Real Time Object Detection for Sustainable Air Conditioner Energy Management System

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***Abstract*—Air conditioning has become indispensable for maintaining human comfort, especially during hot weather, as people rely on it to stay cool indoors. However, the long-term and uncontrolled use of air conditioners has significantly contributed to climate change and environmental degradation. The extensive use of air conditioners releases more carbon dioxide, a greenhouse gas, into the atmosphere, exacerbating global warming and leading to adverse climate impacts. The proposed sustainable air conditioning energy management system aims to address this issue by optimising air conditioner use while minimising its environmental footprint and mitigating climate change. Current air conditioning systems in offices, buildings, and homes typically rely on fixed temperature settings, leading to excessive energy consumption and increased greenhouse gas emissions. Existing solutions, such as fixed timers, manual timer settings, and physical controllers, are ineffective as they cannot dynamically respond to changes in environmental conditions, such as room occupancy and activity levels, resulting in significant inefficiencies and environmental hazards. To overcome these limitations, the proposed system introduces an innovative solution using software engineering technology, specifically real-time object detection, to control air conditioning energy usage. This approach redefines air conditioning management by allowing the system to dynamically adapt to room occupancy, environmental factors, and activity levels, ensuring the right amount of cooling is delivered at the right time. This method represents a concrete and effective response to climate change challenges and demonstrates a commitment to creating a sustainable and environmentally responsible future.**

Keywords*—Deep learning; energy consumption; energy efficiency; global warming; climate change; real-time object detection; Air conditioner optimization; smart meter; environmental footprint; climate action

I. Introduction

Climate change affects every country globally, disrupting economies and impacting vulnerable populations. Climate change affects weather patterns, rising sea levels and more frequent extreme weather events. Notably, a critical concern within this context is the high energy consumption levels and carbon emissions. Sustainability has emerged as a paramount human priority in the increasingly advanced world. Taking this into account, the United Nations adopted the Sustainable Development Goals (SDGs) in 2015 to protect the planet [1].

Sustainable development and reducing energy consumption are two of the project's main objectives. Therefore, the project aligns with SDG 13, which addresses climate change, and SDG 11, which aims to achieve sustainable cities and communities. Goal 13 emphasizes the urgency of acting against climate change, while Goal 11 aims to create inclusive, safe, resilient, and sustainable cities [2]. To achieve these goals, the project sets out to develop a sustainable air conditioning system that incorporates cutting-edge software engineering technology, specifically real-time object detection.

Driven by artificial intelligence (AI) and machine learning, real-time object detection has made significant progress, especially in the field of deep learning. This advanced technology enables computers to identify and locate objects within images or live video feeds swiftly and accurately. Deep learning is a subset of machine learning using convolutional neural networks inspired by the architecture of the human brain at its core. By training these deep neural networks on extensive datasets, computers gain the ability to discern intricate patterns and features, enabling them to recognize and categorize objects in real-time scenarios.

By incorporating real-time object detection, the air conditioner energy management system adapts dynamically to the environment, optimizing energy usage with precision. Unlike traditional technology, the system can automatically adjust the temperature based on the activity levels and the number of occupants in a room. This will ensure that air conditioning energy is not wasted and protect the environment by optimizing energy use. With real-time and remote-control capabilities, the system provides users with more convenience and control. Users can easily adjust temperature settings and ensure optimal energy usage, especially when the room is unoccupied. This user-friendly solution encourages sustainable choices effortlessly.

This project aims to create innovative environmental sustainability solutions and embody buildings by solving the issue of climate change. The objective of this project is to improve existing solutions that have limited function. By optimizing energy usage, detecting human activity and occupancy, and utilizing hardware like Cameras, Smart Sensors, and Smart Remote Controllers, this project aims to use technology to build a more sustainable future.

A. Problem Statement

The current system has several problems that must be rectified. Since it controls the temperature of the air conditioner largely with an infrared remote control, its portability and accessibility may be limited as a result. Furthermore, the focus of this research is on improving user comfort rather than improving energy efficiency, which is a vital component of any smart home system. In the second article, the system's security layer is entirely made up of authentication and authorization functions. Furthermore, it is only compatible with the Android operating system, which implies that only Android users can use it. Third, the existing air conditioner energy management system is based on an outdated algorithm known as YOLOv3 (You Only Look Once), which lacks the enhancements found in the most recent version.

Furthermore, the existing system's technique for controlling air conditioners is limited to counting the number of persons in a room and is unable to recognize individual room activities for the purpose of providing precise temperature adjustment. There is also a method known as deep learning detection, which is based on the behavior of a single resident. It is vital to consider the presence of multiple occupants to increase overall accuracy and ability. These constraints highlight the need for an improved air conditioning management system capable of overcoming these constraints while still ensuring portability, security, accessibility, and efficacy. The proposed improvements are intended to reduce air conditioner energy use for a wide variety of users, including those in homes, businesses, and buildings.

B. Research Objectives

This research paper seeks to fulfil its objectives by addressing three key questions. Firstly, it aims to study existing air conditioning systems to understand how real-time object detection and energy management can be applied within these systems. This involves a thorough analysis of current technologies and methodologies to identify opportunities for improvement. Secondly, the research focuses on designing and developing a sustainable air conditioner energy management system that not only reduces energy consumption but also promotes a more sustainable environment. Lastly, the paper will conduct rigorous testing to ensure the effectiveness of the newly developed air conditioner energy management system in real-world scenarios. This testing is crucial to validate the system's ability to optimize energy consumption, thereby contributing to a reduction in greenhouse gas emissions and fostering a more sustainable future.

II. Literature Review

The Air Conditioner (AC) system is essential for providing human comfort, yet it also contributes to the rising outdoor temperatures seen because of climate change. This creates a concerning and self-perpetuating cycle, with the CO2 emissions from AC units only exacerbating the issue. Considering this, numerous researchers have proposed solutions to reduce the contribution of AC systems to climate change. Thus, this literature review explores the approaches taken in prior research on Air Conditioner Energy Management Systems.

The current air conditioner energy management system has integrated an IoT Smart House System emphasizing the efficient management of indoor environmental conditions to enhance occupants' thermal comfort during leisure activities. It involves analyzing indoor environmental data by sensors for CO2 and particulate matter (PM) and carefully selecting measurement nodes to ensure system stability and reliability. It uses an infrared remote control to control the temperature of the air conditioner. The focus of this system is the application of IoT and user comfort [3].

Another current system, HEMS-IoT (Home Energy Management Systems-IoT), integrates big data and machine learning to manage home energy for comfort, safety, and savings. Machine learning algorithms, such as J48, are used to analyze energy consumption and user behavior patterns, while RuleML and Apache Mahout help create energy-saving recommendations based on user preferences. A case study validates HEMS-IoT's effectiveness in reducing energy consumption while maintaining home comfort. The security layer of the HEMS-IoT ensures the confidentiality and integrity of data by employing two fundamental security components, which are authentication and authorization. While at the presentation layer, HEMS-IoT is working on the Android operating system, which is a constraint to other users such as Apple iOS [4].

Another current solution for reducing energy consumption and sustainability in smart buildings is integrating deep learning and the Internet of Things (IoT). Recognizing the significance of HVAC systems in energy consumption, Elsisi et al. proposed a deep learning-based people detection system employing YOLOv3 to count occupants within specific areas of smart buildings accurately. This innovative system optimizes the operation of air conditioners based on real-time occupancy data, contributing to enhanced energy efficiency. Moreover, the IoT platform's dashboard facilitates data visualization and informed decision-making regarding energy consumption [5]. The current air conditioner energy management system relies on an outdated YOLO deep learning algorithm (YOLOv3) for object detection. However, YOLOv8, the latest version, offers enhancements such as anchor-free, improved CNN architecture, more efficient, and improved average precision score [6].

Furthermore, an existing system employs a data-driven deep learning method employing a convolutional neural network (CNN) model to detect various occupancy activities. The performance of this deep learning framework was assessed in an office space within a case study building, initially identifying activities like 'standing,' 'sitting,' 'walking,' 'napping,' and 'none,' even for detecting no occupancy. This approach achieved an average detection accuracy of 80.62% during live testing, highlighting its potential for real-time monitoring. The Deep Learning Influenced Profile (DLIP) was also evaluated in estimating sensible heat gains driven by occupancy and CO2 concentrations [7].

Machine and deep learning methods are highly effective for building energy prediction due to their advantages over traditional models, including reduced data requirements and faster model development. Machine and deep learning excel in energy forecasting, thermal comfort prediction, and occupancy detection. Deep understanding is gaining popularity in these fields thanks to increased data availability and improved algorithms. Some studies suggest combining deep and traditional machine learning techniques can further enhance application performance [8].

III. Methodology

This real-time object detection of a sustainable air conditioning energy management system will use a life cycle (SDLC) as a prototype of the research method. With this approach, the research process is considered through various stages, each of which contributes to the development of this system. Using the SDLC framework can make research objectives more precise and more organized.

Fig. 1 shows the phase for this research. The research methodology includes requirement gathering, design system architecture, building prototype, and testing.

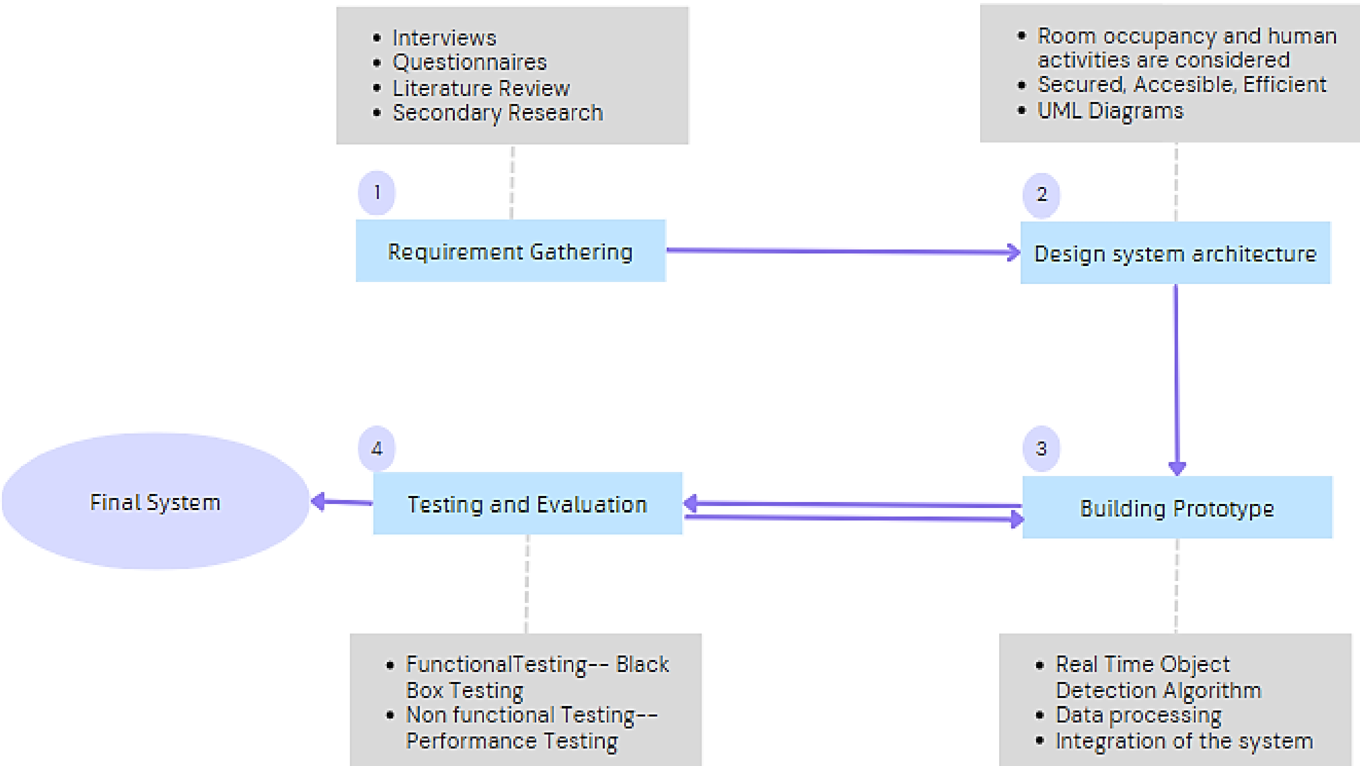

Fig. 1. SDLC prototype.

A. Phase 1: Requirements Gathering

Fig. 2 shows different preferences among respondents when adjusting air conditioner settings, preferences vary among respondents. A significant 76% prefer manual adjustments, while 39.6% use scheduled timers. Technological solutions are also employed: 14% use Wi-Fi remote control, 11% use smart thermostats, and 1% each use occupancy sensors and smartphone controls. Additionally, 2% utilize weather-based control, reflecting a blend of manual and tech-driven methods among the surveyed population.

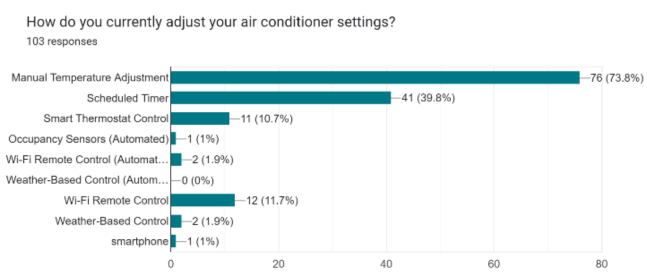

Fig. 2. Common air conditioner settings.

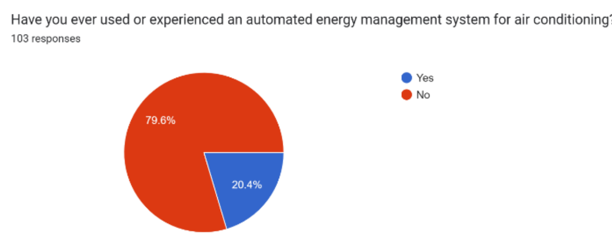

Fig. 3. Automated energy management system for air conditioning engagement report.

Fig. 3 shows that 79.6 per cent of respondents have not used or experienced an automated energy management system for air conditioning, while 20.4 per cent have reported having engaged with such automated systems. This distribution underscores that a significant majority of the surveyed population may not have had exposure to or utilized automated energy management systems in the context of air conditioning, highlighting potential opportunities for awareness and adoption of these technologies.

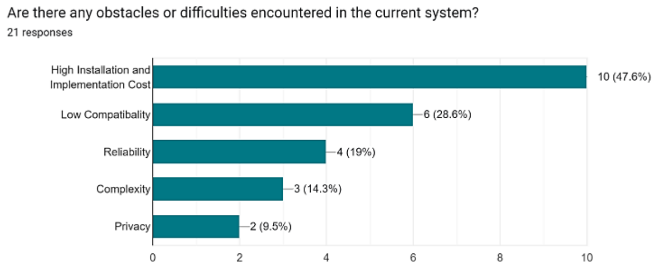

Fig. 4. Difficulties encountered in the current system report.

Fig. 4 shows that when asked about obstacles or difficulties encountered with the current air conditioning system, respondents identified several challenges. The most cited issue, chosen by 10 individuals, is the high installation and implementation cost, indicating a financial barrier that some face in adopting or maintaining their current system. Additionally, 6 respondents express concerns about low compatibility, highlighting challenges in integrating the system with other technologies or components. Four participants note reliability as an obstacle, suggesting issues with system dependability. Three respondents find complexity to be a challenge, indicating difficulties in navigating or understanding the operational intricacies of their air conditioning setup. Lastly, privacy is a concern for two individuals, suggesting a consideration of data security and personal information in the context of their air conditioning system. This diverse set of challenges provides valuable insights into the various hurdles faced by users in their experiences with current air conditioning systems.

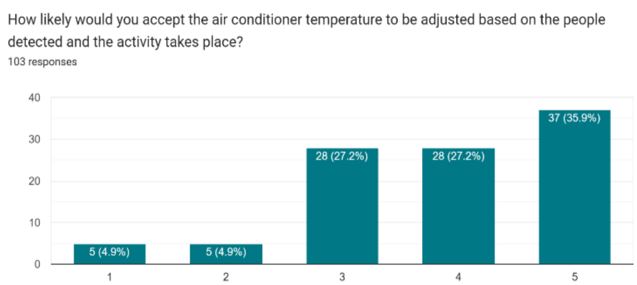

Fig. 5. Smart air conditioning acceptance rate.

Fig. 5 shows the data from respondents on their likelihood of accepting air conditioner temperature adjustments based on detected people and activities presents an interesting trend on the linear scale. A substantial 35.9 per cent expressed a high likelihood (rated 5) of accepting such adjustments, indicating a significant openness to embracing a system that adapts based on occupancy and activities. Furthermore, 27.2 per cent each chose the ratings of 3 and 4, suggesting a considerable portion with a moderate to high inclination. Meanwhile, 5 of the respondents each chose the ratings of 1 and 2, indicating a small minority expressing a lower likelihood. This data reflects a generally positive reception towards the idea of dynamically adjusting air conditioner temperature based on detected people and activities, with a notable majority leaning towards acceptance of such a system.

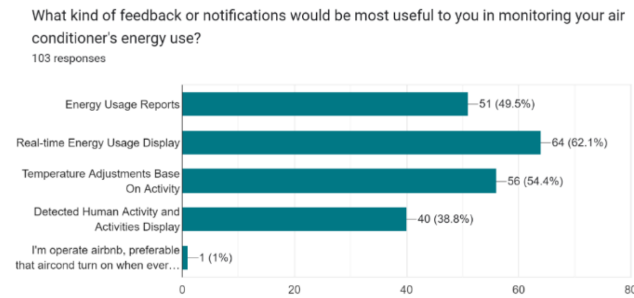

Fig. 6. Responses on preferred feedback for monitoring energy usage.

Fig. 6 shows in response to the inquiry about the most useful feedback or notifications for monitoring air conditioner energy use, most respondents, 62.1 per cent (64 individuals), express a preference for a real-time energy usage display. This indicates a strong interest in receiving immediate and transparent information about the energy consumption of their air conditioning system. Additionally, 54.4 percent (56 individuals) prioritize notifications related to temperature adjustments based on detected activities, highlighting a desire for a dynamic and responsive climate control system.

Moreover, 38.8 per cent (40 individuals) find value in notifications related to detected human activities and activities display, emphasizing the importance of understanding and being informed about the environmental conditions driving air conditioning usage. One additional response provides a unique perspective, as the respondent, operating an Airbnb, prefers the air conditioner to automatically turn on when human presence is detected and turn off when the guests leave, with the goal of optimizing energy savings. These insights collectively illustrate a strong demand for real-time information and dynamic control features that align with user preferences and enhance energy efficiency in the context of air conditioning systems.

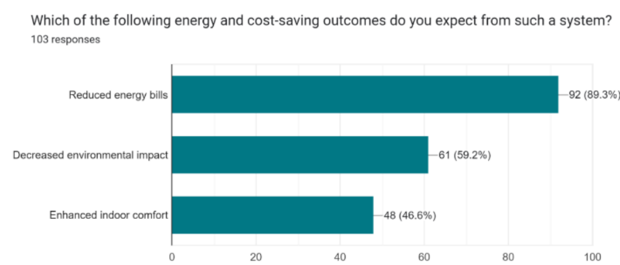

Fig. 7. Expectations of the system.

Fig. 7 shows the expectations regarding energy and cost-saving outcomes from the proposed system reveal a strong consensus among respondents. The most prominent expectation, chosen by 89.3 per cent of participants (92 individuals), is the anticipation of "Reduced energy bills." This aligns with a primary goal for many users, emphasizing the economic benefits associated with energy savings.

Additionally, 59.2 per cent of respondents (61 individuals) expressed the expectation of a "Decreased environmental impact," reflecting a heightened awareness and concern for sustainability and environmental considerations. Furthermore, 46.6 per cent of participants (48 individuals) anticipate "Enhanced indoor comfort" as an outcome. This suggests that, beyond cost savings, respondents value the potential for improved comfort and well-being within their living or working spaces.

These expectations collectively underscore a strong interest in the practical and environmental benefits that respondents associate with the implementation of energy management systems in their air conditioning setups.

B. Phase 2: Design System Architecture

A Rich Picture is created by drawing the system with few instructions, often containing aspects such as architecture, processes, climate, people, issues stated by individuals, and conflicts. While lengthy writing is avoided, some Rich Pictures may include textual elements. The goal is to avoid mimicking organized diagrams such as Theory of Change maps while encouraging flexibility. Arrows can be used to express causal links in Rich Pictures. The analysis of a Rich Picture occurs during the process of drawing and discussing, making these diagrams a dynamic and flexible tool for understanding complex systems [9].

A Rich Picture shown in Fig. 8 is created by drawing the system with few instructions, often containing aspects such as architecture, processes, climate, people, issues stated by individuals, and conflicts. While lengthy writing is avoided, some Rich Pictures may include textual elements. The goal is to avoid mimicking organized diagrams such as Theory of Change maps while encouraging flexibility. Arrows can be used to express causal links in Rich Pictures. The analysis of a Rich Picture occurs during the process of drawing and discussing, making these diagrams a dynamic and flexible tool for understanding complex systems [9].

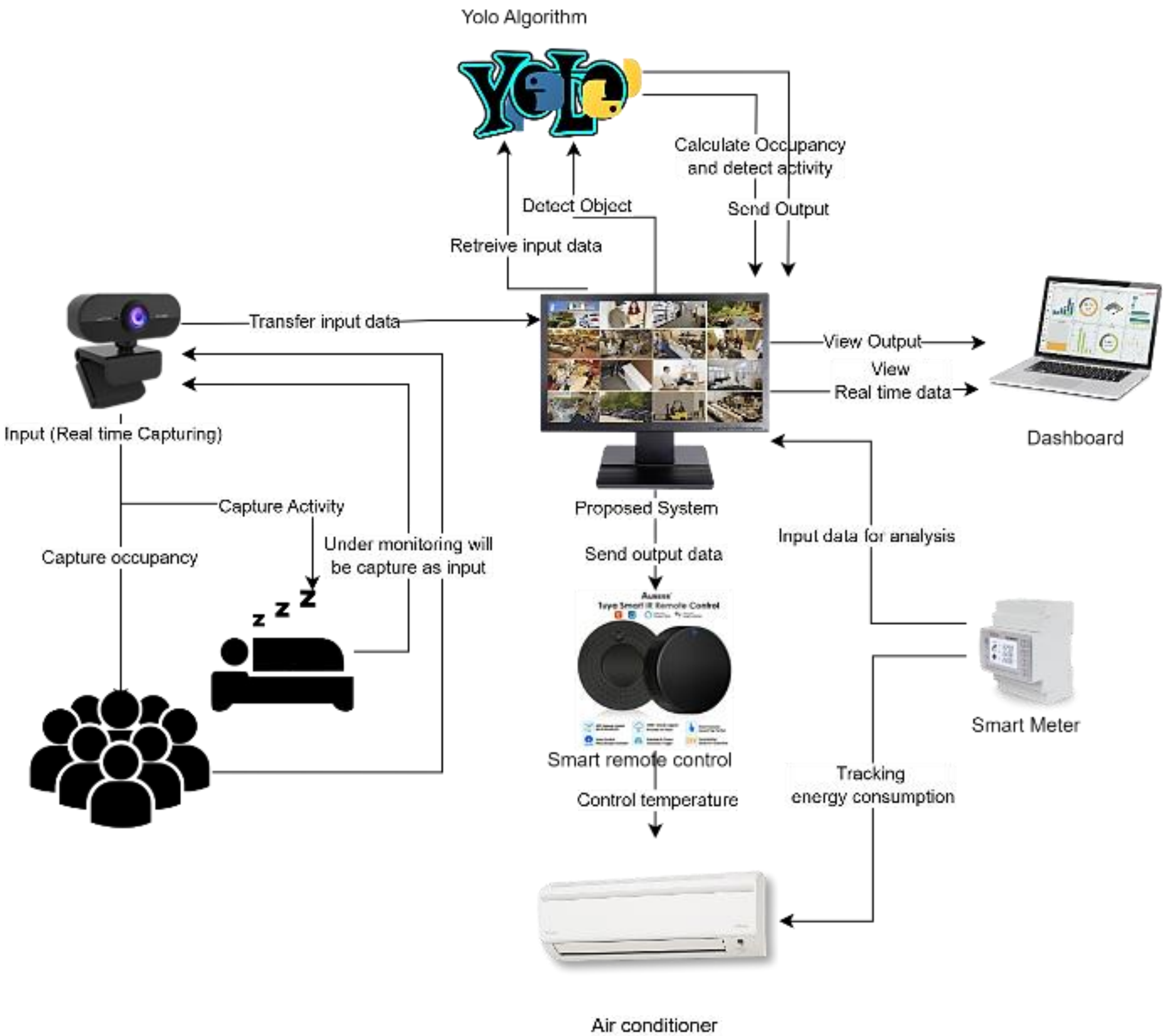

Fig. 8. Rich picture diagram.

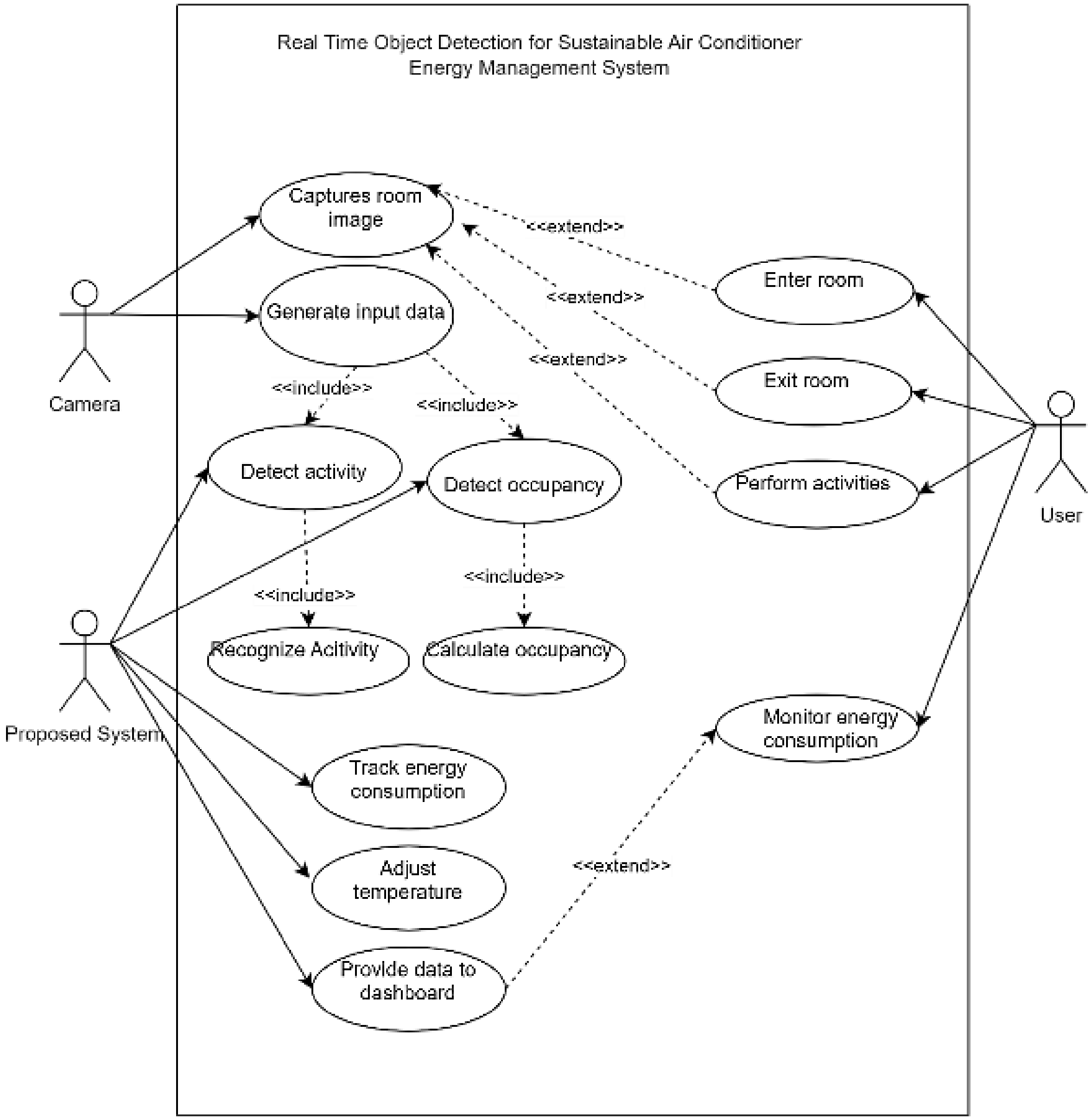

Fig. 9. Use case diagram of the proposed system.

Fig. 9 shows a use case diagram of the system. Use-case diagrams are essential UML tools for modelling system behaviour and capturing requirements. They provide a high-level overview of the system's functions, scope, and interactions with actors, illustrating what the system does without detailing underlying functions. These diagrams help define the context and requirements of the entire system or individual components. Typically created early in a project, they serve as valuable references throughout development, representing complex systems in one or multiple diagrams.

Fig. 10 shows the Class Diagram for the system comprises several distinct classes, each encapsulating specific functionalities within the overall architecture. The "Occupancy Detector" class is responsible for detecting and monitoring occupancy within the designated space, featuring attributes related to detection sensitivity and methods for processing occupancy data. The "Dashboard" class manages the graphical user interface, facilitating user interaction and real-time monitoring of system data. The "Account" class oversees user accounts, storing credentials and preferences, while the "Location" class represents spatial information tied to the physical context of the system. The "Smart Meter" class monitors and records energy consumption data, including parameters for readings. Lastly, the "Temperature Adjuster" class manages temperature settings, incorporating data related to control parameters, user preferences, and methods for adjusting temperature settings. Together, these classes define the static structure and responsibilities of key system components, providing a comprehensive overview of their interactions and collaborations. The Class Diagram serves as a visual guide to understanding the system's architecture and behaviour.

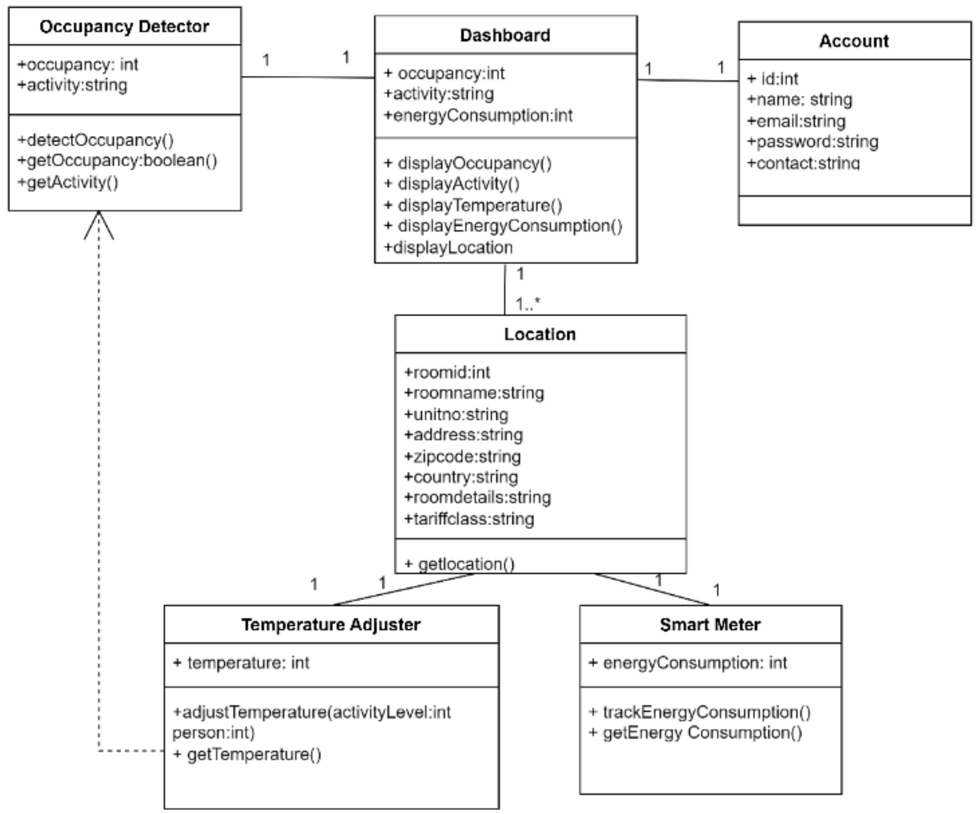

Fig. 10. Class diagram of the proposed system.

C. Phase 3: Building Prototype

Roboflow is employed to create dataset. The five classes in the dataset includes: sleeping, sitting, standing, moving, and exercising. There are a total of 2500 images and each class has an average of 250 pictures. All the images are annotated with the respective classes. 1855 (74%) images are used as train set, 448 images (18%) are used for valid set, and 197 images (8%) are used for testing purposes as shown in Fig. 11. Splitting the data into training, validation, and testing sets is important for developing an effective machine learning model.

Google Collaboratory is employed for the training of the YOLOv8 model. By leveraging Colab's infrastructure, accelerated processing capabilities are utilised, allowing for efficient training of the YOLOv8 model without the need for substantial local computational resources.

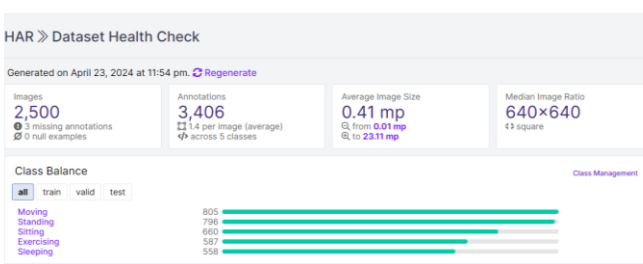

Fig. 11. Shows the health check of the dataset.

Fig. 12. YOLOv8m model confusion matrix.

As shown in Fig. 12, a high value on the diagonal 0.82 for “Sitting”, 0.82 for “Sleeping” and 0.80 for “Exercising” means that the model accurately predicted that class most of the time. In contrast, lighter off-diagonal cells indicate misclassifications, such as “Standing” being incorrectly predicted as “Moving”. The “background” class suggests that the model also tries to differentiate between specific activities and a lack of activity. This matrix can quickly reveal which classes are being confused by the model, guiding further improvements in its performance.

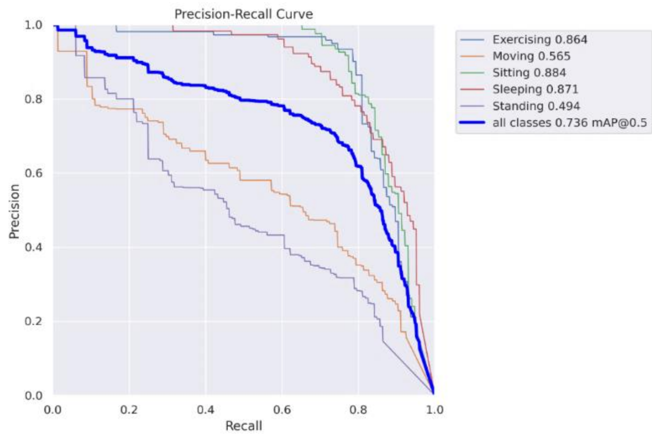

Fig. 13. YOLOv8m precision-recall curve.

The provided Precision-Recall curve in Fig. 13 evaluates a classification model's performance across five classes: “Exercising”, “Moving”, “Sitting”, “Sleeping”, and “Standing”. Precision generally decreases as Recall increases, reflecting the trade-off between accuracy and capturing all positive instances. “Sitting” exhibits the highest performance with an AUC (Area under curve) of 0.894, while “Standing” appears more challenging with a lower AUC of 0.494. The overall mAP at IoU (Intersection over Union) 0.5 is 0.736, indicating reasonable accuracy but room for enhancement, particularly in classes with less favorable Precision-Recall trade-offs.

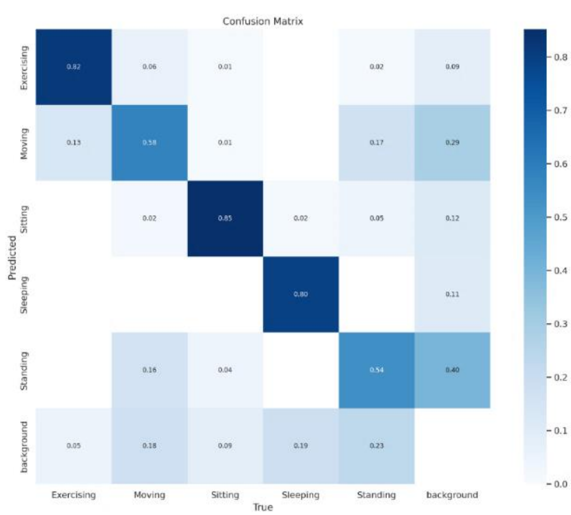

Fig. 14. YOLOv8x confusion matrix.

As shown in Fig. 14, a high value on the diagonal 0.85 for “Sitting”, 0.82 for “Exercising” and 0.80 for “Sleeping” means that the model accurately predicted that class most of the time. In contrast, lighter off-diagonal cells indicate misclassifications, such as “Standing” being incorrectly predicted as “Moving”. The “background” class suggests that the model also tries to differentiate between specific activities and a lack of activity. This matrix can quickly reveal which classes are being confused by the model, guiding further improvements in its performance.

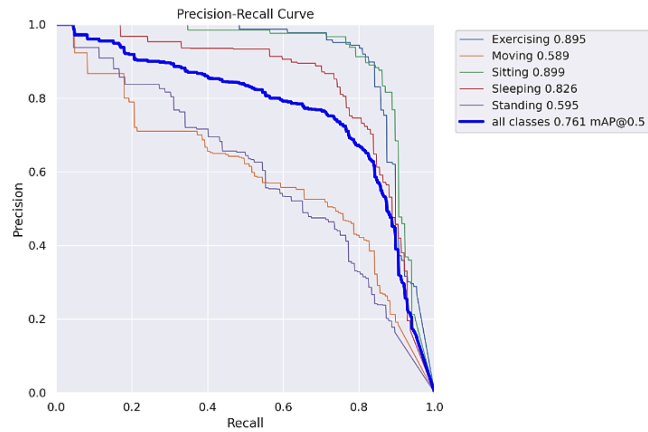

Fig. 15. YOLOv8x precision-recall curve.

The provided Precision-Recall curve in Fig. 15 evaluates a classification model's performance across five classes. Precision generally decreases as Recall increases, reflecting the trade-off between accuracy and capturing all positive instances. “Sitting” exhibits the highest performance with an AUC of 0.899, while “Moving” appears more challenging with a lower AUC of 0.589. The overall mAP at IoU 0.5 is 0.761, indicating reasonable accuracy but room for enhancement, particularly in classes with less favorable Precision-Recall trade-offs.

Based on these comparisons, the YOLOv8x model, which attained an accuracy of 76%, has been selected as the model for the Real-Time Object Detection system.

D. Phase 4: Testing and Evaluation

The testing plan encompasses both functional and non-functional aspects, including user registration, login, room management, profile editing, and system performance evaluations. Entry and exit criteria are established to ensure the proper setup and conclusion of the testing process, with a focus on achieving reliable and accurate system performance. Overall, the testing phase aims to validate the system's functionality and ensure its seamless operation in real-world scenarios, with detailed documentation provided to support the testing outcomes. The result from the usability testing shows that the system design is easy to use for the target user.

IV. Discussion

The project successfully addressed the research question, “What software engineering method can be applied in the Air Conditioner Energy Management System to help reduce energy consumption?” by adopting YOLOv8 for real-time object detection and energy management. A comprehensive study of existing systems led to the development of a prototype integrating these functionalities.

To answer, “How to create a sustainable air conditioner energy management system that reduces energy consumption and contributes to a sustainable environment?” various tools were explored, system architecture was designed, and a user-friendly, efficient prototype was built as shown briefly in Fig. 16, Fig. 17, and Fig. 18.

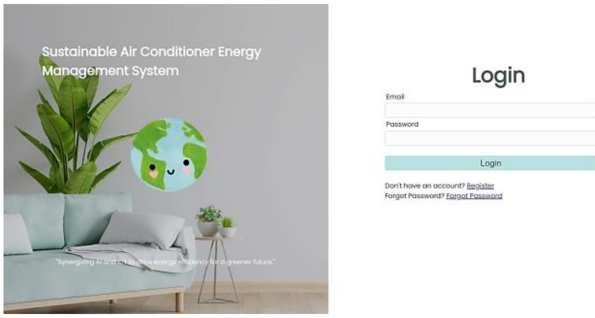

Fig. 16. Shows a screenshot of login page.

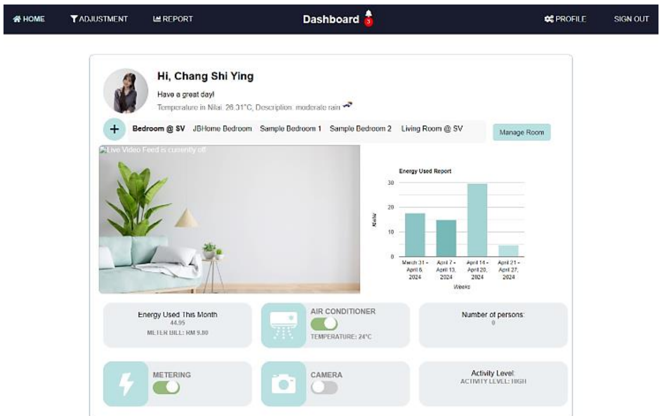

Fig. 17. Shows a screenshot of the home page (main dashboard).

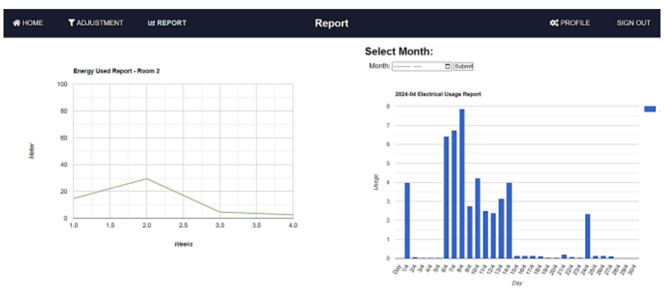

Fig. 18. Shows a screenshot of the report page displaying real-world room smart meter data.

The project also evaluated the question, "How effective is the developed air conditioner energy management system in optimizing energy consumption in real-world scenarios?" by installing a smart meter to measure energy consumption before and after implementation. Testing validated the system's effectiveness and ensured seamless website functionality.

V. Results

The project successfully addressed the limitations of the existing system by adopting YOLOv8, offering significant improvements over the outdated YOLOv3 algorithm. YOLOv8 enabled more accurate real-time object detection and better tracking of room occupancy and activities, resulting in more precise temperature adjustments.

A key improvement lies in energy consumption management. The system optimized air conditioner energy usage by adjusting temperature settings based on real-time occupancy and activity data. This was a significant step forward compared to the previous system, which only counted the number of people in the room without accounting for specific activities. As a result, the new system reduced unnecessary energy consumption by avoiding overcooling or overheating the space.

The system also expanded accessibility by moving beyond Android-only compatibility, offering support for multiple operating systems and devices. Real-world testing confirmed these improvements. While no direct comparison with other systems was made due to project time limitations, the system enables users to monitor energy consumption through smart meter tracking, helping them avoid overuse. Website testing validated the seamless integration of the UI with smart home devices and common air conditioner models. The dashboard provides users with clear, actionable insights into their energy consumption, allowing for more informed energy management decisions.

However, limitations such as budget constraints impacting hardware performance, particularly in real-time object detection and dataset training, hindered optimal system performance. These challenges necessitated compromises in hardware capabilities and cloud platform usage, highlighting areas for improvement to enhance future project outcomes [10].

VI. Conclusion and Future Work

In conclusion, the developed system is deemed to effectively address the challenges outlined in the problem statement.

Enhancing the system's hardware infrastructure involves two key upgrades. First, investing in higher-performance GPUs, made possible with increased funding, accelerates model training and improves real-time object detection, boosting responsiveness and accuracy. Second, acquiring advanced cameras with superior low-light performance, faster capture speeds, and 360-degree adjustability enhances object detection, particularly in challenging lighting conditions and provides wider coverage.

Expanding the dataset and annotation process is crucial with increased resources. Additional time for dataset collection and annotation ensures a diverse range of images, improving the system's ability to accurately detect and classify objects. Including higher angle shots offers a broader perspective, further enhancing accuracy.

Strengthening system security is imperative for safeguarding user data. In addition to existing measures, implementing Secure Video Transmission, Camera Authentication, and Multi-Factor Authentication (MFA) bolsters defences against unauthorized access and cyber threats.

Integrating voice control or voice recognition based on user surveys enhances user experience and system usability. Voice commands for system functions streamline interactions, making the system more accessible and intuitive.

Future enhancements based on user feedback include refining the room selection dashboard with interactive buttons displaying meter data and editing options, integrating meter statistics directly into each room, allowing fixed temperature settings without camera detection, introducing usage limits with notifications, and adding a leaderboard for energy-saving competition among users.

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