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Design of Prototype Early Warning System for Ship Gas Leakage and Fire Using MQ-6 Sensor and Arduino Uno Microcontroller

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ABSTRACT

Maritime transportation is vital for global trade but faces risks from gas leaks and fires, which can endanger ships and crews. Many small and medium-sized vessels lack effective systems to detect hazardous gases early, raising the chance of accidents. This study focuses on developing a prototype early warning system to detect gas leaks and fires on ships using an MQ-6 sensor and an Arduino Uno microcontroller. The goal is to provide a low-cost, real-time monitoring solution to improve maritime safety. The research follows a hardware prototyping and software development process using a waterfall approach, including requirement analysis, system design, implementation, testing, and deployment. The MQ-6 sensor identifies flammable gases like LPG and butane, while the Arduino Uno processes the sensor data and triggers alarms when gas levels become dangerous. The prototype was tested in a simulated ship environment to assess its sensitivity, response time, and reliability. Test results show that the system detects gas concentrations above safe limits within 3 to 5 seconds, activating visual and audio alarms quickly. The device also operates continuously with low power consumption, making it suitable for long-term use on ships. The study shows that this prototype can serve as an affordable and reliable additional safety device for maritime settings. This research supports efforts to improve ship safety systems by offering a practical way to reduce risks from gas leaks and fires. The system's simplicity and effectiveness make it a promising option for enhancing onboard hazard detection.

1. INTRODUCTION

Maritime transportation plays a pivotal role in the global economy, facilitating the movement of goods and people across continents [1], [2]. However, the safety of maritime vessels remains a significant concern, particularly in relation to hazards such as gas leaks and fires. These types of incidents not only threaten human lives but also cause substantial economic losses and environmental damage [3], [4]. According to reports from maritime safety organizations, accidents involving gas leaks and onboard fires have been recurring events, especially on vessels carrying flammable materials or operating in enclosed engine rooms [5], [6], [7]. The confined and isolated nature of ships amplifies the risk, as emergency response capabilities are limited when vessels are far from shore-based assistance.

Traditional fire detection and gas leak alert systems installed on ships have limitations in terms of response time, sensitivity, and flexibility [8], [9], [10]. Many existing systems rely on manual inspections or outdated technologies that may not provide immediate feedback when dangerous conditions arise. In many cases, by the time the crew becomes aware of a gas leak or fire outbreak, containment is difficult, and evacuation procedures are already compromised. Hence, there is a pressing need to integrate smarter, more responsive, and cost-effective solutions that can mitigate such risks at an early stage.

In recent years, the advent of microcontroller-based systems and advancements in sensor technologies have opened new possibilities for developing compact, accurate, and low-cost safety systems. Among the various gas sensors available, the MQ-6 sensor has gained popularity due to its high sensitivity to liquefied petroleum gas (LPG), butane, methane, and other combustible gases. Coupling such a sensor with a versatile microcontroller platform like Arduino Uno offers the potential to create a reliable early warning system that is easily deployable in maritime environments [11], [12].

This research focuses on the design and development of a prototype early warning system intended to detect gas leaks and fire risks on maritime vessels using an MQ-6 sensor integrated with an Arduino Uno microcontroller. The system aims to provide real-time monitoring and immediate alerting mechanisms, which could significantly enhance onboard safety and minimize the potential for catastrophic events. Furthermore, by leveraging low-cost hardware and open-source development environments, the proposed system is designed to be accessible and scalable, especially for smaller vessels or operators with limited budgets [13], [14]. The research identifies key challenges inherent in maritime safety systems, including the need for timely detection, environmental resilience, and user-friendly interfaces for ship crews. Addressing these challenges requires a structured approach that involves both hardware and software development, sensor calibration, system integration, and performance testing in simulated environments resembling real-world maritime conditions [4], [15].

To achieve these objectives, this research adopts an engineering development methodology, encompassing stages of requirement analysis, hardware design, software programming, prototype assembly, and system evaluation. The system's effectiveness is assessed based on its response time, detection accuracy, and reliability under different gas concentrations and ambient conditions. Data from these evaluations inform iterative improvements to ensure the prototype meets the desired functional and safety criteria [16], [17].

2. RELATED WORK

A previous study developed a gas leak detection system for LPG cylinders using an MQ-6 sensor integrated with an Arduino Uno and applied a prototype-based design method. The purpose of the system was to assist the public in easily identifying gas leaks in LPG cylinders during daily use, helping to prevent potential fires. The testing showed that the MQ-6 sensor effectively detected the presence of gas. The testing used a gas stove as the source, and the device successfully identified the gas release. When gas was detected, the buzzer activated with an audible alert, and the LCD screen displayed information indicating whether gas was present or not in the surrounding area [18].

A related study discusses a tool designed to detect LPG gas leaks. In this work, the researcher applies an MQ-6 sensor, which is capable of sensing Propane (C_3H_8) and Butane (C_4H_{10}), the primary components of LPG. The sensor is positioned near potential leak sources, such as the regulator. When gas concentration rises, the sensor's resistance drops, leading to an increase in output voltage, which then triggers an audible alert [19], therefore, the author is interested in designing a device with a similar sensor but applied to ships.

In summary, this study seeks to contribute to the enhancement of maritime safety systems by developing a functional prototype of a gas leak and fire early warning device, leveraging contemporary sensor and microcontroller technologies. The outcomes of this research are expected to offer practical solutions for improving onboard hazard detection capabilities, thereby supporting safer maritime operations..

3. METHODOLOGY

Before initiating program compilation on the Arduino ATmega328P microcontroller, it is essential to design the operational workflow of the entire system. This process involves outlining the functional stages of the device based on the complete circuit configuration and subsequently translating them into a flowchart. The flowchart serves as a fundamental reference for the coding phase on the Arduino Uno microcontroller, ensuring that the sequence of operations is systematically implemented [20], [21]. Figure 1 presents the flow diagram of the developed early warning system for gas leaks and fire hazards onboard ships. The system is structured to perform a series of automated steps that ensure continuous monitoring and rapid response to hazardous conditions detected within the vessel's environment.

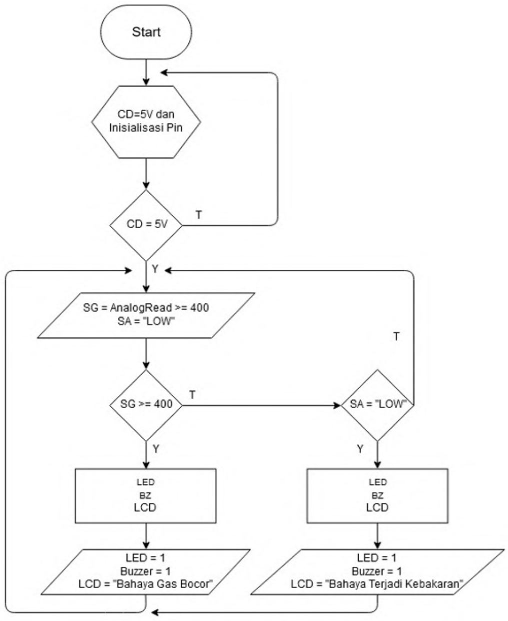

FIGURE 1. FLOWCHART SYSTEM

The operational sequence begins with the initialization of the power supply, ensuring that a stable voltage of 5V is available to activate the system components. In the event the power supply fails to deliver the required voltage, the system is programmed to attempt a reinitialization until the necessary voltage level is achieved. Once stable power is confirmed, the sensors commence their functions: the fire sensor actively monitors for flame presence, yielding a LOW logic signal when a fire is detected, while the gas sensor continuously measures the concentration of gas in the surrounding air. If the gas sensor registers a value equal to or exceeding 400 parts per million, or the fire sensor identifies a fire event, the Arduino Uno microcontroller processes this data to trigger the alert system. Subsequently, it activates three output devices the LED, buzzer, and LCD display. The LED and buzzer are engaged simultaneously to provide visual and audible alarms, and the LCD displays an appropriate warning message. Following the alert activation, the sensors maintain their monitoring roles to ensure ongoing detection of gas leaks or fire incidents, supporting real-time hazard awareness onboard the ship.

To ensure the proper functioning of the entire system, a well-structured block diagram is essential. This diagram provides a clear representation of how each component interacts within the overall circuit architecture. The design is divided into three fundamental sections: the input stage, the processing stage, and the output stage, all of which are integrated with a power source to enable system operation. The input block is responsible for capturing environmental conditions through sensors, the processing block handles data interpretation and decision-making, and the output block delivers real-time feedback to the users. By organizing the system in this manner, it becomes easier to manage the flow of information from detection to alert, thus improving reliability and operational efficiency.

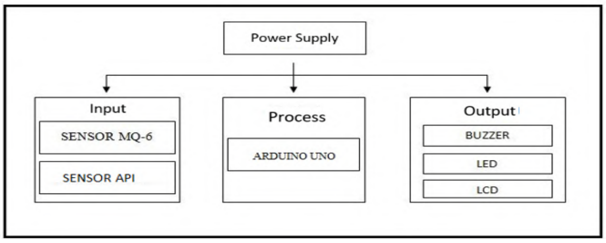

FIGURE 2. BLOCK DIAGRAM

As illustrated in Figure 2, the power supply serves as the main energy provider, activating all circuit components. The MQ-6 gas sensor and the flame sensor act as the primary detection devices, identifying potential gas leaks and fire hazards on board the ship [22], [23]. Data collected from these sensors is transmitted to the Arduino Uno ATmega328P microcontroller, which processes the incoming signals and executes programmed responses. Based on the sensor readings, the microcontroller controls the activation of visual and auditory alerts, such as triggering the buzzer and illuminating red or green LED indicators. Additionally, an LCD screen is incorporated to display warning messages to ship crew members, ensuring timely communication of potential dangers derived from the processed sensor data [24], [25].

4. RESULT AND DISCUSSION

The complete circuit integrates all components into a unified prototype. This system operates based on the block diagram illustrated in Figure 2. The circuit is activated when a 5V power supply is provided, either from a laptop or a power bank. The operation begins with the input section, where the MQ-6 sensor detects the presence of gas leaks and the fire sensor identifies any fire occurrence. The MQ-6 sensor captures gas concentrations and generates signals in analog form, which are read through the analog pin (A0). In this design, the sensor's analog output is directly connected to the Arduino UNO's analog pin (A0), functioning as the input channel. Data from the gas sensor is processed and displayed in the serial monitor of the Arduino IDE. When the sensor reading reaches or exceeds a threshold value of 400, the Arduino Uno processes the signal accordingly. Simultaneously, the fire sensor provides a LOW logic output when fire is detected and a HIGH logic output when no fire is present. Both sensor signals are processed by the Arduino Uno microcontroller, which interprets the input data and activates the corresponding outputs. The output section consists of a buzzer that functions as an audible alarm during gas leaks or fires, LEDs that act as visual indicators of such hazards, and an LCD that displays textual warning messages. The assembled circuit layout for this detection system is depicted in Figure 3.

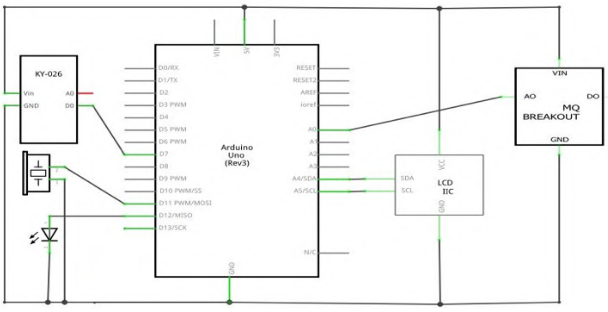

FIGURE 3. CIRCUIT DESIGN

This gas leak and fire early warning system is controlled by Arduino Uno, which fully controls all components installed in this circuit. This tool works after being given a voltage of 5V, after getting the voltage it will activate the MQ-6 sensor and the fire sensor, which will detect leaking gas and fire. If gas or fire is detected, it will turn on the warning alarm in the form of a buzzer, LED, and LCD. The opposite condition if no gas and fire are detected, the warning alarm will not turn on.

Based on Figure 1, the design of the Arduino Uno microcontroller C language program is made by writing the program to the Arduino microcontroller memory with the help of Arduino software. The first step to do programming is to open the Arduino software. The next step is to create a program. After that, the program that has been made is compiled / built first to check whether an error occurs or not. How to compile a program on the Arduino software is by clicking the check button on the software. Figure 4 shows the display during the Arduino program compile process.

FIGURE 4. ARDUINO COMPLIE PROCESS VIEW

If there are no errors, the message "Done Compiling" will appear. Once this message is displayed, the program is ready to be uploaded to the microcontroller. To upload the program, click the arrow button in the software until the message "Done Uploading" appears. The researchers designed and developed a prototype of an embedded system aimed at detecting gas leaks and fires on ships. This system utilizes a fire sensor to identify the presence of fire and an MQ-6 gas sensor to detect gas leaks. The sensors are programmed using the Arduino IDE with C language. The detection results are then communicated through outputs such as a buzzer, LED, and LCD. The developed prototype was subsequently implemented as a gas leak and fire detection system for maritime applications. The following figure illustrates how the prototype is applied within the security system for detecting gas leaks and fires on ships. The prototype of the early warning system for gas leaks and fire hazards on ships is shown in Figure 5.

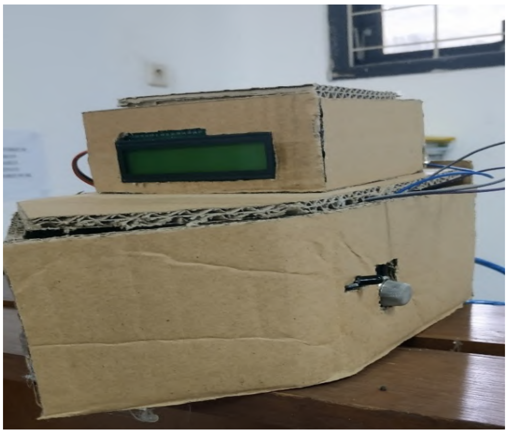

FIGURE 5. SEA SHIP PROTOTYPE

The purpose of testing the gas leak and fire detection system on the ship is to assess the performance of both the hardware and software components that have been developed. This process aims to evaluate the functionality of each interconnected module within the system. To perform the tests, it is necessary to prepare essential tools such as a power supply, multimeter, jumper cables, and other related equipment. Once all preparations are complete, the components and the assembled prototype can be tested for proper operation.

4.1 Fire Sensor Testing

The fire sensor is tested using a multimeter to measure its voltage output. The testing procedure for the fire sensor is shown in Figure 6.

FIGURE 6. TECHNICAL TESTS ON THE FLAME SENSOR

Based on the experimental results, it can be concluded that the fire sensor operates with an active LOW logic, meaning it is activated when the voltage level is low. The detailed results of the fire sensor testing are presented in Table 1.

TABLE 1. TEST RESULTS ON THE FIRE SENSOR

No.	Distance	Condition	Volt
1.	0 cm	inactive	0,008V
2.	2 cm	active	0,006V
3.	4 cm	active	0,005V
4.	6 cm	active	0,004V
5.	8 cm	active	0,006V
6.	10 cm	active	0,004V

4.2 Gas Sensor Testing

The gas sensor testing was conducted by integrating the sensor with the Arduino microcontroller. The primary objective of this test was to evaluate the sensor's responsiveness in detecting the presence of gas within the surrounding air. The configuration and implementation of the gas sensor testing are illustrated in Figure 7.

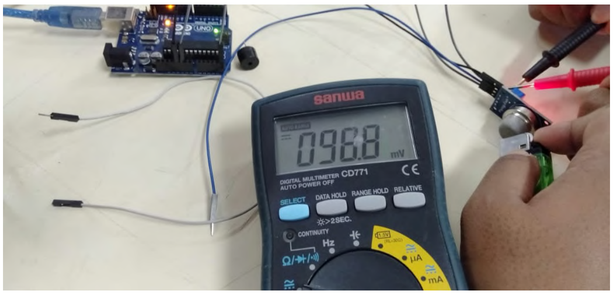

FIGURE 7. TECHNICAL TESTS ON GAS SENSORS

Based on the conducted experiments, it can be concluded that the gas sensor operates in an active LOW state, meaning it is triggered when the input voltage drops to a low level. The detailed results of the gas sensor testing are presented in Table 2.

TABLE 2. TESTING THE GAS SENSOR

Condition	Voltage (V)	Description
HIGH	4,63	The state when the gas sensor does not detect gas
LOW	0,09	The state when the gas sensor detects gas

4.3 LCD I2c Testing

During the testing process of the I2C LCD, a multimeter was utilized to measure the voltage supplied to the LCD module. This measurement aimed to verify the electrical characteristics of the LCD, as illustrated in Figure 8.

FIGURE 8. LCD 12C TECHNICAL TEST

Table 3 displays the outcomes of experimental measurements carried out on the LCD module utilizing a multimeter. These measurements were conducted to examine the voltage levels at several points within the LCD circuit, ensuring the component consistently received the correct and stable power supply throughout its operation. The data presented in the table comprises voltage values measured across various terminals of the LCD, aimed at confirming the module's operational reliability and verifying that the electrical characteristics align with the system's intended design parameters.

TABLE 3. TESTING ON 12C LCD

Condition	Voltage (V)	Description
LOW	0.00	The state when the LCD is inactive or does not display text
HIGH	0.48	The State when the LCD is on or displaying text

4.4 Buzzer Testing

The Buzzer circuit was evaluated by taking measurements at two specific points: the input terminal and the output terminal. At the input terminal, the circuit was connected to a multimeter using the black (negative) probe, while the output side of the Buzzer was linked to the multimeter's red (positive) probe. The testing procedure involved monitoring the voltage readings displayed on the multimeter as the Buzzer was alternately supplied with LOW and HIGH logic signals. The measurement results under both conditions are illustrated in the corresponding figure 9.

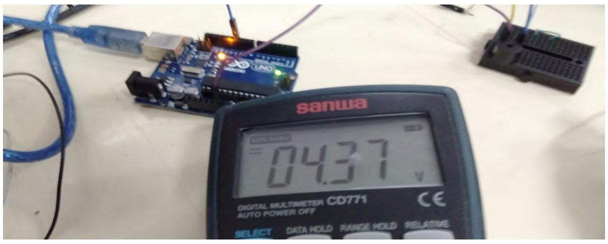

FIGURE 9. BUZZER TECHNICAL TEST

Table 4 presents the results of testing conducted using a multimeter, which was employed to measure and verify the electrical parameters of the developed prototype circuit. The measurements include voltage, current, and resistance values at various points of the system to ensure that each component operates within the expected specifications and that the overall circuit functions reliably under standard operating conditions.

TABLE 4. TESTING THE BUZZER

Condition	Voltage (V)	Description
LOW	0,00	inactive
HIGH	4,37	active

4.5 LED Circuit Testing

The testing procedure for the LED circuit follows the same method as that used for the buzzer circuit, where measurements are conducted at two key points: the input terminal and the output terminal of the circuit. At the input side, the LED circuit is connected to a digital multimeter using the black probe attached to the ground or reference line. Meanwhile, at the output side, the connection is established using the red probe, which is attached to the point where the LED receives its driving voltage. The objective of this testing is to observe and record the voltage levels supplied to the LED under different logic conditions. During the test, the circuit is subjected to both LOW and HIGH logic signals, and the corresponding voltage values displayed on the multimeter are carefully noted. These measurements verify whether the LED receives appropriate voltage levels necessary to indicate its ON or OFF state. The experimental setup and measurement results under these conditions are illustrated in Figure 10.

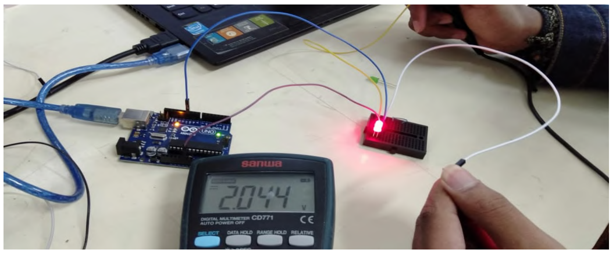

FIGURE 10. LED TECHNICAL TEST

The results of the LED testing process, which was conducted using a multimeter to measure voltage and continuity, are presented in Table 5. This testing aims to verify that the LED indicator operates correctly by confirming its ability to emit light when supplied with the appropriate voltage and to ensure that the circuit connections are functioning as intended.

TABLE 5. TESTING ON LEDS

Condition	Voltage (V)	Description
LOW	0,00	inactive
HIGH	2,04	active

4.6 Functional Testing

Functional testing was conducted to evaluate whether the designed circuit operates in accordance with the intended specifications. The testing procedure focused on verifying the performance of both the fire sensor and the gas sensor. During the test, fire and gas sources generated using a gas lighter were introduced near the sensors to simulate hazardous conditions. The presence of gas or fire causes the corresponding sensor to produce a "LOW" logic signal, indicating detection of a threat. Once either the fire sensor or the gas sensor registers a "LOW" output, the Arduino UNO microcontroller processes the input signals and activates the designated output devices.

In response to the detection, the system triggers three outputs: the buzzer, the LED indicator, and the LCD display. The microcontroller sets these outputs to a "HIGH" logic state, initiating their respective functions. When the buzzer output is "HIGH," it emits an audible alarm to alert users. Simultaneously, the LED illuminates, serving as a visual indicator of the detected hazard. Additionally, the LCD screen displays a warning message in text form, providing clear information about the nature of the threat. The detailed results of the functional testing, including system responses under various scenarios, are summarized in Table 6, which presents the overall evaluation of the prototype's performance in detecting gas leaks and fire incidents onboard ships.

TABLE 6. OVERALL FUNCTIONAL TEST

No.	MQ-6 Sensor (Gas)	Gas Sensor ADC Data	Fire Sensor	LED	Buzzer	LCD
1	not detected	40	not detected	off	off	safe
2	not detected	42	not detected	off	off	safe
3	detected	56	not detected	off	off	safe

No.	MQ-6 Sensor (Gas)	Gas Sensor ADC Data	Fire Sensor	LED	Buzzer	LCD
4	detected	84	not detected	off	off	safe
5	detected	120	not detected	off	off	safe
6	detected	230	not detected	off	off	safe
7	detected	320	not detected	off	off	safe
8	detected	421	not detected	on	on	danger
9	detected	532	not detected	on	on	danger
10	detected	760	detected	on	on	danger
11	not detected	42	detected	on	on	danger
12	not detected	42	detected	on	on	danger
13	not detected	42	detected	on	on	danger
14	not detected	43	detected	on	on	danger
15	not detected	43	detected	on	on	danger

From the test results of table 6, information can be obtained from the MQ-6 gas sensor and the Fire Sensor as follows:

1. The Gas Sensor or Fire Sensor does not detect a gas leak or fire so it does not turn on the Buzzer, LED, and LCD.
2. The Gas Sensor detects gas, but the detected gas has not reached 400 ppm so it does not turn on the Buzzer, LED, and LCD.
3. The Gas Sensor detects gas and the gas detected is more than equal to 400 ppm, so it turns on the alarm in the form of a Buzzer, LED, and LCD.
4. The Gas Sensor detects the presence of gas which is detected to be more than equal to 400 ppm and the Fire Sensor detects a fire, thus turning on the alarm in the form of a Buzzer, LED and LCD.

The gas sensor does not detect any leaking gas, but the fire sensor detects a fire point so that it turns on the alarm in the form of a Buzzer, LED, and LCD.

5. CONCLUSIONS

This research successfully designed and developed a prototype of an early warning system capable of detecting gas leaks and potential fire hazards on maritime vessels by utilizing an MQ-6 gas sensor integrated with an Arduino Uno microcontroller (ATmega328P). The system demonstrated the ability to monitor combustible gas concentrations in real time and trigger immediate alerts when hazardous levels were detected. Through hardware assembly, software programming, and system testing, the prototype proved effective in delivering rapid and accurate responses under simulated shipboard conditions. The combination of low-cost components and open-source technologies indicates that the developed solution is both economically viable and technically feasible for improving onboard safety, particularly for small to medium-sized vessels where advanced commercial systems might be financially inaccessible.

For future improvements, it is recommended to enhance the system by incorporating wireless communication modules, such as GSM or LoRa, to enable remote notifications to shore-based authorities or crew members. Additionally, expanding the sensor array to include smoke and temperature sensors could provide a more comprehensive safety monitoring system. Field testing in real maritime environments is also advised to evaluate long-term reliability and durability against ship-specific environmental factors such as humidity, vibration, and temperature variations. Continued refinement and scaling of this prototype could significantly contribute to strengthening maritime safety standards and minimizing the risk of accidents caused by undetected gas leaks or fires at sea.

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