Explosive Vapor Sensors for Cyber Physical Systems to Protect Crowds

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***Abstract*—Currently, very expensive instruments/tools are being used to detect improvised explosive devices (IEDs) to protect the large gatherings in a closed venue, however all those systems lack in an open environment such as marathons. This project aims to solve this problem by using non stationary sensor systems, where low cost sensors are distributed uniformly across the venue and detect very small amount of gases, such as ammonia (NH_3), which is released by the IED. Particularly, the project is focused on NH_3 detection using low-cost off the shelf sensors by mimicking real life scenarios in a lab environment.**

***Index Terms*— improvised explosive devices, NH_3 sensors, explosive detection, open environment**

INTRODUCTION

Improvised explosive devices (IEDs) are compounds or mixtures of compounds that have explosive properties and are easily prepared in simple conditions for example, homemade bombs. They consist of explosive material that has one or multiple chemical compounds and oxygen to oxidize remaining combustible substance [1]. The problem and danger of IEDs are that the chemicals and materials used are easily accessible and can be bought over the counter. For example, ammonium nitrate (NH_4NO_3) is easily accessible. It is used widely for agriculture [2], and fuel oil is found as close as a nearby gas station. Put these two together and an IED is made.

There are many different ways of explosive detection. There is the terahertz technology, coupling sensors, and even canine detection [3]. In airports and stadiums, which are closed areas, there are already some technology that is used able to detect these IEDs, the problem with these are that they are very expensive and they are stationary. They are stationary as in there is a fixed entry point which a person enters, and sensors or equipment are placed at those points. Therefore, it can easily detect IEDs. But what about in an open venue with no entry point? There are no ideal ways yet to solve this problem in an open environment, in example marathons.

On April 15, 2013 two bombs exploded near the finish line of the Boston Marathon. The bombs were IEDs, they were contained in pressure cookers that were hidden in backpacks. Those bombs killed three people and injured at least two hundred and sixty-four pour people [4]. This isn't the only case that IEDs have been used to cause tragedies. There are has been many different times where similar cases have occurred. In 2015 there were 630 explosion related incidents and 400 bombings [5].

This project aims to solve this issue. Several experiments will be performed with low-cost sensors consisting of off the shelf components such as: Adafruit nRF52 development board, MQ-137 ammonia gas sensor, and 5V portable phone battery bank. The sensor is shown in Figure 1. The experiments will test the performance of such sensors such as sensitivity and selectivity, in recreated scenarios. The sensors will be put throughout both an open and closed area with predefined impermeable barriers and see if any ammonia (NH_3) is present. Performing the experiments will give a sense of how the performance of the sensor system is and what the working distances of the sensors are. That will help calculate how many sensors will be needed in an open area to detect NH_3, which exists in very low amounts, such as part ppm level, in explosives and homemade bombs.

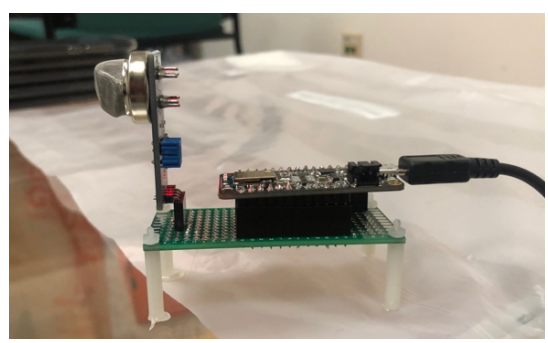

Figure 1: Low-cost sensor with off the shelf components.

Multiple experiments were conducted to test the prototype sensors to assure reliability as well as consistency.

HARDWARE IMPLEMENTATION

The project is to make low cost explosive vapor sensor to detect explosives. To make them as low-cost as possible, the prototype sensor is made up of off the shelf components. The prototype consists of an Adafruit nRF52 development board, MQ-137 ammonia gas sensor, and a 5V portable phone battery bank. The Adafruit development board was about twenty-five dollars [6], the battery was approximately fifteen dollars [7], and the ammonia sensor was approximately thirty-seven dollars [8]. In total it was approximately seventy-seven dollars. Which compared to other sensors is relatively inexpensive.

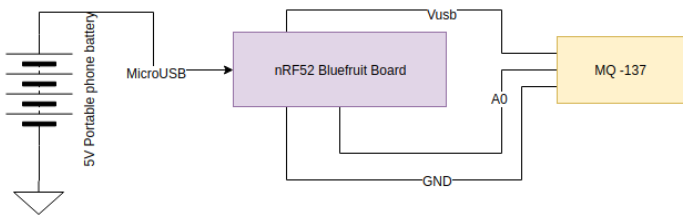

Figure 2: Component Schematic of Prototype Sensor

These components were chosen because of their low cost, availability and capacity to demonstrate the gas sensing mechanism that this project aims to recreate for explosive gases. The MQ-137 has the ability to detect ammonia in the range of 5-500 ppm. The Bluefruit board is a general-purpose microcontroller unit (MCU) with Bluetooth low energy capability. It is responsible for analog-to-digital conversion of the MQ-137's analog out value, as well as broadcasting that value via Bluetooth to a connected Bluetooth client, in example a mobile phone. An app for mobile phones was created so the values can be broadcasted with the Bluetooth and the data can be visually seen and calculated. This will help with experimentation, the data can be recorded and displayed to see sensor sensitivity and readings. This information will be helpful when actual sensor system is developed to make them as efficient and reliable as possible.

The issue with building low cost sensors is that they can possibly be unreliable or not be consistent with the readings. Another issue with the sensors, is that each sensor will have a different gain and offset. This issue however can be solved by just having a base sensor and calibrating the rest of the sensors so they can all have same sensitivity. The hardware was chosen so it can be as low cost as possible, and everything can be purchased off the shelf online at a reasonable price.

EXPERIMENTATION SETUP

Many different experimentation setups were used for this project. Different setups were used to be able to test the different sensitivity distances, the overall sensitivity, and consistency of the sensors. Ammonia was used as the source. Since ammonia is easily accessible at stores, and it is relatively inexpensive to buy. Ammonia is also a product of IEDs, so it was a great option to use. Figure 3 shows the first set up that was used to test the sensors and their performance. At first, the setup was in a closed area with a curtain on one side and the source within that area. This allowed for a small amount of ammonia to escape. Even though that amount of ammonia escaped, when the source was exposed to the sensors, they were very quickly saturated.

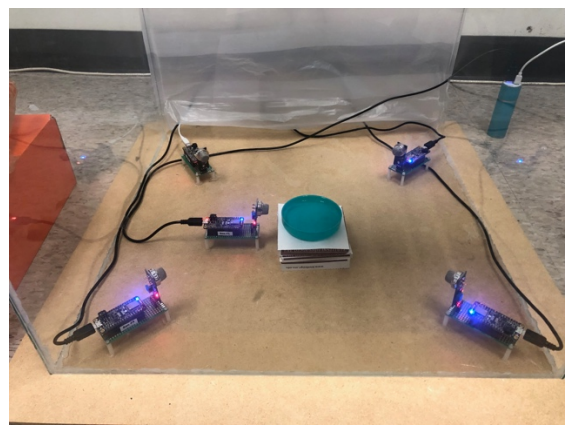

Figure 3: First set up for first experiment

Other experiments were set up in a closed area with different distances. Experiments in an open area were also performed, but outside variables such as air conditioning had negative effects in the experiment. To solve for the saturation of the ammonia with the sensors, an experiment to slow down the dispersion of the source was done. It was done by putting a piece of cloth on top to cover the source as shown in Figure 4.

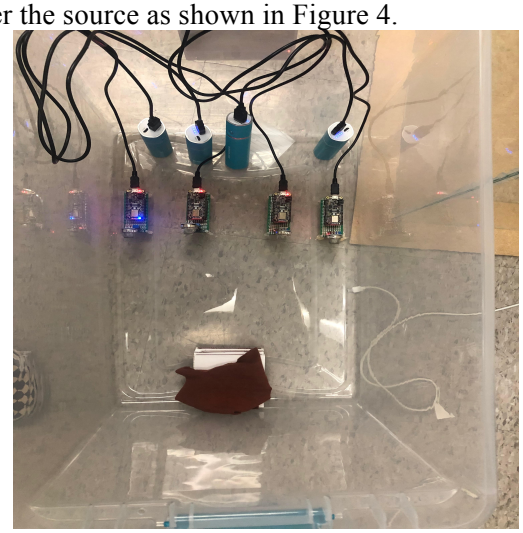

Figure 4: Source is covered with piece of cloth

The experiments were performed by first letting the sensors to preheat for a minimum of two hours, but better data recordings will occur if sensors preheat for twenty-four hours. The sensors were connected via Bluetooth with the gas sensing app on mobile phones to record the data of the sensors. Once the recording starts the first couple of experiments were five minutes with no source, and then the source would be added for another five minutes and recording would stop. For the last experiments, the recording would start the source will not be exposed to the sensors for five minutes, the source would be exposed for five to ten minutes and the source will be removed for five minutes and then source will be exposed again, and so forth.

EXPERIMENT RESULTS

The experiment results were pretty clear. With the experiments done, it was shown that the sensors were able to detect ammonia. As shown in figure 5, it can be seen that all sensors have approximately equal sensitivity, except for sensor number 3. Sensor 3 has higher readings, showing that it is more sensitive than the rest of the sensors.

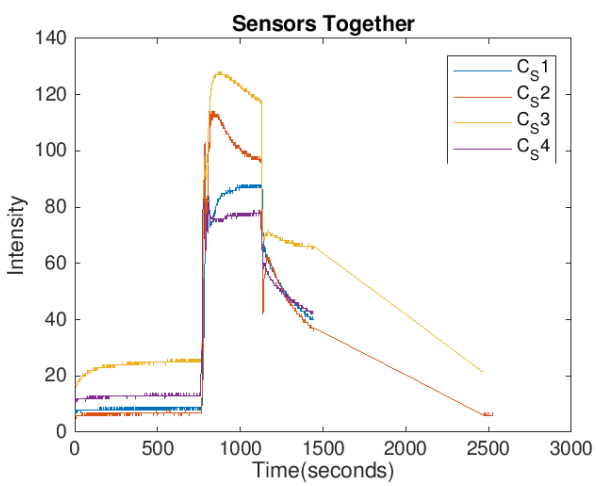

Figure 5: Sensor data showing sensitivity of sensors

Experiments in an open environment were also performed. The experiment took place in a closed room, there was an air conditioning duct which caused a problem. The air conditioning would make the reading of ammonia be lower if the sensor was within the area of which the air was being directed at. In a real-life scenario this can be an issue, but the project has to make sure that the sensors are still operable with these conditions.

Figure 6: Experiment set up in open room

As the experiments progressed, the data would show that saturation would occur very quickly. The slope of the graph was not gradual, it was very steep. To try and solve this issue the source was covered with a piece of cloth to minimize the dispersion time. By doing this it improved the slope of the sensitivity and sensor reading of the source. As shown in figure 7, it can be seen that the slope of when the ammonia was present is more gradual and does not shoot up immediately. This helped with the gain and offset to be calculated so sensors can be calibrated later on.

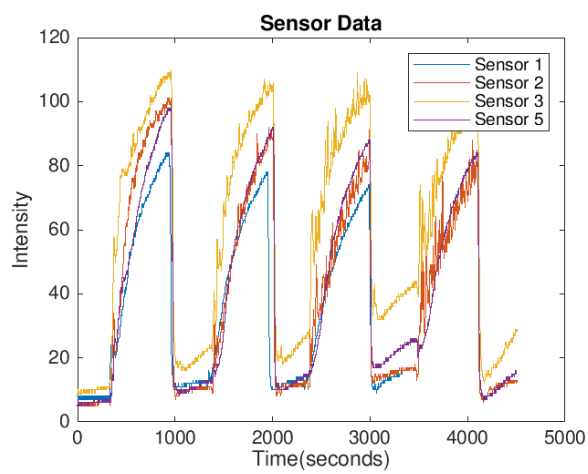

Figure 7: Sensor data for experiment with source covered with cloth

The data shown in figure 7 was used to calibrate the sensors. The intensity was taken at different times and those times and intensities were used to calculate the difference of gain and offset of the sensors. Sensor 1 was used as a base, and the rest of the sensors will be calibrated to that sensor.

The equations used to calibrate the sensors, these examples are using sensor 1 and 2:

- $C_{11}=V_{off1}+G_1*C_1$
- $C_{12}= V_{off2}+G_2*C_1$
- $C_{21}= V_{off1}+G_1*C_2$
- $C_{22}= V_{off3}+G_2*C_2$
- $V_{off1}=-(C_{12}-(G_1'/2)[(C_{11}+C_{21})-(C_{12}+C_{22})]-G_1'C_{11})/2G_1'$
- $V_{off1}-V_{off2}=\Delta V_2$
- $G_1'=G_2/G_1$
- $G_1'= (C_{12}-C_{22})/ (C_{11}-C_{21})$
- $V_{off2}=-(G_1'(C_{11}+C_{21}-2V_{off1})-(C_{12}+C_{23}))/2$

The equations above were used to calibrate the sensors so they can all have the same readings and same sensitivity.

CONCLUSION

This project within the last nine weeks, the sensors were tested and are ready to be calibrated. All the sensors are able to detect ammonia present, and are all at about the same range of sensitivity. Figure 8 shows a calibrated reading of sensor 1 and 2.

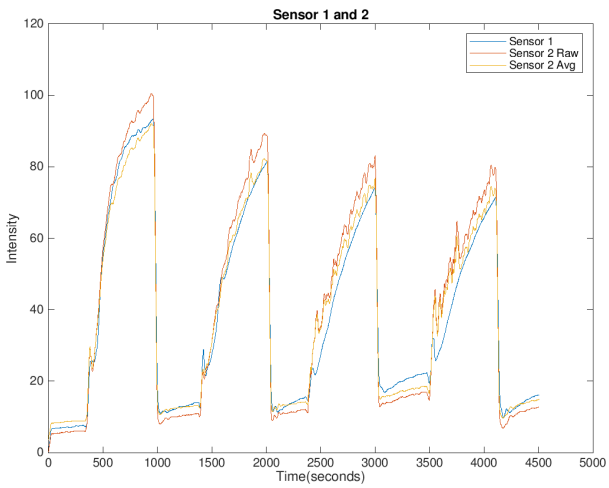

Figure 8: Sensor 1 and 2 data, calibrated and original

More experiments in a more real case scenario will be performed to see how sensors will respond in an actual open area, for example outside. Also, to be able to locate a source in an open area with the sensors. These experiments will be performed to end up improving the sensors overall.

ACKNOWLEDGMENT

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