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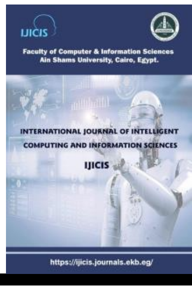

CONTROLLING AND SECURITY SYSTEM USING IOT INFRASTRUCTURE AND IMAGE PROCESSING IN EDUCATIONAL INSTITUTIONS

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Abstract: *The Internet of Things (IoT) has revolutionized the way we live and work. the use of IoT technology setting provide numerous benefits educational institutions. One of the key advantages of using IoT is the ability to gather real-time data from a variety of sensors. In this paper we present a smart system for development and safety educational institutions using ESP32 board and Arduino sensors for temperature, humidity, fire, smoke and light, detecting fires and detecting cracks in the walls that may lead to the collapse of the institution using a camera. The aim of the study is to provide an effective automated system that enhances the quality of the organization's work, reduces time and energy, and increases accuracy and security. The hardware and software components of the system were described in detail, and experiments were conducted to evaluate the performance of the system. The results showed that the developed smart institution system provided accurate and reliable measurements of various parameters, and that the camera-based fire detection system was able to detect and alert users of any potential fire incidents and to detect cracks in the walls that might lead to the collapse of the institution to make measures necessary. The paper concludes with a discussion of the implications of the findings for future research and practical applications.*

Keywords: *Educational Institutions, Image Processing, Arduino Sensors, Temperature, Humidity, Smoke, Light, Fire Detection, Camera.*

1. Introduction

In The rapid advancement of Internet of Things (IoT) technologies provides new opportunities to enhance safety, security, and efficiency in educational institutions. IoT-enabled devices such as sensors, cameras, and microcontrollers can be interconnected to collect real-time data and enable intelligent monitoring and control of various aspects of an academic environment [1].

In particular, developing a comprehensive system using IoT infrastructure and image processing techniques can significantly improve fire safety, infrastructure monitoring, access control, and resource

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optimization in schools and universities. Smart fire detection systems can leverage connected sensors like smoke detectors, thermal cameras, and humidity monitors to identify fire hazards and trigger instant alerts, a crucial capability for institutions containing critical equipment or research assets [2].

Integrating computer vision techniques with security cameras allows for automated intruder detection, improved surveillance, and prevention of threats to students. Sensors can also identify structural failures in buildings early before they escalate into safety risks [3].

For sustainability, IoT-enabled HVAC, lighting, and appliance systems can intelligently adjust usage based on occupancy patterns and environmental conditions, leading to data-driven energy optimization. Students and faculty can also benefit from personalized environmental adjustment based on preferences [4].

Laboratories and data processing centers need to protect sensitive devices such as computers from fires and smoke, which can destroy data and entire devices. In order to protect the laboratory and equipment from fires, a fire, smoke, or wall cracks alarm system can be developed that includes multiple sensors connected to the main control unit, as it can detect any rise in temperature and send an immediate warning signal to officials and firefighting teams.

The proposed system can also save electrical energy by turning off electrical appliances in the absence of people. It can also reduce the consumption of electric lighting in the case of an external light. The proposed system is based on the use of a network of Internet-connected devices (things) installed in buildings and educational facilities, such as surveillance cameras and various sensors, which collect data and send it to the cloud for processing and analysis.

Overall, this technology integration modernizes educational institutions by enhancing security, safety, sustainability, and resiliency in the face of both routine and exceptional challenges. The network of connected IoT devices provides pervasive eyes and ears for data gathering, while software intelligence extracts insights to protect assets. This paper will present the design and implementation of such a system using key IoT and image processing capabilities tailored for the education domain.

2. Related Works

The integration of IoT technologies with fire detection and suppression systems has attracted growing research interest. A review of current literature highlights innovative applications across a variety of environments, from forests and tunnels to smart homes and colleges. Researchers have utilized affordable and versatile hardware such as ESP32 boards along with sensors and connectivity modules to build automated, real-time fire monitoring and response capabilities. Advanced simulations and immersive technologies like augmented reality have also been incorporated to enhance firefighter training and situational awareness during rescue operations. Additionally, integrated fire protection systems with smoke extraction and water mist components have been proposed for enclosed spaces like tunnels.

Amit, Pradeep, Yugal [5] presented a WSN and IoT integrated system to detect fires at an early stage. The implementation of the wireless sensor network (WSN) using outdated hardware proved successful. The fire detection system is designed to operate on a cloud platform, leveraging IoT devices. This innovative design offers an efficient, cost-effective means of collecting and monitoring real-time fire data on a global scale.

P. Kanakaraja et al. [6] proposed a forest protection system utilizing the ESP32 board. The ESP32 board offers integrated Wi-Fi and Bluetooth connectivity, enabling the integration of various sensors for comprehensive forest monitoring. When the sensor readings surpass predetermined threshold values, the system takes action by sending alerts to the relevant departments through ESP32 messaging capabilities. Additionally, a buzzer is activated to warn people in the vicinity about potential risks in the forest area. This integrated approach ensures timely responses to forest-related incidents, contributing to effective forest protection efforts.

Haosen C., et al. [7] introduced a cutting-edge integrated framework for creating a proof-of-concept system that combines Building Information Modeling (BIM), Internet of Things (IoT), and Augmented Reality/Virtual Reality (AR/VR). The primary objective is to enhance situational awareness, empowering firefighters to swiftly and accurately assess fire scenes and make well-informed rescue choices. The development tools employed in this study encompassed Unity 3D, a game engine utilized for creating interactive experiences, Unity's built-in pathfinding algorithm called A*, and an HTC VIVE Focus Plus Head-Mounted Display (HMD). The combination of these technologies allows for the creation of a powerful and immersive platform, enabling firefighters to better comprehend and respond to emergency situations in real-time.

Alireza S. and Sayyed M. [8] developed an innovative water mist system that incorporates ventilation jet fans to achieve economic viability. The system utilizes monitoring cameras to identify fire coordinates, and mist-generating jet fans are deployed to suppress the fire effectively. Through simulation, the proposed system demonstrated several advantages, including a low heat release rate, reduction of smoke and toxic fumes, increased tunnel ventilation speed, and improved visibility. This integrated approach proves to be a promising solution for enhancing firefighting capabilities and minimizing the potential risks and hazards associated with tunnel fires.

N. Selvi and M.S. Balamurugan [9] proposed a cost-effective and versatile home control and monitoring system. They utilized an embedded hardware mote with IP connectivity to enable remote access and control of various devices and appliances through a mobile application. This innovative solution offers homeowners a convenient way to manage their household devices and monitor their status from a distance, enhancing overall home automation and efficiency.

Amira A. Elsonbaty [10] presented a cost-effective wireless smart college system. The system was designed and implemented to enable the control of various devices through IoT technology. It automatically manages and controls lighting systems, fans, fire systems, water management, irrigation systems, and sound systems using straightforward and affordable electronic circuits. The primary goal is to enhance the comfort and convenience within the college premises while also achieving energy savings through efficient device management and automation.

Agazi, W., et al. [11] showcased a straightforward application demonstrating a fire alarm and control system. The system utilizes sensors placed at various locations to detect movements and temperature changes. Users can monitor the temperature of the premises where these sensors are installed at any given time, ensuring that it does not exceed critical limits predefined by the user. This system provides an efficient and reliable solution for early fire detection and control, enhancing safety measures and minimizing potential risks.

Massila,k.,et al. [12] presented the development of a new IoT security requirements library of security requirement for the development of IoT applications.

Building upon these works which showcase innovative detection and response systems across diverse environments, we aim to develop a tailorable IoT architecture for fire protection focused on educational institutions. Through modular sensor designs and building mapping integration, the platform intends to offer systematic monitoring while maximizing scalability across campuses.

3. Proposed System

The proposed system would include a cloud-based platform or server that can receive data from the devices and process it in real-time. The data collected by the sensors and cameras would be processed using image processing techniques to detect any potential threats.

Based on Figure (1), when a fire occurs, the flame, temperature, and gas sensors continuously transmit readings to the Arduino. These readings are then forwarded to a Wi-Fi module, which converts the data into graphical and statistical formats. A dedicated web page is designed to analyze this data, and based on certain conditions, a response is extracted. If the conditions are met, the web page triggers the activation of a water sprinkler system, as illustrated in the diagram.

The proposed system consists of two stages: The first stage is smart fire, smoke, and wall crack detection through image processing. The second stage involves smart fire detection using IoT with an automatic water sprinkler and electrical energy savings mechanisms inside the educational institution. These stages will be described in the next subsections. It was developed by frontend software like HTML5, CSS3 and Bootstrap and backend like PHP and MySQL.

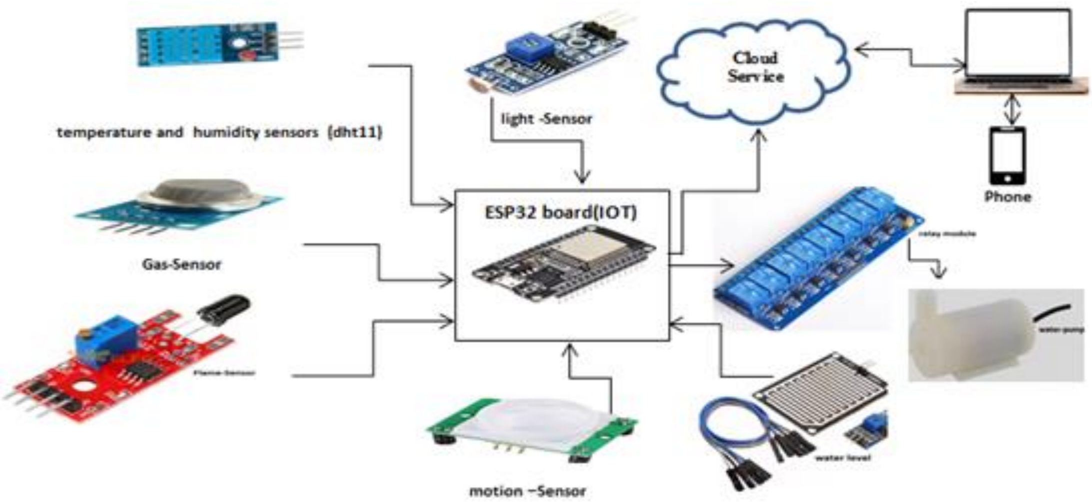

Figure. 1: The proposed system architecture

3.1 Smart Fire, Smoke and Wall Cracks Detection by Image Processing

Early detection and location of fires is critical for preventing property damage and saving lives. Traditional fire detection systems such as smoke detectors and sprinklers have limitations in terms of response time and effectiveness. Therefore, there is a need for new technologies that can detect and locate fires in real-time. In recent years, CNN algorithm has shown promising results in various computer vision tasks. In this paper, we propose a fire, smoke and wall cracks detection algorithms based on CNN.

The proposed algorithm for real-time fire detection and location consists of the following steps:

- Image Acquisition: Images are captured using cameras placed in the area to be monitored. These cameras can be visible light cameras or thermal imaging cameras that can detect temperature changes.
- Image Pre-Processing: The acquired images are processed to remove noise, enhance the image quality, and make it suitable for further processing. Pre-processing can include operations such as filtering, normalization, and edge detection.
- Fire Detection Algorithm: The pre-processed image is analyzed using CNN algorithm that can detect the presence of fire. Different algorithms can be used based on the type of camera used and the characteristics of the image.
- Decision Making: Once a fire, smoke or wall crack is detected, the system will make a decision based on pre-defined rules. The decision can be to alert the authorities or to trigger an alarm.
- Alarm Generation: If the system decides to trigger an alarm, it can generate an audio or visual alarm to alert people in the vicinity of the fire.
- Data Logging: The system can log data related to the fire, such as the location, intensity, and time of the fire.
- Reporting: The system can generate reports based on the data logged to provide insights into the frequency and severity of fires.

The above steps can be repeated in real-time to continuously monitor the area for fires. The system can also be configured to alert authorities automatically and provide the necessary information to help them respond quickly to the fire.

3.1.1 CNN Architectures

A CNN architecture is designed and trained on the dataset using a supervised learning approach. The architecture consists of several convolutional layers, pooling layers, and fully connected layers as shown in figure (2).

The CNN used for detection incorporates region proposal, feature extraction, and classification functionalities. Initially, the CNN receives an image as input and utilizes convolution, pooling, and other operations to generate region proposals. Subsequently, the region-based object detection CNN utilizes convolutional layers, pooling layers, fully-connected layers, and other techniques to determine whether fire is present or absent within these proposed regions.

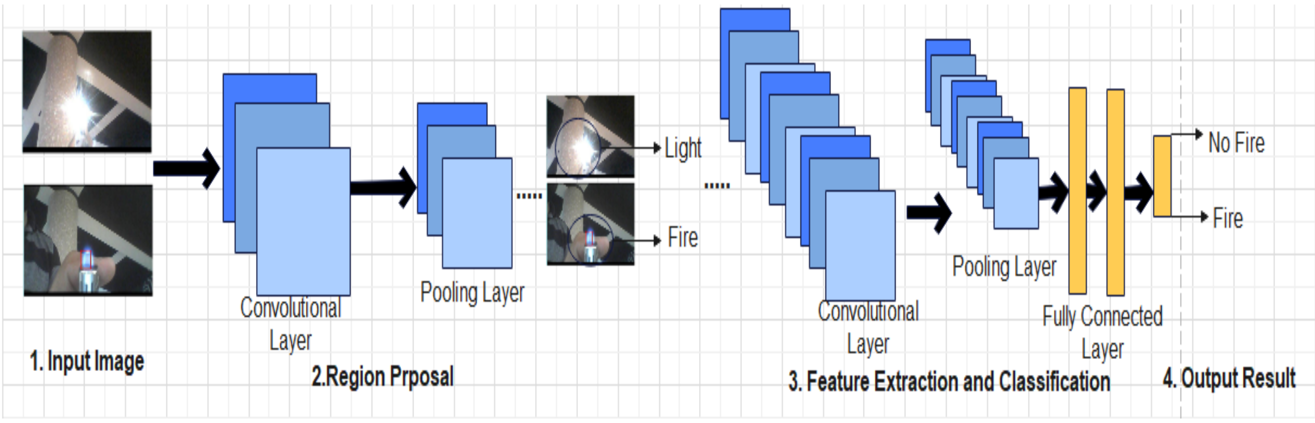

Figure. 2: Flow chart of image fire detection algorithms based on detection CNNs

The convolutional layer is a fundamental component of CNNs. Unlike other neural networks that rely on connection weights and weighted sums, the convolutional layer employs convolution kernels, which are image transformation filters. These kernels generate feature maps from the original images. A convolutional layer consists of multiple convolution kernels. These kernels slide across the images, computing new pixels through a weighted sum of the pixels they cover, resulting in feature maps. These feature maps capture specific aspects or characteristics of the original image. Equation (1) represents the mathematical formula used for the calculations within the convolutional layer [13].

$$y = \sum_{J=O}^{J-1} \sum_{i=O}^{I-1} WijXm + 1n + j + b, (O \leq m \leq M, O \leq n \leq N) \qquad \text{Eq. (1)}$$

In the given equation, the variable "x" represents an input image with dimensions W x H. The variable "w" corresponds to a convolution kernel with dimensions J x I, while "b" represents the bias term. The output feature maps are denoted by the variable "y". During training, the values of the convolution kernel "w" and the bias term "b" are determined through the learning process.

Dataset preparation: A large dataset of thermal images containing fires and non-fires is collected and preprocessed. Real-time detection. To train algorithms based on CNNs effectively, a significant amount of data is required. However, the currently available small-scale fire image/video databases are insufficient to meet this demand. Table (1) presents some examples of these small-scale databases.

Table 1. Small-scale fire image/video databases

Name	Object	Website
FIRESENSE	videos for flame and smoke detection	https://www.kaggle.com/datasets/chrisfilo/firesense
FIRE Dataset	fire images folder contains 755 and non-fire images which contain 244 nature images.	https://www.kaggle.com/datasets/phylake1337/fire-dataset

3.1.2 Detecting Cracks on Walls in Real-Time

Detecting black lines on walls is an important task for many applications such as indoor navigation, mapping, and object tracking. However, detecting black lines on walls can be challenging due to variations in lighting conditions, background clutter, and perspective distortion [14]. In this paper, we present an algorithm for detecting black lines on walls in real-time using computer vision techniques. The proposed algorithm is based on image processing techniques such as color segmentation and edge detection.

Proposed algorithm: The proposed algorithm for detecting black lines on walls in real-time consists of the following steps:

- Color segmentation: The input image is first segmented into black and white regions based on the color of the pixels. This is done by thresholding the grayscale value of the pixels.
- Edge detection: The edges of the black regions are then detected using a Canny edge detection algorithm. This step is used to remove noise and enhance the edges of the black lines.
- Line detection: The Hough transform is used to detect lines in the edge map. The lines detected are then filtered based on their length and angle to remove false positives.
- Line tracking: The detected lines are tracked over time using a Kalman filter. This step helps to improve the accuracy of the detection and reduce false positives.

3.1.3 Smoke Detection in Real-Time

Smoke detection and location in real-time is crucial for the safety of people and property. In this paper, we propose a CNN algorithm for real-time smoke detection and location using a dataset of images and videos. The proposed algorithm is based on a CNN architecture and is trained on a large dataset of smoke and non-smoke images. The proposed algorithm for real-time smoke detection and location consists of the following steps:

- Dataset preparation: A large dataset of smoke and non-smoke images is collected and preprocessed. The dataset also contains videos of smoke and non-smoke scenes.
- CNN architecture: A CNN architecture is designed and trained on the dataset using a supervised learning approach. The architecture consists of several convolutional layers, pooling layers, and fully connected layers.
- Real-time detection: The trained CNN model is used to detect and locate smoke in real-time by analyzing the input stream of images and videos.

3.2 Saving Electrical Energy inside the Computer Laboratory

By directly measuring energy consumption with and without the implemented devices, this study aims to quantify the actual amount of electrical energy saved. The collected data and analysis will serve as a valuable resource for future applications, such as the construction, expansion, or renovation of university buildings.

The findings will help estimate the potential effectiveness of energy-saving systems in reducing electrical energy consumption. Flow chart for protecting and saving electrical energy is shown in figure (3).

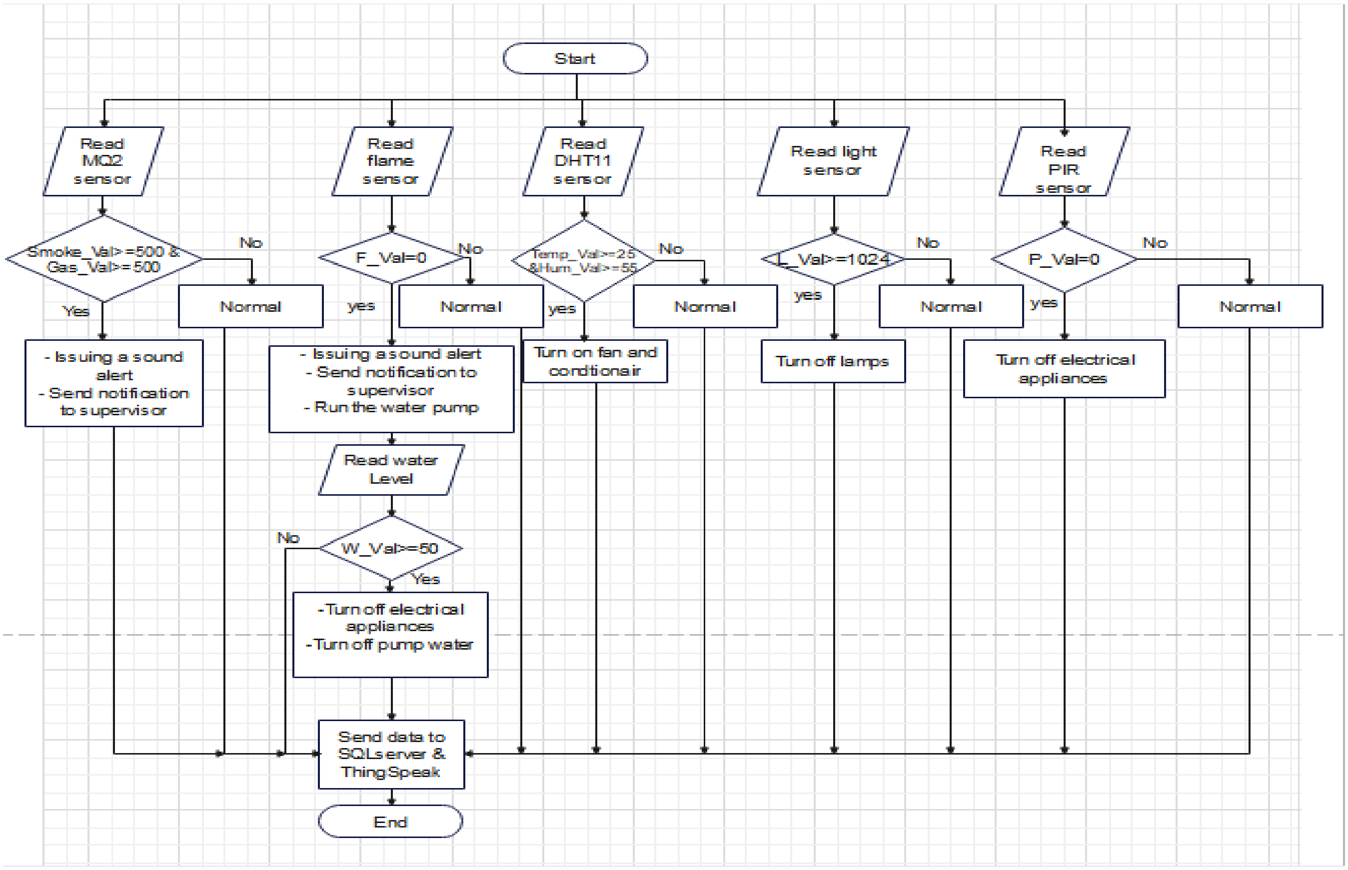

Figure. 3: Proposed flow chart

4. Implementation

Set up of the cloud-based database: we set up a cloud-based database to store the data collected from the sensors and cameras. In our system the data upload from the Arduino ESP32 to the MYSQL database on line.

Development of a user interface: we developed a user interface access and analyze the data collected from the sensors and cameras. user interface is web application which from (PHP code) select final update to system data values and display in frame at GUI. The data was transmitted to a cloud-based database and analyzed using a user interface as shown in figure (4).

In the proposed CNN technique, our approach involved training and testing the network using full images. The algorithm employed takes an input image and divides it into grids of size S × S. From each grid, it extracts the relevant features and makes predictions for the bounding boxes encompassing the detected objects, along with confidence scores for these boxes. This process is illustrated in Figure (5).

The laboratory usually uses a huge amount of lighting, so we installed a sensor to detect light. In the case of lighting coming from the window of the laboratory, the lighting is automatically added. A motion sensor was also installed to detect movement inside the laboratory. In the absence of movement, the electrical appliances are automatically disconnected, as shown in the figure (6).
A temperature sensor has been installed to detect heat and humidity inside the laboratory. In case the temperature exceeds 25 Celsius, the fan is turned on as shown in figure (7).

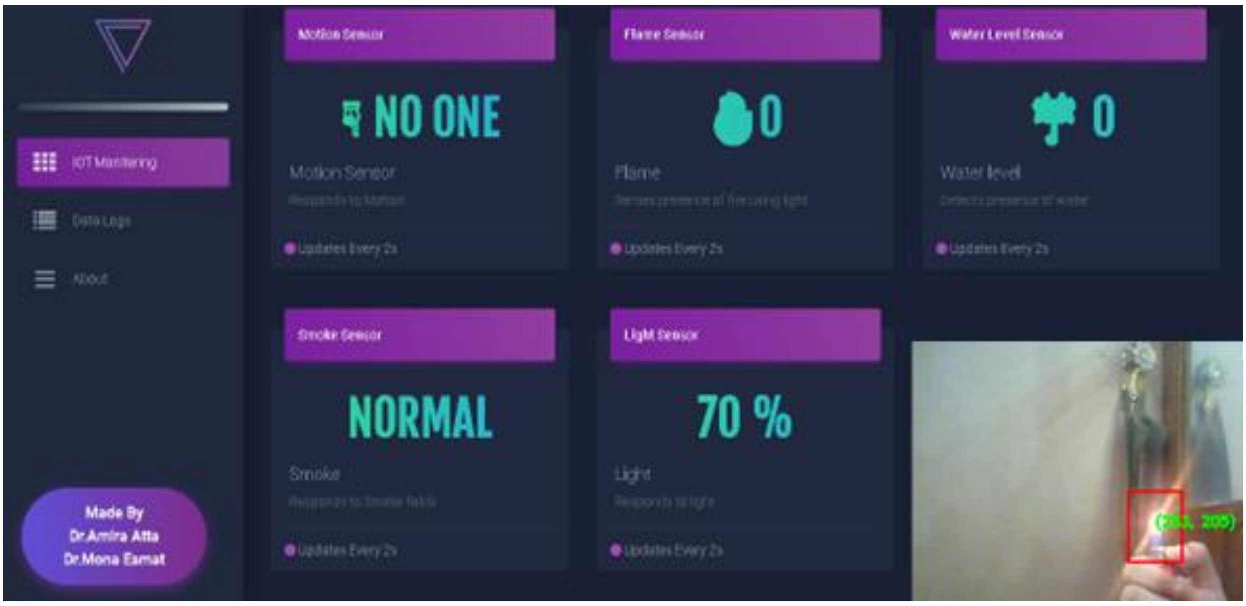

Figure. 4: Web Application display readings real time from ESP 32 controller

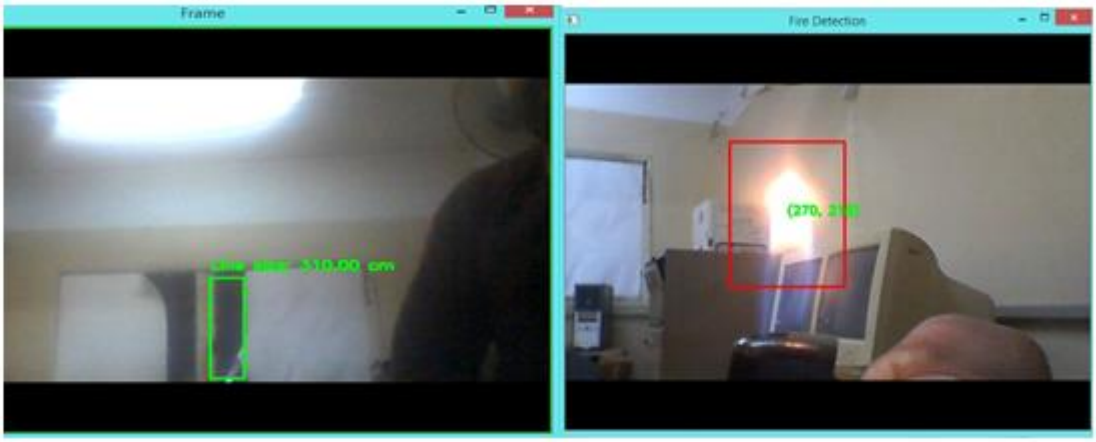

Figure. 5: Fire and wall cracks detection with location by image processing

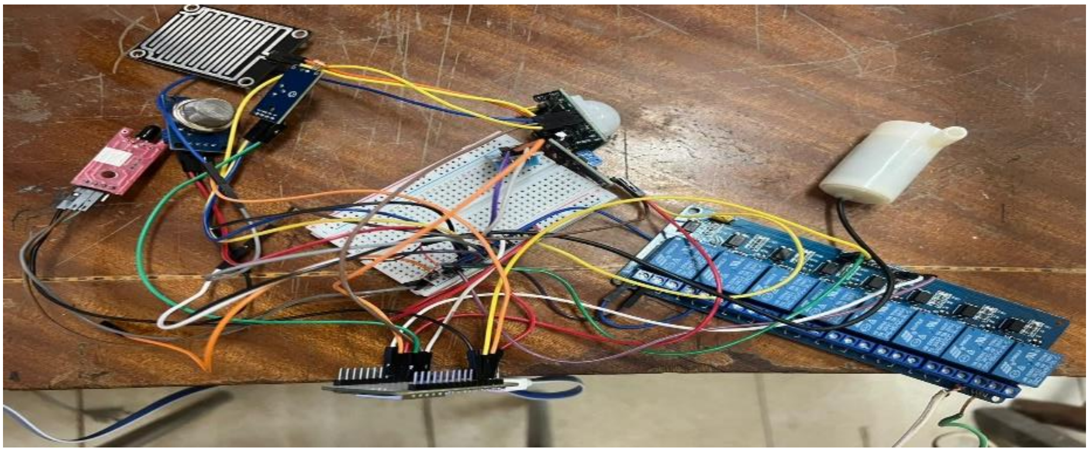

Figure. 6: Sensors for temperature, humidity, fire, smoke, gas, motion, water and light

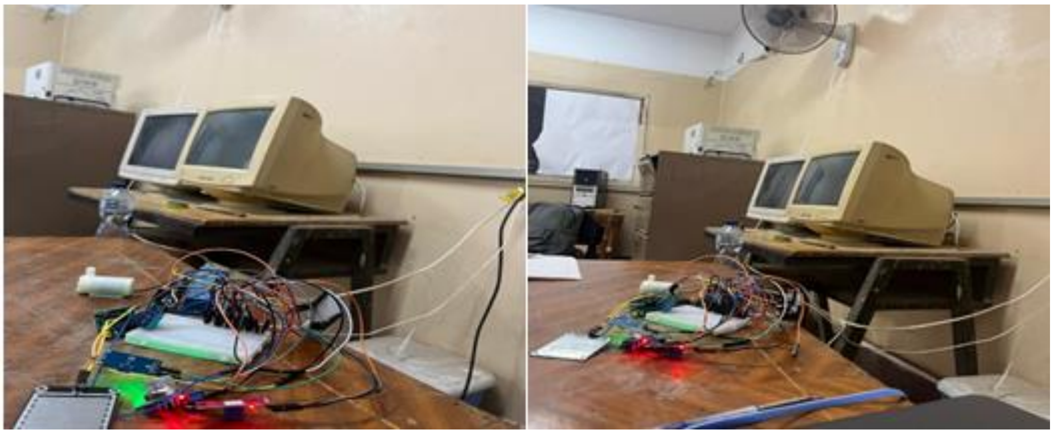

Figure. 7: Fan controlling system

5. Results

The extensive experimentation conducted provides significant insight into the responsiveness and reliability of the proposed firefighting system. As highlighted in Table (2) presents the results of four different tests conducted to monitor changes in the sensors continuously. The goal of these tests was to establish a reliable firefighting system. Each test involved taking continuous readings at 5-second intervals.

During the initial test, the flame sensor was exposed to a flame. However, no fire was detected within the response time of the sensor. Tests 2, 3, and 4, on the other hand, successfully detected the presence of fire and activated a water sprinkler system. The water sprinkler system was designed to stop functioning once the flame sensor reached a value of 1, indicating that the fire has been extinguished. Additionally, the water level was continuously monitored during these tests, taking into account the response time of the system.

Table 2. Experimental results of the proposed system

No	Flame	DHT 11	Smoke Concentration	Status	Water Sprinkler	Water Tank Level	Response Time
1	0	25 °C	33%	No fire	Off	100%	Non
2	1	32 °C	61%	Fire	On	80%	2 Sec
3	1	34 °C	56%	Fire	On	55%	3Sec
4	1	42 °C	20%	Fire	On	32%	2 Sec

Besides, the sensor data in Thing Speak was designed to be visualized as a line chart format within a specific time range fig. (9.a) and fig. (9.b). in this section, Thing Speak based cloud platform. It used for the collection of data and its analysis. In reality, these line charts can show the trend of temperature, gas, etc. changes as time flows. The Thing speak provides regular monitoring of sensed field data.

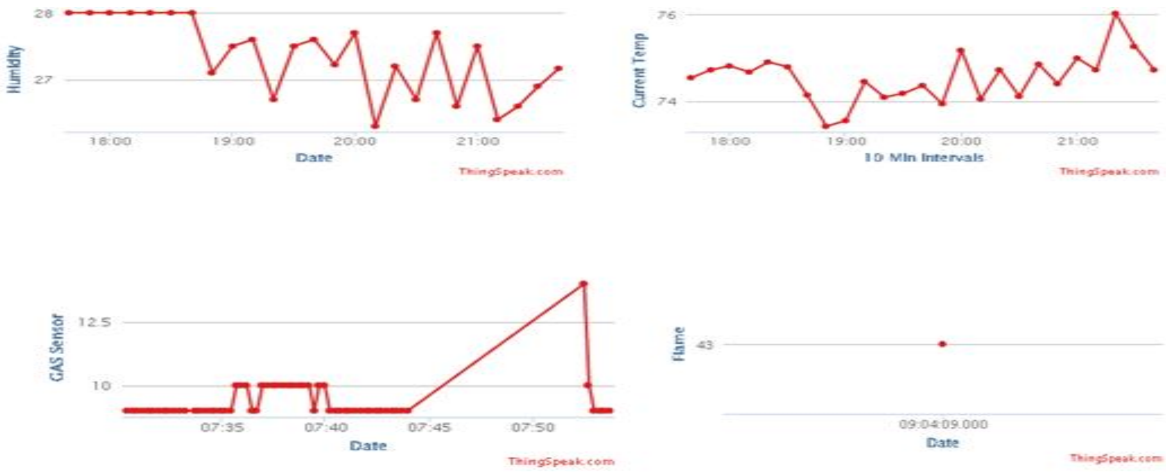

Figure. (9.a). Real time analysis through thing speaks cloud application from different fields

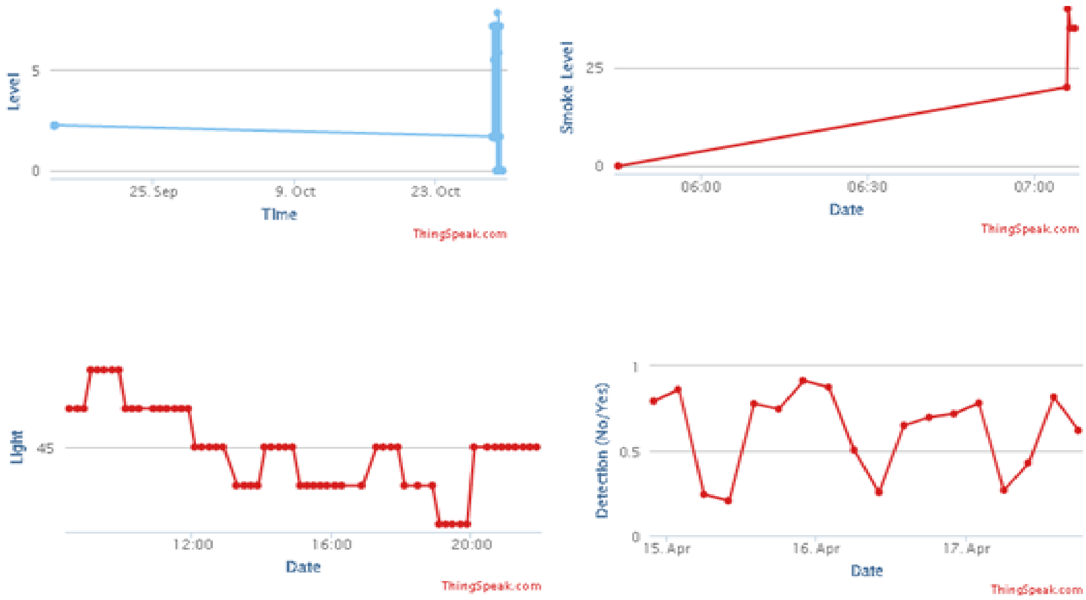

Figure. (9.b). Real time analysis through thing speaks cloud application from different fields

According to the data presented in table (3), when the motion and light sensor were deactivated, the daily average electrical energy consumption per unit area was recorded as 79 Wh/(m²day). However, when the sensor was activated, there was a significant reduction of 21.2%, resulting in an average energy usage of 55.8 Wh/(m²day). This demonstrates that the presence and operation of the sensor had a positive impact on reducing energy consumption in the area.

Table 3: Laboratory' average daily electricity consumption

	Sensor Off		Sensor On	Saving Rate
Electrical Energy	Test 1	81%	40.3%	40.7%
	Test 2	77%	55.8%	21.2
	Average	79	48.05%	30.95%

In order to assess the practical effectiveness of the proposed system for fire detection, we conducted a series of experiments. The primary objective of these experiments was to evaluate the system's efficiency in detecting real fires, smoke, and wall cracks. For this purpose, we captured 40 trials using a webcam. Out of these 40 trials, our system successfully detected actual fire, smoke, and wall cracks in 38 instances. However, there were 2 instances where the system produced faulty detections. Based on the results obtained from the experiments, we have compiled the findings into Table (4) for further analysis and assessment of the system's performance.

Table 4: Experimental values of correct detection, faulty detection and efficiency

No. of trails	Correct detection	Faulty detection	Efficiency
40	2	38	90

The main objective of this paper is to design and implement, Arduino sensors such as temperature sensors, humidity sensors, and etc. can be used to monitor the environment within the educational institution. This information can be used to ensure that the educational institution is suitable for work by monitoring these conditions in real-time, able to detect and alert users of any potential fire incidents and to detect cracks in the walls that might lead to the collapse of the educational institution to make measures necessary and protecting and saving electrical energy also. data collected from sensors can be automatically transmitted and stored in a cloud-based database, which can be accessed from anywhere at any time. This eliminates the need to manually collect and store data, saving time and effort. In addition, the use of IOT technology can also enable automated control of educational institution equipment, reducing the need for manual intervention and increasing efficiency.

6. Future Work

While this study demonstrates the feasibility and potential benefits of implementing an IoT-based smart system for development and safety in educational institutions, further research is needed to optimize and expand upon the system. Areas for future work include:

- Testing the system in a real-world educational setting over an extended period of time to evaluate its robustness, reliability, and long-term performance.

- Integrating additional sensors such as air quality, noise level, and occupancy to provide a more comprehensive monitoring and alert system.
- Enhancing the fire and crack detection algorithms using more advanced computer vision techniques to improve accuracy.
- Developing a centralized dashboard to monitor real-time data flows from multiple institutions to identify broad trends and insights.
- Implementing automated emergency response capabilities once dangerous conditions are detected, such as triggering sprinklers or alarms.
- Analyzing the cost-benefit trade-offs of using IoT technologies compared to traditional monitoring methods in educational institutions.
- Exploring the use of edge computing and AI to process data locally and reduce bandwidth usage.
- Investigating opportunities to scale the system to other public spaces such as hospitals, transportation hubs, and commercial buildings to further validate its applicability.

The initial results of this study highlight the tremendous potential of IoT to create smarter, safer educational environments. Further research and development building on this foundation will help drive widespread adoption and innovation in this critical domain.

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