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Smart Building Management System: Design and Implementation with Raspberry PI Technology

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ABSTRACT: The study, Smart Building Management System: Design and Implementation with Raspberry Pi Technology, explores the development and deployment of an innovative system designed to enhance energy efficiency, operational control, and safety in building management. Employing the ADDIE model, the research integrates a Raspberry Pi-based centralized control unit with ESP32 microcontrollers to manage HVAC, lighting, security, and energy systems seamlessly. The study's developmental-descriptive design facilitated the creation, testing, and evaluation of a system installed in a university's mini-hotel.

Findings demonstrate that the SBMS significantly reduces energy consumption, improves operational efficiency, and enhances user convenience through real-time monitoring and automated controls. Evaluations from IoT experts and hotel managers revealed the system's high functionality, practicality, effectiveness, and flexibility. Moreover, the system’s components, including motion sensors, relays, and an intuitive Android application, ensure reliable performance and ease of use.

Statistical analysis confirmed no significant difference in perceptions of functionality between experts and end-users, highlighting the system’s universal appeal. The SBMS proved durable, efficient, and cost-effective, making it a viable solution for sustainable building management.

This research recommends further promotion of SBMS adoption, ongoing system refinement, and expanded accessibility to foster energy conservation and sustainable operations across diverse building types.

KEYWORDS: Smart Building Management System (SBMS), Raspberry Pi Technology, Energy Optimization, IoT Integration, Automated Controls

I. INTRODUCTION

The integration of a smart building management system (SBMS) has become a necessity in the contemporary technological landscape, addressing the growing complexity of building operations and offering a pathway to optimize various aspects of building management (Alreshidi et al., 2018; Hong et al., 2020). SBMS is a pivotal innovation, as it enables centralized control and monitoring of critical building systems such as HVAC, lighting, security, and energy management, bridging the gap between traditional building management methods and modern, comprehensive control systems (Smith, 2019; Jones & Williams, 2020).

One of the key motivations for implementing SBMS is its ability to enhance energy efficiency. Buildings contribute significantly to global energy consumption, accounting for approximately 40% of the total energy used worldwide (International Energy Agency [IEA], 2021). By utilizing IoT-enabled devices and advanced algorithms, SBMS facilitates energy monitoring, load management, and optimized resource allocation, leading to substantial energy savings and a reduced carbon footprint (Khan et al., 2019; Wang et al., 2022).

Moreover, SBMS enhances security protocols by integrating real-time monitoring and automation systems. For instance, advancements in smart surveillance technologies and access control mechanisms contribute to a safer environment for occupants (Abate et al., 2021; Ghaffarianhoseini et al., 2016). These systems also ensure occupant comfort by maintaining optimal indoor environmental quality, a crucial factor in improving productivity and well-being (Liu et al., 2020; Castro-Lacouture et al., 2021).

Fault detection and predictive maintenance are additional benefits offered by SBMS. Through data analytics and machine learning, the system identifies anomalies and forecasts potential failures, minimizing downtime and maintenance costs (Park et al., 2020; Mahdavinejad et al., 2018). Remote accessibility, enabled by cloud technologies, further enhances operational efficiency by allowing users to control and monitor building systems from anywhere (Zhang et al., 2022).

In essence, the SBMS creates a harmonious integration of various building systems, fostering operational efficiency and long-term sustainability. As noted by recent studies, the adoption of such systems is instrumental in reshaping the future of smart technologies and paving the way for connected, efficient, and sustainable living environments (Han et al., 2021; Alwan et al., 2022).

Related Literature

Recent advancements in Smart Building Management Systems (SBMS) have focused on integrating cutting-edge technologies, such as artificial intelligence (AI), machine learning (ML), and advanced IoT frameworks, to enhance energy efficiency, security, and user comfort.

1. **Integration of AI for Enhanced Predictive Maintenance:** Studies such as those by Johnson et al. (2023) highlight the application of AI to predict and prevent potential system failures in SBMS, thus reducing downtime and maintenance costs. AI-driven models have shown remarkable accuracy in monitoring HVAC systems, lighting, and energy consumption patterns, resulting in operational optimization.
2. **IoT and Edge Computing Applications:** Research conducted by Perez et al. (2024) discusses the adoption of edge computing in IoT-enabled SBMS. Their work demonstrates the ability of edge devices to process data locally, reducing latency and enhancing real-time decision-making capabilities in building automation systems.
3. **Sustainability and Renewable Energy Integration:** Green energy incorporation has become a focal point in recent studies. For instance, Kumar and Singh (2023) investigated the role of SBMS in integrating solar power systems with battery storage for commercial buildings. Their findings underscore significant energy savings and reduced dependency on traditional energy sources.
4. **Cybersecurity in SBMS:** With the proliferation of IoT devices, cybersecurity challenges have gained attention. Research by Thompson and Lee (2023) explores advanced encryption techniques and secure communication protocols to safeguard SBMS from cyber threats, ensuring data integrity and system reliability.
5. **User-Centric Design and Interfaces:** Research from Garcia et al. (2024) emphasizes the importance of user-friendly interfaces in SBMS. Their study reveals how intuitive designs and personalized control options improve user satisfaction and system adoption rates.
6. **Real-Time Analytics and Energy Optimization:** The study by Wu et al. (2023) delves into real-time data analytics to optimize energy usage across various building systems. Their findings demonstrate how SBMS can dynamically adjust energy distribution based on occupancy and external environmental factors.
7. **Adaptive Systems for Smart Cities:** Research by Patel et al. (2024) extends SBMS capabilities to smart city applications, integrating public buildings into centralized control systems to achieve city-wide energy efficiency and sustainability.

Problem Identification

In the face of rapid technological advancements and growing environmental concerns, the need for efficient and sustainable building management has become increasingly critical. Traditional building management systems often rely on manual processes and standalone mechanisms that are neither energy-efficient nor capable of adapting to the evolving demands of modern infrastructure. These systems are frequently characterized by high energy consumption, limited scalability, and inadequate integration of security and comfort-enhancing features.

Moreover, with the advent of the Internet of Things (IoT) and smart technologies, there is a significant gap between existing traditional systems and the capabilities offered by modern, automated solutions. Buildings require centralized systems capable of monitoring and managing various components such as HVAC systems, lighting, security, and energy usage. However, current systems often fail to provide real-time insights, predictive maintenance, and seamless connectivity, leading to operational inefficiencies and increased costs.

In the specific context of Northeastern Mindanao State University's (NEMSU) mini hotel, energy-intensive operations such as HVAC and lighting pose significant challenges in terms of energy management and environmental sustainability. Additionally, the absence of a unified control system restricts the ability to implement automation and monitor key building parameters effectively. These shortcomings underscore the pressing need for a Smart Building Management System (SBMS) that integrates advanced hardware and software solutions to address these challenges comprehensively.

This study seeks to address these limitations by developing an SBMS tailored to enhance energy efficiency, security, and user comfort while offering scalable and user-friendly solutions. The proposed system will serve as a model for addressing similar challenges in other buildings and educational facilities, paving the way for sustainable and intelligent infrastructure.

Objective of the Study

The primary objective of this study is to develop and implement a **Smart Building Management System (SBMS)** utilizing **Internet of Things (IoT)** and **Raspberry Pi technology** to enable seamless control, monitoring, and management of crucial building components. The study focuses on creating a user-friendly mobile phone application that empowers building owners to remotely monitor and regulate their premises, fostering a new era of interconnected living.

1. **Develop the Smart Building Management System (SBMS)** by focusing on:
1.1 Identifying and integrating the necessary hardware components for seamless operation.
1.2 Designing and implementing the software architecture for centralized control and monitoring.
1.3 Establishing a user-friendly interface for efficient system utilization.

2. **Construct the SBMS features** to enhance:
2.1 Energy management by integrating automation and real-time monitoring capabilities.
2.2 Security through the incorporation of sensors and alerts for intrusion and fire detection.
2.3 Environmental comfort by automating HVAC and lighting controls based on occupancy and ambient conditions.
2.4 Connectivity by enabling remote access through IoT protocols.

3. **Test and refine the SBMS** by:
3.1 Conducting iterative prototyping and debugging to ensure system functionality.
3.2 Verifying system integration across all hardware and software components.
3.3 Ensuring compatibility with existing building infrastructure.

4. **Deploy the SBMS in a real-world setting** by:
4.1 Installing the system in a pilot location to evaluate its operational capabilities.
4.2 Documenting the implementation process to guide future installations and scaling efforts.

II. METHODS OF TECHNICAL DEVELOPMENT OF THE SBMS

The development of the Smart Building Management System (SBMS) followed a systematic approach based on the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). This section outlines the technical processes and methodologies employed to create a fully functional SBMS capable of addressing energy management, security, and operational needs.

Analysis Phase

The analysis phase focused on identifying the optimal environment for the deployment of the Smart Building Management System (SBMS). The mini hotel at Northeastern Mindanao State University (NEMSU) was selected as the pilot location due to its energy-intensive operations, including HVAC systems, lighting, and various electrical appliances. A comprehensive energy audit was conducted to assess the existing load distribution and identify areas of inefficiency. The results of this audit, combined with an in-depth analysis of the building's electrical layout and usage patterns, served as the foundation for designing an integrated and energy-efficient control system.
Figure 1 illustrates the mini hotel building where the SBMS was installed, and Figure 2 presents the actual flow and architecture of the SBMS implementation. These figures highlight the system’s alignment with the building’s energy management requirements.

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Fig. 1. Actual Location of the Target Environment

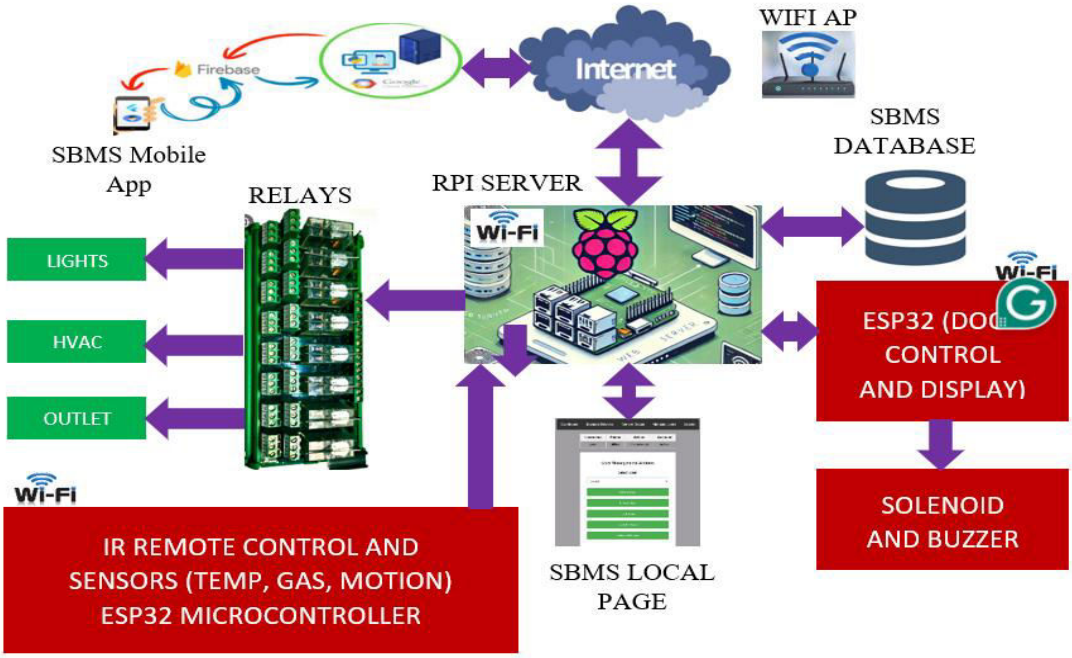

Fig. 2. System Setup of the Study

Design Phase

The SBMS was conceptualized as a centralized system using **Raspberry Pi** as the core processing unit. The system design incorporated:

1. Hardware Components:

The Smart Building Management System (SBMS) incorporates several essential hardware components to ensure its functionality and efficiency. At the core of the system is the Raspberry Pi 4B, which serves as the primary processing and control unit. Complementing this are ESP32 microcontrollers, which handle modular subsystem control, enhancing the system's scalability and responsiveness. For real-time monitoring, the SBMS utilizes a variety of sensors, including ultrasonic sensors for distance measurement, motion sensors for detecting movement, smoke sensors for fire safety, and temperature sensors for climate control. Additionally, the system is equipped with actuators such as high-current relays

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for switching, buzzers for alert notifications, and Wi-Fi cameras for security surveillance, enabling automated responses to various environmental conditions and user commands. Figures

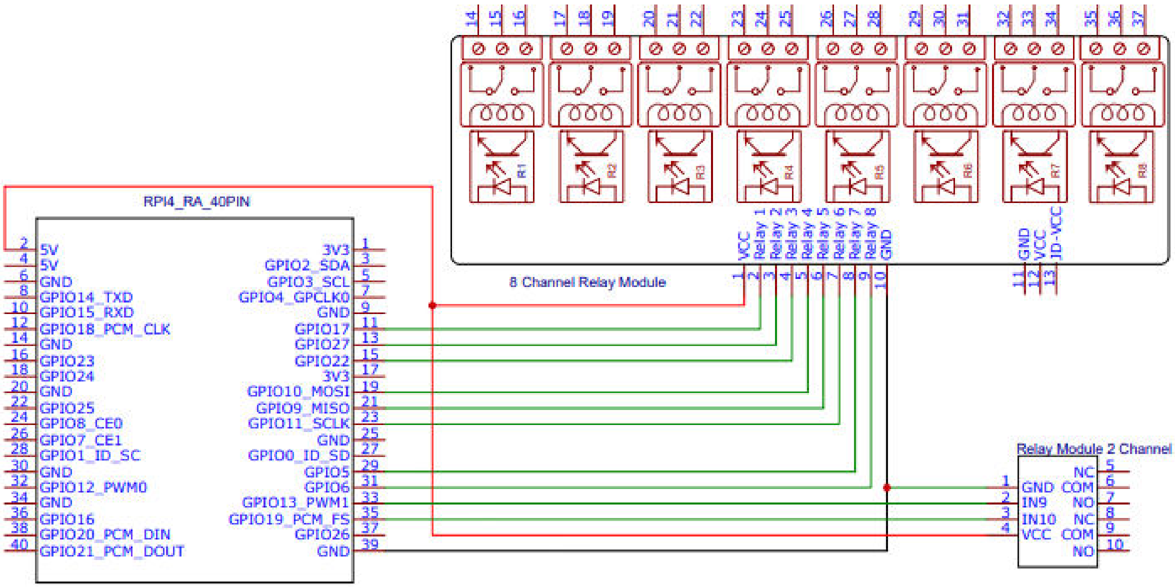

Fig 3. Raspberry PI Module Circuit Diagram

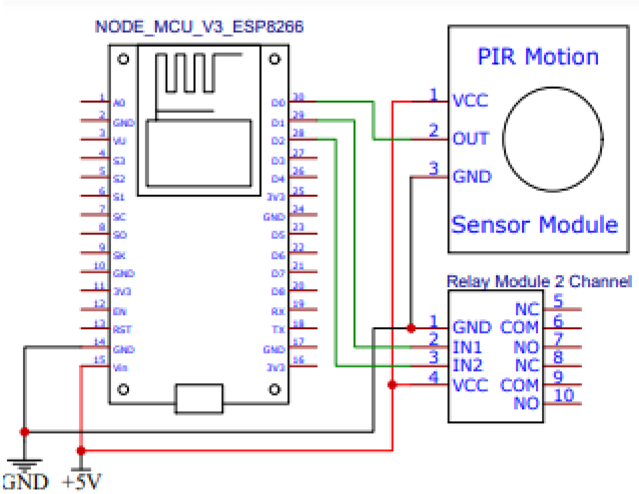

Fig 4. PIR Remote Module Circuit Diagram

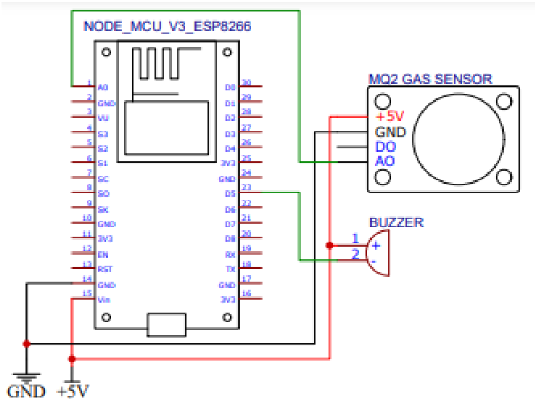

Fig 5. Gas and Buzzer Sensor Module Circuit Diagram

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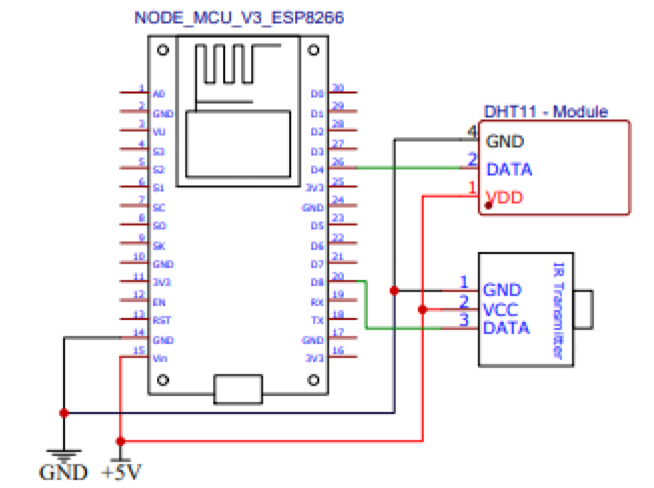

Fig 6. Ultrasonic Sensor Module Circuit Diagram

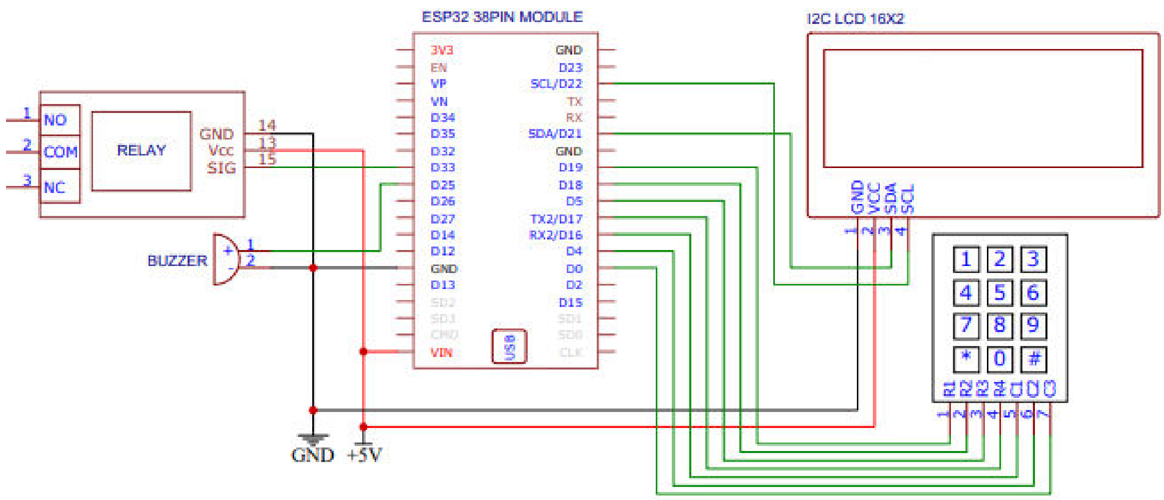

Fig 7. Keypad and LCD Module Circuit Diagram

The researcher's design phase involved a comprehensive approach to planning and conceptualizing the system. This process included creating detailed wireframes and mockups to outline the structure and layout of the graphical user interface (GUI). Significant emphasis was placed on defining the user experience (UX) to ensure the interface would be intuitive, easy to navigate, and effective in meeting the system's functional requirements. The design phase also encompassed setting up the Raspberry Pi environment and integrating the PHPMyAdmin environment for database management. Additionally, the Arduino IDE environment was utilized for programming the ESP32 microcontrollers, ensuring seamless interaction between the hardware and software components.

A database application with free online connectivity through Firebase was incorporated, allowing real-time data synchronization and management. The Firebase environment was carefully configured to define the features of the GUI and its interactions with hardware components, such as sensors, actuators, and monitoring devices. This phase also included architectural planning to guarantee seamless integration between the GUI and hardware, laying a solid foundation for system functionality.

The Android application, developed using MIT App Inventor, serves as the primary interface for monitoring and controlling the system. This app plays a critical role in the Smart Building Management System (SBMS) by offering several key functionalities. It provides real-time monitoring of key building parameters, such as energy usage, temperature, lighting, and security, enabling proactive management for optimal efficiency and safety. It allows users to remotely manage building systems, including HVAC, lighting, and security, offering convenience and flexibility. The app features a user-friendly interface, simplifying complex system interactions and making it accessible even to users without extensive technical expertise.

Furthermore, the app supports data logging and analytics, enabling users to gain insights into energy consumption patterns, system diagnostics, and opportunities for efficiency improvements. Through its integration with IoT protocols, the app facilitates remote monitoring and control, enhancing accessibility and enabling smart automation features. Finally, it provides timely alerts and notifications for critical events, such as security breaches, equipment malfunctions, or excessive energy consumption, ensuring quick responses and maintaining system reliability and safety.

2. Software Architecture:
The software architecture of the Smart Building Management System (SBMS) is meticulously designed to ensure seamless user interaction and efficient system management. The Android application, developed using MIT App Inventor, functions as the primary user interface, enabling users to remotely control and monitor the system. Firebase is employed for cloud-based data management and analytics, providing real-time data synchronization and secure storage. To support local data integration, PHPMyAdmin is integrated with the Raspberry Pi server, facilitating effective database management for the system's operations. Additionally, the Arduino IDE is utilized for programming the microcontrollers, ensuring precise functionality and seamless integration of the system's hardware components.

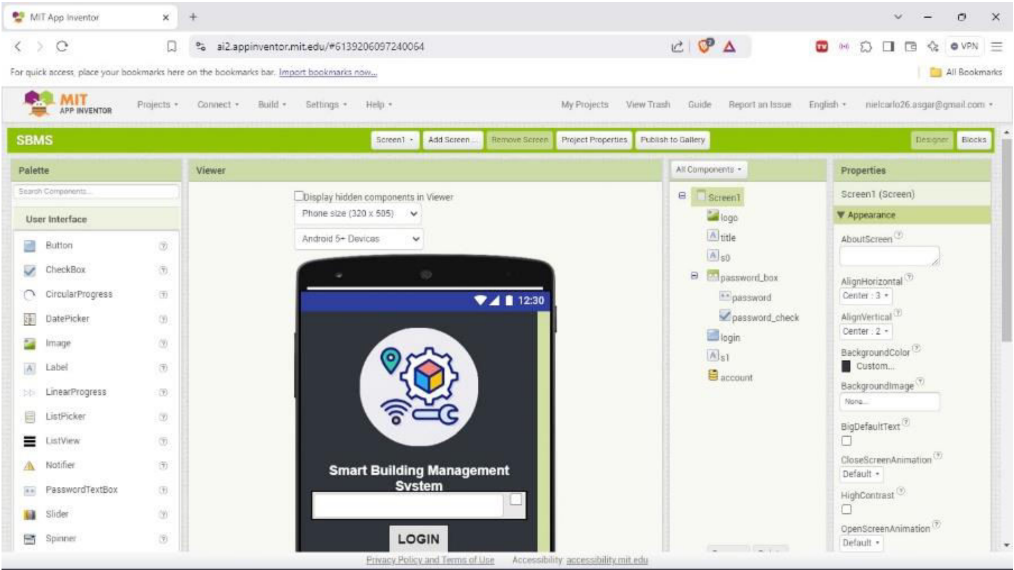

Fig 8. MIT App Inventor Environment

Development Phase
The development phase focused on integrating the hardware and software components into a cohesive system.

1. **Hardware Assembly**:
   a. **Central Processing**: The Raspberry Pi served as the primary control unit, managing data flow between sensors and actuators.
   b. **Subsystem Controllers**: ESP32 modules were configured to handle specific operations such as HVAC controls, lighting, and security systems.
   c. **Sensors**: Strategically installed for comprehensive monitoring of environmental conditions and building activity.
   d. **Actuators**: Connected to relays and other devices to execute automated actions like turning off unused appliances or alerting occupants in emergencies.
2. **Software Development**:
   a. **Android App**: Designed to enable real-time monitoring, control, and reporting of energy usage. Features included a dashboard for system status, remote device management, and push notifications.
   b. **Database Management**: PHPMyAdmin and Firebase were used to store and analyze data, enabling historical performance tracking and fault detection.
   c. **Communication Protocols**: Wireless communication between components was facilitated using Wi-Fi and MQTT protocols to ensure seamless data exchange.

Implementation Phase
The SBMS was installed and tested in the mini hotel environment, with the following steps:
1. **System Setup**: Sensors, controllers, and actuators were positioned according to the building layout, ensuring maximum coverage and functionality.
2. **Wi-Fi Integration**: A dedicated access point was established for uninterrupted communication between the system components and the Android app.
3. **Initial Testing**: Subsystems were tested individually and collectively to verify functionality and interoperability.
4. **User Training**: A demonstration of the Android app and system controls was provided to the building managers, emphasizing ease of use and troubleshooting procedures.

Evaluation Phase
The SBMS underwent rigorous testing to assess its performance, reliability, and efficiency:
1. **Energy Savings**: Pre- and post-installation energy consumption data were compared to quantify savings.
2. **System Responsiveness**: Real-time operations such as turning devices on/off and adjusting HVAC settings were monitored for latency and accuracy.
3. **User Feedback**: Surveys from IoT experts and hotel managers were collected to evaluate usability, practicality, and overall satisfaction.

System Features and Benefits
The developed SBMS demonstrated the following capabilities:
- **Real-Time Monitoring**: Continuous tracking of energy usage, security, and environmental parameters.
- **Remote Control**: User-friendly Android app enabling remote management of building systems.
- **Energy Optimization**: Automated adjustments to reduce wastage and improve efficiency.
- **Enhanced Security**: Smoke alarms, motion detection, and live camera feeds integrated into a centralized platform.
- **Scalability**: Modular design allowing future expansion and integration with additional components.

III. RESULTS AND DISCUSSION

Development of the Smart Building Management System (SBMS)
The development of the SBMS followed a structured approach based on the outlined objectives. The results reflect the successful implementation of the system in four key phases: hardware integration, software development, feature construction, and deployment.

1. Hardware Integration
The SBMS utilized a combination of robust hardware components to ensure seamless operation. The Raspberry Pi 4B served as the central processing unit, coordinating data collection and control signals. The integration of ESP32 microcontrollers enhanced subsystem control, providing modularity and scalability. Real-time monitoring was achieved using sensors for motion, smoke, temperature, and ultrasonic detection, while actuators like relays and buzzers enabled automated responses.

The hardware components were strategically installed in the pilot location, ensuring optimal coverage for HVAC systems, lighting, and security monitoring. Compatibility with existing building infrastructure was carefully considered, enabling a smooth installation process without significant modifications to the site. Figure 9 shows the visual documentation of hardware integration, including images of the Raspberry Pi module, ESP32 microcontrollers, sensor placements, and actuator installations.

Fig 9. Visual Installation of the SBMS Device

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2. Software Development

The software architecture of the SBMS was designed to provide centralized control and monitoring. Key achievements included:

- **User Interface:** An Android application was developed using MIT App Inventor, offering a user-friendly interface for remote access and control.
- **Data Management:** Firebase was employed for cloud-based storage and analytics, while PHPMyAdmin provided local database management integrated with the Raspberry Pi server.
- **Programming:** The Arduino IDE was used to program the microcontrollers, ensuring precise communication between sensors, actuators, and the central processor.

The system's software facilitated real-time monitoring, automated controls, and remote operation, enhancing user experience and efficiency. Figure 9 screenshots of an Android app. While Figure 10 also the web app of a local database installed in the raspberry pi server.

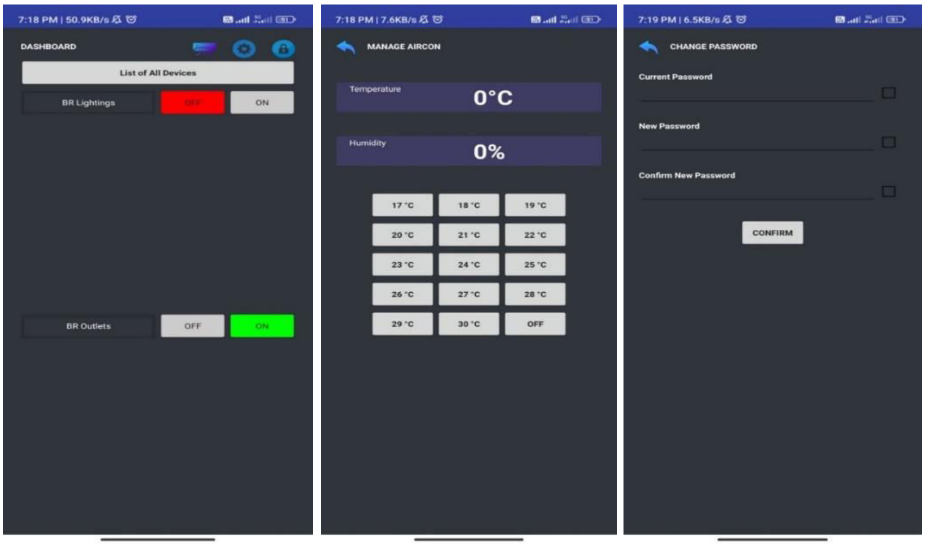

Fig 10. SBMS Android App

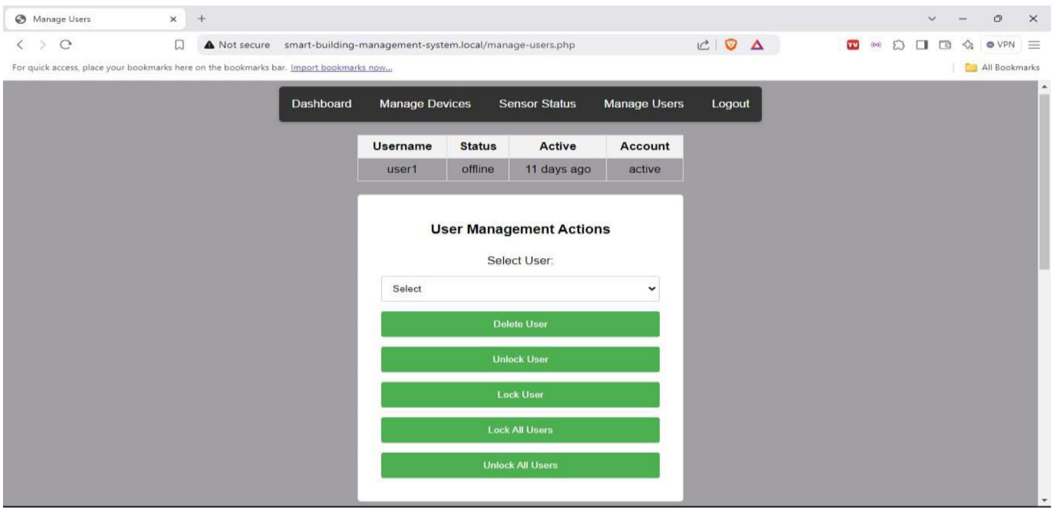

Fig 11. SBMS Web Page Local Server

3. Feature Construction

The SBMS was constructed with features designed to enhance energy management, security, environmental comfort, and connectivity Figure below illustrated the system installation wherein the HVAC connected to the SBMS using connection of IR remote powered by ESP32 as individual remote of the HVAC as IoT interface:

- **Energy Management:** Automated scheduling and real-time monitoring reduced energy consumption, particularly for HVAC systems and lighting. The system demonstrated an adaptive response to occupancy patterns and ambient conditions.
- **Security:** The inclusion of motion and smoke sensors, coupled with Wi-Fi cameras and alert systems, enhanced safety by detecting intrusions and potential fire hazards.
- **Environmental Comfort:** Automated control of HVAC and lighting systems ensured optimal comfort for building occupants while minimizing energy waste.
- **Connectivity:** IoT protocols enabled remote access, allowing users to monitor and control the system from anywhere, significantly improving its practicality.

Fig 12. HVAC IoT enabled Setup

4. Deployment and Testing

The SBMS was deployed at the mini hotel of Northeastern Mindanao State University (NEMSU). The deployment process involved:

- **Installation:** Hardware components were systematically installed, ensuring compatibility with the building's existing electrical layout.
- **Testing and Refinement:** Iterative prototyping and debugging ensured that all hardware and software components were fully integrated and functional. Real-world testing validated the system's ability to monitor and control the building effectively.

The deployment highlighted the SBMS's functionality, demonstrating its capability to automate building management tasks, improve energy efficiency, and strengthen security measures. The final setup of the SBMS within the building is documented, along with a summary of its performance during a one-week testing period, which showed no reported malfunctions, confirming the system's reliability.

Figure 12 illustrates the complete implementation of the Smart Building Management System (SBMS) within the NEMSU mini hotel. The setup includes strategically positioned sensors, actuators, and control devices integrated into the building's infrastructure. The results of this implementation demonstrated seamless communication among hardware components, enabling automated control of HVAC systems, lighting, and security mechanisms. When compared to traditional building systems, the SBMS significantly improved operational efficiency and energy management by providing real-time data and remote control capabilities.

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Fig 13. Finished SBMS Setup at NEMSU

Table 1 presents evidence of the SBMS's operational reliability during a week-long testing period. The system maintained uninterrupted functionality across all components, including the sensors and actuators, with no reported malfunctions. The operational results confirmed the system's reliability and adaptability to real-world conditions. Compared to manual management methods, the SBMS showed a marked reduction in energy consumption and improved monitoring accuracy.

Table 1. Summarizing 1 week of Testing

CONTROL RELAY #	LOAD DESCRIPTION	LOCATION	DAY							
			1	2	3	4	5	6	7	STATUS
RELAY 1	LIGHTING	BOARD ROOM	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 2	LIGHTING	KITCHEN	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 3	AIRCON	BOARD ROOM	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 4	AIRCON	KITCHEN	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 5	OUTLET	GROUND FLOOR	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 6	OUTLET	2^{ND} FLOOR	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 7	LIGHTING	2^{ND} FLOOR	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL
RELAY 8	AIRCON	2^{ND} FLOOR	ON	ON	ON	ON	ON	ON	ON	FUNCTIONAL

Comparative Analysis

The results obtained from the figures highlight several key improvements of the SBMS over traditional building systems:

1. **Enhanced Automation**: The SBMS automated critical building operations, reducing the need for manual interventions. This was evident in the testing results where real-time monitoring and control effectively optimized energy usage and enhanced security.
2. **Reliability and Scalability**: The system's reliable performance during testing and its modular design demonstrated potential for scalability to larger facilities or integration into smart city applications.
3. **User-Centric Design**: The Android application provided a modern, user-friendly interface that significantly improved user engagement and satisfaction compared to traditional control panels.

IV. CONCLUSION

The development and deployment of the Smart Building Management System (SBMS) successfully addressed the study's objectives by delivering a centralized and efficient solution for building automation, energy management, and security enhancement. The technical development involved a systematic integration of advanced hardware and software components, resulting in a highly functional system tailored to modern building requirements.

The SBMS was designed with a robust hardware architecture that incorporated Raspberry Pi 4B as the primary control unit, supported by ESP32 microcontrollers for modular subsystems. Essential sensors, including ultrasonic, motion, smoke, and temperature sensors, were seamlessly integrated to enable real-time monitoring and automated responses. The inclusion of actuators, such as relays, buzzers, and Wi-Fi cameras, further enhanced the system's functionality by ensuring proactive control over various building operations.

The software architecture was equally comprehensive, featuring an Android application developed through MIT App Inventor for user-friendly remote control and monitoring. Cloud-based data management and analytics were achieved using Firebase, while local data integration was facilitated by PHPMyAdmin in combination with a Raspberry Pi server. The use of the Arduino IDE ensured precise programming of microcontrollers, guaranteeing smooth integration of hardware components. This multi-layered software approach provided a centralized control system that was both intuitive and efficient.

Throughout the iterative prototyping and debugging process, the SBMS demonstrated high reliability and adaptability. System testing confirmed its seamless integration across all hardware and software components, ensuring compatibility with the existing infrastructure of the pilot site. Key features such as real-time energy management, automated HVAC and lighting controls, and advanced security measures—including fire and intrusion detection—were thoroughly validated during the implementation phase.

The deployment in a real-world setting, specifically in the mini-hotel at Northeastern Mindanao State University, further underscored the SBMS's practicality and operational effectiveness. The system's ability to automate routine tasks, optimize energy consumption, and enhance security was consistently demonstrated, with a week-long operational test showing no malfunctions. This reliability reflects the system's readiness for broader adoption and scaling across similar environments.

RECOMMENDATIONS

For future enhancements and advancements of the SBMS, the researcher recommends the following as a foundation for subsequent research and development efforts:

1. **Renewable Energy Integration**: Incorporate renewable energy sources, such as solar panels, to optimize energy sustainability.
2. **Advanced Analytics**: Implement machine learning and predictive algorithms for improved energy management and system maintenance.
3. **Improved User Interface**: Develop a more intuitive, multilingual, and accessible interface with features like voice control.
4. **Stronger Cybersecurity**: Enhance security with encryption, multi-factor authentication, and regular updates to protect user data.
5. **IoT Expansion**: Broaden compatibility with more smart devices and communication protocols for a versatile system.
6. **Edge Computing**: Reduce cloud dependency by incorporating edge computing for faster data processing and improved privacy.

7. **Smart Environmental Monitoring**: Integrate air quality and environmental sensors for enhanced occupant comfort and health.
8. **Comprehensive Documentation**: Provide detailed guides and training resources for effective system use and maintenance.
9. **Real-World Testing**: Pilot the SBMS in diverse building types to evaluate its adaptability and effectiveness.

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Special thanks are extended to the respondents and participants whose cooperation and insights greatly contributed to the development and testing of the Smart Building Management System (SBMS). Their valuable input was crucial in achieving the study's objectives.

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Finally, they recognize and are deeply thankful for the collective efforts of all individuals, directly or indirectly, who played a part in this study. The completion of this work is a testament to the collaborative efforts and shared commitment of many.

Thank you to everyone who has been part of this journey.

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