Development of Formaldehyde Detector

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***Abstract*—The paper was a development of a detector that can sense the presence of formaldehyde in air measured in parts per million (ppm). The prototype used storage device (SD) technology to save real time data. The objective of the study was to design and develop a system that can detect formaldehyde concentration and indicate if the reading was below or above the permissible level for formaldehyde. The device can be used in chemical laboratories and mortuaries for air quality monitoring, to lessen the harmful effects of formaldehyde. Developmental method and prototyping technique were used in the study to come up with a working product of the detector. The microcontroller unit was programmed using C programming language. Tests were conducted using 5ml of formaldehyde placed in 5 liters container to determine the accuracy of the system. The device had obtained an average accuracy of 98.33% for the three trials.**

***Index Terms*—Formaldehyde detector, SD technology, gas detector, air quality monitoring.**

I. Introduction

According to OSHA Fact Sheet, formaldehyde is defined as a colorless, strong-smelling gas often found in aqueous solutions known as formalin [1]. Typically, the amount of formaldehyde in an aqueous solution varies from 30% and 56% by mass [2].

Aside from formalin, formaldehyde is also found in many products such as chemicals, particle board, household products, glues, permanent press fabrics, paper product coatings, fiberboard, and plywood. In industries, it is present in fungicide, germicide and disinfectant [1].

Exposure to formaldehyde is higher in indoors than in outdoors. This is because of the stronger sources and lower air exchange rates [3]. In the Philippines, this substance is completely present in hospitals where dead bodies lie. This is why most patients in hospitals were unknowingly exposed to it. Similarly, formaldehyde is used in laboratories and mortuaries to preserve bodies of humans and animals [4].

Even though there isn't any smoke or harmful materials present in formaldehyde, its presence in air can be considered deadly or dangerous enough. Formaldehyde is considered as a chemical that is highly gaseous. In a certain degree, this substance can cause infection or death. Without an accurate detection in indoor air, formaldehyde may affect human health. It may enter the body through ingestion, inhalation, skin absorption and eye contact [5].

When comes in direct contact, formaldehyde is irritating to tissues. The most common symptoms include irritation of the eyes, nose, and throat, along with increased tearing, which occurs at air concentrations of about 0.4–3 parts per million (ppm). NIOSH states that formaldehyde is immediately dangerous to life and health at 20 ppm [6].

Due to its bad effects in human, OSHA had set several standards for the use of formaldehyde. The permissible exposure limit (PEL) for formaldehyde in the workplace is 0.75 parts formaldehyde per million parts of air (0.75 ppm) measured as an 8-hourtime-weighted average (TWA). The standard includes a second PEL in the form of a short-term exposure limit (STEL) of 2 ppm which is the maximum exposure allowed during 15 minute period. In addition, the action level of 0.5 ppm when calculated as an 8-hour TWA is the standard trigger for increased industrial hygiene monitoring and initiation of worker medical surveillance [1].

Workers who are handling formaldehyde can inhale and absorb. People who are prone to inhalation and exposure of this substance are employees who are working in treatment of textiles and the production of resins, healthcare professionals and mortuary workers such embalmer and medical lab technicians. Teachers and students who are handling formalin or formaldehyde to preserved biological specimens are also at risk with the effect of this substance.

To detect the amount of formaldehyde in a certain area, a formaldehyde detector is used. The main purpose of this device is to sense the presence of formaldehyde concentration, whether it is below or over the limit of toxicity that the body can only tolerate.

Usually, formaldehyde detectors are based from the principles of gas sensors and microcontroller. Gas sensors are devices which detects gas molecules. Most gas detectors follow five functional components which are the transport of air samples, the analysis of these air samples, the identification of the target gas concentration, the comparison of the read gas concentrations to the set alarm levels and the actions to these alarm conditions [7]. Light emitting diodes (LED) and alarm buzzers were the common alarm actions of most gas detectors. The microcontroller unit facilitates the implementation of these five functional components to identify the hazardous levels of gases present in an area.

This paper presents the development of a gas detector that can sense the presence of formaldehyde in an indoor

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environment and display its concentration in part per million (ppm). Utilization of storage device (SD) technology was incorporated in the design for data logging.

II. Objectives

The study aimed to develop a system that can detect formaldehyde levels in ppm. Specifically, it aimed to achieve the following sub objectives:

1) To design and develop a system that can:
   - Display formaldehyde levels in 4×20 LCD.
   - Light the different LED colors based from the detected formaldehyde level:
     a. Green for 0 to 0.5 ppm
     b. Yellow for 0.6 to 1.9 ppm
     c. Red for levels greater than 2 ppm
   - Sound alert buzzer if level exceeded 2 ppm
   - Save real time data to micro SD
   - Turn on exhaust fan whenever formaldehyde is detected
2) To determine the system's accuracy in sensing formaldehyde level.

III. Materials and Methods

Developmental research method was used in the study to come up with a full working scale of the system. Prototyping technique was employed. This included hardware assembly and firmware development.

Hardware development was comprised of PCB making, hardware assembly, casing and pin assignment. Firmware development was comprised of code generation using C language programming, integration of the developed programs into one source code, testing and simulation and error debugging.

MQ138 was the semiconductor gas sensor used for formaldehyde detection as shown in Fig. 1. This sensor featured wide scope detection, fast response, has high sensitivity to formaldehyde, has longer life and can be driven using simple circuit [8].

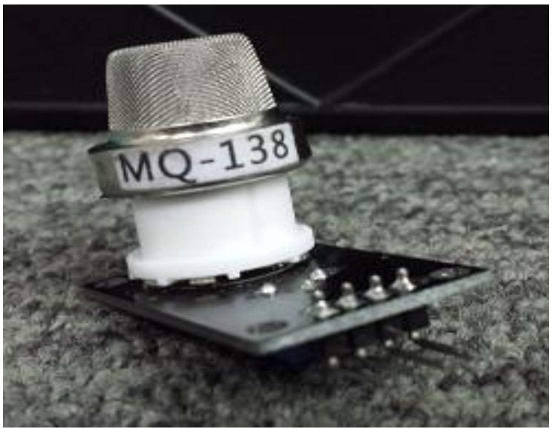


Fig. 1. MQ138 formaldehyde gas sensor.

The microcontroller used shown in Fig. 2 was Atmega 1280 which can hold 1280 kilobytes of program. This served as the brain of the prototype and facilitated the operation of the formaldehyde detector. Input and output peripherals used were all connected to the microcontroller unit.

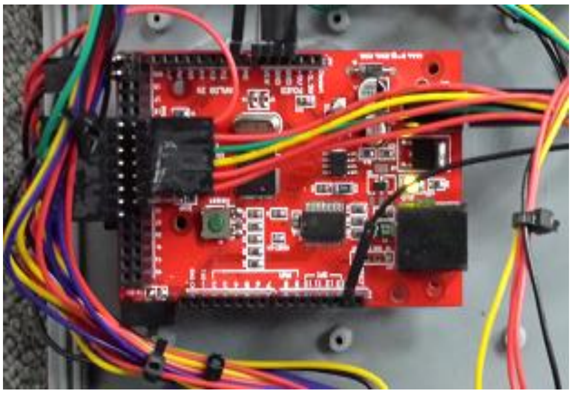


Fig. 2. Microcontroller unit board that housed Atmega 1280.

The detector also utilized storage device (SD) shield shown in Fig. 3. This was added to save secondly readings of the formaldehyde concentration in air.

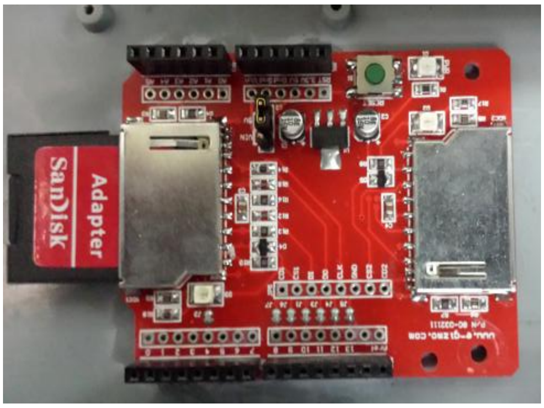


Fig. 3. SD card shield used in the detector.

Other materials used were 4×20 liquid crystal display (LCD), light emitting diodes (LED) of colors green, yellow and red and buzzer to indicate the level of formaldehyde in air. Since the detector can log data, real time clock (RTC) was also used to get current date and time. An exhaust fan was also added in the detector to control or minimize the levels of formaldehyde.

To determine the accuracy of the prototype, it was tested and placed in a 5 liter container where 5 milliliters of formaldehyde was introduced to get 1 parts per million (ppm) of the target gas. Target concentration was computed with respect to the volume of the test environment.

The device was exposed with formaldehyde for 1 minute. Three trials were conducted. The first reading near the target 1 ppm was taken to determine the percent accuracy (%A) of every test as referred to (1). The average accuracy was taken by computing the mean of three trials test.

$$\%A = 1 - \frac{|target\ concentration - first\ value|}{target\ concentration} \times 100\% \qquad (1)$$

IV. Results and Discussions

Fig. 4 shows the block diagram of the system. Once the system had encountered a certain resistivity from the sensor, it will send the reading to the microcontroller. MQ138 was the gas sensor used for formaldehyde detection.

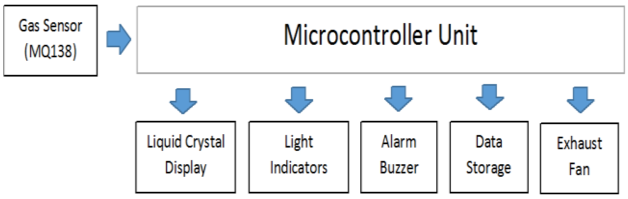


Fig. 4. Block diagram of the formaldehyde detector.

During system start-up, the microcontroller was initialized and performed checking of the real-time clock and storage device as shown in Fig. 5. If properly initialized, the system would display notification message.

Fig. 5. Initialization of RTC and SD functions.

Once the system had encountered a certain resistivity from the sensor, it will send the reading to the microcontroller. The microcontroller converts the resistivity (ρ) to its ppm value as referred to (2). To convert in ppm, resistivity was multiplied with the quotient of the input voltage (Vi) over 1023.

$$\text{ppm} = \rho(Vi/1023) \quad (2)$$

Input voltage of the sensor is at 5Vdc and 1023 was set as conversion constant of byte reading of the microcontroller unit. The concentration reading of formaldehyde will be displayed next to the 4×20 LCD attached to the microcontroller unit.

To test the device's sensitivity and its ability to light corresponding LED, an alcohol was sprayed near the sensor as shown in Fig. 6.

Fig. 6. Test set-up for sensor sensitivity and LEDs.

If the sensed concentration level of formaldehyde is at 0 ppm – 0.5 ppm, green LED lights will be lighted as shown in Fig. 7, as indication that the level of formaldehyde is still permissible.

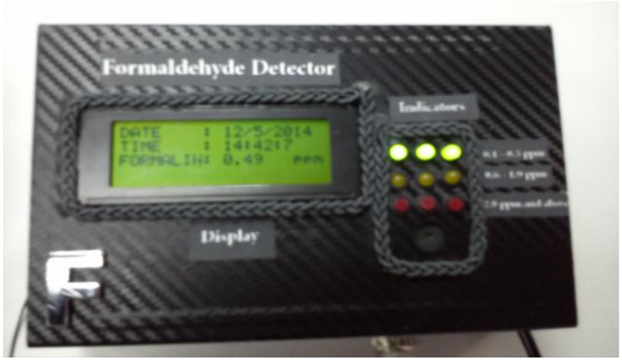


Fig. 7. Green LED lighted as indication that formaldehyde level was at the range from 0-0.5 ppm.

When concentration reading is at 0.6 ppm to 1.9 ppm, yellow LED will be lighted, as shown in Fig. 8, warning people that formalin concentration may bring dizziness and at near the dangerous level.

Fig. 8. Yellow LED lighted as indication that formaldehyde level was at the range from 0.6-1.9 ppm.

However if gas concentration level exceeded 2 ppm, red LED lights will be activated, as shown in Fig. 9 to warn people.

Fig. 9. Red LED lighted as indication that formaldehyde level was at or above 2 ppm.

An exhaust fan was attached to the system to control or minimize the levels of formaldehyde. Every second, the device will read gas level of formaldehyde and it will be saved to the SD shield connected to the microcontroller unit as shown in Fig. 10.

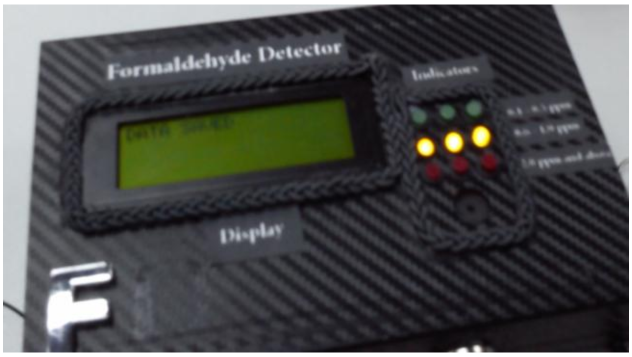


Fig. 10. LCD indicated real-time data was saved to SD card.

However, if SD card was not present, the detector will display "DATA NOT SAVED" as shown in Fig. 11 and will continue reading and displaying formaldehyde levels.

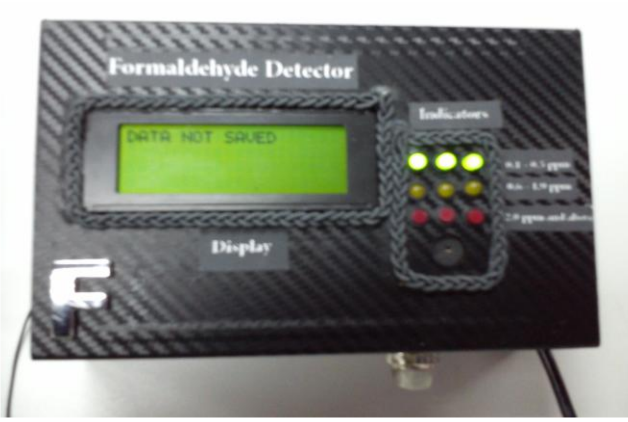
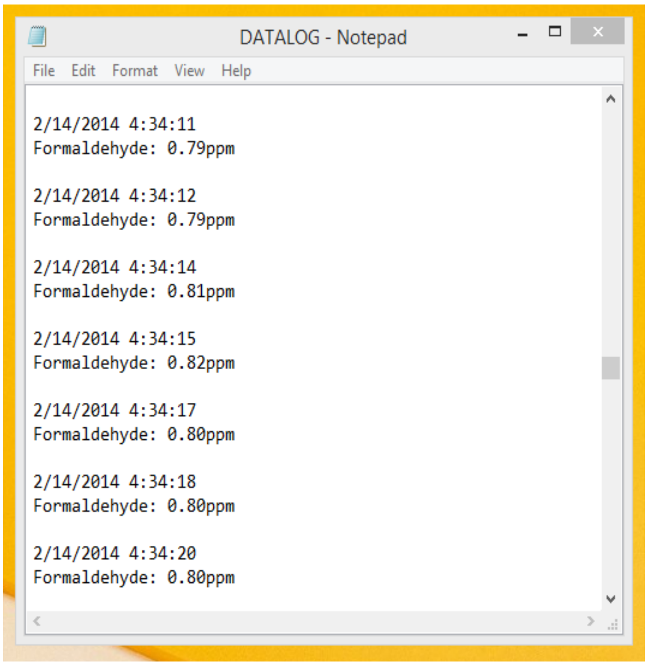


Fig. 11. LCD indicated that there was no SD card attached to the detector.

To determine the accuracy of the device, it was subjected to 5 ml of formalin placed in a 5 liter container box. This results to a target concentration of 1 ppm. Three trials were conducted to test the consistencies of data. Each test had a duration of 1 minute, 30 seconds with the presence of formalin and 30 seconds without formalin. Fig. 12 shows the saved data on SD card. These data were tabulated.


DATALOG - Notepad

File Edit Format View Help

2/14/2014 4:34:11
Formaldehyde: 0.79ppm

2/14/2014 4:34:12
Formaldehyde: 0.79ppm

2/14/2014 4:34:14
Formaldehyde: 0.81ppm

2/14/2014 4:34:15
Formaldehyde: 0.82ppm

2/14/2014 4:34:17
Formaldehyde: 0.80ppm

2/14/2014 4:34:18
Formaldehyde: 0.80ppm

2/14/2014 4:34:20
Formaldehyde: 0.80ppm

Fig. 12. SD card saved readings.

TABLE I: DETECTOR READINGS WITH THE PRESENCE OF FORMALDEHYDE

Time	Formaldehyde Concentration (ppm)		
(seconds)	Trial 1	Trial 2	Trial 3
1.0	1.00	1.95	0.96
2.0	1.24	1.97	1.07
3.0	1.35	1.98	1.03
4.0	1.43	1.01	1.09
5.0	1.49	1.03	1.13
6.0	1.52	1.04	1.17
7.0	1.54	1.09	1.24
8.0	1.55	1.10	1.27
9.0	1.55	1.13	1.30
10.0	1.53	1.14	1.30
11.0	1.49	1.14	1.30
12.0	1.49	1.18	1.29
13.0	1.47	1.18	1.29
14.0	1.49	1.18	1.30
15.0	1.50	1.20	1.30
16.0	1.50	1.20	1.31
17.0	1.50	1.19	1.30
18.0	1.51	1.19	1.29
19.0	1.50	1.20	1.30
20.0	1.47	1.21	1.30
21.0	1.47	1.21	1.30
22.0	1.48	1.20	1.31
23.0	1.48	1.21	1.30
24.0	1.48	1.21	1.32
25.0	1.47	1.22	1.34
26.0	1.49	1.22	1.35
27.0	1.31	1.25	1.37
28.0	1.31	1.24	1.38
29.0	1.32	1.24	1.38
30.0	1.32	1.26	1.40

Table I shows the test result for the three trials of formaldehyde. The system was able to detect the target 1 ppm at 1 second for trial 1, 4 seconds for trial 2 and 2 seconds for trial 3. Repeatability and consistencies of data was obtained. Readings of gas concentrations are very near with each other. After the formaldehyde was removed from the box, it was observed that concentration reading decreases as shown in Table II.

TABLE II: DETECTOR READINGS AFTER FORMALDEHYDE WAS REMOVED

Time	Formaldehyde Concentration {ppm)		
(seconds)	Trial 1	Trial 2	Trial 3
31.0	1.49	1.17	1.37
32.0	1.37	1.13	1.28
33.0	1.37	1.09	1.29
34.0	1.32	1.08	1.21
35.0	1.26	1.07	1.20
36.0	1.22	1.04	1.16
37.0	1.18	1.04	1.16
38.0	1.17	1.02	1.14
39.0	1.15	1.00	1.12
40.0	1.14	1.00	1.13
41.0	1.13	0.98	1.09
42.0	1.11	0.97	1.08
43.0	1.10	0.97	1.08
44.0	1.08	0.94	1.07
45.0	1.07	0.93	1.05
46.0	1.07	0.92	1.06
47.0	1.05	0.92	1.04
48.0	1.05	0.92	1.04
49.0	1.03	0.90	1.03
50.0	1.02	0.91	1.02
51.0	1.10	0.90	1.02
52.0	1.10	0.90	1.03
53.0	0.99	0.91	1.01
54.0	0.99	0.88	1.01
55.0	0.98	0.89	1.01
56.0	0.96	0.88	0.99
57.0	0.95	0.87	1.01
58.0	0.96	0.89	0.98
59.0	0.93	0.88	0.99
60.0	0.95	0.87	0.98

Fig. 13 shows the graph of the test results. Based from the data, the system obtained an accuracy of 100% for the first trial, 99% for trial 2 and 96% for trial 3. The average accuracy of the system was 98.33%.

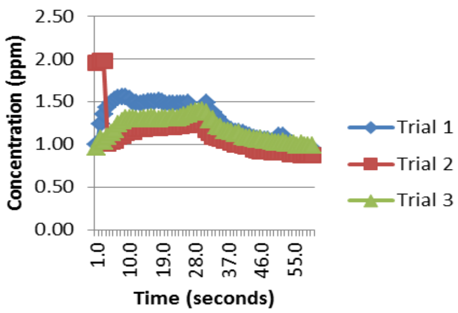


Fig. 13. Graphs of the test results.

V. Conclusions

Based from the findings, the following conclusions were drawn:

1) Development of formaldehyde detector with the capacity of sensing formaldehyde concentration in ppm, saving the reading in SD and activating a control fan is important to work places where formaldehyde is commonly used. The developed device was proven to be sensitive to formaldehyde concentration. The device performed the following functions efficiently:
   - Initialized the SD card to save real time data of formaldehyde concentration level
   - Produced warning sound and lights to indicate correct formaldehyde concentration level
   - Turned on exhaust fan whenever formaldehyde is detected
2) The system obtained an average of 98.33% accuracy in measuring formaldehyde concentration level.

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