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CNN-Based Intelligent LPG detection and Safety Control System using IOT

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Abstract: This paper introduces an IoT, based intelligent LPG detection and safety control system powered by a CNN, aimed at increasing the safety of industrial locations using LPG. Manufacturing plants, chemical plants, and processing industries are examples of industrial facilities that utilize LPG for their operations and, hence, expose the environment to the risk of gas leakage and fire incidents. Most of the time, gas sensors and alarm units are the only components used in traditional LPG detection systems, thus these systems can generate false alarms and they hardly make the right decisions. In an attempt to overcome the problems of these systems, the authors implemented a system that integrates sensor, based monitoring and IoT technology with a CNN for accurate and smart LPG leak detection.The system packs an LPG gas sensor, a camera module, an ESP32 based IoT controller, and a CNN based detection model.The gas sensor functions 24/7 and keeps track of the surroundings for any unusual concentration of LPG. In case a gas leak situation is figured out, the camera module will snap the area through live images or videos.Then, the CNN model, which was trained by the pattern of LPG leaks, is utilized to check the images.By utilizing IoT capability, this system is able to send real, time data, warning messages, and proof figures to a remote industrial monitoring server or mobile dashboard. Thus, safety officers and plant managers have the opportunity to monitor the conditions of LPG remotely and can react very fast during the emergency situations. The associating of CNN with IoT results in smart decision, making, uninterrupted monitoring, and fast communication.The system under discussion is intended to be cheap, expandable, and compatible with the tough industrial environment. Really, it is able to work in industries based on LPG, chemical plants, storage, and manufacturing units. For industrial gas safety management, the CNN, Based Intelligent LPG Detection and Safety Control System is delivering a trustworthy and capable solution by integrating deep learning, sensor, based detection, and IoT, enabled safety control. It provides early warning of leaks, greatly reduces the false alarm rate, and overall significantly increases the safety of the industry

Keywords: CNN (Convolutional Neural Network),LPG Leakage Detection, Internet of Things (IoT), Industrial Safety, ESP32 Microcontroller, Intelligent Safety Control System

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) is an essential source of energy, highly efficient, clean burning, and very convenient to store and transport. Consequently, it finds its way tomanufacturing plants, chemical processing units, food processing industries, metal fabrication workshops, and storage facilities. Still, LPG is extremely flammable and can be very dangerous in case of leakage. A tiny leak of LPG can cause a fire, explosion, human casualties, and heavy damage of industrial buildings. The continuous use of gases, the presence of highpressure pipelines, the complexity of machinery, and human activities make industrial environments very susceptible to accidents. Hence, these conventional safety measures like manual inspection and the use of traditional gas detectors have limited capabilities in dealing with sudden leakages and emergencies. Most systems nowadays depend solely on threshold, based gas sensors and simple alarm mechanisms, which may falsely alert the users or even fail to detect early, stage leaks. The above shortcomings thus serve as an impetus for the development of smart, automated, and real, time LPG detection systems that will not only enhance industrial safety but also avert disastrous accidents [1].

Industrial safety is no longer only relying on traditional sensing methods thanks to the development of Artificial intelligence(AI) and Internet of Things(IoT). IoT based monitoring systems are capable of gathering data continuously, permitting remote control, and generating real time alerts. Therefore, these are regarded most suitable for industrial safety purposes. Gas sensors partnered with microcontrollers such as ESP32 are able to detect LPG concentration and wirelessly transmit the data to the monitoring platform.However, a system based only on sensors will still be subject to environmental interference, sensor drift, and false alarms from temperature changes, humidity, or other gases in the atmosphere. Therefore, to elevate safety supervision even further, computer vision, and deep learning have been incorporated in the toolkits.

Convolutional Neural Networks (CNNs), are a type of deep learning model that is capable of extracting significant visual features from images and videos. CNNs are widely used in various pattern recognition, object detection, and environmental monitoring fields.Combining CNN, based visual analysis, and gas sensor data can remarkably enhance the detection of LPG leaks with high reliability and precision. Moreover, this hybrid system can verify sensor data against the visual information, thus reducing the number of false alarms and increasing the overall system intelligence [2].

The plan of the new smart LPG detection and safety control system mainly refers to the integration of CNN, based intelligence and IoT, enabled safety control. Here, gas sensors constantly monitor the concentration level of LPG, and simultaneously, the camera modules take photos of the industrial area. When an abnormality is detected, the CNN model uses the images taken to figure out if the leakage patterns are there, thus it can accurately confirm if there is a leak.The ESP32 microcontroller works as the main processor that gets inputs from the sensors, CNN outputs, and controls the safety mechanisms like gas shut valves, exhaust fans, and alert systems.The real, time data is sent to the remote monitoring dashboards via IoT so that safety officers and plant managers can intervene in time during emergencies. Automated safety control is less likely to have human error and is faster as compared to manual operation. By combining deep learning, IoT communication, and automated control, the system proposed by the authors offers the advantage of quick leakage detection, thus reducing the number of false alarms, and making it easier to manage industrial safety.Besides, the smart system contributes to preventing accidents, making operations more reliable, and keeping both human life and industrial property safe in cases where LPG is used extensively.

II. LITERATURE SURVEY

Detection of LPG leakage is a critical safety issue in industrial settings because LPG is highly flammable and there is a risk of fire and explosion accidents. A number of researchers have presented various methods with the use of sensors, IoT, and smart systems for improving the safety control and early detection of leaks. Conventional systems are based mainly on gas sensors and alarm units; however, these systems frequently have problems with false alarms and cannot make decisions in real time. To deal with these issues, the integration of IoT and artificial intelligence techniques to improve LPG monitoring and control has been the focus of recent research works [1].In their paper, Sharma et al. suggested an IoT, based LPG gas leakage detection system that is equipped with gas sensors and uses wireless communication to transmit alert messages to the user in real, time. Their system enhanced the capability of remote monitoring but detection was based solely on threshold level [2]. Kumar et al. came up with an automatic gas leakage detection and valve control system that was able to detect and fix the problem of gas leakage without human intervention by using microcontrollers and relays to shut down the gas supply when a leak was detected [3]. The system proved to be efficient but it did not analyze the situation intelligently nor was it adaptable to changes. Patil et al. presented an LPG safety system connected to the Internet of Things (IoT) equipped with a GSM, based alarm system so that users can be notified of a gas leakage event even if they are not at home. The system depended strictly on sensor readings and did not feature a comprehensive analysis [4].As artificial intelligence touched new heights, the research community got excited about using machine learning and deep learning models in gas detection applications. Singh et al. came up with a machine learning, based gas classification framework to distinguish LPG from other gases that has the feature of better detection accuracy [5]. However, the whole system was dependent on the availability of a large pool of training data and also required considerable computational resources.On the other hand, Rao et al. introduced an innovative way of gas detection based on the vision system where they used the image processing technique for the identification of gas leakage pattern in industrial environments [6]. Their method made it easier to visually confirm the leak but it became susceptible to the changes in illumination and environmental noise.Several up, to, date investigations have focused on the usage of Convolutional Neural Networks (CNNs) for intelligent detection tasks. Li et al. utilized CNN architectures to determine a gas leak from a set of camera images and outperformed conventional image processing techniques in terms of the level of accuracy [7]. Chen et al.(continuation) coupled CNN with an IoT framework for real, time industrial gas monitoring and the generation of alert notifications [8]. Their system was able to show a step, up in reliability but at the same time, it demanded that the hardware be of high performance and suitably optimized for the execution in real, time. Ahmed et al. suggested the use of an intelligent LPG leakage detection system built upon ESP32 and cloud, based IoT platforms for round, the, clock monitoring [9]. The drawback of their system was that it didnt have the facility for automated safety control functions.Further research by Zhang and his team was concentrated on the mixture of sensor data and deep learning models to lessen false alarms in gas detection systems [10]. Kumar and Verma came up with an automated LPG safety control system with gas shut, off valves and ventilation control using IoT [11]. The system was quite good, but it did not have intelligent vision, based verification.

Hybrid methods, which combine CNN, gas sensors, and IoT, have lately been the focus of the industrial safety application market. These systems deliver better accuracy, real, time monitoring, and automatic safety responses, thus underlining the necessity for a combined CNN, based intelligent LPG detection and safety control system [12].Further steps have been made in LPG detection systems to include accuracy, automation, and immediate reaction on the basis of intelligent technologies. For industrial safety applications, Mehta et al. designed in their work an IoT, based LPG gas leakage detection system that was equipped with mobile notifications and cloud monitoring [13]. The system facilitated remote monitoring; however, it was heavily dependent on the readings from the gas sensors and did not possess any intelligent validation functionalities. Reddy et al. introduced a smart gas leakage detection and control system based on ESP32 with the automatic valve shut, off feature as a way of preventing gas accumulation in industrial units [14]. This system was very effective in emergency controlling; however, it did not integrate any learning, based detection methods.Since vision, based gas detection methods allow the verification of the leakage events visually, they have been the focus of research works. To detect leaks from industrial pipelines via a camera, Wang et al. , presented a gas leak detection system that is based on image processing techniques [15]. Their system increased the level of situational awareness but it was also very vulnerable to environmental factors such as lighting and background noise. In order to solve these problems deep learning methodologies were suggested. Park et al. took videos frames to develop a CNN, based gas leakage detection of the model, which produced a higher accuracy level as compared to conventional image processing techniques [16]. Nevertheless, the model was highly demanding in terms of computational resources for real, time use.Different scholars have theoretically and practically investigated the integration of IoT and deep learning to significantly improve industrial safety.Al, Khalifa et al. suggested an IoT, based smart gas monitoring system that utilized deep neural networks (DNN) to analyze sensor data and detect dangerous gas conditions automatically [17]. The method raised the accuracy of the forecast; however, the system did not have automatic safety control features. On the other hand, Das et al. built a smart industrial gas monitoring system framework that integrates gas sensors, a cloud, based IoT platform, and machine learning to quickly identify leaks [18]. Even though the monitoring was more fine, tuned, the response was still only partially manual.More and more papers are focusing on fully automated safety systems.Liu et al. described an intelligent LPG leak detection and prevention system where CNN, based image analysis was used for detection, and IoT, based control units ensured the prevention [19]. The system was able to bring down the number of false alarms and enable quicker emergency services through the automatic closure of the valve and the activation of the ventilation system.In conclusion, Sharma and Verma implemented a hybrid LPG safety system that combined CNN, based visual detection, gas sensor data, and IoT communication for usage in industries [20]. Their study emphasized the successfulness of the deep learning and IoT integration for dependable, real, time LPG detection and safety control, thus encouraging the creation of next, generation intelligent systems.

CITATION	MERITS	DEMERITS
[1]	Early LPG leak detection	No intelligent analysis
[2]	Real-time IoT alerts	Threshold-based detection
[3]	Automatic gas valve control	No remote monitoring
[4]	GSM-based notification	Limited scalability
[5]	Improved gas classification	High training complexity
[6]	Visual leak confirmation	Sensitive to lighting
[7]	High detection accuracy using CNN	Requires high computation
[8]	Real-time IoT and CNN integration	Hardware dependency
[9]	Cloud-based monitoring	No automated safety control
[10]	Reduced false alarms	Complex data fusion
[11]	Automated safety mechanisms	No vision-based validation
[12]	Intelligent and reliable detection	Implementation complexity
[13]	IoT-based remote LPG monitoring	No intelligent validation
[14]	Automatic gas valve shut-off	No learning-based detection
[15]	Visual confirmation of gas leakage	Sensitive to lighting conditions
[16]	High detection accuracy using CNN	High computational requirement
[17]	Early leak detection with IoT	Manual intervention required

[18]	Accurate gas prediction using AI	No automated safety control
[19]	Reduced false alarms with CNN	Complex system design
[20]	Intelligent real-time safety control	Higher implementation cost

TABLE 1: SUMMARY TABLE FOR RELATED WORK

III. PROPOSED WORK

The work that was suggested is about a CNN, based intelligent LPG detection and safety control system using IoT to increase safety in the industrial environment where LPG is extensively used.LPG leakage in industries such as manufacturing plants, warehouses, and processing units poses serious risks, including fire hazards, explosions, and loss of human life.Traditional LPG detection systems use gas sensors and threshold, based alarm systems, but they often suffer from false alarms and have limited capacity for decision, making. To solve these problems, the proposed system combines gas detection, vision, based detection with a Convolutional Neural Network (CNN), and IoT, enabled monitoring to provide an accurate, reliable, and real, time safety control.The system that has been proposed includes several modules that are highly integrated and communicate with each other to provide intelligent detection and automatic response. The LPG Gas Sensing Module uses an MQ, series gas sensor to continuously monitor the level of LPG in the industrial environment that is around it. The sensor detects abnormal gas levels and gives early warning signals to the controller. Continuous monitoring allows for the identification of the leakage at the earliest stage, thus the possibility of a severe accident can be minimized. The sensor data is sent to the central control unit for processing and making a decision.

The Vision, Based Detection Module improves the reliability of the system by adding a camera to an ESP32, CAM module. The camera takes real, time photos or videos of the scene when the gas sensor detects a high level of LPG concentration. These photos are then run through a CNN model that has been trained to detect leak, related visual signs and the surrounding environment. The CNN helps to verify the leak by extracting significant features from the photos. This two, type detection system, which uses both sensor input data as well as CNN, based image analysis, greatly diminishes the number of false alarms that are generated due to environmental fluctuations such as changes in temperature or humidity.The Data Processing and Control Module has been designed using an ESP32 microcontroller which functions as the system's central processing unit. The ESP32 receives data from the gas sensor, camera module, and optionally a weight or load cell sensor utilized for LPG cylinder weight monitoring. Through the examination of the combined inputs, the controller decides if an extreme leakage situation is present. Instead of relying solely on fixed thresholds like traditional systems, the proposed work employs smart logic that evaluates both sensor data and CNN results to arrive at the correct decisions.

When an LPG leak is detected, the Safety Control Module gets automatically turned on. A relay, based control unit, which is a part of the module, is connected to safety devices like a gas shut, off valve, exhaust or ventilation system, and alarm indicators. The relay shuts off the gas supply immediately to prevent the leak from getting worse. At the same time, ventilation systems are turned on to help the gas dissipate, while sound and/or light alarms alert workers in the industrial area. This automatic operation reduces the risk of human error and speeds up the response to the safety hazard The IoT Communication and Monitoring Module makes it possible to oversee the system remotely via a web or mobile dashboard. The ESP32 sends the current readings from the sensors, the CNN detection status, system warnings, and log data to the monitoring platform through a wireless connection. The dashboard shows the system status, including gas level, fire indication, camera feed, and safety alerts, thus enabling the safety staff of the industry to supervise the situation from a distance. Besides, data logging can help in safety analysis and work upgrading.In summary, the suggested system is small, cheap, easy to transport, and power, saving. The combination of CNN, based vision analysis with sensor, based LPG detection and IoT connectivity in the proposed work yields a smart and dependable safety system for industrial LPG monitoring and control.

IV. THEORY

A. Algorithm

The CNN-based intelligent LPG detection and safety control system's algorithm is made to function reliably and practically in order to enhance safety in industrial settings. The LPG gas sensor, camera module, ESP32 microcontroller, IoT communication interface, CNN detection model, and safety control devices like ventilation fans, alarms, and solenoid valves are first turned on and initialized by the system. After initialization, the gas sensor continuously scans its surroundings to determine the LPG concentration in real time.

The ESP32 controller regularly receives these sensor readings and uses pre-established safe threshold limits to compare the measured values. The system keeps monitoring on a regular basis without turning on as long as the gas concentration stays within the safe range. The ESP32 controller takes the information generated from the gas sensor and uses it in conjunction to the classification result generated by the CNN to help reduce the amount of false alarms generated from the system. This information is then used to determine whether a detected LPG leak generates the appropriate safety measures initiated by the system. The safety measures initiated when a leak is detected, include; automatically shutting off the gas supply through an automatic valve, ventilating or exhausting to remove the substance, and sounding an alarm to notify others who are near by of the leak. The IoT module transmits a real-time alert, the sensor reading, the detection results, and the status of the system to an off-site monitoring dashboard/mobile app to allow safety representatives and/or operators of the facility to remotely view the situation and take any necessary emergency action. All of the events that are detected and the associated responses are documented for record keeping purposes and will allow for future analysis, maintenance scheduling, and documentation of any incidents.

B. WORKFLOW DIAGRAM:

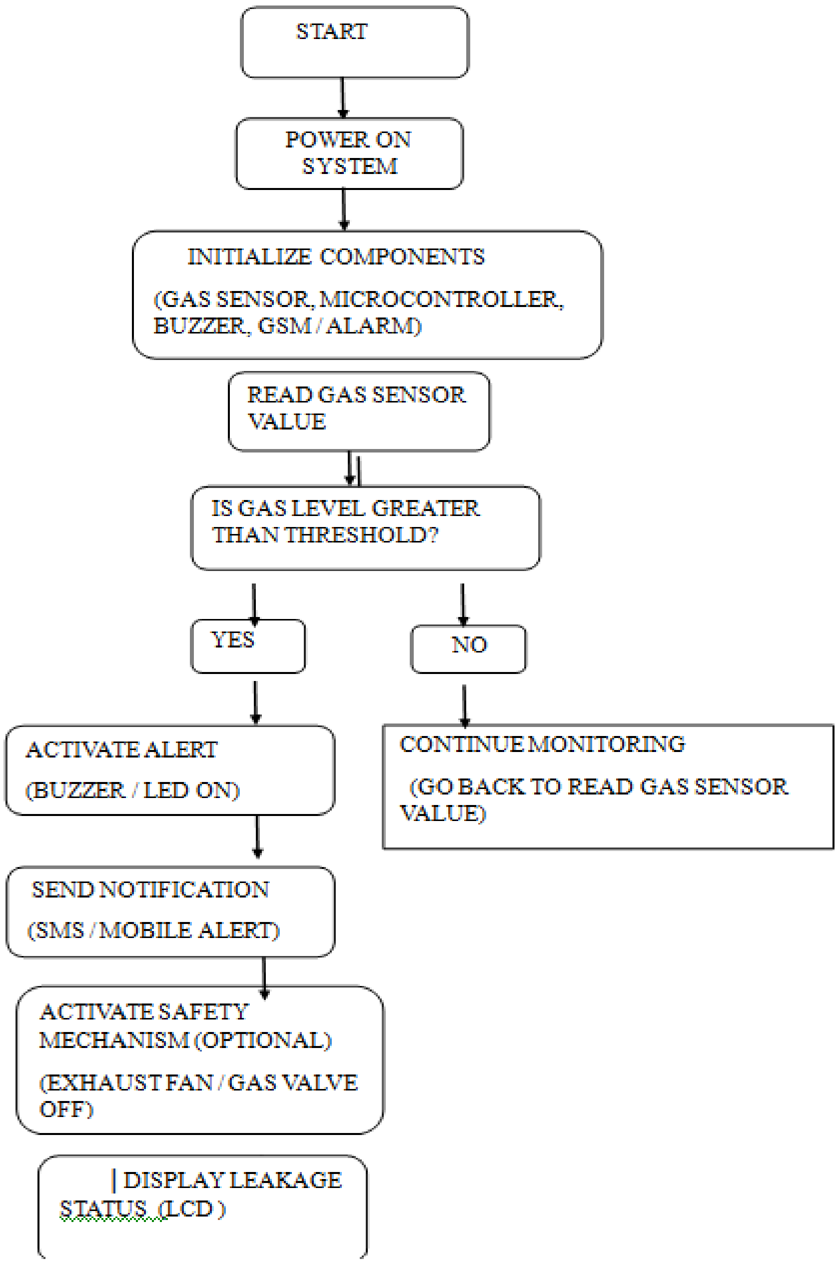

FIG 1: WORKFLOW FOR FINDING LPG LEAKAGE AND FIRE

This diagram shows how to find an LPG leak through a process starting with the system initializing and turning on all components like the LPG gas sensor, camera module, ESP32 controller, IoT communication unit, and safety devices. Once everything is initialized then the gas sensor continuously measures the amount (concentration) of LPG in its environment. The gas readings are sent to the controller which compares the readings to a predetermined safe threshold value. If the gas reading is below the threshold, the system will continue to monitor for leaks without any further action. If the gas reading is above the threshold, the system would detect that there is a possible leak and activate the camera module so it can take images or video of the possibly leaking area. The image or video data collected by the camera module is then pre-processed to enhance its quality (noise reduction, resolution adjustment/contrast adjustment) prior to being fed into a pre-trained Convolution Neural Network model that analyses the data to extract the visual features needed to determine if the observed condition is actually an LPG leak. After evaluating both the LPG gas sensors data and CNN's output, a decision will be made whether or not there was a LPG leak thus reducing the number of false alarms.

C. DATAFLOW:

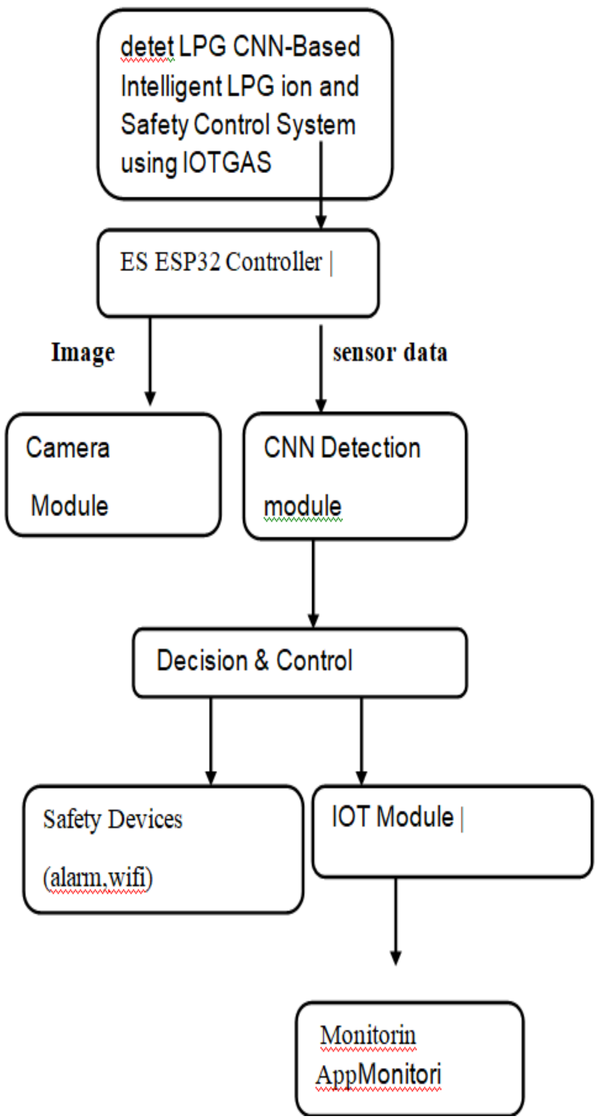

FIG 2: DATAFLOW DIGRAM

The LPG leak detection system's data flow diagram indicates how the flow of information among system elements assures appropriate leak detection and safety controls.

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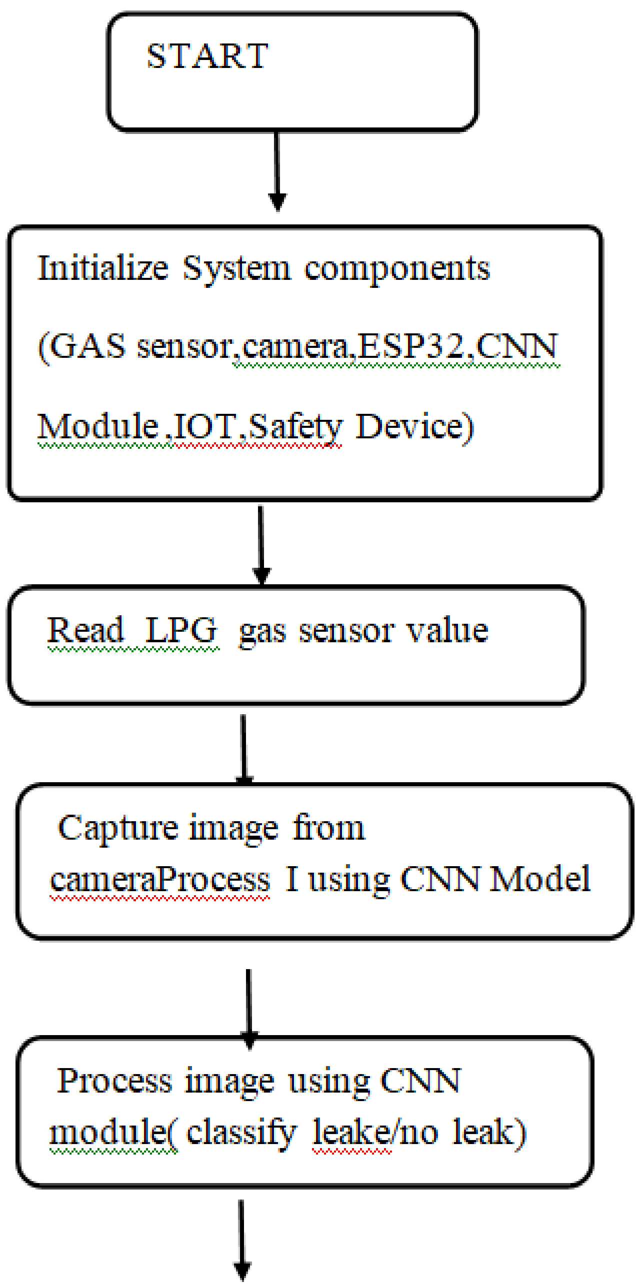
The first element in this system is the LPG gas sensor which continuously measures the concentration of gas in the industrial environment and sends this data to the ESP32 microcontroller where it is compared with preset threshold values. When gas concentrations exceed accepted ranges, the ESP32 controller sends out commands to the camera module to take a real-time photo of the area in which the actual leak has been detected. This photograph is sent to the CNN-based detection module for analysis to produce a leak detection result. Once the CNN processes the visual data and generates a leak detection result, the result is sent back to the ESP32 controller which will combine the output of both the sensor readings and the CNN output to make a final leak detection decision. If a leak is confirmed by the ESP32 controller, it will send control signals to the associated safety devices (i.e., gas shut-off valves, alarms, and ventilation systems). At the same time, all relevant data (sensor readings, detection results, and the alert condition) will be transmitted over the IoT module for real-time monitoring and reporting to the remote monitoring server.

D. FLOWCHART:



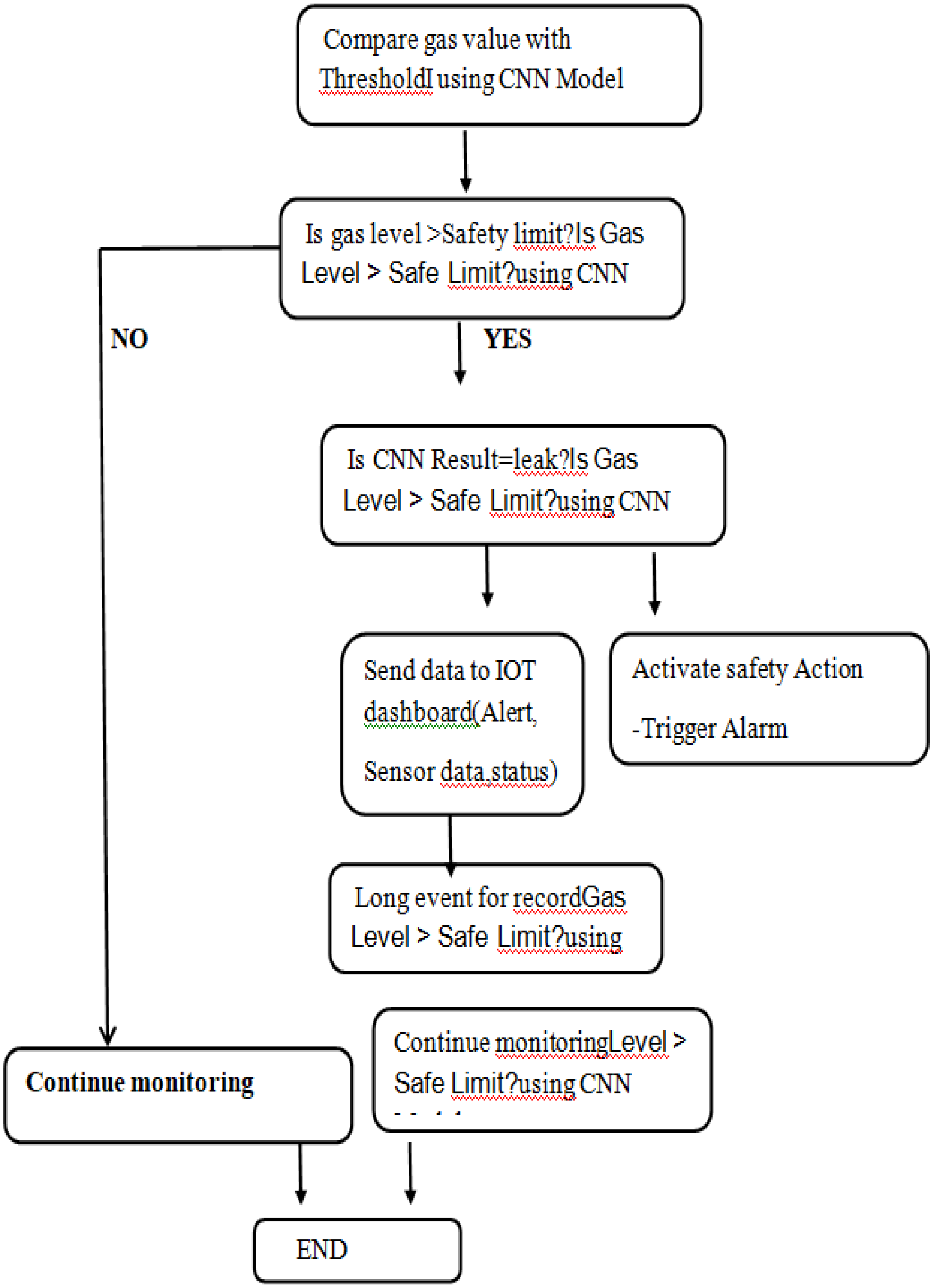


FIG 3: FLOW DIGRAM

The flow diagram shows the LPG detection system in order of how it operates, including all the actions to detect gas leaks and what safety measures need to be taken as a result of gas leaks. The process begins with the system being powered up, at which point the LPG sensor, the Camera Module, the ESP32 microcontroller, the CNN model, the IoT system and any necessary safety equipment have been powered up. After the system is powered up, the LPG sensor will continuously monitor the concentration level of LPG in the ambient air and report that information to the microcontroller. The microcontroller will determine whether the LPG concentration level detected by the sensor exceeds the safe limit established previously.

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Should the concentration level be below the safe limit, the system will just continue to monitor for leaks. When the LPG concentration level is above the safe level, the camera will take one or more pictures of the area suspected of leaking LPG. Those pictures are processed and analyzed by the CNN model to verify whether there is an LPG leak present or not. At that point, the microcontroller will use the information received from the sensor and the output of the CNN to make a final determination as to whether a leak exists or does not exist. If a leak is found to exist, the microcontroller will activate all safety devices for shutting off the gas, opening ventilation ducts and activating alarms, and will send alerts through the IoT system.

V. EXPERIMENTAL RESULT

In this way, the results show that the proposed LPG intelligent detection system, along with the control system, is effective and reliable; its performance was tested under several conditions that approximated those found in industrial settings (normal operations, minor gas leakage, and high concentrations of leaked gas). While under normal conditions, the readings on the gas sensors were below the threshold, meaning that no false alarm was triggered and the system was stable. When there was an LPG leak, the gas sensor detected higher than normal gas concentrations and activated the camera module so that a visual assessment of the leak could be made. Using the CNN to identify visual patterns associated with the leak and to differentiate between real leaks and false alarms (caused by ambient lighting variations or movement in the background) resulted in far fewer false alarms than if the sensor had been used alone to make an assessment. As an example, when there was a confirmed leak, the system acted immediately by activating the gas shut-off valves, the ventilation system, and the alarm system. An IoT (Internet of Things) alert for the gas leak was sent to the monitoring dashboard, thereby enabling a rapid response. In conclusion, the results indicate that the detection accuracy of gas leaks has been improved, the response time to gas leaks has been reduced, and the safety performance of the system has been enhanced.

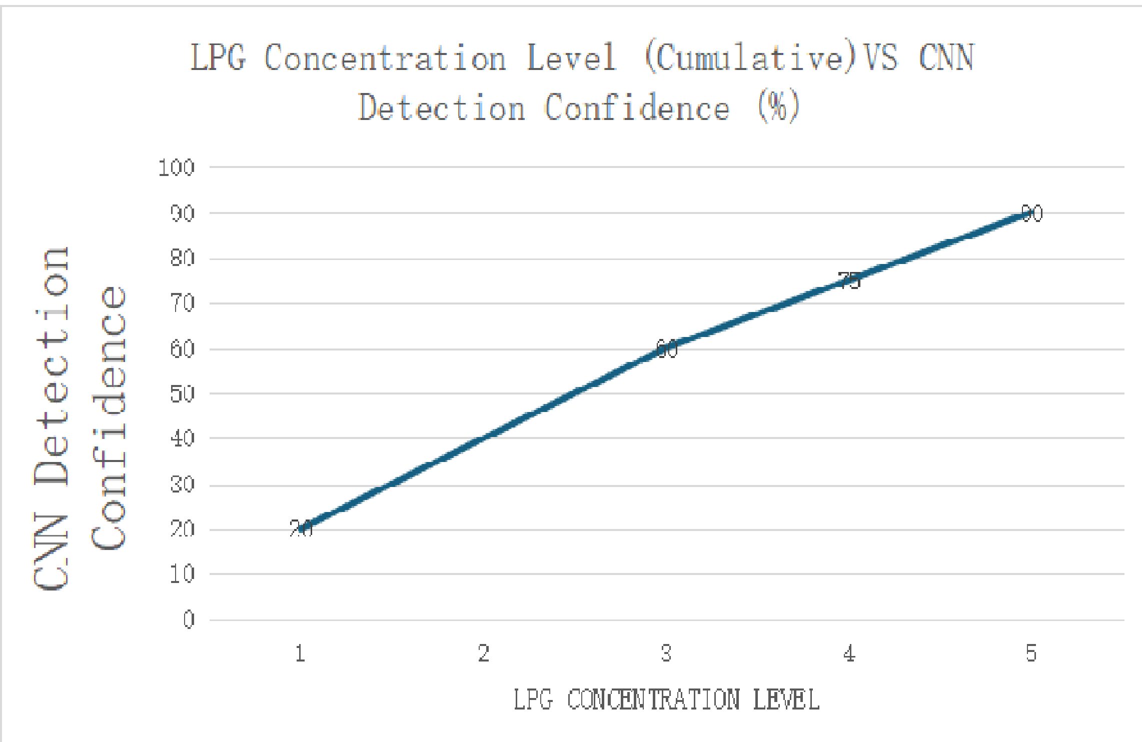

FIG 5: LPG Concentration Level (Cumulative)VS CNN Detection Confidence

VI. CONCLUSION

In many industrial applications, LPG is consumed in large quantities, so providing greater safety through an intelligent LPG detection and safety Control System using CNN technology has practical applications. The CNN system collects data from different types of gas sensors located in various locations, while CNN provides visual analysis capabilities that can detect the presence of gas. This innovative development solves the problems associated with traditional sensor-only detection methods and supports increased accuracy in detecting real threats from false alarms.

An ESP32 Controller is used to carry out real-time data processing, perform automated safety control operations, and provide connectivity to the Internet of Things (IoT) for remote monitoring of systems associated with these processes Experimental data obtained during testing show that the proposed intelligent system correctly detects the presence of LPG leaks, but that it also responds quickly (within 2 seconds) to critical events and initiates safety mechanisms (gas shutoff, ventilation, and alarms) in a timely manner.

Alerting users through IoT-based alerts, such as text messages, along with data logging, will provide users with greater situational awareness and support incident investigation.The proposed system has a low cost, is scalable and will be suitable for many industrial environments. The incorporation of deep learning analytics, sensor-based monitoring and IoT technology will enhance operational safety, protect human life and reduce additional risk of industrial accidents or damage to infrastructure.

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