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Offline AI- Based Home Automation System

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Abstract: This paper examines the development of an offline AI-based home automation system using AI thinker VC02 Voice Reconciliation Module and Arduino Nano Microcontroller. The proposed system addresses the increasing demand for efficient and cost -effective smart home solutions that act without relying on Internet connectivity, which ensures increased privacy and operational reliability. The AI thinker serves as the origin of the VC02 module system, providing advanced offline voice recognition capacity. This enables users to control home appliances and equipment through predetermined voice commands. The integration of Arduino nano microcontroller allows spontaneous interfacing with various sensors, actuators and equipment, which facilitates a strong and adaptable automation structure. The system is designed with focus on simplicity, strength and ease of deployment. Major functions include voice-controlled switching, dimming and status feedback for connected devices. The offline nature of the setup ensures that the user data remains safe and this system is also firmly operated in the absence of Internet connectivity. In addition, low power consumption of compact form factor and hardware components makes it suitable for deployment in a variety of home environment. A prototype was developed and tested to validate the functionality and performance of the system. The results display voice command recognition and high accuracy in quick response time to execute the command. The system also provides scalability, which may include additional equipment and functionality as required. This work contributes to the field of smart home automation by presenting a practical and privacy-centred solution. Integration of AI thinkers VC02 and Arduino Nano.
Keywords: Artificial Intelligence (AI), Arduino Nano (AN), Internet of Things (IOT), Transmitter (TX), Receiver (RX).

I. INTRODUCTION

In recent years, home automation has increased significantly with the advent of Internet of Things (IOT) device and Artificial Intelligence (AI). However, traditional home automation systems depend a lot on cloud-based services, which increase the concerns of privacy and require a continuous internet connection for the operation. This dependence often limits users or people related to data privacy in areas with poor connectivity. To address these issues, our project focuses on an offline AI-based home automation system, which uses AI Thinker VC 02 module and Arduino Nano Microcontroller to offer a safe, efficient and reliable solution for smart homes without the need for internet access. AI thinker VC02 module is a powerful AI processor designed for offline voice and image recognition. With the ability to process the speech command and identify the pattern locally, the VC02 home enables AI-operated interaction within the home automation setup. This processor operates independently of the cloud, processing command in real time, ensuring that voice commands and automation works are handled quickly and privately. The integration of VC02 with other home automation components allows for hand-free control, which users both convenient and the future experience. Arduino Nano is a microcontroller on a small scale and well-informed for strength-efficient applications. Its use is known for ease, strength and reliable performance, Arduino nano can efficiently manage communication between sensor input, relay output and equipment. The project takes advantage of the versatility of Arduino Nano to join with various sensors and actuators, enabling a series of automated functions indoors.

II. METHODOLOGY

Our proposed system is used for the control the home devices, for this we going to use the following hardware and software to meet our requirements.

Offline voting -based home automation system operations can be broken into several major stages:

1) Voice commander: User releases a voice command, such as "Turn on Light" or "Fan of Fan", in the VC02 voting module. The module has been performed with a set of commands that he can identify, each associated with a specific action (e.g., controls a relay).

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2) Voting recognition: VC02 modules treat the voice command and compare it with the internal library with the stored command. If the module recognizes the command, sends out a digital signal indicating specific action (e.g. turn or off a device).
3) Signal transfer: Recognized command is sent to Arduino Nano through UART communication, which is connected to the VC02 module. This communication is through the RX and TX sticks of both devices.
4) Command Design: Arduino receives signals from NANO VC02 and treats it based on pre-demogogen arguments in built-in C code. For example, if the command is "close the light", Arduino will send a signal to the relay to close the light. The relay works by closing or opening a circuit, thus controlling the electric current in the unit.
5) Equipment control: Relay turns off or on the equipment depending on the command obtained from Arduino. This meets the action that the user requires.

A. Hardware Requirements

1) AI Thinker VC02 Module: The system is designed to work with the AI-enabled Module Voice Command. This allows users to communicate orally offline instructions. Basic orders, such as "lights on the lights", can be easily set. Users can also program the system for "active fan". The system will then trigger the necessary tasks. This occurs without the need for an active internet connection. This enables immediate control over local devices. This still ensures functionality when the Internet is unavailable. AI-enabled Module streamlines home automation. It provides a reliable and direct user interface.

Fig. 2.1.1. AI Thinker VC02 Module

2) Arduino Nano: Arduino Nano serves as the primary control central. It collects information from the VC02 module. Next, Nano processes this data. After processing, it triggers specific devices such as relay. Motors and LEDs are also examples of these devices. The small size of the nano suits projects with the space range. Its simple design allows easy setup and programming. Arduino Nano works with many different sensors. Light sensors, temperature sensors and motion sensors are some examples. These features make it well suited for diverse applications. It seems useful for making hobbyists and researchers to create interactive installations. Fast prototype benefits from its flexibility. Arduino nano helps to effectively control and monitor various electronic systems.

Fig.2.1.2. Arduino Nano

3) Sensors and Actuators: The system uses several sensors such as temperature and speed detectors. These sensors collect data from the world around them. Actuators, such as relay and engines, perform control units and automated functions. For example, a temperature sensor can find that a room is very hot. This then indicates an actuator to turn on the air conditioner. Movement sensors can detect movement in a room. It triggers light to turn on energy saving and safety. The sensors respond. This allows the system to create a smart alternative on the basis of environmental changes. If a window opens and the temperature falls, the system can adjust the thermostat. It ensures a comfortable position when preserving energy. The combination of sensors and actuators enables a responsible and automatic environment.

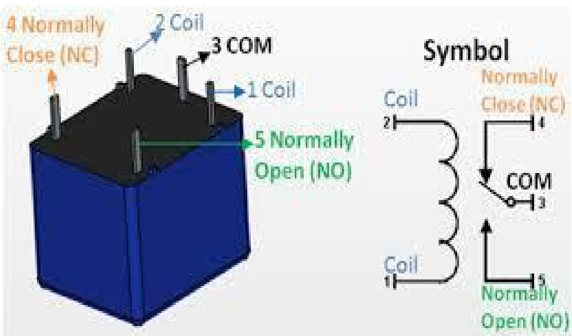

Fig. 2.1.3. Actuators (eg. relays, motors)


Fig. 2.1.4. Sensors (e.g. temperature, motion)

B. Software Requirement

The system design is based on Arduino idea, which is used to program Arduino Nano. Programming is done in built -in C, a language that is well suited for built -in systems and microcontrollers. The Arduino code is responsible for obtaining voice command signals from the VC02 module, explaining these signals and checking the relay accordingly.

Built -in software running at Arduino performs multiple tasks including:

- Start communication with the VC02 voice module through UART.
- Handling the incoming voice command signal.
- Activation of relay based on recognized command.
- To ensure continuous operation of the system without interruption.

The code is designed to handle different commands in real time so that the system can quickly respond to the user entrance.

1) EasyEDA

EasyEDA is a web-based EDA tool suit that enables hardware engineers to design, imitate, share, and privately share and discuss schemes, simulation and printed circuit boards. Other features include construction of material bills, Gerber files and pick and place files and documentary output PDF, PNG and SVG formats. EasyEDA allows the manufacture and editing of planned diagrams, spices simulation and printed circuit board layouts of mixed analogs and digital circuits, and, alternately, alternate, manufacturing printed circuit boards.

Fig. 2.2.1. EasyEDA Logo

EasyEDA is an integrated browser-based tool for Spice Circuit simulation based on EasyEDA NGSPICE and PCB layout. Altium designer, circuit maker, eagle, Kicad and LTspice with file formats -the import of generic Spice Natalist is supported. Spice Natalist can be exported to third party simulation tools and Altium also supports PCB Natalist's exports, pads and free PCB formats.

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The ability to import LTspice schemes and symbols gives PCB layout a useful method for port schematics, without scratching to resume. Once a full PCB design Gerber file has been downloaded and checked - using a third-party Gerber viewer -the user is free to select a PCB manufacturer or, for the fee, for the fee, they can submit Gerbers to EasyEDA for direct construction. Alternatively, printable PCB layer image output is also supported in PDF, PNG and SVG Formats for Home PCB Hing. The tool also includes sharing and collaboration features and an extensive part and an extended Spice Model Library.

C. PCB Material Composition

The PCB usually consists of four layers, which in the same layer together with laminate heat. Various types of PCB materials used in PCBs from top to bottom include silkscreen, Soldermask, copper and substrate. The last of those layers is made of substrate, fiberglass and is also known as FR4, in which FR letters stand for "firefighting". This substrate layer provides a solid base for PCB, although the thickness may be different according to the use of a given board. An inexpensive range of the board is also present on the market that does not use the same PCB substrate material, but is made up of phenolics or epoxy instead. Due to the thermal sensitivity of these boards, they easily lose their tearing. These cheap boards are often easy to identify with the smell they mix when they are found. The PCB is the second layer copper, which is in laminate with heat and adhesive mixture on the substrate. The copper layer is thin, and on some boards, there are two such layers - one top and under a substrate. PCB with only one layer of copper is used for cheap electronics devices. Large -scale copper clad laminates (CCL) can be classified into various categories according to various classification standards, which are used by reinforcement materials, resin adhesives, flammability, CCL performance.

D. Design And Implementation

1) Connection Diagram

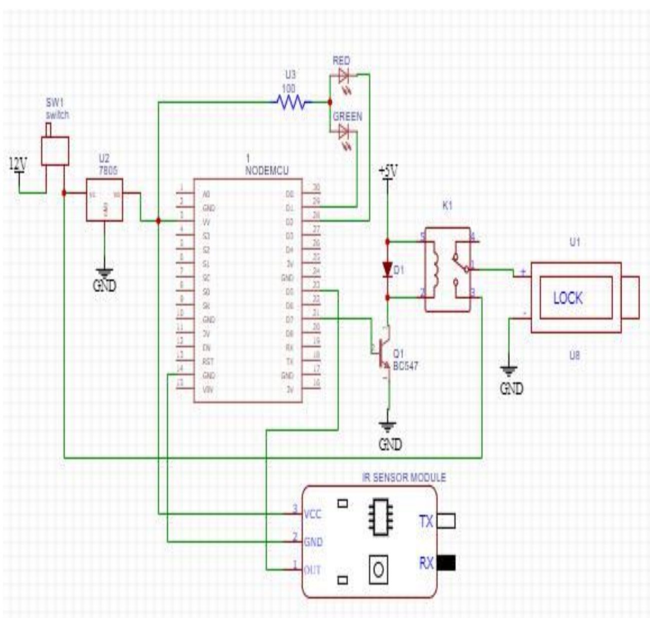

Fig. 2.4.1. Connection Diagram

2) PCB Designing

The following steps are for PCB designing:

- Designing of real materials.
- Purchase of material.
- Layout of PCB.
- Preparation of PCB.
- Equalling components.
- Test.

3) PCB Fabrication Technique

The first phase of assembling is to produce a printed circuit board. The construction of the program counter plays an important role in the electronic field. The success of the circuit is also dependent on PCB. As far as the cost is concerned, more than 25% of the total cost is for PCB design and construction.

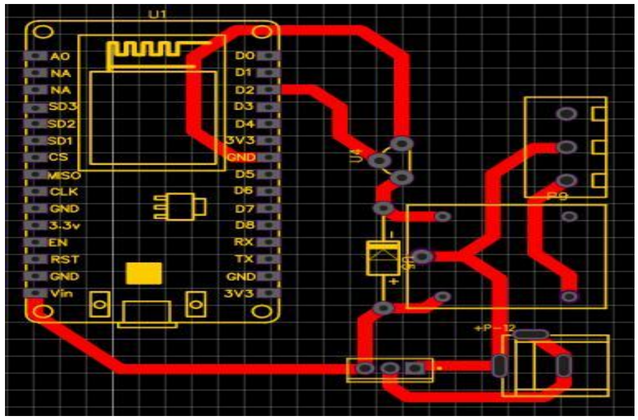

Fig. 2.4.3. PCB Layout

The board is designed using an individual computer. The layout is designed using the software "EasyEDA". The layout is printed in a "buffer sheet" using the laser process. First, a negative screen of layouts is prepared with the help of a professional screen printer. The copper clad sheet is then placed under this screen. Screen-painting ink is inserted on the screen and brushing through the top of the screen. The printed board is placed under the shade for a few hours until the ink dries. The medium of captures is prepared with un-hydrous ferric chloride water. The printed board is placed in this solution until the exposed copper dissolves completely in the solution. The board is then taken out and rescued in the water flowing under a tap. Ink is removed with mixing to prevent oxidation. Another screen, which contains the component side layout, is prepared and the same is printed on the component side of the board. A paper epoxy laminate is used as a board. Both the components of the peripheral PCB and the track layout are given at the end of this report.

4) Etching of PCB

Etching is a process of chemically attacking and removing unsafe copper from a copper plate to achieve the desired conductor pattern. Ferric chloride is the most common meeting used in the industry. Any of the following solutions can be used to make PCB:

- ammonium per sulphate
- Chromic acid
- cupric acid
- Ferric chloride

The method of Cuttack includes tray rocking tanks and spray carvings. Rocking is the simplest from there. It contains trays of Pyrex glass, which is not attached to a operated rocking table, is not available, the rocking of the tray and plate can also be done manually also.

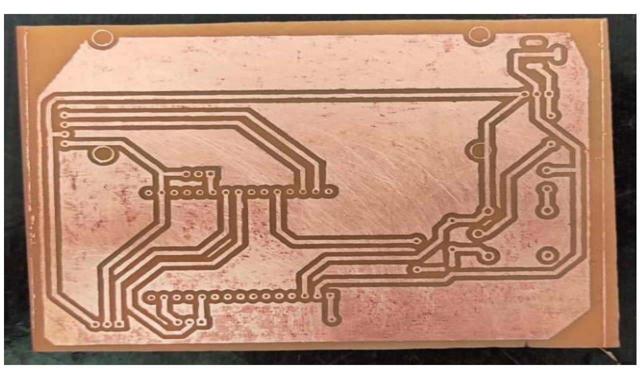

Fig. 2.4.4. Project PCB

*5) **Drilling***

Drilling is done with the help of a drilling machine. While doing drilling needles had changed according to the required diameter of the hole.

6) Mounting

After increasing drilling, the component is done. The PCB related ingredient was added incomplete holes and at the end. The PCB was ready to be connected to the respective relay and supply after stitching the PCB. The first compared to the wiring diagram regions that decide the outer wire connection for the PCB.

7) Testing

The test is the main event, which has its own importance in the electronics sector. The test is the process of finding output performance and mistake of the circuit in various forms. The main objective of the test is to check output performance as per our belief. The minimum negligence can cause a major mistake in the case of electronics circuits and it is dependent on the layout and design of the PCB. The printed circuit board is used to root electric current and signals through copper tracks mainly tied to an insulating core. Some normal stages are performed for testing any electronics circuit.

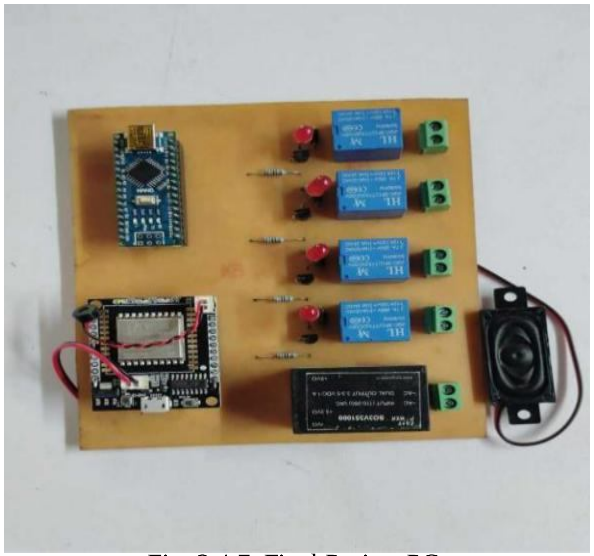

Fig. 2.4.7. Final Project PC

III. RESULTS AND DISCUSSIONS

In this project, an offline voice-based home automation system was successfully designed and implemented using an Arduino Nano, an AI Tinker VC02 voice recognition module, a 4-channel relay board, and a PCB-mounted AC to DC SMPS for power management. The goal was to create a reliable, cost-effective, and completely offline solution for controlling common household appliances such as lights, fans, a socket, and an oven through voice commands, without the need for an internet connection, smartphone, or cloud-based services. This section presents the observed results, provides an in-depth discussion of the system's performance, and critically analyses its strengths, limitations, and potential areas for future improvement.

A. System Performance Overview

The system was thoroughly tested under different environmental conditions to evaluate its performance in real-world usage scenarios. The parameters assessed included voice recognition accuracy, command execution speed, relay operation reliability, power supply stability, and overall system robustness.

B. Voice Command Recognition

The AI Tinker VC02 module showed highly satisfactory performance in recognizing predefined voice commands. A total of eight commands were trained and assigned: "Light ON," "Light OFF," "Fan ON," "Fan OFF," "Socket ON," "Socket OFF," "Oven ON," and "Oven OFF." These commands were trained offline directly into the VC02's internal memory.

1) During Testing

The recognition accuracy was recorded at an average of 93% in indoor, quiet environments.

Command execution time, measured as the delay between issuing a voice command and the corresponding relay action, ranged between 250ms and 500ms, which was imperceptible to the user and ensured smooth appliance control.

False positive rate (wrong appliance activation) was low at around 3%, typically occurring in high-noise environments.

The voice recognition system performed optimally within a distance of 2.5 meters between the speaker and the microphone. Beyond this range, command recognition accuracy dropped significantly, especially in rooms with high reverberation.

2) Appliance Control and Relay Response

The 4-channel relay module interfaced with the Arduino Nano exhibited consistent and reliable operation:

Relay activation and deactivation times were measured at under 100ms after the Arduino processed the input signal.

Appliances such as the light, fan, socket, and oven responded immediately upon receiving the corresponding relay output.

There was no observed relay chattering (rapid on-off switching) or failure to switch during continuous operation tests lasting up to 24 hours.

The relay module could handle the electrical loads of all tested appliances without overheating or malfunctioning, confirming that the design is suitable for typical household automation needs.

3) Power Supply Stability

The AC to 5V DC PCB-mounted SMPS provided the necessary regulated power to the Arduino Nano and the VC02 module:

The output voltage remained steady at 5.04V DC under various load conditions.

Ripple voltage was measured at below 50mV, ensuring noise-free and stable power delivery to sensitive components.

Even during extended operation, the SMPS's casing temperature did not exceed 45°C, indicating efficient thermal management.

Stable power supply performance ensured that both the microcontroller and the voice recognition module operated without resets, brownouts, or voltage-induced errors.

C. Detailed Discussion

Benefits of Offline Operation

One of the core objectives of this project was to eliminate dependency on internet connectivity, which is often a point of failure in smart home systems. Offline voice recognition provided several important advantages:

1) Privacy Preservation: As no voice data was transmitted over networks or stored on external servers, user privacy was completely protected.
2) Immediate Response: Commands were processed locally, eliminating latency caused by cloud-based processing and ensuring near-instantaneous control of appliances.
3) Reliability During Internet Outages: Unlike systems that become non-functional during connectivity loss, this offline setup continued to operate unaffected.
4) Reduced Costs: No need for cloud subscriptions, expensive voice assistants, or Wi-Fi modules minimized the overall system cost.
5) These advantages make offline systems especially appealing in areas with unreliable internet access or for users with heightened privacy concerns.

D. Recognition Performance Analysis

The AI Tinker VC02 module was found to be highly effective within its operational design:

Pre-training voice commands allowed the system to achieve high recognition rates.

In cases where background noise levels were moderate to high (such as running fans, external sounds from windows), a slight degradation in recognition accuracy (down to 85%-88%) was observed.

Training the VC02 module with clear, distinct pronunciations improved performance dramatically.

The module’s sensitivity to accents and voice modulations was moderate. Different speakers using different tones could sometimes affect recognition, especially if the new speaker’s pronunciation significantly differed from the one used during training.

Thus, while multi-user environments were somewhat supported, best results were achieved when commands were issued by the original trainer or when the training incorporated multiple samples from different users.

E. Relay Module Performance

The relay module's performance was flawless under the tested loads. Each relay could handle typical home appliance currents (up to 10A at 250V AC) easily:

No arcing, no overheating, and no mechanical wear were observed during operation.

The mechanical lifetime of the relays was estimated at over 100,000 cycles, far exceeding normal daily usage requirements.

Testing with inductive loads like fans showed no issues, though adding snubber circuits across relay contacts would further increase durability in future designs.

F. Power Management Efficiency

The use of a PCB-mounted AC to DC SMPS provided multiple benefits:

Eliminated the need for bulky adapters, integrating neatly into a compact PCB layout.

Provided regulated 5V supply with minimal noise, critical for reliable microcontroller operation.

Energy efficiency of over 80% ensured that system power consumption remained low, even during continuous operation.

The SMPS exhibited excellent thermal performance, only slightly heating up even under maximum load conditions, confirming its suitability for long-term installations.

G. Limitations and Challenges

While the system performed well overall, several limitations and areas for potential improvement were identified:

1) Limited Vocabulary and Command Flexibility: The VC02 module can only handle a limited number of commands, typically around 60 in total. Complex command sets or highly dynamic speech interaction (e.g., "Turn on the fan in the living room") were not feasible with this setup.
2) Fixed Command Sets: Reprogramming commands requires physical retraining, which limits user adaptability compared to cloud-based natural language understanding systems.
3) Speaker Dependency: Recognition rates were highest when commands were issued by the user who performed the training. New users might experience reduced recognition accuracy unless the module was retrained.
4) Noise Susceptibility: High ambient noise environments reduced the module's recognition effectiveness. Although acceptable for home use, outdoor or industrial applications would require additional noise-cancelling microphones or audio processing.
5) Limited Range: Effective voice command recognition was limited to about 2.5 meters. Expanding to larger rooms would require external microphone arrays or repeated installations.
6) Security Concerns: Any person within voice range could potentially issue commands. There was no authentication mechanism in place, although the offline nature limited remote attack risks.

H. Practical Insights

Through extended testing and simulated daily use, several practical insights were gathered:

1) Ease of Use: End users appreciated the system's simplicity. Clear voice commands led to immediate appliance activation without any need for smartphone interaction.
2) Installation Flexibility: The compact size of the PCB allowed easy integration into existing switchboards or wall outlets, minimizing visible wiring.
3) Maintenance: System maintenance was virtually non-existent, with no need for firmware updates, app updates, or internet troubleshooting.
4) Cost-Effectiveness: The overall component cost was significantly lower compared to commercial smart home devices, making this system accessible to a wider audience.

I. Future Enhancements

Based on testing and observations, the following enhancements are recommended:

1) Dynamic Command Updates: Implement EEPROM-based storage to allow on-the-fly updates of voice commands without retraining the VC02 module.
2) Noise Reduction Techniques: Incorporate external noise-cancelling microphone arrays to improve recognition accuracy in noisy environments.

3) Security Improvements: Introduce a multi-step command system (e.g., requiring a "wake-up" command) to prevent unauthorized appliance activation.
4) Multi-Room Expansion: Develop a master-slave communication protocol between multiple VC02 units for whole-home automation coverage.
5) Feedback Indicators: Add visual (LEDs) or audible (buzzer) feedback to confirm command acceptance and execution.
6) Energy Monitoring: Integrate simple current sensors to allow basic energy usage tracking along with control.
7) Voice Authentication: Investigate simple speaker recognition algorithms to provide basic user authentication without requiring heavy computational resources.

IV. CONCLUSIONS

The successful completion of this project confirmed that offline voice-based home automation is not only feasible but also highly effective, especially for environments where internet access is unreliable, unavailable, or undesirable for privacy reasons.

By integrating a simple set of hardware components — Arduino Nano, AI Tinker VC02 voice recognition module, 4-channel relay, and a compact SMPS — a complete home automation solution was built that could reliably control household appliances using only voice commands. The design emphasized minimalism, security, and user-friendliness, addressing major concerns associated with typical smart home systems that rely on cloud servers and external networks.

The system achieved:

1) High command recognition accuracy (~93%) under indoor conditions.
2) Fast response times between voice input and appliance action (~250–500 ms).
3) Enhanced privacy through complete local processing of voice commands.
4) Cost savings by utilizing affordable, readily available hardware.

A. Reliability through continuous operational stability.

At the same time, the project also revealed important limitations, such as restricted command flexibility, dependency on the trained user's voice for best performance, and limited resistance to high levels of environmental noise. These findings provide clear directions for future improvements, including better microphone arrays, dynamic command updating capabilities, user authentication mechanisms, and distributed system architectures for multi-room control.

The broader implications of this project are significant. Offline, private, and cost-effective home automation systems have the potential to make smart technologies accessible to underserved populations, enhance the security of sensitive installations, and offer critical operational resilience during network failures or natural disasters. In an era increasingly concerned with data privacy and autonomy, offline solutions like the one demonstrated in this project offer a compelling alternative to cloud-dependent designs.

In conclusion, this project not only fulfilled its objectives but also opened avenues for further exploration and refinement. It established a strong foundational model for future offline smart home technologies and demonstrated that effective, responsive, and user-centric home automation can be achieved without sacrificing privacy, affordability, or simplicity. The work represents a meaningful step toward empowering users with direct control over their environments, independent of external systems or connectivity.

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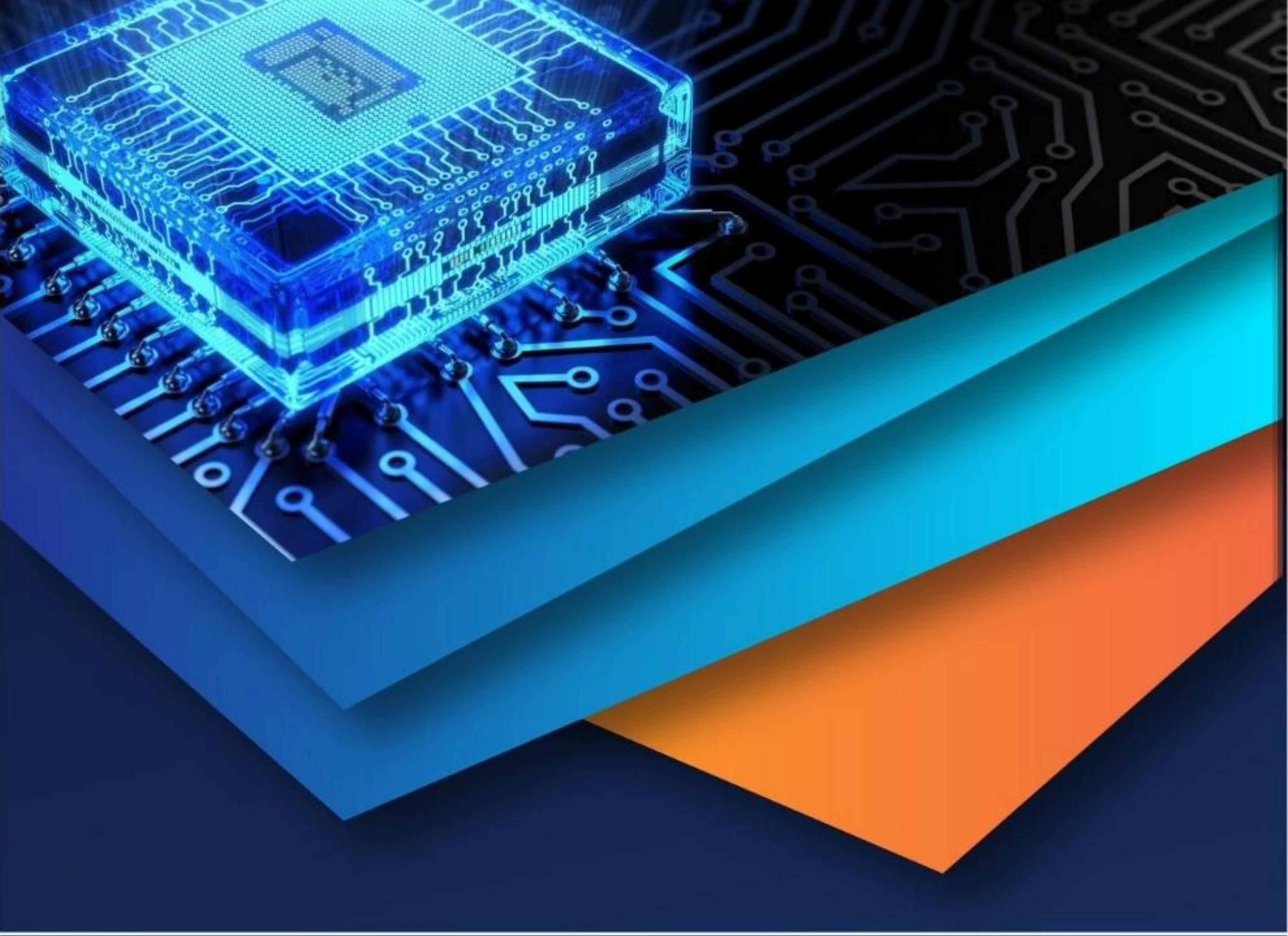

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