An Intelligent Crowd Monitoring and Air Quality Surveillance System Using AI and IoT

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Abstract—**The high rate of increase in the size of public assemblies in railway stations, temples, trading malls, auditoriums, and at industrial settings has provided a serious safety consideration, as the assemblies have posed a risk of overcrowding and poor air quality. Conventional ways of manual follow up are not efficient and in responding to cases of emergency at the right time. The present research project suggests a Smart Crowd Guardian System that would help improve the level of safety within the population by combining the monitoring of the level of the crowd and the environment. The system integrates real-time people counting of the camera- based vision analysis system with the continual air quality checking module provided by the IoT-connected sensors. Hazardous conditions are monitored through environmental conditions, which include levels of gas concentration, smoke, temperature and humidity. In case of the abnormal crowding density or unsafe air quality is observed, the system creates immediate alerts and notifications to provide quick preventive measures. The presented solution facilitates a scalable implementation and helps to make smart public infrastructure safer.**

Index Terms—**Crowd Safety, Public Space Monitoring, Air Quality Surveillance, Smart City Infrastructure, Real-Time Safety Monitoring, Environmental Awareness, Intelligent Safety Systems.**

I. INTRODUCTION

The fast urbanization and population explosion has contributed highly to the rising number of people found in the social places like railway stations, temples, shopping malls, stadium, auditoriums, and industrial facilities. Such places are often full of people, particularly at the busy times, at festivals, or when attending major events. The safety of management in such environments is now a big problem to the authorities and administration of the facilities. The congestion that can occur due to overcrowding can cause such hazardous conditions as stampedes and lack of exit routes in case of fire, and not rapid evacuation of people in terroristic situations. Meanwhile, lack of environmental conditions including the rates of harmful gases and smoke, high temperature, and humidity may contribute to the further safety risks of individuals that are present in these overcrowded areas. The management of crowds as well as safety of the environment has thus emerged as a significant concern in the contemporary infrastructure of the people [1].

The outdated safety monitoring systems can be quite manual and simple surveillance structures. Security officers usually observe the conditions of a crowd with either cameras or a direct insight and base judgement on decision making. Manual monitoring is however not efficient when it comes to penetrating a very large crowd or years of monitoring areas. Human operators might not observe those overcrowding conditions at the initial stages as it happens in the complex conditions where the people keep moving constantly. Moreover, some of the environmental threats like smoke leakage or accumulation of the toxic gas might not necessarily be instantly noticeable by human beings. Such a lag in detection may cause consequence that are of dire effects such as health risks, panic among humans and a slow emergency response [2].

Current technological trends in artificial intelligence, computer vision and Internet of Things (IoT) have created possibilities of designing automated safety monitoring systems. Computer vision systems that work based on AI can be used to process live video feeds and track and identify people in real-time, enabling a crowd density to be accurately estimated. These systems are capable of detecting people in a highly complicated scenario with the use of sophisticated detection models that are also able to detect moving and partially obscured persons. This feature renders AI-based crowd monitoring to be much more accurate than the manual approaches to counting. Automated crowd analysis allows Io in charge to make preventive actions in case the population in a particular area is larger than the safe measures of the capacity [3].

Besides crowd monitoring, the other significant aspect of the public areas is the environmental security. Human health can be impacted on air pollution, leakage gases, accumulating smoke and variations in temperature and humidity that cause hazardous conditions. Such environmental risks especially tend to damage industrial plants and confined areas of the population. Regular observation of air quality parameters through sensor has become a valid way of detecting dangerous environmental conditions at an early level. Contemporary IoT sensors have the ability to monitor several indicators of environmental conditions such as the concentration of gases, the content of smoke, the temperature changes, among others. Such sensors are able to send real time information to monitoring platforms where quick analysis and reaction can be done [4].

Intelligent safety system construction is an effective solution, which can be achieved with the help of artificial intelligence and Internet of Things. AI is able to process visual data and detect crowds, and the IoT devices can gather IoT sensor data at the same time. An integration will enable the creation of a whole monitoring system which will monitor human activity and environmental measurements on a real time basis. These integrated systems will be able to constantly compare the acquired information with a set of predetermined safety levels and automatically issue warnings when there are deviant circumstances. The automated warning systems assist law enforcers in acting fast before the situation deteriorates into major incidences.

One more benefit of IoT-based monitoring systems integration is that it allows gaining remote access and visualization in the cloud. Sensors and cameras help gather data that can be relayed to cloud platforms where administrators can observe the conditions using dashboard or mobile gadgets. This will give the benefit of the ability to monitor a number of different places at the same time to enhance operational efficiency and time. Moreover, real time alerts sent by mobile notifications, visual cues or audible alarms will make sure that even in cases of critical conditions, the safety personnel will be notified at once. These capabilities will enhance the situation awareness in the areas of high people density [5].

The global projects in smart cities are gradually shifting to smart infrastructure to enhance civic security and city management. Smart city systems are undergoing a change in adding crowd management and environmental monitoring systems. Using automated monitoring technologies, the administrators of the city will be able to control the public area even more closely, minimize the threat to safety, and enhance the quality of the city in general. Even smart monitoring systems enable the usage of data to make decisions, which allows authorities to study the tendencies in past data, and future crowd management techniques.

In spite of the technological development, integrated systems that can monitor at the same time the level of crowds and environmental conditions can be found in very limited locations in the society. The current systems in the market tend to concentrate on video surveillance or the sensing of the environment independently, therefore they are not effective in resolving complex issues of safety. The innovative solution based on the integration of crowd detection and environmental surveillance can help greatly in the early detection of hazards and respond to the emergency situation much quicker. These systems should also be economical, expandable and fit various kinds of social set ups.

To meet these issues, this paper suggests a Smart Crowd Guardian System that would combine the AI-based tracking of the number of people in crowds with the IoT-coordinated monitoring of the air quality and automatic warning systems. The system relies on the concept of camera-based vision analysis to identify and preserve number of individuals in real-time as well as captures data about the environment in sensor modules that are linked to a microcontroller. The evaluated data are examined at all times to detect cases of overcrowding and risky environmental factors. The system provides alerts in the case of abnormal situations detected by warning devices and remote notifications so that one can take preventive measures.

The intended system is expected to offer a high-quality, and user-friendly and smart safety surveillance solution to the population. The system is able to improve situational awareness through real-time crowd detection, environmental sensing and facilitates proactive safety management using IoT-based communication improvements. This strategy is helpful in the creation of more intelligent yet safer civic infrastructure that would be able to secure human lives in ever more densely populated cities.

II. LITERATURE SURVEY

The UWB (ultra-wideband) technology has proven a significant communication strategy due to the capability to transmit the information through a very broad spectral range with low power consumption and high data rate. UWB systems have a large bandwidth that enables good communication with low interference and higher penetration of the signal across barriers. The above features allow the use of UWB in wireless body area networks, indoor positioning system, radar sensing, and short-range high-speed communication. The researchers in the recent years have directed attention towards increasing the efficiency of UWB systems by improving the design of the antenna, techniques of signal processing, and also communication architectures. The ongoing research on improvement of materials, miniature designs, and optimization processes is assisting the researchers in coming up with high-performance devices that can accommodate the needs of the current wireless communication.

The compact antenna based communication systems and flexible materials of UWB have been studied in several research works. One of the works introduces a mini antenna design on flexible substrate material that can be applied in wearable communication setup and wireless body area network to enhance the portability of the antenna and better the communication performance [6]. The other study addressed optimization of ultra-wideband optical communication parts through the use of smart algorithms, which integrates the neural network anticipation with system optimization methods to enhance amplifier functionality and system stability [7]. Coupled-line filters have also been suggested with high-performance to facilitate wideband wireless communication and focus on reducing the signal interference and the insertion loss of the filter [8]. Moreover, through-wall human activity recognition using ultra-wideband radar devices and deep learning methods has been used, which provide the correct monitoring and sensing of individuals in a self-complex building area [9].

The additional advancements of UWB technology have concentrated on enhancing the auxiliary antenna effectiveness and electromagnetic competence to form unique uses. The ultra-wideband antennas have been designed by evolutionary algorithm-inspired techniques that have been applied to develop antennas optimizing to support efficient radio frequency energy harvesting systems [10]. Rectenna structures with high efficiency have also been proposed to transform ambient RF energy to electrical power to promote the prediction of self-powered wireless sensor systems [11]. Antenna design procedures have been performed with machine learning aided optimization tools to enhance the convergence rate and get the best bandwidth and radiation attributes [12]. Also, additional electromagnetic absorber designs that are developed on the theory of multiport network have been suggested as a way of reducing radar cross-section as well as achieving better electromagnetic compatibility to ultra-wideband communication systems [13].

Other studies with advanced antenna array designs and analysis to enhance the performance of the system in broad band communication networks have also been conducted by researchers. Mantel, Guttler, and Watzel propose the use of ultra-wideband vortex wave arrays using Vivaldi antenna elements to facilitate the use of broadband communications and improved methods of electromagnetic wave manipulation [14]. Comparative modeling work has evaluated nonlinear interference of hybrid optical amplification was done in ultra- wideband optical networks to enhance the reliability of signal transmission in systems [15]. To increase passband performance and reduce out-of-band interference in communication systems miniaturized ultra-wideband filters with resonator specifications have also been invented to inhibit unwanted out-of-band interactions [16]. All these enhancements will help in making the next-generation wireless and optical communications technologies more stable and efficient.

Integration of artificial intelligence, and signal processing methods in ultra-wideband systems have also been highlighted recently by research. Also proposed are advanced designs of electromagnetic absorbers incorporated on mixed absorption principles to facilitate wideband absorption and enhanced electromagnetic shielding results [17]. The self- organizing approach of a network based on ultra-wideband has been explored to provide better positioning systems and improved coordination through networks in the wireless setting [18]. There is also the use of machine learning models to be accurate in classifying between line-of-sight and non- line-of-sight scenarios in indoor positioning systems based on characteristics of channel impulse responses [19]. Moreover, there are deep neural network models that have been built to reduced ultra-wideband antennas in the case of ground penetrating radars, and it improves the prediction of the performance of the antenna and electromagnetic phenomena therein [20]. These advances have shown the increasing role of intelligent designs and optimization methods in the progress of ultra-wideband communication technologies.

III. METHODOLOGY

The Smart Crowd Guardian System is aimed at supplying an unified system of safety monitoring that can observe the number of people as well as the conditions in the environment in the open areas. The system integrates computer vision crowd analysis with environment sensing, which is performed by IoT, in order to identify dangerous scenarios in real time. The process adoption entails various steps such as data collection, video analytics, individual record, environmental surveillance, data transfer, and notification. The camera is linked to a laptop and provides live video streams, which were used to analyze a crowd, whereas there are some environmental sensors, which are tied to a microcontroller and able to measure air quality parameters. The digital information obtained is continually compared with the set safety limits. The system sends alerts and notices when abnormal crowd density is monitored or when the environment is hazardous so that the response can be quick and some preventive measure can be taken.

The Smart Crowd Guardian System is designed to provide a unified safety monitoring solution for open areas by combining computer vision and IoT-based environmental sensing. It continuously analyzes live video streams from cameras to monitor crowd density while also collecting environmental data such as air quality through sensors connected to a microcontroller. The system processes and compares this data with predefined safety limits to identify abnormal or hazardous situations in real time. When high crowd density or unsafe environmental conditions are detected, it immediately sends alerts and notifications to ensure a quick response. This integrated approach reduces the need for manual monitoring, improves decision-making, and helps prevent accidents during public gatherings. Overall, the system enhances safety and efficiency in managing large crowds and environmental risks.

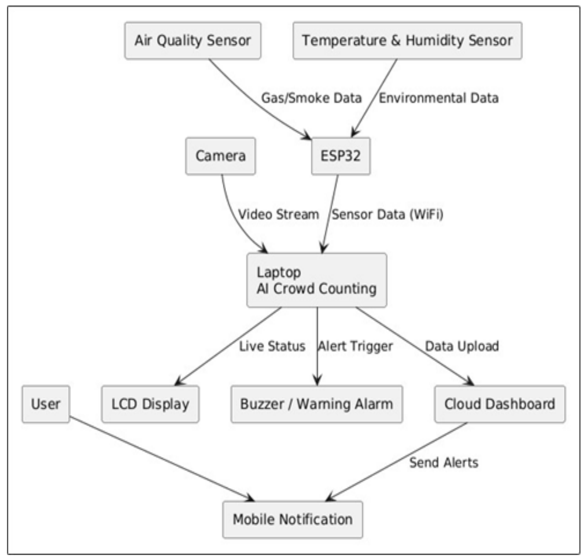

Fig. 1: System Architecture

A. Video Data Acquisition and Crowd Monitoring

The initial phase in the approach implies the continuous purchasing of graphic information to track the movement of people and crowd density. There is a digital camera that is placed at strategic points to record real-time video transmissions within the area under monitoring. The camera is linked to a laptop which is the main processing unit of processing the video frames. To maintain constant control the video stream is recorded with fixed frame rates so that it doesn't delay too much. Every frame is taken as a reflection of the observed setting where several people are walking in the scene. Cameras should also be placed appropriately so as to cover as much of the covered area as possible and eliminate blind areas. The captured video frames are then sent to the image processing pipeline where they are sent to be processed to the next stage. This phase assures us that we can reliably have visual input in the detection of the number of people that are in the area being monitored.

B. Image Processing and Preprocessing

After capturing of the video frames, the system undertakes various preprocessing functions to make the visual data quality and useful. Image preprocessing is used to enhance accuracy in the detection because it lessens the noise, alters the brightness levels, and increases the contrast. All the frames that are processed out of the video stream are resized and converted to a standard format that can be analyzed further. The color normalization and filtering processes are used to eliminate distortions due to lighting variations or camera noise. The analysis of background elements also helps to identify objects that are on the move in the scene and structures that are not moving. The operations of preprocessing are used to enhance a cleaner dataset which the detection model would work on. The ready frames are then sent to the crowd detector phase where the machinery identifies people in the surrounding. Adequate preprocessing is significant in the improvement of genuine performance during detection in real-time observation condition.

C. AI-Based Crowd Detection and Headcount Estimation

The preprocessed system then carries out real-time recognition of persons in each frame of the video stream. In the detection process, human figures are detected in the scene, and this is counted to determine the density of the crowd. The laptop processes the detected model to apply the trained model to each frame and identify the number of persons in the frame. When the individuals are detected, bounding regions are created around them and then the system can follow and count them precisely. This counting is carried out until each incoming frame is counted and this way the crowd density is updated on-the-fly. Whenever the number of individuals detected is more than the set safe limit of the area under surveillance, the system identifies it as a state of overcrowding. This crowd monitoring system is an automated device that allows to track the dangerous crowd formation at an early stage, as the police can take the necessary precautionary measures before the situation can get out of control.

D. Environmental Monitoring Using Sensor Modules

Along with the crowd monitoring system, it also monitors the environmental status through sensor modules that are connected to a microcontroller unit. These parameters are the environmental parameters that are constantly monitored, which include gas concentration, smoke presence, temperatures and humidity. Such sensors are fitted to that area being monitored to obtain real time data of the environment. The microcontroller gathers data of each sensor at fixed intervals and transforms analog data to digital data to be processed. In congested or enclosed areas where respiratory handicaps might happen rapidly (poisonous gases, smoke) it is necessary to monitor the air quality parameters. Measures of temperature and humidity also offer environmental comfort and possible fire hazard. They should have continuous environmental monitoring to ensure that dangerous conditions can be detected in time and the system will be able to give early warnings where the air quality is deemed to become unfit to occupants.

E. Wireless Data Transmission and Cloud Monitoring

The microcontroller then sends the information collected in the environment wirelessly to the central monitoring system after gathering the environmental data. Wireless communication will facilitate a smooth integration of sensor unit and the laptop or cloud platform where data is analysed and visualised. The information passed is retained and analyzed to keep a record of the constant situation in the area being monitored. Cloud-based technologies enable the administrator to monitor the state of the system remotely with dashboards showing the most recent sensor data and the number of attendees. This connectivity makes certain safety personnel to be able to monitor various locations in real time and not have to be physically on site. The processes of collecting historical data in the cloud also can be performed to reveal trends in the movement of the crowds and the changes in the environment. This knowledge assists in enhancing long term safety planning as well as structure management.

F. Alert Generation and Safety Response Mechanism

The last methodology step is to compare the gathered crowd and environmental data to set safety limits. The system keeps on benchmarking the actual number of crowd and environmental indications against acceptable safety levels. In case the density of the crowd surpasses the safe limit of the covered territory or the environmental parameters show the risky situation the system automatically triggers warning systems. Such warnings can be audible warning mechanism, signs and light sources and also remote warnings that are delivered by monitoring personnel. The warning system will provide the authorities with the instant data about any danger, providing them with the opportunity to make quick remedial actions. Automated alert and real-time monitoring decreases by far the time of response in emergency periods. The stage finishes the workflow of the Smart Crowd Guardian System because it processes the information gathered into a response to safety.

IV. RESULT AND DISCUSSION

The Smart Crowd Guardian System performance was tested in an experimental system under controlled conditions that attempted to produce various crowd densities and environmental conditions. The aim of the assessment was to determine the ability of the system to correctly predict the number of people within an area under surveillance and also monitor such environmental factors as the gas concentration, smoke presence, temperature, and humidity. A camera was used to monitor continuously and was interfaced to a laptop through which the visual analysis was done and a sensor module was interfaced to a microcontroller over which the environmental sensing was done. The results of the data collected were sent to the monitoring interface where safety limits were used to determine abnormal conditions.

In the course of the experiment, various crowd situations were formed in order to examine the efficiency of the crowd surveillance module. The system took constant video streams and identified the number of people in the field of view. Since there was a gradual increase in a number of people, the system periodically updated the number of people on the screen and presented the data on the monitoring interface. The experimentation results revealed that the system was still able to stay consistent in its performance as the crowd density was being increased. There were minor differences in the observed number in case of the overlapping of the individuals or in cases where the individuals crossed quickly across the frame. Nevertheless, the total detection rate was consistent and predictable to real-time safety surveillance tasks.

The environmental monitoring module was also tested by making a records of sensor readings at varying conditions. The sensors were able to collect the variation of air quality parameters and sent the data to the monitoring platform immediately. The system monitored the level of gas concentration or smoke; once they reached unsafe levels, warning alerts would be created. These alerts were shown on the monitoring interface and were able to cause external notification mechanisms. Constant checks of the environment will care to guarantee that the poor quality of air is detected at the earliest possible time especially in closed places where dangerous gases or smoke can be more likely to build up.

By combining the concepts of crowd tracking and environmental scanning, a safety observation system, which is able to detect various categories of dangers, was established. This combination enabled the administrators to monitor the human movement trends, as well as the safety situation in the environment, in the same monitoring platform. This system thus enhances situational awareness and minimized chances of delayed response in case of emergencies.

Table 1 is the quantitative output of crowd detection performance at various densities of crowds at the different experimentations. The table is used to compare the actual population in the area under monitoring with the population double its shape that has been identified by the system.

Table 1. Crowd Detection Accuracy Analysis

Scenario	Actual People Count	Detected People Count	Detection Accuracy (%)
Low crowd	6	6	100
Medium crowd	12	11	91.6
High crowd	20	19	95
Very high crowd	30	28	93.3
Critical crowd	40	38	95

According to the values in Table 1, the system had high accuracy regarding detection in a variety of situations in a crowd. The little deviations noted in the increased crowd formations were attributable to partial blockages and overlaps in people in camera field perspective. Notwithstanding such illogical differences, the system was able to run the overcrowding conditions as soon as the number above which the safety threshold was established was reached. This is a necessity towards avoiding hazardous crowd structuring in the open spaces.

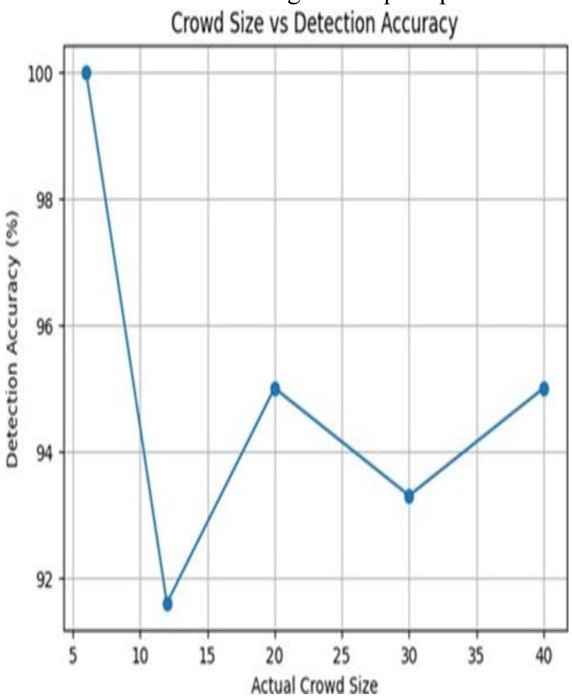

Figure 2. Crowd Size vs Detection Accuracy

The correlation between the crowd size and the accuracy of the detection on the process of the experimental evaluation is demonstrated in Figure 2. The graph shows that the accuracy does not change much even though the number of people will increase. As depicted in the graph, the detection accuracy was above ninety per cent in majority of the cases. This level of precision shows that the suggested monitoring system is capable of estimating the crowd density with high reliance in real-time situations. It is also important that the administrators can take some preventive crowd control measures before the congestion becomes unsafe because they have an accurate estimation of the crowd.

Table 2 displays the result of environmental monitoring on the sensor modules. Sample values have been recorded in the table both under normal operating conditions and under the simulated conditions of the hazardous environmental conditions.

Table 2. Environmental Sensor Monitoring Results

Parameter	Normal Value	Warning Threshold	Recorded Hazard Value
mperature (°C)	27	35	38
Humidity (%)	55	75	82
Gas concentration (ppm)	120	300	420
ıoke level (ppm)	30	120	210

Compared to Table 1, the values in Table 2 indicate that the environmental sensors were very effective where the variations of air quality conditions needed to be observed. Once the levels of temperature and the level of humidity surpassed the alert level, the system sent environmental alerts. On the same note, the concentration of gasses and smoke levels higher than the safe level were the causes of hazard warnings. This is because these alerts can give advance warning of the potentially hazardous environmental conditions and this gives the administrators time to react to safety measures before the situation deteriorates further.

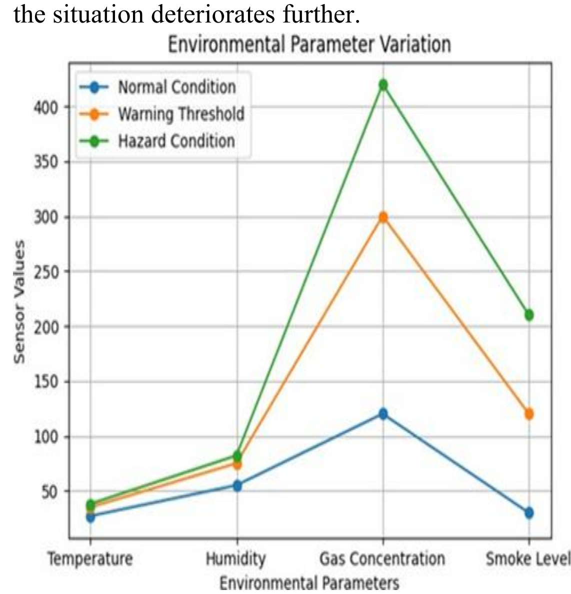

Figure 3. Environmental Parameter Variation

The graphical representation of the environmental parameter variation that were recorded at test phase is shown in figure 3. The graph demonstrates the manner in which various parameters vary with time and how abnormal conditions can be determined by the sudden rise in the sensor values. According to the graph, temperature and humidity do not change much during the normal environment but increases to greatly high levels under simulated environmental conditions of stress. On the same note, there are sharp rises in gas concentration and smoke levels in the introduction of hazardous conditions. It is these patterns which enable the monitoring system to recognize the normal environmental variability as opposed to the dangerous situations which demand urgent interventions.

The other key performance measure that was measured in the course of the experiments was the alert response time of the system. Response time is the time interval between the recognition of a dangerous situation and the work of the warning system. Table 3 shows the response times measured with respect to various safety simulated scenarios.

Table 3. Alert Response Time Analysis

Event Detected	Sensor or Source	Detection Time (s)	Alert Activation Time (s)	Total Response Time (s)
ercrowdi ng	Crowd detection module	2.1	0.7	2.8
Gas leakage	Gas sensor	1.8	0.6	2.4
Smoke detection	Smoke sensor	1.5	0.5	2.0
nperature rise	Temperature sensor	2.0	0.6	2.6

The values of the response time show that the monitoring system responds fast to abnormal conditions. Alerts were turned on after only a few seconds in most instances of the occurrence of a hazardous event being detected. Quick alert generation is involved in any public safety system as the alert generated initially allows the authorities to act faster and the risk of accidents or injuries is minimized. smoke detection gave the shortest response since the smoke sensor is highly sensitive. The short response times were also indicated by the gas leakages, as well as overcrowding, thus providing the confirmation that the system is able to create an immediate notice to the authorities on the possible hazards. The real-time safety monitoring systems placed in the crowded places of people must have a rapid response capability.

The outcomes of the experiment prove the fact that the Smart Crowd Guardian System is a reliable and efficient tool of controlling the crowd density and the environmental conditions. By combining the visual analysis of crowds with the sensor-based surveillance of the environment, one will have the ability to observe the safety in the public realm at a complete level. This system has a high rate of detection, can take effective captures of variations in the environment and give timely alerts in case of dangerous conditions. These functions prove the potential of smart monitoring systems in the improvement of citizens safety and assisting the creation of smart infrastructure in contemporary cities.

V. CONCLUSION

This work described the Smart Crowd Guardian System that is aimed at enhancing the safety of people as it is an IT product that combines crowd monitoring mechanisms in real time with the analysis of the environmental conditions. The system is a combination of visual surveillance and environmental sensing to deliver twenty-four hour watching of the spaces in which the large masses of people regularly gather. The proposed framework, functioned by the analysis of the density of the crowd along with air quality parameters, will improve situational awareness and allow the predicted safety risk to be identified in time. The malpractice monitoring system also provides an automated alarm system that notifies responsible officials whenever unusual conditions are outpicked to allow timely preventive measures. The suggested solution shows that intelligent monitoring is the key to the advanced monitoring in the contemporary public infrastructure. Future development opportunities could be to expand large-scale deployment potentials, add remote monitoring capabilities and introduce more advanced analytics to help enforce predictive safety in smart city settings.

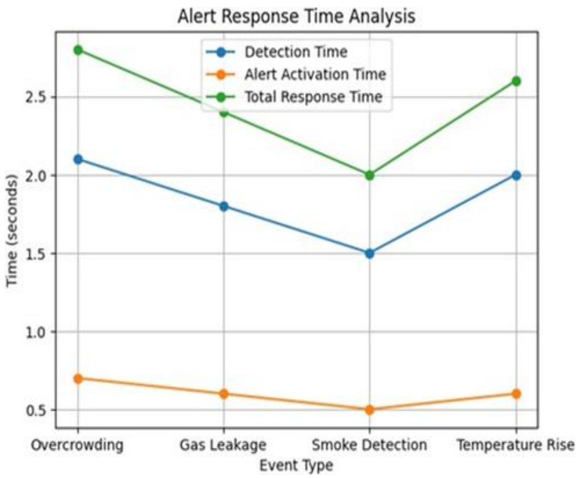

Figure 4. Alert Response Time Comparison

Figure 4 presents the response time in alert when various events are detected. The graph brings to focus the ability of the system to provide timely warnings on both crowds and environmental-based dangers. The graph indicates that the

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