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Design and Implementation of an IoT-Based Gas Leakage Detector Using Arduino Microcontroller

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Abstract

This paper presents the Design and Implementation of an IoT-based gas leakage detector using an Arduino microcontroller. This was borne out of the concern of the rampant fire incidents in homes and other areas of gas usage, and the need to develop a system to mitigate this. The methodology consists of two parts, namely the hardware and the software. The hardware involves the use of an Atmega328P microcontroller for both data acquisition and control. The controller was interfaced with the gas sensor MQ2, a thermistor for temperature monitoring, an LCD, a servomotor for regulating the gas supply, a buzzer, and an ESP8266 Wifi module for connecting to an IoT server. The software implementation involves the programming of the microcontroller using C++ programming language in an Arduino IDE environment and the configuration of the Blynk platform through the IoT to receive monitored readings of the system's sensors. The system was tested for efficiency and accuracy. The results of the test on the efficiency of the system showed that it takes between 1.44s to 75.66s for gas leakage to be detected and acted on by the microcontroller and 3.3s to 66.5s for temperature increase to be detected and acted on by the microcontroller with a distance range of 0 to 25cm in the case of the gas sensor and 0 to 6cm in the case of the temperature sensor respectively. The result also showed that the microcontroller was able to receive data from the various sensors and control the servomotor accordingly. This shows that the developed prototype is reliable and efficient.

Keywords: Microcontroller, IoT, servomotor, sensor, gas leakage.

INTRODUCTION

Gas leakage constitutes a critical safety concern in both residential and industrial environments, particularly in scenarios involving the utilization of Liquefied Petroleum Gas (LPG) or other flammable gases. Unrecognized leaks harbor the potential to provoke fires, explosions, and considerable health hazards, thereby accentuating the necessity for efficient and reliable detection systems. Notwithstanding the existence of various gas detection technologies, numerous current solutions are either excessively costly, lack the ability for real-time monitoring, or fail to integrate seamlessly with contemporary smart home systems.

The emergence of the Internet of Things (IoT) has radically altered safety and automation paradigms by enabling instantaneous data monitoring, remote operational management, and advanced alert mechanisms. Leveraging on these technological innovations, this paper articulates the design and implementation of an IoT-based gas leakage detection system specifically designed for domestic gas cylinders. The system employs Arduino as its core microcontroller, integrating a gas sensor for leak identification, a buzzer and LED for immediate alerts, and Wi-Fi connectivity to relay real-time notifications to users via a mobile application or cloud-based platform.

The design and implementation of IoT-based gas leakage detection systems have emerged as a critical area of research due to the increasing risks associated with gas leaks in residential, industrial, and commercial settings. For example, Arpitha *et al*. (2016), proposed a GSM-based gas leakage detection system with a signal conditioning circuit composed of a Wheatstone bridge responsible for converting the analog signal detected by the MQ6 gas sensor to voltage, the ADC then converts this voltage analog signal to its corresponding digital signal which is then compared with the threshold to make a binary decision between triggering the alert system which is the FPGA-GSM, or simply just resuming the monitoring of the gas level. The FPGA-GSM is interconnected using a Universal Asynchronous Receiver/Transmitter (UART) to facilitate the parallel and serial transmission between the FPGA and GSM as the UART is responsible for proceeding with the communication between the interfaces after the gas leakage has been detected. Through the use of the FPGA-GSM, the effectiveness of this system is increased as it is designed to immediately inform the designated person(s) about gas leakage. However, this system does not possess the ability to cut off gas supply once gas leakage is detected. In a similar way, Gomathy *et al*. (2021) proposed a system which consisted of the major components used to construct a simple gas detector but differed in voltage regulation and auxiliaries circuitry connected to the main components. The circuit also consisted of an exhaust fan to suck out the leaked gas away from the system. The use of the exhaust to automatically remove the gas from the atmosphere away from the system may be a good feature in preventing a fire outbreak, however, a gas cutoff mechanism would increase the effectiveness of this system as it will serve to cut off the gas supply in the presence of a gas leakage. Therefore, with the integration of a cutoff mechanism, the gas supply will be cut-off and the gas which has leaked into the atmosphere nearest to the system will be removed by the exhaust fan.

Alshammari and Chughtai (2020) proposed a gas detection system capable of monitoring the gas concentration in the atmosphere by setting minimum and maximum gas ranges which will represent the threshold (maximum level) that has to be exceeded to trigger the operation of the circuit. The methodology involved the interfacing of a solenoid valve, an ESP8266 module for connecting to the internet, a buzzer, an LCD, a fan, and an MQ-5 gas detector to an Arduino Uno. The solenoid was used for the closure of the gas supply. The system was able to execute the cutoff mechanism and dispatching of messages to the personnel through the IoT platform. However, the temperature of the environment was not taken into consideration as this could contribute to fire outbreak. Kommey *et al*. (2022), proposed a gas leakage detector system which consists of three units namely the sensor unit, the processing unit, the alert and response unit. This system incorporates a sprinkler to release the extinguishing agent if any flame is detected and also a solenoid valve which will be responsible for the cutoff of gas supply when gas leakage is detected. Due to the usage of a sprinkler and gas cutoff mechanism, this system may be effective in preventing the outcomes of a gas leakage. However, this system fails to incorporate a temperature sensor that can help to detect the temperature of the system as fire outbreaks do not only involve gas leakages but can be triggered by the high temperature of the environment which could then lead to burning or smoke. Anitha and Robin, (2022) in their paper proposed a system that continuously monitors the gas level to ensure it is within the set limit and that the output will be a green glowing LED. If the gas threshold is exceeded, the output will be a red glowing LED and consequently, a signal will be sent to the solenoid valve to close it. The system also has an alert system consisting of a GSM module and an alarm. This system can be further optimised by integrating a temperature sensor which will help to prevent the completion of the fire triangle by cutting off the gas supply when the temperature threshold of the system is exceeded.

The temperature of a gas environment could contribute to any gas leakage rapidly resulting in fire outbreak or not. Conscious of this, researchers have looked for ways of monitoring this. Working in this direction, Vishnu and Kowsalya, (2021) proposed a system which integrated a temperature sensor, a Passive Infrared (PIR) sensor, a valve, an LCD, a buzzer, and an MQ-2 gas sensor into an Arduino Uno microcontroller. The PIR sensor detects if any human being is close to the stove or not. The setup closes the gas supply whenever leakage is detected. Though the result shows that this system was good as it monitors the temperature of the environment, it is however not an IoT-based system.

The smartness of a system can be enhanced by integrating features that will allow users to visualise the data being produced by the system, monitor the state of the system through the Internet, and other related features that facilitate the interpretation of the data by the users. Shahewaz and Prasad, (2020) proposed a system that detects gas leakages using an Arduino Uno and an alert mechanism which consists of a buzzer and a GSM module to inform the necessary personnel. It works by simultaneously sending messages through the GSM module and triggering the buzzer upon detection of the gas leakage signal by the three gas sensors which monitor the gas levels in the three zones in which they are positioned. This system can be optimized through the integration of a device capable of providing remote monitoring features such as ESP8266 WiFi Module. This would enhance the smartness of the system as the state of the system can be monitored on various IoT analytics platform. Continuing along this path, Thakare *et al*. (2023), proposed a simple and easy-to-use gas leakage detection system comprising of an Arduino Uno, a buzzer, an LED, a gas sensor, and an LCD. This system was designed with the purpose of being adoptable in households due to the ease of its operation, cost-effectiveness and requiring a less complex circuit. However, it would be very beneficial to include cloud monitoring in the system which will enable the users of the system to observe its state through the use of the Internet.

From the foregoing, it is evident that there has not been any system that have been able to incorporate a mechanism for cutting off gas supply in the event of leakage detection, monitor the temperature of the gas environment, use a servomotor to cutoff gas and uses IoT to relay monitored data in real-time to the cloud for effective gas leakage detection and control in one standalone system. Therefore, there is the need to have an IoT-based system that takes all the parameters that could lead to the risk of fire outbreak due to gas leakage into consideration which this paper seeks to carry out.

MATERIALS AND METHODS

A. Component Descriptions and Specifications

i. Bulk Converter LM2595

In this project, the LM2595 chip is used as a step-down voltage regulator (also known as a buck converter). It can take in up to 40 volts and reliably reduce it to a steady 5 volts output. The device can supply up to 1 amp of current, maintaining stable performance even when the input voltage or output load changes. It operates efficiently with a switching frequency of 150 kHz. (Texas Instruments, 2016).

ii. MG995 High Speed Servo Actuator

This high-speed servo actuator delivers a stall torque of 8.5 kgf·cm at 4.8 V and operates at a speed of 0.2 seconds per 60° at the same voltage. It has a rotation range of 120° (±60° from the center) and supports an operating voltage between 4.8 V and 7.2 V. Weighing just 55 grams, the servo measures 40.7 × 19.7 × 42.9 mm. It features a precise 5 µs dead band and a durable, shock-resistant design with double ball bearings for stability. The operating temperature range is 0 °C to 55 °C, making it suitable for various controlled environments (Marlin P. Jones & Assoc & Assoc.).

iii. MQ-2 Semiconductor Sensor for Flammable Gas

The MQ-2 gas sensor uses a sensitive material called tin dioxide (SnO_2), which gives it high sensitivity to propane and smoke. It can also detect natural gas and other flammable gases effectively. The sensor has a sensitivity ratio of **Rs/Ro ≥ 5** in the presence of 2000 ppm of propane (C_3H_8), and it typically produces an output voltage between **2.5V and 4.0V** under these conditions (Flammable Gas Sensor).

iv. ESP8266 WiFi Module

This module is a self-contained system-on-chip (SoC) with a built-in TCP/IP protocol stack, making it easy to connect any microcontroller to a Wi-Fi network. It comes preloaded with AT command firmware for simple communication and control. The module operates within a frequency range of 2.4 to 2.5 GHz, supports a maximum input voltage of 3.6 V, and typically draws around 80 mA of current during operation (Espressif IOT Team, 2018).

v. Atmega328P Microcontroller

The ATmega328P is a low-power, 8-bit CMOS microcontroller based on the advanced AVR RISC architecture. It delivers up to 1 MIPS (Million Instructions Per Second) per MHz, allowing developers to balance processing speed with power efficiency. Operating at voltages between 1.8 V and 5.5 V, it supports clock speeds of up to 20 MHz within that range.

The AVR core features a powerful instruction set and 32 general-purpose working registers, all directly connected to the Arithmetic Logic Unit (ALU). This setup enables two independent registers to be accessed in a single instruction cycle, significantly improving execution speed and code efficiency. As a result, it outperforms traditional CISC microcontrollers by up to ten times in terms of processing speed (Atmel Corporation, 2009).

B. Implementation

The realization of this work was carried out in two stages, namely the hardware realization and the software realization.

i. Hardware Implementation

The hardware implementation consists of the interfacing of the various components such as the gas sensor, the thermistor, LCD, the ESP8266 module the buzzer, the bulk converter and the servomotor to the microcontroller. The block diagram is shown in Figure 1.

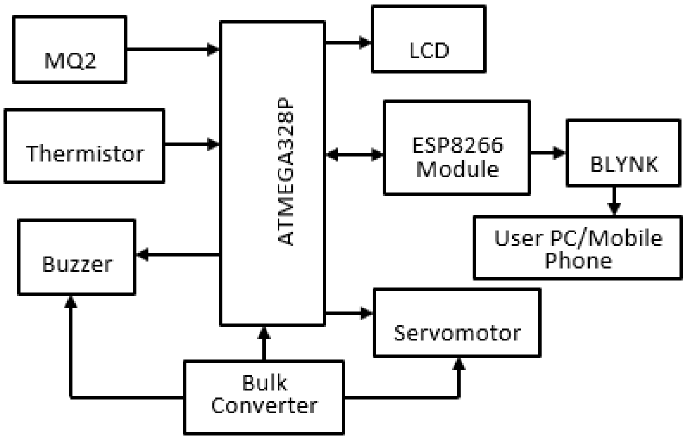

Figure 1. Block diagram

The hardware implementation started with design calculations that enabled the values of the various components to be determined. This was followed by the PCB production on which the system was implemented. The complete connection of the circuits is shown in Figure 2.

ii. Software Implementation

The ATmega328p microcontroller was programmed in C++ to be able to control the functionalities of the system and communicate with the various components interfaced with it. Thereafter the Blynk platform was setup to enable the visualization of the data received in the cloud.

C. Testing

After the successful implementation of the circuit, various tests were carried out on the system to ascertain its effectiveness and the maximum range of operation for different parameters.

Component test

Here, the actual voltage sourced as input to each of the components was measured and compared with the desired input voltage and the error was determined. Table 1 shows the result.

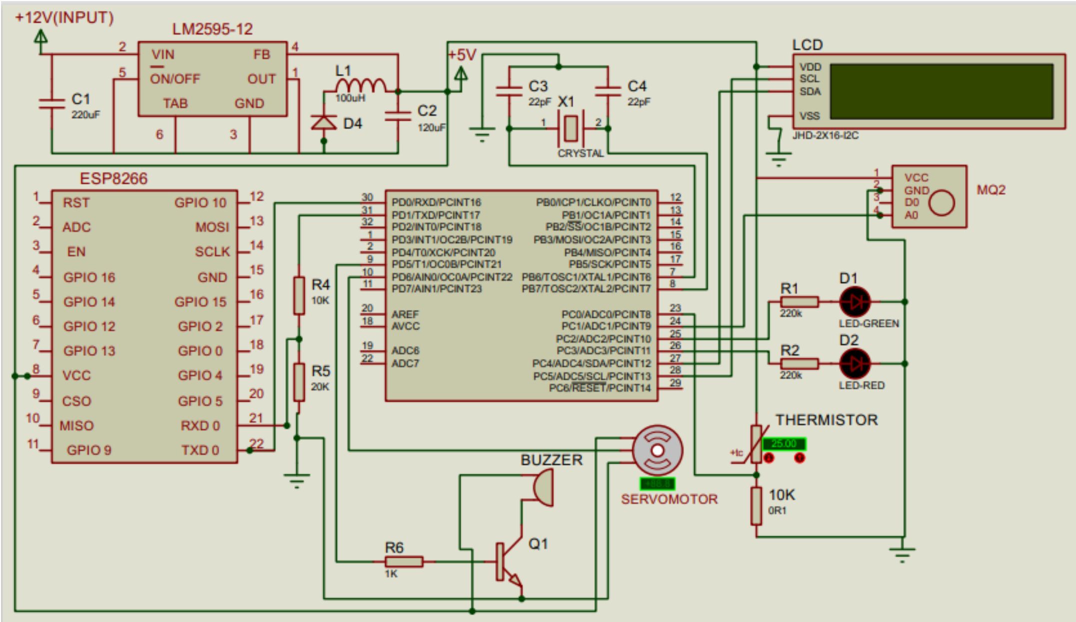

Figure 2. Circuit Diagram

Table 1: Components Results

Components	Voltage Input (V)		Error
	Desired	**Actual**	
Thermistor	5V	4.99V	0.01
Gas Sensor	5V	4.99V	0.01
Buzzer	12V	11.89	0.11
Servomotor	5V	4.99	0.01
LCD	5V	4.89	0.11
ESP8266	5V	4.99	0.01

Gas Sensor Performance test

Here, the gas was deliberately turned on and the prototype with the sensor was placed at a distance from the gas source, and the time it took from the start of the gas leak to the time it took for the system to detect it was recorded. This was carried out starting from 5cm and incremented by 5cm till 25cm. Each distance test was carried out four times, and the percentage of success was calculated. Table 2 shows the result of this test.

Table 2. Result for the response of the Gas sensor

Distance (cm)	Average Time Taken (sec)	Tests	Success Rate (%)
5.00	1.44	4	100
10.00	2.56	4	100
15.00	5.20	4	75
20.00	22.00	4	25
25.00	75.62	4	25

Thermistor and Temperature Response Test

This test was carried out by increasing the temperature of the environment at a distance from the thermistor (the temperature sensor), and the time it took for the sensor to detect the temperature increase was recorded. This test was carried out four times, each at 2cm, 4cm, and 6cm away from the sensor, and the percentage success was determined. The result is presented in Table 3.

Table 3. Result of thermistor response test

Distance (cm)	**Average Time Taken (sec)**	**Tests**	**Success Rate (%)**
2.00	3.30	4	100
4.00	10.24	4	75
6.00	66.5	4	50

D. Working Principle

The flowchart in Figure 3 shows the working principle of the system. At the start, the microcontroller initializes and connects to the ESP8266 WiFi module and other interfaces, such as those of the various sensors connected to its ports. It then reads and displays the values from the temperature and gas sensors. The system would check if the WiFi module has detected any hotspot connection for internet connectivity. Once a connection is made to the IoT server, it will display the sensor readings received by the microcontroller on the Blynk platform. The microcontroller will then check if the received values from the sensors exceed the threshold values. If the values are less, it keeps monitoring, but once it is more than the threshold preset, the servomotor is activated to close the gas supply; a buzzer is sounded to warn the people around of imminent danger and a WhatsApp message is sent from the IoT platform to alert the personnel responsible for possible action. This condition of monitoring will remain until the values read from the sensors are less than the preset threshold, and the servomotor will be turned off. Figure 4 shows the prototype.

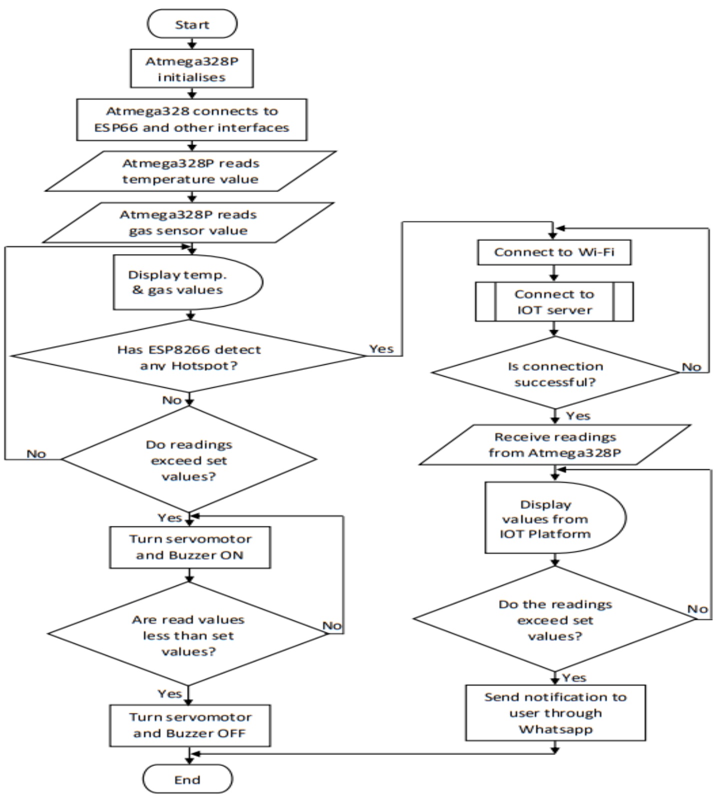

Figure 3. Flow Chart of the System

Figure 4. Prototype

RESULTS AND DISCUSSION

Table 2 shows the average time for the gas sensor to react to a gas leakage at a distance of 5cm to 25cm away from the sensor. The success rate of the sensor declines as the distance increases. The increase in the time for the detection of leakage as the distance increases from the sensors shows the behavior of gas movement under the various gas laws. This shows that the system is effective in the detection of a gas leak. Similarly in Table 3 shows the average time taken for the thermistor to react to a temperature change at a distance of 2cm to 6cm away from the sensor. The success rate of the sensor declines as the distance increases, as expected. In both tables, the success rate of each test is high, showing the efficiency of the prototype. These results and those of Table 1 show that the developed system has a good performance. However, the range of operations is somewhat limited, which can be improved by using higher precision components.

CONCLUSION

Detection of gas leakage in homes and industrial settings and prevention of fire outbreaks as a result of the leakage is a key measure of safety in most environments. The effect of gas leakage and fire is very costly. Hence, anything that helps to detect these early enough or prevent their occurrence is highly needed and worth pursuing. In line with the above, this work has undertaken the development of an IoT-based gas leakage detection, closure of the gas supply, and integration of a temperature monitoring system to be able to avert fire outbreaks. It also incorporates an online monitoring system of the various parameters and an alert system to notify people and personnel in the event of leakage detection. The tests carried out show that the system is effective and reliable in monitoring and detecting gas leakage and temperature, as the time for gas detection ranges from 1.44s to 75.66s. With this, the objective of this work has largely been achieved, and it is therefore recommended that it should be adapted for use by all stakeholders in the gas industry.

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