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SmartNest-Pico: A Lightweight IoT Home Automation System Using Raspberry Pi Pico W

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Abstract: In recent years, advancements in embedded systems and wireless communication have significantly influenced the development of smart home technologies. This work introduces an Internet of Things (IoT)-based home automation system utilizing the Raspberry Pi Pico W microcontroller for real-time control of domestic appliances. The system is designed to manage lights, fans, and doors using a mobile application or web interface via Wi-Fi. The Raspberry Pi Pico W, integrated with relay driver modules, acts as the central controller, receiving commands from users over a wireless network and triggering the corresponding output devices. A key advantage of this implementation is the seamless integration between hardware and software components, providing reliable and low-latency communication. The solution emphasizes user accessibility, remote operability, and minimal energy consumption. Security mechanisms are incorporated through password-protected access, reducing the risks of unauthorized usage. Additionally, the use of open-source libraries and modular hardware components ensures easy scalability and customization. The proposed architecture enhances convenience and control while addressing the growing need for intelligent, remotely operable environments, making it suitable for both urban and semi-urban households seeking automation-driven living.

***Index Terms** - IoT, Raspberry Pi Pico W, home automation, Wi-Fi, relay modules, remote control, smart appliances, security.*

1. INTRODUCTION

The Internet of Things (IoT) has significantly transformed modern living by enabling the interconnection of devices, systems, and services to enhance automation and control. Among its many applications, home automation has emerged as a prominent domain where IoT technologies have led to greater efficiency, security, and user convenience. The ability to control household appliances through smartphones or web platforms has introduced new dimensions to residential living, particularly in terms of remote accessibility and intelligent control [1]. With increasing urbanization and the demand for smart solutions, the integration of microcontrollers with wireless communication modules has gained considerable attention in embedded systems and electronics research communities [2].

Raspberry Pi Pico W is a recent advancement in microcontroller platforms, offering low-cost, compact, and efficient performance with built-in Wi-Fi connectivity. This feature makes it an ideal choice for wireless home automation systems. Unlike traditional microcontrollers, the Pico W provides the processing capability needed to manage multiple connected devices while maintaining real-time responsiveness and energy efficiency [3]. Its compatibility with open-source software and ease of integration with sensors and relays enhances its utility for embedded IoT solutions [4]. The system architecture typically includes relay driver modules to control appliances like lights, fans, or electric locks, enabling the switching mechanism through GPIO pins controlled by commands received over Wi-Fi. These relays form the backbone of physical interfacing between electronic logic and high-voltage devices used in households.

The need for automation has increased with the rise in digital lifestyles, where remote control and voice or app-based commands are becoming standard. In this context, mobile or web interfaces serve as user-friendly dashboards that allow individuals to monitor and control appliances from any location, offering both convenience and control [5]. Wi-Fi-based communication ensures low latency and real-time updates. Furthermore, cloud services can be optionally integrated for data logging or voice assistant compatibility, expanding the use case to include smart analytics and predictive maintenance [6].

An intelligent automation setup also contributes to energy conservation. By allowing the scheduling of operations, monitoring appliance usage patterns, and automatically turning off unused devices, the system supports sustainable energy use. Security is another significant benefit, with features like automatic door control or intrusion detection integration, creating safer living spaces [7].

The main objective is to develop an IoT-enabled smart automation system using Raspberry Pi Pico W for controlling essential home appliances like lights, fans, and doors through a mobile application or web interface. The system aims to provide secure, real-time, and remote operation with a focus on energy efficiency, scalability, and enhanced user experience using wireless communication and relay integration.

2. RELATED WORK

Home automation systems have undergone substantial development in recent years, particularly with the integration of IoT technologies that allow for remote and intelligent control of household devices. Numerous studies have explored different approaches, hardware platforms, and communication protocols to optimize performance, cost-efficiency, and energy consumption in smart home environments. One significant trend has been the use of lightweight microcontrollers such as the Raspberry Pi series to create compact, functional, and scalable home automation systems. The use of Raspberry Pi Pico W, equipped with onboard Wi-Fi, is a notable evolution in this context, offering a balance between computational capability and energy efficiency.

In [8], the authors propose an IoT-based smart security and home automation system that utilizes a microcontroller to control appliances and security mechanisms. Their system employs sensors and actuators to monitor environmental conditions and to automate tasks such as lighting and access control. This approach highlights the importance of real-time feedback and alerting mechanisms in enhancing the safety and responsiveness of the automation framework. It also demonstrates the role of relays and embedded systems in achieving seamless hardware integration.

The review and performance analysis conducted in [9] provides a comprehensive comparison of wireless smart home systems using IoT. The study emphasizes various wireless technologies such as Zigbee, Bluetooth, and Wi-Fi, concluding that Wi-Fi is one of the most suitable options for modern smart homes due to its widespread availability and higher data transfer rates. The authors underscore that Wi-Fi-enabled microcontrollers like the Raspberry Pi Pico W offer improved interoperability with smartphones and web interfaces, allowing for greater user control and interaction.

The work in [10] discusses the integration of machine learning algorithms into smart home automation systems. While the focus is primarily on intelligent decision-making, the underlying architecture still relies on IoT-enabled hardware for real-time device control. This study reinforces the relevance of IoT microcontrollers in creating foundational infrastructure on which advanced algorithms and automation scenarios can operate. Machine learning adds a layer of intelligence, allowing the system to learn from user behavior and optimize appliance usage accordingly.

Client-server architecture is explored in [11], where the authors implement a home automation system that not only enables control through web interfaces but also integrates notification systems for user alerts. By deploying a web server using the Raspberry Pi Pico W, the system facilitates bidirectional communication between users and appliances. This research demonstrates how the Pico W's built-in Wi-Fi can serve not only for device control but also for hosting lightweight web services to improve usability and accessibility.

Recent advancements in healthcare-oriented automation systems, as discussed in [12], reveal the versatility of Raspberry Pi Pico-based platforms. The authors design an in-home healthcare monitoring system that uses sensors connected to the Pico for continuous data acquisition and remote transmission. Although the primary focus is on health, the underlying IoT architecture mirrors that of home automation setups. This crossover shows how the same hardware and connectivity principles apply to diverse application areas, reinforcing the Pico W's adaptability and reliability.

A more technical approach is presented in [13], where MQTT protocol-based adaptive estimation is implemented over a distributed network using Raspberry Pi Pico W. The authors highlight MQTT's lightweight nature, making it suitable for constrained devices like the Pico W. This protocol allows for efficient message delivery between the central controller and multiple appliances, optimizing bandwidth usage and reducing system latency. These characteristics make MQTT a viable communication choice for robust and responsive home automation systems.

In [14], a proposal is introduced for an IoT module capable of monitoring and controlling residential lighting systems. The implementation focuses on low-cost, scalable hardware, and the research presents the Raspberry Pi Pico W as a key component due to its cost-effectiveness and integrated Wi-Fi capability. The system supports basic control functions while offering the possibility of integrating cloud services for extended functionality. This work showcases how a simplified design can still meet the essential requirements of real-time control and energy optimization.

The study in [15] explores various low-cost and energy-efficient alternatives for home automation using IoT. The research evaluates different microcontrollers and sensors, ultimately concluding that systems like those based on the Raspberry Pi Pico W are ideal for balancing performance with affordability. The study also discusses strategies to reduce energy consumption, such as intelligent scheduling and automated shut-off mechanisms, which align with the growing emphasis on sustainable living.

Collectively, these studies affirm the growing importance of compact, low-power microcontrollers like Raspberry Pi Pico W in the domain of home automation. The integration of Wi-Fi for wireless control, compatibility with web-based interfaces, and ability to support various sensors and actuators make such platforms ideal for scalable and secure automation systems. The literature consistently emphasizes real-time control, user convenience, energy efficiency, and modularity as core design considerations, all of which are directly supported by the architecture and capabilities of the Pico W-based systems.

3. MATERIALS AND METHODS

The proposed system presents an IoT-based home automation framework using the Raspberry Pi Pico W, enabling remote control of household appliances such as lights, fans, and doors through a mobile application or web interface. Leveraging its built-in Wi-Fi capabilities, the Pico W ensures real-time communication between users and appliances, allowing instant command execution and monitoring [11]. Relay modules are interfaced with the microcontroller to facilitate safe and efficient switching of high-voltage appliances [14]. The system supports advanced features like scheduling, which enhances energy efficiency by automating appliance usage based on predefined conditions [15]. Furthermore, the integration of webserver functionality directly on the Pico W offers a lightweight yet effective solution for user interaction [13]. This setup aims to deliver a cost-effective, scalable, and secure automation solution adaptable to various household environments. The proposed work emphasizes convenience, sustainability, and safety, making it an ideal approach for enhancing modern living through IoT technology.

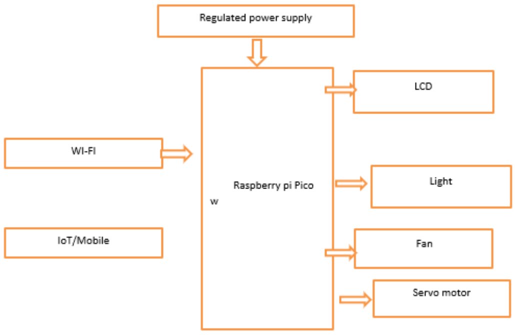

Fig.1 Block Diagram

The provided image depicts a block diagram illustrating a system centered around a Raspberry Pi Pico. A regulated power supply provides the necessary power to the Raspberry Pi Pico. The Pico receives input from Wi-Fi and an IoT/Mobile interface, suggesting it can be controlled or receive data wirelessly. The outputs from the Raspberry Pi Pico include an LCD for display purposes, a light, a fan, and a servo motor. This setup indicates a system designed for automation or remote control of various devices, potentially for smart home applications, environmental control, or other IoT-based projects.

i) Components Used:

In this automation framework, several key hardware components collaborate to enable real-time control and monitoring of home appliances. Each module serves a dedicated purpose in ensuring the system's functionality, efficiency, and responsiveness. By integrating microcontrollers, sensors, actuators, and communication modules, the setup supports seamless IoT-based interaction for remote device management, contributing to the development of a reliable and cost-effective smart home system.

Raspberry Pi Pico W: The Raspberry Pi Pico W is a compact, low-power microcontroller equipped with a dual-core ARM Cortex-M0+ processor and integrated Wi-Fi connectivity, making it an ideal controller for IoT applications. Its GPIO pins enable easy interfacing with relays, sensors, and other peripherals, ensuring flexibility in automation setups. The built-in Wi-Fi module facilitates real-time wireless communication between the user and connected devices. Additionally, its cost-effectiveness and support for MicroPython and C/C++ programming enhance ease of development and scalability. In this system, the Pico W acts as the central controller that processes user commands received over the internet and triggers corresponding device actions accordingly [11].

LCD: The Liquid Crystal Display (LCD) is used for visual feedback within the home automation system, displaying device status, network connectivity, and real-time activity logs. Typically, a 16x2 LCD is interfaced with the Raspberry Pi Pico W through I2C or parallel communication. The LCD enhances user interaction by providing information without requiring constant access to a smartphone or web interface. It improves system usability by allowing users to verify command execution and monitor system state locally. Its low power consumption, simple interfacing, and high visibility make it an essential component for embedded systems where real-time display is beneficial [14].

Wi-Fi: Wi-Fi connectivity is crucial for enabling remote access and control in home automation systems. In this implementation, the Raspberry Pi Pico W's onboard Wi-Fi module ensures real-time communication between the user interface (mobile or web app) and the automation hardware. It allows bidirectional data transmission, making it possible to both send commands and receive status updates instantly. This wireless connection eliminates the need for physical interaction, allowing control from any location with internet access. Wi-Fi also supports integration with cloud platforms for extended functionalities such as data logging and voice assistant compatibility. Its wide range, ease of deployment, and high data throughput make Wi-Fi a preferred communication technology in modern smart homes [13].

Light: Lights are among the primary appliances automated in smart home systems. In this setup, they are connected to relay modules controlled by the Raspberry Pi Pico W. Users can switch lights on or off remotely via Wi-Fi, and also set automated schedules to control lighting based on time or occupancy. This functionality not only enhances convenience but also reduces energy wastage by ensuring lights are only used when necessary. LEDs or compact fluorescent lamps (CFLs) are typically used due to their low power consumption and rapid switching capability. Automation of lighting is one of the most effective and commonly implemented features in IoT-based home systems, directly contributing to energy efficiency [15].

Fan: The fan is another essential appliance in home environments, and its automation contributes significantly to both comfort and energy conservation. Connected via a relay to the Raspberry Pi Pico W, the fan can be turned on or off remotely and scheduled to operate under specific temperature or time-based conditions. This reduces unnecessary usage, especially during unoccupied periods. Integration into the system allows users to control fan speed or trigger fan operation based on real-time data from temperature sensors (if included). Fan automation is especially valuable in climates requiring frequent airflow management and contributes to sustainable home operation when properly programmed [9].

Servo Motor: The servo motor is used to control mechanical movement within the automation system, such as door locking mechanisms or window adjustment. It operates by receiving Pulse Width Modulation (PWM) signals from the

Raspberry Pi Pico W and rotating to precise angular positions as programmed. Servo motors are favored in home automation for their accuracy, low power consumption, and ease of integration with microcontrollers. They enable secure and automated door operations, which improve home security and accessibility. In smart homes, servos are commonly used where controlled movement is necessary and enhance the interactive nature of automation systems [8].

Regulated Power Supply: A regulated power supply ensures consistent and safe voltage levels for all electronic components in the system. It converts standard AC mains power to a stable DC output, typically 5V or 3.3V, which is essential for operating the Raspberry Pi Pico W, relays, LCD, and other modules. Voltage fluctuations can cause erratic behavior or permanent damage to sensitive electronics, making regulated power vital for system reliability. Additionally, it allows for isolation and protection circuits to be incorporated for added safety. The regulated supply must provide sufficient current while maintaining voltage stability across varying load conditions. Its role is fundamental in embedded and IoT systems where uninterrupted and reliable power is crucial [12].

ii) Working Process:

The working process of the proposed home automation system using the Raspberry Pi Pico W is designed to ensure efficient, secure, and real-time control of household appliances. The first step involves connecting the Raspberry Pi Pico W to a local Wi-Fi network, which enables cloud-based communication and remote accessibility. This connection is crucial for receiving and executing user commands from a mobile or web-based interface, making the system operational from virtually any location [13].

Users interact with the system through a mobile application or web interface, which sends control signals over Wi-Fi. These commands are processed by the Raspberry Pi Pico W, which serves as the central controller. Lights and fans are connected to the controller via relay modules. When a command is received, the relays toggle the power supply to these appliances, turning them on or off as per the user's input [14]. Additionally, a servo or relay-operated electric lock mechanism is integrated for door control, enabling secure locking or unlocking through the same interface [8].

Real-time feedback mechanisms are implemented to update the user interface with the current status of each appliance. This two-way communication ensures users have accurate and instant information about device states, enhancing usability and trust in the system [11]. Furthermore, secure protocols and user authentication measures are used to prevent unauthorized access, adding a critical layer of safety to the setup. Overall, the system delivers a cost-effective, scalable solution for smart living by combining IoT connectivity, control accuracy, and enhanced user interaction.

4. CONCLUSION

The IoT-based home automation system using the Raspberry Pi Pico W presents an efficient, scalable, and cost-effective solution for modern smart homes. By leveraging Wi-Fi connectivity, the system enables remote control of appliances via a mobile app or web interface, enhancing convenience, security, and energy efficiency. The use of relay modules ensures seamless operation of electrical devices, while real-time monitoring allows users to stay informed about appliance status. Additionally, features like automation and scheduling optimize power consumption and improve home security. The proposed system is adaptable and expandable, allowing integration with voice assistants, AI, and cloud storage for future advancements. This project demonstrates the practical application of IoT in daily life, paving the way for smarter and more connected living spaces.

The proposed IoT-based home automation system has immense potential for future advancements. Integration with AI and machine learning can enable predictive automation, optimizing energy usage based on user behavior. Voice control using Alexa or Google Assistant can enhance accessibility. Cloud storage can allow remote monitoring and data analysis. Additionally, incorporating biometric authentication and smart sensors for security can make homes more intelligent, secure, and energy-efficient, paving the way for next-generation smart home solutions.

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