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An AI-Based Smart CCTV System for Classroom Energy Monitoring and Management

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Abstract: ***Electricity wastage in the educational institutions is a problem that is often ignored, wherein ceiling fans are often not switched off even after classrooms are vacated. Manual monitoring of such situations is not efficient, and can be a challenge to keep up over a large campus, leading to unnecessary energy consumption. Although a number of occupancy detection systems based on computer vision have been proposed, most of them only deal with the recognition of the human presence; there is little dealing with the verification of the true operating state of electrical appliances. To overcome this drawback, this paper introduces an AI-based smart classroom monitoring mechanism based on the existing CVC system infrastructure, capable of detecting the human presence and ceiling fan operation and report them, in real time. The proposed system is constructed according to a modified YOLOv8 deep learning system with a custom classroom dataset for a two-object detection. In addition, a simple motion analysis technique is used within the region detected fan to identify if the fan is running or stationary. By combining the detection of people with the verification of the state of the appliances, the system added a context-aware decision mechanism that generates alerts only when a fan is found to be operating in an empty classroom. Such an approach helps in reducing false alarms while also focused on the direct root cause of wastage of electricity. The proposed solution is cost-effective, scalable and can be deployed in smart classrooms and academic campuses to aid efficient energy management.***
Keywords: Deep Learning, Smart Classroom, Computer Vision, YOLOv8, CCTV Monitoring, Energy Conservation.

I. INTRODUCTION

The rapid growth of educational infrastructure has significantly increased the demand for electrical energy in academic institutions. Modern classrooms are commonly equipped with electrical appliances such as ceiling fans to provide a comfortable learning environment. However, this convenience often results in an unnoticed issue—unnecessary energy wastage. In many institutions, ceiling fans continue to operate even after classrooms become vacant, especially once lectures are over [20]. Although leaving a single fan switched on may appear insignificant, its repeated occurrence across multiple classrooms and over long durations leads to considerable financial loss and environmental impact [2],[4]

At present, energy conservation in classrooms largely depends on manual supervision by staff or faculty members. Such an approach is difficult to sustain in large campuses, as regular monitoring of every classroom is time-consuming and often overlooked. While artificial intelligence–based occupancy detection systems have been explored in recent years [1].[2],[4], most existing solutions focus only on identifying human presence and assume that appliance usage automatically corresponds to occupancy. As a result, these systems fail to verify whether electrical appliances are actually operating, limiting their effectiveness in practical energy management [3],[9].

To overcome these limitations, this paper proposes Class-Sense, an AI-based smart classroom monitoring system that utilizes existing CCTV infrastructure to enable intelligent and context-aware energy monitoring. The proposed system combines human presence detection with appliance status verification, allowing more accurate identification of electricity wastage scenarios. By integrating computer vision techniques with deep learning–based object detection, the system provides a practical and automated solution for reducing unnecessary power consumption in educational environments [24].

A. Objectives of the Proposed System

The primary objective of this work is to develop an automated framework that minimizes human involvement in classroom energy management. The system is designed to accurately detect both human presence and the operational status of ceiling fans using computer vision techniques. By correlating these two parameters, the proposed system generates reliable triggers for energy-saving actions, ensuring that electricity is consumed only when it is genuinely required.

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B. Organization of the Paper

The remainder of this paper is organized as follows. Section II presents the proposed system architecture and overall design framework. Section III explains the methodology adopted for human and fan detection, along with the decision-making process. Section IV discusses the experimental results and key observations obtained from system evaluation. Finally, Section V concludes the paper and outlines the future scope of the proposed system.

II. PROPOSED SYSTEM ARCHITECTURE

The proposed Smart Class Sense system is designed to offer an intelligent and automated solution for reduction of electricity wastage in classroom environments. The architecture exploits the existing CCTV infrastructure and combines the computer vision with the deep learning techniques to allow monitoring of the context aware energy [2],[24]. The system is constantly monitoring the activity in the classroom while analyzing the human presence and checking the operation of appliances, also generating the alert only when it identifies an unnecessary electricity consumption. The general architecture is sequential and modular, which guarantees reliability, scalability and easy deployment in a real learning environment (academics).

A. System Overview

The system begins by recording live video in classrooms from CCTV cameras installed in the classrooms. It processes each frame using OpenCV in order to use it for a deep learning model. Then, it uses a detector based on the YOLOv8 to determine whether there are people in the room [5],[17],[19]. If people are found, it is deemed that the room is busy and nothing else does anything.

If no people are in sight, the system determines if the ceiling fans are functioning. It uses a custom-trained fan detector to detect fans in the frame. Then it determines whether the fan is spinning or merely sitting still, or else it will cause a false alarm. An alarm is only given out when a fan is in operation in an empty classroom, which helps prevent the waste of electricity.

B. Representation of Workflow

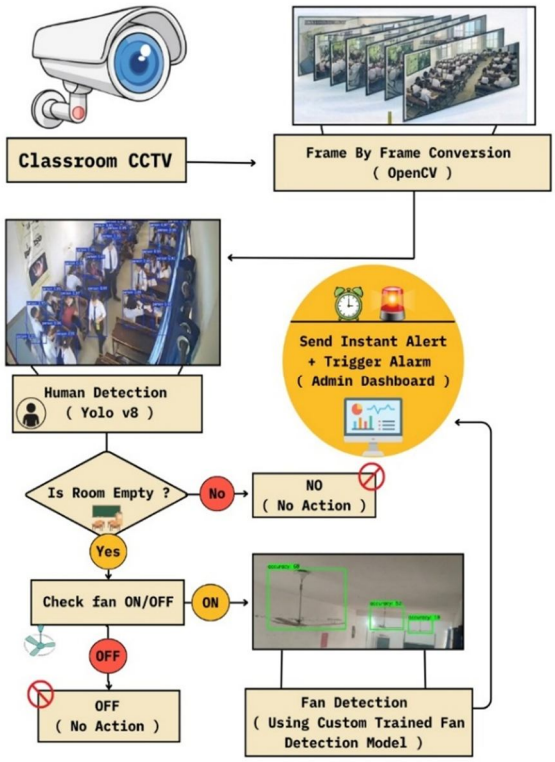


Fig. 1. Flowchart of proposed Smart Class Sense system.

The flowchart as shown in Fig. 1 presents the working of the system on a step-by-step basis. First of all, the system continues to record video from CCTV cameras in the classroom. It then converts the video into individual pictures, or frames, using OpenCV, in order to analyze it immediately. Each frame is passed through the YOLOv8 model in order to verify if there are any people in the room.

If people are found however, the system does not continue to check more frames and does not sound any alarms. If no one is in the room, the next step of the system is to look for ceiling fans using a special fan detection model, which we trained. After it finds a fan, it tests to see whether that fan is truly working or not by checking for the presence of motion. If the fan is turned off nothing happens. If it detects the fan is running when the classroom is empty, the system immediately sends an alert to the admin dashboard allowing the problem to be fixed quickly.

C. Comparison with Traditional Approaches

Table I
Comparison of Traditional Approach and Smart Class Sense System

Aspect	Traditional Methods	Smart Class Sense
Object Detection	Human	Human + Fan
Appliance Verification	Not included	Explicit fan detection
Context Awareness	Very Low	High
Cost Effectiveness	Moderate	Very Low

Table I reveals the major differences between old methods in monitoring energy as well as the new Smart Class Sense system.

Old methods typically require people to check or only realize if someone is in a room [1], [3], [4]. They do not see use appliance, such as the fans, are turned on [2], [20]. Because of that, they don't understand whole situation and miss effective waste of real power. In contrast, the new system is able to detect both people and ceiling fans simultaneously. Making the fan on or off known allows the system to make accurate decisions. It also uses the cameras that are already in the room, so it stays cheaply while nonetheless knowing what's really going on [9]. This demonstrates Smart Class Sense is a better, easier and more efficient approach to classroom energy management.

D. Important Architectural Benefits

The proposed design ensures that alarms occur only when they genuinely belong; that is, only when a real alarm is present and not as a false alarm that does not actually need to be acted on. The system is constructed in separate parts so that it is easy to increase the number of electrical appliances later. Also, as it utilizes existing infrastructure, it can be deployed on a large scale in schools without requiring large new hardware investments.

III. METHODOLOGY

The Smart Class Sense system has a clear step-by-step method for reducing extra electricity usage in schools [2], [4], [24]. Its primary objective is to discover when ceiling fans keep running when nobody is in the room. To do this, it makes use of cameras and intelligent software to monitor the room in real time and send alerts. The design is clear and pragmatic so that all the steps help the system to make good decisions without being complicated. The entire process begins by obtaining video from the CCTV cameras in the classroom. The video of the cameras is then looked at one frame at a time by using smart object detection. First it checks to see if there is any person in the classroom. If no one is found then the system moves on to check whether the ceiling fan is running. Doing this in order means that the system doesn't spend time and only notifies that the fan is wasting power.

A. Processing Data and Running Model

The live video feed received from CCTVs is processed with OpenCV from which individual frames suitable to perform real-time analysis are derived [12], [21].

These frames are supplied to an YOLOv8-based object detection model to determine the presence of human inside the classroom [5], [17], [19], [23]. YOLOv8 is chosen because it is fast in terms of inference speed and also reliable in real-time environments. If one or more humans are detected, the system immediately fits in further analysis for that frame on the assumption of normal usage from a classroom.

In case there is no human presence in the facility, the system engages a custom-trained ceiling fan detection model. This model is specifically trained on pictures of fan being used in classrooms for better accuracy in detecting ceiling-mounted fans which are frequently captured as being small in CTE footage. After identifying a fan, the system will check the operating status of the fan base on the detected areas of the fan by analysing its motion [5], [26]. This step ensures that stationary fans do not register false alarms.

B. Decision Logic / Alert Generation

The last stage in the methodology is context-aware decision making. The system considers simple logical conditions like human presence and fan status to make a decision about the usage of electricity wastage or not. Alerts are only generated when a fan is detected running in an empty classroom, so they are also highly reliable and generate minimal false alarms.

The decision logic of the system can be summarized as below:

Human = 1 → No action

Human = 0 AND Fan = ON → Alert

Human = 0 AND Fan = OFF → No action

Once an alert condition has been met, the system sends a message to the administrator dashboard as well as logs an event for future analysis. This structured but unintrusive approach facilitates effective energy monitoring but at the same time is easy to deploy and extend to more appliances in the future.

IV. RESULTS AND OBSERVATIONS

The proposed Smart Class Sense system was tested with CCTV video data obtained from the classroom environments. During the test, the system was able to understand the condition of a classroom correctly in most of the cases. Human detection done with the YOLOv8 model worked correctly even when students were sitting quietly or moving at a slow pace. This shows that the system works well in real classroom situations and does not only work in ideal conditions.

When no human was detected in the classroom, the system automatically entered the next step and checked the condition of the ceiling fan. The custom-trained fan detection model was able to classify ceiling fans from CCTVs. After fan detection, motion analysis helped the system to understand whether the fan was actually running, or just visible in the frame. This prevented a lot of false alerts and greater system reliability.

A. Context-Aware Decision Analysis

TABLE II
Context and Aware Decision Matrix for Energy Management

Scena-rio	Human Presence	Fan Motion	System Output	Energy Status
S1	Detected	Yes	No Action	Normal Usage
S2	Not Detected	No	No Action	Optimized
S3	Not Detected	Yes	Generate Alert	Wastage Detected
S4	Detected	No	Suggest Action	Potential Inefficiency

A summary of the context-aware decision behavior of the system is illustrated in Table II. This table denotes the system's response under various situations in the classroom using a combination of the information on human presence and fan motion.

In Scenario S1 when human presence is detected and the fan is running the system takes no action since this is normal classroom usage. In Scenario S2, if no human is detected and the fan is not running, again the system does not take any action as the energy usage is already optimized.

In Scenario S3, which is the most possible and critical scenario, no human presence is detected but the fan is found running. In this case, an alert is immediately generated by the system and the condition is tagged as electricity wastage. This proves that the system is able to correctly identify scenarios of wastage. In Scenario S4, human presence is detected but the fan is not activated, the system suggests a possible action, and then indicates a possible inefficiency, in this case on the comfort and not on the energy loss.

This context-aware decision matrix is a clear way of seeing that the system is not based on one factor. Rather, it is a combination of various conditions to grasp a real understanding of the situation in the classroom, in order to make the process of decision-making more intelligent and practical.

Overall, the observations suggest that the proposed system works as expected in various real world situations. Alerts are only generated when necessary and no unnecessary notifications are made. With the help of simple logic and low cost infrastructure, the system offers effective results. These results indicate Smart Class Sense is a strong and practical project in reducing electricity wastage in smart classrooms especially in the large educational institutions where it is difficult to do manual monitoring.

V. ADVANTAGES AND APPLICATIONS

A. Advantages

There are many practical benefits to classroom energy monitoring offered by the proposed Smart Class Sense system. One of the biggest advantages is that the system relies on already existing CCTVs cameras, which means no additional hardware installation is required. This makes the solution low-cost to implement and is easy to deploy in schools and colleges.

Another key benefit is that of context-aware decision making. Unlike traditional occupancy-based systems, this system checks the human presence and fan motion together simultaneously. Because of this, alerts will only be generated when the real electricity wastage occurs as it reduces false alarms and enhances reliability [2], [24].

The system also operates in real time and needs very little human involvement. Once deployed it automatically monitors classrooms and notifies the administrator only when they need to. This helps to reduce the manual checking effort and help the institutions to save electricity in a very efficient manner.

B. Applications

The Smart Class Sense system could be used in a wide range of real-world educational situations. It is very appropriate for schools, colleges, and universities, where various classrooms are used throughout the day and it is difficult to monitor manually. The system can also be employed in smart classrooms and smart campus setup, where energy optimization is a required important task [24].

In addition, the proposed method can be extended to other indoor environments such as libraries, laboratories and seminar halls, in which ceiling fans or other similar appliances are employed. Due to its flexible and modular design, the system can be further used in intelligent energy management of modern education building [2].

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

Electricity wastage in classroom is one of the most common and serious issues in educational institutions. Manual classroom monitoring is not reliable and tends to be overlooked because of time and manpower limitations. In this study, the concept of Smart class sense is introduced as an intelligent and automatic solution for energy savings on electricity consumption in classrooms.

The proposed system manages to merge human presence detection and ceiling fan operation verification by computer vision and deep learning techniques.

Using existing CCTV cameras is another advantage in that the system does not require extra hardware cost, and is still simple to deploy. The context aware decision logic makes sure that the alerts are pushed out only when the fan is running in an empty classroom, resulting in less false alarms and better reliability.

The results and observations show that the system works well in the real classroom-like conditions. Even with simple logic and light models, the system is able to spot electricity wastage scenarios correctly. Overall, Smart Class Sense is an effective, low cost, and practical solution for smart classroom energy monitoring, particularly for large campuses to which manual supervision is difficult.

B. Future Scope

While the proposed system is an effective system, there is considerable scope for improvement as well as extension. One major future improvement is the integration of IoT based sensors and actuators. Instead of just generating alerts, the system can then be linked to smart relays or the IoT controllers that can automatically turn OFF ceiling fans when the classroom is empty.

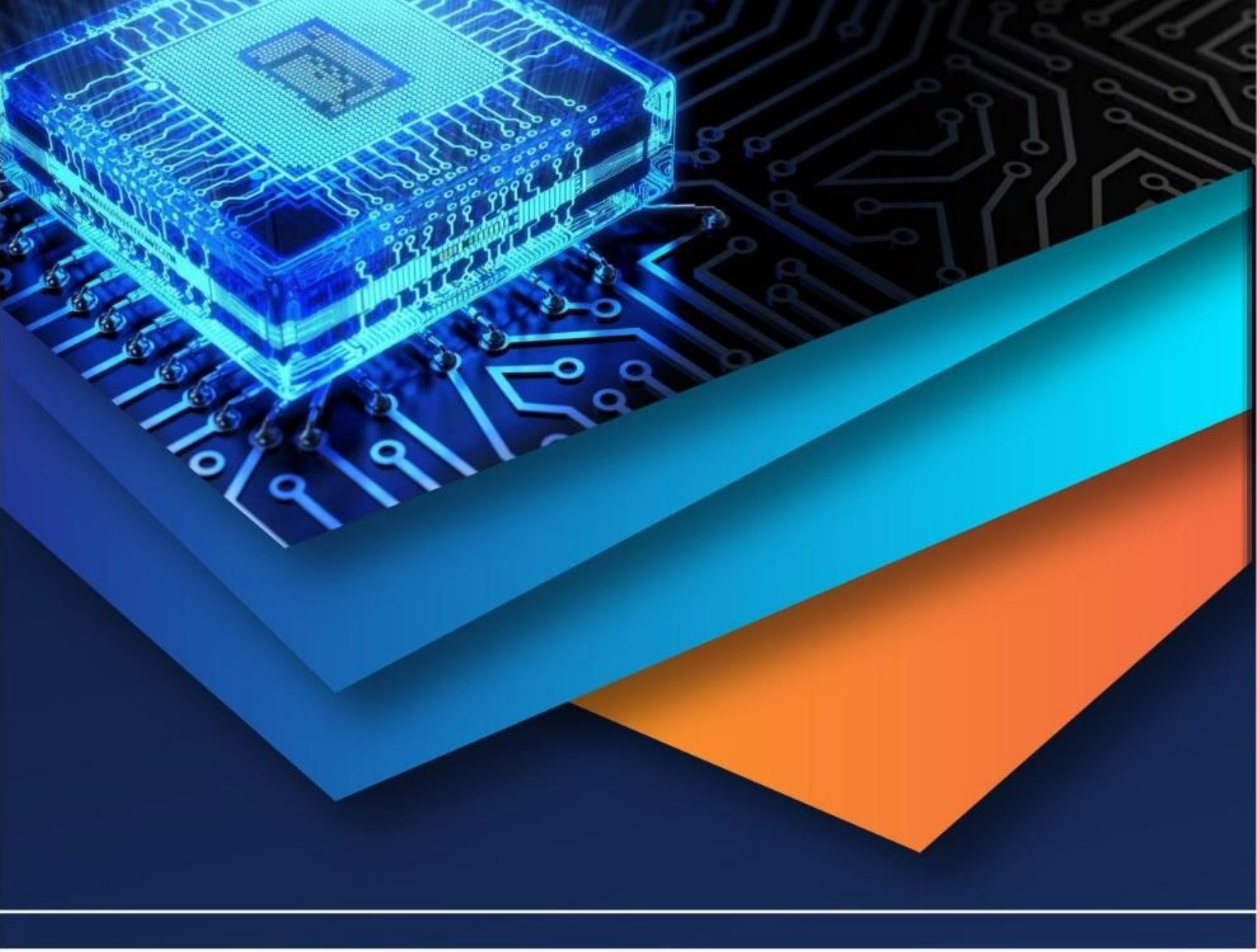
In addition to fans the system may be extended to control lights, projectors, and other electrical appliances. By integrating computer vision with IoT sensors such as motion sensors, current sensors or smart switches the system is able to take quicker and more accurate decisions. This will transform the system from a monitoring solution to a complete automated energy management system.

Further improvements may suit to offer centralized monitoring with based dashboards for central dashboard, notifications through mobile to admin and better optimization for large scale deployment in multiple buildings. With these additions, Smart Class Sense can play an important role in creating smart campuses and energy-efficient educational environments in the future.

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