European Journal of Computer Science and Information Technology, 13(41),1-11, 2025
Print ISSN: 2054-0957 (Print)
Online ISSN: 2054-0965 (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Integrating Embedded Systems and Control Theory for Energy-Efficient Smart Homes with Dual Sensitivity Motion Detection

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doi: https://doi.org/10.37745/ejcsit.2013/vol13n41111 Published June 17, 202

Citation: Divine-Will OO and Joe E. (2025) Integrating Embedded Systems and Control Theory for Energy-Efficient Smart Homes with Dual Sensitivity Motion Detection, *European Journal of Computer Science and Information Technology*, 13(41),1-11

Abstract: *This study delved into the development of a cost-effective, intelligent energy management and control system to address the pressing issues of energy wastage and rising electricity costs in developing countries, with a focus on Nigerian households and businesses. The problem stems from inefficient and underutilized energy distribution systems, which lead to excessive consumption and financial strain. To mitigate these challenges, the study introduces a smart solution that leverages dual-sensitivity motion sensors and embedded systems to regulate energy usage in real time based on environmental occupancy. The methodology involves the integration of hardware and software components, including an Arduino-based microcontroller, dual motion sensors, relay switches, and a Real-Time Clock (RTC) module. The system dynamically switches between high and low sensitivity modes—high during daytime for active responsiveness and low at night to prevent false triggers—ensuring appliances operate only when necessary. Environmental simulations and controlled testing were conducted to validate performance and reliability. The proposed solution offers a scalable, adaptable, and affordable approach to smart energy management, balancing user comfort with significant energy savings. By automating appliance control and optimizing power consumption based on human presence, the system enhances sustainability and economic efficiency. It also contributes to the advancement of smart home technologies and presents a viable pathway for widespread implementation in resource-constrained environments.*

Keywords: energy management, control system, sensors, microcontroller, simulations.

INTRODUCTION

The increasing global demand for energy and the growing emphasis on sustainability have driven significant interest in optimizing energy management within smart homes [1]. Smart homes integrate technology and automation to enhance energy efficiency, convenience, and security, making them an essential component of the future of residential living. One of the most promising technologies in this space is the use of motion sensors for energy management [2]. Motion sensors can optimize energy use by detecting human presence and automatically controlling lighting, heating, cooling, and other appliances, ensuring that energy is only consumed when necessary. Dual sensitivity motion sensor technology offers a more refined approach by employing sensors with different sensitivity levels to adjust energy consumption based on varying conditions, such as daytime activities and night time rest [3]. These systems help reduce energy wastage by ensuring appliances are only active when needed, contributing to both environmental sustainability and cost savings [4].

Despite the potential benefits, there are numerous challenges associated with implementing dual sensitivity motion sensor technology in smart homes [1]. One major is-sue is achieving accurate and reliable occupancy detection without frequent false triggers. For instance, standard motion sensors may react to minor movements like the shifting of curtains or pets, leading to unnecessary activation of appliances, which counteracts the intended energy savings [3]. This issue is exacerbated in sleep mode, where the system must be sensitive enough to respond to significant movements without disturbing the occupants unnecessarily. Balancing energy efficiency with user comfort is another critical challenge, as overly sensitive systems may cause frequent on-off cycles, which can be disruptive and lead to dissatisfaction among users [2]. Consequently, optimizing the sensitivity of motion sensors for different environments, such as bedrooms, living rooms, or kitchens, requires careful consideration to maintain both energy efficiency and comfort.

Furthermore, integrating motion sensors into broader smart home ecosystems adds a layer of complexity [5]. While motion sensors have been successfully used in lighting systems and security applications, expanding their role to control a wider range of household devices requires sophisticated algorithms and interoperability with other smart home technologies [6]. The challenge lies in creating a seamless system where various smart devices communicate effectively, allowing for coordinated responses to occupancy detection [4]. For instance, when a motion sensor detects occupancy in a particular room, the system might need to adjust not just the lighting, but also the temperature and even entertainment devices. Ensuring that these systems work together harmoniously without causing conflicts or inefficiencies is an ongoing challenge in the field of smart home automation [7].

Scalability and adaptability are additional challenges, especially in households with varying layouts, room functions, and occupancy patterns. Smart homes differ in size and design, which means that a one-size-fits-all solution may not be effective. Devel-oping a system that can adapt to different home configurations and user habits is critical for widespread adoption [8]. The system must be customizable enough to accommodate specific user preferences while still delivering the promised energy savings. This need for adaptability also extends to installation and maintenance, as the complexity of these systems can increase the cost and effort required for setup and ongoing management [9].

Addressing the challenges of energy management in smart homes requires continuous innovation in both sensor technology and system integration. Dual sensitivity motion sensors offer a significant advancement by enabling more precise control over house-hold energy consumption, dynamically adjusting based on occupancy and activity levels [10]. However, further research and development are necessary to refine these systems, addressing current limitations to ensure that they are both effective and us-er-friendly. By overcoming these challenges, dual sensitivity motion sensor technology has the potential to play a pivotal role in reducing energy consumption, contributing to a more sustainable and cost-efficient future for residential living [11]. This research draws from expertise in sensor technology, embedded systems, and user experience design to create a robust energy management system tailored to the needs of modern homes and businesses.

The intelligent energy management and control system developed in this research leverages dual motion sensors to optimize power consumption by automatically adjusting energy usage in real-time based on human presence. The system operates in both active and sleep modes, ensuring that energy is conserved without compromising com-fort or convenience. By automating the switching off of devices when not in use and activating them, when necessary, this approach achieves substantial energy savings, contributing to both environmental sustainability and economic efficiency. The research extends the existing body of knowledge in smart energy management by introducing a system that is adaptable to various contexts and user needs, balancing efficiency with user control. Through the integration of intelligent algorithms and the latest advancements in the Internet of Things (IoT) and embedded systems, this research aims to pave the way for more effective energy management solutions. The system, built on an Arduino-based microcontroller with real-time clock (RTC) modules, is de-signed to be both cost-effective and scalable, making it a practical option for energy-conscious households and businesses seeking to reduce energy waste while maintaining comfort.

RELATED WORKS

The growing concern for energy efficiency, rising costs, and environmental sustainability has prompted a surge in the development of Home Energy Management Systems (HEMS) [12]. These systems aim to optimize energy consumption in residential settings by offering real-time monitoring and control over household energy usage. In this literature review, we explore the existing landscape of HEMS and discuss how the proposed intelligent energy management system, which incorporates dual-sensitivity motion sensors, seeks to address the limitations of traditional HEMS. HEMS have long been recognized for their potential to reduce energy consumption by providing users with the tools to monitor and control energy usage [13]. These systems typically include components such as smart meters, programmable thermostats, and smart appliances that communicate over a home network to offer real-time insights [3],[14]. However, while traditional HEMS provide significant benefits, they often rely on user-defined schedules and manual interventions to optimize energy consumption. This dependency on active user participation limits their effectiveness, as users may not always accurately predict occupancy patterns or remember to adjust settings to optimize energy use [15]. Furthermore, these systems tend to be costly, complex to install, and may present compatibility issues with older appliances and home infrastructure [16]. As such, there is a need for more intuitive and affordable solutions that reduce user intervention and adapt to real-time energy needs automatically.

The proposed intelligent energy management system aims to fill these gaps by employing dual-sensitivity motion sensors to dynamically control energy usage based on occupancy. Unlike traditional HEMS, which rely heavily on preset schedules, the proposed system adjusts energy consumption in real-time using data from motion sensors to automatically switch appliances on or off [17]. This approach significantly reduces energy waste by ensuring that energy is only consumed when necessary, improving user comfort while minimizing intervention [18]. The dual-sensitivity motion sensors provide different levels of sensitivity during active and sleep periods, allowing the system to respond appropriately to human presence while also conserving energy during inactive times, such as nighttime. This novel approach aligns energy consumption with actual occupancy, offering a more flexible and adaptive solution compared to static schedules traditionally used in HEMS [11],[19].

One of the primary limitations of existing HEMS is their high initial investment cost, often making them inaccessible to the average consumer [4]. Professional installation and specialized devices such as smart meters, thermostats, and connected appliances contribute to this cost barrier [6]. In addition, the complexity of these systems can be a deterrent for users who are not tech-savvy, resulting in underutilization of their full capabilities [20]. Furthermore, static schedules do not always align with actual occupancy patterns, leading to inefficiencies in energy consumption [21]. Compatibility with legacy systems is another challenge, as many existing homes may not be equipped to support the integration of new smart devices without significant retrofitting [16], [21]. The concept of smart lighting systems is closely related to the proposed intelligent energy management system. Smart lighting systems use sensors and wireless communication to adjust lighting based on occupancy, ambient light levels, and user preferences [23]. These systems can significantly reduce energy consumption by up to 40%

compared to traditional lighting while also enhancing user comfort [24]. However, smart lighting systems tend to focus solely on lighting optimization, whereas the proposed system offers a more holistic approach by also managing other household appliances. This broader scope provides additional energy savings and further enhances user comfort, particularly during sleep periods when unnecessary energy consumption can be minimized [25]. Despite their potential, smart lighting systems also face challenges such as high initial costs, compatibility issues with existing fixtures, and reliance on internet connectivity, which can limit their usability during network outages [19], [14], [16]. The proposed system overcomes these limitations by offering local control capabilities, ensuring that it remains functional even during connectivity issues, thus enhancing its reliability and accessibility [13].

Building Energy Management Systems (BEMS) also provide valuable insights into energy optimization, particularly in commercial settings. BEMS typically offer centralized control of energy subsystems such as heating, ventilation, air conditioning (HVAC), and lighting. However, these systems often require significant upfront investment, professional installation, and ongoing maintenance, making them less viable for smaller residential settings [26]. Moreover, the complexity of BEMS can deter users who lack the specialized knowledge required to manage them effectively [27]. BEMS also face challenges in scalability and adaptability, as retrofitting older buildings with centralized control systems can be both expensive and logistically difficult [20]. The proposed intelligent energy management system addresses these issues by using affordable motion sensors and decentralized control, allowing for real-time occupancy-based adjustments without the need for extensive retrofitting or high installation costs. This decentralized approach eliminates the vulnerability of single points of failure commonly associated with centralized control systems [28].

In summary, the proposed intelligent energy management system utilizes affordable motion sensors and existing home networks, eliminating the need for expensive devices and extensive installations. By automating energy management based on real-time occupancy data, the system reduces complexity, making it more accessible to a wider range of users [22]. While traditional HEMS, smart lighting systems, and BEMS have advanced energy management in both residential and commercial sectors, they are often hindered by high costs, complexity, and limitations in scalability and user-friendliness. The proposed intelligent energy management system, which leverages dual-sensitivity motion sensors and real-time occupancy data, offers a more accessible, cost-effective, and user-friendly alternative. By automating energy management based on human presence and dynamically adjusting consumption, the system promises to reduce energy waste, enhance user comfort, and contribute to environmental sustainability. With its flexible and scalable design, the proposed system paves the way for broader adoption of energy-efficient technologies in residential settings, providing a valuable solution to the growing demand for smarter and more sustainable energy management practices.

METHOD

The methodology for designing and implementing an optimized energy management system in smart homes using dual sensitivity motion sensor technology involves a systematic approach that integrates hardware and software components [4]. The primary focus is on leveraging dual sensitivity motion sensors to detect varying levels of human presence and adjust energy consumption dynamically. The system is designed to minimize energy wastage by intelligently controlling lighting, HVAC, and appliances based on real-time activity and patterns. The hardware aspect includes installing motion sensors in for dual sensitivity. Dual sensitivity motion sensors offer a more nuanced detection mechanism by distinguishing between minor movements, such as when occupants are stationary, and more significant motions, like walking [19]. This allows the system to adapt energy usage precisely to the occupants' needs. The sensors are connected to a central control unit via a wireless home network, ensuring seamless data transmission without the need for extensive wiring.

The embedded system component involves developing intelligent algorithms that process data from the motion sensors and make real-time adjustments to energy usage. These algorithms are built to optimize energy efficiency by learning the occupancy patterns of users over time. For instance, the system can detect when a room is unoccupied and automatically turn off appliances and lighting, then reactivate them when motion is detected. One of the key challenges in this implementation is the integration of dual sensitivity motion sensors with existing smart home infrastructure. A challenge in the methodology is the accurate calibration of sensor sensitivity to avoid false positives or negatives [19]. If the sensors are too sensitive, they may activate devices unnecessarily, while too little sensitivity may lead to energy wastage due to delayed responses [6]. Additionally, ensuring robust data security and privacy is critical, as the system collects and processes sensitive information regarding occupancy patterns, raising concerns over potential breaches and unauthorized access [3]. To address these issues, the system is designed to operate locally, minimizing reliance on cloud-based solutions that are more vulnerable to cyber-attacks, while also offering optional remote access features for users [11]. The dual sensitivity motion sensor-based system provides a more accessible and cost-effective solution for residential users, as it is scalable and easy to integrate into existing home systems without the need for extensive retrofitting [21].

RESULTS AND SIMULATIONS

The proposed intelligent energy management system operates through a combination of motion sensing, time-based control, and adaptive automation to optimize energy usage in smart homes [14]. The system uses dual sensitivity motion sensors to detect human presence and activity. During the day, a highly sensitive sensor triggers appliances and lighting based on detected motion, ensuring energy is used efficiently. At night, a less sensitive sensor takes over, only activating appliances for significant movements to minimize sleep disruptions (Figure 1). This setup ensures that energy consumption aligns with the occupants' needs while maintaining comfort and efficiency. Furthermore, the system incorporates user-defined time settings that allow customization of transitions between day and night modes, enhancing its flexibility in managing energy and sleep schedules.

The system also features adaptive automation, dynamically adjusting energy consumption based on real-time conditions and user preferences (Figure 1). For instance, it automatically powers off devices during sleep mode to conserve energy and foster a restful environment. Notably, the system is cost-effective, utilizing readily available motion sensors and microcontrollers, which minimizes both initial investment and maintenance costs. This combination of advanced functionality and affordability makes the system an improvement over traditional energy management system [17]. By integrating motion sensing, time-based controls, and adaptive automation, the solution offers a user-friendly and efficient approach to managing energy consumption while promoting better sleep quality in both residential and commercial environments.

The Passive Infrared (PIR) motion sensor operates by detecting changes in infrared radiation levels emitted by objects in its vicinity [7]. PIR sensors consist of a pyroelectric sensor divided into multiple segments, each equipped with a pair of infrared sensors [21]. When an object moves within the sensor's detection range, it alters the infrared radiation levels, which are then converted into an electrical signal. This signal is processed by the sensor’s circuitry to identify motion [8]. PIR sensors are vital components in intelligent energy management systems due to their ability to detect human presence and trigger energy-saving actions such as adjusting lighting and appliance usage [11]. By integrating PIR sensors, energy management systems can optimize energy

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consumption and create more responsive, automated environments that adapt to the presence and activities of occupants [16].

Relay modules are another essential element deployed in the systems, offering a way to control high-power electrical loads with low-power control signals from microcontrollers or digital circuits. The module uses electromechanical relays, where an electromagnet operates a set of contacts to switch electrical loads like motors, lights, and appliances [19]. The relay module incorporates opto-couplers, an isolation method to protect the control circuitry from high-power loads, ensuring safety and durability. The relay modules' ability to switch loads based on control signals allows the intelligent energy management system (IEMCS) to operate efficiently, based on real-time sensor data [6]. For instance, appliances can be turned on or off depending on human presence, significantly reducing energy wastage and contributing to a more sustainable energy management approach.

The IEMCS incorporates several key features to optimize energy usage and enhance sleep quality [15]. Firstly, the system utilizes motion sensors to monitor occupancy and adjust energy consumption dynamically throughout the day. The sensors allow the system to control lighting and appliances based on the occupants' activities, minimizing unnecessary energy usage. Secondly, the system offers sleep enhancement by employing motion sensors with varying sensitivity levels to detect significant movements during sleep without causing disruptions (Figure 2). This ensures that the system maintains a comfortable and restful sleep environment, which contributes to the overall well-being of users. Moreover, real-time monitoring of energy usage and environmental conditions provides users with valuable insights into their habits, allowing them to make informed decisions to improve both energy efficiency and sleep quality.

The integration of a Real-Time Operating System (RTOS) is crucial for the seamless functioning of the IEMCS [21]. An RTOS enables the system to prioritize and execute tasks with strict adherence to timing constraints, ensuring that tasks related to energy optimization and sleep enhancement are performed without delays [6]. This is particularly important for maintaining comfort and energy efficiency when motion sensors detect changes in occupancy or environmental conditions. For instance, the system must quickly adjust lighting and other settings when occupants enter a room or transition to sleep mode. The RTOS enhances the system’s responsiveness and reliability, ensuring that all actions are executed predictably and efficiently. This real-time capability allows the IEMCS to effectively manage energy and environmental settings, ultimately achieving its goal of optimizing energy usage while promoting healthier sleep patterns in a variety of settings [17].

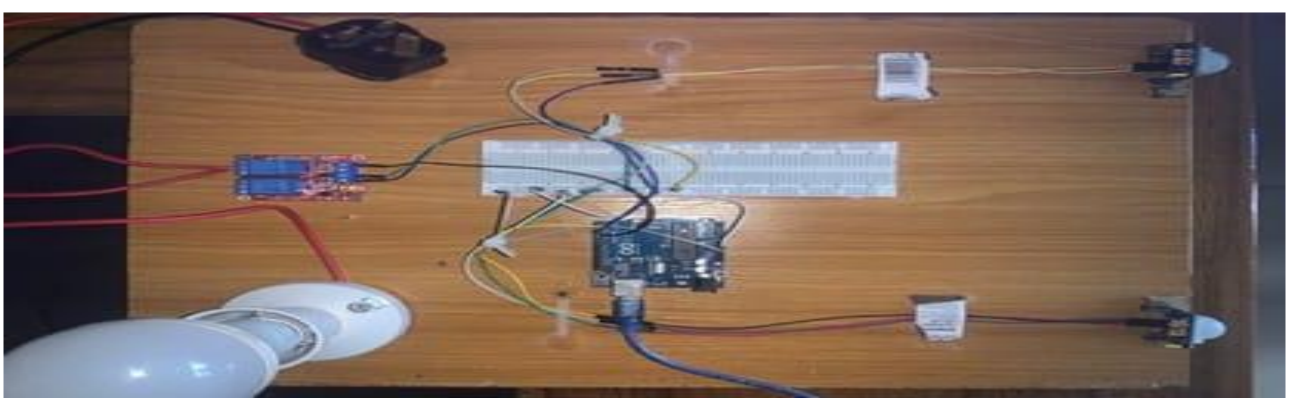

Figure 1. Physical test and representation of the system

The Arduino Uno acts as the central control unit in this system, processing inputs from PIR motion sensors to manage energy usage and sleep settings effectively (Figure 1). The system employs two types of PIR sensors: one with high sensitivity for detecting activity during the day and another with lower sensitivity for minimizing disturbances during sleep mode (Figure 1). The Arduino Uno processes data from these sensors and sends control signals to the relay module, which acts as a bridge between the digital control signals and physical devices like lights and sockets. This relay module is responsible for switching these devices on or off based on the system's programmed logic. A breadboard is used for prototyping and connecting all the electronic components, allowing easy assembly and testing of the circuits. The light bulb represents the controllable output devices, demonstrating the system's capability to manage external devices based on sensor inputs and programmed settings. Additionally, the power management module ensures that each component receives the appropriate amount of power, using batteries or AC adapters as necessary. Connecting cables play a crucial role in linking the various components, facilitating the transfer of data and power essential for the system's seamless operation. Together, these components create an integrated system that optimizes energy usage and improves sleep quality, offering a comprehensive solution for energy management and comfort.

MODE OF OPERATION

The system integrates two motion sensors with distinct sensitivity levels to optimize energy usage and enhance user comfort based on activity and time of day. It uses Motion Sensor 1, which has high sensitivity and a broad field of view (120 degrees) with a range of up to 23 feet, for daytime operation. This sensor detects movement during the day and triggers the system to activate lights or appliances (Figure 2). If no further motion is detected within 20 seconds, indicating inactivity, the system transitions into sleep mode. At night, Motion Sensor 2, positioned 5-10 feet from the sleep area, takes over. This sensor has lower sensitivity to avoid detecting minor movements, ensuring that only significant motions are registered to maintain a restful sleep environment. The system remains in sleep mode for 60 seconds before automatically reverting to daytime operation with Motion Sensor 1 resuming control.

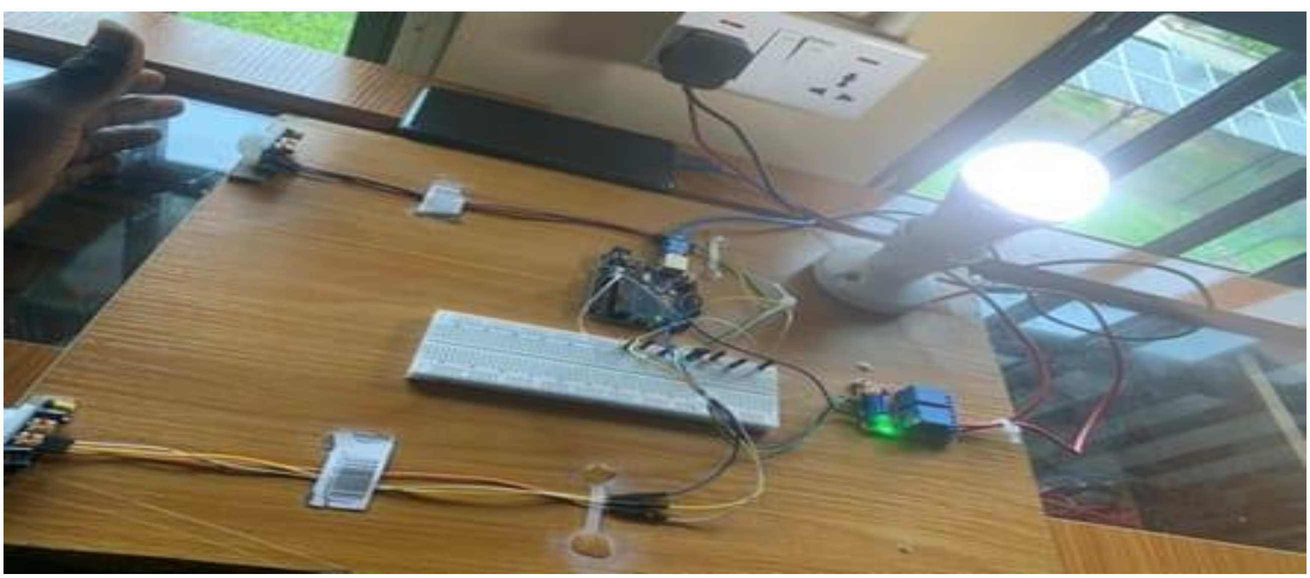

Figure 2. The system when motion is detected in day mode

The system's appliance control is designed for immediate response; when motion is detected, it directly powers connected devices like lights to enhance convenience and energy efficiency. This allows for instantaneous activation based on real-time needs. While the current setup uses a countdown timer for transitioning between modes, future versions might incorporate a real-time clock (RTC) module to align more closely with user-defined sleep schedules. The user interface allows for customization of sensitivity settings, motion detection timeouts, and other parameters, enabling a personalized experience that adapts to individual preferences. By leveraging these motion sensors and intelligent control logic, the system effectively optimizes energy use, improves sleep quality, and provides a tailored user experience.

CONTROL ALGORITHM DESIGN

The system integrates two motion sensors with distinct sensitivities to optimize energy management and enhance user comfort. Sensor 1, characterized by high sensitivity, operates during the day to detect general movement within its wide field of view. In contrast, Sensor 2, with lower sensitivity, takes over during sleep mode to identify only significant movements, minimizing disturbances during sleep. When Sensor 1 detects motion, it triggers a countdown timer; if no further motion is sensed within 20 seconds, the system shifts to sleep mode (Figure 3). In sleep mode, Sensor 2 becomes active to monitor significant motion, while Sensor 1 remains off to conserve energy. If significant motion is detected by Sensor 2 and persists beyond a specified timeout period of 20 seconds, the system remains in sleep mode and activates appliances or lighting accordingly.

After a predefined sleep mode duration of 60 seconds, the system exits sleep mode and resumes normal operation, reactivating Sensor 1 for daytime motion detection and deactivating Sensor 2 until the next sleep mode cycle (Figure 3). This dynamic switching between sensors and modes allows the system to optimize energy usage by aligning with user activity patterns. Users can customize the system by adjusting settings such as sleep mode duration and motion timeout periods to better fit their preferences. The system also provides real-time feedback through serial communication, allowing users to monitor motion detection events and transitions between modes, and make necessary adjustments based on the provided feedback. Overall, this control algorithm ensures efficient energy management and improved sleep quality by adapting to varying user activity levels and environmental conditions using sensors with tailored sensitivities.

MOTION SENSOR SENSITIVITY

Sensitivity in motion sensors, particularly in Passive Infrared (PIR) sensors like the SR501, denotes the sensor's ability to detect and respond to motion within its field of view. Higher sensitivity allows the sensor to detect even minor changes in infrared radiation, making it more responsive to small movements [9]. Conversely, lower sensitivity requires more substantial changes in heat patterns to trigger a detection event. This adjustment is crucial for tailoring sensor performance to specific applications. For instance, a security system benefits from higher sensitivity to detect subtle movements, whereas a lighting control system might use lower sensitivity to avoid false triggers from minor temperature fluctuations.

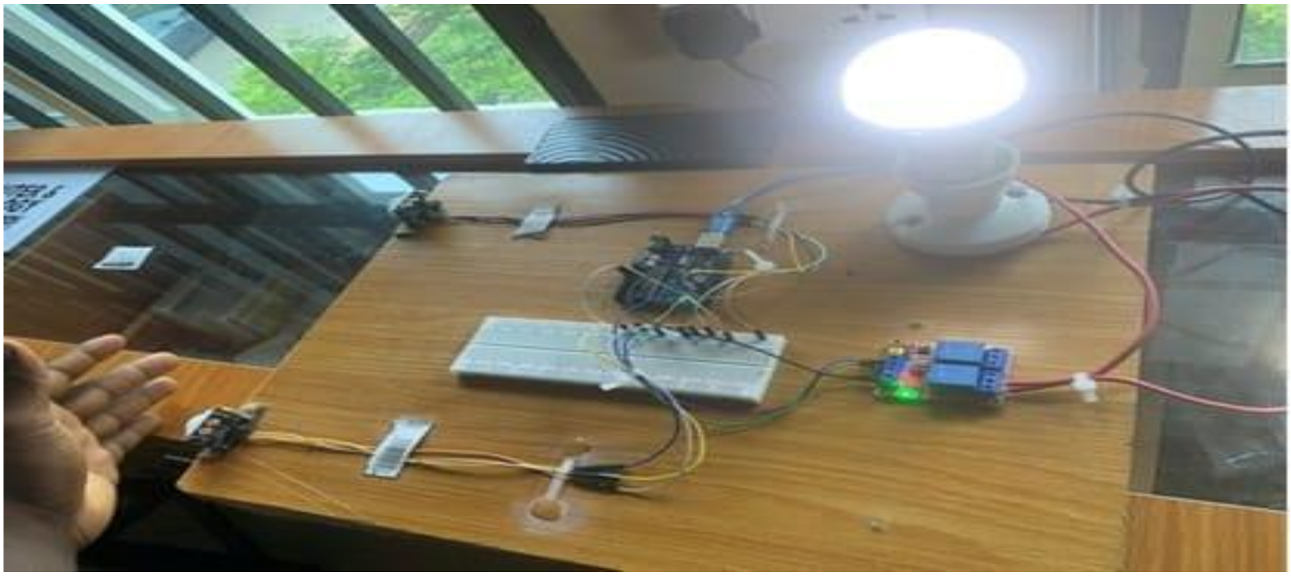

Figure 3. The system when motion is detected in night mode

The SR501 PIR sensor features a default sensitivity setting that can be fine-tuned using a potentiometer. Lowering the sensitivity decreases the sensor's responsiveness to small infrared changes, which in turn may shorten its effective detection range. For example, while the SR501 typically detects motion up to 20 feet away, reducing its sensitivity could limit this range to approximately 10 feet. Consequently, when the sensitivity is lowered, the sensor will only detect larger movements or those occurring closer to the sensor. To ensure accurate detection, especially in applications where only significant movements need to be captured, the sensor should be placed at an optimal distance, typically around 9 to 11 feet. This setup ensures that only notable actions, like someone standing up, are detected effectively, minimizing false triggers and optimizing the sensor's performance based on its adjusted sensitivity.

SYSTEM INTEGRATION AND EVALUATION

System Integration Testing (SIT) is a crucial step in developing the Intelligent Energy Management and Control System (IEMCS) [22]. This phase focuses on evaluating how well the system's components work together to ensure they meet the specified requirements. SIT involves comprehensive testing of the integrated hardware, software, and communication interfaces to identify and resolve issues that may arise when individual modules interact. By simulating real-world scenarios and operational conditions, SIT verifies that the system functions cohesively, enhances reliability, and ensures that the IEMCS delivers effective energy management and control. This process is essential for validating the overall performance and robustness of the final product, ensuring that it operates efficiently and as intended in practical applications.

Motion Detection by Sensor 1: When Motion Sensor 1, which is highly sensitive with a detection range of approximately 120 degrees, detects movement, the system responds by activating a countdown timer. In the absence of further detected motion for 20 seconds, the system initiates a 60-second sleep mode, effectively simulating a transition to nighttime. Although an RTC module would normally handle this transition in a full implementation, a countdown timer is used here for demonstration purposes. During this sleep mode, control is transferred to Motion Sensor 2, which has a lower sensitivity level, allowing it to detect only significant movements and minimize disturbances during this period. This setup ensures the system adapts to different operational states, optimizing energy management and enhancing user comfort.

Motion Detection by Sensor 2: During sleep mode, Motion Sensor 2, positioned 7-10 feet away for optimal sensitivity, continuously monitors for motion to ensure minimal disturbance during this period. If Motion Sensor 2 detects movement, the system remains in its active state, maintaining responsiveness. Once the 60-second sleep mode elapses without further detected motion, the system transitions back to its normal daytime mode. At this point, Motion Sensor 1, which is more sensitive and suited for daytime operation, takes over control. This process effectively demonstrates the system's capability to dynamically switch between operational states based on both sensor inputs and predefined time intervals, ensuring efficient energy management and seamless functionality throughout different periods of use.

DISCUSSION

The intelligent energy management and control system provides a range of immediate and long-term benefits that enhance society, health, and lifestyle [15]. It delivers notable energy savings by automating the control of lighting and appliances based on occupancy, which lowers energy consumption and utility costs. The system also contributes significantly to environmental sustainability by reducing energy consumption and carbon emissions, thus lessening the ecological footprint [14]. The ongoing energy savings also translate into substantial financial advantages for homeowners and businesses. The advancement and adoption of such smart home technologies contribute to the Internet of Things (IoT) ecosystem, driving innovation and progress in home automation. Societal benefits include improved home security through simulated occupancy when residents are away, which can deter intruders and enhance neighborhood safety. Economically, the system offers significant cost savings on utility bills, providing financial relief and increasing property value and marketability, making homes with these technologies more appealing to potential buyers and renters [22].

This research introduces a pioneering advancement in home automation and energy management through the use of motion sensor technology. By integrating motion sensors with different sensitivity levels, the system addresses critical limitations of traditional home automation setups, providing a sophisticated solution for optimizing energy consumption and enhancing sleep quality. The research also aligns with the increasing demand for sustainable living solutions by optimizing energy use based on real-time occupancy data. This not only minimizes energy waste but also helps lower utility costs, contributing to global efforts for energy efficiency and reduced carbon emissions. By utilizing lower sensitivity sensors during sleep mode, the system prevents unnecessary disturbances, a common problem with traditional systems that may disrupt rest with false triggers or inappropriate lighting adjustments.

What distinguishes this research is its unique implementation of adjustable sensitivity levels across multiple sensors, tailored to different operational scenarios. This specific integration of technology for both energy management and sleep optimization set a new benchmark in smart home systems, ensuring enhanced performance and user satisfaction. The innovative combination of these features not only enhances functionality but also establishes a new standard in the industry, demonstrating the project's significant impact on modern home automation.

CONCLUSIONS

The conclusion of the intelligent energy management and control system project highlights its pivotal role in modernizing home automation and enhancing energy efficiency. This innovative system represents a substantial advancement in the integration of motion sensors and intelligent algorithms, offering a robust solution for real-time energy management based on occupancy. By utilizing cutting-edge technology, the project not only demonstrates the feasibility of smart home solutions but also revolutionizes how individuals interact with their living environments, significantly improving comfort, convenience, and sustainability [18]. The research underscores the importance of interdisciplinary collaboration in tackling complex challenges. Combining expertise from engineering, data science, and behavioural psychology, it exemplifies how cross-disciplinary approaches can address multifaceted issues effectively. This integration of diverse fields contributes to a more holistic and functional system, highlighting the project's role in advancing home automation technology. The intelligent energy management and control system thus stands as a testament to the potential of smart solutions to enhance quality of life, promote environmental sustainability, and pave the way for a more connected and efficient future. Key contributions of the project include the innovative integration of motion sensors with varying sensitivity levels, which enables more precise detection of human activity and improves both energy management and sleep quality.

Future research in this field could explore several promising areas to further enhance the system's capabilities. Integrating advanced sensor technologies, such as infrared cameras or machine learning algorithms, could improve the accuracy and reliability of occupancy detection. Additionally, developing sophisticated energy optimization algorithms that analyse patterns, behaviours, and environmental conditions could lead to more dynamic and efficient energy management. Incorporating machine learning or AI-based systems could allow the system to adapt to user preferences, automatically adjusting settings based on individual habits. These advancements have the potential to significantly enhance the system's functionality and contribute to a more sustainable and efficient future.

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