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A Multimodal Monitoring Platform for Predictive Hazard Assessment, and
Intelligent Emergency Intervention Plan (PreSee)

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Plateforme de surveillance multimodale pour l'évaluation prédictive des risques et le plan d'intervention d'urgence intelligent (PreSee)

Résumé

Ce mémoire traite de l'étude et du développement d'un système intelligent de surveillance destiné à renforcer la prévention des risques industriels et la gestion des situations d'urgence. Les systèmes classiques de détection présentent des limites, notamment des fausses alertes, des retards d'intervention, raison pour laquelle on a proposé une solution intégrant les technologies de l'Internet des Objets (IoT), des capteurs intelligents et un système de supervision. Le système mis au point permet de détecter plusieurs paramètres liés aux risques industriels, notamment les gaz inflammables, les flammes, la température et l'humidité, et assure la transmission et la visualisation des données en temps réel sur une plateforme de monitoring. Ce travail inclut également une partie théorique sur la gestion des risques industriels, les méthodes d'analyse des risques, les systèmes de sécurité et les technologies intelligentes appliquées au domaine industriel. Des essais expérimentaux et des scénarios de simulation ont permis d'évaluer le comportement du système et de montrer son intérêt pour la sécurité, la rapidité de détection et l'efficacité des interventions. Bien que le prototype présente certaines limites techniques, cette étude ouvre des perspectives prometteuses pour le développement de systèmes industriels intelligents reposant sur l'intelligence artificielle et la maintenance prédictive.

Mots-clés : risques industriels, sécurité industrielle, Internet des Objets (IoT), capteurs intelligents, surveillance intelligente, détection des risques, supervision en temps réel, systèmes d'alerte, gestion des urgences, intelligence artificielle, maintenance prédictive.

A Multimodal Monitoring Platform for Predictive Hazard Assessment, and Intelligent Emergency Intervention Plan (PreSee)

Abstract

This thesis focuses on the study and development of an intelligent monitoring system designed to enhance industrial risk prevention and emergency management. Conventional detection systems present several limitations, particularly false alarms and delayed interventions, which motivated the proposal of a solution integrating Internet of Things (IoT) technologies, intelligent sensors, and a supervision system. The developed system is capable of detecting several parameters related to industrial risks, including flammable gases, flames, temperature, and humidity, while ensuring real-time data transmission and visualization through a monitoring platform. This work also includes a theoretical part covering industrial risk

management, risk analysis methods, safety systems, and intelligent technologies applied to the industrial field. Experimental tests and simulation scenarios were conducted to evaluate the system's behavior and demonstrate its contribution to improving safety, detection speed, and intervention efficiency. Although the prototype presents certain technical limitations, this study opens promising perspectives for the development of intelligent industrial systems based on artificial intelligence and predictive maintenance.

Keywords: industrial risks, industrial safety, Internet of Things (IoT), intelligent sensors, intelligent monitoring, risk detection, real-time supervision, alarm systems, emergency management, artificial intelligence, predictive maintenance.

(presee) منصة مراقبة متعددة الوسائط لتقييم المخاطر التنبؤية، وخطة التدخل الطارئ الذكية

الملخص:

تتناول هذه المذكرة دراسة وتطوير نظام ذكي للمراقبة يهدف إلى تعزيز الوقاية من المخاطر الصناعية وإدارة حالات الطوارئ. تعاني أنظمة الكشف التقليدية من عدة محدوديات، من بينها الإنذارات الكاذبة وتأخر التدخلات، مما أدى إلى اقتراح حل يعتمد على تقنيات إنترنت الأشياء، والمستشعرات الذكية، ونظام للإشراف والمراقبة. يتيح النظام المطور الكشف عن عدة عوامل مرتبطة بالمخاطر الصناعية، مثل الغازات القابلة للاشتعال، واللهب، ودرجة الحرارة، والرطوبة، مع ضمان نقل البيانات وعرضها في الوقت الحقيقي عبر منصة مراقبة. كما يتضمن هذا العمل جانباً نظرياً يتعلق بإدارة المخاطر الصناعية، وطرق تحليل المخاطر، وأنظمة السلامة، والتقنيات الذكية المطبقة في المجال الصناعي. وقد تم إجراء اختبارات تجريبية وسيناريوهات محاكاة لتقييم أداء النظام وإبراز مساهمته في تحسين السلامة، وسرعة الكشف، وفعالية التدخلات. وعلى الرغم من وجود بعض القيود التقنية المتعلقة بالنموذج الأولي، فإن هذه الدراسة تفتح آفاقاً واعدة لتطوير أنظمة صناعية ذكية تعتمد على الذكاء الاصطناعي والصيانة التنبؤية.

الكلمات المفتاحية: المخاطر الصناعية، السلامة الصناعية، إنترنت الأشياء، المستشعرات الذكية، المراقبة الذكية، كشف المخاطر، الإشراف في الوقت الحقيقي، أنظمة الإنذار، إدارة الطوارئ، الذكاء الاصطناعي، الصيانة التنبؤية

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Dedication

I dedicate this work with all my love and gratitude to my dear mother, whose endless prayers, unconditional love, and constant support have always been my greatest strength. Your sacrifices and encouragement have inspired me throughout every step of my life.

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This achievement is dedicated to you all.

Zennane amira

Dedication

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List of abbreviations

AI: Artificial Intelligence
COPD: Chronic Obstructive Pulmonary Disease
DCS: Distributed Control System
ESD: Emergency Shutdown
ETA: Event Tree Analysis
F&EI: Fire and Explosion Index
FMECA: Failure Mode, Effects and Criticality Analysis
FMEA: Failure Modes and Effects Analysis
FTA: Fault Tree Analysis
GIS: Geographic Information Systems
HAZID: Hazard Identification
HAZOP: Hazard and Operability Study
HRA: Human Reliability Analysis
IoT: Internet of Things
LEL: Lower Explosive Limit
LOPA: Layer of Protection Analysis
LOTO: Lockout/Tagout
LPG: Liquefied Petroleum Gas
MSD: Musculoskeletal Disorder
NDT: Non-Destructive Testing
PHA: Preliminary Hazard Analysis
PII: Internal Emergency Plan
PLC: Programmable Logic Controller
PPE: Personal Protective Equipment
PPI: Particular Intervention Plan
RTD: Resistance Temperature Detectors
SCADA: Supervisory Control and Data Acquisition
SIL: Safety Integrity Levels
SIS: Safety Instrumented System
SMS: Safety Management Systems
SOP: Standard Operating Procedure
VOC: Volatile Organic Compound
VWF: Vibration White Finger

General Introduction

In recent years, industrial systems have become more complex due to rapid technological development, automation, and the integration of digital tools. While these advances improve productivity and efficiency, they also introduce new types of risks and increase the complexity of hazard management. Industries such as energy, manufacturing, petrochemicals, and large infrastructures operate in environments where a simple malfunction can lead to serious human, environmental, and financial consequences.

Detection systems play a key role in the prevention and control of industrial hazards. Conventional detection systems, based on parameters such as gas concentration, temperature, pressure, and fire detection, are widely used to monitor industrial installations. However, these systems often suffer from important limitations, including false alarms, delayed detection, and the absence of intelligent decision-support mechanisms. Such limitations can lead to inefficient emergency response, improper allocation of intervention resources, and an increase in the severity of accident consequences.

The main question guiding this research is therefore:

How can we design a hybrid system capable not only of detecting hazards in real time, but also of predicting their evolution and supporting intelligent emergency intervention?

Recent technological advances, particularly in the fields of the Internet of Things (IoT), Artificial Intelligence (AI), and Geographic Information Systems (GIS), offer new opportunities to enhance industrial safety systems. These technologies enable real-time monitoring, intelligent data analysis, reduction of false alarms, and improved anticipation of hazardous situations. By integrating these tools, it becomes possible to move from simple hazard detection toward predictive risk assessment and decision-making for emergency management.

This work is carried out within this framework and aims to propose and develop an intelligent industrial monitoring and risk management system that integrates sensing technologies, IoT communication, intelligent data processing, and advanced visualization tools. The main objective is to improve the reliability of hazard detection, optimize alert management, and support faster and more effective emergency intervention in industrial environments.

This Master dissertation thesis is divided into two main parts. The first part presents the theoretical background, covering industrial risk management concepts as well as the regulatory and technological framework, including conventional detection systems and emerging technologies.

The second part focuses on the practical work, describing the development of the proposed system, its architecture and functionalities, followed by its validation, results analysis, and discussion of limitations and future improvements.

Industrial Risk Management

Introduction

Industrial activities inherently involve various risks that can threaten human safety, installation integrity, environmental impact, and economic stability. Effective risk management is therefore essential to anticipate, identify, analyse, evaluate, and control potential hazards. This chapter focuses on the theoretical foundations of industrial risk management, including the key concepts, types of risks, methods for identifying and analysing them, and the consequences of industrial accidents. Additionally, it presents strategies for preventing and mitigating these risks, laying the groundwork for understanding how advanced systems like PreSee can enhance safety and operational reliability.

1.1. Fundamental concepts related to industrial risk:



Figure 1 fundamental concept related to industrial risks

- Danger/hazard: Anything with the potential to cause harm (e.g., chemicals, machinery, unsafe behavior). [1]
- Risk: Risk is the effect of uncertainty on objectives, usually expressed in terms of likelihood and severity. [1]
- Hazardous situation: a dangerous situation arises when a hazard is present in a specific context or scenario, such that the risk of harm is significant. For example, a chemical stored correctly is a hazard, but a spill or leak creates a dangerous situation. [1]
- Hazardous event: A dangerous event is an occurrence or incident in the workplace where exposure to one or more hazards actually happens, potentially causing harm, injury, illness, damage, or loss. [1]
- Damage: Damage is the physical or functional harm to people, property, equipment, or the environment resulting from exposure to a hazard or a dangerous event. [1]

- Dangerous phenomenon: This refers to a physical, chemical, or biological process (like fire, explosion, or toxic release) inherent to a hazard that can unleash energy or substances, potentially causing damage to people, goods, or the environment in industrial accidents. [2]
- Major industrial risk: involves accidental events on industrial sites with dangerous substances or processes, causing serious immediate or delayed harm to people, property, or the environment, as defined in the French environmental code (Code de l'environnement, Articles L511-1 to L597-46) and Seveso III (Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012). [3]

1.2. Typologies of industrial risks:

Industrial risks are generally classified into four major categories: technological, human, organizational, and environmental risks. This classification facilitates risk identification, analysis, and implementation of appropriate preventive measures.

1.2.1. Technological risks:

Technological risks refer to hazards arising from the malfunction, failure, or loss of control of industrial equipment, installations, or technical processes. These risks are directly related to the technology used in production systems and may lead to major accidents such as fires, explosions, toxic releases, structural collapse, or system shutdowns.

In high-risk industries (oil and gas, petrochemicals, and power generation), technological risks often result from:

- Equipment failure (valves, pipelines, reactors)
- Instrumentation or control system malfunction
- Loss of containment of hazardous substances
- Overpressure or overheating
- Electrical faults or short circuits

Technological risks in the process industry are associated with hazardous events caused by failure of safety instrumented systems or loss of control of industrial processes.

Technological risks are typically analysed using structured methods such as Hazard and Operability Study (HAZOP), Failure Mode and Effects Criticality Analysis (FMECA), Fault Tree Analysis (FTA), and Layer of Protection Analysis (LOPA), which aim to identify failure modes and evaluate their potential consequences. [4]

1.2.2. Human risk:

Human risk, in the context of process industries, is defined as the probability that an operator's error or inappropriate behaviour may lead to an accident or loss. The causes of human risk can be grouped into three main categories: skill-based errors, judgment errors, and errors related to fatigue or stress. These factors can contribute to undesirable events such as leaks, fires, or explosions, even when technical equipment and systems comply with standards. [5]

Human errors arise not only from individual actions but also from organizational conditions, inadequate procedures, and the overall safety culture of the company. Preventing human risks therefore relies on a combination of measures, including training, supervision, ergonomic design of workstations, and implementation of organizational barriers. For instance, standardized procedures, automated alert systems, and rapid intervention devices can mitigate the impact of human errors on industrial safety.

Finally, the assessment of human risk involves methodologies such as **Human Reliability Analysis (HRA)**, which quantifies the likelihood of human errors in industrial process scenarios and integrates this data into overall safety analyses, such as **HAZOP** (Hazard and Operability Study) or **FMEA** (Failure Modes and Effects Analysis).

1.2.3. Organizational risk:

Organizational risk in process industries refers to failures in the company's structure, procedures, and culture that can lead to accidents or losses. These risks primarily arise from shortcomings in the planning, coordination, and communication of industrial operations. Poor organization can manifest as inadequate procedures, lack of supervision, poorly defined responsibilities, or inefficient management of maintenance and personnel training.

The main causes of organizational risk can be classified as follows:

- Inadequate procedures: Work instructions, safety protocols, and standard operating procedures may be incomplete, ambiguous, or outdated, increasing the likelihood of human errors and incidents.
- Deficient communication and coordination: Critical information regarding operations, maintenance, or safety may not be effectively shared among teams, leading to inconsistent or delayed responses to hazards.
- Lack of supervision and control: The absence of rigorous monitoring of processes and employee performance can prevent the early identification of risky behaviors or technical malfunctions.
- Insufficient safety culture: An organization that does not prioritize safety or adequately train its employees in risk management fosters an environment conducive to accidents.

The consequences of organizational failures are often severe, ranging from minor accidents to major catastrophes, particularly in high-risk industries such as chemicals, oil, and gas. Controlling these risks requires the implementation of integrated safety management systems, regular organizational audits, and the promotion of a proactive safety culture. [6]

1.2.4. Environmental risk:

Environmental risks in industrial settings refer to the potential for accidents or operational failures to negatively impact the natural environment, including air, water, soil, and ecosystems. These risks arise from uncontrolled releases of hazardous substances, emissions, effluents, or energy, and they can result from technological failures, human error, or organizational deficiencies. Common industrial environmental risks include chemical spills, toxic gas leaks, fires, explosions, and waste mismanagement. Environmental risks can be categorized as follows:

1. Air Pollution Risks – Emission of gases, vapours, or particulates that can harm human health and ecosystems. Examples include volatile organic compounds (VOCs), greenhouse gases, and flammable vapours.
2. Water Contamination Risks – Accidental discharge of chemicals, effluents, or process water into surface or groundwater, potentially affecting aquatic life and potable water sources.
3. Soil and Ground Contamination – Leakage or disposal of hazardous substances leading to long-term soil degradation and bioaccumulation of toxins.
4. Ecological Disturbances – Industrial operations can disrupt local ecosystems, threatening flora and fauna and reducing biodiversity.
5. Cumulative and Long-Term Impacts – Continuous low-level emissions or repeated minor incidents may lead to chronic environmental degradation and cumulative ecosystem damage.

Mitigating environmental risks requires an integrated approach, combining process safety management, environmental monitoring, and emergency response planning. Modern approaches.

Table 1 Examples of Industrial Risk

Chemical hazards	Toxic gas exposure	Leaking storage tanks inadequate ventilation in confined areas Improper handling during mixing.
	Solvent skin contact	Unlabeled containers spills on unsealed surfaces Lack of gloves during cleaning.
	Dust inhalation	Poorly maintained dust extraction systems grinding without masks Open powder storage.
Physical hazards	Excessive noise	Unguarded machinery operation lack of ear protection Concurrent equipment running.
	Extreme heat	Faulty cooling systems proximity to furnaces High ambient temperatures in summer.
	Vibration exposure	Prolonged use of handheld power tools unmaintained vibrating machinery No anti-vibration gloves.
Mechanical hazards	Crushing injuries	Pinch points on unguarded conveyors unexpected machine startups Material jams.
	Cuts from blades	Worn guards on saws rushed manual adjustments Dull tooling.
	Amputations	Rotating parts contact lockout-tag out failure

		Emergency stop inaccessibility.
Ergonomic hazards	Manual lifting strains	Objects over 25kg without aids improper grip points Elevated load heights.
	Repetitive motion overuse	Fixed workstation heights high-volume pipetting No rotation schedules.
	Prolonged static postures	Non-adjustable chairs Monitor misalignment Extended data entry.
Combustion hazards	Flammable liquid spills	Improper storage in non-approved containers Leaks from faulty drums Overfilling during transfers
	Electrical faults	Frayed wiring in hot environments Overloaded circuits near vapors Ungrounded equipment sparks
	Hot work activities	Sparks from welding without screens Grinding on dusty surfaces Open flames near combustibles

1.3. Consequences of Industrial Accidents:

Industrial accidents in process industries can generate severe and multidimensional consequences. These impacts generally affect human health, the economy, and the environment and may extend over short, medium, or long terms depending on the severity of the event.

1.3.1. on human health:

Accidents at work and exposure to harmful substances can cause a wide range of health problems, which can be divided into acute (short-term) injuries and chronic (long-term) illnesses. [7]

1.3.1.1. Short-term health effects:

- **Deaths and Serious Injuries:** Accidents can kill people at work or cause serious injuries like amputations, fractures (other than to fingers), and crush injuries that damage internal organs.
- **Burns:** Workers can get serious burns that cover more than 10% of their bodies or damage important organs. This often happens when they are near fire, explosions, or corrosive chemicals.
- **Respiratory Distress and Asphyxiation:** Breathing in poisonous gases, fumes, or places with low oxygen levels can make you pass out, choke, or have a sudden asthma attack.
- **Sensory and Skin Damage:** Immediate effects include loss of vision, "arc eye" from welding radiation, and contact dermatitis from chemicals that irritate the skin.

1.3.1.2 Long-term health effects:

- **Work-Related Cancers:** Long-term exposure to dangerous substances can cause cancers, such as mesothelioma and lung cancer from asbestos, leukaemia from radiation, and nasal cancer from wood dust.
- **Respiratory Diseases:** Breathing in respirable dusts like silica or coal for a long time can cause lung scarring that can't be fixed, like fibrosis, silicosis, and asbestosis, as well as chronic obstructive pulmonary disease (COPD).
- **Musculoskeletal Disorders (MSDs):** Bad manual handling and bad ergonomic design can cause back injuries, slipped discs, tenosynovitis, and carpal tunnel syndrome.
- **Hearing and Vibration Damage:** Constantly loud noises can cause permanent hearing loss and tinnitus. When you shake your hands and arms, it can cause Vibration White Finger (VWF), which makes it harder for blood to flow and can lead to gangrene in advanced cases.
- **Organ Failure:** Toxins that get into the bloodstream can hurt the liver and kidneys a lot, which can lead to cirrhosis or organ failure.

1.3.1.3 Psychological and Reproductive Impacts:

Psychological and reproductive consequences are often treated separately because their effects may appear either immediately or after a long period. Unlike physical injuries, their manifestations are not always directly observable and may develop progressively over time

- **Mental Ill-Health:** Intense or prolonged workplace pressure and traumatic events can cause mental illness: stress, anxiety, and depression that last for a long time or are very strong can be caused by a lot of stress at work or traumatic events. These conditions cause millions of missed workdays every year.
- **Reproductive Damage:** Ionizing radiation and some industrial chemicals (mutagens and teratogens) can make people sterile, cause genetic defects, and cause birth defects in the children of workers who are exposed to them.

1.3.2. Economic consequences:

Industrial accidents cost a lot of money, and they hurt not only the company involved but also the national economy and the communities around it. In high-risk fields like oil and gas, petrochemicals, and power generation, a big accident can cost billions of dollars. [8]

1.3.2.1 Direct and Indirect Costs:

The financial impact falls into two main categories:

- **Direct costs:** cover things like medical bills, rehab, and lost earnings when someone cannot work. Basically, it is the money that stops coming in while they're out, minus whatever they get from sick pay or state benefits.

- Indirect costs are trickier to pin down. These show up over time: a higher chance of unemployment, not being able to do physically demanding jobs or work long hours, slower career growth, and a permanent drop in what you can earn.

1.3.2.2 Consequences for Employment Probabilities:

An industrial accident really hurts a worker's chances of staying in the workforce.

- Immediate and Persistent Loss: Right after an injury, people are much less likely to hold onto their jobs, and this does not improve quickly. The struggle to get back into work often sticks around for years.
- Seriousness of Injury: The more serious the injury, the less likely someone is to stay employed. There is a clear link: the longer the disability lasts, the worse it gets for job prospects.
- Regional Economic Factors: Where you live matters too. In regions with high unemployment or a weak economy, it is even tougher. Fewer jobs, more competition, and not many positions fit someone with new limitations. Injured workers in these areas face an even steeper uphill climb.

1.3.3. Environmental consequences:

Industrial accidents in process industries hit the environment hard, and you really see the damage depending on where the chemicals end up and what exactly spills out. [5]

- Atmospheric Impacts and Dispersion: When something goes wrong, toxic or flammable gases can shoot up into the atmosphere. Sometimes these gases drift off as light plumes, but other times they hang low as dense clouds—what happens depends a lot on the weather and the landscape around the plant. Once those chemicals get into the air, they do not just disappear. They mix, react, and stick around, sometimes causing new problems or messing up air quality for a long time. In addition, it is not just big accidents—smaller leaks and fugitive emissions keep adding to the local pollution, long after the main event is over.
- Contamination of Water and Soil: Usually, this happens when a plant's drainage or waste systems fail, or when tanks spring a leak. It does not matter if it is an underground tank or a tanker truck—if dangerous chemicals escape and there are not proper barriers, they can quickly spread. They poison the soil, seep into rivers or groundwater, and start disrupting local ecosystems. Sometimes, the effects last for years, making water unsafe and threatening all sorts of wildlife.
- Then there is the bigger picture: sustainability and following the rules. Every accident like this is a real setback for sustainable development. It means a company dropped the ball, and that often leads to tough legal trouble. Meeting environmental standards gets a lot more complicated when you are dealing with accidental chemical releases. Clean-up can drag on, with ongoing monitoring and recovery efforts needed to manage the fallout. It is a heavy burden, both for the environment and for the companies involved.

1.4. Methods for identifying and analysing risks:

Methods for identifying and analysing risks can be broadly divided into two categories: qualitative and quantitative. These techniques seek to detect possible risks, assess their consequences, and assist in industrial safety management decision-making.

1.4.1. Qualitative methods:

Without using numerical calculations, qualitative approaches use expert judgment and descriptive analysis to identify risks and evaluate their likelihood and severity. They are frequently employed early in a project to get a broad picture of possible risks. [9]

- **Checklists:** Traditional checklists are comprehensive lists of desired system characteristics or actions that an operator or system should take. Typically based on experience, it evaluates the system's or operation's acceptability or status in relation to accepted norms.
- **Preliminary Hazard Analysis (PHA)** is an early-stage systematic risk assessment technique to identify potential hazards within a system, process, or project prior to detailed design or the start of operation. It aims to: Detect possible sources of danger, Use Statistics to Estimate the Potential Severity of and Likelihood of accidents, and Propose preventive or protective measures
- **What-If:** a brainstorming method where a group of experienced people that know the topic in detail ask questions or express concerns about possible undesired events. The guidewords are not used to assist the brainstorming process.
- **HAZOP (Hazard and Operability) Analysis:** A structured technique in which potential operational problems are identified through a series of guidewords that explore deviations from the intended process. It can be used for any type of interaction of a flow process, and it also might be used in any type of procedure or flowchart.
- **Hazard Identification HAZID:** Mentioned in the context of preliminary hazard analysis, this technique is typically used early in the design phase of a project to identify initial hazards and safety concerns.
- **Failure Mode and Effects Analysis FMEA:** This technique involves breaking a system, hardware, or process into components to analyse how each may fail, the mechanisms behind these failures, and their resulting consequences. It is used during design, manufacturing, or operation to improve system design, choose between design alternatives, or plan maintenance programs.
- **Bow-tie analysis:** One risk assessment technique that can be used to examine and explain the evolution of high-risk situations is the bowtie method.

The diagram's bow tie design makes it easy to distinguish between the proactive and reactive aspects of risk management.

1.4.2. Quantitative methods:

In contrast, quantitative techniques predict the likelihood and consequences of hazardous events using mathematical models, probability calculations, and numerical data. They are frequently applied to complex or high-risk systems and offer a more accurate assessment of risk levels:

- **Layer of Protection Analysis (LOPA):** A technique that provides an order-of-magnitude estimate of risk using predetermined values for initiating events, independent protection layers, and consequences. There is only one cause-and-effect pair covered by LOPA. There are identified scenarios somewhere else (usually in a qualitative hazard assessment).
- The Dow Chemical Company created **the Dow Fire and Explosion Index (F&EI)**, a system for rating the relative potential fire and explosion risk effect radius and property damage/business interruption impacts associated with a process. Analysts use process data and material properties to compute a variety of exposure and hazard indices.
- **Fault Tree Analysis (FTA):** A logic model based on a graphical representation of combinations of failures that will produce a certain main failure or incident of interest (top event). This technique with Boolean Logic (AND & OR logic gates). We can then assign statistical values to each end point of the branch, which enables us to calculate risk.
- **Event tree Analysis (ETA)** Binary logic, in which an event has or has not occurred or a component has or has not failed, is the foundation of event tree analysis. Analyzing the effects of a failure or undesirable event is beneficial.

An initiating event, such as a component failure, an increase in temperature or pressure, or the release of a hazardous material, is where an event tree starts. The event's effects are tracked via a number of potential routes. A chance of occurrence is assigned to each path, and it is feasible to determine the likelihood of the different possible outcomes.

1.5. Risk Prevention and Control Measures:

1.5.1 Technical (Engineering) Barriers:

Technical barriers are physical or automated systems designed to prevent hazardous events or reduce their impact. [10]

1.5.1.1 Inherently Safer Design:

This approach focuses on eliminating hazards at the source rather than controlling them. Principles include:

- Substitution (replace hazardous substances with less dangerous ones)
- Minimization (reduce quantities of dangerous materials)
- Moderation (use less hazardous conditions such as lower pressure/temperature)
- Simplification (design processes to reduce complexity and human error)

1.5.1.2 Process Control Systems:

- Automated control systems (PLC, DCS)
- Real-time monitoring of temperature, pressure, flow rate
- Alarm systems for abnormal conditions

These systems ensure the process remains within safe operating limits.

1.5.1.3 Safety Instrumented Systems (SIS):

- Automatic shutdown systems
- Emergency shutdown valves (ESD)
- Safety relief valves
- Fire and gas detection systems

1.5.1.4 Physical Protection Systems:

- Fire-resistant walls
- Explosion-proof equipment
- Containment dikes and bund walls
- Ventilation systems
- Gas detectors

1.5.1.5 Maintenance and Inspection Programs:

- Preventive maintenance
- Predictive maintenance (vibration analysis, thermography)
- Periodic inspection of pipelines and pressure vessels
- Non-destructive testing (NDT)

1.5.2 Organizational Barriers:

Organizational barriers involve management systems, policies, and procedures that structure safe operations.

1.5.2.1 Safety Management Systems (SMS):

A Safety Management System includes:

- Risk assessment procedures
- Hazard identification (HAZID, HAZOP)
- Incident reporting systems
- Performance monitoring
- Continuous improvement

1.5.2.2 Risk Assessment and Analysis:

Common tools include:

- HAZOP (Hazard and Operability Study)
- FMEA (Failure Mode and Effects Analysis)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Bow-Tie Analysis

1.5.2.3 Standard Operating Procedures:

- Written procedures for normal and emergency operations
- Permit-to-work systems
- Lockout/Tagout (LOTO) procedures
- Confined space entry procedures

1.5.2.4 Emergency Preparedness and Response Plans:

- Evacuation plans
- Fire drills
- Spill containment strategies
- Coordination with local authorities
- Crisis communication systems

1.5.2.5 Safety Culture and Leadership:

- Management commitment to safety
- Encouragement of incident reporting
- No-blame reporting culture
- Continuous safety training programs

1.5.3 Human Barriers:

Human barriers focus on individual behavior, competence, and awareness.

1.5.3.1 Training and Competency Development:

- Technical skills training
- Emergency response training
- Simulator-based training
- Certification programs

1.5.3.2 Human Factors Engineering:

- Ergonomic workplace design
- Clear labeling and signage
- User-friendly control panels
- Alarm management to avoid alarm fatigue

1.5.3.3 Personal Protective Equipment (PPE):

- Helmets
- Safety goggles
- Fire-resistant clothing
- Respiratory protection
- Chemical-resistant gloves

1.5.3.4 Behavioral Safety Programs:

- Observation and feedback systems
- Reporting of near-misses
- Safe work behavior reinforcement

What is particularly innovative in PreSee is its holistic approach to industrial safety. Unlike traditional approaches that mainly focus on technical detection, PreSee offers a holistic approach to technical, organizational, and human safety barriers within a single framework. This makes PreSee a valuable tool for supporting decisions on risk control and safety in complex industrial facilities

1.6. Conclusion:

To sum up, understanding hazards and risks is not just about definitions; it is about protecting people's lives and well-being. A hazard is anything that can cause harm, and risk is the chance that this harm could actually happen. When hazards are ignored or not properly managed, the consequences can be serious, affecting not only individuals but also families, workplaces, and communities. Injuries, illnesses, financial losses, and even loss of life can result from simple dangers that were overlooked.

The good news is that many of these situations can be prevented. By being aware of potential hazards, carefully assessing risks, and putting the right control measures in place, we can greatly reduce accidents and create safer environments. Safety is everyone's responsibility, and taking small but thoughtful steps can make a big difference. In the end, understanding hazards and risks helps us make smarter decisions and protect what matters most: people.

Regulatory Framework and Intelligent Technologies

Introduction

This chapter will discuss the framework, the regulations, the norms, and the technology regarding the management of industrial risk and the detection systems for hazardous situations. It will, among other things, discuss the major regulations and standards that govern the industrial sector, especially regarding safety. It will, moreover, discuss the conventional detection systems, the drawbacks of such systems, and the contribution of the Internet of Things, artificial intelligence, geographic information systems, among other emerging technologies, to the management of industrial risk.

2.1 Regulatory framework:

IEC 61511:

It is an international standard that outlines the specifications for creating, putting into practice, and overseeing Safety Instrumented Systems (SIS) that are used to stop or lessen industrial hazards. [11]

It offers a practical safety framework that assists industries in identifying hazards, keeping an eye on dangerous situations, and automatically initiating protective measures when they arise. The entire safety lifecycle—hazard analysis, system design, implementation, testing, operation, and maintenance—is covered by the standard. [12]

In order to guarantee that monitoring and control systems can identify possible hazards early and initiate the proper safety responses to protect people, equipment, and the environment, IEC 61511 is widely used in process industries such as oil and gas, chemical plants, and energy systems. [13]

IEC 61508:

IEC 61508 is an international standard that establishes a generic framework for the functional safety of electrical, electronic, and programmable electronic (E/E/PE) safety-related systems. It defines a unified approach for all activities throughout the overall safety lifecycle, ranging from the initial concept and design through implementation to operation, maintenance, and decommissioning. The standard adopts a risk-based methodology to determine safety integrity requirements and introduces Safety Integrity Levels (SIL) to specify the target level of reliability for the safety functions implemented by these systems. [14]

PRESEE relates directly to IEC 61508 because it is an intelligent monitoring and decision-support platform designed for industrial and high-risk facilities, which are primary application sectors governed by the standard. By integrating industrial sensors, AI, and IoT to detect hazards in real-time and propose emergency intervention plans, PRESEE functions as a programmable electronic safety-related system. As such, its development must adhere to the standard's rigorous requirements for hardware and software realization and systematic fault control to ensure its predictive analyses and decision-support functions effectively achieve the required tolerable risk.

NFPA 72:

The Fire Alarm Code (NFPA 72) is the standard for fire alarm systems and their respective applications, installations, locations, performances, and maintenance in the U.S. It governs all types of alarm systems associated with emergency communications systems, supervising station alarm systems, public emergency reporting systems, and fire and carbon monoxide detection systems. The main goal of the code is to specify the minimum performance, reliability, and quality levels for signal initiation, transmission, notification, and annunciation of alarm signals to protect life and property. [15]

PRESEE utilizes industrial sensors, artificial intelligence (AI), and Internet of Things (IoT) devices to detect hazards and create an immediate response plan to those hazards, making PRESEE a next-generation emergency communications and detection system needing to comply with the performance/reliability requirements stated in NFPA 72. In addition, PRESEE being a networked solution, is subject to the expanded cybersecurity provisions of the 2025 edition of NFPA 72. These provisions require that network-connected equipment meet specific security levels in order to prevent unauthorized access and/or damage to the safety-critical hardware/software.

IEC 60079-10:

IEC 60079-10 is an international standard that specifies the main principles and procedures for the classification of hazardous areas where explosive atmospheres can occur. More precisely, IEC 60079-10-1 focuses on areas that contain flammable gas or vapor and/or mist, while IEC 60079-10-2 addresses areas containing combustible dust atmospheres and layers. The main aim of this standard is to provide the technical background for the correct selection and installation of the equipment through the assessment of the frequency and duration of the explosive atmosphere using a detailed method of analysis of the environment. The essential criteria for the assessment of ignition hazards and the associated guidance for the design and control parameters for explosion prevention in the plant area are provided in this standard.

The relationship between IEC 60079-10 and PreSee is based on the evolution of safety standards from traditional safety to intelligent risk prevention. While IEC 60079-10 offers a set of criteria for traditional systems that focus on indication, alarm, and control when a predetermined limit is breached, PreSee offers an evolutionary monitoring and decision support system. This is achieved by using industrial sensors deployed by standards such as IEC 60079-10, which classify hazardous areas. The evolution is based on integrating these sensors with AI, IoT, and GIS to not only identify risks but also predict risks before they actually happen. This is achieved by analyzing data collected from sensors deployed in classified hazardous areas. This allows PreSee to move beyond the basic alert functions of IEC 60079-10 to predict risks and offer specific emergency intervention plans. [16]

ISO 31000:2009:

ISO 31000:2009 is an organized framework for risk management. It assists organizations in identifying possible risks, assessing the degree of risk, analyzing their impact and likelihood, and putting the right controls in place to lessen or control those risks. The standard plays a significant methodological role in PreSee, supporting the process of identifying hazards detected by multimodal sensors, assessing the likelihood and severity of these hazards, and choosing the best intervention strategies. It encourages a methodical and ongoing process of

monitoring, reviewing, and improving risk management practices to ensure safety, reliability, and effective decision-making. By adhering to it, the platform can methodically convert gathered monitoring data into risk assessments and intelligent emergency response plans. guaranteeing that hazard prediction and decision-making conform to globally accepted risk management principles. [17]

In summary, ISO 31000 provides the risk management methodology that guides how PreSee detects hazards, evaluates their risk level, and recommends the most appropriate emergency intervention actions.

API RP 752:

It is a recommended practice developed by the American Petroleum Institute; it provides guidelines for evaluating and managing hazards related to the location of buildings and personnel within industrial facilities, especially in oil, gas, and chemical plants. The standard focuses on assessing risks from events such as explosions, fires, or toxic releases and ensuring that buildings and control rooms are located and designed to minimize harm to people and equipment. [18]

API RP 752 can support the risk evaluation and safety planning stage. The guidelines help determine how hazards detected by the PreSee monitoring system could affect critical infrastructures and personnel areas. [19]

2.2 SIS:

The Safety Instrumented System is an important protection system that is designed to automatically find hazardous conditions and take action to prevent accidents or make the consequences of accidents less severe.

The Safety Instrumented System is a system that is made up of parts including sensors that detect abnormal conditions like high pressure or gas leaks or a big rise in temperature; a logic solver that is like a controller—it looks at the data from the sensors and this is often a Programmable Logic Controller or a safety controller; and final control elements such as valves or shutdown systems or alarms [20]

The main job of the SIS is to make a process safe when the safety limits that have been set are exceeded. For example, in the oil and gas industry, if the SIS detects a gas leak, it can automatically trigger an emergency shutdown to prevent an explosion.

SIS works according to standards, like the International Electrotechnical Commission 61511 standard, which says how safety systems should be designed and implemented and maintained. SIS is very important. It has to be done correctly to keep people safe.

SIS is an important safety layer in industrial environments. It automatically finds conditions and brings processes to a safe state. It does this with the help of sensors, logic solvers, and control elements.[21]

In this PreSee the SIS is the part that makes sure everything is safe. The new platform that uses intelligence and checks everything in multiple ways makes the SIS better. It does this by adding analytics and intelligent decision support to the SIS.

By using real-time data from the SIS, the system can find hazards early, reduce alarms, and

make emergency plans work better. This makes safety systems that just react to problems into systems that can prevent problems and adapt to new situations. The Safety Instrumented System and the new platform work together to make this happen:

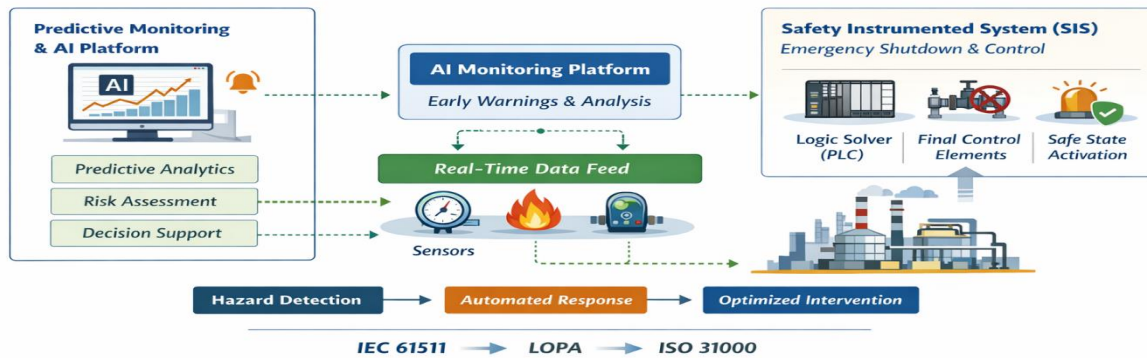


Figure II AI and Industrial Security Integration Diagram

2.3 detection system:

The detection systems are an important tool in ensuring safety in an industrial environment. The systems are designed to detect abnormal conditions such as gas leaks, fire, excessive temperature, changes in pressure, and abnormal liquid levels, which are likely to cause hazardous events in an industrial environment. The systems monitor these parameters and detect abnormal changes through sensors, enabling the operators to take appropriate corrective measures to prevent hazardous events in an industrial environment.

In most industrial facilities, the detection systems are composed of sensors, control systems, communication systems, and alarm systems. When a parameter exceeds a predetermined threshold value, the system alerts the operators through an alarm system.

The detection systems can be classified in various ways according to their architecture and technology. Among the various types of detection systems is the classical detection system, which is the most popular and traditional approach to hazard detection in an industrial environment.

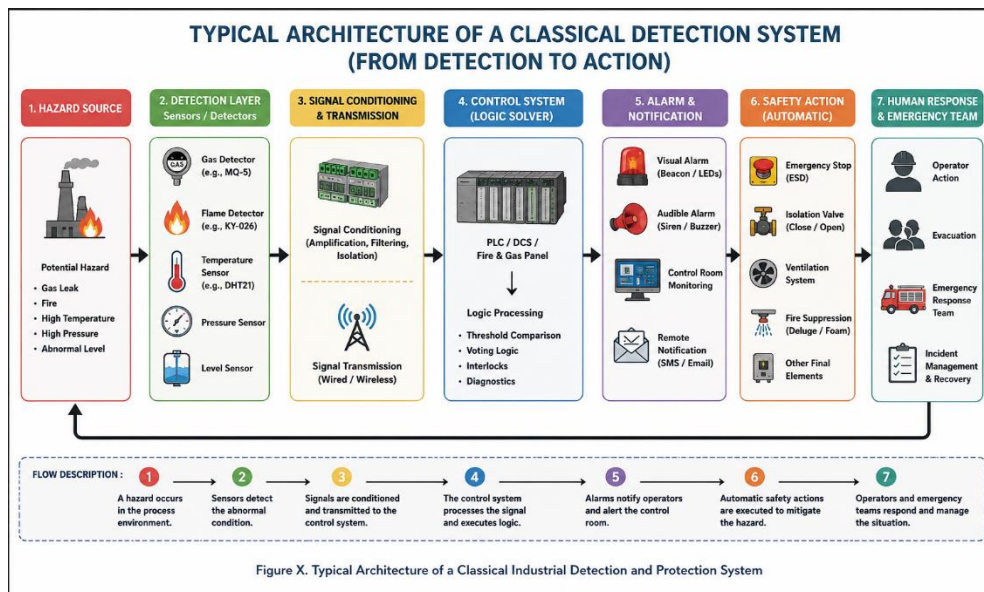


Figure III classical detection system

2.3.1 Classical detection system:

Classical industrial detection systems are intended to watch over and sustain the safe, reliable operation of facility support systems, which provide a base for understanding the condition of critical facility support systems.

Classical systems normally have three basic elements: indication, alarm, and control. Indication shows the current parameters on a display in a central location; alarm signals alert personnel when parameters exceed preset limits, and control automatically starts or stops equipment to sustain specific parameter or conditions. [22]

Classical systems are typically divided into the following types based on the specific parameters they measure:

➤ Temperature Detection:

Resistance Temperature Detectors: RTDs rely on the ability of the electrical resistance of certain metals, such as platinum, copper, or nickel, to change as the temperature changes. As the temperature increases, the resistance increases.

Thermocouples: A thermocouple consists of two wires of dissimilar metal joined at one end. When the "measuring junction" is heated, it creates a voltage proportional to the difference in temperature between the junction and a reference junction.

➤ Pressure Detection

Bellows-Type Detectors: In this type of pressure detector, the system pressure causes expansion or contraction of a metallic component, which is then linked to a mechanical system to produce the desired signal.

Bourdon Tube-Type Detectors: In the Bourdon Tube-Type Detectors, a flattened tube is used. The flattened tube is then formed into an arc. The pressure inside the tube then causes the arc to straighten, thus creating the desired signal.

Strain Gauges: The strain gauge is a pressure detector that depends on the measurement of the resistance of a fine wire mesh.

➤ Level Detection

Direct Level Detectors: The direct level detectors include gauge glasses, which rely on direct observation of the liquid level. The direct level detectors also include the use of floats, which depend on the physical contact of the liquid with the float.

Inferred Level Detectors: The Inferred Level Detectors include the use of differential pressure detectors. In the differential pressure detectors, the weight of the liquid is compared to the pressure. In systems where the liquids are under pressure, it is important to use density compensation to ensure the desired results are obtained despite the temperature variations.

➤ Flow Detection

Head Flow Meters: In these meters, a restriction is placed in the flow path, which may be an orifice plate, a venturi tube, or a Dall flow tube. The flow rate is proportional to the square root of the differential pressure.

Mechanical and Electronic Meters: There are various types of such meters, which include rotameters, notating disks, hot wire anemometers, and electromagnetic/ultrasonic meters.

➤ Position Indication

Synchro Equipment: These are self-synchronizing motors, which electrically follow the motion of a mechanical device. They are used to provide an accurate indication of the position of a control device such as a control rod.

Switches: Limit switches are mechanical devices that are tripped by the motion of the equipment to provide ON/OFF signals, such as fully open or shut.

Variable Output Devices: These include potentiometers and linear variable differential transformers, which provide accurate indication over the full range of motion of the equipment.

➤ Smoke-Sensing Detectors:

Ionization: This detector employs a limited amount of radioactive material to ionize the air. The smoke particles interfere with the electrical conductance.

Photoelectric (Light Scattering/Obscuration): This detector employs a light source and a sensor. The smoke either obstructs the path of the light (obscuration) or reflects the light onto a sensor normally in darkness (scattering).

➤ Flame and Radiant-Energy Detectors:

These detectors detect ultraviolet, visible, or infrared light produced by a fire. Spark/Ember detectors are specialized detectors used to detect moving particles of burning material.

➤ System Circuitry and Environment:

The classical instruments generally employ a transducer to transform the mechanical motion or

physical variations into an electrical signal, which is then boosted for remote indication. The accuracy of classical instruments is affected by the ambient temperature, which may alter the resistance of the component, and ambient humidity, which may lead to corrosion or short-circuiting.

2.3.2 Limitations of a conventional detection system:

Conventional detection systems in the oil and gas industry, such as fixed and portable gas detectors, face several key limitations that can compromise safety and efficiency. [23], [24], [25]

False Alarms:

Frequent false alarms occur due to environmental factors like high humidity, chemical particles, and non-food chemicals (e.g., disinfectants or aerosols), leading to unnecessary evacuations, resource waste, and operator complacency.

Periodic Monitoring:

Traditional methods rely on scheduled inspections, allowing leaks to go undetected for weeks or months between checks.

Physical Obstructions:

Beams from detectors can be blocked by birds, trucks, piping, or facility structures like distillation columns, potentially missing real threats.

Limited Coverage:

Fixed detectors create blind spots in dynamic or obstructed areas, while portable ones only monitor nearby locations; open-path systems cover large zones but miss many toxic gases and require multiple installations.

Sensor-Specific Issues:

Catalytic bead sensors are poisoned by contaminants, degrade after high gas exposure, and need oxygen to function, limiting use in low-oxygen or inert atmospheres. Infrared detectors can't sense non-IR absorbing gases like hydrogen and struggle with multiple gases or high humidity/dust.

Offshore Difficulties:

Detector siting is hard in enclosed/open mixes, with incorrect selection, poor design/installation, and maintenance issues being common; users often lack knowledge of principle limits. Harsh conditions like fog, rain, and mechanical friction heighten risks without reliable coverage.

High Costs and Labor:

Initial investments are steep, with ongoing calibration, maintenance, and labor-intensive checks adding expenses; networks need many sensors for full coverage, increasing complexity. Although the classical systems described above are termed "traditional systems," which are

based on the detection of a problem and the generation of an alarm, it is evident that the PreSee system represents an advancement of the classical technology. In the case of the PreSee system, the classical industrial sensors are integrated with IoT technology, artificial intelligence, and geographic information systems to move beyond late reactions to a problem to intelligent risk prediction. Unlike the classical systems, the PreSee system analyzes the data to predict a problem and provide emergency intervention plans.

2.4 Contribution of New Technologies:

A collection of physical devices connected to the Internet that can collect, send, and even process data through communication systems is called the Internet of Things (IoT). IoT in industrial environments typically comprises sensors, communication modules, and microcontrollers used to monitor key metrics like temperature, pressure, liquid level, gas concentration, and flame presence alongside monitoring platforms.

In industrial settings, these technologies add a lot of value by helping with early detection, reducing false alarms, making decisions easier, and making emergency interventions more effective. They also make it easier to process and use the data that has been collected, which lets us move from a reactive safety approach to a more proactive and predictive one.

2.4.1 IoT:

The Internet of Things (IoT) is a network of physical devices that are all connected to the internet or other communication networks. These devices can be anything from sensors and actuators to wearables and smart appliances. They collect, send, and act on data. These devices are built into things we use every day, like buildings, cars, and public spaces. This lets us keep an eye on environmental, structural, and human factors all the time. A working IoT architecture usually has a sensor layer for collecting data, a communication layer that uses protocols like Wi-Fi, LoRa, or 5G, and edge or cloud computing nodes that process the data to make it possible to know what's going on in real time and respond automatically. [26]

IoT is the main sensing backbone of the PreSee platform, which allows traditional systems that "react late" to switch to intelligent risk prevention. PreSee combines a distributed network of industrial IoT sensors with artificial intelligence (AI) and geographic information systems (GIS) to find hazards in real time and cut down on false alarms. IoT's role in PreSee is not just to send an alert after something happens. Instead, it sends a steady stream of data that the system's AI analyzes to predict risks and incidents. This connection lets the platform do more than just show and control basic information. It can also suggest specific emergency intervention plans and help decision-makers choose the best course of action.

2.4.2 AI for false alarm detection:

False alarms happen a lot in places because of many things, like sensors not working right or the environment being bad with things like humidity, dust, and wind, and also because of

maintenance work, gas leaks, and equipment shaking. These false alarms can cause problems like stopping work for no reason, losing production time, and people who work there getting tired of all the alarms, which can make them not pay attention to real dangers. To make this better, artificial intelligence offers solutions to tell the difference between real dangers and false alarms. By looking at data, machine learning models can predict when sensors might fail or need maintenance, which helps stop alarm problems before they start and makes the system work better. [27]

AI also uses computer vision to check alarms by looking for smoke, fire, or leaks with cameras and comparing this to what the sensors say. Using information from sensors, like gas, heat, and light sensors, makes it more accurate and helps get rid of interference from things like humidity or temperature changes. For example, if a gas sensor says there is a leak but the cameras do not see any gas and the pressure is fine, AI can say it is a false alarm. [28]

AI also helps find sensor problems by checking itself and finding sensors that are not working right or giving information, and it can tell when the information from sensors does not match; for instance, if only one gas sensor says there is a leak and the others do not, the system can say the sensor is bad, not the equipment. Finally, AI can look at maintenance records, incident reports and notes from workers to find out why false alarms keep happening and what the systems weaknesses are, which makes industrial work safer and more reliable. [28]

AI is really important for making alarm systems. It helps reduce alarms and makes decision-making easier in industrial environments. Traditional systems are not as good because they only look at fixed thresholds. AI looks at data in a way. It learns what is normal. Finds things that are not normal. [29]

AI takes information from sensors. It looks at what happens over time. Thinks about the context. This helps it figure out what is a problem and what is not. AI can also find sensors that are not working right. It can ignore noise. Look at many alarms to find the real reason they are happening.

The system gets better over time because it keeps learning from data and from the people who use it. This means that the people who use the system do not get tired of all the alarms. They can trust that the important warnings will be seen. This makes everything safer. Helps people predict hazards better. AI really helps with this. It makes alarm systems more reliable. That is a good thing for industrial environments and for artificial intelligence. [29], [30], [31]

2.4.3 GIS geographic information system:

2.4.3.1 Definition:

Is a computer-based system designed to collect, store, manage, analyze, and visualize geographically referenced data. It allows users to understand patterns, relationships, and trends based on location. [32]

2.4.3.2 Role:

GIS plays a part in managing risks for industries. They do a lot of things. First, they help us find areas that are not safe, like places where things can explode or where bad air can spread.

This makes it easier to figure out where accidents are likely to happen.

When we are trying to understand the risks, GIS combines information about where things are with other factors that can be dangerous. This helps us see how bad things can be for people, machines, and the environment around us.

GIS also helps us keep an eye on the environment. They track things in the air, water, and soil. They even watch over ecosystems near industrial areas.

They are very important for planning safety. They help us decide how away things should be from each other and create safe areas around them. This helps us design plants that are safer.

Lastly, GIS makes emergency plans better. They help us plan how to get people out of danger and find important things, like fire stations, hospitals, and exits. This means we can respond to emergencies faster and do a job.[33]

2.4.3.3 Application:

GIS applications in industrial risk management use a step-by-step process. This process changes data into information that people can actually use.

First, people collect data from different places. These places include sensors that measure things like temperature and gas levels. They also use drones and satellites. They even go out into the field to inspect things. They use something called SCADA systems too.

All of this data is then put together with a location like a map coordinate. This means that lots of types of information can be used together in one system.

Next the GIS application does some work on the data. It looks at how far apart things are and what is near to what. It can even find patterns. Figure out where the riskiest areas are.

Then the results are shown on a map. This makes it easy to see what is going on. The map can show things like areas that are too hot or cold.

GIS applications are really helpful for people who make decisions. They can use the information to make choices quickly. This helps to keep people safe and makes things run smoothly. GIS applications in industrial risk management are very useful for making decisions.[32]

2.5 Emergency Situation Management:

Emergency situation management is the collection of organizational, technical, and operational actions that are put in place to prepare for responding to hazardous situations in a way that minimizes the harm to human life, equipment, and the environment. In an industrial environment, particularly with high-risk industries like oil and gas, early detection of and quick response to incidents are critical to preventing a larger-scale incident from happening.

2.5.1 Phases of emergency situation management:

Emergency situation management is a methodical way to deal with unexpected events in a way that protects people, property, and the environment. It usually has a number of connected steps that help organizations get ready for, respond to, and recover from emergencies in the best way possible.

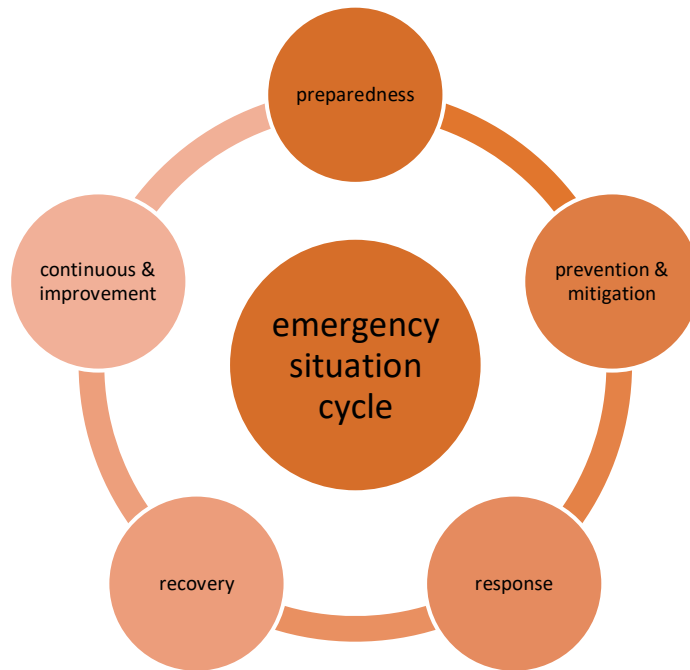


Figure IV Emergency Situation Cycle

➤ **Preparedness:**

The main focus of this phase is planning and being ready. It includes figuring out what the risks are, training staff, making plans for emergencies, and setting up rules for how to talk to each other. Preparedness makes sure that resources and procedures are ready to go when something happens. [34]

➤ **Prevention and mitigation:**

This stage includes steps to make emergencies less likely and less harmful. Some examples are putting in detection systems, putting up safety barriers, and checking industrial equipment on a regular basis. The goal of preventive strategies is to lower risks before they get worse. [35]

➤ **Response:**

A Response is what you do right away when there is an emergency. It includes setting off alarms, sending out emergency teams, starting evacuation procedures, and using detection and monitoring systems to make decisions in real time. To protect human life and limit damage, a quick and coordinated response is very important. [34]

➤ **Recovery:**

After an emergency, recovery is all about getting things back to normal and figuring out how well the response worked. This includes fixing broken infrastructure, doing an analysis of what happened after the incident, and making changes to emergency plans based on what was learned. Recovery also includes mental and social support for the people who were affected. [36]

➤ **Continuous improvement:**

Learning from past events to be better prepared for the future is a key part of good emergency management. Organizations can improve their response times by regularly practicing, auditing,

and getting feedback. They can also add new technologies, like AI and IoT-based monitoring systems, to their protocols.

2.5.2 Main components of an industrial emergency management system:

For an effective industrial emergency management system, it is imperative to integrate various components of an IEMS in order to provide timely detection, decision-making, and response in case of an emergency. These components are integrated in order to minimize human, environmental, and economic effects. [34], [35], [36]

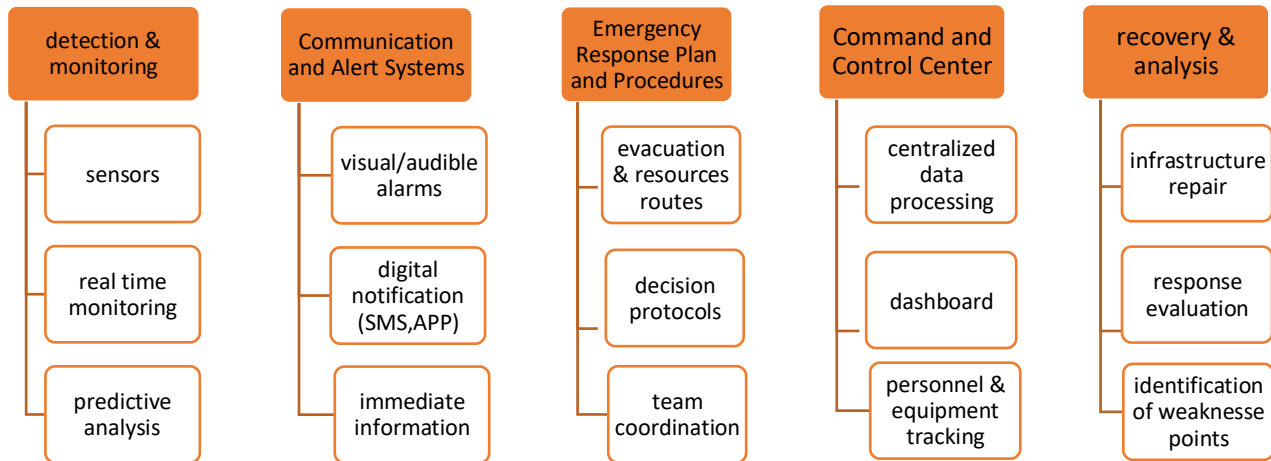


Figure V IEMS Main Components

2.5.3 Emergency situation plan:

There are many dangers that industrial facilities in Algeria face, so they need to be ready for emergencies in a structured way. Three main plans make sure this happens: The Internal Emergency Plan (PII) for responding on-site, the Particular Intervention Plan (PPI) for protecting people outside, and the ORSEC plan for coordinating rescue and emergency services on a large scale.

➤ PII-Internal Emergency Plan

The PII is the emergency plan that the industrial operator makes for itself. It applies to the inside of the installation and tells the company what to do in case of a fire, explosion, toxic leak, or any other industrial accident. It usually includes procedures for alarms, responsibilities, evacuations, first aid, communication, and safety measures for workers and equipment. In Algeria, it is against the law for industrial operators not to make this kind of plan for installations that are very dangerous. [37]

➤ PPI-external emergency plan

PPI is the external or off-site emergency plan, i.e., the external plan coordinated by the public authorities, especially at the Wilaya level. The PPI is implemented when an accident is liable to affect areas external to the industrial site, such as the population, the environment, etc. The

PPI is also based on the information provided by the operator, especially the danger study and the internal plan. In Algeria, the role of the wali is central in the implementation of the PPI. [37]

➤ ORSEC

The ORSEC plan (Organisation des Secours) is the overall framework for civil protection and public emergencies. It is not limited to the field of industry, although it can be called upon in the event of major industrial catastrophes when the situation is beyond normal intervention capacity. In Algeria, the ORSEC plans can be at the national level, the inter-wilaya level, the wilaya level, the communal level, and the sensitive site level. They are organized into phases including the response phase, the evaluation/control phase, and the rehabilitation phase. [38]

2.6 Conclusion:

This chapter explored the integration of Artificial Intelligence (AI), Geographic Information Systems (GIS), and Safety Instrumented Systems (SIS) within a structured regulatory framework to enhance industrial safety environments. Adhering to international standards such as IEC 61511 and IEC 61508 provides a reliable, risk-based baseline for functional safety management and system lifecycles. Furthermore, factoring in emergency preparedness frameworks like Algeria's ORSEC plan ensures that localized, multi-tiered emergency responses are effectively accounted for.

By combining these technical pillars under strict regulatory guidelines, we establish an intelligent safety paradigm capable of predictive risk assessment, early hazard detection, and optimized spatial emergency planning. Ultimately, this synergy between compliance and advanced technology directly supports the primary objective of this thesis: designing a robust, legally compliant safety platform capable of dynamically predicting, mitigating, and responding to high-risk industrial hazards.

Development of the Proposed System

Introduction

This chapter is about making the proposed PreSee system, which will make workplaces safer by using smart monitoring, hazard detection, and emergency response support. It talks about the project's practical side by going over the system's goals, design approach, and implementation choices.

The chapter also talks about the system's overall architecture, the main hardware and software parts that make it up, and how alert and supervision functions like real-time monitoring, visual and sound alarms, and decision-support tools work together. The goal is to show how the suggested system can help prevent and deal with risks more effectively in industrial settings.

3.1 Presentation of the Project and Functional Objectives:

3.1.1 Project Presentation:

The motivation behind this project's development stems from various operational constraints frequently encountered in traditional industrial safety systems, such as erroneous detections and alarms, delayed identification of abnormal conditions, sluggish emergency response, and inadequate visibility concerning the availability of intervention resources and equipment. These restrictions could make emergency management much less effective and make industrial accidents much worse.

In order to solve the problems noted above, PreSee has designed a multidisciplinary and integrated approach that utilizes real-time sensing, intelligent monitoring, alarm management, and spatial decision support. Their system is intended to be used in a variety of environments, including oil and gas facilities, industrial facilities, public facilities, and emergency response units. The prototype combines a number of industrial/environmental sensors with a processing unit such as a microcontroller, microprocessor, or another type of computer and a real-time monitoring dashboard.

3.1.2. Functional Objectives of the Proposed System:

PreSee's purpose is to develop a smart way for industries to keep track of their safety by being able to quickly respond to hazardous situations and prevent them from happening again. It was built to try to resolve some of the limitations with traditional systems, including false alarms, slow reactions, and slow responses to emergencies.

The PreSee system will provide the following benefits:

- Sensors will detect abnormal or hazardous events.
- Real-time monitoring of critical industrial parameters.
- Giving visual and audible warnings of imminent hazards.
- A supervisory dashboard to visually see the information and locate an incident.

-Assist with emergency response by integrating useful information such as intervention plans, materials involved, and what equipment might be available to respond.

Thus, PreSee is more than a hazard monitoring system; it will allow industry to make quicker and

better decisions during an emergency, and it will also provide support in responding to an emergency more effectively.

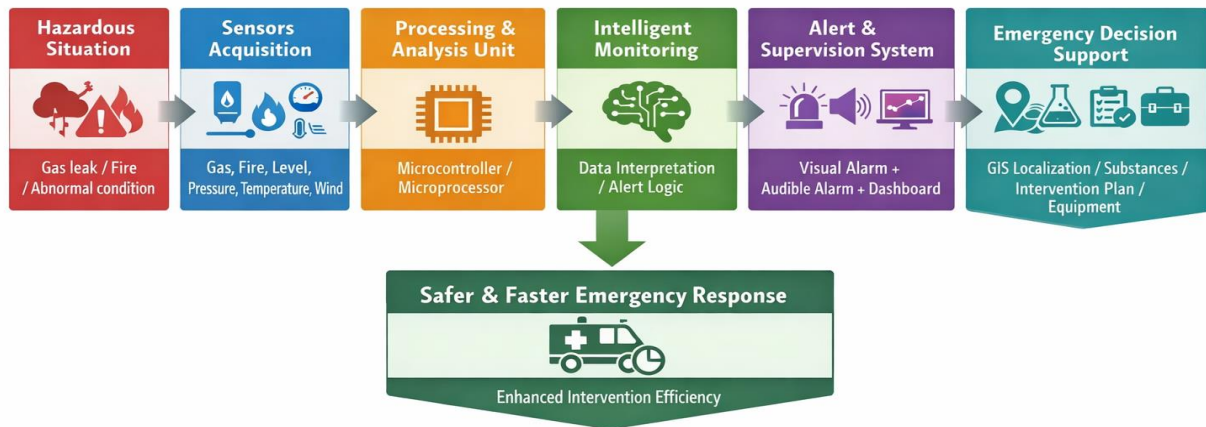


Figure VI General Fonctionnal Concept of The Proposed Presee System

3.2 Choice of Components and Technologies Used for the Presee prototype:

The selection of electronic components for this prototype is based on criteria such as reliability, accuracy, cost-effectiveness, and ease of integration within a real-time monitoring system. The components offer a balanced combination of performance and affordability, making them suitable for developing an efficient and scalable industrial safety prototype.

3.2.1 Sensors used:

The detection layer uses sensors placed in the area to track important things like gas levels, temperature, and pressure. These sensors give us data so we can spot unusual situations that might mean danger. The sensors help find problems with gas concentration. Also keep an eye on temperature and pressure. This way we can act fast if something is not normal.

- **Gas Sensor – MQ-5:**

The MQ-5 gas sensor is really good at finding out if there are gases like methane or propane in the air. It does this by checking how much the air affects it. The MQ-5 gas sensor is very useful in places like factories or oil and gas facilities. In these places it is very important to know if there is a gas leak. It is a part of the system. It helps to figure out if the gas levels are bad, and it sends out warnings. This way people can stay safe [39].

- **Temperature Sensor – DHT21 (AM2301):**

The DHT21 (AM2301) is a digital type of sensor that can be used to detect both temperature and humidity. Within the PreSee system, this particular sensor will be used to monitor the environment and detect any unusual changes in temperature and humidity, indicating a malfunctioning machine or even a risk of fire.

In terms of performance relative to other sensors with similar functionality, the DHT21 is characterized by a relatively high level of precision at an affordable price point, thus making it an ideal choice for use in industrial prototypes. The sensor provides precise readings with $\pm 0.5^{\circ}\text{C}$ of error in temperature measurements and $\pm 3\%$ error in humidity measurements [40].

- **Flame Sensor – KY-026:**

The KY-026 Flame Sensor is really good at finding fires or flames by feeling the radiation that flames give off. It can find flames that are a certain distance away, and it only looks for flames that give off a certain kind of infrared radiation. It is very important in the system because it helps us find fires early. This means we can react quickly and stop the fire from spreading. When the flame Sensor finds a flame, it can make the alarm go off away [41].

Table 2 Sensors used

Component	Type	Function in the System	Key Characteristics
MQ-5 Gas Sensor	Gas detection sensor	Detects combustible gases (methane, LPG, propane) to identify gas leaks	response rapid, analog output
DHT21 (AM2301)	Temperature & humidity sensor	Monitors environmental conditions to detect overheating or abnormal humidity	High accuracy ($\pm 0.5^{\circ}\text{C}$), digital output, stable performance
KY-026 Flame Sensor	Infrared flame sensor	Detects fire or flame presence using IR radiation	Fast detection, adjustable sensitivity, digital/analog output

3.2.2 Processing unit:

The processing unit represents the core of the PreSee prototype. The primary functions of the processing unit involve the acquisition of sensory data, real-time processing of the measurement results, comparison with predefined safety limits, and generation of the required alerts/notifications. The processing unit that we have designed uses the Arduino UNO board since it provides enough input/output pins, allows easy coding, and supports various sensors. The processing unit makes sure that all components are synchronized in their activities.

- **Microcontroller Board – Arduino UNO R3:**

The Arduino Uno R3 will be used as the processing element of the device because it is based on the ATmega328P and is known for its efficiency and ease of programming in embedded systems.

Thus, the task assigned to the Arduino Uno R3 in the PreSee device will be collecting data from the sensors installed (MQ-5, DHT21, and KY-026). The board will then process that data and determine the presence of a threat situation, sending out alerts in case of exceeding certain limits in the form of alarm lights and sounds.

In addition to collecting and analyzing the data from the sensors, the Arduino Uno R3 also sends that data via communication with ESP32 CAM. Although it offers less memory and input/output pins than other models, the Arduino Uno R3 is quite capable of working efficiently within the proposed prototype [42].

Table 3 Processing Unit

Component	Type	Function in the System	Key Characteristics
Arduino UNO R3	Microcontroller board	Central controller for sensor acquisition, alarm logic, and peripheral coordination	suitable for multi-module integration

3.2.3 Communication module:

This communication module provides the means for the PreSee prototype to relay information beyond the local hardware interface and facilitate remote control and supervision. The importance of communication is crucial in the design of an industrial safety system, as it is not just about detecting danger within the environment but also about ensuring the transmission of information to the relevant authorities. Communication in the PreSee prototype design can be facilitated by one wireless modules – the ESP 32 CAM Wi-Fi module.

- **Wi-Fi Module and camera– ESP32 CAM:**

The ESP32-CAM on PreSee's platform is a module for visual surveillance to validate risks during live events, either through video or thermal footage. The camera will assist in reducing the number of false alarms, which is one of the biggest obstacles to industrial safety. The information transmitted to the monitoring dashboard via the on-board Wi-Fi allows for intelligent decision-making and the creation of emergency intervention plans when developing or supporting intelligent business decisions. The ESP32-CAM will allow for developing predictive hazard assessments, moving from just detecting problems to proactively preventing future occurrences [43].

Table 4 Communication Module Components

Component	Type	Function in the System	Key Characteristics
ESP32 CAM	Wi-Fi communication module and camera	Transmits sensor and alarm data to remote monitoring/dashboard systems and visual confirmation	suitable for IoT connectivity

3.3 Alert and monitoring system:

The alarm and monitoring system is made to find problems away and let people know what is happening when something is wrong. It uses sensors to get information all the time and a microcontroller, which evaluates the risk level based on predefined thresholds. If the alarm and monitoring system finds something that could be a problem, it turns on lights. Sounds to warn people. This helps the people in charge see what is happening and figure out if there really is a problem.

3.3.1 Visual alarm:

- Red LED (5mm):

The red LED is used to show when something is wrong. It lights up when it finds a problem. This helps people see there is a problem. This is really helpful in factories where you might not hear a warning sound [44].

3.3.2 Sound alarm:

- Buzzer:

The buzzer is a warning sound that tells people something is wrong. It makes a noise when it goes off so people who are nearby know there is a problem right away. The buzzer is very important when there is an emergency and people need to act, like when they have to leave the area quickly or do something to fix the problem [45].

Table 5 Alert and Monitoring System

Component	Type	Function in the System	Key Characteristics
LED (5mm)	Visual alarm	Provides visual alert when hazard is detected	Low power, high visibility, simple interface
Buzzer	Sound alarm	Emits audible alert to warn personnel	Immediate sound signal, easy integration

3.4 Global architecture of PreSee:

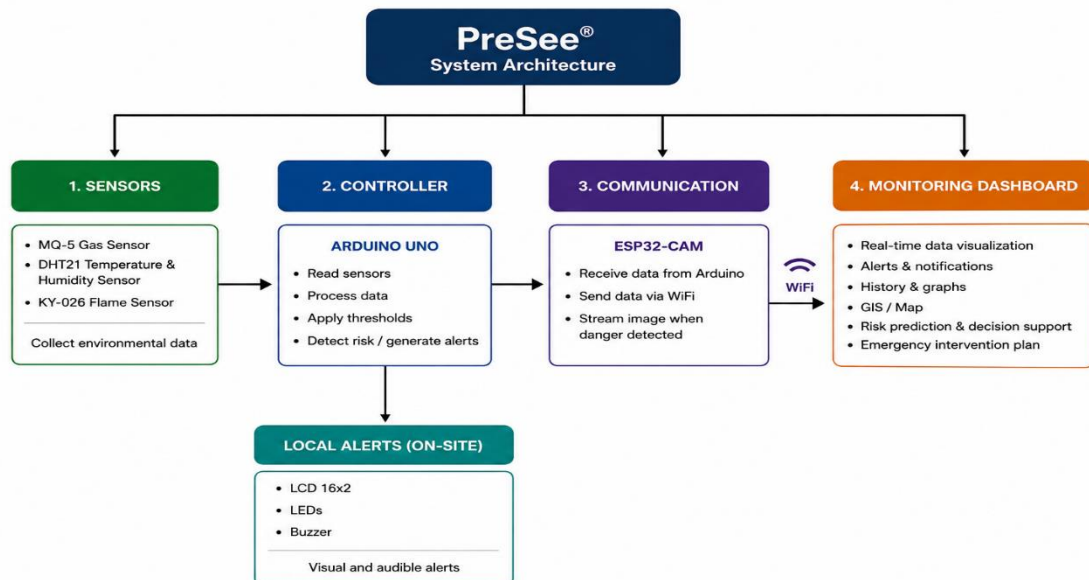


Figure VII Presee's Architecture

3.5 Dashboard Presentation and System Functionality:

This section presents the developed dashboard and explains how the monitoring system

operates in real time. The dashboard was designed to provide a clear and interactive interface that allows users to monitor environmental conditions continuously and react quickly in case of danger. Through this platform, operators can visualize sensor readings, receive alerts, and follow the evolution of hazardous situations directly from the interface.

The system combines data acquisition, analysis, and visualization in order to improve industrial safety and facilitate decision-making during emergency situations.

3.5.1 Main Dashboard Interface:

The main dashboard interface represents the central supervision platform of the proposed system. It was designed with a simple and interactive layout that allows the operator to monitor the industrial environment easily and access important information in real time. The interface gathers all the essential monitoring tools in a single platform, making the system more practical and efficient during normal operation as well as emergency situations.

The dashboard continuously displays live sensor readings collected from the monitoring system, including gas concentration, temperature, humidity, and flame detection status. These values are updated in real time through the ESP32 communication module, allowing the operator to follow environmental changes instantly.

In addition to the monitoring panels, the dashboard also includes a dedicated alert section that becomes active whenever dangerous conditions are detected. Visual and sound notifications are generated automatically to warn the operator and ensure rapid intervention.

One of the important features integrated into the interface is the camera monitoring zone. When the flame sensor detects the presence of fire, the camera automatically captures an image of the monitored area and displays it on the dashboard. This feature helps the operator verify the situation visually and reduces the possibility of false alarms caused by temporary disturbances or sensor inaccuracies. By combining sensor detection with visual confirmation, the reliability and effectiveness of the monitoring system are significantly improved.

This subsection can be illustrated with screenshots showing:

The main dashboard interface

Navigation menu

Real-time sensor values

Alert notification area

Camera monitoring section

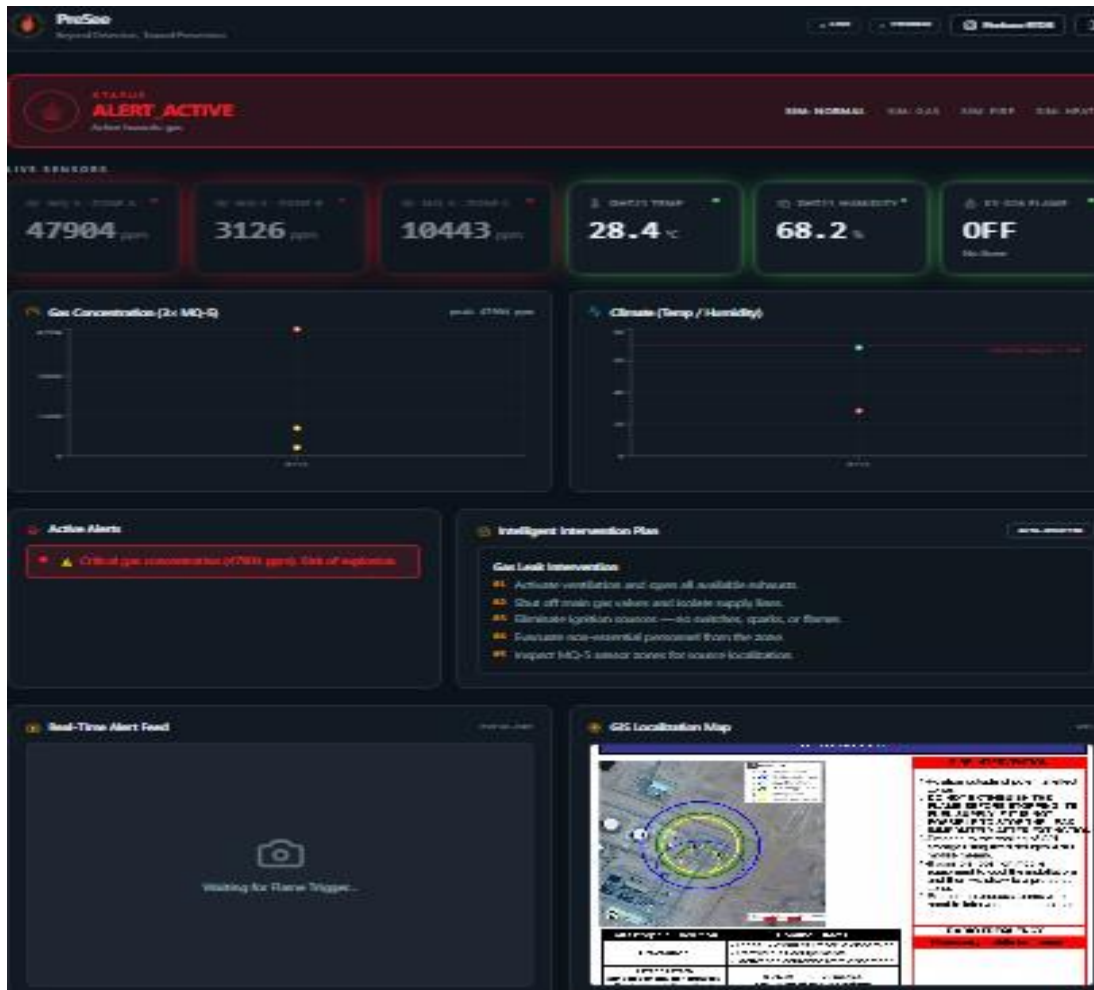


Figure VIII The Main Dashboard

3.5.2 Data Visualization and Monitoring:

The core purpose of the dashboard is to turn raw sensor data into clear, actionable safety information. Instead of just displaying numbers, the system compares live readings against pre-set safety thresholds so that anyone looking at the screen can immediately tell if the environment is safe or hazardous.

The dashboard tracks three main risk factors:

- Gas levels:

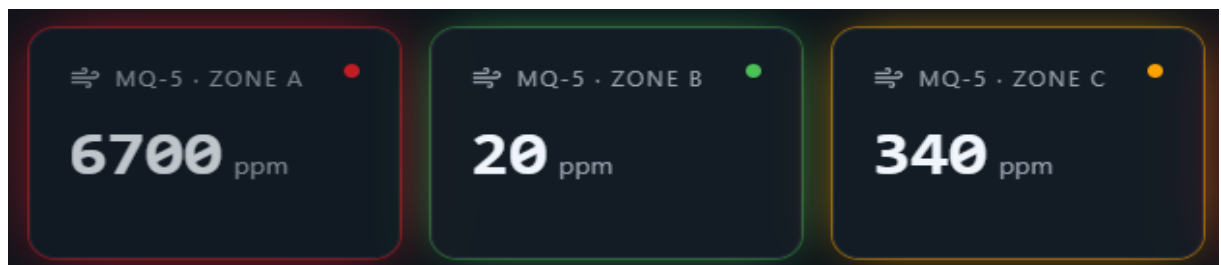


Figure IX Gas Levels

- Climate conditions:



Figure X Climate Conditions

- Flame detection:

Table 6 Alert and Monitoring System

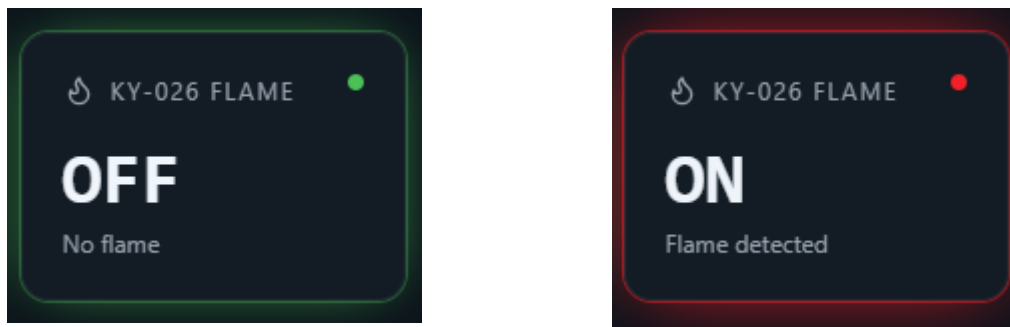


Figure XI Flame Detection

The monitoring workspace is broken down into four key components:

- Predictive Trend Graphs:

Rather than just showing the current sensor numbers, the dashboard features two real-time analytical charts. The **Gas Concentration Graph** tracks the overlapping curves of the three MQ-5 sensors simultaneously, making it easy to see how gas is dispersing across Zones A, B, and C. Next to it, the **Climate Graph** maps temperature and humidity data over time. These lines help operators spot sudden rate-of-change spikes—like a rapid jump in heat—before they trigger an actual emergency.

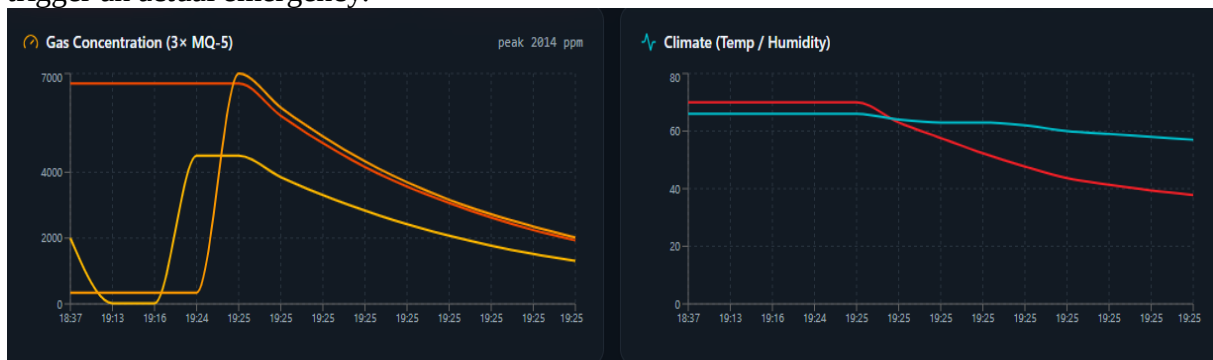


Figure XII Predictive Trend Graphs

- Active Alerts Log:

This widget acts as the central hub for immediate situational awareness. Under normal conditions, it displays a reassuring green confirmation stating that all systems are nominal and the environment is safe. If a threshold is crossed, this log instantly shifts color and archives the

incident, pulling historical hazard logs directly from the Firebase database backend.

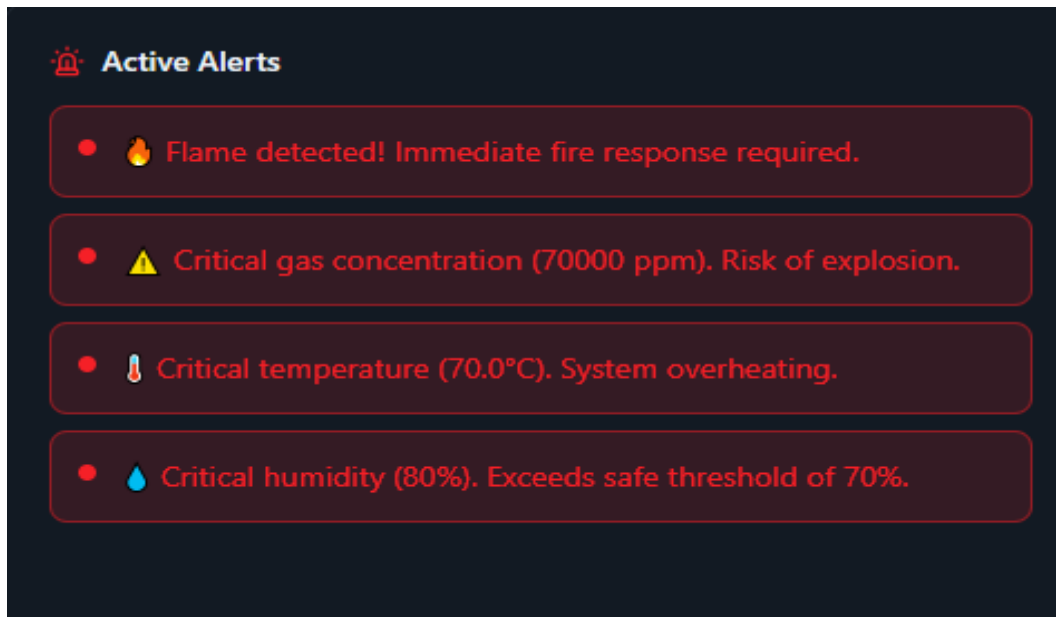


Figure XIII Active Alerts Log

- **Intelligent Intervention Plan:**

To remove guesswork during a crisis, the dashboard features a dynamic action guide. Under normal operations, it lists routine maintenance tasks like verifying sensor calibrations. However, if a sensor threshold is breached, this panel automatically updates to show step-by-step Standard Operating Procedures (SOPs), telling the operator exactly how to respond to that specific hazard.

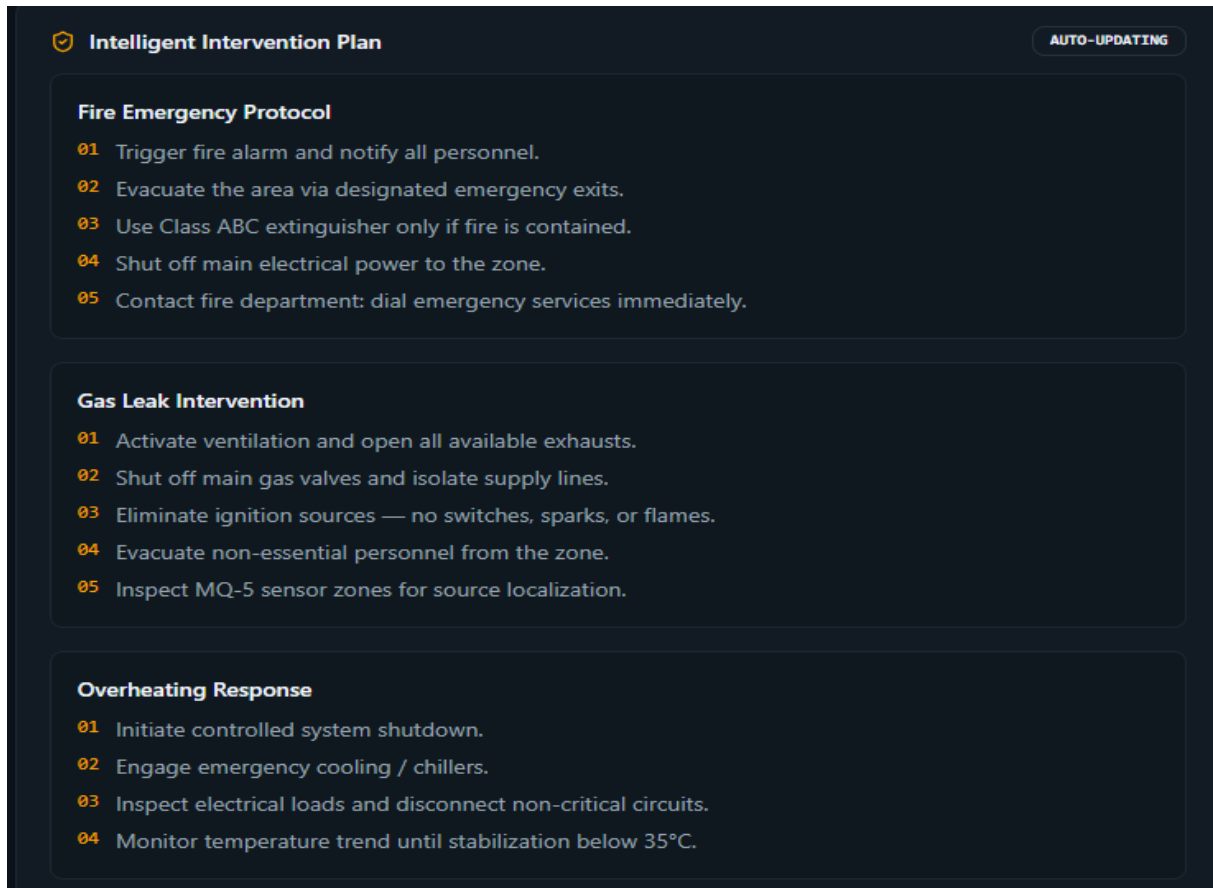


Figure XIV Intelligent Intervention Plan

- **Real-Time Alert Feed (Camera Verification):**

Located at the bottom of the dashboard, this dedicated media container works directly with the ESP32-CAM. In standby mode, it displays a "Waiting for Flame Trigger..." message to save bandwidth. The moment the flame sensor detects a fire, the camera captures a live snapshot of the area and uploads it straight to the dashboard. This gives operators instant visual verification of a fire without needing to step into a dangerous zone.

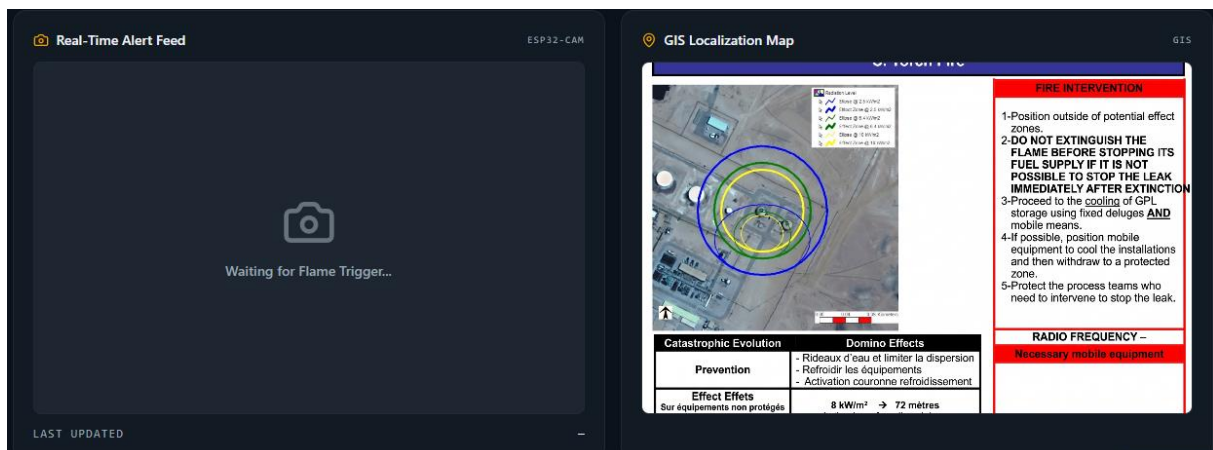


Figure XV Real-Time Alert Feed

3.5.3 Operational Workflow:

The operational workflow describes the sequence of actions performed by the system, starting from data collection and ending with alert visualization on the dashboard. First, environmental data is captured through the different sensors connected to the Arduino and ESP32 modules. The collected information is then transmitted and analyzed by the system in order to evaluate the presence of potential hazards.

When abnormal values are detected, the system automatically triggers a risk detection procedure and generates visual and sound alerts. The detected hazard is then displayed on the dashboard to inform the operator and support rapid intervention.

The workflow of the proposed system can be summarized as follows:

Data Input → System Analysis → Risk Detection → Alert Generation → Dashboard Visualization

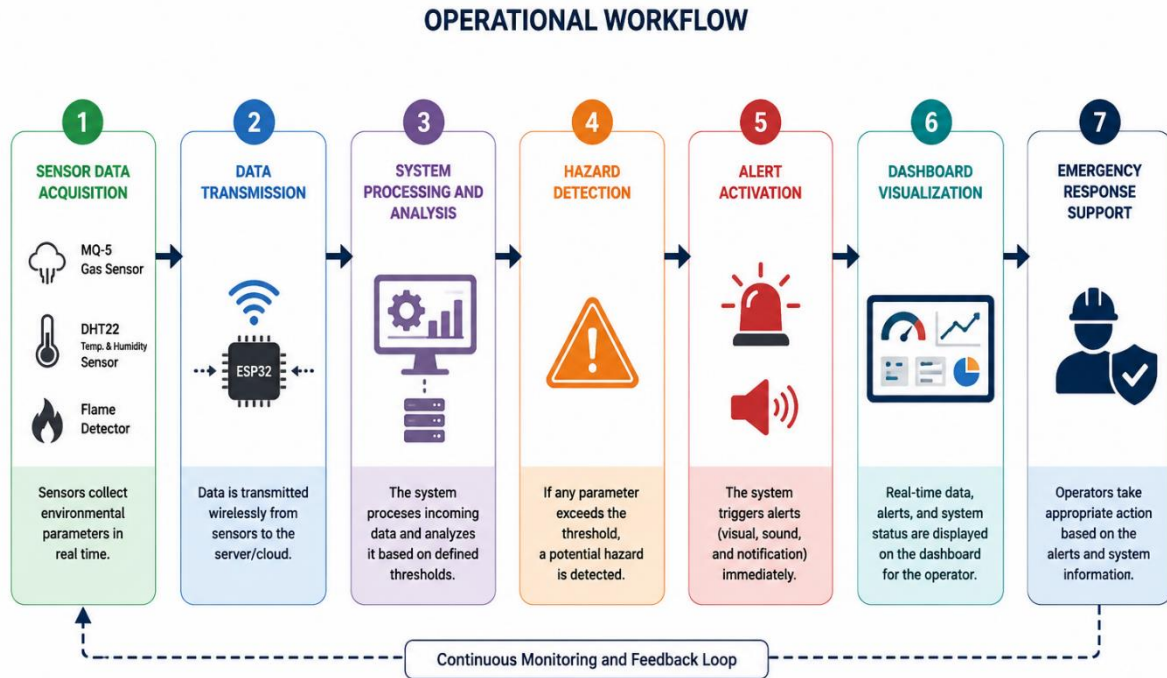


Figure XVI Operational Workflow

3.6 Conclusion:

This chapter describes the comprehensive design and implementation of PreSee, an intelligent multi-modal monitoring solution tailored specifically for predictive hazard detection and support of emergency intervention in industrial environment. First, the basic goals of operation were specified along with the main advantages of the developed solution, which include fast detection and recognition, reduction of false alarms, and efficient response to the detected situations. Further on, the architecture of the system was provided by describing the incorporation of sensing, processing, communication, and supervision into one single real-time monitoring system. The choice of hardware components, including sensors for gas detection,

temperature sensors, and flame detectors, was explained according to the characteristics of the respective devices. These include reliability, cost-efficiency, and appropriate functionality in the scope of continuous monitoring in industrial facilities. Also, the choice of processing and communication unit has been described by explaining the reasons for the selection of specific hardware modules. Finally, the functionality of the alerting and monitoring system was presented. Visual alarms, auditory alarms, and the real-time dashboards are provided by the developed monitoring system. In addition to its monitoring and alerting capabilities, PreSee incorporates Geographic Information System (GIS) technology to improve situational awareness and emergency management. The platform combines spatial information with real-time sensor data to allow the visualization of hazard locations, critical infrastructures, emergency resources, and intervention routes on an interactive map. This geographical dimension improves decision-making processes and allows a faster and more coordinated reaction in emergency situations. Therefore, the integration of GIS is an important step towards a comprehensive intelligent industrial safety platform.

Validation, Analysis and Discussion

Introduction

This chapter deals with the validation and analysis of the proposed intelligent system, PreSee, for early detection of industrial risks and support of emergency response management. After the hardware and software design of the system has been presented in the previous chapter, it is necessary to evaluate its operational behavior, reliability, and performance under different experimental conditions.

The main goal of this phase is to test the ability of the system to successfully detect dangerous scenarios such as gas leaks, fire incidents, and drastic changes in temperature and humidity while reducing false alarms through a multi-sensor voting system. The validation is also targeted towards the assessment of the alarm system performance, the real-time monitoring interface, and the data transfer to the intelligent dashboard.

Some test scenarios are presented in this chapter to evaluate the performance of the prototype in real industrial environment-like conditions. We also compare with existing solutions to show the contributions of the proposed system in terms of monitoring, responsiveness, and industrial safety. Finally, the current limitations of the prototype are discussed together with future perspectives for improvement, in particular the integration of artificial intelligence techniques and advanced predictive detection capabilities.

4.1. Operational Behaviour of the Proposed System:

The PreSee system works by constant and real-time sensing of environmental and industrial parameters through a large number of sensors integrated into a single embedded architecture. The system is developed to discover dangerous situations as early as possible and to trigger instantaneously the corresponding alarms and visual supervision mechanisms.

4.1.1 Gas Detection Mechanism:

We use a gas detection mechanism to keep an eye on the air. We have three MQ-5 sensors to make sure we find any gas leaks. These gas detection mechanism sensors help us avoid alarms. We have a way to figure out how bad a gas leak is. Here is how the gas detection mechanism works:

- If one sensor says there is gas, the gas detection mechanism system goes into a -alert state. It turns on one light shows "Pre-Alert" on the screen and the buzzer makes a noise sometimes.
- If two sensors say there is gas the gas detection mechanism system goes into a state. It turns on two lights changes the screen to "Alert" and the buzzer makes a noise more often.
- If all three sensors say there is gas the Gas Detection Mechanism system goes into a danger state. It turns on all the lights and the buzzer makes a noise all the time.

This way of using sensors for the Gas Detection Mechanism makes it more accurate and helps

us ignore wrong readings from one sensor.

4.1.2. Flame Detection Mechanism:

The KY-026 flame sensor is what we use to find out if there is a fire or an open flame. If the KY-026 flame sensor detects a flame, the system turns on a light right away to let us know something is wrong. The KY-026 flame sensor works on its own. It is also a part of the bigger plan to handle emergencies.

4.1.3. Temperature and Humidity Monitoring:

We use the DHT21 sensor to keep an eye on the environment. The system has rules for what to do when the temperature changes.

For example:

- If the temperature goes above 35°C, we get a warning. This means one red light turns on and the buzzer goes off slowly.
- If the temperature goes above 40°C, we have a risk. So two lights turn on. The buzzer goes off faster.
- If the temperature goes above 45°C, we have a problem. This means three lights turn on and the buzzer does not stop.

We also check the humidity. We use rules for dry and humid places. This helps us understand what is going on with the environment.

4.1.4. Data Transmission and Visualization:

The system has an ESP32-CAM module. This lets us watch what is going on in time. We can take pictures or videos. Send them to the monitoring dashboard. This helps us see if there are any problems.

The sensor data goes to the microcontroller. Then it shows up on the LCD screen. At the time it goes to the dashboard, and the dashboard shows us what is going on with the sensors the system and any alarms. This helps us know what to do in an emergency. We can make decisions because we have all the information.

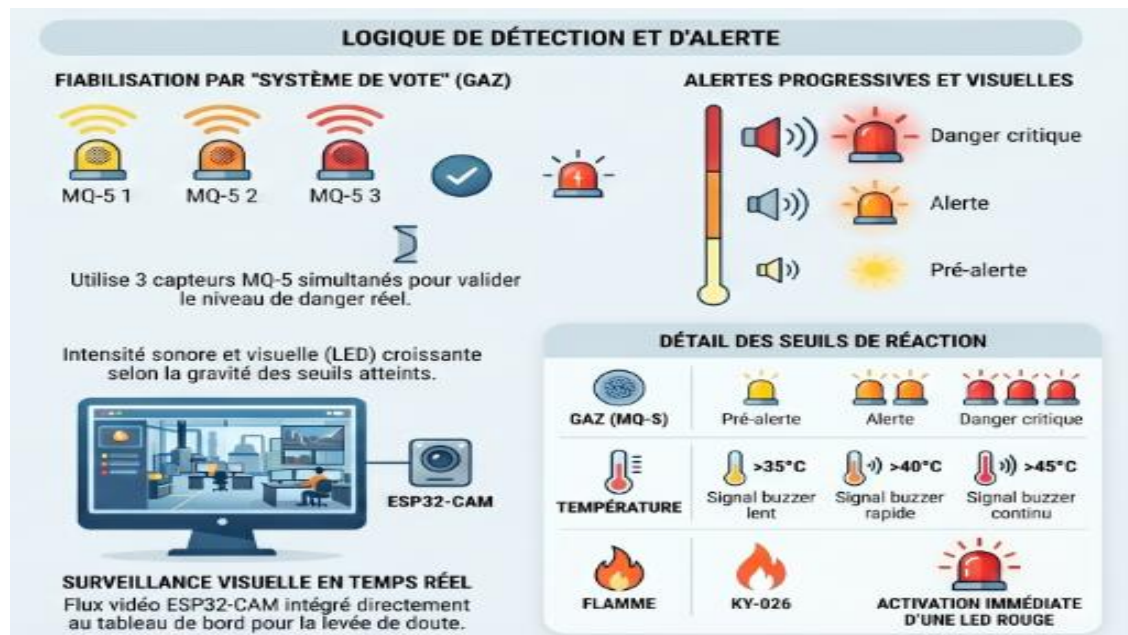


Figure XVII Operational Behaviour of the Proposed System

4.2 Test Scenarios and Experimental Conditions:

In order to evaluate the efficiency and reliability of the proposed intelligent HSE monitoring system, several experimental scenarios were carried out under different operational conditions. These tests were designed to simulate realistic industrial situations that may occur inside a working environment. The main objective was to verify the system's capacity to monitor environmental parameters, detect abnormal situations, and assist decision-making through real-time supervision and visualization.

The experimental conditions were established by considering both normal operating situations and abnormal events that may represent potential safety risks.

- Scenario 1 – normal operating condition:**

Table 7 Scenario 1-Normal Operating Condition

Element	Description
Objectives	Verify the normal operation and stability of the intelligent monitoring system under standard industrial conditions.
Initial condition	All monitored parameters such as temperature, gas concentration, and humidity remain within safe operational limits.
Trigger event	No abnormal variation or dangerous situation is introduced into the system.
Expected behavior	The system continuously supervises all parameters without generating alerts or emergency notifications. Data visualization remains stable on the monitoring interface.
Observed result	The prototype operated successfully in

	continuous monitoring mode and displayed real-time values without interruptions or false alarms.
--	--

- **Scenario 2 – high temperature/humidity detection:**

Table 8 Scenario 2–High Temperature/Humidity Detection

Element	Description
Objectives	Evaluate the system's ability to detect abnormal temperature/humidity elevation and generate a warning response.
Initial condition	The temperature and humidity parameters are initially within the predefined safe threshold.
Trigger event	The sensor is exposed to a heat source, causing the temperature value to exceed the authorized operational limit.
Expected behavior	The system identifies the abnormal increase, flashes a warning on the dashboard..
Observed result	The prototype successfully detected the abnormal thermal condition and updated the real-time dashboard view with an alert message.

- **Scenario 3 – gas leakage detection:**

Table 9 Scenario 3–Gas Leakage Detection

Element	Description
Objectives	Test the capability of the system to identify hazardous gas leakage conditions in the work environment.
Initial condition	Gas concentration remains within acceptable safety standards.
Trigger event	A simulated gas leakage causes the concentration level to exceed the safety threshold.
Expected behavior	The system immediately detects the abnormal gas level, triggers an alarm notification, and displays the critical status on the interface.
Observed result	The prototype successfully detected the simulated gas leakage and generated a rapid alert response.

- **Scenario 4 – critical flame event and camera:**

Table 10 Scenario 4—Critical Flame Event and Camera

Element	Description
Objectives	Validate the hardware-to-cloud visual validation pipeline during a critical fire event.
Initial condition	The flame sensor registers no infrared flame signatures; the ESP32-CAM is in a low-power standby or ready state.
Trigger event	A flame is introduced in front of the flame sensor, breaking the safety threshold.
Expected behavior	The system registers a critical fire event, instantly commands the ESP32-CAM to execute its <code>captureAndUpload</code> logic.
Observed result	Upon flame detection, the ESP32-CAM successfully captured a live image, which updated the dashboard view in real-time.

4.3 Industrial Operational Logic for LPG:

4.3.1 Gas detection:

For a LPG mixture composed of 30% butane (C_4H_{10}) and 70% propane (C_3H_8), the Lower Explosive Limit (LEL) is approximately the following:

- Propane LEL $\approx 2.1\%$ volume
- Butane LEL $\approx 1.8\%$ volume
- Mixed LPG LEL $\approx 2.0\%$ volume (average industrial approximation)

$$\text{LEL (mixe LPG)} = \frac{100}{\frac{70}{2.1} + \frac{30}{1.8}} = 2.0\%$$

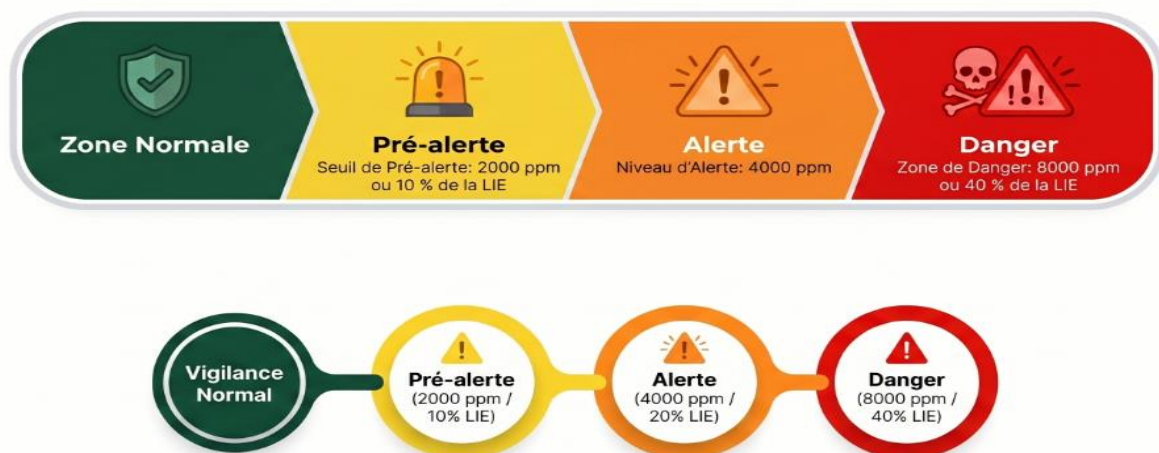


Figure XVIII Alert Thresholds Based on LPG Explosive Limits

Table 11 Gas Detection

C1	C2	C3	Final decision
N	N	N	normal
N	N	P	Pre-alert
N	N	A	Pre-alert
N	N	D	Pre-alert
N	P	P	Pre-alert
N	P	A	Alert
N	P	D	Alert
N	A	A	Alert
N	A	D	Alert
N	D	D	alert
P	P	P	Alert
P	P	A	Alert
P	P	D	Alert
P	A	A	Alert
P	A	D	Alert
P	D	D	Alert
A	A	A	Danger
A	A	D	Danger
A	D	D	Danger
D	D	D	Danger

4.3.2 Temperature detection:

Table 12 Temperature Detection

condition	output
$T < 35^{\circ}\text{C}$	Normal
$35^{\circ}\text{C} \leq T < 40^{\circ}\text{C}$	Pre-alarm
$40^{\circ}\text{C} \leq T < 45^{\circ}\text{C}$	alarm
$T \geq 45^{\circ}\text{C}$	Critical emergency

4.3.3 Flame detection:

Table 13 Flame Detection

state	Output
No flame	Normal
flame	danger

Emergency Response Workflow:

Table 14 Emergency Response Workflow

Step	System action	Industrial function
1	LPG detection	Sensing gas, temperature and flame
2	Signal filtering	Noise reduction
3	Threshold comparison	LEL% evaluation
4	Voting logic (for gas)	Validation
5	Alarm activation	Multi-level warning
6	Data transmission	Dashboard update
7	Operator action	intervention

4.4 comparative analysis with existing solutions:

The proposed intelligent monitoring system was compared with traditional industrial monitoring approaches in order to evaluate its added value and practical contribution.

The comparison focuses on several important criteria related to safety management, operational efficiency, and technological integration.

Table 15 Comparative Analysis With Existing Solutions

Criteria	Traditional Monitoring Methods	Proposed Intelligent System
Monitoring Method	Manual or periodic inspection	Continuous real-time monitoring
Data Visualization	Limited or absent	Interactive and dynamic visualization
Alert Generation	Human-dependent	Automatic instant alerts
Response Time	Relatively slow	Rapid and immediate
Risk Detection	Delayed identification	Early anomaly detection
Data Accessibility	Local and fragmented	Centralized and accessible
Decision Support	Limited assistance	Improved operational support

Automation Level	Low	High
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4.5 system limitations and constraints:

Despite the advantages offered by the proposed prototype, certain limitations and constraints were identified during the implementation and testing phases.

One of the main limitations concerns hardware resources. The performance of the system depends on the quality and precision of the sensors used for data acquisition. Low-cost sensors may sometimes produce slight measurement inaccuracies under specific environmental conditions.

Another limitation is related to communication stability. In industrial environments characterized by electromagnetic interference or network instability, temporary communication interruptions may affect data transmission between sensors and the monitoring platform.

Additionally, the prototype remains limited to a simulated experimental environment. Real industrial deployment would require more advanced infrastructure, higher scalability, and stronger cybersecurity mechanisms to ensure secure data exchange and system reliability.

Power consumption and maintenance requirements also represent important operational considerations, especially for continuous monitoring systems operating over long periods.

4.6 future improvements and perspectives:

The new PreSee system is really good at watching things in time and finding hazards. There are some things that can be done to make it work better and be more reliable. This is the step to making a smart safety system for industries.

One big thing that needs to be improved is adding intelligence and machine learning to the PreSee system. If we look at what the sensors have seen in the past and what is going on in the environment the machine learning can help figure out what is a hazard. What is not. This means we can make decisions and not have to rush into emergencies when it is not necessary. The PreSee system with machine learning can also look ahead. Find problems before they become big issues. This is a way to make the PreSee system even better, at keeping people safe.

The installation of high-tech IoT techs, plus cloud-based technologies should increase the ability to establish high capacity communications among many Industrial Plants. The additional features of these technologies also allow for large numbers of plant locations to be monitored centrally, remotely, or securely store real-time data. To ensure that Industrial Communication & Information Systems remain secure, new measures are necessary to further enhance protection against cyber attacks.

Future innovation may also include GIS (Geographic Information System) technology, incident management, and emergency response management systems that will assist with real-time incident identification and locating, provide better evacuation plan calculations, and increase the reliability of communication between both the Industrial and Emergency Service teams.

Another important thing to think about is when we move from a prototype design to a system that's really sturdy. This change means we have to swap out the parts that were only meant for

prototypes with equipment that is certified for industry use and can handle tough conditions. We are talking about the transition from a prototype architecture, to an industrial-grade system. The industrial-grade system needs certified equipment that can work well in harsh operating environments

Table 16 List of The Materials Used in The Future

Sensor Type	Industrial Example	Typical Specifications (Industrial Grade)	image
Gas Sensor	Fixed gas detector (serie ULTIMA) -CH ₄ (Methane), LPG, H ₂ S, CO, O ₂	Detection range: 0–100% LEL (Lower Explosive Limit) • Response time: <10 s • Accuracy: ±2–5% • Output: 4–20 mA / Modbus [46]	
Flame Detector	UV/IR flame detector (triple infrarouge IR3 de Flamegard modèle 40/40I)	Response time: 5s • Detection distance: up to 50–90 m • False alarm rejection: high [47]	
Temperature Sensor	RTD Pt100 industrial sensor	Range: –200°C to +600°C • Accuracy: Class A ±0.15°C • Response time: 1–5 s • Material: stainless steel probe [48]	
Humidity Sensor	Industrial humidity transmitter (Vaisala HUMICAP HMT120)	Range: 0–100% RH • Accuracy: ±1% RH • Output: 4–20 mA / RS485 • Operating temp: –40°C to +80°C [49]	

Smoke Detection System	VESDA (Very Early Smoke Detection Apparatus)	Detection sensitivity: 0.001–0.1% obscuration/m • Air sampling system • Response: early pre-smoke detection [50]	
Pressure Sensor	Industrial pressure transmitter (Emerson Rosemount 3051 Pressure Transmitter)	Range: 0–100 bar (or higher) • Accuracy: $\pm 0.04\%$ of span • Output: 4–20 mA / HART protocol [51]	
Level Sensor	Radar level transmitter (Endress+Hauser Micropilot FMR67 Radar Level Transmitter)	Range: up to 30–70 m • Accuracy: ± 2 –5 mm • max measurement distance: 125 m [52]	
Vibration Sensor	Industrial accelerometer (SKF CMSS 2100 Industrial Accelerometer)	Range: 0–25 g • Resonance frequency minimum: 30 000 Hz [53]	
Thermal Camera	Industrial infrared camera		
Processing Unit	Industrial PLC (Siemens SIMATIC S7-1500 PLC)	Cycle time <10 ms • industrial certifications [54]	
Communication Module	Industrial Ethernet / Fieldbus (Modbus TCP, OPC UA)	Real-time deterministic communication • high reliability	
Monitoring Dashboard	SCADA system	Multi-site monitoring • alarms • historical data logging [55]	

Alarm System	Industrial siren + stack light system	<ul style="list-style-type: none"> multi-color tower light (red/yellow/green) [56] 	
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Industrial Detector Selection Recommendations:

1. Evaluate risks:

- Understand the types of fire possible (eg quickly developing versus slowly developing)
- Identify types of explosive or toxic gases within the area of concern
- Consider ambient conditions where detectors might be installed (eg dust/humidity/temperature).

2. Seek Compatible Detectors:

- Choose optical to detect the smoldering fire caused by cables or wood
- Choose heat based on the rate of temperature change that might occur with rapid development like when using ovens in kitchens
- Choose a fire detector that uses UV or IR technologies to detect hydrocarbon or rapidly developing fires d. Choose gas detectors that can detect explosive/toxic gases using either catalysts/electro-chemical/IR technologies

3. Review ATEX Classification Areas — Only certified detectors (Ex ia, Ex d) for areas with potential of explosion risk to be installed in potentially explosive atmospheres.

4. Assess installation site environmental factors — Install robust or aspirating detectors if the installation site may experience moderate levels of dust/contamination; install sealed/protected detectors in extreme cold weather.

4.7 conclusion:

This chapter successfully demonstrated the functional validity of this prototype. Through rigorous testing scenarios involving simulated gas leaks, thermal spikes, and fire hazards, the system proved its capability to process multi-sensor inputs synchronously. While constrained by network dependencies and hardware processing boundaries, the addition of trend-based analysis and automated visual capture represents a significant evolutionary step over traditional, reactive industrial safety systems. This prototype establishes a robust foundation for scalable, proactive, and intelligent HSE monitoring architectures in modern industrial environments.

General conclusion

Industrial hazards form some of the key problems that industries face today, owing to the impacts these have on people, the environment, and economics. As the complexity of industrial environments continues to increase, the need arises to adopt highly reliable, intelligent, and adaptive monitoring systems that not only identify hazardous conditions as early as possible but also support emergency responses.

The aim of this research has been to examine the ideas associated with industrial risk management and come up with an intelligent safety system, which will enable faster identification of hazards and better emergency responses. During the process of working on this thesis, the weaknesses associated with traditional systems of detection have been looked at. These include late identification of hazards, false alarms, and lack of coordination during emergencies.

Through the use of this system, we have seen the need of incorporating different detection and supervision techniques into industrial safety systems. Through the use of both visual and sound alarms, as well as environmental detection and remote supervision, we have been able to enhance the responsiveness of the system and increased awareness. Furthermore, through practical research and examples, we have seen how an intelligent monitoring system may be used in order to mitigate risks in industries and enhance preventive safety practices.

It is also clear that contemporary technologies such as artificial intelligence, Internet of Things, and Safety Instrumented Systems will play a major role in the development of industrial safety management.

However, some issues have been faced when working on the project, such as hardware limitations, lack of effective communication channels, and the limited capabilities of prototype hardware components. Nevertheless, the achieved results can be regarded as positive and prove that it is possible to develop intelligent and inexpensive solutions for industrial safety.

Some possible directions for improvement include using machine learning algorithms for forecasting, utilizing industrial-grade hardware, cloud storage and data management, more advanced communication methods, and large-scale testing in industrial settings. In addition, further research could be dedicated to enhancing the security and efficiency of communication channels, reliability of the system, and meeting industrial safety standards.

To conclude, the work done shows that incorporating intelligent systems into industrial monitoring tools can effectively help increase safety levels and reduce the risks associated with potential accidents and disasters in industry.

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