduino opens the gate automatically by triggering the motor.

Fig. 9. Police alert notification

As illustrated in Fig. 9, if the owner denies, a notification alert is immediately sent to the nearest police station through the configured Telegram bot or additional communication system. This adds a strong extra layer of manual security control.

Fig. 10. Automatic street light control based on day/night detection

As illustrated in Fig. 10, using the LDR (Light Dependent Resistor) sensor connected to the Arduino, the system continuously monitors ambient light conditions. During daytime, the LDR detects enough natural light and automatically turns OFF the streetlight placed in front of the gate. At nighttime, when the surroundings get dark, the system automatically turns ON the streetlight. This automation improves energy efficiency and ensures the area remains welllit at night without manual operation.

Fig. 11. Indoor light and fan automation when person enters home

As illustrated in Fig. 11, when a person enters the home, the PIR motion sensor (or ultrasonic-based sensing) detects the person's movement. Immediately after detecting presence, the Arduino sends a control signal to relay modules connected to the home lights and fans, turning them ON automatically. This automation ensures that residents enjoy comfort without needing to manually switch on the devices, promoting a smart living experience inside the house.

Fig. 12. Gas leakage detection and warning system

As illustrated in Fig. 12, if there is any gas leakage, the MQ-series gas sensor (like MQ-2) detects the dangerous concentration of gases in the environment. Once detected, the Arduino triggers the buzzer to emit a loud alarm sound to alert people nearby. Simultaneously, the LCD Display inside the house updates with the message "Gas Detected" to provide clear information to the residents. This quick alert system helps prevent accidents and ensures immediate action is taken.

V. CONCLUSION AND FUTURE WORKS

The study of large-scale Internet of Things (IoT) networks underscores a pressing need for resilient and adaptive mechanisms to manage the ever-changing patterns of network traffic and to counter increasingly sophisticated cyberattacks targeting IoT devices. In such complex environments, malicious actors frequently alter their tactics, making it essential for security systems to operate dynamically— capable of identifying and responding to a wide range of threats, including Distributed Denial of Service (DDoS) attacks, spamming, phishing, and other forms of malicious behavior. One of the key challenges in this domain is the phenomenon of concept drift, where the statistical characteristics of network traffic evolve over time. This makes static or traditional detection models insufficient, as they fail to adapt to new and unforeseen attack strategies.

To tackle these challenges, this study proposes a scalable and flexible data pipeline architecture that integrates Apache Kafka, Apache Spark Structured Streaming, and MongoDB. This architecture is specifically designed to handle the highthroughput, low-latency requirements of real-time threat detection in large-scale IoT deployments. Kafka serves as a reliable and fault-tolerant messaging system for ingesting large volumes of data, while Spark Structured Streaming enables continuous data processing and dynamic model updates. MongoDB offers a robust storage solution for both historical data and model outputs, supporting efficient retrieval and analysis. A key feature of this pipeline is its ability to detect and respond to concept drift, ensuring that the security models remain accurate and responsive as network conditions change. By enabling real-time threat classification and continuous model adaptation, the proposed system significantly enhances the resilience and intelligence of IoT network defenses.

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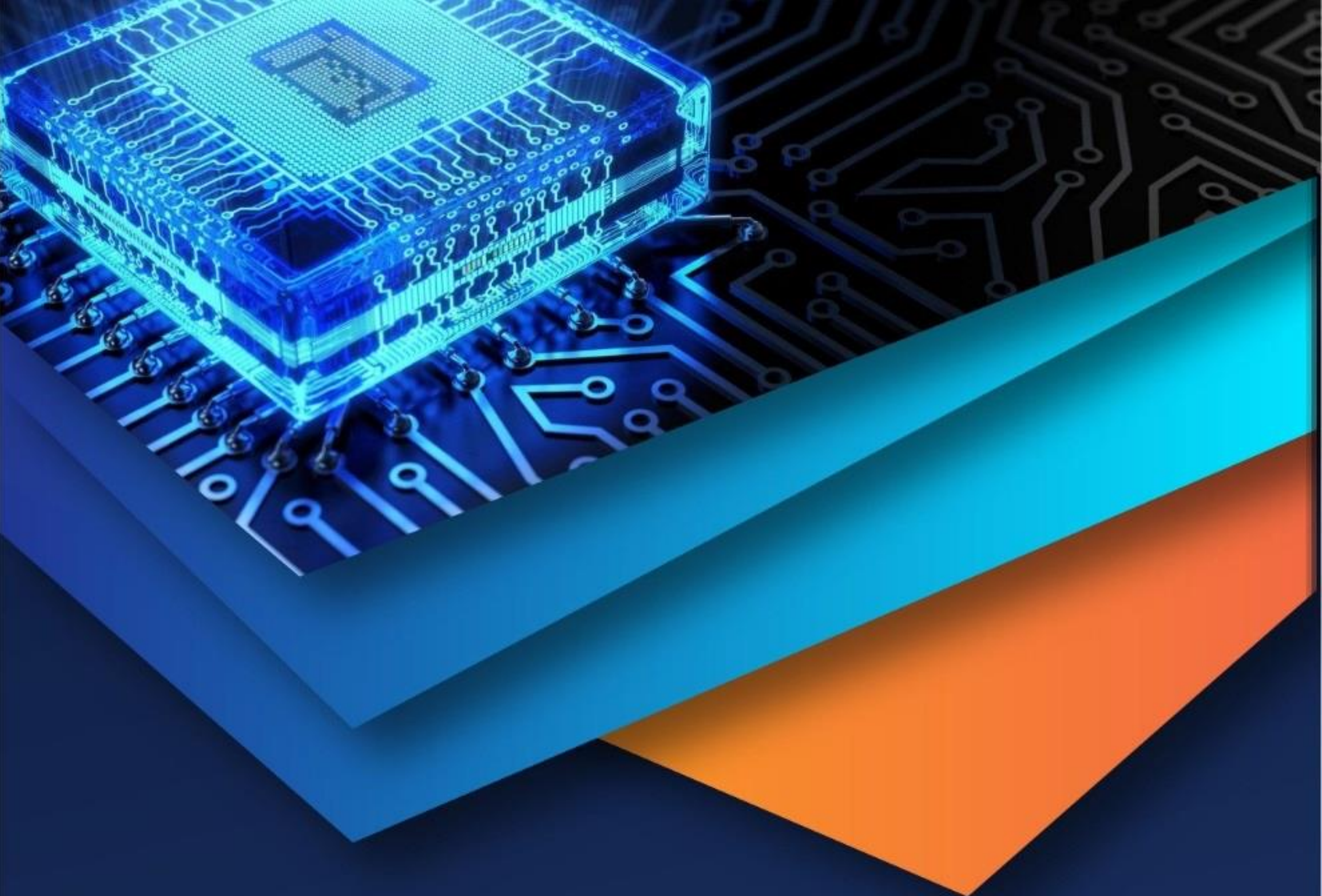

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