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HOMENETEDGE: A LIGHTWEIGHT EDGE-AI SMART HOME FRAMEWORK WITH SECURE BLOCKCHAIN INTEGRATION AND MULTI-MODEL PREDICTIVE LEARNING

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Abstract. The proliferation of the Internet of Everything (IoE) has transformed smart home environments, necessitating intelligent, secure, and responsive systems that can make real-time decisions at the network edge. This paper presents HomeNetEdge, an edge-AI-enabled smart home automation framework that combines lightweight ensemble learning models with blockchain-based security to address the pressing challenges of privacy, identity theft, and autonomous device control. The system integrates logistic regression and random forest classifiers using principal component analysis (PCA) for feature selection, ensuring accurate and efficient predictions of device states ("ON"/"OFF") with minimal computational overhead. HomeNetEdge operates on commercial off-the-shelf hardware, including Raspberry Pi servers, 5V relay modules, and sensor arrays, and leverages local edge computing to eliminate reliance on cloud infrastructure. A custom Android application interfaces with the system via HTTP and Apache servers for seamless user control. To ensure robust security and trustworthy communication between devices, blockchain-based authentication mechanisms are embedded. The framework is evaluated under both controlled and real-life conditions, demonstrating real-time performance, scalability, and resilience against cyber threats. This work contributes a practical, cost-effective, and scalable edge computing architecture that supports real-time AI-driven decision-making, personalized automation, and secure data handling – critical for the future of intelligent IoT ecosystems.

Keywords: Edge AI, smart home automation, Internet of Everything (IoE), blockchain security, lightweight machine learning, multi-model learning

Mathematics Subject Classification 2010: 68T40, 68U35

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1 INTRODUCTION

The Internet of Everything (IoE) involves using software programs and sensors in devices to control events using smart devices, either in person or remotely through Internet technology [1]. It integrates different technological advancements like RFID, sensor apparatus, nanotechnology, smart technology, and sensor technology among others to facilitate the effective collection and processing of information [2]. Instead of functioning on its own, IoT utilizes major developments to close the divide between reality and the metaverse [3]. In the current busy society, with people having jam-packed schedules, there is an increasing need for ease and help in different areas of life. While the Internet of Things covers a wide range of research topics, this research specifically targets smart homes [4, 5] and similar environments because they are easy for users to interact with. An intelligent home is an automated home, in which all devices are linked and managed via a smartphone, tablet, or computer with internet access. In recent years, home automation has become increasingly popular as people want the ability to control and oversee their devices from any location worldwide. As a result, home automation is now a necessary aspect of modern living.

IoT provides cost-effective and adaptable frameworks that greatly improve users' luxurious living by tackling day-to-day problems [6]. By seamlessly incorporating smart devices and sensors into various settings, IoT technology simplifies tasks, enhances efficiency, and increases convenience. For example, smart home systems can automate lighting, heating, and security, ensuring comfort and safety while lowering energy expenses [7]. In healthcare, IoT devices allow for remote patient monitoring, enabling timely interventions and decreasing the need for frequent hospital visits. Additionally, IoT applications in transportation can optimize traffic flow and reduce commute times [8]. Overall, IoT's capability to connect and manage a wide range of devices transforms our interactions with our environment, making daily life easier and more efficient. Prior research has showcased varying home automation systems that include numerous sensors [9, 10]. Nevertheless, it is crucial to elucidate the rationale for suggesting a thorough and organized home automation system due to constraints in research endeavors. The existing home automation systems have multiple limitations, such as being expensive due to the purchase of Internet-Protocol (IP) based devices, low range due to Bluetooth usage, no security implementation, and privacy concerns.

This research has recognized several research gaps to address. It is crucial to overcome these gaps and address these deficiencies to support the ongoing advancement of intelligent home automation systems.

1. Interoperability: Compatibility problems between devices made by different manufacturers might make it more difficult for a smart home to function smoothly. This study suggests an application that functions on all smart devices.
2. Security Concerns: Hacking and cyberattacks can damage home security and reveal personal data on smart devices. This study suggests a more secure

blockchain-based security architecture for smart home automation.

3. Complex Installation and Setup: Non-technical customers may find it difficult to set up and configure smart home gadgets, so this research created user-friendly interfaces and streamlined setup procedures that let users establish their complete home model using a drag-and-drop platform.
4. Bill Reduction: Predictive models are utilized to automatically turn ON and OFF electrical devices using data logging data.

An interactive graphical user interface (GUI) for home prototyping is a novel feature in this framework and is not present in earlier frameworks. The use of a GUI makes it more difficult for users to comprehend how the system works. Current home automation systems cannot restore devices or accurately forecast electricity costs, which can be both costly and harmful to household appliances. The proposed system for smart home automation focuses on these deficiencies. Users can control and oversee sensors and devices, while the linked mobile app allows them to adjust their home's design layout and carry out additional tasks. This study established secure communication and verification among IoT devices using blockchain technology, enabling users to modify device status. This effective method exceeds the constraints of past resolutions. The major contributions of this research work are:

1. This study presents a cost-effective system for automated smart homes that allows remote management of electrical devices without the need for IP-based devices.
2. HomeNetEdge employs an IoT-based system along with an Android-based application for cell phones. The users can move and place items to create smart home designs effectively.
3. HomeNetEdge comes equipped with a GSM modem. Through this connectivity, SMS messages can be used to manage home equipment, including lighting, climate control, and security systems.
4. A device restoration function in the proposed system lets users return appliances or electronic devices to their factory settings. This capability comes in handy for those who want to return their devices to factory settings or a former state.
5. The developed system makes use of Raspberry Pi and Arduino, two crucial components for novices and enthusiasts in the realm of electronics. Not only are these tools popular, but they are also reasonably priced. Due to its simple internet connectivity, although Raspberry Pi is perfect for networked jobs, Arduino is better suited for real-time hardware and software tasks.
6. HomeNetEdge has data-logging capabilities to help users improve energy efficiency and appliance performance, along with a function for smartly categorizing the status of IoT devices.
7. The integration of PCA features helps in the reduction of less important data and extraction of significant features from logging the bulk of raw data for better training of the LR-RF ensemble model.

8. HomeNetEdge integrates blockchain technology for both user identity verification and secure authentication.

The rest of the paper is structured as follows: The summary of recent research and significant advancements in the field of IoT solutions is discussed in Section 2. The research methodology employed in this study to identify a workable solution is described in Section 3. Section 4 describes the information and techniques used in the experiments, while Section 5 explains the implementation of the proposed technique, hardware, and software that are used, including smart houses and buildings. Section 7 includes the results of the experiments, as well as an in-depth examination. Section 8, in conclusion, ends the article.

2 RELATED WORK

Internet of Everything (IoE) covers all domains like Internet of Things (IoT), Internet of Medical Things (IoMT), and Industrial Internet of Things (IIoT) [11]. In [12], researchers explained the vision of the Internet of Everything in data, processes, people, and non-living things connected to flourish the industries. While research works [13] provide an overview of IoT-based applications and technologies that lay the foundation for IoE implementations. In [14], researchers explore the sub-domain of IoE by researching smart cities. This research improves urban living and sustainability. Meanwhile, this proposed research work is based on IIoT, where buildings and homes are automated using IoT technologies. In [9], authors employed the ZigBee microcontroller to enable device connectivity in households, but it suffers from limited range covering and low data transfer rate limitations. Similarly, in [10], researchers made a web-server system in which the status of all devices can be seen online and can be changed, but again, it requires a lot of wiring cost with less usability. In another research [15], these limitations are removed, but it still lacks an interactive GUI for user understanding [16]. Developed a distinctive hand-gesture-operated smart home system; however, it faced challenges in accurately detecting hand gestures, leading to user inconvenience.

In [17], a home automation system connects electrical switches to the Internet for electronic device monitoring. However, when it came to guaranteeing safe transmission and communication between network devices, this technology had a drawback. In their research, [18] created speech recognition, and GPRS was included in a home automation system. Yet, the system had a deficiency in secure user identification and authentication. In the same way, [19] sought to enable elderly and disabled individuals to remotely control household devices through an Android APK. However, the system's capabilities are limited to controlling lighting and turning electronic devices on and off.

In [20], an automated house system was designed that is controllable using a Bluetooth-enabled mobile phone. Nonetheless, the system's graphical user interface (GUI) is only suitable for Symbian OS cell phones, and the Bluetooth distance is limited to 100 meters. In the same way, [21] utilized Bluetooth technology, but their

proposed method faced challenges because of the intrusive installation process. Interest in the dependability of blockchain technology has grown recently. In [22], they successfully tackled the technology selection challenge by implementing blockchain into their approach. Moreover, researchers have shown that blockchain technology is utilized in e-government services, as demonstrated in [23].

The network security threat environment has drastically deteriorated due to the increase in intrusion techniques and cyberattacks [24] proposed a practical anomaly detection method that considers the complex interactions between node Features and network organization. In a recent study [25], researchers investigated current cyber-attacks using AI methods and discovered various strategies to combat these AI attacks. A new authentication mechanism was developed specifically for RFID systems [26]. The researchers investigated how blockchain technology can be integrated with the Internet of Things to create a system that conserves energy. In a different study [27], the surveillance system was combined with a Blockchain network by the authors.

In another study [28], the study focused on cyber-attacks using the Internet of Things, investigated defense strategies, and highlighted related issues. In [29], the authors introduced a technique for assessing the security of block ciphers designed for GPU machines, utilizing the branch and bound method. An architecture for signing without certificates was constructed using blockchain technology [30], employing Arduino Tmega2560 and IoT technology to assist individuals with disabilities in overseeing and managing their domestic devices. The recommended system did not have a reliable authentication method for users.

Sensors are strategically placed throughout the home, with an LCD providing real-time information on solar input, charging efficiency, and discharge rate. Wi-Fi technology enables continuous remote monitoring and control. The system is designed to handle unforeseen circumstances in the owner's absence, promptly notifying them of any issues. This smart home operates entirely on self-generated solar energy. Rajeshkumar et al [31] introduce an innovative deep learning-based Faster R-CNN system integrated with the Internet of Things (IoT) to enhance face recognition security in smart office automation. The system utilizes a database of employee images, which are pre-processed to train a neural network.

3 METHODOLOGY

This research introduces a HomeNetEdge framework in which users can manage different types of devices using a smartphone application, such as lighting, sensors, heating, ventilation, and air conditioning, from any part of the world where the internet is available. The system aims to save time and energy by offering users information on how devices consume energy. This affordable and eco-friendly option could be used in different places such as hotels, restaurants, homes, and factories. The system has a simple and easy-to-use graphical user interface (GUI) and an icon-based alerting system, enabling users to get alerts and stay linked to their homes

no matter their location. Moreover, the proposed system is economical as it can automate common household electrical devices, eliminating the need for specific IP gadgets like RJ-45 [32]. Figure 1 depicts the planned automated system visually.

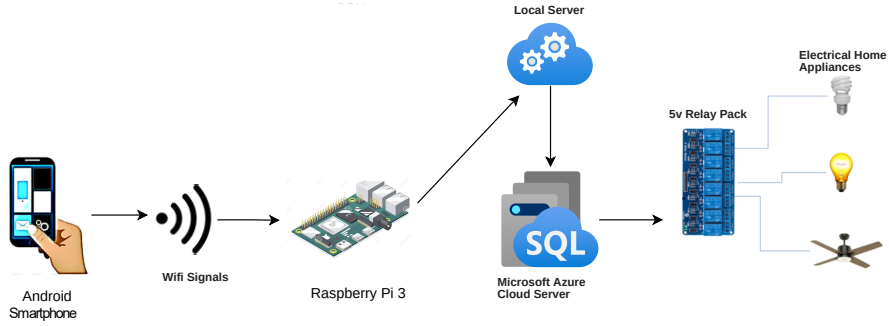


Figure 1. Schematic diagram of HomeNetEdge framework

The best thing about the HomeNetEdge framework is that users can design the complete prototype of their homes utilizing the drag-and-drop interface from the admin panel. Users need to add floors, then rooms, and then an arrangement of home appliances according to the room's actual arrangements [33]. The interface also permits you to personalize the house design by incorporating special devices, spaces, or levels. When a user finishes setting up their home layout in the admin panel, their home structure is synchronized with the server in JSON format, and the database is updated. The database is updated through the use of VOLLEY in this synchronization process [34]. Once the syncing is completed, the user can use their login details to access the admin panel and view the home layout. The synchronization of the database and its availability in the admin panel usually takes around 30 seconds. The app interface shows accurate details about all levels and different house equipment. At the base of the primary screen are three tabs. Sensor status is displayed on one tab, while device activity history and the person who modified the device's state are shown on the other. The option to exit the application is available to the user on the last tab of this navigation menu. User credentials are managed through shared preferences to guarantee data durability.

Additionally, the condition of domestic appliances is divided into two groups using a supervised learning classifier: "OFF" and "ON." This classifier is developed based on the patterns of the devices' usage. The classifier's input data comprises continuous numerical values such as time_of_device, light_of_room, temperature_of_room, and the current state of the device, in addition to categorical variables like device_id, floor_id, and room_id. To choose the best predictive model for the task of classification, a comparison is made to assess the effectiveness of different traditional models. The system will implement the model that exhibits the best performance. In addition, our upcoming system ensures authentication of credentials and secure communication between users who want status updates and IoT devices.

This is achieved through the utilization of blockchain technology, which guarantees the safe transfer of data among smart home applications, servers, devices, and users.

Providing safe and reliable identification and authentication for Internet of Things devices is the primary objective of a home automation system. To accomplish this, this research have integrated blockchain technology, ensuring these goals are met. In [35], is credited with creating blockchain technology, which possesses key Features like anonymity, decentralization, and security [36]. By leveraging blockchain technology, the Internet of Things can construct an extremely secure central server, reducing dependence and enhancing overall protection. Blockchain technology is utilized in smart homes that are based on IoT to establish a structured and secure data system. Data integrity and sensitive information security are ensured by the use of hash functions, encryption, timestamping, and Java-based modules.

The initial phase involves constructing a block utilizing a Java block class. This class generates the hash value using the data string, the previous hash, and the timestamp. After the block is produced, the SHA-256 algorithm is used to create a hash. After generation, the blocks are stored. Confirming that the generated hash matches the saved hash authenticates the blockchain. The user gains access to the hash values that come before and after the match. The entire process needs to be restarted if the hash values are different.

4 IMPLEMENTATION

This section investigates the methods employed to ascertain device status through data collection, visualization, and supervised machine learning.

Data that is later saved in an Excel spreadsheet is stored in the application that is generated. Subsequently, the information is examined to investigate the relationships and links between various Features. The attribute data includes temperature, light, and smoke measurements. In the status column, a 0 denotes "OFF", and a 1 denotes "ON". All devices are set up to return to their original settings if there is a power outage or Raspberry Pi restart to ensure consistency. This is accomplished by storing and retrieving each device's most recent status data via a database server. Updates for the gadgets housed within the household are planned regularly. If the temperature in the house goes above a certain level, the ventilation fans will turn on by themselves.

To regulate the timing of lights while accounting for the cycles of day and night, light sensors are fitted. The project is robust and unique due to its inclusion of features like sensor upgrading, recording data, being compatible with Raspberry Pi, using deep learning models, and having a cloud-based database. The system is designed to be user-friendly and flexible, featuring personalized device designs that are customized to meet the unique needs of every household.

PCA technique is used for dataset dimension reduction using statistical calculations. It finds the correlated variables and transforms them to linearly uncorrelated variables called principal components [37]. The first principal component accounts

for the largest possible variance in the data, with each succeeding component orthogonal to the previous one and capturing the next highest variance. PCA helps in simplifying data complexity, reducing noise, and identifying important patterns and structures in high-dimensional datasets.

This research requires thorough tests to assess the state of appliances using advanced models. Several ML and deep learning models are employed for this specific purpose, as outlined in the subsequent sections.

5 INTEGRATION OF HOMENETEDGE

The integration of HomeNetEdge is shown in Figure 1, showcasing the incorporation of multiple devices to offer a comprehensive understanding of smart home solutions. The illustration shows the project progress. A route of arrows to control the status of equipment with a smartphone. Two modules allow the user to communicate with a Raspberry Pi server, depending on where they are located [38]. The initial module enables communication with IoT devices at home without requiring an internet connection. The main benefit of this module is the fast interaction between the user and the device through a local network. The second module relies on an internet connection for global accessibility, regardless of user location, but only functions outside of the home network. In this scenario, the connection request is transmitted to the Microsoft Azure Cloud for processing [39]. Next, the credentials are entered, and synchronized with a Raspberry Pi processing server that is connected to an Azure database for processing. Microsoft Azure Cloud ensures individual account management by utilizing separate databases for each user. Services are provided to individual users after they input their credentials upon making a request. Cloud APIs can be accessed without being connected to the user's home network. However, while connected to their home network, the Raspberry Pi server maintains duplicates of the identical APIs.

During communication between the server and the user, information is transmitted in JSON format. Hashing algorithms are used to secure APIs. The Raspberry Pi general purpose input-output (GPIO) pins [40] are utilized for managing and altering the condition of electronic devices within the system. After receiving a request, Upon the user's request, the Raspberry Pi establishes a connection with the devices. The users' requests are stored in a database on the cloud. Setting a period enables the analysis of all user interactions on their smartphone. The household's sensors synchronize with the server and update their status every thirty seconds. Therefore, the Raspberry Pi updates information from the entire cloud-based database and adjusts the values on the mobile app.

5.1 Hardware Components

The proposed system combines various sensors and electrical parts, as shown in Figure 1. An extensive description of the hardware components of the system is

given in this section. For convenience, a summary of these elements is provided in Table 1.

Components	**Details**
Motor control shield L293D	Range of supply voltage: 4.5–36 V; current output per channel: 600 mA
Temperature sensor DS18B20	Range of temperatures: −55 °C to 125 °C (−67 °F to +257 °F)
The LM393 LDR sensor	outputs for digital switching (0 and 1), external 3.3 V to 5 V VCC
Relays pack	The 8-relay circuit pack run on 5 V.
ARM Cortex A7	Central Processing Unit, quad-core, 900 MHz, operating voltage 7–12 V
MQ2 smoke detector	smoke and combustible gas
Mobile smartphone	compatible with Android
Raspberry Pi 2B	1 GB RAM and 40 GPIO pins

Table 1. Explanation of HomeNetEdge hardware components

A low-cost single-board computer (SBC) with the primary purpose of teaching computer science in schools and underdeveloped nations is the Raspberry Pi. It has one gigabyte of RAM and a quad-core ARM Cortex-A7 CPU that runs at 900 MHz. The Raspberry Pi has 40 GPIO pins, four USB ports, a card interface, and a 100 Mbps Ethernet connection. In addition, it is fully compatible with SD cards and HDMI, making it possible to utilize a camera. It also supports composite video display and has a 3.5 mm audio connector for audio transmission. One electrical component that is used in automatic control system circuits is a relay. The input circuit includes a control system with an input contractor, while the output circuit comprises a controlled system with an output contractor. By using a low-current signal to regulate the high-current circuit, the relay functions as a switch. It is powered by electricity and is employed to regulate how power is distributed within a circuit.

L293D [41] is a single-chip driver with four channels designed for high-current and high-voltage uses. This means that the chip L293D can be utilized to incorporate DC motors with a voltage of up to 16 volts and power sources. for each channel, even accommodating larger motors. The chip circuit is capable of delivering up to 600 mA of current. This component (L293D) contains a series of H-Bridges, circuits that can provide power to a motor, for example, in both directions. With just one cable needed, the DS18B20 temperature sensor interface makes it simple for users to monitor and store temperature data. The bus communication system enables connections for multiple devices, with temperature readings from each device accessible through a single GPIO pin on the Raspberry Pi. Among the MQ2 sensor family, the chemiresistor, often known as the MQ2 sensor, is a frequently used alternative for sensing smoke and various gasses. It detects changes in resistance in its sensing component when it comes into contact with smoke particles. The

amount of smoke concentration might be assessed using a primary voltage divider network. The MQ2 sensor is capable of detecting 200–10 000 parts per million (ppm) of hydrogen gas, propane, alcoholic beverages, carbon elements, carbon monoxide, natural gas, fumes, and liquefied petroleum gas. Powered by a 5V direct current (DC) source, it draws about 800 milliwatts (mW) of electricity.

The dual-mode capability of the GSM module is extensively employed in the Internet of Things (IoT) and the embedded software. This operates between 900 and 1 800 MHz in frequency. The GSM module is renowned for requiring very little power. Fast data transfer is made possible by its multislot class capability, which is similar to that of classes 8 and 10. The voltage range that the TXD and RDX pins operate in is between 3.4 and 4.5 V. This is where they send and receive data. Going beyond this limit could damage the module.

5.2 Software Components

There are numerous platforms for developing mobile apps, including Symbian, Windows Mobile, iOS, and Android. Because of the Android platform's enormous global use and popularity, this project was developed exclusively on it. Practically all smartphone makers back Android apps, which makes it a versatile platform. The Android Software Development Kit (SDK) is used to create and implement the smart home system using the Java programming language. The Android SDK comes with all the necessary tools and materials for creating Android applications. In this project, Android Studio is used to develop Android APKs [42]. The package consists of resources such as libraries, emulators for handsets, and debuggers for testing apps on various handsets without the need to buy them. The project includes the Volley library to facilitate the integration and usage of various sensors by offering simple functions for managing sensor data. Moreover, the Android app achieves an interactive user interface through the use of the Material Design toolkit. LAMP, which stands for Linux, Apache, MySQL, and PHP, is used in this project as a cloud-based backend development platform on the Raspberry Pi system.

5.3 User Interface: Using the Mobile Application

The application includes two separate modules designed to improve user satisfaction. Within the **Admin module,** individuals can easily generate a digital representation of their residence through the use of a simple drag-and-drop system. Every part in the prototype is associated with a particular Raspberry Pi pin, allowing for seamless handling of many electrical gadgets' backends. The users can see the home design of their devices on the screen of the cell phone in admin and user modules. With the aid of Figure 2, users may easily manage and control their technological devices. The primary screen of the app offers users important details about the house, such as floor plans and the list of gadgets that are in place. Accessing different functions is made easier with the use of tabs for navigation.

In the **front-end module,** a user-friendly and visually pleasing design of graphical user interface (GUI) makes user interaction simpler, as demonstrated in Figure 3. Icons that are dynamic change to show the current status of electronic devices in real time. Users can quickly change device settings by using touch buttons that respond effectively. Additionally, a user-friendly intensity bar allows users to easily adjust the speed of the fan and the brightness of the light. Distinctively labeled as "active", devices that are not in use are designated as "inactive."

On the second tab of the app, users can track the temperature and light level and can monitor in real time the data of sensors, as shown in Figure 4. The backend updates these sensor readings every 30 seconds to keep users informed about their surroundings. An example is shown in Figure 5 where the light sensor reads 0.0, signifying that it is in the "OFF" state and sensing daylight. The third tab on the main page offers users in-depth information about the past of their devices. The system keeps a detailed record of user actions, such as modifications in device statuses, along with recorded timestamps. With this notebook, users can keep track of how long electronic devices have been on or off.

The system alerts users if a device has been running for over 2 hours, promoting responsible energy use. This characteristic encourages monitoring of power, regardless of whether people are using the space or whether there is a lot of electricity being used. The devices' usage statistics are shown in Figure 6. Moreover, the cell phone application makes it easier to calculate electricity usage by analyzing the power consumption information of electronic devices and the specific periods.

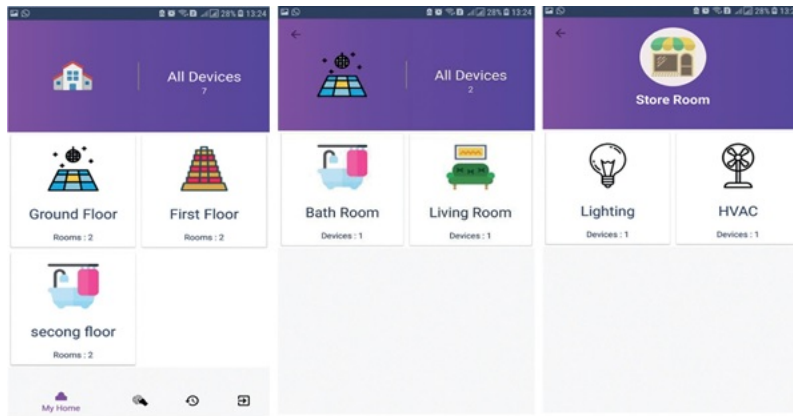


Figure 2. Usage of household electronics

6 EXPERIMENTS AND RESULTS

The proposed structure is divided into a few circumstances. The initial situation caters to users who are away from home and utilize a Microsoft Azure cloud database

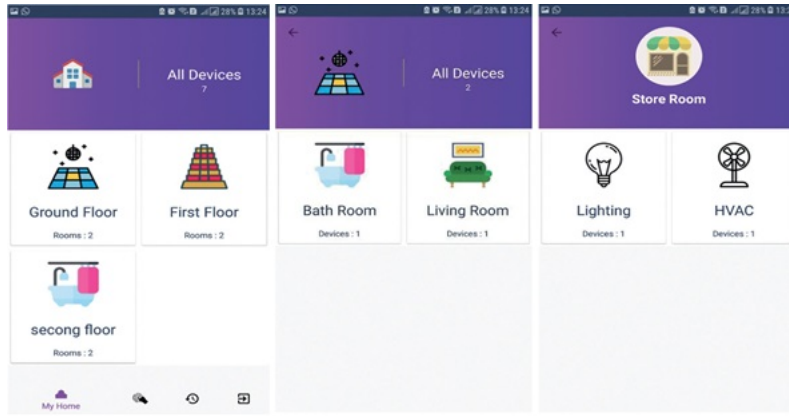


Figure 3. Screen user interface

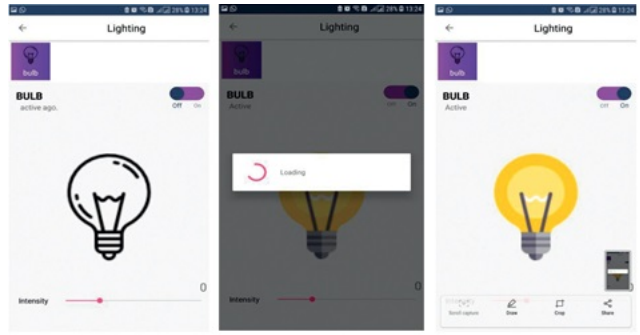


Figure 4. The condition of household appliances

for remote access. The cloud receives the user's request through its APIs. The second situation involves people who are connected to a Raspberry Pi in their homes. The Raspberry Pi is the first device to respond to user inquiries which then routes them to the cloud. Local processing enables faster processing without depending on the cloud.

7 EXPERIMENTAL ANALYSIS

Thorough experiments were conducted using robust classifiers to evaluate the condition of the gadget in automated smart homes. The tests included a variety of classifiers, including GBM, ETC, LR, CNN, RF, LSTM, SVM, and voting classifiers (LR-RF). The data has been recorded and split in a ratio of 70:30 between training and test sets. Every examination is carried out on a Dell server model PE-T430 GPU, matched with two 2.4 GHz Intel Xeon eight-core CPUs and 32 GB of DDR4

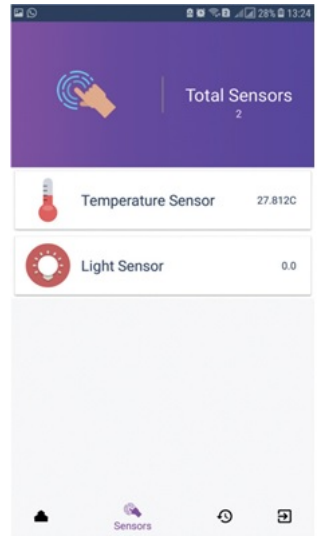


Figure 5. Sensor data

RAM. The research is conducted in the Jupyter Notebook platform with the utilization of Python and Anaconda. The classifiers are developed using TensorFlow, sci-kit-learn, and Keras. Table 2 and Figure 7 display the classifier's predictions for home appliances in the "ON" and "OFF" classes.

Classifiers	**Accuracy**	**Precision**	**Recall**	**F-score**
SVM	93.77 %	90.66 %	91.64 %	91.08 %
RF	97.67 %	96.64 %	98.81 %	97.52 %
LR	94.87 %	90.96 %	91.94 %	91.41 %
SGD	88.77 %	82.04 %	84.42 %	83.06 %
DT	94.07 %	92.36 %	94.51 %	93.61 %
GBM	92.67 %	90.24 %	91.81 %	91.16 %
ETC	94.97 %	90.76 %	91.74 %	91.18 %
LSTM	91.87 %	84.40 %	85.84 %	85.39 %
CNN	92.47 %	86.24 %	88.81 %	87.36 %
Voting Classifier (LR-RF)	97.83 %	98.38 %	98.82 %	98.68 %

Table 2. Experimental evaluation of all learning models

The Voting Classifier (LR-RF) performs the best in all metrics, achieving a 97.83 % accuracy, 98.38 % precision, 98.82 % recall, and 98.68 % F-score. The high values suggest that the Voting Classifier is very efficient in terms of both precision and recall, establishing it as the top model among those assessed. Closely following, the Random Forest (RF) classifier shows outstanding performance with 97.67 % accuracy, 96.64 % precision, 98.81 % recall, and a 97.52 % F-score. RF is

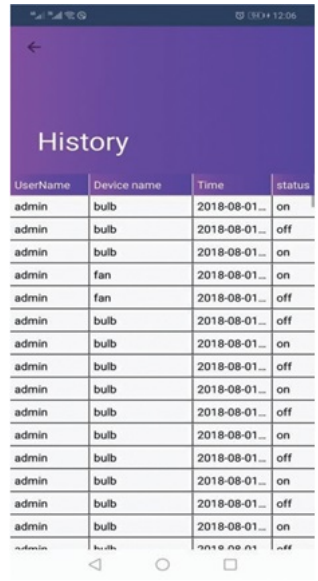


Figure 6. History record



Figure 7. Comparison of all learning models

ranked as the second most successful model, just slightly trailing the Voting Classifier. The Decision Tree (DT) demonstrates strong performance in recall (94.51 %) and F-score (93.61 %), achieving an accuracy of 94.07 % and precision of 92.36 %. Logistic Regression (LR) and Extra Trees Classifier (ETC) achieved similar results, with LR performing at 94.87 % accuracy, and ETC at 94.97 %, alongside F-scores of around 91.41 % and 91.18 % respectively. SVM and GBM classifiers show slightly reduced performances, achieving accuracies of 93.77 % and 92.67 % individually. Both exhibit strong precision and recall, but their F-scores suggest they are less balanced than the top performers. CNN and LSTM models, despite being powerful, display reduced F-scores, recall, accuracy, and precision. when compared to other models, with CNN achieving an accuracy of 92.47 % and LSTM of 91.87 %. The SGD classifier is the least efficient among the models, showing the lowest metrics overall – an accuracy of 88.77 %, precision of 82.04 %, recall of 84.42 %, and an F-score of 83.06 %. The top performer is the Voting Classifier (LR-RF), followed by Random Forest and Decision Tree which also show high effectiveness. SVM, LR, and ETC show strong performance, whereas SGD falls short of every statistic of the other models assessed. The smoothness of ROC-AUC curve shows the smoothness and reliability of the proposed model. The ROC-AUC curve is shown in Figure 8.

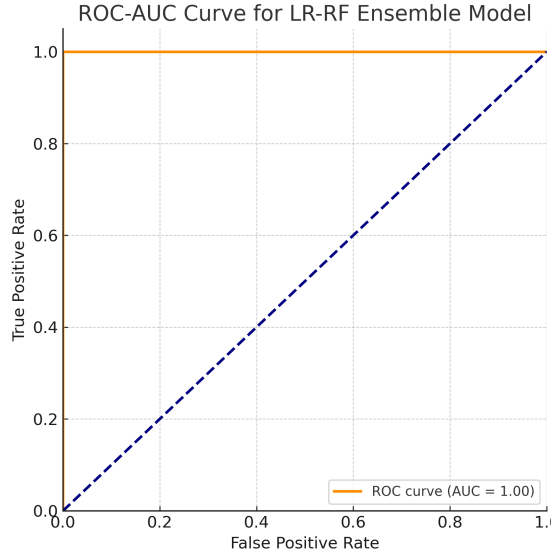


Figure 8. ROC-AUC curve of proposed framework

7.1 Cross-Validation Results for Generalizability

To ensure robustness and generalizability regarding model evaluation, this research applied 5-fold cross-validation on the proposed LR-RF ensemble model. The results, summarized in Table 3, demonstrate consistent performance across folds with minimal variance, confirming the reliability of the model. While cross-validation could be extended to all baseline models, this research focused on the proposed ensemble due to space limitations and to highlight its stability compared to single classifiers. The consistent performance across folds further strengthens the validity of the reported results.

Fold	**Accuracy (%)**	**Precision (%)**	**Recall (%)**	**F1-Score (%)**
Fold 1	97.65	98.21	98.74	98.52
Fold 2	97.92	98.40	98.89	98.69
Fold 3	97.84	98.35	98.81	98.65
Fold 4	97.95	98.43	98.86	98.72
Fold 5	98.00	98.51	98.79	98.83
Mean ± SD	**97.87 ± 0.12**	**98.38 ± 0.11**	**98.82 ± 0.06**	**98.68 ± 0.11**

Table 3. 5-fold cross validation results of proposed LR-RF ensemble model

7.2 Statistical Analysis of Proposed Model

In this subsection, this research have performed a t-test analysis on the results of the proposed LR-RF model with RF model standalone results.

Understanding the Data:

The provided data appears to be accuracy scores for two different machine learning models:

- RF (Random Forest): 97.17 %, 96.64 %, 97.34 %, 97.02 %
- Voting Classifier (LR-RF): 97.83 %, 98.38 %, 98.82 %, 98.68 %

T-Test Analysis:

A t-test is used to compare the means of the two groups. In this case, this research want to determine if there is a statistically significant difference between the mean accuracy of the RF model and the Voting Classifier.

1. **Calculate the mean and standard deviation:**
   - RF: Mean = 97.0425, Standard Deviation = 0.2937
   - Voting Classifier: Mean = 98.4275, Standard Deviation = 0.3543

2. **Perform the t-test:**
   - t-statistic = -5.2213
   - p-value = 0.00197
   - The p-value is less than the significance level (usually 0.05), indicating that there is a statistically significant difference between the mean accuracies of the two models.

T-Test Conclusion:

Based on the t-test analysis, this research can conclude that there is strong evidence to suggest that the Voting Classifier (LR-RF) has a significantly higher mean accuracy than the RF model.

7.3 Electricity Cost Reduction

The HomeNetEdge framework presents an innovative approach to cutting utility expenses in smart home environments by enhancing energy utilization. By employing the HomeNetEdge system, devices that are inadvertently left "ON" during idle times are automatically powered "OFF" with a precision rate of 97.83 %. This framework also facilitates the scheduling of high-energy activities, like using washing machines or dryers, during times when electricity is cheaper, thereby further trimming costs. Another feature of HomeNetEdge is smart lighting management, which leverages motion and daylight sensors to modulate lighting according to occupancy and available natural light, preventing needless energy use. It allows for dimming or turning off lights in empty areas and supports zonal control to further streamline energy consumption. Likewise, HomeNetEdge boosts the efficiency of thermostats and HVAC systems by modifying heating or cooling based on user habits and preferences. The framework identifies devices in standby mode, notifying users or cutting off power to stop unnecessary energy draw. Through these capabilities, HomeNetEdge not only offers economical energy management but also encourages sustainability and improved efficiency in smart homes.

7.4 Relevance to Real-World Scenarios

While initial demonstrations of HomeNetEdge focused on lamp control for proof-of-concept validation, the framework is designed to be scalable across diverse smart home devices and applications. Beyond energy cost reduction and lighting management, the system can be extended to control and optimize HVAC systems, kitchen appliances, and security sensors, thereby covering the full spectrum of household automation. Importantly, the low-latency edge-based inference enables real-time responsiveness, which is critical for assistive technologies supporting elderly or disabled individuals. For example, HomeNetEdge could be integrated with wearable sensors or voice-activated interfaces to automate critical tasks such as fall detection alerts, smart climate adjustment for comfort, or automated control of medical devices in the home. By combining blockchain-secured authentication with lightweight

predictive learning models, the framework ensures both privacy and reliability, making it suitable for large-scale deployment in practical smart home ecosystems. This scalability highlights HomeNetEdge as a practical, real-world solution that extends far beyond narrow use cases and contributes to inclusive, sustainable, and adaptive living environments.

7.5 Comparision with the Other State of the Art System

To assess the importance of the proposed system, It is contrasted with earlier proposed frameworks of home automation systems. A performance comparison involves addressing various significant elements. One of the key factors that affect installation and costs is the specific devices or sensors utilized. Additionally, the proposed system comes with beneficial features such as real-time sensor data, automatic sensor data logging to improve user experience, remote access, and a system recovery mechanism. Table 4 contrasts our proposed system with other automated smart home systems, concentrating on the performance measures that are employed in contrast. Table 4 enumerates all of the features and functions that set our proposed system apart from other systems.

7.6 Limitations of HomeNetEdge

The current implementation of HomeNetEdge, while effective in enabling lightweight edge-based automation, is not without limitations. Potential disruptions may arise due to GSM network outages or limited coverage, which could affect real-time responsiveness. Although Raspberry Pi and Arduino provide cost-effective and accessible hardware, their limited processing capabilities may constrain performance as the system scales to larger deployments. The PCA-based feature selection approach depends heavily on the quality and completeness of the collected data, and inaccuracies in data logging can affect prediction reliability. Blockchain integration, though enhancing security, introduces additional computational overhead and may increase latency in certain scenarios. From a usability perspective, the Android application limits accessibility for users of other mobile platforms. Furthermore, challenges such as language support for voice commands, sensitivity to ambient noise during device interaction, and partial reliance on internet connectivity for updates or external integrations remain open issues. The physical security of edge devices and robustness against advanced cybersecurity threats are also critical concerns. These limitations highlight important directions for refinement, including optimizing hardware utilization, expanding platform support, and reducing dependency on network conditions to ensure resilient, user-friendly, and scalable smart home automation.

8 CONCLUSION

This study provides a detailed summary of an automation project for smart homes and its features. The primary objective is to create a system that is easy to use

Features	[43]	[44]	[45]	[46]	[47]	[48]	[49]	[50]	[51]	[52]	**Home NetEdge**
An app to create a prototype at home	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓
Data logging of device status	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓
Displaying data from sensors in real time	✓	✗	✓	✓	✓	✓	✓	✗	✗	✗	✓
The Raspberry Pi or any microprocessor is used	✗	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓
Internal network in the event that the gateway fails	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✓
Sensors' most recent state of recuperation	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓
Using pulse wave modulation to adjust light and fan intensity	✗	✗	✗	✗	✓	✗	✗	✗	✓	✗	✓
Temperature Regulation	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
Intelligent Lighting Management	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓
Using blockchain security	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓
Predictive model using sensor data and appliance consumption	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓
Using commonplace electrical appliances	✓	✗	✓	✗	✓	✗	✗	✗	✓	✓	✓

Table 4. Comparison with the other state-of-the-art systems

and can be personalized, empowering consumers to make informed choices regarding the condition of their household appliances. HomeNetEdge framework consists of two modules: one for administrators and one for regular users. These modes are created for carrying out particular tasks. The admin mode lets users design their home layout for automation tasks, while the user mode enables the operation of home appliances through a GUI. Users can control the status of individual devices by considering their past usage habits and data. A voting ensemble model that uses logistic regression and random forests to determine whether home appliances are in the "ON" or "OFF" state supports the decision-making process. Moreover, the proposed framework utilizes blockchain technology for validating IoT devices. In the modern world, the significance of smart and adaptable decision-making in home automation cannot be emphasized enough. Risk assessment emphasizes the significance of integrating privacy and security measures into the development of a system for smart homes. This project for home automation provides a solution that is inexpensive, dependable, adaptable, and simple. In the future, deep ensemble learning models will be utilized to enhance the efficiency of the system's decision-making. Two potential areas for further research in the proposed project are: Including edge computing in the smart home system enables analysis of data closer to its origin, decreasing latency and bandwidth usage while enhancing rapid decision-making. Examine how energy use and e-waste from IoT-enabled smart homes affect the environment, and look into environmentally friendly design options

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