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Original Article

Design and Development of Fuel Adulteration Detection and Alert System

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Abstract - *Since existing laws are not fully implemented, and more importantly, adequate tools for determining the quality of fuel are too expensive, ownership of a storage tank, car operators, and fuel users face significant risks from substandard fuels. To curb this problem, an Arduino microcontroller in combination with MQ2 sensors was used to design a fuel contaminant detection system. It has been programmed using the Arduino IDE in C++. The operation of the sensor is based on the measurement of gas conductivities through Synthetic Tin Dioxide (SnO_2) thin-film layers, where impurities such as methanol, diesel, and paraffin can be identified. It was attached to some fuel samples and run in impurity/oil mode. The reading was presented, showing the level of the fuel in Parts Per Million (PPM) on an LCD in 2-7 s. For all clean fuels tested, readings remained more than 55 PPM, while for contaminated samples, it was as low as 22 PPM. The system demonstrated high accuracy and efficiency, making it a dependable tool for real-time fuel monitoring. By enhancing fuel quality control and promoting regulatory compliance, this solution fosters market confidence and safeguards consumers from substandard products.*

Keywords - *Arduino microcontroller, Fuel adulteration detection, Gasoline purity analysis, MQ2 sensor, Real-time monitoring.*

1. Introduction

Fuel adulteration is a critical economic and ecological destabilizer, most notably within regions that depend heavily on the consumption of petroleum products for transport and industrial development. The most common form of adulteration is quality dilution, wherein the quality of gasoline or diesel is lowered by cutting them with cheaper and inferior substances like kerosene or methanol. Principle driving forces behind this practice are economics because unfaithful stakeholders rebrand but also hurt various engine systems and increase the emission of hazardous pollutants to the environment. Moreover, the detection of adulterated fuels is complex because of the similar chemical nature between adulterated fuel and base fuel; thus, old detection methodologies are inappropriate. Further, economic impacts of tax evasion where significant government revenue is lost through fuel adulteration [1]. Environmental impacts also include increased tailpipe emissions, which lead to indoor and outdoor air pollution and pose serious health risks to people [2]. Although there are various methods to detect fuel contamination, such as ultrasound, imaging, and IoT-based systems, most methods are either very expensive or require specialized equipment, which limits their accessibility and widespread use [3, 4]. There is a growing need for more efficient, cost-effective, and user-friendly detection systems, especially in areas where fuel quality standards are difficult to enforce. This work proposes the development of a functional fuel contamination detection system that aims to address these issues using an Arduino microcontroller and an MQ2 sensor. The system can monitor and detect common fuel contamination in real-time, providing a practical solution for tank owners, car owners, and other fuel users. By providing accurate and timely detection, the system aims to increase regulatory compliance, protect consumers from out-of-specification products and improve the overall fuel quality in the market. This research work seeks to develop a cost-effective fuel contaminant detection approach through the use of Arduino microcontroller and MQ2 sensors, such that accurate recognition of fuel adulteration is done in real time, thus improving fuel quality supervision and encouraging compliance. The method proposed in this case resolves the problems connected with the high price and the unavailability of small-scale fuel users and operators with other detection techniques. This system is reliable, cost-effective and efficient because it employs MQ2 sensors that are sensitive to contaminants like methanol, diesel and paraffin through the use of Synthetic Tin Dioxide (SnO_2) thin-film layers. The hypothesis guiding this research is supported by the assertion that an Arduino based fuel contaminant detection system is held to be capable of real time detection of fuel impurities in a cost-effective manner so as to be favorable to the enhancement of fuel quality monitoring, regulatory compliance and consumer safety compared to other expensive detection processes.

2. Review of Past Works

Fuel adulteration poses a significant risk to the economy, environment, and public safety, and various approaches have been developed to detect and prevent this problem, ranging from ultrasonic techniques to advanced IoT systems. In this section, we review key prior research that has contributed to advances in fuel adulteration detection. [5] proposed a method for detecting fuel contamination in gasoline and diesel using ultrasound.

The method measured the velocity of ultrasound waves in pure and adulterated fuels and identified contaminants based on the change in sound velocity. Dharurkar and Wadhekar (2016) proposed a statistical signature analysis method for detecting impurities in gasoline. Their system was based on image analysis techniques to distinguish contaminants in fuel samples. Although this method is effective in a controlled environment, it faces challenges in real-time applications due to its complexity and time-consuming nature (Dharurkar & Wadhekar, 2016). processing techniques were studied. In this work, a sensor-based system is proposed to capture images of fuel samples and analyze them for contaminants. Although the technology is promising, it requires advanced computing resources and limits its feasibility for widespread use (Ranhotra, 2013). The integration of IoT technologies significantly improves the capabilities of fuel contamination detection systems. Gatti et al. (2019) proposed a fuel level, pressure, and leakage potential monitoring system; the IoT-based system is designed for real-time monitoring.

It gives an alert on contamination and contraband attempts in any means of transportation and proposes a viable solution toward real-time fuel management. Gatti et al. (2019) A Real-Time Solution for Fuel Management. IoT-Based Fuel Quality Monitoring and Anti-Theft System for Real-Time Fuel Management: Concept Validation. SPR-Based Approach to Adulteration Sensing in Real Time. SPR sensors are versatile, highly sensitive devices that enable very advanced monitoring systems for various applications and are capable even of the minutest levels of contamination of any type.

SPR-based sensors could be used for highly sensitive contaminant detection but require relatively complex equipment and, therefore, may not be possible for wide use-fiber optic sensors for real-time detection of diesel paraffin in diesel oil. A portable refractometer was developed for impurity detection. This method uses a dielectric constant to measure impurity levels and can detect impurities as low as 5%, making it an easy and effective screening tool (Kanyathare et al., 2018). Recent developments have combined image processing and fiber optic technology to more accurately detect contaminants in the fuel.The emphasis has been on research combining thermal imaging and the gray level co-occurrence matrix of a contaminant can detect contaminant levels equally high 5% in a fuel (De et al., 2011). In addition, the dual internal photonic crystal fibers are highly sensitive, and the sensor is based on a metal-plated planar waveguide which nearly absorbs all the incoming electromagnetic radiation (Bhardwaj et al. 2021 & Zhang et al. 2012) designed a handheld Raman spectrometer for determining impurities in petrol.

It discriminates Raman spectra of fuel samples with the impurity by recourse to chemometric technologies, providing a speedy and infallible method for impurity detection in fuel samples (Zhang et al.). Fuchs et al. (2017) described a 3D-printed microfluidic viscometer for fuel viscosity measurement and impurity detection. This work bridges a knowledge gap between two viscometers and provides detection of impurities with 95% or more relevance in the area of rapid detection of viscous concentration (Sankaran et al., 2017).

Alabi et al. (2023) developed an Arduino-based Engine Protection Device (EPD) that monitors fuel flow, temperature, and quality. Their system demonstrated an average detection time of 35 seconds, highlighting its real-time capabilities for fuel monitoring. However, the reliance on low-cost hardware introduces potential issues with long-term durability and precision in harsh environments. Onyan and Okhueleigbe (2022) presented a point-of-sale detection system using MQ-4 and MQ-6 gas sensors integrated with GPS and GSM modules for real-time alerts. While their system enables location-based reporting and timely alerts, its effectiveness is limited in areas with poor mobile network connectivity, particularly in remote locations.

In the domain of IoT-based monitoring, Devi et al. (2023) proposed a system that utilizes ultrasonic sensors and the ThingSpeak cloud platform for real-time fuel monitoring and theft detection. This system enables continuous remote tracking via GSM, making it suitable for large-scale fuel management. However, IoT-based systems are prone to data transmission failures in low-signal regions, and the integration of cloud services increases operating costs for long-term deployments. Similarly, Singha et al. (2020) introduced an etched Fiber Bragg Grating (FBG) sensor for detecting fuel adulteration.

Their experiments demonstrated exceptional sensitivity, with values of 49.98 nm/RIU for petrol and 26.97 nm/RIU for diesel, but FBG sensors require careful calibration and are highly susceptible to environmental changes. Additionally, the sensors' fragility makes them less suitable for rugged outdoor conditions. In this work, though it builds on closely related predecessors that advanced the field of fuel impurity detection, there remains a large unmet need for solutions that are accessible, cost-effective, and easy to use and deploy on a smaller scale. Therefore, this research helps bridge that gap and brings a new system into the market that meets these criteria and has the potential to revolutionize how fuel quality is monitored and controlled in the industry.

3. Materials and Methods

This section presents the materials and methods used for the development of the fuel adulteration detection system. The system is composed of several major units, namely power supply, microcontroller, sensor, and display units, as indicated in Figure 1. Every unit is very important in its functionality toward the common objective of a well-functioning adulteration detection and reporting system in real time.

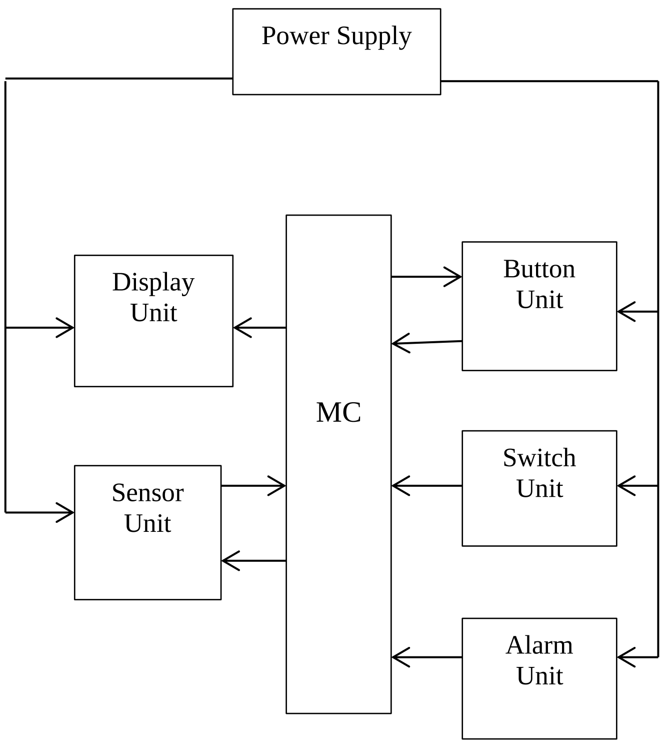

Fig. 1 System block diagram

The power supply unit delivers the required operating voltage for the whole system. It accepts an input voltage of 220/240 V AC at a frequency of 50 Hz and produces 12 V DC output across the circuit. The unit constitutes a step-down transformer, a bridge rectifier, a filtering capacitor, and an LM7805 voltage regulator for achieving a 5 V stable output.

The step-down transformer was chosen for its capability of accepting the input variation over a range of 220-240 VAC and offering the output over 12-19 VAC. Rated at 1 KVA, it meets the circuit's power demands. Its coil specifications, including the number of turns and wire gauge, were optimized for effective voltage transformation.

The capacitors used were selected based on ripple reduction and voltage endurance. A 47 µF, 25 V capacitor was chosen after calculations using Kirchhoff's voltage law to ensure effective filtering and minimal ripple. The LM7805 regulator, from the 78xx series, was selected for its ability to maintain a steady 5 V output regardless of input fluctuations or varying load conditions.

The Arduino microcontroller serves as the system's control center, managing interactions between the sensors and the display module. This microcontroller features a USB interface, six analog input pins, and 14 digital I/O ports, six of which support Pulse-Width Modulation (PWM).

Operating at 5 V with a clock speed of 16 MHz, it is programmed using the Arduino IDE, a user-friendly platform compatible with Windows, Mac, and Linux systems. The open-source nature of the Arduino IDE allows for customization to suit specific project requirements.

The MQ-2 sensor is used for fuel contamination detection because of its high sensitivity and due reliability in the detection of a wide range of combustible gases and fumes. It is long-lasting with a sturdy construction that includes a Bakelite body and a protective metal case. This sensor can detect combustible gases within a range of 300 to 10,000 ppm and also operate on a heater voltage of 5.0 V ± 0.1 V with a loop voltage below 24 VDC, therefore fitting into various designs of the circuit.

It has an adjustable load resistance through which its output can be fitted to the voltage requirements of the application, where it gives an output voltage between 2.5 V to 4.5 V. It detects methane concentration at 0 V for 2000 ppm, giving wide sensitivity capable of giving true readings. This requires 48-hour pre-heating for essential applications.

The display unit is a 16x2 yellow-green LCD module that presents fuel analysis results to the user. With a display area of 66 x 16 mm and a 5 VDC operating voltage, it is a popular choice for microcontroller-based systems due to its low power consumption and easy integration. The module displays messages indicating whether the fuel is pure or contaminated based on sensor data, making it a crucial component in the monitoring system.

The operational flow of the fuel adulteration detection system follows a flow chart depicted in Figure 2. Initially, the control button is pressed to start the system. The sensor then analyzes the fuel sample, and the microcontroller processes the sensor's output. The system was subjected to a series of tests involving different fuel samples, including pure petrol and petrol mixed with kerosene at defined ratios. Each sample underwent multiple tests to confirm consistency in the readings. The fuel samples were prepared under laboratory conditions to minimize variability. During testing, the sensor's output was displayed on the LCD within 2 to 7 seconds. To evaluate repeatability, the same sample was tested ten times, and the PPM readings were compared. The system maintained stable readings for pure petrol at 85 PPM, while adulterated samples showed lower readings, as low as 22 PPM.

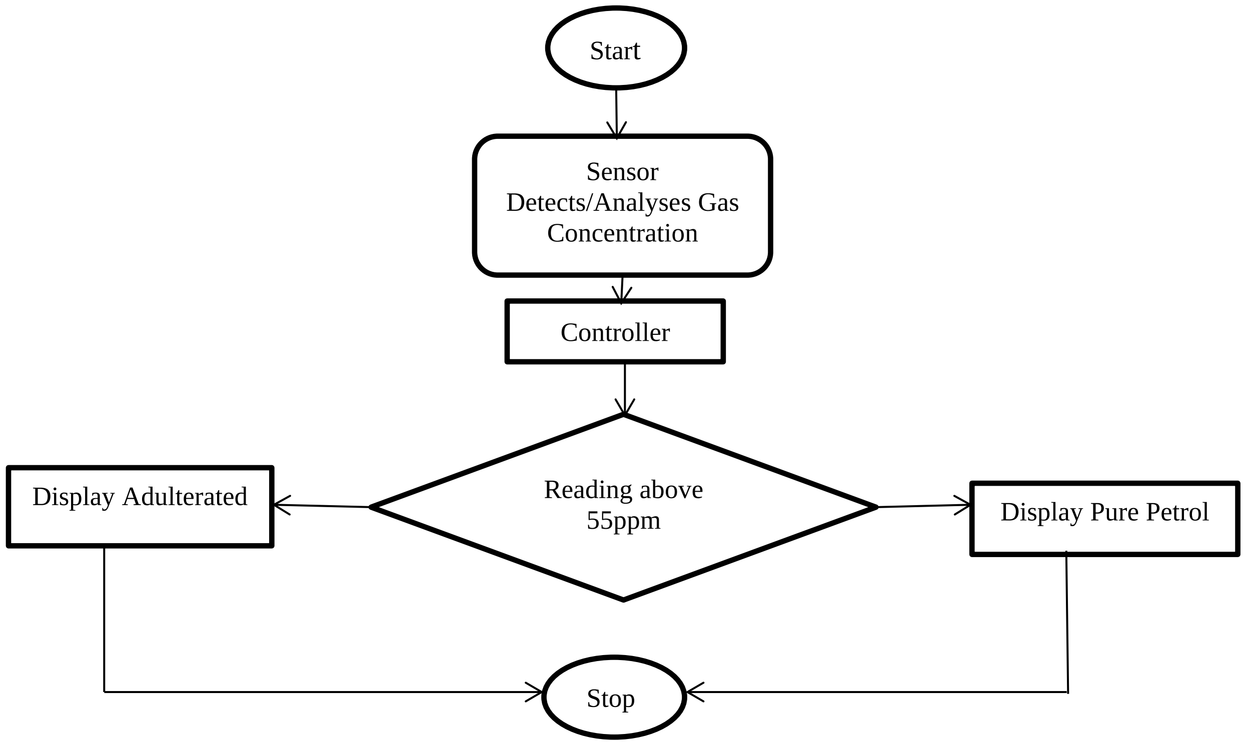

Fig. 2 System flow diagram

The circuit design integrates the MQ2 sensor with the Arduino microcontroller. The sensor's analog output is connected to the A0 pin of the Arduino, and the other components, including the LCD and buttons, are connected according to the system's requirements. This setup allows for efficient and accurate detection of fuel adulterants in real-time. Figure 3 shows the system circuit diagram of the system.

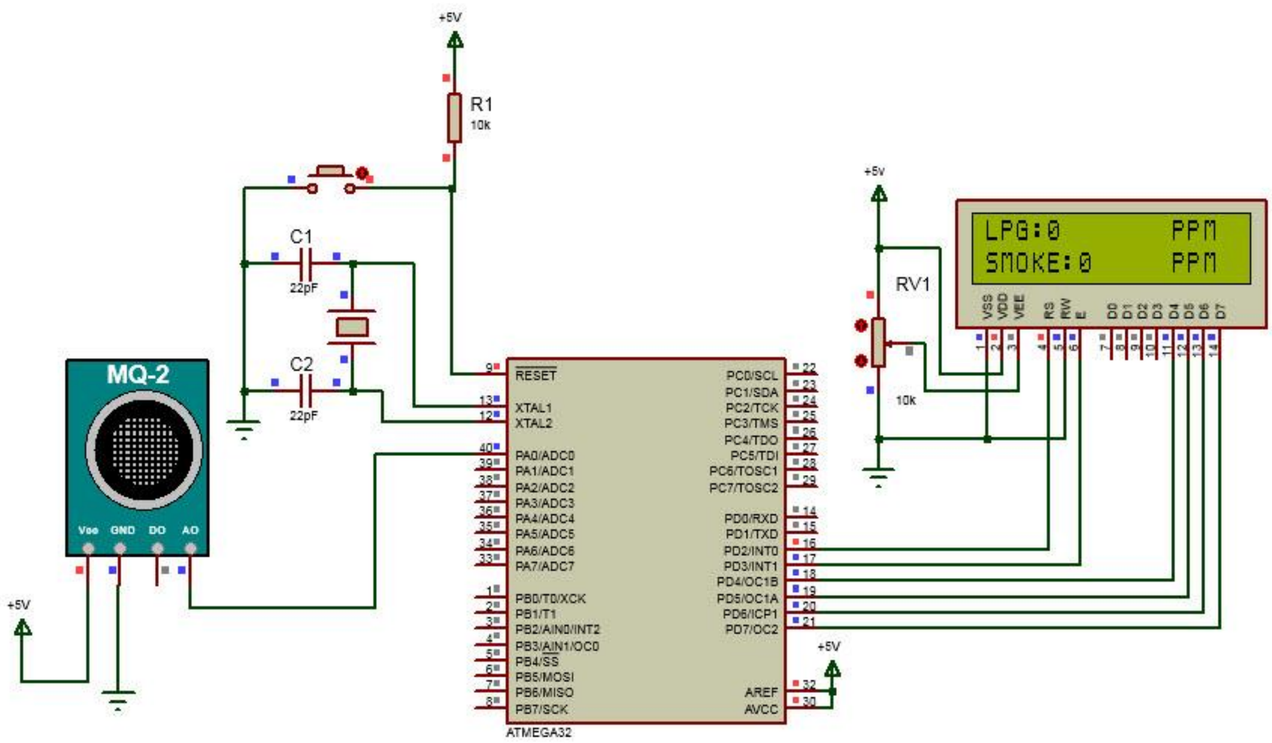

Fig. 3 Circuit diagram of the system

4. Test, Result and Discussion

This section presents the results obtained from the design, development, and testing of the Arduino-based fuel adulteration detection system. The discussion covers the hardware and software developments, the evaluation of system performance, and the interpretation of the test results. The Arduino fuel adulteration detection system was housed in a Polyvinyl Chloride (PVC) box, which securely contained all the components.

The system was programmed using the Arduino Integrated Development Environment (AIDE), which utilizes C++ for coding. The software was configured to operate a web-based application connected to the developed system. The system’s interface consists of a 16x2 LCD that provides real-time feedback on fuel quality. Upon activation, the display shows the system status and analysis results. If the PPM value exceeds 55, the message Pure Petrol (PP) is displayed. Readings below this threshold prompt a “Fuel Contaminated” alert.

The LCD design aims to simplify user interaction by presenting concise messages. An alarm also sounds during contamination detection, enhancing its usability in noisy environments.

Fig. 4 Fuel adulteration detection system

The overall view of the fuel adulteration detection system is shown in Figure 4. The system used an Arduino processor, MQ2, and MQ4 sensors to detect impurities in the fuels. The sensors formed a sensitive layer of tin dioxide (SnO2) that responds to gases by increasing their conductivity.

The fundamental principle behind the system is that the interaction of tin dioxide with gas makes it a changeable conducting material and, thereby, changes the resistance of the sensor. This change in resistance is then estimated by concentration. System testing involves checking accuracy and time of response for fuel detection that would eventually lead to the finding of adulteration, sensitivity towards fuel composition variations, and verifying reliability over the long term.

More specifically, testing covered the ability of the system to detect fuel/gas concentration in Parts Per Million (PPM), which is an important measure related to fuel purity. The tests were carried out both on pure gasoline and gasoline samples contaminated with kerosene and diesel. Response times were measured, and PPM values were recorded to evaluate system performance. The results of the tests are shown in Table 1.

PPM values were obtained for the different samples from which the system was able to distinguish between pure and adulterated petrol effectively.

Generally, pure petrol gave consistent PPM values of 85, which correspond to high gas concentration and confirm its purity. On the other hand, the sample of petrol mixed with kerosene gave significantly low PPM values of 22, specifically confirming the presence of adulterants.

The system also achieved a response time within a practical range with results between 2-7 seconds. Quick detection is important for real-time monitoring and would make the system usable in various settings, including fuel depots and by individual consumers. In all these trials, the system exhibited high sensitivity and reliability in detecting fuel adulteration.

What makes it an invaluable tool is its ability to offer accurate results in real-time, hence preventing substandard or harmful fuel products from getting into the market. Arduino and MQ2/MQ4 sensors used proved to be an effective approach in creating a cost-efficient and practical fuel adulteration detection system.

Table 1. Table of results

S/N	Test (Sample Type)	Response (sec)	Result (ppm)	Indication
1	Pure Petrol	2 - 7	85	Pure Petrol
2	Petrol and Kerosene	2 - 7	22	Adulterated Petrol

4.1. Environmental Impact on Sensor Performance

The MQ2 sensor's performance can be affected by external factors such as temperature and humidity, which may influence the accuracy of fuel contamination detection. Variations in temperature impact the sensor's internal heating element. Higher temperatures can make the sensor overly responsive, resulting in higher readings even for uncontaminated fuel, while lower temperatures can slow down the response, causing delays in detection. Humidity levels also affect the sensor's operation.

In humid environments, moisture can accumulate on the sensor's surface, reducing its ability to detect contaminants accurately. In contrast, dry conditions may introduce static buildup, potentially causing minor fluctuations in readings. To address these challenges, the system can be improved by including additional sensors that monitor temperature and humidity, allowing real-time adjustments to the readings. Protective casings can help shield the sensor from excess moisture and sudden temperature shifts, while periodic recalibration under varying environmental conditions ensures consistent performance. These measures can help maintain the sensor's reliability across different usage environments.

5. Conclusion

This paper designed a system to monitor and detect fuel adulterants, such as paraffin and methanol in gasoline, with high accuracy in real-time applications. In the test, it could distinguish between normal and adulterated gasoline based on gas concentration measured in parts per million. Results obtained showed that for pure gasoline PPM values were above 55 while for adulterated fuel PPM values were much less, thereby showcasing the fast and reliable analysis that this system can support. Having a latency between 2 to 7 seconds, it is highly recommended for on-site installations at fuel depots, filling stations, and even for individual consumers who want to ensure the quality of fuel purchased.The system was tested in a practical setting at a local fuel station. It successfully detected kerosene adulteration in petrol, with results aligning with laboratory tests. The detection process was completed within 5 seconds, supporting real-time fuel quality assessments. The portable design allows for use at fuel depots, filling stations, and for individual quality checks. Broader field testing across different locations will provide further validation and insights into performance in various conditions. This system holds great potential in fuel quality control plus regulatory compliance towards protecting the consumer against inappropriate or hazardous fuel products. It provides an easy, inexpensive way of detecting fuel impurities and therefore supports broader initiatives not just to enhance fuel standards but also to promote consumer safety. As a recommendation of the findings to improve the practicality and efficiency of the system, first deploy it in different kinds of real-world settings that include fuel depots, gas stations, and consumer-level use. Field tests will take place on a large scale and provide useful data to validate how well it works in different environments. Future work may involve enhancing the sensitivity of the MQ2 and MQ4 sensors to pick up even minute traces of contaminants that may not influence the present PPM readings much.

Moreover, the addition of IoT capabilities for remote monitoring as well as centralized data collection is proposed. This would be apt, especially in features needed by the regulatory bodies to monitor fuel quality in real-time at multiple sites. Furthermore, coming up with a design that is more compact and easier to carry around would make it better, easy for consumers and inspectors to carry it and work with it in many settings. Making the user interface by giving clearer explanations plus detailed analyses plus support for a mobile application would make the customer experience much better and thus make this system more available and friendly. In turn, it would also boost its acceptance and efficacy in assessing fuel quality.

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