Development of a portable electronic device for the detection and indication of fireworks and firecrackers for security personnel

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ABSTRACT

The use of fireworks and firecrackers to celebrate festivities is a very common activity in the Philippines. But due to the lack of strict control and regulation, there are unwanted risks of accidents from occurring due to the poor handling and storage conditions of these devices. Proper monitoring is important to reduce any unnecessary risks imposed on human life and property. While existing storage monitoring devices exist, the developed prototype is designed to contain sensors that are more suited in monitoring the ideal conditions of where the fireworks are stored. Monitoring the climate conditions on these devices may seem trivial at first, but such climate change can involve a rapid rise in temperature that can accidentally ignite the fireworks and deal with catastrophic damage. Another concern is the rise of humidity that may alter that chemical characteristics of the gunpowder stored in the fireworks. Such changes may not have any noticeable effects until it arrives in the consumer that may experience an unwanted and unintended change in the performance of the fireworks leading to accidents. Therefore, it is important for this device to properly monitor the surrounding area then indicate various forms of alarms as a method of redundancy.

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1. INTRODUCTION

One of the main chemical compositions found in fireworks is black powder [1]. Black powder is used as the main source of fuel for fireworks and is highly flammable. Improper handling and storage of fireworks can lead to accidents from occurring [2]. There are many factors that can increase the risks of accidents from occurring while also factors that would decrease the quality of the fireworks [3].

An increase in the moisture level would result in a significant increase in the burning time of black powder grains [4]. Water commonly would degrade the quality of pyrotechnics due to the creation of multiple side reactions from its presence. An increase in the moisture level of 1-3% can sufficiently reduce the burning rate by approximately half [5, 6].

To store the fireworks safely, they should be kept away from sources of heat and ignition [7]. The use of the temperature sensor and the carbon monoxide sensor would allow the detection of rapid environmental changes and the presence of smokers in the storage location [8, 9].

2. THEORETICAL CONSIDERATION
2.1. Factors that affect the quality
2.1.1. Humidity
Humidity naturally is inversely proportional to temperature. This means as the humidity increases, the temperature decreases. The moisture content is an important factor in the flammability of a material [10]. When a material is in a very dry condition it becomes increasingly flammable [11]. Black powder, a key ingredient for fireworks have a high hygroscopicity, meaning it absorbs high amounts of moisture. High amount of humidity would cause erratic behavior in the fireworks. An environment with humidity below 30% would expose the material in the possibility of generating a spark and the fire produced would also be bigger. Making humidity a very important factor in making sure that the facility is in good condition. The safe range of relative humidity for storing fireworks is between 30%-50%. Thus, the sensor used for the system is set to alarm once the relative humidity levels go below 30% or beyond 50%.

2.1.2. Temperature
The factors considered for the flammability of a material are its autoignition temperature and its heating value. The autoignition temperature or kindling point is the lowest temperature where a material or a substance starts to ignite on its own in a normal environment with no external source of ignition presents like a flame or a spark [12]. While the heating value or heat of combustion of a substance is the amount of heat released when the material is burning [13, 14].

Key ingredients in manufacturing fireworks such as Black Powder, Red Flare Composition, Flash Powder and Green Flare Composition have ignition temperatures ranging from 315-482°C. While sulfur has an auto-ignition temperature of 232°C [15]. Nitrocellulose, on the other hand, has an autoignition temperature ranging from 132°C-148°C. Corrugated cardboard or paper in general, often used for packing fireworks has an autoignition temperature of 218-246°C. Paper also has a very high heating value of 6000 BTUs/lb; thus it can easily catch and spread fire. Another factor considered for the study is the welfare of the employees especially since the storage facilities often acts as a work area for the employees as well. Based on the Philippine's Department of Health, having a heat index of 41°C already place the employees in great danger thus the temperature sensor limit is set to 41°C.

2.1.3. Hydrogen
Hydrogen is extremely flammable in fact it has the highest rating of 4 in the flammability scale [16]. A mixture of hydrogen and air can start to ignite even with just a small spark that is invisible to a naked eye [17]. Since hydrogen is the most abundant gas in the universe it is used for industrial purposes such as in manufacturing fireworks. Bonds between hydrogen and carbon are broken to provide fuel or energy for the fireworks [18]. Hydrogen also when combined with other elements is used as a green colorant in fireworks. Since the lower explosion limit (LEL) of Hydrogen is at 4.1% Getting 10% of the LEL would define the safe amount of Hydrogen in the environment [19, 20]. In the case of Hydrogen, it is 4,100ppm, when this amount is reached the facility is in danger of experiencing a fire or an explosion [21].

2.2. GSM
The Global System for Mobile Communications, or GSM for short, is one of the two major systems available that started from the second-generation (2G) digital cellular network [22]. The other system being code-division multiple access (CDMA). It maintains a majority in global market share and enjoys a market dominance everywhere except the United States. It is the de-facto standard for 2G networks to send and receive SMS text messages. GSM employs the use of subscriber identity modules (SIM cards) to identify its users. GSM technology can operate at frequencies of 850MHz, 900MHz, 1800MHz, and 1900MHz frequency bands [23, 24].

3. DESIGN PROCEDURES
Figure 1 displays the overall system block diagram of the firework safety monitoring device. The sensors are integrated and read by the ESP32 microcontroller. The microcontroller is the main hub that bridges the sensors, the graphical user interface, and the alarm system altogether. The microcontroller is powered by a lithium-ion battery that can supply 5 volts and 2 amps of current.

3.1. Prototype design
The developed prototype can be seen in Figure 2. Five different sensors are used to monitor the storage conditions of the fireworks. While the LCD display shows the sensor data readings. The alarm system is currently in-active until one of sensor data readings go beyond the specified values.

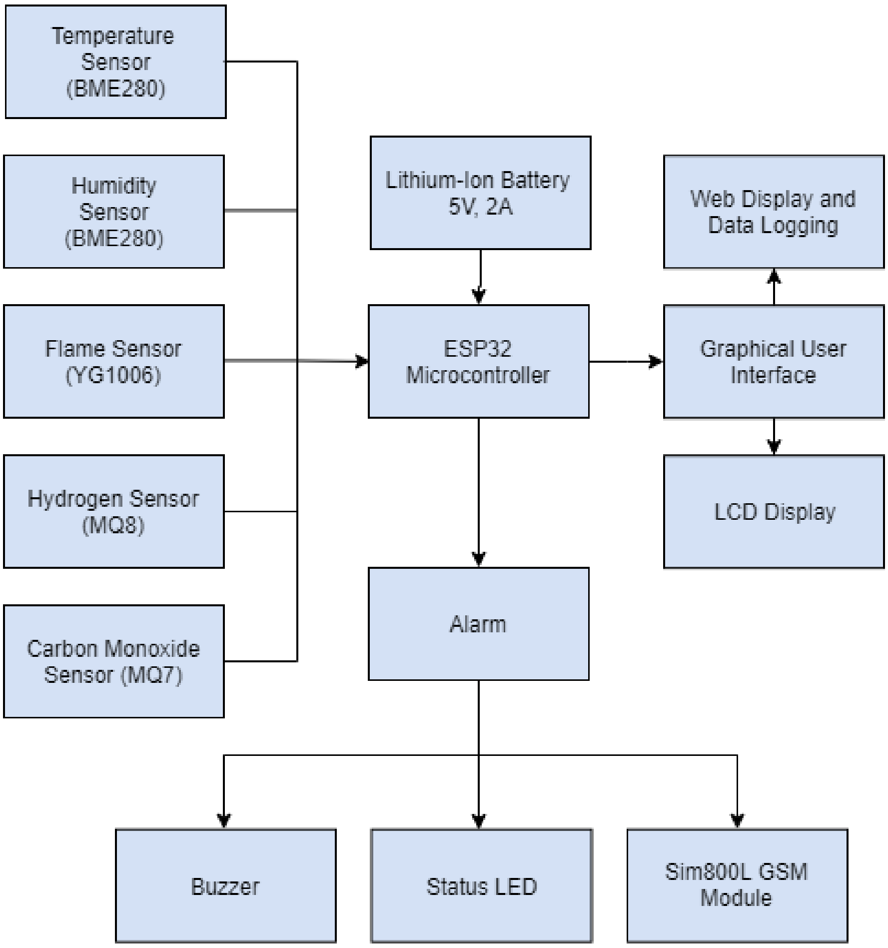

Figure 1. Overall system block diagram

Figure 2. Developed prototype

3.2. ESP32 nodeMCU

The researchers implemented the usage of the ESP32 NodeMCU module that utilized the ESP32 microchip developed by Espressif Systems. It is the successor to the popular family of low-cost WiFi microchips-the ESP8266. The researchers chose the ESP32 over the Arduino as the main microcontroller because of it being a smaller and a lower-cost alternative; while also having the ability to connect to the web with its integrated WiFi Module. The ESP32 operates at a clock frequency of 240 MHz, and also contains 34 GPIO pins with various features and functionality.

3.3. Temperature and humidity sensor
The BOSCH BME280 is an environmental sensor used to detect humidity, pressure, and temperature. With dimensions of only 2.5mmx2.5mmx0.93mm, paired alongside with its capability to consume low amounts of power, the BME280 is a perfect choice to measure the surrounding temperature and humidity needed for the device.

3.4. Flame sensor
The flame sensor module is used to detect the presence of fire near the device, at a maximum distance of 1 meter. The infrared sensor of the module is using the YG1006-5mm IR diode, and it is known to be sensitive to both flame and radiation. According to the product page, the IR diode is a high speed and highly sensitive NPN silicon phototransistor; and the black epoxy of the diode provides it with the sensitivity to detect infrared radiation.

3.5. Hydrogen sensor
Hydrogen gas obtains the highest rank inflammability in the NFPA 704, a standard created by the National Fire Protection Association of the United States. It poses an unwanted safety risk to the storage location of the fireworks. The MQ8 hydrogen gas sensor is used to detect whether or not its concentrations exceed the assigned safety limits.

3.6. Carbon monoxide sensor
Carbon monoxide gas is released during the combustion process of black powder, one of the main chemical compositions used in fireworks. The MQ7 carbon monoxide gas sensor is used as another method to detect if a fire is present or if smokers are in the surrounding vicinity.

3.7. Sim800L GSM module
The SIM800L GSM Module is used to send SMS text messages over the cellular network. It can be used to inform individuals even if they are not physically present in the device location. It can be controlled by the microcontroller by using the Hayes or AT command set. Communication occurs between the microcontroller and the module by using the UART serial communication protocol. While the protocol for sending and receiving SMS text messages is done through the general packet radio service (GPRS) data standard for global system for mobile communications (GSM).

3.8. Lithium-ion battery
To provide portability to the design, a lithium-ion battery was implemented to the design to power all the available electronics. The battery chosen was developed by Xiao Mi with a total capacity of 10000mAh. It has a supply voltage of 5 volts while also having a maximum current of 2 Amps to power all the available electronics. The chosen battery at a capacity of 10000 mAh is chosen as it can last long hours from the chosen low-power electronics, while also providing the benefit of having a small form factor [25, 26].

3.9. Nextion LCD display
The Nextion LCD is a human-machine interface (HMI). Simply put, it allows data obtained from the sensors to be easily understood by the users [27]. It is one of the two graphical user interfaces implemented [28, 29].

3.10. Adafruit IO web interface
The Adafruit IO web interface is the second graphical user interface created. It operates in a publish and subscribe model. The obtained sensor data is transmitted through the message queuing telemetry transport (MQTT) protocol to be seen across the web. Built-in logging also exists to check back on the status of the device [30-33].

4. METHODOLOGY
Part 4 discusses the Methodology. Figure 3 shows the overall system flowchart.

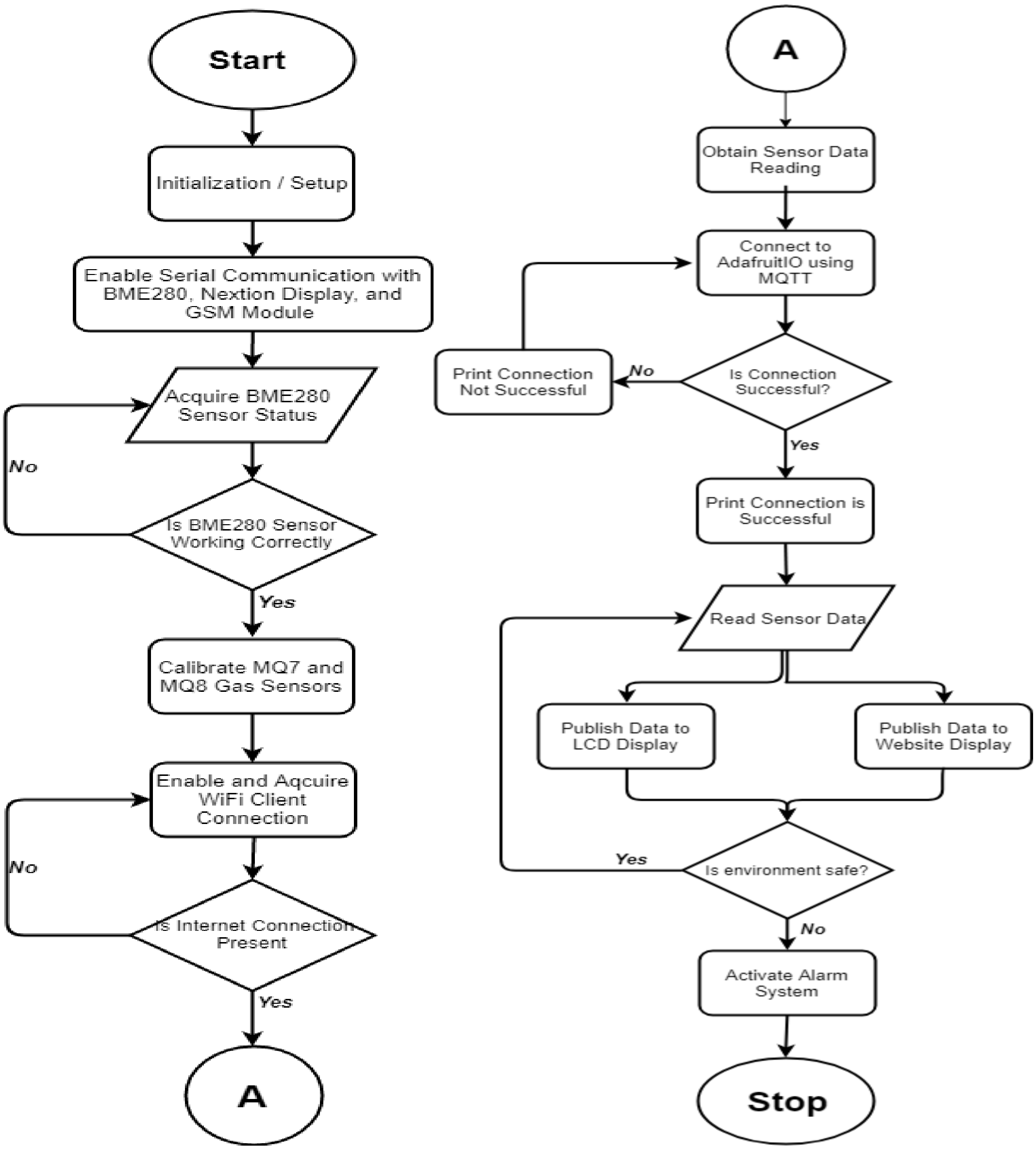

Figure 3. Overall system flowchart part a

5. RESULTS AND DISCUSSIONS

5.1. Technical analysis on temperature and humidity

To be able to test the reliability and accuracy of the temperature and humidity sensor, the researchers used the system in a total of 7 different environments [34]. 5 of the chosen environments target the reliability of the device in varying environments, which includes a school laboratory, a parking area with poor air circulation, a bakery, a public park, and an open-air food park [35, 36]. Two setups were also made to target the maximum threshold set for the temperature and humidity sensor. To verify the accuracy of the device, the researchers used a separate thermohydrometer and a thermal gun to verify the data gathered by the device. The equation for the Percentage Error was used to compute for the difference between the data obtainsed by the device and the hygrometer [37, 38]. The average percentage error was used to determine the accuracy of the results obtained [39, 40].

The researchers used a blow dryer directed towards the device to reach the limit set which is 41°C. For the humidity sensor, the researchers used the water vapor gathered from a boiling water set-up for the device to reach the danger levels set for the humidity sensor. Using the formula for the percent error, the students were able to conclude that the temperature sensor has an accuracy of 97.9123% while the humidity sensor achieved an accuracy of 98.63358% as shown in Figures 4 to 6.

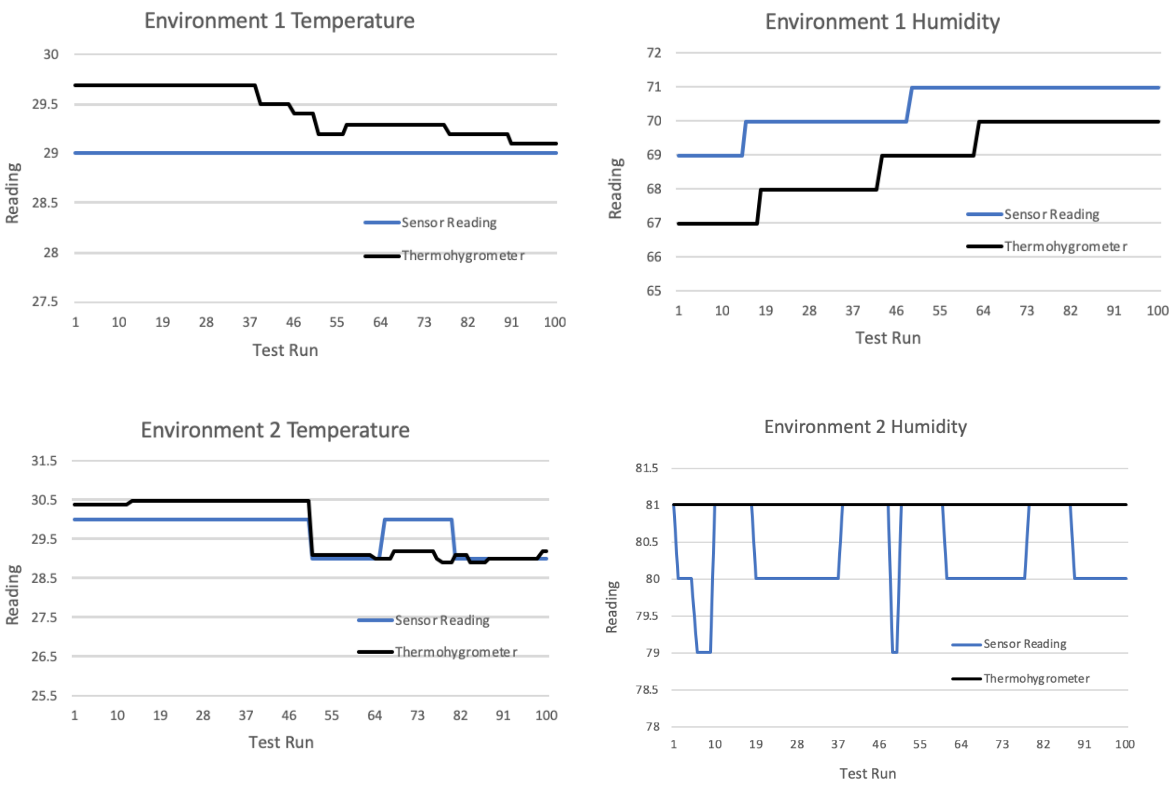

Figure 4. Temperature and humidity for STRC 110 and enrique razon sports complex parking

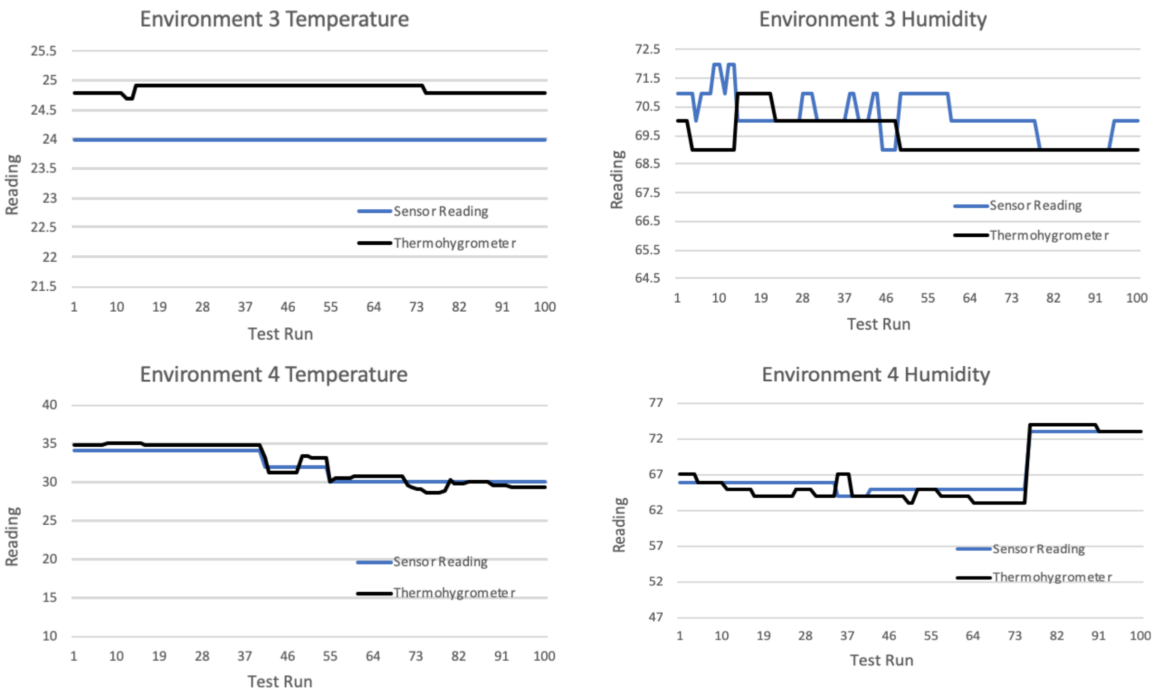

Figure 5. Temperature and humidity for pan de manila bakery and Rizal park

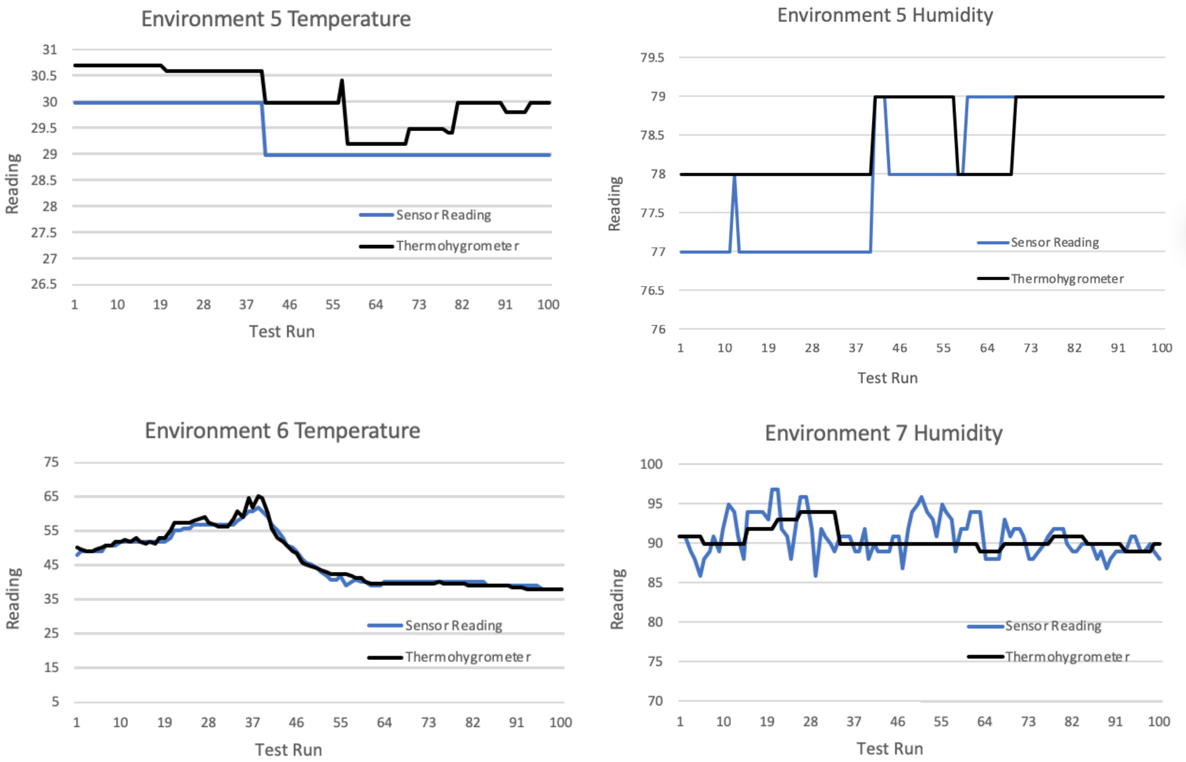

Figure 6. Temperature and humidity for agno Food Park and blow dryer set up

5.2. Technical analysis on flame detection

The researchers obtained an average accuracy of 89% for flame detection at three varying distances, marked at 0. meters, 1.0meters and 1.5meters respectively. However, the inability of detecting the flame was only experienced on the further distance. On the other hand, no false reading of the presence of flame is experienced as shown in Table 1.

Table 1. Flame detection

Distance of Flame Sensor	No. of Trial	Success Rate	
		Flame Detection	No Flame Detection
0.5 meters	100	100%	100%
1.0 meters	100	94%	100%
1.5 meters	100	73%	100%
Average		89%	100%

5.3. Technical analysis on the hydrogen sensor

To be able to test the MQ8 sensor in Figure 7, the researchers made an electrolysis set-up. Upon starting the electrolysis procedure, the Hydrogen reading reacts accurately. The Hydrogen count gathered in clean air also agrees with the theoretical amount of Hydrogen in clean Air.

5.4. Technical analysis on the carbon monoxide sensor

The easiest way to make Carbon Monoxide is through the burning of paper. Upon exposing the system to the burning paper set-up the readings were able to clearly show the reaction. The value obtained also proved the theoretical study that for the presence of smoke a minimum of 100ppm of Carbon Monoxide should be read. And for clean air, 0-10ppm is the theoretical amount of Carbon monoxide, which the readings on the device agree with.

5.5. SMS technical analysis

The testing for the response time of the SMS feature of the device showed that the time the notification is received is correlated with the strength of the signal both on the receiving and sending ends. Moreover, the baseband testing was performed in an area with a fair signal strength of -97dBm with an average of 8.50 seconds response time which was also used as the standard for the device as shown in Table 2. The MQ8 sensor readings and Baseline testinh Histogram are shown in Figures 7 and 8 respectively.

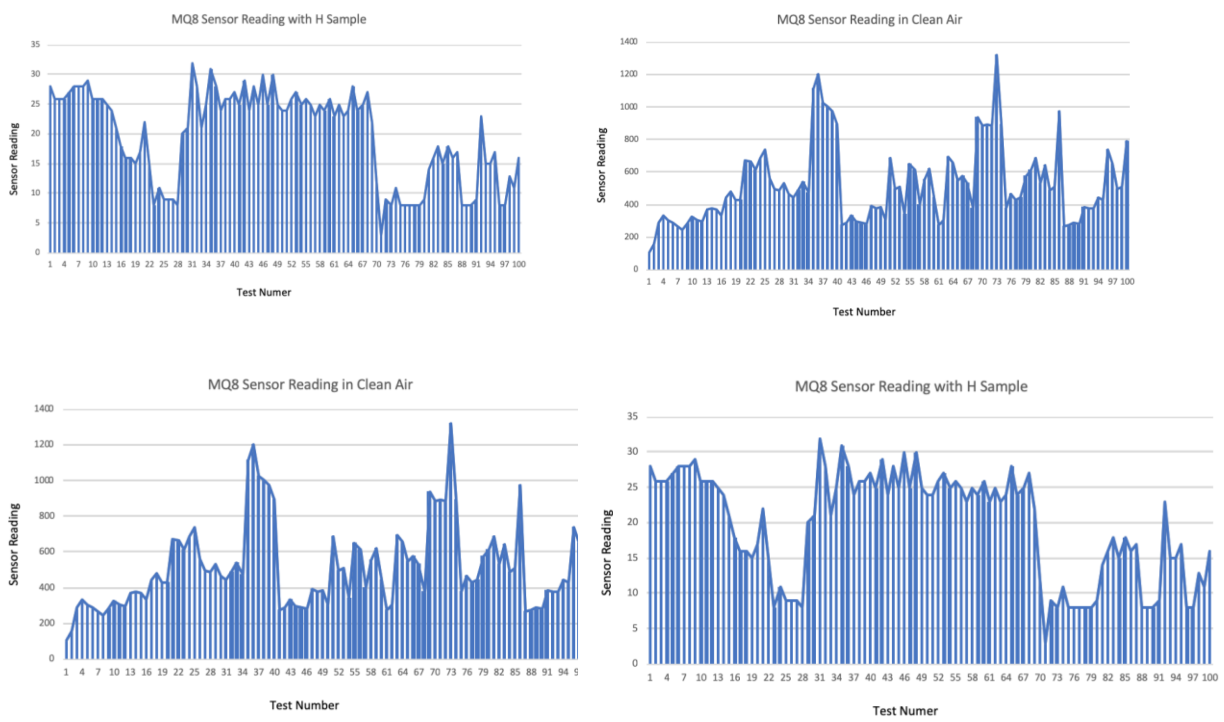

Figure 7. MQ8 sensor readings

Table 2. SMS testing

Signal Strength	Average Time
High	6.90 seconds
Normal	8.97 seconds
Low	10.91 seconds

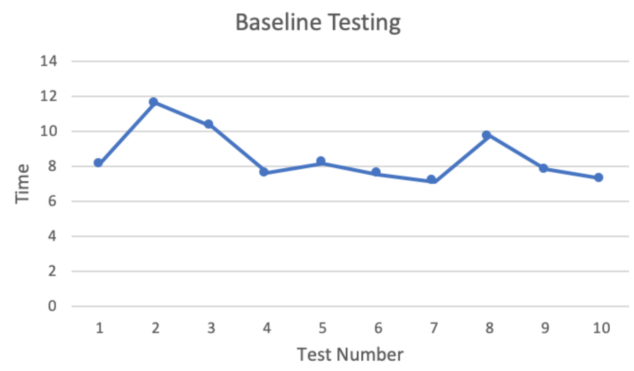

Figure 8. Baseline testing histogram

6. CONCLUSION

This research paper provided a means to develop a low-cost device that can safely monitor the storage conditions of fireworks. This prototype has the ability to detect fireworks which can be used by industry personel. The developed prototype could display sensor data readings through its LCD display and through a web interface, while also having logging features that can store sensor data readings. The research is also accurate as it gives the correct readings. Once the storage location is determined to no longer be suited to ideally store fireworks, the alarm system is then activated. An SMS text message is sent by the Sim800L GSM Module, and the audio and visual alarms are also triggered. The system developed is low cost meaning it can be easily reproduced with a low price.

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