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Smart Control System for Ceiling Fan

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ABSTRACT

This study designed, constructed, tested, and evaluated a Smart Control System for Ceiling Fan intended to automate fan operation through human-presence detection, remote monitoring, and safety mechanisms. A descriptive quantitative project-development design was used. The prototype integrated a Seed Studio XIAO ESP32S3 Sense Kit, a passive infrared sensor, a relay module, a 5-V power supply, enclosed circuitry, a cooling mechanism, and mobile-based monitoring and control. Technical performance was examined through repeated human- and animal-activity trials across four detection zones, while acceptability was evaluated by 30 randomly selected teachers from B.A. Calamba National High School using an expert-validated questionnaire covering convenience, effectiveness, and safety. Frequency counts, percentage distributions, and mode were used to analyze the data. Human entry was detected with 100% accuracy in all zones; exit detection was 100% in Zones 1 and 2 and 90% in Zones 3 and 4, while animal activity produced no activation. The system obtained an overall modal rating of 5, interpreted as Very Acceptable, for convenience, effectiveness, and safety. Users particularly valued its automatic response, ease of setup, enclosed components, overheating protection, and reduced need for manual operation, although compatibility, automatic shutoff consistency, and overload protection remained areas for improvement. The study concluded that the developed system is a practical classroom automation solution that supports energy conservation, user comfort, and safer fan operation. Its design may also serve as a hands-on instructional resource and a basis for future Internet of Things and renewable-energy integration.

Keywords: *ceiling fan automation, human presence detection, smart control system, energy efficiency, remote monitoring, electrical safety*

INTRODUCTION

Electric fans are essential for thermal comfort in homes, schools, and offices, particularly in warm climates. However, ceiling fans are frequently left operating in unoccupied rooms, resulting in unnecessary electricity consumption and higher operating costs. Smart automation offers a practical response by linking fan operation to room occupancy and allowing users to monitor or control the appliance without continuous manual intervention. Sensor-based fan systems can therefore improve both energy management and convenience by operating only when their service is needed (Ciputra & Muchlas, 2023; Khan et al., 2024).

Developments in the Internet of Things have made appliance automation more accessible through compact controllers, wireless communication, and mobile interfaces. Modern smart-control systems combine sensing, signal processing, and actuation to make real-time decisions about device operation. Human-presence detection is especially useful because it provides direct information about whether a room is occupied, while remote monitoring gives users an additional means of supervising equipment from a distance (Ghadage et al., 2021; Liu et al., 2020). When correctly calibrated and positioned, occupancy sensors can reduce avoidable operating time and support more responsive indoor environments.

Safety remains equally important in automating electrical appliances. Prolonged use, faulty wiring, blocked ventilation, and overloaded components can increase the risk of overheating or electrical malfunction. Smart controllers may reduce these risks through automatic shutdown, circuit enclosure, controlled power switching, and protection mechanisms that limit unnecessary operation (Morris, 2024; Taylor et al., 2024). These design requirements are particularly relevant in classrooms, where equipment may be used for extended periods and by multiple users.

Despite the availability of smart-home technologies, there remains a need for affordable and context-appropriate systems that can be developed, tested, and evaluated in actual public-school settings. This study therefore designed and constructed a Smart Control System for Ceiling Fan; tested its human-presence detection accuracy; determined its acceptability in terms of convenience, effectiveness, and safety; and identified areas for further improvement. The project was intended to provide an energy-efficient and user-friendly control option for classrooms while offering a practical model for automation, electronics, and sustainable technology education.

Literature Review

Smart Ceiling Fans and Energy-Efficient Automation

Ceiling fans remain a common and comparatively low-energy means of improving indoor comfort. Their energy advantage can be strengthened when operation is linked to occupancy and environmental conditions. Kommey et al. (2022) described automatic ceiling-fan control using temperature and occupancy information, while Raftery et al. (2020) showed how smart ceiling fans can be integrated with communicating controls to provide efficient comfort. These approaches reduce dependence on continuous manual switching and help ensure that fans operate only when conditions require them.

Home-automation systems have also become more practical because microcontrollers and wireless platforms allow household appliances to be connected, monitored, and controlled remotely. Ghadage et al. (2021) demonstrated the role of the Internet of Things in energy-efficient ceiling-fan automation, and Khan et al. (2024) emphasized that occupancy-based fan control can improve both energy use and user comfort. In institutional environments, similar systems can reduce unnecessary equipment operation and support more consistent implementation of energy-conservation practices.

The effectiveness of automation depends on the coordination of sensing, decision-making, and power switching. Devi et al. (2024) presented a sensor-based fan system that responds to occupancy and environmental conditions, illustrating how multiple components can function as one control architecture. Such designs support the present study's integration of a human-presence sensor, ESP32 controller, relay module, power supply, and mobile-access capability.

Human-Presence Detection and Sensor Reliability

Human-presence detection provides the information needed for occupancy-driven automation. PIR sensors are widely used because they are affordable and can identify changes in infrared energy associated with human movement. Chuah and Teoh (2020) demonstrated the potential of thermal sensing for presence detection, while Liu et al. (2020) reviewed wireless approaches for sensing and recognizing human activity. These technologies enable control systems to distinguish occupied from unoccupied conditions and to trigger appropriate device responses.

Reliable detection requires more than selecting a sensor. Performance may be influenced by distance, angle, room layout, environmental conditions, placement, and calibration. Wilhelm et al. (2020) noted that occupancy can be monitored through environmental indicators, but no single sensing method is free from limitations. Multi-sensor and smart-building research similarly shows that system accuracy improves when sensor deployment, processing logic, and operating context are considered together (Alsafery et al., 2023).

False activation and missed detection are especially important in energy-management systems. A false positive keeps an appliance operating when no person is present, whereas a false negative may switch it off while

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a user remains in the room. The inclusion of timing delays and sensitivity adjustments can reduce rapid switching and improve stability. The present system therefore used repeated trials in four zones to assess entry and exit detection and verify that animal movement did not activate the fan.

Smart Controllers, Remote Monitoring, and Safety

Smart controllers serve as the central decision-making component of an automated system. They receive sensor signals, apply programmed logic, and instruct relays or other actuators to control electrical loads. Aziz et al. (2023) showed how intelligent controllers can process environmental inputs to support responsive building operation. Remote monitoring extends this capacity by allowing users to inspect system status and manage devices through wireless communication, thereby increasing flexibility and reducing the need for direct physical access.

Electrical safety must be incorporated into both hardware and software design. Enclosed circuitry can reduce accidental contact and protect components from dust and moisture, while controlled switching and automatic shutdown can reduce excessive operating time. Shokrollahi et al. (2024) emphasized safe enclosure design in connected appliance systems, and Taylor et al. (2024) highlighted circuit protection and thermal management as important elements of electrical-fire prevention. These considerations support the system's use of a plastic enclosure, cooling fan, insulated wiring, and programmed shutdown functions.

Acceptability: Convenience, Effectiveness, and Safety

Convenience concerns whether users can understand, install, operate, monitor, and maintain a system with minimal difficulty. Mobile access and automatic operation reduce the need for repeated manual switching and can help smart technologies fit into daily routines. Torres-Hernandez et al. (2025) associated smart-home automation with greater perceived control and security, while Fernando et al. (2025) illustrated the usefulness of integrated lighting and fan automation for energy-efficient room management.

Effectiveness refers to the system's ability to perform its intended functions accurately, consistently, and responsively. Occupancy-based energy-management systems are effective when sensors detect users reliably and controllers respond without unnecessary delay or interruption. Elkhoukhi et al. (2025) identified occupancy-driven control as a central strategy for smart-building energy management, while Prasad et al. (2023) emphasized user evaluation and reliable performance in automated institutional systems.

Safety acceptability reflects users' confidence that the device can operate without exposing them to electrical hazards, overheating, or unsafe contact with components. Protective enclosures, overload controls, stable power supplies, and clear warnings contribute to that confidence. Safety ratings are therefore not merely perceptions of comfort; they indicate whether users believe that the system can be installed and operated responsibly in real environments.

The study followed an input-process-output framework in which ideas, references, materials, tools, and equipment served as inputs; planning, designing, constructing, testing, revising, and evaluating formed the process; and the completed Smart Control System for Ceiling Fan constituted the output. The original conceptual framework is retained in Figure 1.

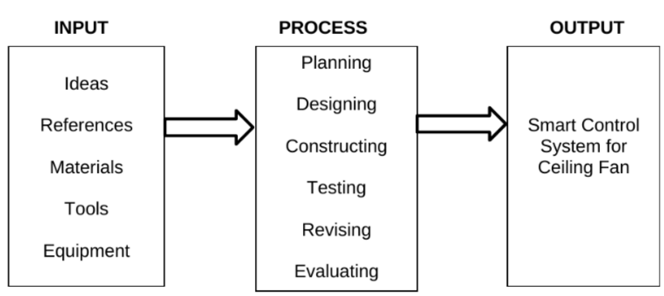

Figure 1. *Conceptual framework of the study.*

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METHODS

Research Design

The study used a descriptive quantitative project-development design. The development component covered planning, designing, construction, assembly, programming, testing, revision, and evaluation. The descriptive component was used to present the prototype's technical performance and the respondents' acceptability ratings without manipulating comparison groups. The project was completed over five weeks: one week for planning and preparation, two weeks for designing and construction, and two weeks for testing, revision, and evaluation.

System Design and Construction

The prototype integrated a Seed Studio XIAO ESP32S3 Sense Kit, a PIR human-presence sensor, a single-channel relay module, a 220-V AC to 5-V DC power supply, a cooling fan, an external antenna, terminal blocks, wiring, and an enclosed plastic casing. The estimated bill of materials was PHP 5,039.00, while fabrication and programming labor cost PHP 3,000.00, resulting in a total project cost of PHP 8,039.00. Construction included circuit assembly, installation of sensors and electrical components, wiring based on the schematic diagram, programming of the ESP32, enclosure fabrication, and functional testing.

The PIR sensor transmitted an occupancy signal to the ESP32. The controller processed the signal and activated or deactivated the relay supplying power to the ceiling fan. The programmed design turned the fan on when human presence was detected and turned it off after a 10-second interval without detected presence. Mobile-based monitoring and control, enclosed circuitry, and a cooling mechanism were included to improve convenience and reduce overheating risk. Figure 2 presents the original block diagram of the system.

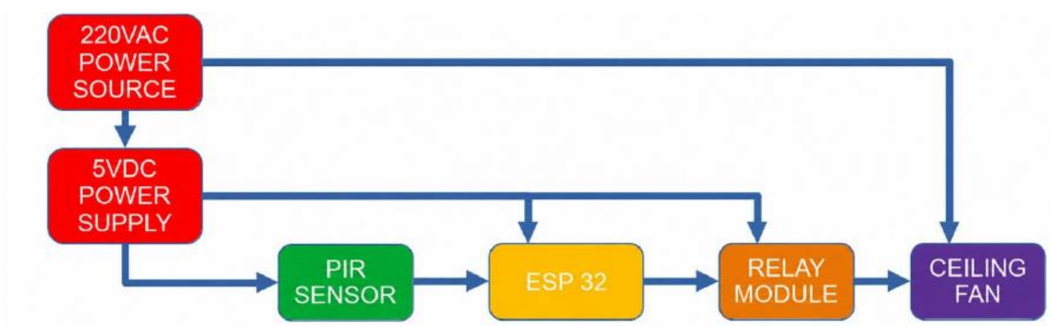

Figure 2. *Block diagram of the Smart Control System for Ceiling Fan.*

Research Locale

Development testing and user evaluation were conducted at B.A. Calamba National High School in Barangay Pangao-an, Magpet, North Cotabato, Philippines. The school was selected because it provided an actual classroom environment in which the system's detection, operation, and usability could be observed under normal institutional conditions.

Participants and Sampling Technique

Thirty teachers from B.A. Calamba National High School participated in the acceptability evaluation. They were selected through random sampling so that eligible teachers had an equal opportunity to participate. Teachers were considered appropriate evaluators because they regularly use classroom facilities and could assess the system's convenience, effectiveness, and safety in the intended environment.

Research Instrument

A researcher-developed questionnaire, reviewed by three experts, was used to evaluate the system. Technical performance was recorded using binary activation data, where 0 indicated deactivation and 1 indicated activation. Acceptability was measured through a five-point scale: 5 = Very Acceptable, 4 = Acceptable, 3 = Fair, 2 = Poor, and 1 = Not Acceptable. The instrument contained indicators for convenience, effectiveness, and safety.

Data Gathering Procedure

Permission to conduct the study was secured from the school principal. Informed-consent forms were distributed to the selected teachers, and the purpose and procedure of the evaluation were explained before questionnaires were administered. Technical trials were conducted by repeating human and animal movement activities at entrance and exit points across four detection zones. Completed questionnaires and trial results were collected, recorded, organized, and prepared for analysis.

Data Analysis

Frequency counts and percentage distributions were used to summarize technical detection performance and response distributions. Mode was used to identify the most frequently selected acceptability rating for each indicator and dimension. Detection accuracy was computed from ten repetitions per activity and zone.

Ethical Consideration

Participation was voluntary and based on informed consent. Respondents were informed about the study's purpose and how to complete the questionnaire. Survey responses were used only for research and project evaluation, and the presentation of results did not identify individual participants. Testing was conducted with attention to electrical safety, enclosed components, and supervised operation of the prototype.

RESULTS AND DISCUSSION

Design and Construction of the System

The completed system combined occupancy sensing, microcontroller-based decision-making, relay switching, remote access, and protective design. Its architecture allowed the PIR sensor to detect movement, the ESP32 to apply the programmed delay and control logic, and the relay to switch power to the ceiling fan. The enclosure reduced direct exposure to electrical components, while the cooling feature and shutdown logic were intended to reduce overheating during prolonged use. The five-week development period and total cost of PHP 8,039.00 demonstrate that the project was completed as an affordable school-based prototype.

Table 1. *Core system components and functions*

Component	Function
Seed Studio XIAO ESP32S3 Sense Kit	Processes sensor input, applies programmed timing, and controls the system.
PIR human-presence sensor	Detects human movement within the monitored area.
Relay module	Switches the 220-V supply to the ceiling fan on or off.
5-V DC power supply	Provides low-voltage power for the controller and sensor.
Mobile monitoring interface	Allows remote observation and control of system operation.
Plastic enclosure and cooling fan	Reduces contact risk and supports thermal management.

The configuration is consistent with smart-building automation research that treats sensing, control logic, actuation, and communication as interdependent system elements (Alsafery et al., 2023; Aziz et al., 2023). The prototype's successful construction also shows that commercially available components can be combined into a functional classroom energy-management device.

Technical Performance in Human-Presence Detection

Table 2 shows the results of ten repeated human-movement trials for each entry and exit condition. Entry detection was 100% across all four zones. Exit detection was also 100% in Zones 1 and 2 but decreased to 90% in Zones 3 and 4. In all animal-activity trials, the device remained deactivated, indicating that the system did not register the tested animal movement as human presence.

Table 2. *Human-presence detection accuracy by zone and direction*

Zone	Direction	Activations (n = 10)	Accuracy	Remark
1	Entrance	10	100%	Accurate
1	Exit	10	100%	Accurate
2	Entrance	10	100%	Accurate
2	Exit	10	100%	Accurate
3	Entrance	10	100%	Accurate
3	Exit	9	90%	Accurate
4	Entrance	10	100%	Accurate
4	Exit	9	90%	Accurate

The results indicate high detection reliability within the tested four-meter range. The slight decline in exit detection in the farther zones suggests that distance, angle, movement direction, or environmental conditions influenced sensor response. This pattern supports the literature emphasizing careful sensor placement and calibration (Chuah & Teoh, 2020; Wilhelm et al., 2020). Although the results were strong, the 90% exit detection in two zones shows that broader deployment would benefit from additional calibration and multi-condition testing.

Acceptability in Terms of Convenience

The convenience indicators were generally rated Very Acceptable. Eight of the ten indicators had a modal rating of 5, including ease of setup and operation, visibility of controls, availability of a user guide, maintenance, daily-routine integration, and improved comfort through automatic control. The results show that respondents found the prototype understandable and practical for classroom use.

Two indicators had a modal rating of 4: compatibility with different fan types and reduction in the need for constant checking or monitoring. These responses indicate that the system was convenient but not yet perceived as fully adaptable or completely independent of user supervision. Broader hardware compatibility and more dependable status reporting could improve confidence in routine use. Remote and centralized control remain important strengths because they reduce direct interaction with electrical equipment and give users greater flexibility (Fernando et al., 2025; Torres-Hernandez et al., 2025).

Acceptability in Terms of Effectiveness

Effectiveness was also rated Very Acceptable overall, with eight of ten indicators obtaining a modal rating of 5. Respondents particularly recognized rapid human-presence response, reduced unnecessary fan usage, classroom functionality, ventilation support, reduced manual control, reliable operation, and occupancy-based management. These ratings agree with the technical trial results and indicate that the system generally performed its intended automation functions.

Automatic shutoff when the room was unoccupied and operation with minimal errors or interruptions obtained a modal rating of 4. These lower ratings correspond with the missed exit detections in Zones 3 and 4 and identify consistency as the main performance area requiring improvement. Occupancy-based systems can provide meaningful energy savings, but their effectiveness depends on reliable detection and stable control logic (Elkhoukhi et al., 2025; Khan et al., 2024).

Acceptability in Terms of Safety and Overall Evaluation

Safety received a Very Acceptable overall assessment. Eight of ten indicators had a modal rating of 5, including safe operation, enclosed wiring and components, overheating prevention, safe standby power, ventilation openings, long-duration operation, installation safety, and warning signs. Respondents therefore recognized the prototype's protective enclosure and thermal-management features as important design strengths.

Avoidance of direct contact with electrical components and protection against electrical overload and short circuits received a modal rating of 4. These results indicate that additional insulation, fusing, surge or overload protection, and clearer physical separation between low- and high-voltage sections would strengthen user confidence. Such improvements are consistent with research identifying circuit protection, enclosure integrity, and thermal control as essential elements of safe connected appliances (Shokrollahi et al., 2024; Taylor et al., 2024).

Table 3. *Overall acceptability of the Smart Control System for Ceiling Fan*

Dimension	Indicators with Mode 5	Indicators with Mode 4	Overall Mode	Interpretation
Convenience	8	2	5	Very Acceptable
Effectiveness	8	2	5	Very Acceptable
Safety	8	2	5	Very Acceptable

Table 4. *Priority areas identified for system improvement*

Dimension	Indicator receiving Mode 4	Development implication
Convenience	Compatibility with different fan types	Develop adaptable connectors and settings for additional fan models.
Convenience	Reduced need for constant monitoring	Improve status feedback and automation reliability.
Effectiveness	Automatic shutoff in an unoccupied room	Refine sensor placement, timing, and exit detection.
Effectiveness	Consistent operation with minimal interruptions	Strengthen calibration and conduct longer-duration trials.
Safety	Avoidance of direct contact with electrical components	Improve insulation and physical separation of components.
Safety	Overload and short-circuit protection	Add dedicated protective devices and clearer safety indicators.

Taken together, the findings show that the Smart Control System for Ceiling Fan met its principal design and evaluation objectives. The system detected human presence accurately in most tested conditions, rejected the tested animal movements, and was viewed as convenient, effective, and safe. The lower-rated indicators do not negate the positive assessment; instead, they provide a focused agenda for technical refinement before wider installation.

CONCLUSION

The Smart Control System for Ceiling Fan was successfully designed, constructed, tested, and evaluated as an occupancy-based classroom automation device. By integrating a PIR sensor, ESP32 controller, relay switching, remote monitoring, enclosed circuitry, cooling, and programmed shutdown, the system provided automatic and responsive fan operation with limited manual intervention. Human entry detection was completely accurate in all four zones, while exit detection remained highly accurate, with only two zones recording 90%. The absence of activation during animal trials indicates that the prototype differentiated the tested human and nonhuman movement conditions. The system was rated Very Acceptable in convenience, effectiveness, and safety, demonstrating its practical value for energy conservation, comfort, and safer appliance control. The findings also identify compatibility, automatic shutoff consistency, user-contact protection, and overload protection as areas for further enhancement. Overall, the study contributes a functional and affordable prototype that may support classroom energy management and technology instruction while providing a foundation for more advanced smart-building applications.

Recommendation

Sensor positioning, sensitivity, detection range, and timing should be further calibrated through longer trials in rooms of different sizes and layouts. The control logic should be refined to improve exit detection and automatic shutoff consistency. Future versions should include stronger electrical safeguards such as dedicated fuses, overload and short-circuit protection, improved insulation, clearer separation of high- and low-voltage components, and more visible warning indicators.

The enclosure and connection system should be redesigned to accommodate additional ceiling-fan models, while the mobile interface should provide clearer real-time status, alerts, and manual override functions. Schools may pilot the system in selected classrooms while monitoring energy use, operational reliability, maintenance requirements, and user safety. Educators may also use the prototype as a practical learning resource in electronics, automation, programming, energy conservation, and sustainable technology.

Future research should evaluate the system using larger groups of users, extended operating periods, actual electricity-consumption measurements, and varied environmental conditions. Subsequent development may integrate multiple sensing technologies, cloud-based data logging, artificial intelligence for occupancy prediction, and renewable power sources such as solar energy.

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