Climatrix: An IR-Based Embedded System for Smart Temperature–Controlled AC Automation

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Abstract. In the era of smart technology, energy efficiency and user comfort have become crucial in the domain of home and industrial automation. This project, titled "CLIMATRIX - A Smart IR-Based Universal AC Control System," presents an innovative solution that automates the operation of air conditioners (ACs) based on real-time temperature monitoring. CLIMATRIX uses a combination of sensors, infrared (IR) transmission, and embedded control logic to intelligently control AC power, fan speed, temperature, swing, and mode, minimizing manual intervention while optimizing energy consumption. The system continuously reads the ambient temperature through a DS18B20 digital sensor and compares it with a predefined setpoint. Based on this comparison, it generates appropriate IR signals to control various AC brands, functioning as a universal remote. The IR codes for different functions are brand-specific and are handled through software libraries, ensuring compatibility with popular models like LG, Samsung, Panasonic, and Mitsubishi.
The prototype was initially implemented using a 5V DC fan as a substitute for an actual AC unit, allowing the team to validate core functionalities such as IR signal transmission, temperature-based control logic, and feedback indication through LEDs. The final design is scalable and can transition seamlessly to control real AC units in household or industrial settings. CLIMATRIX bridges the gap between traditional remote-based control and modern smart automation by offering a low-cost, customizable, and efficient AC management system. This project showcases practical applications in embedded systems, IoT, and energy-conscious automation, offering significant potential for further development and real-world deployment.

Keywords: Smart Automation, Infrared Control, Energy Efficiency, Temperature Monitoring

1 Introduction

In today's rapidly evolving world, the demand for comfort, convenience, and energy efficiency in indoor environments has never been higher. Air conditioners (ACs) are an essential part of residential, commercial, and industrial buildings, especially in regions with warm climates. However, despite the wide adoption of AC systems, many conventional models still operate manually or with limited automation. These outdated systems are not energy-efficient and often require constant user interaction to maintain desired temperature conditions. In sensitive environments such as medicine storage rooms, laboratories, or server rooms, a lack of precise temperature control can lead to significant losses, including the degradation of pharmaceuticals or the malfunctioning of electronic equipment.

As the Internet of Things (IoT) gains traction, smart home technologies have introduced automated AC solutions. However, these systems are often expensive, brand-specific, dependent on cloud services or Wi-Fi connectivity, and not user-friendly for people who are unfamiliar with advanced technology. This poses a challenge to achieving widespread adoption of intelligent climate control in cost-sensitive or infrastructure-limited environments.

The CLIMATRIX project was conceptualized to bridge this technological and affordability gap. By leveraging the capabilities of the ESP32 microcontroller and integrating it with a temperature sensor, IR transmitter, and local control interface, CLIMATRIX aims to deliver a smart, universal, and standalone AC controller that ensures both user convenience and operational efficiency.

Fans are widely used in areas with moderate temperatures. Although the idea of Smart Homes has existed for decades, it has only recently started gaining global popularity [1]. One issue with traditional fans is that while their speed can be adjusted, it must be done manually. This means users have to physically walk to the fan and press a button to change its speed. Another common problem is that many users forget to switch the fan off after using it. They often leave the room without realizing it's still running, which leads to higher electricity bills and results in 5–10% of energy being wasted [2]. In some cases, leaving a fan on for too long can even pose a fire risk. Since the motor generates heat during extended use and the fan body is typically made of plastic, overheating can cause it to catch fire easily. Using a remote-controlled system offers a safer and more convenient solution, as it allows users to operate the fan without direct contact [5] [7]. To make any household appliance smart, a controller is required to act as its central processing unit or "brain" [2]. In this system, microcontrollers serve as the control unit, and Arduino is considered one of the most suitable and cost-effective options for prototype development [3]. Smart appliances not only enhance user comfort but can also provide valuable support to the elderly and people with disabilities [4]. Energy wastage is a major contributor to environmental problems, accounting for about 25% of the factors causing the greenhouse effect [5]. To gain a better understanding of sensor technology, studies were conducted on the DHT22 and HC-SR04 modules.

When it comes to motion sensing, two types of sensors are commonly used. The first is the Passive Infrared (PIR) sensor, which detects movement by sensing changes in infrared radiation caused by objects passing through its detection zone. The second is the ultrasonic sensor, which emits high-frequency sound waves and measures the time it takes for the waves to reflect back from an object, such as a person or a wall, to calculate the distance. The main distinction between the two lies in how they detect presence. A PIR sensor only responds to motion, so if a person enters its field of view, it detects the movement. However, if the person remains still or falls asleep, the sensor no longer detects any activity and may assume the area is empty, causing connected devices like fans to turn off [7] [9] [10]. The ultrasonic sensor continuously measures distance, so it can detect the presence of a stationary object. This makes it more reliable in scenarios where constant presence needs to be monitored, even without movement. The ESP8266 NodeMCU was selected as the main controller for the system. Initially, two microcontrollers were considered: the Arduino UNO and the ESP8266. One of the key differences is that the Arduino UNO lacks built-in Wi-Fi functionality [6]and is almost twice the size of the ESP8266. The compact size of the NodeMCU made it the preferred choice, as it needed to fit within the limited space inside the fan's casing. Additionally, its smaller circuitry helps reduce power consumption. Wi-Fi connectivity was not essential for this phase of the project; future enhancements are planned to integrate Internet access. One minor drawback of the NodeMCU is that it uses a micro USB port to upload code, which is slightly less durable compared to the Arduino UNO's more robust Type-B USB port.

2 Problem Statement

The key problem identified is the lack of affordable, brand-independent, and easy-to-use AC automation systems. Traditional air conditioners require users to adjust settings manually, which is not only inconvenient but also leads to significant energy waste. Furthermore, users may forget to turn the AC off when it's not needed or leave it running under inappropriate temperature conditions, resulting in high electricity bills and reduced device lifespan. Existing smart solutions are not always feasible for the average user due to their high cost, dependence on internet connectivity, complex installation procedures, or compatibility limitations. This gap creates a pressing need for a device that can intelligently control air conditioners without relying on external networks or third-party ecosystems.

3 Methodology

System Design

This section offers a detailed overview of the CLIMATRIX system design, emphasizing the hardware architecture, IR signal processing, user interface layout, as well as testing and troubleshooting procedures. All elements are carefully integrated to enable smooth and automated control of air conditioners using live temperature readings. The system analysis phase provided a strong foundation for developing a smart, intuitive, and versatile AC control solution. The design was centered on automation, multi-brand compatibility, ease of use, and cost-effectiveness. The integration of the ESP32 microcontroller, DS18B20 temperature sensor, and IR transmitter enabled intelligent control functionality, with the overall system architecture with PCB design illustrated in Fig. 1. Feedback from users was instrumental in refining the system, supporting the use of rapid prototyping. As a result, CLIMATRIX effectively addresses both functional and non-functional requirements, making it well-suited for modern, temperature-responsive applications.

Hardware Architecture

The hardware architecture of the CLIMATRIX device is designed to ensure efficient and accurate control of the air conditioning unit. The core components of the hardware architecture include the ESP32 microcontroller, DS18B20 temperature sensor, LCD, IR LED, mechanical potentiometer for setpoint adjustment and LEDs for status indication. The technologies selected for CLIMATRIX were chosen based on their availability, performance, and suitability for offline automation:

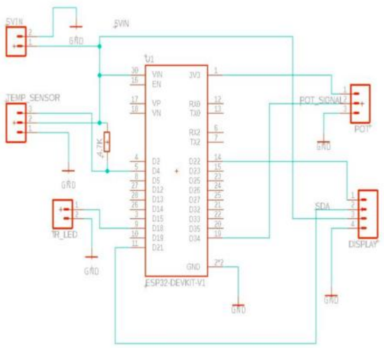


Fig. 1. Schematic of Climatrix Device

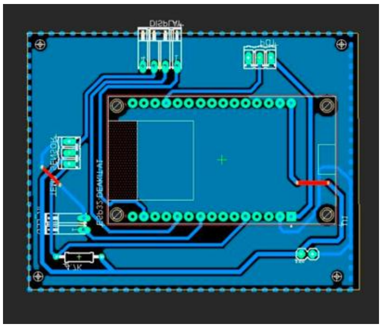


Fig. 2. PCB Design of Climatrix

The first step in preparing this circuit was to create the circuit using Proteus software. It is shown in the attached Fig. 1. The circuit was then converted to a PCB layout shown in Fig. 2. The PCB is printed and then the component is mounted. The components are listed below in Table 1. The output control circuit in this system controls all the electronic components. This process captures all the data captured by the sensors and provides outputs relevant to the conditions. Generally, two basic signal systems are used for analog and digital signal transmission in the electronic control circuit. Although it is somewhat difficult to control with analog signals, the accuracy of the analog signal system is more reliable than the digital signal-based control. So, for this system, an analog signal-based control system is used and the circuit is constructed using only a few simple electronic components.

Table 4. Components with Specification

Component	Specification/Function
ESP 32	Core microcontroller with Wi-Fi & Bluetooth capabilities (optional for future upgrades)
DS18B20 Sensor	Digital temperature sensor with ±0.5°C accuracy
IR Transmitter	Sends AC commands via encoded infrared pulses
LCD Display	Displays current and setpoint temperature
Potentiometer	Mechanical counter for adjusting target temperature
LED Indicators	Visual feedback for system states (ON/OFF)
Power Supply	5V regulated via USB or adapter

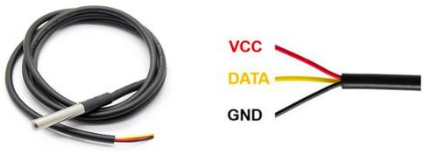
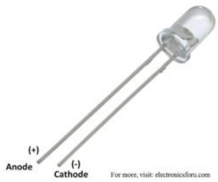


Fig. 3. ESP32 Microcontroller.

Fig. 4. DS18B20 Temperature Sensor

ESP32 in Fig. 3 is chosen for its processing power, Wi-Fi capabilities (for future expansions), and versatile I/O ports. It serves as the central unit that processes the temperature data, makes decisions based on the user's setpoint, and controls the AC through IR signals. DS18B20 is a digital temperature sensor with excellent accuracy and reliability shown in Fig. 4. It is used to continuously measure the ambient temperature in the room. The sensor communicates with the ESP32 using the One Wire protocol, providing temperature readings that are processed in real-time.



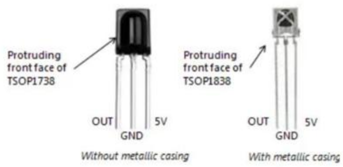


Fig. 5. 16*2 LCD Display.

Fig. 6. IR LED

Fig. 7. IR Receiver

16x2 LCD shown in Fig. 5 with an I2C interface is a crucial user interface component in the Climatrix system, enabling clear and real-time visualization of key operational data. It can display two lines of 16 characters each, which is ideal for showing room temperature, setpoint values, system status, and IR signal feedback. The I2C (Inter-Integrated Circuit) module significantly simplifies wiring by reducing the number of control pins from 12 to just two (SDA and SCL), freeing up valuable I/O pins on the microcontroller. This serial communication protocol enhances scalability and allows multiple devices to communicate over the same bus. The backlit display ensures visibility in various lighting conditions, while the compact design integrates seamlessly into the enclosure. Overall, this display improves usability by providing immediate, readable feedback, making the system more intuitive for users.IR LED is used to send infrared signals to the AC units shown in Fig. 6, Fig. 7, and Fig. 8. The ESP32 controls this LED to transmit commands like power on/off, temperature adjustments, fan speed control, and mode selection. The IR receiver is used to capture signals for testing and validation of commands.

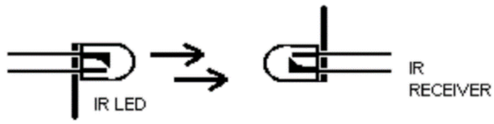


Fig. 8. IR LED transmits the signal and the IR LED receives the signal

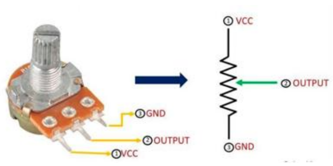


Fig. 9. Mechanical Potentiometer pinout.

Fig.10. LED Indicators

A potentiometer shown in Fig. 9 is used for adjusting the temperature setpoint. It acts as an analog interface, allowing the user to manually set the desired temperature. LED indicators shown in Fig. 10 play a crucial role in providing real-time visual feedback to users and improving the overall interactivity and usability of the Climatrix system. In this project, multiple LEDs are used for different purposes: a general-purpose signal LED and three separate LEDs to indicate the current fan speed (LOW, MEDIUM, HIGH). The signal LED briefly lights up whenever an IR signal is received, confirming communication between the transmitter and receiver. The speed indicator LEDs help the user understand the fan's operational status at a glance, lighting up according to the IR command interpreted by the system. This immediate visual confirmation ensures better monitoring and simplifies troubleshooting during testing. Their low power consumption, high visibility, and simplicity make LEDs ideal for status indication in embedded control systems like Climatrix.

User Interface Design

The user interface (UI) of the CLIMATRIX system is designed for simplicity and ease of use. The physical interface consists of a mechanical potentiometer for temperature setpoint adjustment, and the digital interface consists of the LCD and status LEDs. The potentiometer allows users to manually set the desired temperature shown in Fig. 11. It is connected to an analog pin on the ESP32, and its position is read to adjust the setpoint accordingly. This provides a tactile interface that is easy to use and adjust. The LCD continuously shows the current temperature, setpoint, and system status. It is an intuitive way for the user to understand how the system is performing at any given time. The display updates in real time, providing immediate feedback shown in Fig. 12.

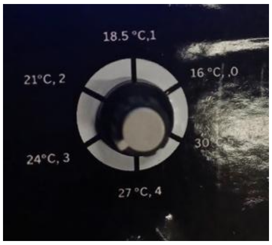


Fig. 11. Potentiometer

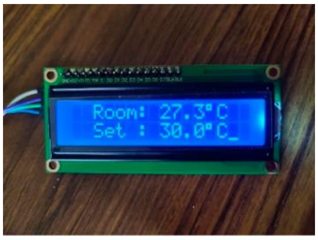


Fig. 12. LCD Display for Feedback

The green and red LEDs provide visual cues about the system's current state. This simple yet effective feedback mechanism ensures that users can quickly understand whether the AC is cooling or in standby mode.

4 Testing and Results

Testing and debugging are critical steps in ensuring that the CLIMATRIX device functions reliably and as expected. The system undergoes rigorous testing at each stage of development.

a. Unit testing

Each component (e.g., temperature sensor, IR LED, display) is tested individually to ensure it functions properly. This helps to identify and resolve any issues early in the development process.

b. System Integration Testing

Table 2. Temperature VS. Time variation according to the Climatrix device AC control.

Time (a.m.)	Temperature (C^o)
9.00	30
9.05	27.5
9.07	25.5
9.10	23.8
9.13	23
9.17	23.4
9.20	22.9
9.23	23.6
9.25	23
9.29	23.5
9.32	22.9
9.36	23.6
9.38	23
9.42	23.5
9.44	23
9.48	23.6
9.51	23
9.55	23.5
9.57	22.8
10.01	23.6

Once all components are integrated, the entire system is tested to verify that the hardware and software interact as expected. The testing includes checking the temperature reading accuracy, the response to setpoint changes, and the correct transmission of the IR signal. When the device is checked for a 24,000 BTU/h AC in a 10 m × 8 m room with an input power of 2.3 kW was evaluated under manual control versus automation based on CLIMATRIX. In the manual scenario, the AC consumed 18.4 kWh and ran continuously for the entire 8 hours. Under CLIMATRIX control with a hysteresis band (23.0–23.5 °C) ±0.3°C accuracy, the AC operated for only about 65% of the time (approximately 5.2 hours out of 8) and consumed 11.96 kWh. The total consumption was 11.97 kWh, which included the ~0.0072 kWh overhead of the CLIMATRIX device. Below Table 2 shows the change in temperature over a 1-hour period, and Fig. 13 presents the corresponding graph plotted using the values from Table 2. Compared to manual operation, this represented a savings of 6.44 kWh, or almost 35%. These findings demonstrated that CLIMATRIX significantly reduced unnecessary runtime while consuming less than 1 W of device power.

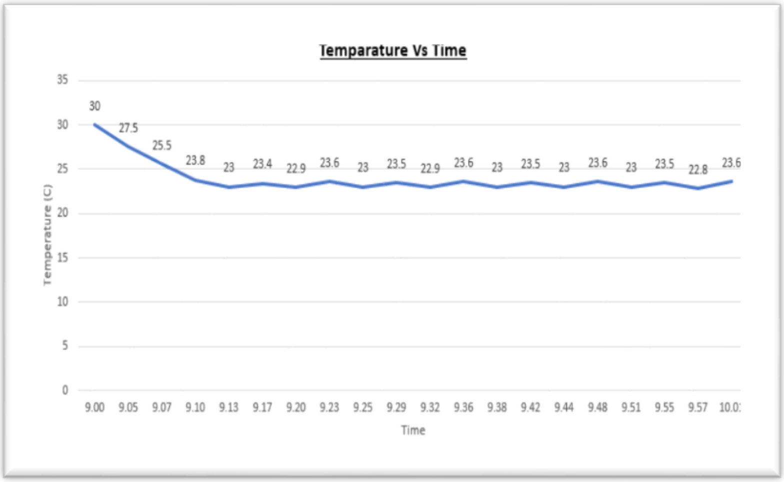


Fig.13. Temperature vs. Time Graph according to the Climatrix device AC control

Energy of the AC in Manual mode	= 2.3kW*8h
	=18.4kWh

When the AC was used with the CLIMATRIX device, it switched off when the temperature fell below the threshold level, and it started operating again when the temperature rose above the threshold level.

Energy of the AC after control with Climatrix device	= 2.3kW*5.2h
	= 11.96kWh
Over head of the Climatrix device	= 0.0009kW*8h
	= 0.0072kWh
Total power in Climatrix	= 11.97 kWh
Energy Saved	= 18.4kWh - 11.97kWh
	= 6.43kWh

Percentage Saved (%)	=	(6.44/18.4) *100%
	=	<u>35%</u>

System latency was evaluated by recording the instant the DS18B20 sensor detected the room temperature rising above the upper threshold (23.5 °C). The AC was configured with a setpoint of 23 °C, and the time taken for it to change states was measured using an indicator LED. The average delay over 25 iterations was 1 s ± 0.3 s, indicating that CLIMATRIX responded quickly and reliably.

To assess communication robustness, a total of 50 IR commands were transmitted from CLIMATRIX to the AC at 1 m, 3 m, and 5 m in both line-of-sight (LOS) and angled conditions. Command reception was verified through AC responses. Reliable operation was confirmed, with success rates of 100% at 1 m LOS, 97% at 3 m LOS, and 90% at 5 m LOS. Performance consistently exceeded 90%, though it declined slightly under occlusion.

A total of 25 IR commands were transmitted from CLIMATRIX to the AC, and within a range of 3 m and up to an angle of 40 degrees, all commands were transmitted successfully.

c. Remote Dashboard Interface

CLIMATRIX leverages ThingSpeak for cloud-based monitoring and control, shown in Fig. 14 and Fig. 15. The ESP32 transmits temperature data to ThingSpeak's servers using a dedicated API key, where it's visualized on a custom dashboard featuring real-time graphs and historical analysis. This integration enables remote system monitoring and control via both web and mobile interfaces, transforming the device into a complete IoT climate solution with secure, accessible functionality from anywhere with internet connectivity.

Fig.14. Remote Dashboard Interface

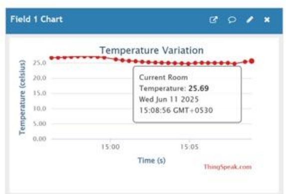


Fig.15. Temperature Variation

The CLIMATRIX system underwent rigorous testing to assess its performance in automating air conditioner (AC) control through real-time temperature monitoring. The results highlighted the system's effectiveness in meeting its primary goals of energy efficiency, enhanced user comfort, and broad device compatibility. The views of the Climatrix device are shown in Fig. 16.

Fig.16. Side View of the Climatrix Device

The DS18B20 temperature sensor provided accurate and consistent ambient temperature readings with a precision of ±0.5°C, making it ideal for environments that demand strict temperature regulation, such as medical storage and server rooms.

The system successfully transmitted IR signals to manage various AC functions, power, temperature settings, fan speed, and operational modes, and demonstrated compatibility with several leading AC brands, such as LG, Samsung, Panasonic, and Mitsubishi, confirming its universal control capability, as shown in Fig. 17. The ESP32 microcontroller efficiently processed temperature data and executed control logic to automatically adjust AC settings in response to setpoints, reducing the need for manual input and improving energy efficiency. The 16x2 LCD provided real-time feedback on current and target temperatures, while LED indicators and a potentiometer offered intuitive user interaction and visibility of system status, as shown in Fig. 18. Integration testing with a 5V DC fan used as a stand-in for an actual AC unit validated the system's operation in a test environment.

Fig. 17. Selecting the Brand Name

Fig. 18. Real-time feedback

The user manual for the CLIMATRIX system is shown in Fig. 19 and Fig. 20. A user manual is essential as it provides clear instructions on how to operate, maintain, and troubleshoot the system effectively. It helps users understand the key features and functionalities, ensuring they can make the most of the system while minimizing errors. A well-written manual enhances user experience and reduces the need for customer support.

Fig. 19. User Manual

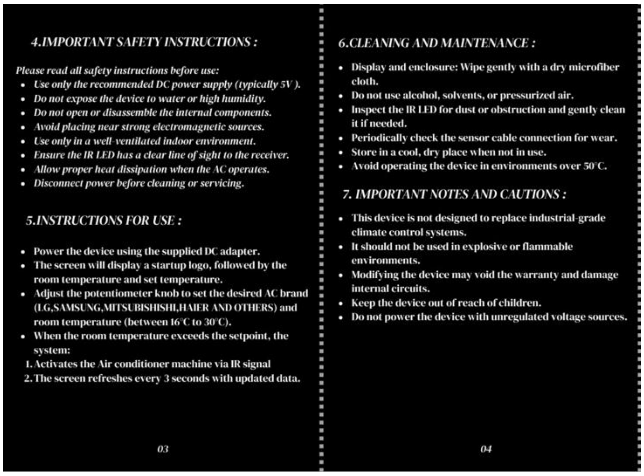


Fig. 20. User Manual

The modular architecture and use of standard components also support scalability for future use in both residential and industrial applications. By automating AC operations and limiting unnecessary runtime, the system demonstrated strong potential for energy conservation, aligning with its objective to reduce electricity consumption and support sustainable practices. The CLIMATRIX system proved to be a reliable, cost-effective, and intelligent solution, showing strong promise for real-world deployment and further development. The comparison of the existing system and Climatix is shown in Table 3.

Table 3. Comparison of the Solutions

Feature	**Manual AC with Remote**	**Smart AC Systems**	**CLIMATRIX**
Temperature Automation	×	√	√
Brand Compatibility	× (brand-specific)	× (usually fixed brand)	√ (multi-brand support)
Real-Time Temperature Display	×	√	√
Internet Dependency	×	√ (cloud-dependent)	× (offline operation)
Cost	Low	High	Low
Setup Complexity	Low	High	Low
Usability for the Elderly	Moderate	Low (app-based interfaces)	High (physical knob, LCD)
Remote-Free Operation	×	√	√
IR-Based Control	√	× (most use WiFi/IoT relays)	√

5 Discussion

The CLIMATRIX system introduces an innovative approach to automating air conditioner (AC) control by leveraging real-time temperature monitoring and infrared (IR) signal transmission. By integrating an ESP32 microcontroller, a DS18B20 temperature sensor, and an IR transmitter, the system offers a cost-effective, scalable, and energy-efficient solution for smart AC automation. The core functionality revolves around continuously measuring ambient temperature and comparing it with a user-defined setpoint, triggering appropriate IR commands to adjust cooling settings automatically. This eliminates the need for manual intervention, ensuring optimal comfort while minimizing energy wastage. The ±0.5°C accuracy of the DS18B20 sensor makes the system reliable for environments requiring precise temperature regulation, such as medical storage facilities, laboratories, and server rooms.

One of the standout features of CLIMATRIX is its universal compatibility with multiple AC brands, including LG, Samsung, Panasonic, and Mitsubishi. By storing brand-specific IR codes, the system functions as a smart universal remote, eliminating the dependency on multiple controllers. This enhances user convenience and broadens the system's applicability across different households and commercial settings.

6 Conclusions

The CLIMATRIX—Smart IR-Based Universal AC Control System successfully demonstrates how embedded systems and automation technologies can be integrated to solve real-world problems in energy management and climate control. By intelligently monitoring ambient temperature and autonomously controlling AC operations through infrared signals, the system provides a smart, user-independent solution that enhances comfort, improves energy efficiency, and reduces manual dependency. The prototype phase, utilizing air conditioner, effectively validated the system's core functionalities including real-time temperature sensing, IR communication, signal-based control, and multi-level fan speed simulation. This approach allowed safe, low-cost testing while laying the foundation for full AC integration. CLIMATRIX is designed with scalability and compatibility in mind, offering support for multiple AC brands such as LG, Samsung, Panasonic, and Mitsubishi.

Its modular architecture makes it easily adaptable for future upgrades, including mobile control, Wi-Fi/Bluetooth integration, and cloud-based monitoring. As future upgrades enabling secure remote login through Wi-Fi to Climatrix would allow users to modify device settings and operating modes without direct physical access. Second, integrating a scheduling function would allow users to program time-bound control profiles (pre-cooling a room to a set temperature for a fixed duration before automatic shutdown). Such features would enhance usability, flexibility, and adoption in real-world.

In conclusion, the CLIMATRIX project achieves its objectives by delivering a reliable, efficient, and intelligent AC control solution. It stands as a testament to practical innovation in embedded technology and serves as a stepping stone toward advanced smart home and industrial automation systems. With further refinement and integration, CLIMATRIX holds strong potential for widespread adoption and impactful contributions to sustainable energy use.

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