Development of an Odor Recognition System for E. Coli and Staphylococcus Aureus Bacteria Detection

Timothy M. Amado[1], Ma. Rica Bunuan[2], Relamae F. Chicote[3], Sheila May C. Espenida[4], Honeyleth L. Masangcay[5], Camille H. Ventura[6]
Electronics Engineering Department, College of Engineering
Technological University of the Philippines - Manila
[1]timothy_amado@tup.edu.ph, [2]rica.bunuan@tup.edu.ph, [3]relamae.chicote@tup.edu.ph, [4]sheilamay.espenida@tup.edu.ph,
[5]honeyleth.masangcay@tup.edu.ph,[6]camille.ventura@tup.edu.ph

Abstract— Foodborne illness had been affecting human's life ever since. According to World Health Organization (WHO) in 2015, there are 600 million or approximately one out of ten people around the world fall ill due to contaminated food and causing 420,000 deaths annually. The study is conducted in order to ensure the safety of people in consuming food. The goal is to develop an odor recognition system composed of Arduino Mega 2560 and eight gas sensors, particularly MOS and Electrochemical Sensors such as MQ and TGS, that are much cheaper but can produce accurate readings for the detection of the present gases in the food sample. Each gas sensors correspond to the specific gases emitted by the bacteria. The output of the eight sensors are implemented in Arduino IDE program and displayed through an open-source terminal named Tera Term. The system works fast and can gather several output in ppm (parts per million), in a span of three to five minutes. The data will be saved directly into Excel file and uploaded in Shiny web app. The data gathered from the developed system are trained in R and shows same results in the food laboratory test.

Keywords—foodborne illness, electronic nose, sensor, detection, Volatile Organic Compound

I. Introduction

One of the basic necessities of human to survive is food. Food serves as source of nutrition that supplies energy to the body for a man to work on daily activities. Most countries in the South-East Asian Region are applying informal food production and marketing system, which present challenges for implementation of food safety precautions and regulations[1]. Food adulteration and contamination can occur, thus causing foodborne illnesses. Foodborne illness comes from the consumption of food products contaminated by pathogens, toxins, chemicals or radioactive materials that can be a source of disease, and worst results to death[2]. In the Philippines, the Epidemiology Bureau of the Department of Health statistically illustrated the Jan-March 2018 cases of Waterborne and Foodborne Diseases including Acute Bloody Diarrhea or ABD[3]. Food products containing pathogenic microorganisms cannot be easily distinguished by human perceptions, thus it is impossible to determine whether the food is contaminated without microbial testing. Based on Centers for Disease Control (CDC), the most common microorganisms causing foodborne diseases include Campylobacter Jejuni, E. coli O157:H7, Salmonella, Staphylococcus aureus, Norovirus, Listeria monocytogenes, Clostridium perfringens and Toxoplasma gondii[4].

The researchers aim is to develop a device that will detect the presence of bacteria causing foodborne illness particularly: Campylobacter, E. Coli O157:H7 and Staphylococcus aureus that emits volatile organic compounds (VOC) and fixed gases by using gas sensors. The study will be beneficial to people, whose unaware of consuming food products that have harmful bacteria. It will work for food quality assurance and safety of people, most especially who suffers from anosmia and ageusia. The human senses are subjective wherein individual variations may occur and difficult to reproduce. The physical system and health conditions can be affected, hence, gives way for the researchers to develop a convenient device. In addition to that, the intention is to reduce the time-consuming food laboratory test and cost.

The study will contribute significantly to future researchers whose interested in developing Electronic Nose Technologies. This may serve as an instrument and reference for further development and related subject.

II. Review of Related Literature

"The Sensor Array Optimization of Electronic Nose for Detection of Bacteria in Wound Infection" reviews the identification of bacteria causing wound infection using electronic nose system with 34 array sensors. The researchers used different kinds of analysis and algorithm (e.g. Wilk lambda statistics, Linear Discriminant Analysis and Genetic Algorithm), particularly five methods, to optimize the array of sensor and develop the recognition of the bacteria present in the test sample, and to gain efficient output without costing too much. The study uses different analysis for array of sensors optimization and different algorithms for bacteria recognition enhancement, wherein the comparison results to practical system design construction and knowledge in class information or predictive models for different applications[5].

According to the journal entitled "An Investigation on Electronic Nose Diagnosis of Liver Cancer" proven that the diagnosing of liver cancer is feasible using an electronic nose. In this study the construction of the project was first to consider, then demonstrated the test and examined the method. After collecting exhaled breath samples, the gathered samples were analyzed using PCA (Principal Component Analysis) to extract the main features. In addition, they applied other methods: LDA (Linear Discriminant Analysis), DDA (Distance Discriminant Analysis) and SVM (Support Vector Machine) to classify accurate liver cancer and healthy controls. Then, compared the results obtained by different methods[6]. Electronic nose can accurately define the sensed odor and effectively deals with the odor analysis problem, and may provide an assurance, affordable and non-invasive test not just for liver cancer but for other purposes.

The study entitled “Bacteria – Contaminated Meat Detector” presents a method of determining the level of bacterial contamination of the meat sample using gas analysis. The functioning of the device starts when the meat lays inside the device. The bacteria level will be determined through methane, organic vapor and odorous gas sensors by analyzing the air around the surface of the meat. The information from the sensors will be process with PIC 16F877A microcontroller, programmed using a Proton IDE Lite software. A keypad will be used as an input for user interaction and for the reading of each sensor an LCD will be use. The device can verify if the meat is still suitable for human consumption through the reading of sensors. Also, this study considered the possibility that an AC source .23might not have in some locations that the device can be used, so the researchers make a device that can be powered by AC or DC source[7].

The study entitled “An Electronic Nose to Classify Smell into Ten Categories with ANN Pattern Recognition Using Visual Studio and MATLAB” creates a great benefit in food industry. The researchers developed a device that detects the odorant into ten categories. The categories include fragrant, fruity, lemon, minty, sweet, woody, popcorn, pungent, chemical, and decaying. They used Artificial Neural Network in MATLAB in order to recognize the pattern of the detected odorant. The used of MQ Gas Sensors is very important because it is the main component of the device. The device works whenever a sample is placed into the chamber. When the gas sensors react to that particular smell, the recognized odor will deliver that pattern into the pattern recognition system and then an audio will utter the detected odor. For further research related to this, some recommendations were obtained. This includes the following: To use more sensitive sensors give better results; to deploy a portable energy source of the device to consider its portability; and to extend its database by increasing the sample in each category[8].

The study of E-nose had been an enormous help in several applications with its advantage over the traditional odor analysis, techniques are fast, simple and economical.

III. Methodology

The methodology of research includes the block diagram, design of the device and its components, the schematic and circuit diagram of the hardware system, and the working process of the whole system.

A. Block Diagram

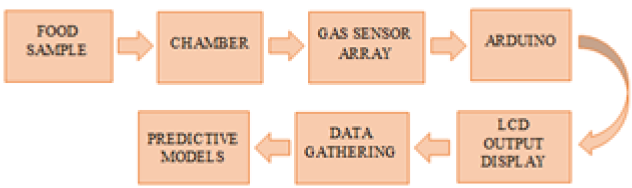
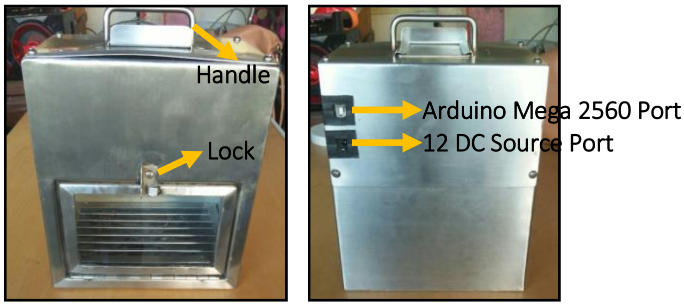


Fig. 1 Main Block Diagram

The block diagram shows how the system works which includes the food sample that will be placed into the chamber, an array of gas sensors for the detection of gases, the Arduino Mega 2560 for the acquisition of data and LCD for the output display. After the samples are obtained and the predictive models are implemented through accuracy and cross validation, the data gathering is attained.

B. Design of the Device

The system is composed of a chamber for the input assembly and laptop for the output display. The device has a final structure of 9-inch height and 8-inch width, grill-type tray and 4-inch by 4-inch fan. The port for the Arduino connector and 12 DC source is located at the back.

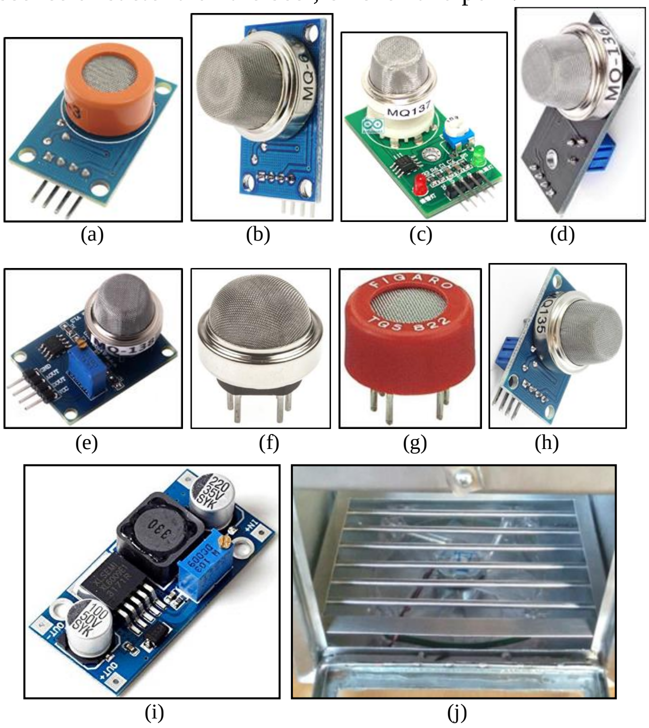


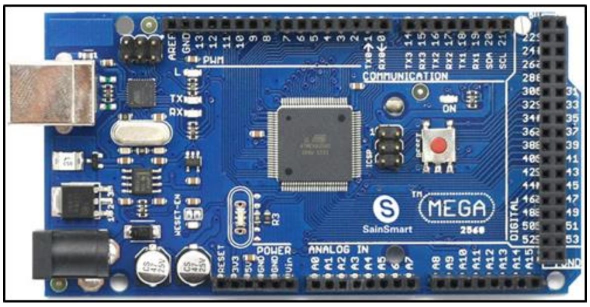
(a) (b)

Fig. 2 Actual photo of the Chamber: (a) Front, (b) Back

C. Components of the Device

The hardware is composed of eight gas sensors, particularly MQ and TGS, integrated to Arduino Mega 2560. Each sensor detects specific gases that the bacteria in the food sample emits. The gas indicates the presence or absence of bacteria on the beef, chicken and pork.





(k)

Fig. 3 Actual photo of (a) MQ3, (b) MQ6, (c) MQ137, (d) MQ136, (e) MQ138, (f) TGS821, (g) TGS822, (h) MQ135, (i) DC-DC XL6009 Boost Converter Module, (j) 4-inch by 4-inch Plastic Fan and (k) Arduino Mega 2560

D. Schematic Diagram

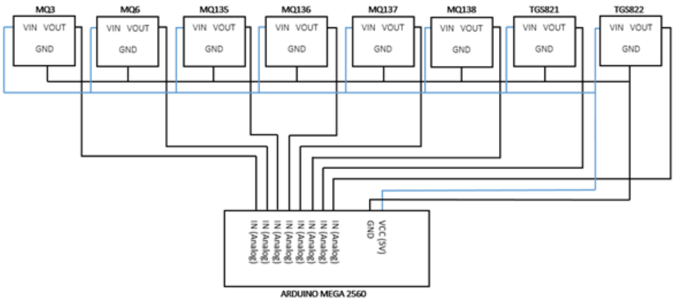


Fig. 4 Schematic Diagram

Each gas sensor has VIN, VOUT and GND pin. The VIN of each sensor is connected in series to the 5V pin of the Arduino and VOUT pin of each sensor is connected to the Analog input pins of the Arduino. Lastly, the GND pin of each sensor is connected in series to the GND pin of the Arduino.

Fig. 5 Actual Circuit Inside the Chamber

The circuit is integrated to Arduino Mega 2560 and the output will proceed to the software terminal, named Tera Term, for the readings of the data in ppm (parts per million). The booster DC-DC XL6009 is a module that will convert or step up the voltage from the laptop source to supply the 12V DC fan.

E. Gas Sensors and Specific Gas Detection

TABLE I Gas Sensors and Bacteria

Sensors	Gas and Sensitivity	E. Coli	S. Aureus
MQ3	Hexane (200-1000ppm)	✓	
MQ6	Propane (100-1000ppm)		✓
MQ136	Hydrogen Sulfide (1-200ppm)	✓	
MQ138	Formaldehyde (1-10ppm)	✓	
	Acetone (10-300ppm)	✓	
	Toluene (10-100ppm)		✓
MQ137	Ammonia (10-300ppm)		✓
TGS822	Ethanol (50-5000ppm)	✓	✓

The table shows the gas sensors used and integrated inside the device. Each sensor corresponds to specific gases that can be emitted by the mentioned bacteria so that the device may detect and identify the presence or absence of the bacteria.

F. Array of Gas Sensors

Selectivity is an essential property of a gas sensor and the ability to respond to a particular gas in the presence of other gases. The term array means displaying in particular arrangement, in which the researchers formed. The orientation of the gas sensors is downward as shown in the figure, head facing the food sample, to obtain the optimum output odor thus will be easier to acquire the required readings, with the application of the fan located at the bottom of the chamber.

Fig. 6 Actual Orientation of the Sensors Inside the Chamber

G. Flow Chart

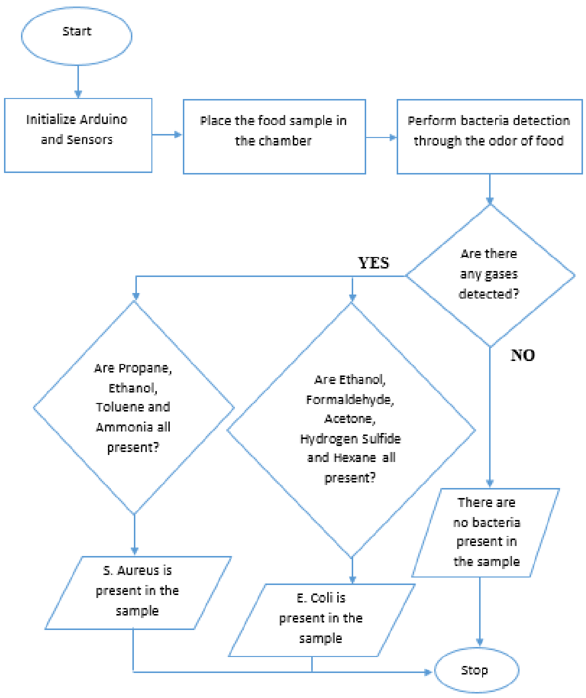


Fig. 7 Flow Chart

The flow chart simply shows that the system will start in initializing the Arduino and gas sensors. Users may place the food sample in the chamber and the sensors will process the detection. If the gas present satisfies the gas combination of each bacteria in the food sample then, the output will be displayed in the LCD.

IV. Data and Results

The gathered data and obtained output results are summarized and presented through figures and plots.

A. *Results of the Gas Sensor Readings*

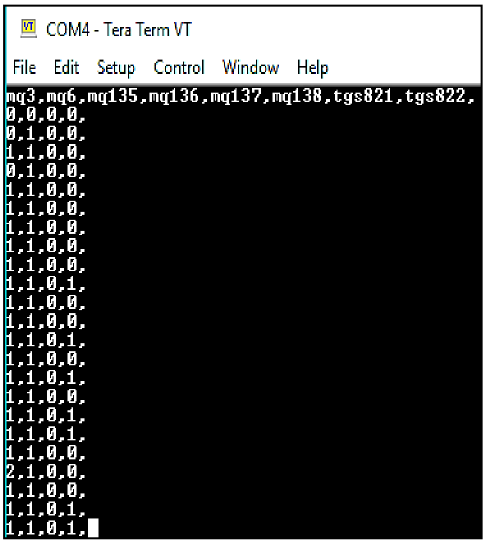
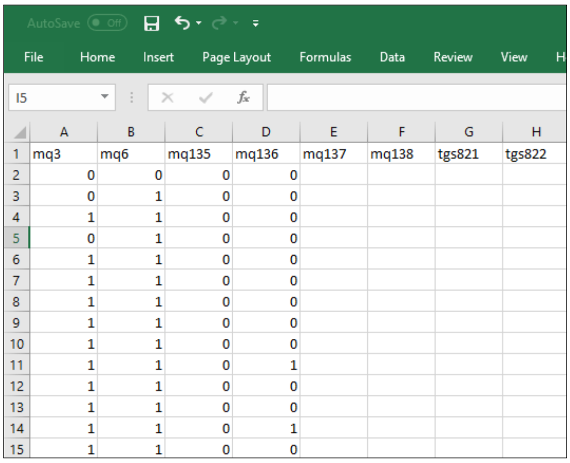


Fig. 8 Data shown in Tera Term



	A	B	C	D	E	F	G	H
1	mq3	mq6	mq135	mq136	mq137	mq138	tgs821	tgs822
2	0	0	0	0				
3	0	1	0	0				
4	1	1	0	0				
5	0	1	0	0				
6	1	1	0	0				
7	1	1	0	0				
8	1	1	0	0				
9	1	1	0	0				
10	1	1	0	0				
11	1	1	0	1				
12	1	1	0	0				
13	1	1	0	0				
14	1	1	0	1				
15	1	1	0	0				

Fig. 9 CSV file format in Excel

The data (ppm) of meat sample is forwarded to an open source software terminal that serves as serial monitor, named Tera Term and saved in CSV file format. Thus, it converts the result extracted from the Arduino to save directly into the format that can be easily fed to the R Studio Software.

B. *Results of Data Collection*

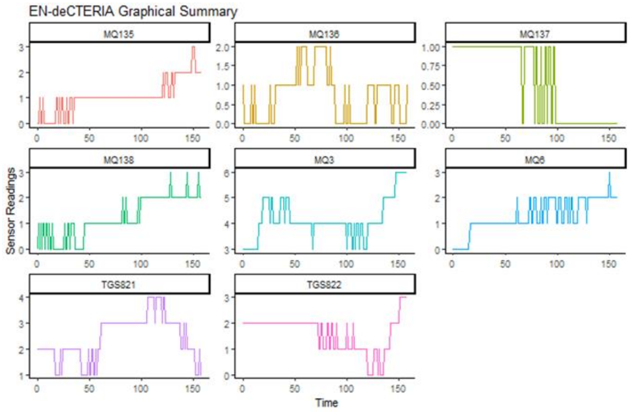


Fig. 10 Plot of Sensor Readings VS Time

The plot interprets the output of each gas sensors (ppm) over a period of time that depends on the presence of the bacteria on the meat sample. Since each sensor are detecting particular gases only and each bacterium mentioned emits particular gases, the output is not the same. After many trials and several testing, the device produced the preferred output results. The eight sensors used are sensitive enough to detect the gas contents of the meat sample. The data collected will be trained in R for the identification of the present bacteria.

V. Conclusion

Based on the results of the study, the eight sensors are effectively integrated to Arduino Mega 2560. Although at first, the proponents encountered difficulty in operating the sensors, the components worked properly with appropriate sensitivity during the simultaneous testing and trouble shooting. The outputs of the gas sensor are displayed in Tera Term, organized and saved in CSV format in Excel. The gathered data are successfully uploaded in web app Shiny so the users can easily operate the device, display the data and analyze to determine the absence or presence of the bacteria. The device performed its function well according to set factors and tested the reliability through multiple testing. The device itself is very convenient due to its small size, easy to operate and transports fast results unlike the food laboratory tests that takes a week or two. The device also shows accuracy from the readings of the sensors up to the training of the models based on the performance. The project was successfully executed and done. However, the proponents would like to recommend the following for further improvement of the project: (1) addition of high-quality sensors for more accurate readings; (2) use a fan that can fully operate to obtain good performance; and (3) use other variety of food sample such as vegetables, poultry or liquid.

Acknowledgment

The authors would like to acknowledge Ma'am Remedios Micu and all the staffs of the National Meat Inspection Service Quezon City for their cooperation in doing this project and Paco Market Manila vendors for allowing the proponents to deploy the project in the place.

REFERENCES

[1] World Health Organization (2017, October 31). Food Safety. Retrieved from https://www.who.int/news-room/fact-sheets/detail/food-safety

[2] "Nutrition", *South-East Asia Regional Office*, 2018. [Online]. Available: http://www.searo.who.int/entity/nutrition/en/. [Accessed: 15- April- 2018].

[3] Republic of the Philippines, Department of Health (DOH), “Food and Waterborne Diseases”, Report No. 3, pp 1-3, 2018. Available: 2018 Food and Water Borne Diseases Morbidity Week 1-13.pdf [Accessed 14 April 2018].

[4] T. Switaj, K. Winter and S. Christensen, "Diagnosis and Management of Foodborne Illness", *Aafp.org*, 2019. [Online]. Available: https://www.aafp.org/afp/2015/0901/p358.html. [Accessed: 15- Apr-2018].

[5] Hao Sun, Fengchun Tian, Zhifang Liang, Tong Sun, Bin Yu, Simon X. Yang, Senior Member, IEEE, Qinghua He, Longlong Zhang, Xiangmin Liu (2017), "Sensor Array Optimization of Electronic Nose for Detection of Bacteria in Wound Infection", *IEEE Transactions on Industrial Electronics*, vol. 64, no. 9, pp. 7350-7358, 2017. Available: 10.1109/tie.2017.2694353.

[6] L. Hao and F. Xu, "An investigation on electronic nose diagnosis of liver cancer", *2017 10th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)*, 2017. Available: 10.1109/cisp-bmei.2017.8302211.

[7] Nilo M. Arago, Niño L. Basas, Krisselle Anne M. Coliflores, Aldrin E. Dumaop, Ma. Cezare C. Enriquez, Jennifer T. Orense, Editha S. Salo, Paul John C. San Pedro, Mary Ann Javier Tingala, (2011). “Bacteria-Contaminated Meat Detector” [Published]

[8] Timothy M. Amado, Riniel C. Camacho, Christian Joseph L. Lastimosa, Lemuel J. Magpantay, Elaine Clariz V. Madiana, Maria Luisa P. Serrano, (2016). “An Electronic Nose to Classify Smell into Ten Categories with ANN Pattern Recognition using Visual Studio and Matlab” [Published]

[9] FMQ3- Alcohol Gas Sensor, *for Fig. 3.3 (a)* [Available: www.makerlab-electronics.com/product/mq-3-alcohol-gas-sensor-module/]

[10] MQ6 Gas Sensor *for Fig. 3.3 (b)* [Available: pandaelectronicsbd.com/shop/mq6-gas-sensor/]

[11] Gas Sensor Ammonia MQ137 *for Fig. 3.3 (c)* [Available: www.arduinoall.com/product/1395/mq-137-gas-sensor-ammonia-mq137/]

[12] MQ136 Gas Sensor Hydrogen *for Fig. 3.3 (d)* [Available: www.sainsmart.com/products/mq-136-gas-sensor-hydrogen]

[13] MQ138 Gas Sensor *for Fig. 3.3 (e)* [Available: www.baudaeletronica.com.br/sensor-de-gas-mq-138-compostos-volateis.html]

[14] Figaro TGS821 Hydrogen Gas Sensor *for Fig. 3.3 (f)* [Available: mt.rsdelivers.com/product/figaro/tgs821/figaro-tgs821-hydrogen-gas-sensor/5390005]

[15] Figaro TGS822 *for Fig. 3.3 (g)* [Available: www.soselectronic.com/products/figaro/tgs-822-7719]

[16] Air Quality Gas Sensor MQ135 *for Fig. 3.3 (h)* [Available: potentiallabs.com/cart/air-quality-control-gas-sensor-mq135]

[17] XL6009 Step-up Module Adjustable Booster *for Fig. 3.3 (i)* [Available: www.amazon.in/XL6009-Step-up-Module-Adjustable-Booster/dp/B00HV59922]

[18] Arduino Mega 2560 *for Fig. 3.3 (k)* [Available: kitskart.com/product/arduino-mega-2560-r3-with-usb-cable/]

[19] Sohrabi, Mohsen, Zhang, Li, Zhang, Kai, Ahmetagic, Adnan, Wei, Ming (2014), “Volatile Organic Compounds as Novel Markers for the Detection of Bacterial Infections,” *for Table 1*, [Published] Clinical Microbiology.Available:doi.org/10.4172/2327-5073.1000151.[Accessed 15 April, 2018]