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IoT-based system to detect and control natural gas leaks in residential kitchens

Max Jhonatan Pillco-Sanchez, Alex Antonio Huatuco-Villanueva, Jhony Miguel Sanchez-Ramirez, Maritza Cabana-Cáceres, Cristian Castro-Vargas
Facultad de Ingeniería, Universidad Privada del Norte, Lima, Perú

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ABSTRACT

Natural gas is widely used in many homes for cooking, but a lack of gas leak detection has led to large fires and accidents. This article presents the design and implementation of a natural gas detection and extraction system for domestic kitchens in Lima, Peru. The ESP32 microcontroller allowed remote circuit control, resulting in a more convenient setup than the Arduino UNO microcontroller. After calibration of the sensors and their corresponding programming, three actions were established in response to different gas levels: alarm activation, space ventilation and gas extraction, and thermal shutdown. Strategic sensor placement and improved physical presentation of the system were performed to ensure accurate readings and effective deployment. The results demonstrate the proper functioning of the circuit and its ability to prevent accidents related to gas leaks. The designed system offers the advantage of remote monitoring, providing access to the user from any location. In conclusion, this project offers a comprehensive solution to prevent accidents caused by gas leaks in home kitchens. With satisfactory results in terms of operation and rapid response, the project demonstrates its effectiveness in accident prevention. This design offers a practical and accessible solution, improving security and bringing peace of mind to homes.

Corresponding Author:

Cristian Castro-Vargas
Facultad de Ingeniería, Universidad Privada del Norte
Av. Tingo Maria Nro.1122, Breña 15083, Lima, Perú
Email: cristian.castro@upn.pe

1. INTRODUCTION

Natural gas is widely used as a fuel [1] in cooking appliances in homes worldwide [2]. However, inadequate systems for detecting gas leaks have caused numerous domestic accidents, including explosions and large fires [3]–[5]. Epidemiological studies in United States estimate that up to 12,7% of childhood asthma cases could have been prevented by avoiding exposure to natural gas from leaks in the home [6]–[8]. In Latin America, catastrophic events have been reported due to gas leaks, such as the explosion of a building and the multiple accidents recorded in Lima, Peru, where the most significant number of daily reports on this problem are concentrated [9]–[12].

Prolonged exposure to natural gas due to leaks poses serious health risks [13]. When inhaled, the gas enters the lungs, displacing oxygen and affecting the home's structure [14]. Previous research has explored alternatives for detecting LP gas and natural gas leaks in domestic environments using platforms such as Arduino and Raspberry Pi, along with MQ-type gas sensors [15]–[17]. However, these works focus mainly on detection without implementing mitigating actions in case of a leak. They also do not explore the possibility of remote monitoring, limiting user access to the system only when physically on site.

This article describes the design and implementation of a natural gas detection and extraction system for kitchens in homes in Lima, Peru. By using the ESP32 microcontroller with integrated Wi-Fi, remote control of the circuit was achieved, resulting in a more practical and convenient setup compared to the Arduino UNO microcontroller. After calibration of the sensors and corresponding programming, three specific actions were established that are automatically activated at different detected levels of gas concentration: audible alarm, ventilation/extraction of the space, and closing of the thermal tap. Additionally, strategic placement of sensors and improvements to the physical presentation of the system were made to ensure accurate readings of gas levels and practical implementation in kitchens.

The results demonstrate the implemented circuit's correct functioning and its ability to prevent accidents caused by natural gas leaks. The main advantage of the proposed system is the incorporation of remote monitoring, providing access to the user from any location through a mobile application. In conclusion, this research project offers a comprehensive solution to improve domestic security, preventing accidents caused by gas leaks in kitchens through early detection, activation of alarms, gas extraction, and isolation of the electrical supply. The satisfactory results in terms of operation and rapid response to emergencies demonstrate the effectiveness of this design as a practical and accessible alternative for homes. Looking to the future, this work lays the foundations for developing more advanced systems incorporating new technologies, such as artificial intelligence, for analyzing sensor data and automating responses. In addition, it allows for exploring its implementation in other critical environments such as laboratories, hospitals, and industries.

2. LITERARY REVIEW

Jumaa *et al.* [18] addresses the need for a comprehensive system to manage gas leaks in industrial environments. The objective is to develop an efficient detection and alert system using IoT and Blynk platforms: the NodeMCU ESP8266 Wi-Fi microcontroller and the MQ2 gas sensor monitor methane and carbon monoxide. The results demonstrate the system's effectiveness by activating a fan and audible alarm in cases of leaks, highlighting its preventive relevance in industrial environments prone to these risks. This background contributes to understanding technological solutions for managing risks associated with dangerous gases.

The research project [19] represents an essential background in the literary review, focusing on implementing a gas detection system using the ESP32 microcontroller and a fire alarm system. Its main objective is to address the need for an effective solution for the early detection of dangerous gases, thus contributing to safety and incident prevention. The outcomes showcase the system's effective deployment, highlighting the accuracy of gas detection by the ESP32 and its ability to activate an alarm. This background highlights the relevance of technological solutions to improve safety in environments prone to risks from dangerous gases.

The study by Sisinni *et al.* [20] successfully implemented an IoT system with ESP32 and the MQ-2 sensor for gas detection in Italian homes, achieving efficient remote leak monitoring using an application. Their approach addressed the need for more connected solutions for gas leak detection in home environments. The results highlighted the system's effectiveness in inaccurate leak detection and remote monitoring via the app, supporting the importance of comprehensively connected solutions for proactive risk management in homes prone to gas leaks. This background guides this project towards comprehensive mitigation measures beyond early warning.

3. METHOD

The block diagram of the circuit is divided into 5 phases. As shown in Figure 1, we will start by identifying the work area where the project is to be implemented; for the second section, we will develop the circuit design; in the third part, thanks to the design, we will identify and classify the materials to be implemented. Then, in the fourth section, we will conduct the programming, concluding with the respective tests.

3.1. Identification of the work area

The system was implemented in Lima, Peru, urban areas because this city concentrates the most significant number of reports on gas leaks in the entire country [21]. This decision was made after extensive data analysis that revealed the high incidence of incidents related to gas leaks in this region. Districts with high percentages of vulnerable middle-class populations were carefully selected as target users of the proposed system, as shown in Table 1. This choice was based on prioritizing the protection of groups most susceptible to the risks associated with leaks. Gas, thus guaranteeing a quick and effective response to any emergency that may arise in these urban communities.

3.2. Materials selection

For this project, we use the ESP32 microcontroller [22], a series of energy-efficient and cost-effective SoC chips that feature certified dual Wi-Fi and Bluetooth technology, offering wireless connectivity and an integrated processor with interfaces for connecting peripherals. Thus allowing us to operate the system remotely. We can see its main features in Table 2. Also, could you visit its physical system in Figure 2.

Figure 1. Block diagram of system creation

Table 1. Urban areas districts of Lima

Urbanized Districts of Lima (Population and % of the district's middle class)		
	Vulnerable middle class	% of the district's middle class
San Martín de Porres	248.946	45.1%
San Juan de Lurigancho	163.242	47.4%
Comas	138.388	49.0%
Ate	92.980	42.4%
Los Olivos	88.796	34.3%
Lima-Cercado	83.727	39.9%
Villa María del Triunfo	79.745	49.9%
Santa Anita	79.631	44.0%
La Victoria	74.063	43.9%
San Juan de Miraflores	72.624	39.9%

Table 2. ESP32 features

Microcontroller	ESP32
Voltage	3.3V – 5V
Channels A/D	18 A/D
Flash memory	High gas level
RAM	520Kb

Figure 2. ESP32

In addition to the microcontroller, we must have a sensor; we opted for the MQ5 sensor [23]; it is an electrochemical sensor that changes its resistance when in contact with Liquefied Petroleum Gas (LPG) and natural gas, being a little sensitive to gases such as natural gas, butane, alcohol vapor, and smoke, the detection range and most important characteristics are observed in Table 3. The physical sensor is shown in Figure 3. It has two outputs, one analog and one digital.

Table 3. MQ5 sensor features

Gas sensor	MQ5
Voltage	5V
Operating current	160mA
Detection range	200ppm a 10000ppm

Figure 3. MQ5 module

Since we will have both a digital and a power part in our system, we decided to use the MOC3041 [24]; this is a 6-pin DIP encapsulated device that functions as an output optocoupler using a zero-crossing triac. This component includes an infrared emitting diode optically coupled to a bilateral triac. We can observe its main characteristics in Table 4. Also, see its physical system in Figure 4.

Table 4. MQ5 sensor features

Optocoupler	MOC 3041
Voltage	1.5 V
Operating current	15 mA
Operating temperature	-40 °C ~ 80 °C

Figure 4. MOC 3041

To connect the optocoupler and the power part of the circuit, we use the BT16-600B [25], a conventional Triac suitable for switching the AC mains supply in general-purpose applications. It can be used as a simple on/off switch and for controlling the phase angle in devices such as static relays, light dimmers, and motor speed controllers. We can observe its main characteristics in Table 5. Also, see its physical system in Figure 5.

Table 5. Triac BTA16-600B features

Triac	BTA16-600B
Trigger voltage	1.3V
Current RMS (max.)	16A
Activation current	50mA

Figure 5. Triac BTA16-600B

3.3. Circuit design

It identified the stages of the circuit through which it will pass from its input with the gas sensor to its output with the actions to be executed. To begin with, a data collection stage is needed, which will be provided by the sensor, and then a data processing stage will be required to understand the information sent and thus take actions that will be carried out in the execution stage. From Figure 6, it can be seen that a gas sensor that can measure the natural gas at the moment of the leak in the kitchen will be used to obtain data; the signals produced by this sensor will be sent to the ESP32 processor, which programming will be incorporated based on the concentration levels of the gas detected. Depending on the level of gas, the output of the circuit will be activated; if the gas level is low, a sound alarm will be activated; if the story is medium, a fan and extractor fan will be activated; if the class is high, the thermal tap will be closed avoiding the release of an electric spark that would cause a fire. As for the simulation of the circuit, we can see it in Figure 7. The printed circuit board (PCB) schematic is in Figure 8, and the 3D simulated course is in Figure 9.

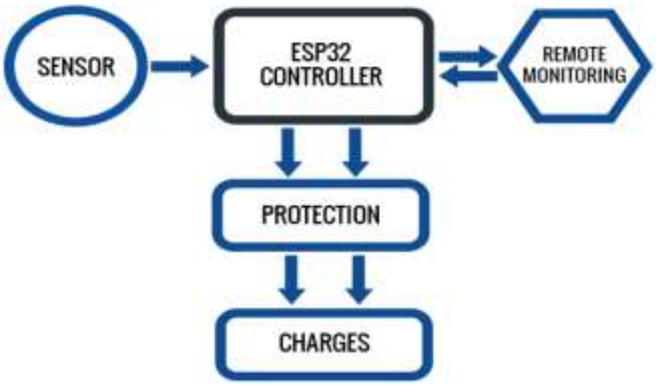

Figure 6. Block diagram of system operation

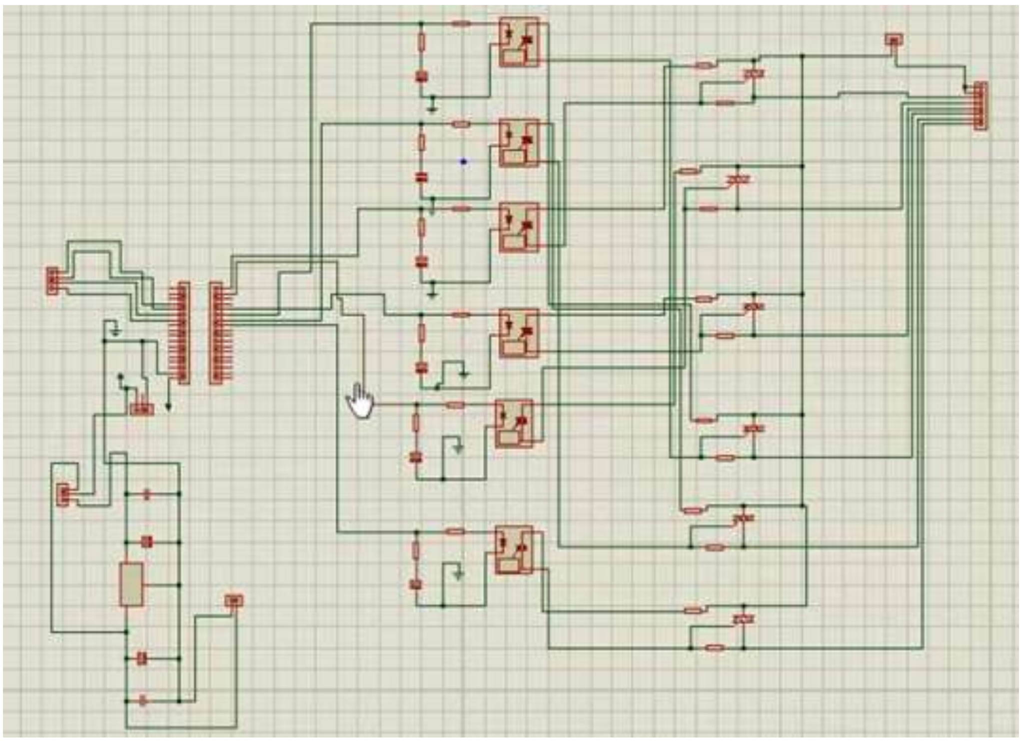

Figure 7. Circuit design in Proteus

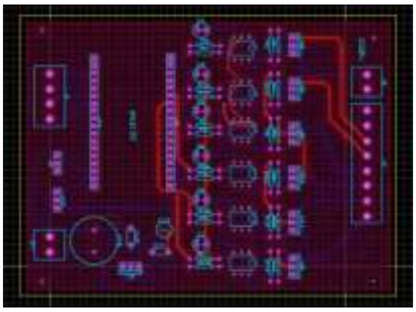

Figure 8. Circuit diagram for PCB board fabrication

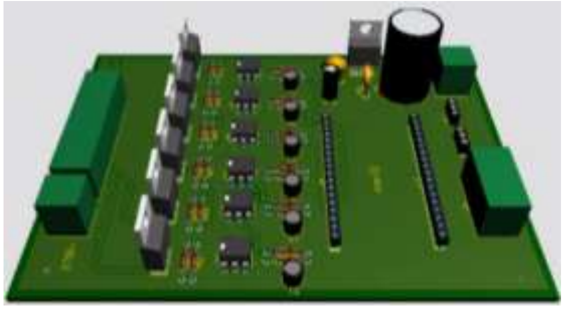

Figure 9. 3D simulated circuit for PCB fabrication

3.4. Algorithm Development and Programming

Figure 10 specifies and summarizes the order of each programming process, from the detection stage to the actuators. Passing through the three detection levels and their specific actions. The Arduino IDE is the software we use for programming the ESP32, as shown in Figure 11. We downloaded the microcontroller driver and the ESP32 board module in the IDE to start programming. Once these two steps are done, we must choose the card for the software to recognize the board, the ESP32 DEV Module.

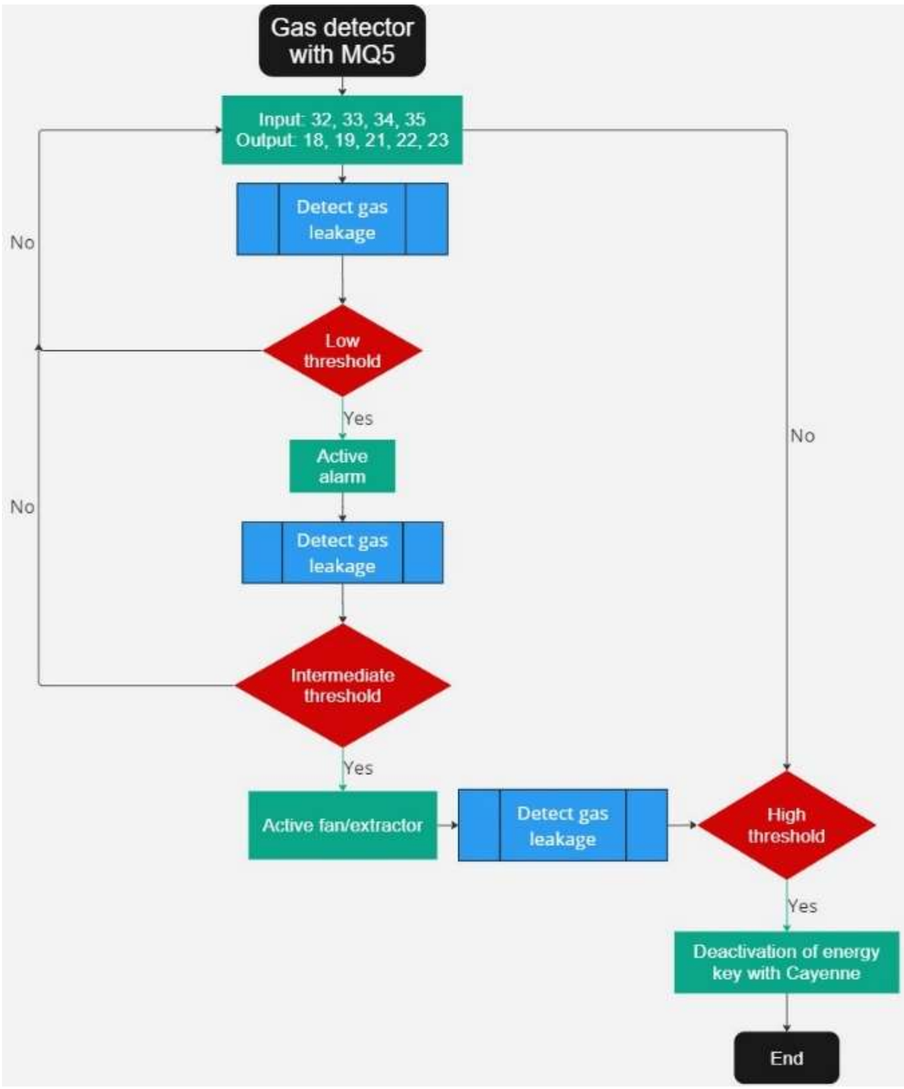

Figure 10. Block diagram of system operation

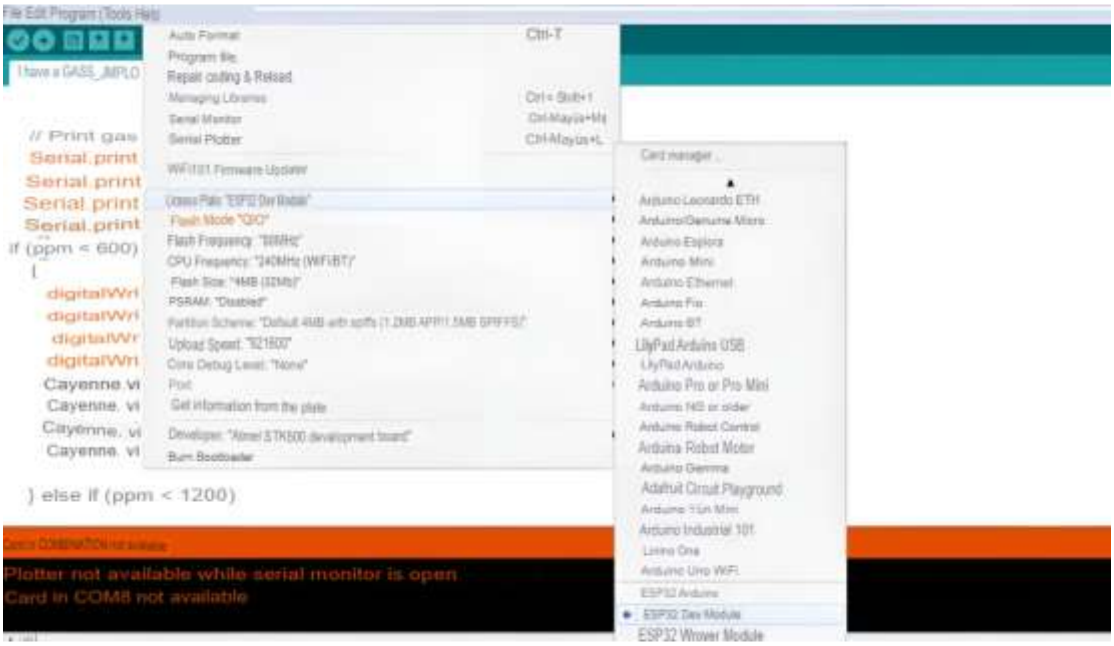

Figure 11. Selecting the ESP32DEV module board in the Arduino IDE

After connecting the ESP32 to the software to start with the programming, we use the Cayenne portal; in this portal, we can create a small server on the internet to monitor the system and integrate action buttons for remote use. To connect to the Cayenne portal, we must create an account with the requested data, as shown in Figure 12. Once registered, we have to make our server, which has data that we will use to connect the server with our programming so we can visualize the data taken by the system in the Cayenne portal.

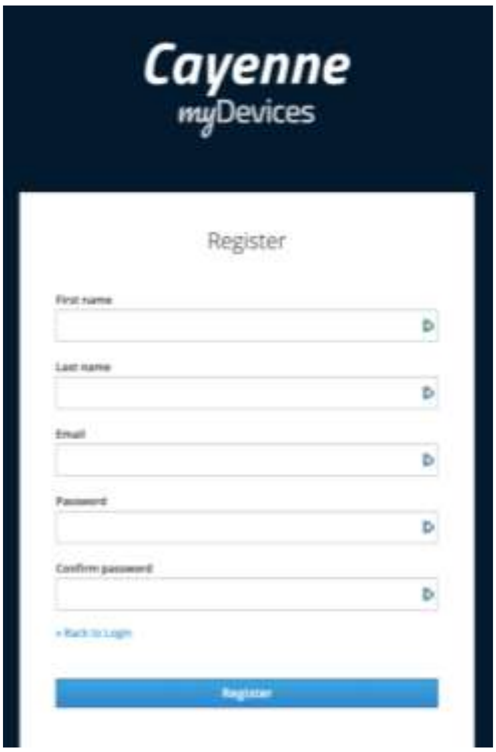

Figure 12. Cayenne portal account registration

As shown in Figure 13, the data we will use will be the MQTT username, password, and client ID. Once these data have been copied, we must also copy the name of the WiFi network to which we will connect and the password of this network. Once we have declared the connection data in the programming, we assign the pin of the sensor in the microcontroller; in our case, it will be given to pin 34. As shown in Figure 14, we already have the server created, and we can add different actuators, and monitoring graphs.

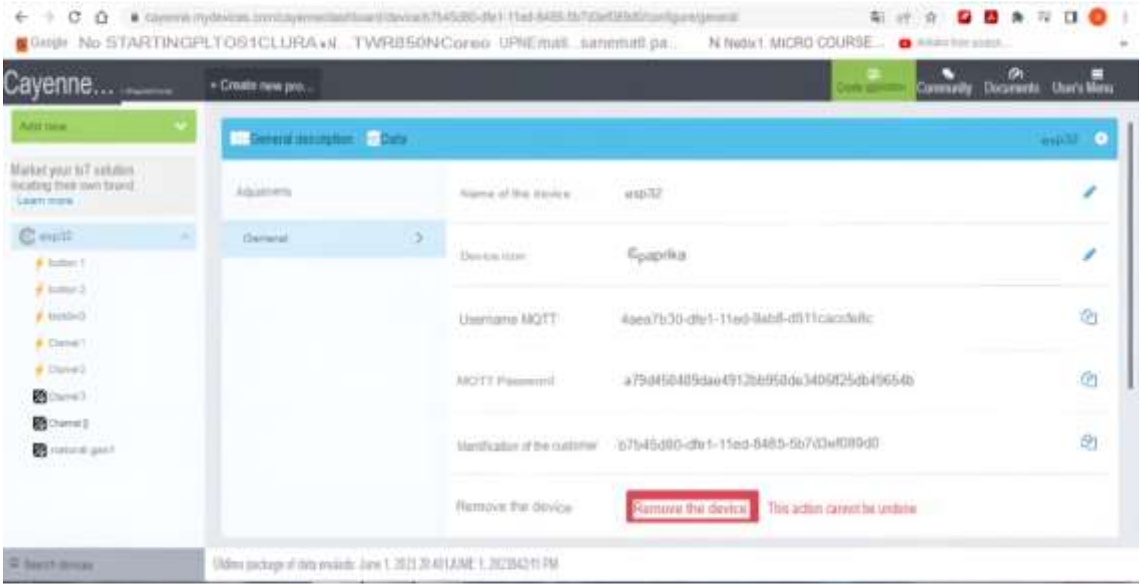

Figure 13. Creation of the server in the Cayenne portal

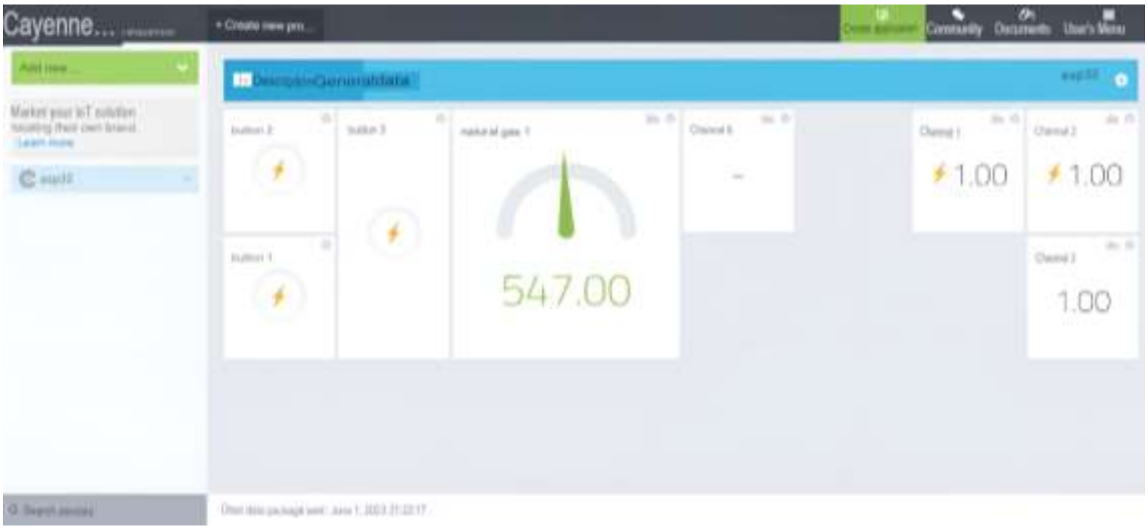

Figure 14. Server for remote control of the system

We define the input and output values, as shown in Figure 15, which will perform these actions according to the system flowchart. Next, we place the data obtained when creating the server in Cayenne, including the Wi-Fi ID and its password. In this case, we define the outputs that will be our LEDs, as for the ESP32 outputs will be pins 5,2,4 and 18, as shown in Figure 16. In addition, we place values for closing the thermal tap that feeds the kitchen area in case gas leakage is detected. In this part of the programming, we will connect the gas reading of the sensor to define its parameters in ppm (particles per million), as shown in Figure 17. In addition; we represent the sensor reading on the Cayenne server with the virtual pins, which will alert the user in case of a leak. Continuing in Figure 18, we define the action of each actuator, from activating an alarm to turning on the fan and exhaust fan. All this considers that each actuator is executed according to the detected gas level.

```
#include <CayenneMQTTESP32.h>
#include <MQUnifiedsensor.h>
#define LED_PIN_1 23
#define LED_PIN_2 22
#define LED_PIN_3 21
#define LED_PIN_4 19
#define VIRTUAL_PIN_1 V1
#define VIRTUAL_PIN_2 V2
#define VIRTUAL_PIN_3 V3
#define VIRTUAL_PIN_4 V4
#define VIRTUAL_PIN_1_1 V5
#define VIRTUAL_PIN_1_2 V6
//////// cayenne connection
char ssid[] = "ALEXNET";
char wifiPassword[] = "mercu.22";
```

Figure 15. Variable declaration and Cayenne configuration

```

void loop() {
Cayenne.loop();
/////gas reading
  float gasValue = analogRead(pinMQ5); // Reads the analog value of the MQ-5 sensor
      float ppm = map(gasValue, 0,1023, 0, 255);
  Serial.print("Gas value: ");
  Serial.println(gasValue);
    Serial.print(" , ppm: ");
  Serial.println(ppm);
    float gasValue1 = analogRead(pinMQ51);  // Reads the analog value of the MQ-5 sensor
      float ppm1 = map(gasValue1, 0, 1023, 0, 255);
  Serial.print("Gas value1: ");
  Serial.println(gasValue1);
    Serial.print(" , ppm1: ");
```

Figure 16. Declaration of circuit inputs and outputs

```
void setup() {
  Serial.begin(115200);
  Cayenne.begin(username, password, clientID, ssid, wifiPassword);
  pinMode(LED_PIN_1, OUTPUT);
  pinMode(LED_PIN_2, OUTPUT);
  pinMode(LED_PIN_3, OUTPUT);
  pinMode(LED_PIN_4, OUTPUT);
  pinMode(5, OUTPUT);
  pinMode(2, OUTPUT);
  pinMode(4, OUTPUT);
  pinMode(18, OUTPUT);
```

Figure 17. Sensor reading and connection to Cayenne

```
if (gasValue > 800)
 {
  digitalWrite(LED_PIN_1, 1); // Pin 21 activates an alarm


 }
 else {

  digitalWrite(LED_PIN_1, 0); // Pin 21 activates an alarm


   Cayenne.virtualWrite(8, "Alert! High gas level"); // Send the text to Cayenne.
  }

 if (gasValue > 1600)
  {

   digitalWrite(LED_PIN_2, 1); // Pin 22 disable fan
    digitalWrite(LED_PIN_3, 1); // Pin 22 disable extractor

  }

 else {

  digitalWrite(LED_PIN_2, 0); // Pin 22 disable fan
   digitalWrite(LED_PIN_3, 0); // Pin 22 disable extractor
```

Figure 18. Definition of Cayenne system actuators

For the final stage of programming, we finish with the last actuator, which is to close the thermal tap in the kitchen area. This action can be done in case a high gas level is detected. In addition to being able to complete the faucet remotely from the Cayenne server, as shown in Figure 19.

```
 CAYENNE_IN(6)
{
 /////// power key control from Cayenne
  int valor_canal_6=getValue.asInt();
  digitalWrite(2, valor_canal_6); // to get the value from the website
  digitalWrite(5, valor_canal_6); // to get the value from the website

}
```

Figure 19. Remote control of the kitchen thermal key locking system

4. RESULTS AND DISCUSSION

The results of this research were obtained through a systematic process that included the design and implementation of a functional prototype, as well as rigorous testing and comparative analysis. The primary purpose was to create a reliable and efficient electronic system for detecting and extracting natural gas in domestic kitchens to prevent accidents caused by gas leaks. To achieve this goal, it was necessary to carefully research and select electronic components, calibrate sensors, thoroughly test system operation, and improve aspects such as physical presentation and remote monitoring capabilities. The results can be grouped into the following subsections, which describe the research process in detail:

4.1. ESP32 microcontroller selection

Initially, it was considered to use the Arduino UNO microcontroller, one of the most accessible and easy-to-find components on the market. However, after carefully evaluating the circuit design and system needs, it was determined that remote control capabilities were essential. For this reason, the decision was made to use the ESP32 microcontroller. The ESP32 is an energy-efficient system-on-a-chip (SoC) that integrates certified dual-band Wi-Fi and Bluetooth wireless technologies. This unique feature allows for wireless connectivity and an integrated processor with interfaces for connecting peripherals. Thanks to its built-in Wi-Fi module, the ESP32 would enable us to operate the system remotely, which would be a significant advantage over the Arduino UNO. Despite the technical advantages of the ESP32, we faced a significant challenge during the initial configuration. It was necessary to install the specific driver for this microcontroller and add the corresponding libraries in the Arduino integrated development environment (IDE). These steps required the ESP32 to have been recognized and functioned correctly with the programming software.

4.2. MQ5 sensor calibration

Once the hurdle of microcontroller configuration was overcome, a rigorous process of calibrating the MQ5 gas sensor began. This electrochemical sensor changes its resistance upon contact with liquefied petroleum gas (LPG) and natural gas. Although it is slightly sensitive to other gases, such as alcohol vapor and smoke, its primary function is to detect combustible gases, such as natural gas and butane. Calibration was essential to stabilize the sensor's detection ranges and ensure that the programming correctly evaluated these ranges to execute the corresponding actions. As shown in Figure 20, several tests and adjustments were performed to optimize the accuracy of the sensor readings.

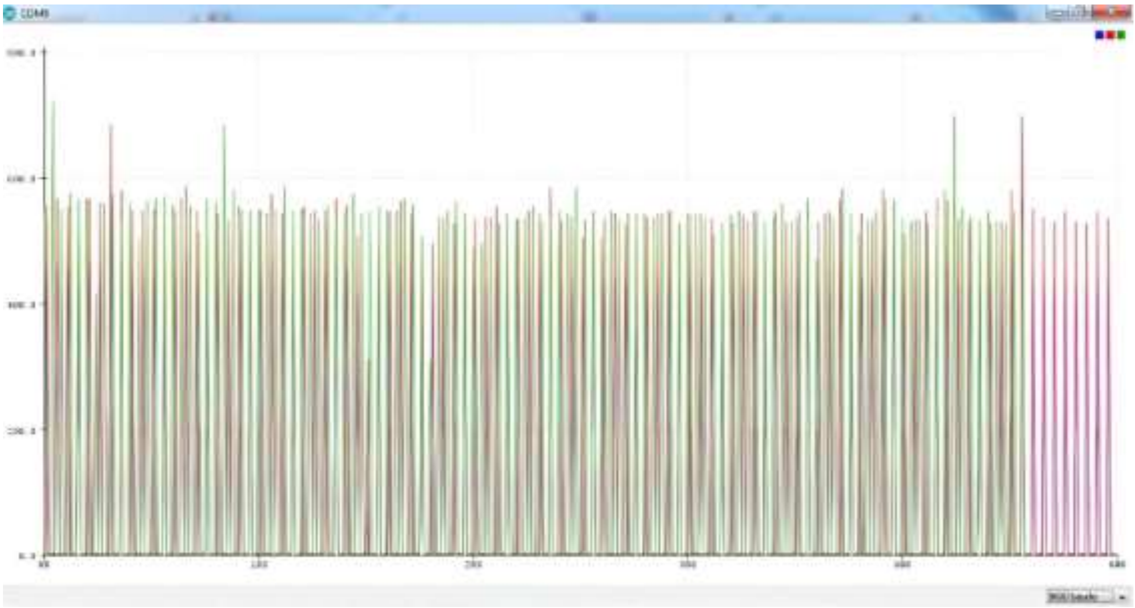

Figure 20. Calibration of the MQ5 sensor

4.3. Optimal sensor positioning

Experimental tests were carried out by systematically varying the height, distance, and placement angle concerning the stove burner to identify the ideal gas position sensor within the kitchen. The tests consisted of simulating controlled gas leaks and measuring the speed and accuracy of detection in different sensor positions. The best location was placing the sensor vertically at a height of 47 cm from The surface of the land, at a separation of 50 centimeters on the side of the burner, with an angle of 0° concerning the axis of the burner. In this position, the MQ5 sensor demonstrated maximum speed and reliability in detecting gas concentrations similar to those in the case of a leak in the kitchen pipe. The response time was optimal, and no false positives or negatives were obtained during the tests. Therefore, based on controlled experiments under conditions similar to the actual use environment, it was concluded that the best location to ensure accurate sensor readings was vertical at 47 cm and 50 cm from the burner with an angle of 0°. This optimal position, determined experimentally, was implemented in the system's final prototype. Based on these recommendations, the sensor's location inside a stove was simulated, as seen in Figure 21. In this way, it was ensured that the values measured by the sensor would be adequately evaluated to determine the subsequent action and execute the methods raised in the system's design.

Figure 21. Physical simulation of the sensor inside a stove

4.4. Detection thresholds

After exhaustive calibration and analysis of the values measured by the MQ5 sensor, the gas detection thresholds that would guide the system's actions were defined. These thresholds, expressed in parts per million (ppm), are shown in Table 6. These ranges were programmed in the ESP32 microcontroller to execute the corresponding action upon detecting a gas concentration within each threshold: alarm activation at a low level, fan, and extractor switching on at a medium level, and thermal tap closing at a high level of gas detected.

Table 6. Defined thresholds of gas measured with the sensor

Measured gas value in ppm	Measured gas level
800 – 1600	Low gas level
1600 – 2200	Average gas level
3000 – 4000	High gas level

4.5. Improvement of the physical presentation of the circuit

Once the circuit was printed on a printed circuit board (PCB) and the necessary electronic components were soldered as shown in Figure 22, functional tests were carried out to validate the correct assembly and programming of the system. However, the need to improve the physical presentation of the circuit was identified to facilitate its implementation and use in a real kitchen. To achieve this, the individual elements were separated. Each gas sensor was placed in a unique box awaiting strategic placement in the kitchen, while the main circuitry and reference keys for the actuators were housed in separate containers.

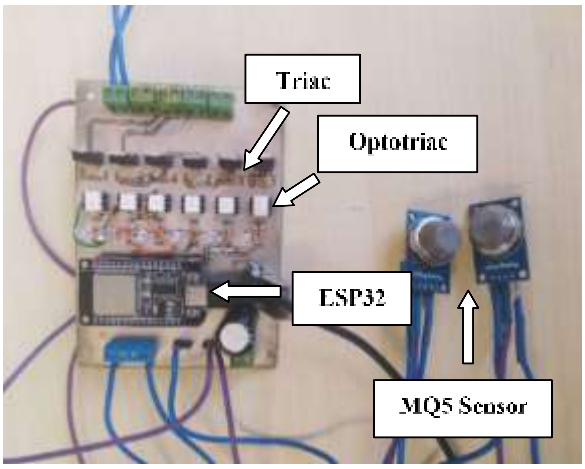

Figure 22. Physical circuit

Additionally, resistor-capacitor (RC) circuit filters were added to attenuate any interference or electrical noise that could affect the system's signals and readings. These filters can be seen in Figure 23. To control the actuators safely and efficiently, individual electrical contactors were installed for each one, as shown in Figure 24. Finally, with all these improvements implemented, the system was finished and ready for installation, as seen in Figure 25.

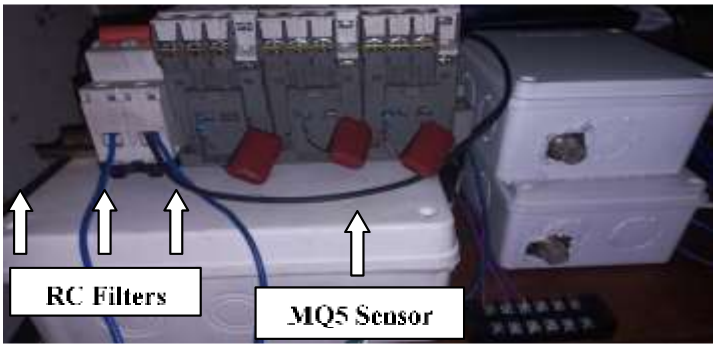

Figure 23. Physical system, side view

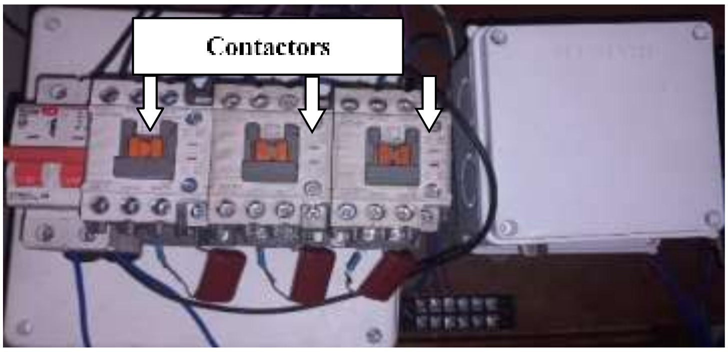

Figure 24. Physical system, top view

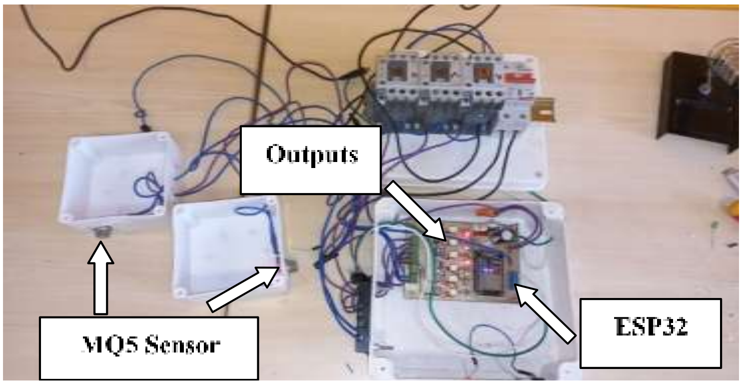

Figure 25. Physical system, internal view

4.6. Installation and testing in a real kitchen

With the physical presentation of the system improved it was installed in a real kitchen to evaluate its performance in a real-use environment. As shown in Figure 26, the gas sensor was strategically placed near the gas supply tap, as this is one of the critical points where most gas leak accidents occur in domestic kitchens. Once the complete system was installed, the final tests and fine calibrations were carried out to ensure its correct operation. In Figure 27, you can see the Cayenne portal open and ready to remotely control the closing of the thermal key in case of an emergency. To validate the detection capacity of the system, a controlled test was carried out in which the gas supply valve was partially opened. As shown in Figure 28, the installed sensors responded adequately and detected the presence of gas in the environment, demonstrating their ability to identify real leaks.

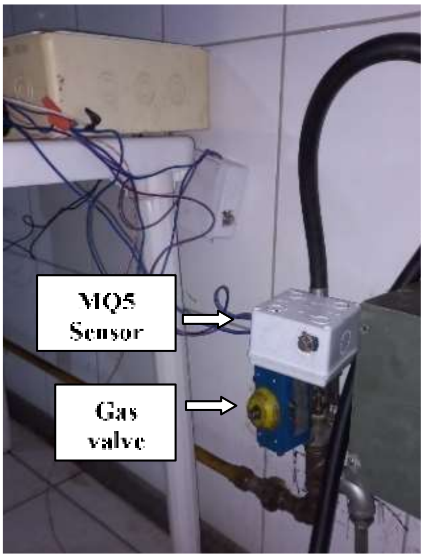

Figure 26. Physical system implemented with sensor at gas tap

Figure 27. Physical system implemented with sensor at gas tap

Figure 28. Physical system implemented gas detection test

4.7. Remote monitoring and data logging

This allows the user to access system information from any location with an Internet connection. The real-time reading of both gas sensors on the Cayenne server was verified to verify this functionality. In addition, the correct operation of the actuator button that controls the closing of the stove's thermal lid in case a high gas level is detected was tested.

Figures 29 and 30 show real-time sensor readings, capturing intermediate and high gas levels, respectively. This data is transmitted wirelessly to the Cayenne server and can be viewed by the user at any time. Additionally, the system records a history of sensor readings, allowing the user to analyze trends and patterns in gas detection over time. An example of this record is shown in Figure 31, where the variations in the gas levels measured during a specific period can be observed.

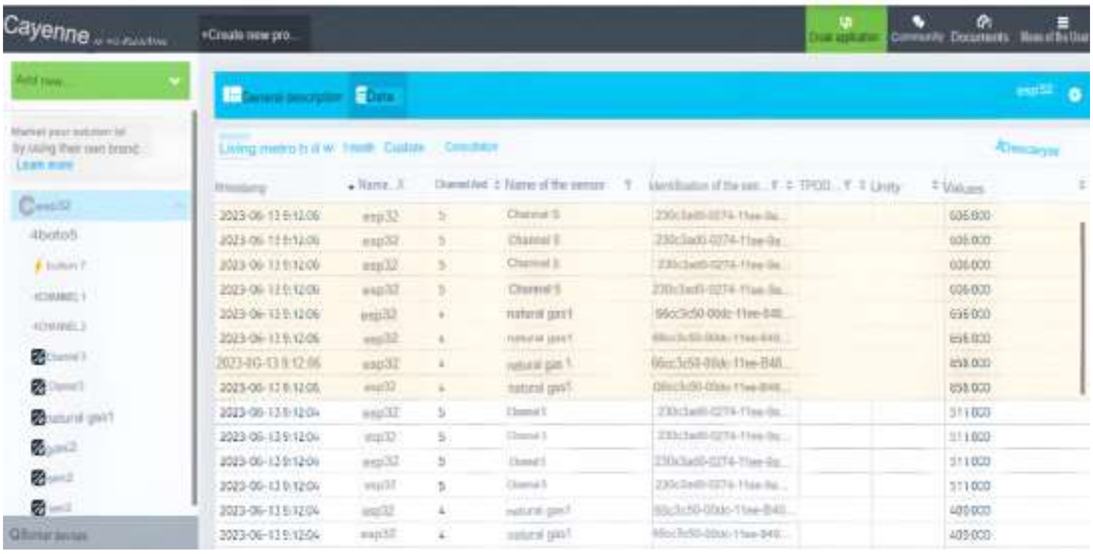

Figure 29. Real-time sensor readings at intermediate gas level

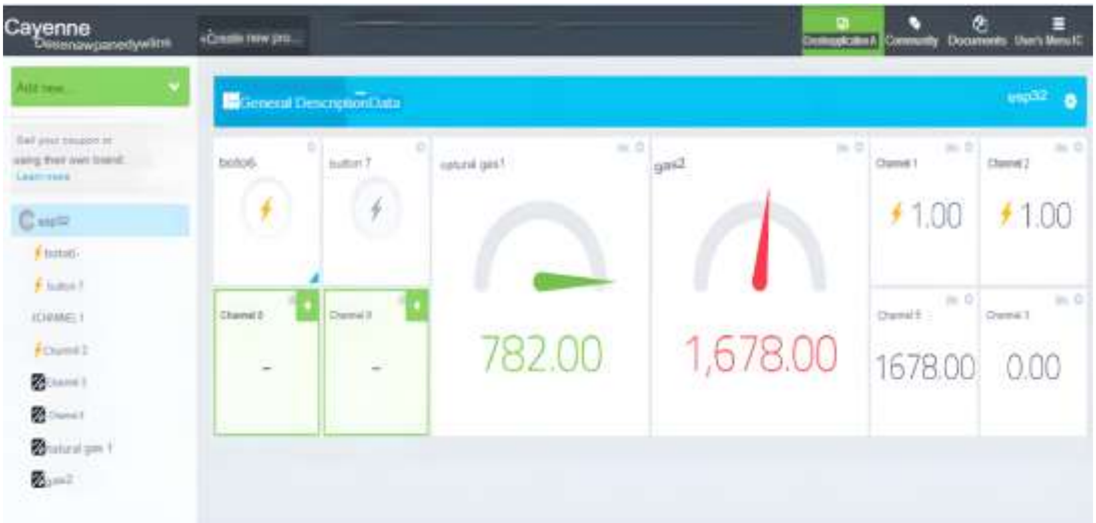

Figure 30. Real-time sensor readings at high gas level

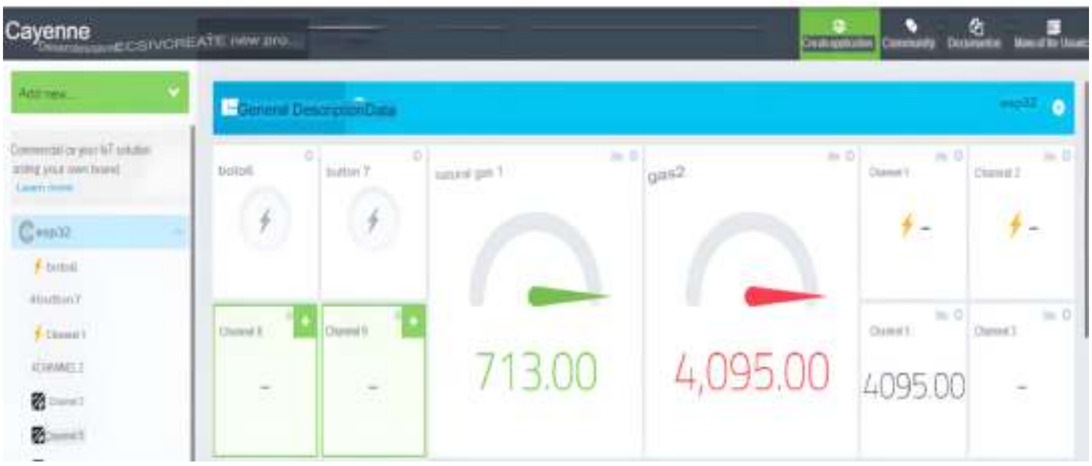

Figure 31. Recording the sensor reading in real time

4.8. Comparison with previous research

While research such as [18] addressed the need for comprehensive systems in industrial environments using IoT and platforms like Blynk to activate alarms and fans, this project focuses on the domestic environment, with specific solutions for home kitchens. Other studies, such as [19], have explored ESP32-based gas detection systems and fire alarms. Although they highlight detection accuracy and alarm activation, they do not incorporate gas extraction or additional risk mitigation measures.

More recent research, such as that of Sisinni *et al.* [20], come closer to the comprehensive approach of this project, implementing IoT systems with ESP32 and MQ sensors to detect and monitor domestic gas leaks using mobile applications. However, these systems still need to execute automatic actions beyond alerts. Faced with these limitations, the system developed in this project not only detects gas leaks accurately using the MQ5 sensor and the ESP32 microcontroller but also autonomously activates alarms, gas extraction, and shutting off the supply in case of low dangerous levels. This enables a more comprehensive mitigation of associated risks.

Additionally, unlike Arduino-based solutions, the greater processing power of the ESP32 (240MHz vs. 16MHz of the Arduino UNO) translates into faster response time in emergencies. Its integrated WiFi connectivity also allows for more advanced monitoring and remote control functions through the Cayenne server, which is unattainable with local systems limited to basic alarms. In conclusion, compared to the reviewed background, this project represents a more comprehensive, faster, and connected home automation solution for detecting, extracting, and automatically controlling natural gas leaks based on the ESP32 microcontroller, the MQ5 sensor, and remotely controlled actuators. These advanced capabilities increase the security of users against these types of risks at home.

5. CONCLUSION

The main objective of this research project was to design and implement an electronic system for detecting and extracting natural gas in domestic kitchens, seeking to prevent accidents caused by gas leaks. As stated in the Introduction, the widespread use of natural gas in homes entails significant risks of fires and explosions in the event of leaks. Considering the high incidence of these domestic accidents in cities like Lima, it was proposed that a system of sensors, alarms, and actuators be developed to detect abnormal gas concentrations and respond automatically to mitigate the risks.

The Results and Discussion demonstrate that this objective was satisfactorily met through the design and implementation of a functional prototype. The ESP32 microcontroller was carefully selected for its WiFi connectivity, superior processing power, and ability to integrate the system with remote servers. The MQ5 sensor calibration process ensured accurate and reliable readings of gas concentrations.

The complete system comprises sensors, alarms, ventilation, supply shut-off, and remote monitoring and represents an advanced home automation solution that goes beyond simple leak detection. Automate responses to actively mitigate risks, providing greater security to users. Compared to previous research focused solely on gas detection, this project implements a comprehensive contingency system, taking advantage of the capabilities of the ESP32 microcontroller. Remote monitoring and control through Cayenne also constitutes added value for users' peace of mind.

As for future lines of research, integration with virtual assistants and intelligent alarm systems could be explored to activate automated responses to detected leaks, even with users outside the home. The use of machine learning algorithms to see patterns and predict pipeline failures could also be investigated. In conclusion, this project culminates with a functional and reliable system that meets the initial objective of improving safety against domestic gas leaks. The results obtained, and future perspectives provide concrete contributions to advance this problem and save lives through applied technological solutions.

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BIOGRAPHIES OF AUTHORS

Max Jhonatan Pillco-Sanchez is a student of electronic engineering. He is currently in the ninth cycle of electronic engineering at Universidad Privada del Norte, focusing on industrial automation research. He can be contacted by e-mail: n00179451@upn.pe.

Alex Antonio Huatuco-Villanueva is a graduate of industrial electronics with eight years of experience. He is studying the ninth electronic engineering degree cycle at the Universidad Privada del Norte. He worked as an industrial electronics officer in various companies that needed to improve their processes. He can be contacted at email: n00176008@upn.pe.

Prof. Ing. Jhony Miguel Sanchez-Ramirez is an electronic engineer who graduated from the Universidad Tecnologica del Peru, specializing in programming and development of microcontroller systems; they also work as supervisor of electronic engineering laboratories, networks, and automation in the engineering program of the Universidad Privada del Norte as professor of industrial electronics at the Instituto Superior Metropolitano Lima-Perú. He can be contacted at email: jhony.sanchez@upn.edu.pe.

Prof. Dra. Maritza Cabana-Cáceres Holds a doctorate in education, a master's degree in university teaching, and a diploma in electronics engineering (UNAC). She has experience as a university president, electronics engineering coordinator, and teacher-researcher and has published in indexed journals. Experience as a Consultant in research, thesis, electronic projects, artificial intelligence, automation, and telecommunications. She can be contacted at email: maritza.cabana@upn.pe.

Prof. Dr. Cristian Castro-Vargas is an electronics engineer and a National University of Callao graduate. He holds a doctorate in education and a master's in university teaching. He has extensive experience in research, electronic project development, networks, automation, and telecommunications. He uses active methodologies of different specialties in electronics and systems in several universities in Peru and is a member of IEEE-RAS-UPN. He can be contacted at email: cristian.castro@upn.pe.