Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2020, 7(6):1-12

Research Article ISSN: 2394 - 658X

Design, Implementation and Testing of a Microcontroller-based Formalin Detection Kit

Abdulla Al Mamun[1], Aklima Begum[2], Ariful Islam[3]*, Ashraful Mamun[4], Md. Asaduzzaman[5], A F M Mustafizur Rahman[6], M Nazmul Haque Siddique[7] and M Shafiul Alam[8]

[1,2,3,4,5,8]Department of Electrical and Electronic Engineering, University of Dhaka, Bangladesh
Emails: [1]mamun.eeedu.bd@gmail.com, [2]akhi.eeebd97@gmail.com, [4]ashraful.mamun@eee.du.ac.bd, [5]sajib454@yahoo.com, [8]msalam@du.ac.bd
[6]Department of Applied Chemistry and Chemical Engineering, University of Dhaka, Bangladesh, Email: banglatapu@yahoo.com
[7]School of Computing, Eng& Intelligent Systems, Intelligent Systems Research Centre, University of Ulster, NI, UK, Email: nh.siddique@ulster.ac.uk
*Email: [3]*Corresponding author:ariful.islam@du.ac.bd*

ABSTRACT

Formaldehyde contamination has increased alarmingly and terrifyingly in Bangladesh in almost all kinds of foods, vegetables, poultry and dairy products that pose a potential threat to public health. In this paper we have designed and implemented a microcontroller based formalin detection kit. Since formalin is self-vaporized so the presence and concentration of formalin are detected by sensing the presence of formaldehyde gas using a volatile organic compound (VOC) sensor. The output of a VOC sensor is directed to the microcontroller unit (MCU) which converts the electrical signal to a readable digital value. The hardware module is interfaced with an android smartphone app using the Bluetooth module. A complete device with a suitable display, alarm system and Bluetooth connectivity with a mobile phone is implemented and tested. The kit is tested and results are validated with sample solutions prepared in the laboratory containing formalin of different levels of concentrations. Industrial grade pure formalin is also used to prepare sample solutions to test the kit. The kit displays the level of formalin present in test samples. Results show that the detected level of formalin is consistent with formalin concentration used in solution samples. It also displays the temperature and humidity of the sample. Moreover, it has an alarm system when an excessively high level of formalin is detected in a sample which is regarded as either "unsafe" or "danger" for health. Furthermore, the comparative assessment shows that the developed kit can detect & measure the presence & level of formalin present in samples under investigation both qualitatively and quantitatively which is a clear advantage of our device over existing ones.

Key words: E-nose, Formaldehyde, Organic compound sensor, Bluetooth, Microcontroller

INTRODUCTION

Formalin, a liquid form of formaldehyde (35-40% aqueous solution) is widely used in many industries as a starting point to produce different raw materials and compounds [1]. Many useful products (i.e. automobile industries) are made where derivatives from formaldehyde are carefully utilized. But if excessive amount formalin is employed specially as a food preservative it could cause adverse effects on human health like burning sensation in the eyes, nose, and throat etc. Due to its carcinogenic property it is prohibited to use formalin as a food additive in many countries in the world [2]. Several national and international cancer research institutes (i.e. IARC, NCI) have studied on the exposed people to formaldehyde in their work also highlighted that there is a high risk of leukemia as well as brain cancer to these individuals compared with others [3,4].

In Bangladesh situation is much worse as formalin has been added intentionally to foods as a preservative to look fresh and artificially increase the life time of foods [5]. As one of the most populous developing countries in the world, Bangladesh has experienced rapid agricultural and industrial growth. Coinciding with this growth, formaldehyde, pesticides and toxic chemical pollution has also increased terrifyingly in Bangladesh, particularly in almost all kinds of foods, vegetables, poultry and dairy products. A study on fishes collected from several local markets in Dhaka shows that about 50% of the total fish contains formalin [6]. Moreover, study on marketing status of formalin treated fishes in six different districts of Bangladesh is reported in [7].

Considering the increasingly alarming abuse of formalin and lack of portable, user-friendly, and effective detecting kits, we realize the necessity to an electronic kit that can detect formaldehyde in edible products instantly and correctly. To design the kit, a formaldehyde sensor head is used to detect formalin in food samples under investigation. An electronic circuit-based on a microcontroller is designed to process the signal in order to detect the presence and show the concentration of formalin, if present in a food sample. The device will be connected to a smartphone with Bluetooth connectivity that can send data to a mobile app for the end-users. A mobile app is also designed to display results on smartphones.

Detection of formaldehyde in contaminated foods can be done in the laboratory analytically which requires state of the art equipment's and do not come with filed portability. Among these methods, gas chromatography-mass spectrometry (GC–MS) [8], and high-performance liquid chromatography (HPLC) [9] have been reported for the determination of formalin in food. A cost-effective technique for formaldehyde detection is Electrochemistry [6]. But in real life applications there is a high chance of signal interference with many other compounds. Fluorometric methods [10, 11] is another formaldehyde detection technique but since the production of particular fluorescent compounds that react with formaldehyde is very hard to get it is not very cost effective.

Several colorimetric methods for on-site formaldehyde detection have been proposed which provide rapid detection with visual qualitative feedback. They are based on the basic chemical reaction to induce a color change, such as chromotropic acids [12], sol-gel matrix [13], polymers [14], and porous glass [15]. But these are not biodegradable and therefore cause environmental problems. A solution to this is provided in [16], where a biodegradable colorimetric film has been proposed for determination of formaldehyde contamination. For better sensitivity, colorimetric film using gold nanoparticles and silver nanoparticles has also been reported [1]. However, colorimetric methods provide only qualitative assessment. For quantitative analysis, spectrophotometers are required [16] which limit the field applications.

Formaldehyde Meter Z-300 [2] had been widely used in Bangladesh for detecting formalin in food markets. But there was a certain drawback according to a report published in 2015 to use this machine as existence of formaldehyde in fresh and wet fruits depends on time, temperature, and moisture. Moreover, if the fruits stay in warm temperature for a longer period of time then this machine detects slightly higher level of formaldehyde. So, accurate reading was not found for fruits in warm temperature [17]. Later, a formalin detection kit for fish using chemical solutions was developed by Bangladesh Council for Scientific and Industrial Research (BCSIR) [6].The limitation of this kit is that, it probably suitable for expert users only to test collected samples in the laboratory. Moreover, detection depends on physical inspection of color papers used in test that require good eye sights and attention as well. Another commercial product FOODsniffer is a smart portable kitchen gadget designed by Swiss scientists to check if meat, poultry, fish etc is fresh or not. Many volatile organic compounds are emitted by decomposing beef, poultry and fish that can be detected by volatile organic compound (VOC) gas sensor employed in FOODsniffer [18]. The freshness of food whether it is harmful for human health can be checked by this kit. Limitation of this device is that, it gives only qualitative assessment of food samples under investigation whereas quantitative indication of any/specific harmful chemicals/agents present in food samples is missing that could limit its use in many applications, especially for law enforcing agencies and food inspectors to monitor quality and contamination of food, if any.

HARDWARE DESIGN AND IMPLEMENTATION

Our proposed system aims to include both qualitative and quantitative assessment of food samples. Formaldehyde can be naturally present in raw foods at low levels. This makes the quantitative analysis a certain necessity to detect those food samples where formaldehyde of high concentration has been added intentionally.

Formaldehyde is a volatile organic compound with a low boiling point (-19° C). This causes large numbers of molecules to evaporate from the aqueous solution of the compound (Formalin) and enter the surrounding air [19]. This property can be used to determine the concentration level of formaldehyde in samples. Because, the concentration in surrounding air is directly dependent on the concentration in the sample. In open air, diffusion will occur quickly but if the sample is kept in a closed container better results can be obtained. The conductivity in sensor changes with the concentration of formaldehyde [19]. Higher the concentration is, higher the conductivity in sensor gets which is based on a metal oxide semiconductor material on the ceramic substrate of sub-miniature Al_2O_3[19]. This conductivity changes result an output signal that is tantamount to the gas concentration (ppm).

Schematic diagram of the formalin detection kit is shown in Fig. 1. HCHO sensor is used as input device which is placed very near to food sample under investigation and the concentration of formalin are displayed in smartphone android app. Using Bluetooth module, the hardware of microcontroller-based formalin detector is interfaced with android smartphone app which is named “Formalin Detector”. Based on the concentration of formalin present in food, this app shows the status of foods along with the concentration value.

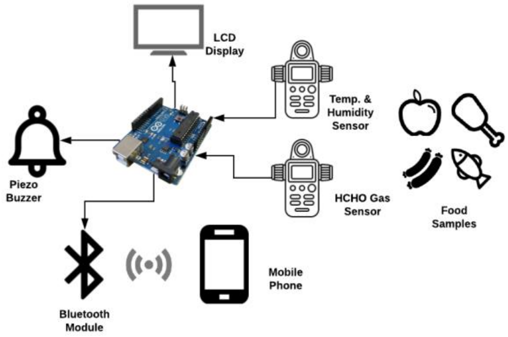

Fig. 1 Schematic Diagram of the Formalin Detector Device

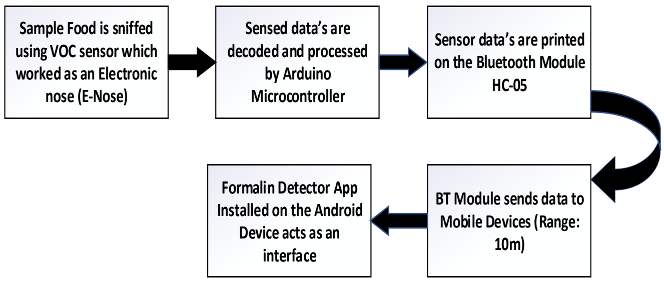

Fig. 2 Working Principle of the Formalin Detector

This formalin detector shows three different statuses based on the concentration of formalin present. It considers a food as “safe” if it has negligible amount of formalin, as “unsafe” if it has moderate concentration of formalin, as “danger” if it has high level of formalin. The working principle of the microcontroller-based formalin detector is shown in Fig.2. It is straightforward. The sample food will be sniffed using the sensor. For better measurement, the food should be kept in a closed container. From there, the sensed data values will be processed by microcontroller. Depending on the defined threshold values in the code it will produce different results and status of the food. Then, the results will be broadcast within short range (Approx. 10m) using the Bluetooth module HC-05. Any android device within that range where the app is installed can receive that data. Finally, if the app is kept open the results for a sample sent using Bluetooth module will be visible on the smartphone’s display.

The microcontroller Atmega 328/P is interfaced with other components: display unit, piezo buzzer, sensor, and bluetooth module. The Atmega328/P achieves the outputs close to 1 MIPS per MHz. This allows designing the device with optimized power consumption versus processing speed.

Sensor

Two types of sensor are needed to make the device. One is Humidity Sensor and another one is temperature sensor. A combination of this both can be found by using DHT sensor that contains two parts: a capacitive humidity sensor and a thermistor [20]. This is required to assess the temperature and humidity of the sample food if kept in a closed container. DHT sensor has thermistor capable of operating temperature range 0-50°C [20].

Bluetooth Module

For short distance communication and range not more than 10 meters a wireless technology standard like Bluetooth can be employed. The access method of bluetooth module is time division multiple access (TDMA).In this research work HC-05 is used as a Bluetooth module. This Bluetooth module performs well as a Serial Port Protocol module and it has a clear wireless serial connection system [21].

VOC Gas Sensor

In this work, a Grove-HCHO Sensor is employed as a semiconductor volatile organic compound (VOC) gas sensor. If the concentration of VOC gas changes, its conductivity also varies. This conductivity can be transformed by using an external circuit to an output signal that corresponds to the gas concentration (ppm) [22]. The most important feature of this sensor is that its range of detection of gas concentration is from as low as 1ppm to above.

Piezo Buzzer

Piezo buzzer is an electronic device that can produce sound. It has simple procedure to make sound with microcontroller unit. It works (produces an alarming sound) by applying a mechanical pressure on certain materials called as piezoelectric materials when it is introduced with an alternating electric field [23].

Microcontroller Programming Compiler

The Arduino which is based on Atmel microcontroller unit is programmed solely by using C programming language. Programming has been done for four separate components: LCD display unit, DHT sensor, Bluetooth module, VOC sensor.

Complete Kit

The detector kit is shown in Fig. 3. It consists of five components: microcontroller unit, display unit, piezo buzzer, temperature and humidity sensor, and Bluetooth module. All components are housed in a transparent box. There is a small opening in the box for the sensor so that it can be held near samples.

Fig. 3 Developed Formalin Detection Kit (Top View)

ANDROID APPLICATION DEVELOPMENT

For developing the Android app, MIT app inventor (version 2) is used which is a cloud based integrated development environment (IDE).The programming language used here is termed as block programming[24]. We can design the user interface by visual programming which can be done by using this drag-and-drop feature. A user interface of particular interest can be developed by using web-based graphical user interface (GUI) builder. The App Inventor programming environment has three key sections which is App Inventor: The Designer, the Blocks Editor and Android Emulator.

App Interface Design

For developing our app, we used the following components from the palette-

i. User interface palette- Fourteen Labels (Label1 to Label14) & one ListPicker (ListPicker1) are selected. All of these are visible components. That means, when user will open the app these components will be used for showing instructions, to choose and tap as button, for displaying the results, etc. Label12 to Label14 will be used to show the instructions for how the use the device properly for detecting formalin in a sample food. Label9 is used to indicate whether the device is connected with the app or not. Initially, it is set as 'Not Connected' (When the device is not connected with smartphone, the app interface shows the text 'Not Connected' in red color). ListPicker1 is used as a button to tap whose text is set as 'Get'. The user will be required to press the button when he/she needs to analyze a sample food. Label1 to Label10 is used for displaying the results (Formalin conc., temperature, humidity, status of the food, etc.) received from our device. Initially, their texts are set as empty.

ii. Connectivity palette- two nonvisible components are used- BluetoothClient& Clock which are the key components of this app. BluetoothClient is required for connecting the app with the bluetooth when the smartphone's bluetooth is kept on. Clock is required to provide the instant in time when the app will look for new data coming from the device.

Developed Program

After designing the interface, the flow chart of the program is developed and then the code is written, debugged and finally tested. The flow chart of the program is shown in Fig. 4.

At the beginning, Label1 to Label10 text will be set as empty list and ListPicker1 text as 'Get'. When ListPicker1 will be picked, it will display the paired bluetooth addresses and their names. Upon selection, if the device's bluetooth address is connected, Lebel9 text will be changed to 'Connected' and the text color will be green. Otherwise, Label9 text will be 'Not Connected' in red color. A global variable 'Global Data' is initialized and is set equal to received text from bluetooth module. 'Global Data' will be split at each comma (,) available at received text and split sections will be displayed sequentially on Label1 to Label10. After displaying, the 'Global Data' will be cleared and thus will be ready for receiving new set of data. Anytime the back button of the phone is pressed, the app will be closed.

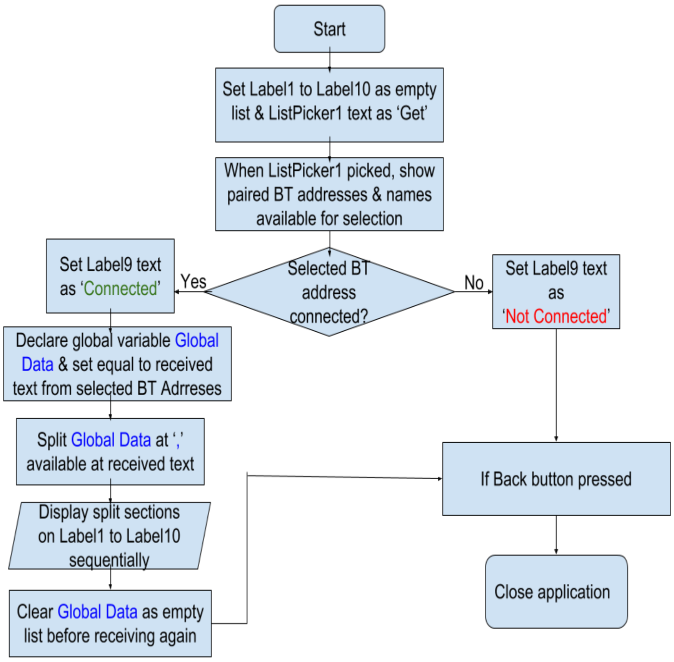

Fig. 4 Flowchart of the Program

Now, the several parts of the written program are explained below:

Segment One

This segment of the program shown on Fig. 5 is used for two functions. Block at the right is used so that when user will press the back button of the mobile device, the app will close itself.

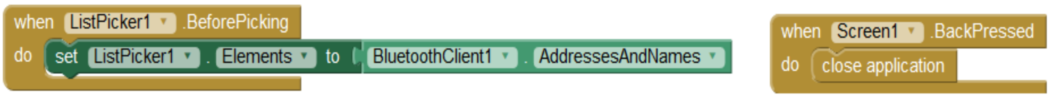

Fig. 5 Segment One - Highlights Two Functions

Block at the left defines the ListPicker1 (which will user see as a 'Get' button). Its elements are set as paired bluetooth addresses & names with the android device so that when user press the button it will show the paired bluetooth addresses (48 bit) which is unique for every bluetooth device & names associated with it. A new screen as shown in Fig.6 will emerge.

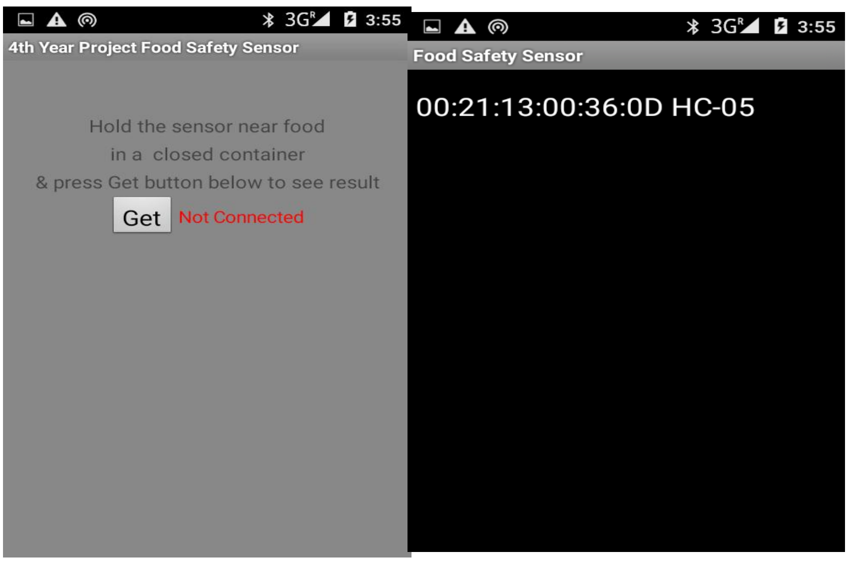

Fig. 6 Screen of the App (Left-Side) and Another Screen (Right-Side) where Displays Bluetooth Addresses

Segment Two

Segment two is shown on Fig. 7. Here, when ListPicker1 picked, the program will call the BluetoothClient1 (non-visible connectivity component) which will deploy connection with the formalin detector device. When the device is connected, the Label9 text will be changed to 'Connected'. The previously shown instructions for proper use of the device will disappear as Label12 to Label14 visibility will be set to false. That means, they will no longer appear on the screen. Otherwise, Label9 text will remain as before.

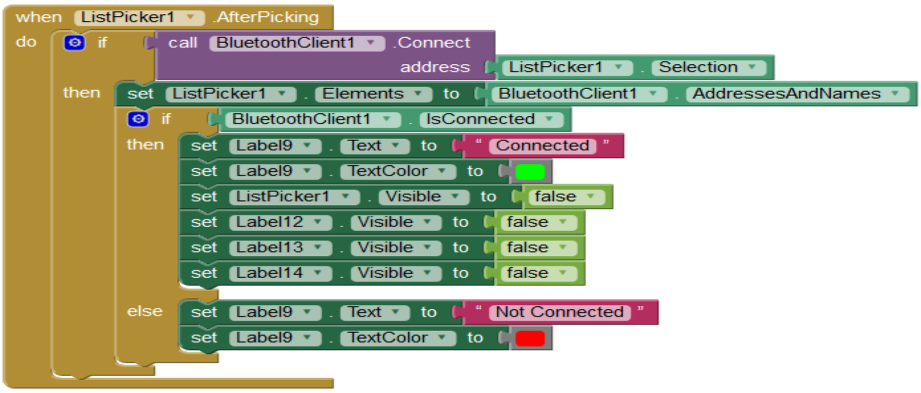

Fig. 7 Segment Two which Highlights Bluetooth Module Address & Name

Segment Three

Here at Fig. 8, we declare a global variable 'Global Data' and initialize its value as empty list. Empty list will not contain any character or word. A global variable can be used anywhere in the program. But a local variable can be used only in one segment of the program.

Fig. 8 Segment Three which Highlights the Declaration of Global Variable

Segment Four

The final segment of the program is shown on Fig. 9 which is used for displaying the results of the sample taken. With each pulse (A defined time interval in milliseconds) of the Clock1, BluetoothClient1 will receive text from the device sent through an UTF-8 encoding, and the program will set the Global Data equal to the received text. The Global Data is split into 9 index lists separated by ',' available in the received text, and each index list is shown in Label1 to Label10 (Except Label9) sequentially.

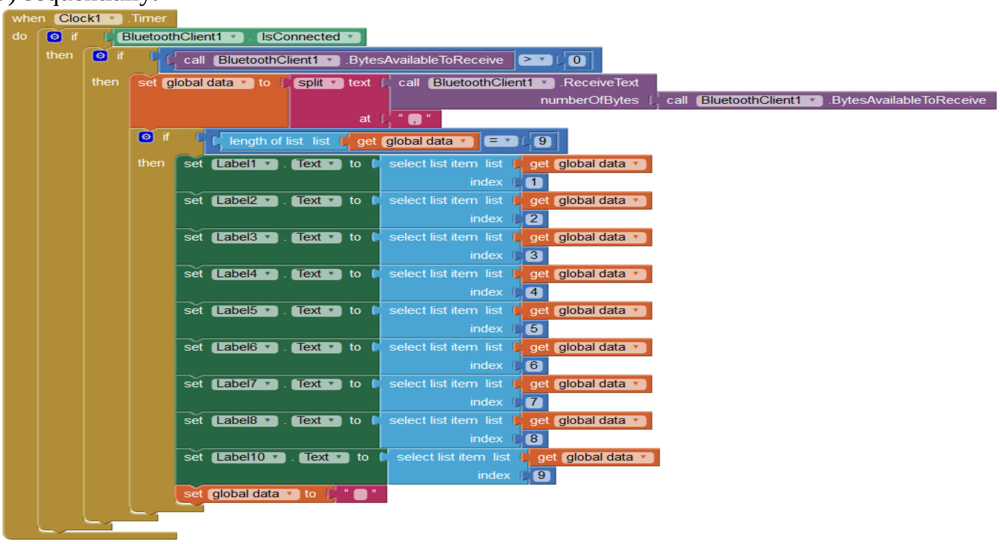

Fig. 9 Segment Four which Used for Displaying the Result of the Sample Taken

Label1 and Label2 is used for displaying formalin concentration. Label3, Label4 and Label5 is set for displaying status and necessary actions required for the sample food. And finally, Label6 to Label10 is used for displaying temperature and humidity respectively. After then, Global Data is cleared (Set to empty text) before displaying the results of next sample taken.

RESULTS AND DISCUSSIONS

After installing the app on an android smartphone, we connected the whole hardware device with that smartphone using bluetooth module HC-05. For testing, we decided to use our device on formaldehyde solutions with different concentrations obtained from the Department of Applied Chemistry and Chemical Engineering, University of Dhaka and Beximco Pharmaceuticals Company Ltd, the leading pharmaceutical company in Bangladesh. When we kept the sensor near the sample solution, the android app displayed the sensor value, humidity, temperature, status and also the necessary instructions.

Data set for Experiment-1

In our first experiment we took 1ml HCHO for measuring the concentration of formalin using our device and write down the value of sensor when it is shown on the smartphone app. Then we mixed the previous sample with 1ml $H2O$ to make the formalin concentration one half of the previous one. Thus, we repeated this process and the sensor values are recorded below in Table-1.

Table-1 Formalin Concentration and Sensor Value (Experiment-1)

SL. No.	Concentration of water and formaldehyde	Sensor Value (ppm)
01	1 ml 40% HCHO	656
02	1 ml 40% HCHO + 1ml H_2O	577
03	1 ml 20% HCHO + 1ml H_2O	571
04	1 ml 10% HCHO + 1ml H_2O	481
05	1 ml 5% HCHO + 1ml H_2O	401
06	1 ml 2.5% HCHO + 1ml H_2O	304
07	1 ml 1.25% HCHO + 1ml H_2O	252
08	1 ml 0.625% HCHO + 1ml H_2O	196
09	1 ml 0.3125% HCHO + 1ml H_2O	132
10	1 ml 0.15625% HCHO + 1ml H_2O	96
11	1 ml 0.078125% HCHO + 1ml H_2O	80
12	1 ml 0.0390625% HCHO + 1ml H_2O	70
13	1 ml 0.01953125% HCHO + 1ml H_2O	67
14	1 ml 0.009765625% HCHO + 1ml H_2O	67

Data set for Experiment-2

As with the previous case, we collected the formalin and then mixed it with water to obtain formalin solutions with different concentrations.

Table -2 Formalin Concentration and Sensor Value (Experiment-2)

SL. No.	Concentration of water and Formaldehyde	Sensor Value (ppm)
01	1 ml 40% HCHO	630
02	1 ml 40% HCHO + 1ml H_2O	602
03	1 ml 20% HCHO + 1ml H_2O	529
04	1 ml 10% HCHO + 1ml H_2O	480
05	1 ml 5% HCHO + 1ml H_2O	401
06	1 ml 2.5% HCHO + 1ml H_2O	326
07	1 ml 1.25% HCHO + 1ml H_2O	261
08	1 ml 0.625% HCHO + 1ml H_2O	211
09	1 ml .3125% HCHO + 1ml H_2O	148
10	1 ml 0.15625% HCHO +1ml H_2O	118
11	1 ml 0.078125% HCHO + 1ml H_2O	85
12	1 ml 0.0390625% HCHO + 1ml H_2O	80
13	1 ml 0.01953125% HCHO + 1ml H_2O	74
14	1 ml 0.009765625% HCHO + 1ml H_2O	73

Data set for Experiment-3

The experiment is repeated again for the third time and data are recorded in the following table.

Table -3 Formalin Concentration and Sensor Value (Experiment-3)

SL. No.	Concentration of water and Formaldehyde	Sensor Value (ppm)
01	1 ml 40% HCHO	541
02	1 ml 40% HCHO + 1ml H_2O	477
03	1 ml 20% HCHO + 1ml H_2O	417
04	1 ml 10% HCHO+ 1ml H_2O	333
05	1 ml 5% HCHO + 1ml H_2O	257
06	1 ml 2.5% HCHO + 1ml H_2O	207
07	1 ml 1.25% HCHO + 1ml H_2O	137
08	1 ml 0.625% HCHO + 1ml H_2O	98
09	1 ml .3125% HCHO + 1ml H_2O	85
10	1 ml 0.15625% HCHO + 1ml H_2O	80
11	1 ml 0.078125% HCHO + 1ml H_2O	75
12	1 ml 0.0390625% HCHO + 1ml H_2O	64
13	1 ml 0.01953125% HCHO + 1ml H_2O	62
14	1 ml 0.009765625% HCHO + 1ml H_2O	60

Data set for Experiment-4

In experiment 4, we collected industrial grade pure formalin from Beximco Pharmaceuticals Company Ltd. We note down the sensor values for different concentrations of formaldehyde in the following table.

Table -4 Formalin Concentration and Sensor Value (Experiment-4)

SL. No.	Concentration of water and Formaldehyde	Sensor Value (ppm)
01	37% HCHO	702
02	37% HCHO + 1ml H_2O =18.5% HCHO	701
03	18.5% HCHO + 1ml H_2O = 9.25% HCHO	701
04	9.25% HCHO + 1ml H_2O = 4.625% HCHO	664
05	4.625% HCHO + 1ml H_2O = 2.3125% HCHO	600
06	2.3125% HCHO + 1ml H_2O = 1.15625% HCHO	529
07	1.15625% HCHO + 1ml H_2O = 0.578125% HCHO	403
08	0.578125% HCHO + 1ml H_2O = 0.2890625% HCHO	229
09	0.2890625% HCHO + 1ml H_2O = 0.14453125% HCHO	197
10	0.14453125% HCHO + 1ml H_2O = 0.072265625% HCHO	133
11	0.072265625% HCHO + 1ml H_2O = 0.0361328125% HCHO	107
12	0.0361328125% HCHO + 1ml H_2O = 0.01806640625% HCHO	80
13	0.018*06640*625% HCHO +1ml H_2O = 0.009033203125% HCHO	62
14	0.009033203125% HCHO + 1ml H_2O = 0.0045166015625% HCHO	62
15	0.0045166015625% HCHO + 1ml H_2O = 0.00225830078125% HCHO	60

Data from all experiments are plotted on a single two-dimensional graph. Concentration of formalin and sensor value are displayed in X-Y-axis. Sensor value is found maximum for 40% formaldehyde which is termed as pure formalin solution. As the formaldehyde concentration in the solutions is decreased, the sensor value is also decreased as it should be. It is to be noted that, the sensor does not display the percentage concentration of the formaldehyde in which we generally measure, rather its unit is in parts per million (ppm) [19].

Volatile organic compound (VOC) measurements depend on medium, temperature, concentration of gas, humidity, etc. Sensor values from all sets of data do not start from zero rather they start from 50-80 which indicates the lowest concentration of formaldehyde. Then, as the concentration is increased, the sensor value increases linearly. When the concentration of formalin is very large, the sensor value goes into saturation and hold a constant value.

Fig. 10 shows the concentration of Formalin (at X-axis) vs. Sensor Value (at Y-axis) of experiments-1- 4. The graph is almost linear when the concentration of formalin is about 5-10%. When the concentration of formalin is above 10%, the concentration of Formalin vs. Sensor Value graph is a nonlinear one.

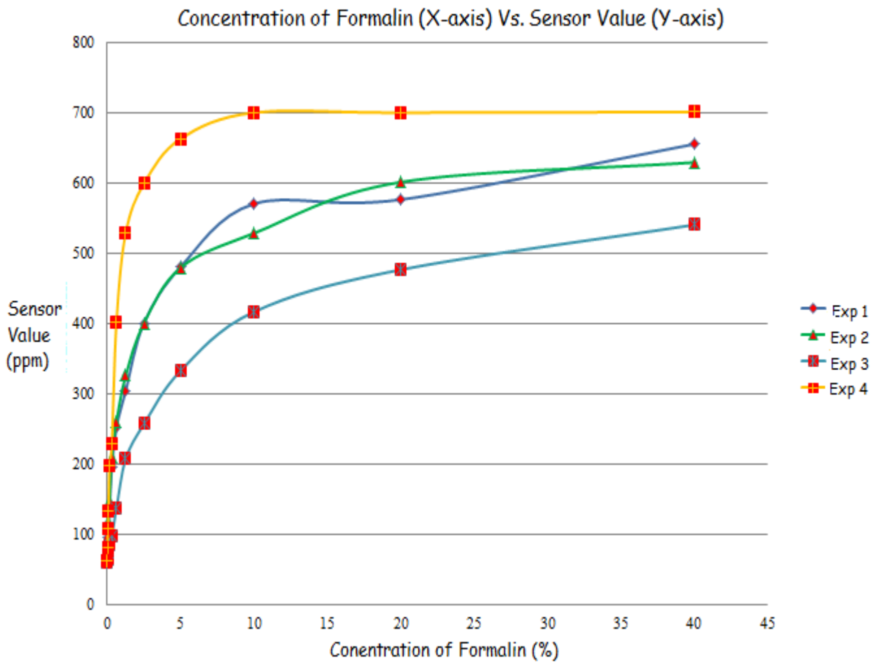

Fig. 10 Graph Shows on Combined for the Data of Experiments 1, 2, 3, and 4

It is mentionable that, the values from experiment- 4 are much higher than the other ones because of its industrial grade purity.

App Screenshots for Different Concentrations

The designed android app shows three different status of sample fool based the on concentration of formalin present. These are shown in Fig. 11. Here, we defined two different threshold values of the sensor at 150 and 300 ppm. When data taken from a sample cross the lower threshold, it will display "Unsafe" status and if it crosses the upper threshold, it will display "Danger" status. The threshold values can be easily changed in the program to match the national and international safety limits.

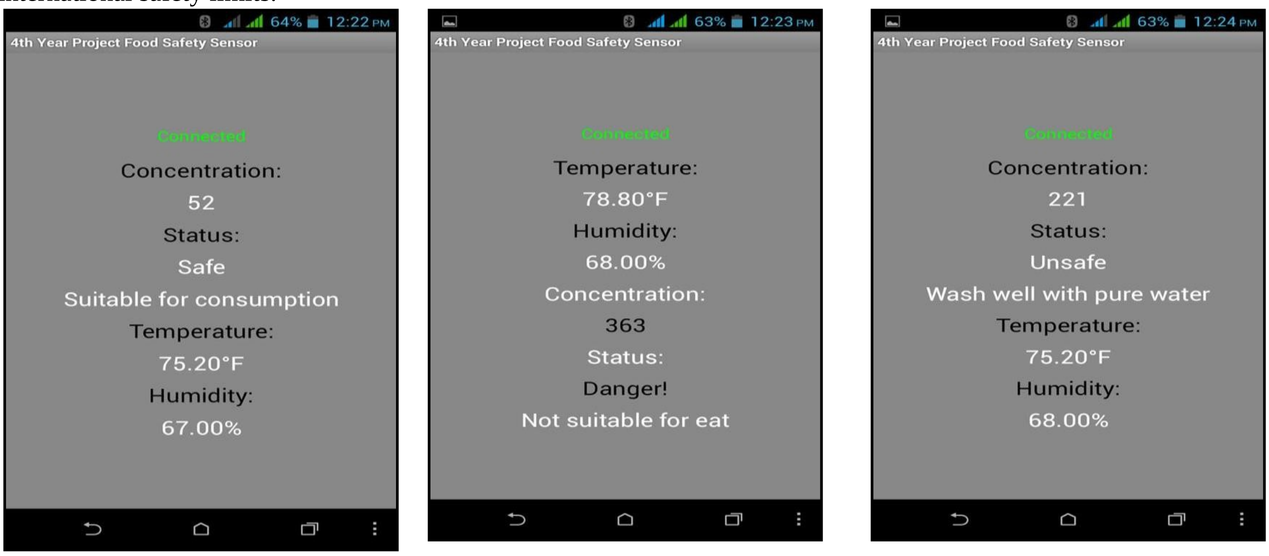

Fig. 11 App Screenshots for Different Status

Remark-1: Our microcontroller-based formalin detector kit can detect the concentration level of formalin present in solid as well as liquid edible samples. It can also determine and display both the humidity and temperature of that sample. This device can help people to be well aware of the safety and the purity of the foods before consumption. The feature of displaying the results on smartphone app also can make the people more interested in using this device as more and more people are using smartphones in modern world.

Remark-2: For now, this device has some limitations. When the concentration of formaldehyde is too high, the volatile organic compound (VOC) gas sensor cannot show accurate value. We mention that formalin is a solution of water and about 40% formaldehyde by volume. When the value of the gas of formaldehyde is above the value of 40%, our "Microcontroller-based formalin detector" cannot detect and display the results on the app accurately. The highest saturated value of volatile organic compound (VOC) gas sensor is recorded as 702 unit. But as we are concerned with the safety of edible products, this limitation does not cause any problem. Because for much lower concentration of formaldehyde, the safety limits of foods will be exceeded which can be measured accurately by our kit.

Comparative assessment

The developed kit is compared against two commercially available kits; one locally developed formalin detection kit by BCSIR and another developed by Swiss Scientists, called FOODsniffer as described in Section-3. BCSIR detection kit is designed to detect formalin in fish using changes in colors in a solution prepared by suitable mixing of chemicals associated with the kit. The kit is tested with same samples prepared for testing the developed kit and it can detect the presence of formalin by changing colors in solutions. However, the kit is unable to measure/detect level of formalin present in samples under investigation and for low levels of formaldehyde concentration, color change is unobservable. The required procedure and preparation of solution are not easy to follow by general consumers during shopping and hence the kit has not attracted general consumers despite their health concerns. Furthermore, much more time to detect formaldehyde in a single sample which is a significant inconvenience when it is required to use commercially in food markets.

FOODsniffer is also tested with same samples prepared for testing the developed kit and it is found that it can detect the presence of formalin qualitatively not quantitatively whereas our developed kit can successfully and accurately detect formalin in samples qualitatively as well as quantitatively. The detection time for FOODsniffer and the developed kit is comparable and almost instantaneous in both cases.

CONCLUSION

A smartphone-based formalin detection kit is designed that can offer a simple and faster detection of harmful formaldehyde in foods. Our device makes use of a volatile organic compound (VOC) gas sensor which can reliably detect concentration of formaldehyde presence in edible products. The developed kit not only detects the presence of formalin, if any, in food samples, like most other kits available in market, it will also show the level(amount) present in the samples. This device acts as an Electronic-Nose to better replicate the human sensing system to detect this harmful element in edible products. The concentration level of formalin can be shown in ppm (parts per million). Moreover, comparative assessment has shown that the developed kit can detect & measure the presence & level of formalin present in samples under investigation both qualitatively and quantitatively which is a clear advantage of our device over existing ones. Further development of our device will focus on bringing more promptness, efficiency and effectiveness in formaldehyde sensing operations. Greater portability through miniaturization will be a key feature for future development. In adopting the device for commercial applications, it will require reproducibility and robustness. Specialized industrial processes will be needed to develop for reproducibility. Some focus will be on designing the outer visible portion of the device which is important while the device is being used by the end-consumer. The total package (device & app) will also need to be cost effective. The app will be made available for downloading from the app store. Much of the focus will be on improving the Android app. The app is in receiving mode now. Java based program will be developed for further improvements of the app. The app should be able to show past detection results with conc. of formalin, safety status using the data storage capabilities of smartphone and better user-friendly interface. These features along with some other will be added to the android app. Connection to cloud or server may also be considered where all the previous data will be stored. Concentration values for both safe & potentially harmful samples will be stored before commercial use. By checking similarity of sensor data with those, the app will decide the safety status of the sample food. These will also be useful for calibration of the device. These are the further improvements we need to work on. This device can be used by consumers to ensure food safety for their families. This device can also be used reliably by government officials or mobile court for conducting safety operation in various fish markets, fruit shops etc. Moreover, it can be useful in fields of forestry & a variety of commercial agricultural related industries for detecting the naturally occurring formaldehyde in foods.

Acknowledgements

We are thankful to University Grant Commission (UGC) for funding the project. We are also thankful to Anglia Ruskin IT Research Institute where the concept was developed. We thank Beximco Pharmaceutical Ltd, Bangladesh for providing pure industrial grade formalin that helped us to detect the maximum range of our kit. Finally, we acknowledge Fab Lab Dhaka University for providing us logistic supports and experimental facilities.

REFERENCES

[1]. Wongniramaikul, Worawit, WadcharawadeeLimsakul, and AreeChoodum. "A biodegradable colorimetric film for rapid low-cost field determination of formaldehyde contamination by digital image colorimetry." *Food chemistry* 249 (2018): 154-161.

[2]. Chaiendoo, Kanokwan, SawarinSooksin, SirinanKulchat, VinichPromarak, ThawatchaiTuntulani, and WittayaNgeontae. "A new formaldehyde sensor from silver nanoclusters modified Tollens' reagent." *Food chemistry* 255 (2018): 41-48.

[3]. International Agency for Research on Cancer (IARC), 1995. Formaldehyde, Wood Dust and Formaldehyde. IARC Monographs on theEvaluation of the Carcinogenic Risks to Humans, vol. 62. World HealthOrganization, pp. 1–405.

[4]. Hauptmann M, Stewart PA, Lubin JH, et al. Mortality from lymphohematopoietic malignancies and brain cancer among embalmers exposed to formaldehyde. *Journal of the National Cancer Institute*(2009); 101(24):1696–1708.

[5]. Wahed, P., Md A. Razzaq, S. Dharmapuri, and M. Corrales. "Determination of formaldehyde in food and feed by an in-house validated HPLC method." *Food chemistry* 202 (2016): 476-483.

[6]. Uddin, Riaz, MoinIbna Wahid, TasbiraJasmeen, Naz Hasan Huda, and Kumar BishwajitSutradhar. "Detection of formalin in fish samples collected from Dhaka City, Bangladesh." *Stamford Journal of Pharmaceutical Sciences* 4, no. 1 (2011): 49-52.

[7]. Islam, Rafiad, Shahin Mahmud, Abdul Aziz, AnimeshSarker, and Marufa Nasreen. "A Comparative Study of Present Status of Marketing of Formalin Treated Fishes in Six Districts of Bangladesh." *Food and Nutrition Sciences* 6, no. 01 (2015): 124.

[8]. Chandralekha, A. P. L., Chandra Baranage, and U. Samarajeewa. "Formaldehyde levels in fish from the Kandy market." Journal of the National Science Foundation of Sri Lanka (1992), volume 20(1): 115-121

[9]. Bianchi, F., M. Careri, M. Musci, and A. Mangia. "Fish and food safety: Determination of formaldehyde in 12 fish species by SPME extraction and GC–MS analysis." Food Chemistry 100, no. 3 (2007): 1049-1053.

[10]. Premaratne, Gayan, Sabrina Farias, and Sadagopan Krishnan. "Pyrenyl carbon nanostructures for ultrasensitive measurements of formaldehyde in urine." Analytica chimica acta 970 (2017): 23-29.

[11]. Liang, Linlin, Min Su, Li Li, Feifei Lan, Guangxin Yang, Shenguang Ge, Jinghua Yu, and Xianrang Song. "Aptamer-based fluorescent and visual biosensor for multiplexed monitoring of cancer cells in microfluidic paper-based analytical devices." Sensors and Actuators B: Chemical 229 (2016): 347-354.

[12]. Zhao, Mei, Huifang Li, Wei Liu, Weiru Chu, and Ying Chen. "Paper-based laser induced fluorescence immune device combining with CdTe embedded silica nanoparticles signal enhancement strategy." Sensors and Actuators B: Chemical 242 (2017): 87-94.

[13]. Woo, Ching S., Stuart E. Barry, and Solomon Zaromb. "Detection and estimation of part-per-billion levels of formaldehyde using a portable high-throughput liquid absorption air sampler." Environmental science & technology 32, no. 1 (1998): 169-176.

[14]. Bunkoed, Opas, Frank Davis, ProespichayaKanatharana, PanoteThavarungkul, and Séamus PJ Higson. "Sol–gel based sensor for selective formaldehyde determination." Analytica chimica acta 659, no. 1-2 (2010): 251-257.

[15]. Feng, Liang, Yongjun Liu, Xiaodong Zhou, and Jiming Hu. "The fabrication and characterization of a formaldehyde odor sensor using molecularly imprinted polymers." Journal of colloid and interface science 284, no. 2 (2005): 378-382.

[16]. Maruo, Yasuko Yamada, Jiro Nakamura, Masahiro Uchiyama, Masanori Higuchi, and Katsuyuki Izumi. "Development of formaldehyde sensing element using porous glass impregnated with Schiff's reagent." Sensors and Actuators B: Chemical 129, no. 2 (2008): 544-550.

[17]. BC Group International, Inc."FormaldehydeMeterModel Z-300." Available online: http://www.bcgroupstore.com/Assets/PDF/DataSheets/z-300_datasheet.pdf (Accessed on February 7, 2020)

[18]. ARS Lab US, Inc. "FOODsniffer- sense based device for food quality determination- presentation." Available online: http://www.myfoodsniffer.com/media/full/presentation.pdf (Accessed on February 7, 2020)

[19]. Kesselmeier, John, and Michael Staudt. "Biogenic volatile organic compounds (VOC): an overview on emission, physiology and ecology." Journal of atmospheric chemistry 33, no. 1 (1999): 23-88.

[20]. Aosong Electronics Co., Ltd."Digital-output relative humidity and temperature sensor/module AM2303." Available online: https://cdn-shop.adafruit.com/datasheets/DHT22.pdf (Accessed on February 7, 2020)

[21]. Datasheet of Bluetooth to Serial PortModule HC-05." Available online: https://wiki.eprolabs.com/images/8/87/Datasheet.pdf (Accessed on February 7, 2020)

[22]. Zhengzhou Winsen Electronics Technology Co., Ltd. "Grove HCHO Sensor Model: WSP2110." May 2014. Available online: http://wiki.seeedstudio.com/Grove-HCHO_Sensor/ (Accessed on February 7, 2020)

[23]. TDK Corporation. "Piezoelectronic Buzzers Pin Terminal/Lead without Oscillator Circuit." May 2011. Available online: http://www.tdk.co.jp/tefe02/ef532_ps.pdf (Accessed on July 7, 2018)

[24]. Wolber, David. "App Inventor: create your own Android apps". Sebastopol, CA: O'Reilly, 2011. E-book Available: http://www.appinventor.org/book2.

[25]. Walter, Derek, and Mark Sherman. "Learning MIT App Inventor a hands-on guide to building your own android apps". Upper Saddle River, NJ: Addison-Wesley, 2015.