Advanced Fire Prevention for Methanol Ships

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Project Report

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Abstract - **The transition to low- and zero-carbon fuels in the maritime industry creates safety concerns. In particular, methanol poses special fire safety risks because of its nearly undetectable smokeless flame, even while it lowers emissions. This project aims to create an enhanced fire prevention system for ships utilizing methanol. It focuses on the high-risk pumproom area due to its fuel-handling equipment and the high likelihood of fuel gas mixing. Continuous monitoring of heat and methanol concentrations, an early warning alert system, and an emergency shutdown strategy are all key objectives. The system combines thermal imaging cameras for real-time heat detection with gas sensors to monitor fuel concentrations, consolidating data on a central platform. An alert is triggered when safe heat or gas levels are exceeded. An automated power shutdown to the pumproom is triggered if both hit critical levels. By using automation and technology, this proactive solution improves fire safety while safeguarding the crew and the ship.**

1. INTRODUCTION

Fire safety has become a critical concern in the shipping industry. While accidents often occur unexpectedly, many ship fires could have been prevented with proactive measures. In 2022 alone, there were 209 reported fire incidents, the highest total in a decade. Over the past five years, 64 ships have been lost to fires. According to an analysis by AGCS of 250,000 marine insurance claims, fire emerges as the most significant cause of loss, representing 18% of the total value of the claims reviewed.

As the industry shifts toward sustainable fuel practices, enhancing fire safety for low- and zero-carbon fuels is essential. Currently, there 29 ships are in operation with methanol capabilities, and an additional 228 are on order, signalling significant growth in methanol-fuelled vessels, according to DNV. While methanol is considered one of the sustainable future fuels, its fire safety implications must be thoroughly addressed. Notably, methanol flames are invisible to the naked eye, creating unique challenges for detection and response.

Currently, the probability of methanol vapours accumulating in the pump room is significantly elevated, making this area a critical focus for our project. For demonstration, our methodology will concentrate specifically on the pump room, where the risk is most pronounced. However, it is important to note that this proactive approach can be effectively adapted and extended to other areas of the ship as well.

By employing advanced detection systems and safety protocols in the pump room, we can create a robust framework for identifying and mitigating vapor hazards. This targeted strategy not only addresses immediate safety concerns but also serves as a model that can be replicated in other high-risk zones, such as cargo holds and engine rooms. This comprehensive methodology aims to enhance overall safety across the vessel, protecting both crew members and valuable assets from potential fire hazards associated with methanol vapours.

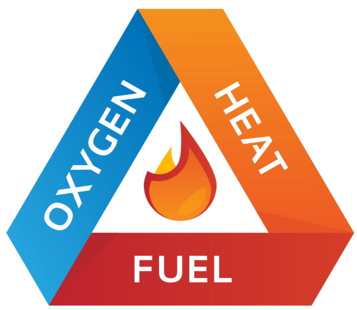

Fig 1.1 - Fire Triangle

Fire requires three essential components: fuel, an ignition source, and oxygen. While oxygen is omnipresent aboard a ship, this project aims to focus on managing the fuel and ignition source components to effectively prevent fires. By implementing a comprehensive system that identifies and mitigates potential ignition sources and controls fuel availability, we can significantly enhance fire safety onboard.

This approach not only seeks to reduce the risk of fire but also promotes a system where a fire is prevented from happening by adoption of best practices. By prioritizing these two critical elements, we can create a safer environment for crew and cargo alike, minimizing the risk of fire incidents and ensuring operational continuity.

2. LITERATURE REVIEW

At standard temperature and pressure (STP) conditions, methanol remains in a liquid state but exhibits gradual evaporation. As temperature increases, the rate of vaporization accelerates, with methanol reaching its boiling point at 62.7°C. This relatively low boiling point indicates that methanol transitions into a vapor phase more readily compared to many other liquids.

One of methanol's key safety concerns is its flashpoint of 12°C, which means that even at temperatures as low as 12°C, it produces enough flammable vapours to ignite when exposed to an ignition source. Methanol onboard a ship is stored at ambient temperature, and this makes it more vulnerable to the formation of flammable vapours as most regions in the world have an ambient temperature of more than 12°C. This property highlights methanol's potential fire hazard, even at mild temperatures.

The flammability range of methanol is notably wide, spanning from 6% to 36.5% in air, making it capable of sustaining combustion over a broad concentration range. This wide range enhances the risk of fire or explosion in environments where methanol vapours might accumulate.

Methanol has an autoignition temperature of 450°C, which is the temperature at which it can spontaneously ignite without an external flame or spark. This further reinforces the need for careful handling and storage in environments where high temperatures could be reached. Existing studies highlight the risks associated with methanol as a fuel source, including its flammability and the potential for explosive mixtures in enclosed spaces.

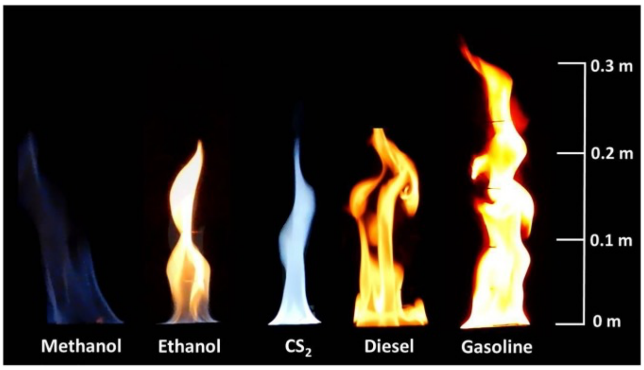

Fig 2.1 - Comparison of Methanol fires with other fuels

In the existing methanol ships, in the fire detection system, the detectors used are primarily combination of smoke detectors and IR Flame detectors. Traditional fire prevention systems often lack the specificity and sensitivity required for newer fuels. Recent advancements in thermal imaging and gas detection technologies offer promising solutions for enhancing fire safety in maritime applications.

However, methanol's high flammability, low flashpoint, and nearly invisible flame present fire safety challenges, makes gas detection difficult. Gas detectors are essential for detecting leaked methanol vapor, as they help identify the formation of both flammable and toxic atmospheres. The most common type of gas detector used onboard a methanol is the electrochemical one. By regulation, all ships are supposed to have a certified fixed gas detection system onboard a ship covering various location including pump room. All the gas detectors are connected to a centralised system which is used for alarming purposes.

3. PROPOSED SYSTEM

The proposed system has three embedded components to achieve the desired output.

3.1. Detection:

The system uses two types of detection system. One for the heat detection and other for the detection of flammable gases, in this case methanol. Thermal imaging cameras are used for sensing the temperature of the area to be monitored. The cameras installed will be giving a video output, which fed to a computer program, which in turn processes the image at each second and gives an alarm output when the set threshold level is reached.

In case of gas detection system, a continuous measurement of methanol vapours is carried out. Area classification is an essential process for analysing and categorizing locations where explosive gas atmospheres may be present.

Zone 0: covers areas where methanol vapours are continuously present or present for long periods which includes interiors of methanol fuel tanks, piping for pressure-relief systems, and other venting equipment that contains methanol fuel.

Zone 1: areas having higher likelihood of methanol vapor but not as frequently as Zone 0 such as Cofferdams, fuel preparation areas like pump room etc.

Zone 2: Lower risk of methanol vapor exposure, typically under abnormal conditions.

In this proposed system, we are considering only the example for pump room which typically a zone 1 location. The system continuously measures the methanol vapours and gives audible alarm when the set limits are reached.

3.2. Alerting system:

The system is designed with two critical alert types that work in tandem to significantly enhance safety onboard, ensuring that crew members are promptly informed of potential hazards and can take immediate action to mitigate risks associated with temperature fluctuations and flammable gas concentrations.

3.2.1. Temperature Alert:

This alert notifies crew members of any abnormal rise in temperature within the pump room. A thermal camera captures video footage, which is analysed by a Python program. If the temperature exceeds predetermined thresholds, the system generates an output that can be fed into the ship's alarm system. This alert serves as a warning to the crew about potential overheating, which could lead to a fire. For instance, if equipment in the pump room malfunctions and triggers a high-temperature alert, the crew can swiftly power off the equipment, preventing a fire before it occurs.

3.2.2. Flammable Gas Alert:

Every ship is required to have a fixed gas detector installed in the pump room. The detector continuously monitors for flammable gas mixtures, and if levels exceed safe limits, it sends a signal to the central system. This alert informs crew members of the presence of dangerous gas concentrations. Since heat can ignite these gases, timely notification allows the crew to take action, such as stopping the gas leak, thus averting the risk of a fire.

Together, these alert systems enhance safety by enabling proactive measures against both overheating and flammable gas hazards, helping to protect the crew and the vessel from fire incidents.

3.3. Shutdown system:

In a critical scenario where both temperature and flammable gas alerts are activated, immediate action is imperative to avert a potential fire. The system should first trigger both audible and visual alarms to alert all personnel while simultaneously sending automated messages detailing the emergency. It will then initiate an automated shutdown of the electrical power supply to the pump room, with a contingency plan for trained personnel to execute a manual disconnection if necessary.

4. METHODOLOGY

4.1. Heat Detection:

The thermal imaging analysis system is designed to identify potential hot spots that may indicate a fire risk, utilizing advanced image processing techniques for effective early fire detection. The initial step in programming involves setting up the path to the thermal video file. This video is crucial for the analysis, as it provides the visual data needed to assess temperature variations. By examining the video frame by frame, the system can detect subtle changes in heat that may signal a fire hazard. This setup ensures that the subsequent analysis is both precise and thorough.

Once the video path is established, the program enters the video processing phase. The core function, process_video, opens the specified video file and retrieves its frames per second (FPS), a key parameter that dictates how many frames are displayed in one second. Understanding the FPS allows the system to determine how frequently it should check frames for analysis. For example, in a video running at 30 FPS, the system would typically analyse every 30th frame, effectively sampling the video at one-second intervals. This strategy balances the need for timely detection with the computational resources required for video frame processing. After attempting to read the first frame, the system checks for any integrity issues; if the frame cannot be read, an error message is generated, and the analysis is halted to prevent further complications.

During the frame analysis stage, the program methodically tracks the current frame being processed, focusing solely on frames that are multiples of the defined interval (e.g., every 30th frame). This targeted approach streamlines the analysis and reduces the workload on the system while still maintaining a robust detection capability. When a frame is selected for analysis, the system invokes the check_heat_spot function. This function plays a pivotal role in transforming the selected frame into various colour formats, which enhances the identification of excessively hot areas. By converting the image data, the system can more easily differentiate between normal temperature ranges and heat anomalies.

For effective heat detection, the system generates a mask that highlights regions identified as "hot." This mask is crucial for visualizing hot spots within the frame. The program then calculates the percentage of hot pixels within this mask, providing a quantitative measure of heat concentration in the frame. If this percentage exceeds a predefined threshold, such as 0.1%, the system triggers an emergency alert. This alert not only serves as an immediate warning but also documents the time of detection for record-keeping, ensuring that there is a traceable response to potential fire risks.

Upon completing the analysis of all relevant frames, the system presents images of any detected hot spots alongside their corresponding heat masks. This visual feedback is essential for users, as it allows them to see exactly where the potential risks lie. If no hot spots are identified throughout the analysis, the system concludes with a message stating, "Thermal Analysis Ended. No heat spots were found." This outcome reassures users that the area is currently safe. Additionally, the system includes final output messages that handle various scenarios. If problems arise while reading the video, it prints, "Problem with Analysis: Unable to read frames from the video," alerting the user to technical issues. Conversely, if hot spots are detected, an alert is generated, including a warning and the exact time of detection.

Overall, this thermal imaging analysis system serves as a vital tool for early fire detection. By monitoring temperature changes in critical areas, it enables timely interventions by personnel, ultimately contributing to fire prevention and safety. The integration of advanced image processing techniques and systematic frame analysis underscores the importance of early detection in mitigating fire risks.

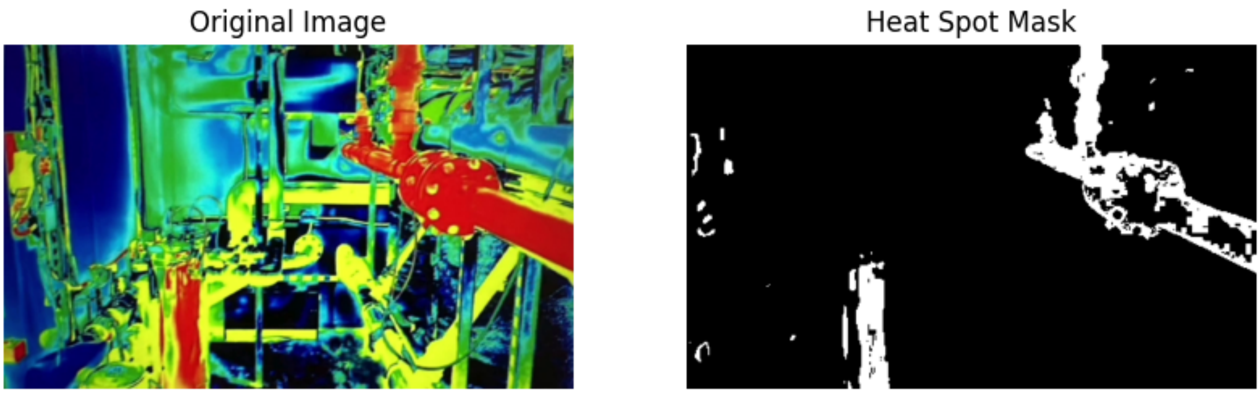

Fig 4.1 - Sample thermal image and its corresponding Heat spot mask

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🚨 Emergency Alert! 🚨
Time of analysis (SGT): 2024-10-27 08:09:02 (YYYY-MM-DD HH:MM:SS)
Image at Second: 32 analyzed. Stopping Analysis.
Heat spot threshold of 0.1% exceeded.
Estimated Heat percentage = 7.29%
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Fig 4.2 - Output for the thermal image in Fig 4.1

4.2. Flammable Gas Monitoring:

The implementation of a continuous methanol gas monitoring system is crucial for ensuring safety in environments where methanol is used as fuel. This system is designed to provide real-time monitoring of fuel vapor concentrations and to alert operators whenever safe thresholds are exceeded. Specifically, it activates an audible and visible alarm when the methanol vapor concentration reaches 20% of the lower explosion limit (LEL). This early warning mechanism is vital for enabling rapid responses to potential fuel leaks or hazardous conditions, thereby minimizing the risk of fire or explosion.

Various types of gas sensors can be employed for this monitoring system, each with unique advantages. These include:

- Solid Electrolyte Gas Sensors: These sensors are known for their stability and reliability in detecting specific gas concentrations.
- Infrared Absorption Gas Sensors: Utilizing infrared light to measure gas concentration, these sensors are effective for detecting hydrocarbons, including methanol.

- Ionised Gas Sensors: These sensors operate by measuring the conductivity of air when gas is present, providing accurate readings in real time.
- Semiconductor Gas Sensors: These are sensitive to a wide range of gases and are often used for their cost-effectiveness and compact size.
- Electrochemical Gas Sensors: Typically employed for detecting toxic gases, these sensors can also be adapted for combustible gases like methanol.
- Catalytic Combustion Gas Sensors: These sensors measure the heat produced by the combustion of gas, providing a reliable indication of gas presence.

The selection of an appropriate sensor type is essential for ensuring the reliability and accuracy of the monitoring system.

According to the International Maritime Organization (IMO) guidelines for the safety of ships using methyl or ethyl alcohol as fuel, it is mandated that permanently installed gas detectors be strategically fitted in various critical areas. These include:

- Ventilated Annular Spaces of Double-Walled Fuel Pipes: Monitoring these areas is essential to detect any leaks that could pose a risk.
- Machinery Spaces Containing Fuel Equipment or Consumers: Since these spaces house equipment that can generate sparks or heat, continuous monitoring is crucial.
- Fuel Preparation Spaces: These areas are critical during the fuel handling process, making them high-risk zones for leaks.
- Enclosed Spaces with Fuel Piping or Equipment Without Ducting: These spaces are prone to vapor accumulation, necessitating effective monitoring.
- Cofferdams and Fuel Storage Hold Spaces Surrounding Fuel Tanks: These areas need constant vigilance to detect any leaks from the tanks.
- Airlocks: Monitoring these transitions is vital as they connect potentially hazardous spaces with safe areas.
- Ventilation Inlets to Accommodation and Machinery Spaces: Ensuring that air entering these spaces is free from harmful fuel vapours is essential for overall safety.

With these guidelines in mind, all ships utilizing methanol as fuel will be required to have approved gas detectors installed. The overarching goal is not only to comply with safety regulations but also to enhance the overall safety framework onboard.

By integrating the gas detection system into the proposed fire prevention system, operators can benefit from a comprehensive safety approach. This integrated system will not only monitor for leaks but also contribute to the early detection of fire risks associated with methanol vapours, thereby enhancing the crew's ability to respond swiftly and effectively to any hazardous situations.

Ultimately, the implementation of a continuous methanol gas monitoring system, in conjunction with the required sensor types and strategic installation, underscores a commitment to safety and compliance in maritime operations. This proactive measure is essential for safeguarding both the crew and the vessel while ensuring safe operations in environments where methanol is utilized as fuel.

4.3. Integration of Systems:

The outputs from both the heat detection system and flammable gas monitoring are integrated into the central unit, which manages alerts and shutdowns to ensure safety in hazardous conditions.

For heat detection, a thermal camera monitors for hotspots continuously. The video output from the camera is processed by a Python-based program that identifies temperature anomalies. When a hotspot is detected, the program sends a signal to the central unit, prompting it to activate the alert system. Similarly, a 4-20mA signal from the gas detector feeds into the central unit. Upon detecting gas, the gas detector sends a signal, which the central unit interprets as a cue to activate the alert system.

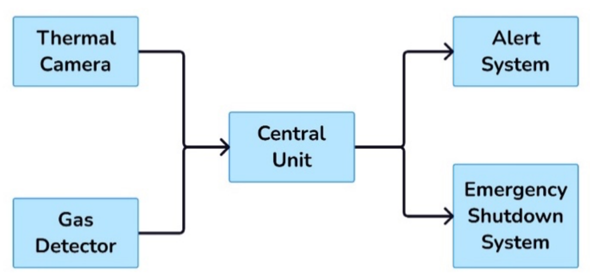

Fig 4.1 - Block Diagram of the system

If both the thermal camera and gas detector detect dangerous conditions simultaneously, the central unit initiates an emergency shutdown sequence, cutting power to the entire pump room. This automated shutdown mechanism prevents potential ignition by responding immediately when both heat and gas exceed predefined safety thresholds, thereby safeguarding the facility.

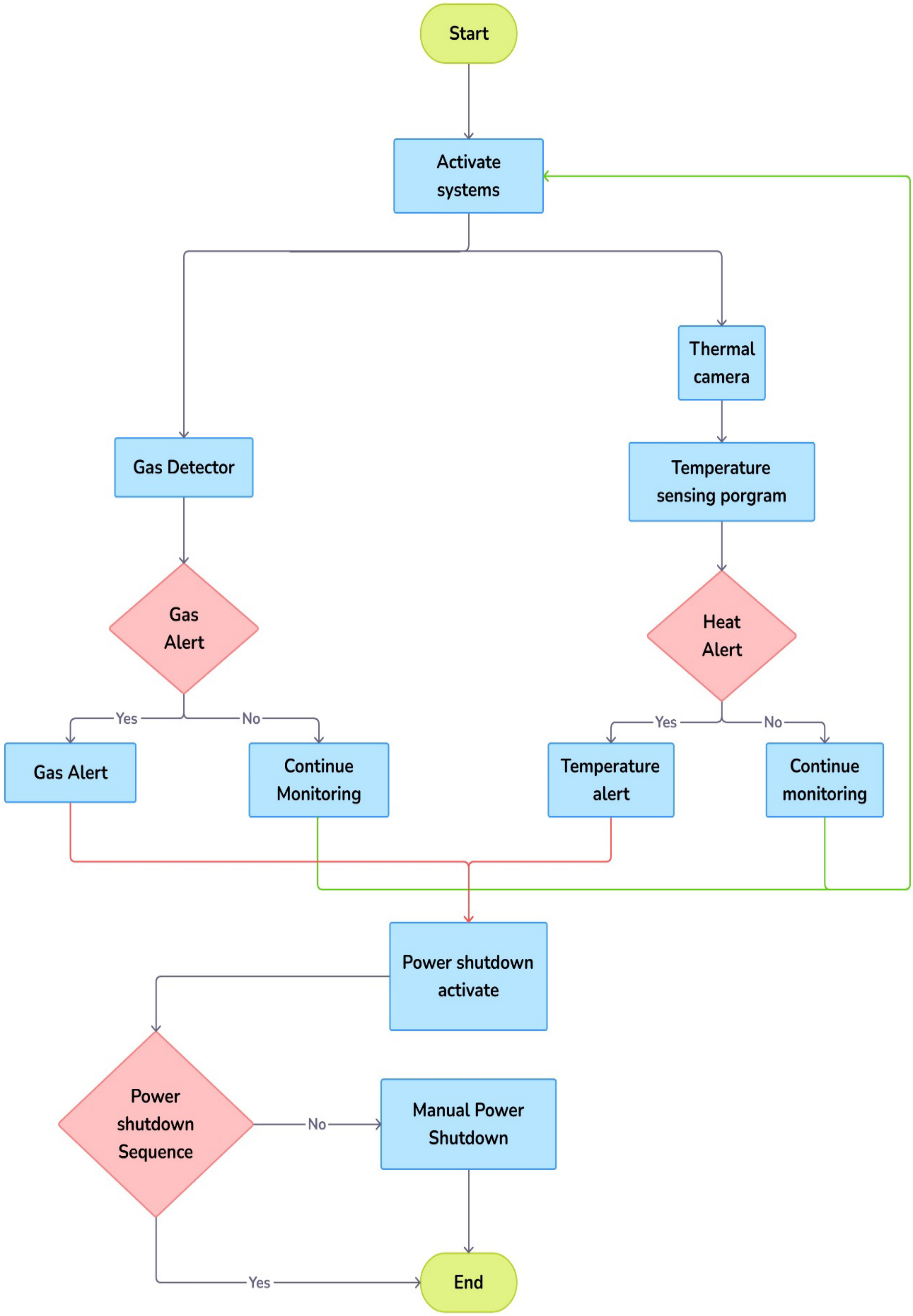

Fig 4.2 - Flowchart of central unit

5. RESULTS AND DISCUSSIONS

5.1 Heat Detection:

The thermal imaging system's frame-by-frame analysis method is expected to provide real-time monitoring of temperature fluctuations, rapidly identifying hotspots that exceed preset safety thresholds. Such a system, applied in high-risk zones like the pump room, can generate early alerts, offering a pre-emptive measure against potential fire hazards, including those from invisible methanol flames. The approach of continuous thermal data processing aligns with industry standards for heat detection systems, suggesting that this system could operate with minimal latency between anomaly detection and alert activation.

5.2 Flammable Gas Monitoring:

Similarly, the gas detection system, calibrated to respond when methanol vapor concentrations reach 20% of the Lower Explosion Limit, follows recommended safety practices for early-stage hazardous gas detection. The design includes compatibility with multiple sensor types such as electrochemical and catalytic sensors. These sensors are chosen for their stability and responsiveness in identifying volatile organic compounds, especially methanol vapours. Theoretical implementation indicates that these sensors, when integrated into a centralized alert system, would enable the crew to receive timely notifications, allowing them to respond swiftly and manage emerging risks before critical levels are reached. Overall, based on the planned configuration and alignment with industry practices, the integrated thermal and gas detection system is expected to serve as a comprehensive early warning system for fire prevention in the pump room and other high-risk areas.

5.3 System Integration:

When either heat or gas levels exceed preset safety thresholds, the system is programmed to activate alerts, notifying the crew of potential risks. For scenarios where both heat and gas indicators are simultaneously triggered, the system includes an automated response to power down the pump room, preventing ignition hazards. This layered response strategy aims to ensure protection for both personnel and equipment in high-risk conditions. However, certain challenges are expected, such as the need for precise sensor calibration to avoid detection errors and adjustments for the camera's performance in high-humidity environments. Overall, the system's integrated approach offers a promising model for enhancing shipboard safety.

6. CONCLUSION

This project effectively showcases an integrated safety approach for methanol-fuelled vessels by merging thermal imaging for heat detection with real-time gas monitoring. This dual system specifically addresses the unique risks posed by methanol's flammability and its nearly invisible flames. The central unit's capability to promptly respond to hazard signals by activating alerts and shutting down the pump room in critical situations highlights the importance of automated safety measures in high-risk environments. Although the system has been tested within a pump room context, its design allows for seamless adaptation to other critical areas on the ship. This study underscores the importance of proactive fire prevention, particularly as the maritime industry increasingly embraces low-carbon fuels like methanol. Future enhancements could aim at refining sensor calibration and improving the system's adaptability to various environmental conditions, thereby ensuring even greater reliability.

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