Fish Quality Recognition using Electrochemical Gas Sensor Array and Neural Network

Muhammad Rivai
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
muhammad_rivai@ee.its.ac.id

Misbah
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
misbah@umg.ac.id

Muhammad Attamimi
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
attamimi@ee.its.ac.id

Muhammad Hamka Firdaus
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
mhamkaf.its@gmail.com

Tasripan
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
tasripan@ee.its.ac.id

Tukadi
Department of Electrical Engineering
Institut Teknologi Adhi Tama
Surabaya, Indonesia
tukadi71@gmail.com

***Abstract*— Identification of the fish quality is needed to determine the level of freshness so that it can be consumed safely. Usually, the recognition of the fish quality through physical and odor examination by humans. This can be dangerous because spoiled fish produces poisonous gas and a pungent odor from the metabolic processes of microorganisms. This study has developed a tool for recognition of the fish quality using an electrochemical gas sensor array and a Neural Network algorithm. The electrochemical gas sensor consists of amperometric and conductometric types. This sensor data is then fed to the Neural Network algorithm which is implemented in the Arduino Due microcontroller. The experimental results show that the fish quality produces a different sensor response. The more fish decay, the greater the sensor response. This system can recognize the fish quality including fresh, half-fresh, and rotten with a success rate of 80%.**

Keywords—Electrochemical gas sensor array, Fish quality, Neural Network

I. INTRODUCTION

The smell, color, texture, and taste of a food can be used as an indicator of food quality. The quality of food, including fish, is influenced by the presence of decay compounds produced by the activity of microorganisms. One indicator of the quality of fish based on SNI 01-2729.1-2006 is odor, which in spoiled fish produces a very strong odor [1]. This unpleasant odor is generally composed of hydrogen sulfide (H_2S) and ammonia (NH_3) [2]. The ammonia is included in Total Volatile Basic - Nitrogen (TVB-N) [3]. Ammonia can also be produced by Pseudomonas sp., Enterobacteriaceae, lactic acid bacteria, yeasts, and anaerobic rods.

Identification of fish quality is needed to determine whether the fish can be consumed safely. However, at this time, assessment of the freshness level of fish is usually only through physical and smell observation by humans. This can increase inaccuracy and even harm humans due to toxic gases produced by the microorganisms [2]. The effects of exposure to high concentrations of hydrogen sulfide gas can cause loss of consciousness and even death. Whereas in low concentrations, it can disrupt the respiratory system [4]. For this reason, we need a device that can safely assess the quality of fish.

Gas chromatography is a sophisticated tool for assessing the fish quality, however, it is time-consuming and requires an expert in interpreting the results of the chromatogram. Electronic nose is a tool that mimics the working principle of the mammal nose. This system consists of a gas sensor array and a pattern recognition algorithm [5] - [9]. Several studies have been conducted in the use of gas sensors for electronic nose to measure the freshness of food [10], [11]. However, the use of gas sensors has high cross-sensitivity, so that other gases can disrupt the measurement results [12].

In this study, electrochemical gas sensors are used to measure the gas produced by the fish samples. The electrochemical sensors in this experiment are amperometric and conductometric types. The electric current and conductivity are then transformed into electrical voltage by the Analog to Digital Converter (ADC) module and the Arduino Due microcontroller. The data are then processed by the Neural Network for recognition of the fish quality. The Neural Network can learn the relationship between inputs and outputs that are not linear only with an iterative learning process. In addition, this method is still able to recognize unexpected inputs, for which they have never been trained.

Sensor is a device that transforms a certain quantity into another, in this case an electrical signal. An electrochemical sensor is a device composed of a chemical layer with an electronic transducer. In this way, energy from the interaction between chemical species and sensor can be converted into electrical signals. Various types of electrochemical sensor can be distinguished based on the type of signal output, namely potentiometric, conductometric and amperometric [13]. On this amperometric sensor, as shown in Fig. 1, consists of three electrodes. Electron transfer reactions occur in the working electrode. The reference electrode provides a reference potential to the working and counter electrodes. The counter electrode acts to balance the working electrode reaction. If the working electrode oxidizes the gas, the counter electrode must reduce several other molecules to produce equivalent currents [14]. On carbon monoxide (CO) gas sensor, the chemical reactions can be explained as follows:

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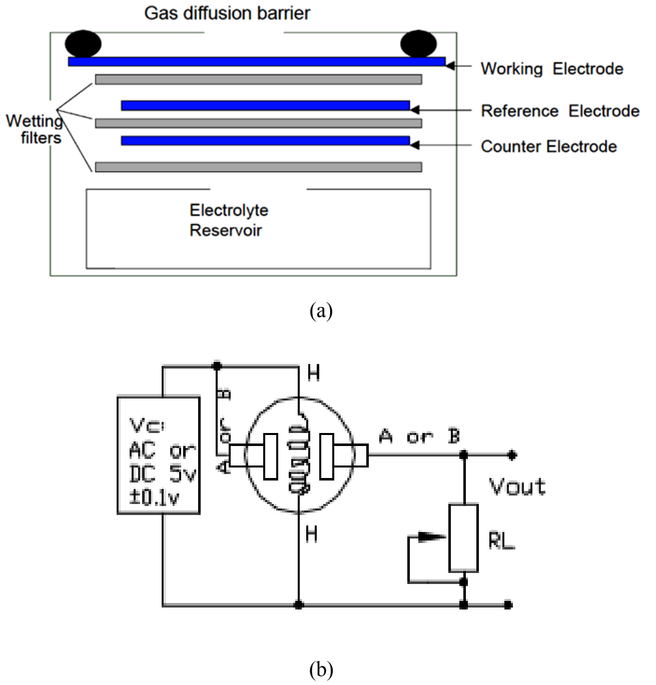

Fig. 1. Construction of the electrochemical gas sensors: (a) amperometric, and (b) conductometric types.

Chemical reaction on the working electrode:

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^- \quad (1)$$

Chemical reaction on the counter electrode:

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (2)$$

The MQ-136 and MQ-137 are conductometric type gas sensors called semiconductor sensors which are generally Tin oxide (SnO_2) material. The process of oxidation and reduction on the surface of the sensor material causes changes in its resistance. In clean air, the sensor material has a higher resistance and will decrease with the presence of reducing gas. In this semiconductor sensor, it requires a certain temperature to maintain the redox process.

II. Methods

This fish quality recognition system consists of three gas sensors, a 16-bit ADC module, a Neural Network algorithm implemented on Arduino Due microcontroller, and LCD display, as shown in Fig. 2. The gas sensors are H2S-B4 (amperometric type), MQ-136, and MQ-137 (conductometric type). The ADS1115 module is a 16-bit ADC device that has an internal oscillator, a programmable gain amplifier (PGA), and also a comparator. This module is able to convert data up to 860 samples per second. This PGA has an input range from ± 256 mV to ± 6,144 V. This module is also equipped with a multiplexer so that it has 4 inputs for single ended configuration and 2 inputs for differential configuration. The data can be accessed using the I2C protocol.

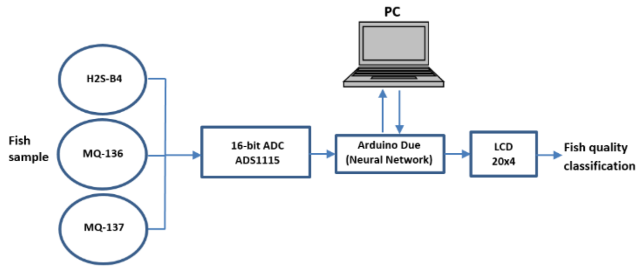

Fig. 2. Block diagram of the fish quality recognition system.

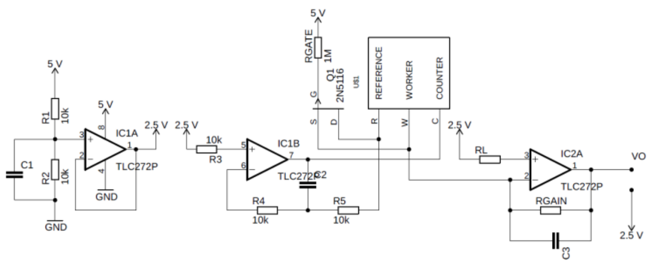

Fig. 3. Electronic circuit for the amperometric gas sensor.

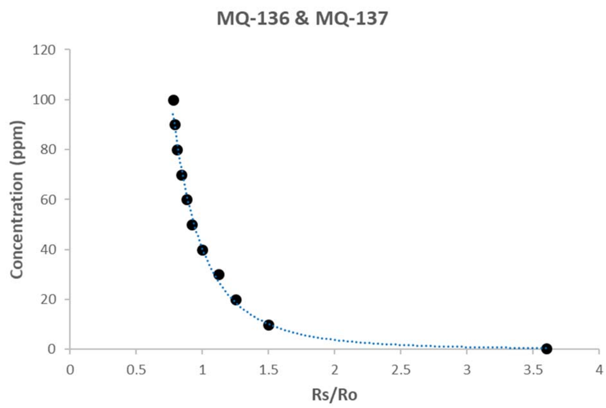

Fig. 4. Calibration curve for the conductometric gas sensors.

The gas sensor array measures the gas concentrations in the fish sample chamber for 60 seconds. After data are collected, the learning process of the Neural Network is carried out on the computer. This learning process produces weights and biases that will be used by the Neural Network implemented on the Arduino Due microcontroller.

A. Gas Sensors

The electrochemical gas sensor of H2S-B4 has a sensitivity of 1675 nA / ppm. This sensor requires a potentiostat circuit and a transimpedance amplifier, as shown in Fig. 3. Whereas in Fig. 4 shows the characteristic of the MQ-136 and MQ-137 gas sensors for hydrogen sulfide and ammonia, respectively, which are used for sensor calibrations. The gas concentration can be expressed as:

$$\text{Concentration (ppm)} = 40.3 \times \left(\frac{Rs}{Ro}\right)^{-3.4} \quad (3)$$

where the resistance of *Ro* can be found when sensor resistance of *Rs* is exposed to clean air [15], expressed by:

$$Ro = Rs/3.8 \quad (4)$$

Fig. 5. Realization of the electrochemical gas sensor array.

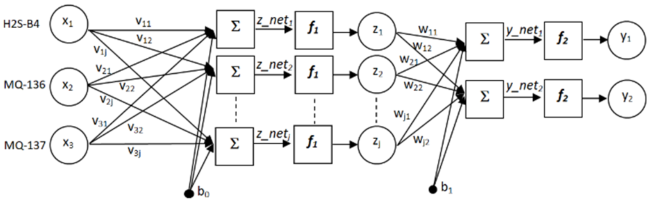

Fig. 6. The Neural Network architecture used in the fish quality recognition system.

The moving average (MA) method is applied to reduce noise in the sensor data, as follows:

$$MA_n = \frac{\sum_{i=1}^{n} A_i}{n} \tag{5}$$

where n is the number of time period, and A_i is the value of the sensor. The sensor array used in this experiment is shown in Fig. 5.

B. Neural Network

The Neural Network architecture used in this study is a multilayer perceptron with 3 layers, as shown in Fig. 6. The input layer has 3 nodes that correspond to the number of sensors. The hidden layer consists of 12 neurons, and the output layer has 2 neurons representing 3 classes of fish quality. The calculation process of the Neural Network can be described as follows:

$$\{x_1, t_1\}, \{x_2, t_2\}, \ldots, \{x_n, t_n\} \tag{6}$$

where x is the input vector and t is the target vector.

$$z\_net_j = \sum_{j=1}^{k} v_{ij}.x_j + v_{0j} \tag{7}$$

where v_i is the weight of the neuron, and v_0 is bias of the neuron.

$$z_j = f_1(z\_net_j) = \frac{1}{1+e^{-z\_net_j}} \tag{8}$$

where z_j is the output of neurons in the hidden layer using the sigmoid activation function.

$$y_k = f_2(y\_net_k) = \frac{1}{1+e^{-y\_net_k}} \tag{9}$$

$$e_k = t_k - y_k \tag{10}$$

$$e = \frac{1}{2}\sum_{j=1}^{i}(t_k - y_k)^2 \tag{11}$$

where e is the sum of the squared error.

$$\dot{f}_2(y\_net_k) = f_2(y\_net_k)[1 - f_2(y\_net_k)] \tag{12}$$

$$\delta_k = e_j(y\_net_k)\dot{f}_2(y\_net_k) \tag{13}$$

$$\delta net_j = \sum_{k=1}^{m} \delta_k \, w_{jk} \tag{14}$$

$$\delta_j = \delta net_j \, \dot{f}_1(z\_net_j) = \delta net_j \;\; z_j \, (1 - z_j) \tag{15}$$

$$\Delta w_{jk}(n) = \alpha \delta_k(n) + \varphi \Delta w(n-1) z_j \tag{16}$$

$$w_{jk}(n+1) = w_{jk}(n) + \Delta w_{jk}(n) \tag{17}$$

$$\Delta v_{ij}(n) = \alpha \delta_j(n) + \varphi \Delta v(n-1) x_i \tag{18}$$

$$v_{ij}(n+1) = v_{ij}(n) + \Delta v_{ij}(n) \tag{19}$$

where Δw is a change in weight, Δv is a change in bias, φ is a momentum value, and α is a learning rate.

(a)

(b)

Fig. 7. (a) Prototype of the fish quality recognition system, (b) fish samples.

III. Results and Discussion

The gas sensor array is installed in a chamber that can hold a fish sample, as shown in Fig. 7. The measurements are carried out for 60 seconds for every hour until the fish becomes rotten. The samples consist of Bubara, Terisi, Mackerel, Mullet, and Fusilier fishes with a weight size of about 100-200 grams. The response of the gas sensors to the fish samples is shown in Fig. 8. This indicates that the condition of fish quality produces a different sensor response. The more fish decay, the greater the sensor response.

At ambient temperature, the fish will decay within 6-12 hours after death [16]. Based on sensory tests, we classify three types of fish quality, namely fresh, half-fresh, and rotten. Therefore, in this study, the fresh quality is at the initial time (after death), the half-fresh quality is at the 6^{th} hour, and the rotten quality is at the 12^{th} hour. The measurement data by the gas sensors are used for the learning process of the Neural Network. The network will recognize three levels of fish quality represented by the value of 00 for fresh, 01 for half-fresh, and 11 for rotten. The response of the gas sensor array to fresh, half-fresh and rotten fish is shown in Tables I, II, and III, respectively. Fig. 9 shows that the gas sensor array produces different patterns for all three qualities of the fish.

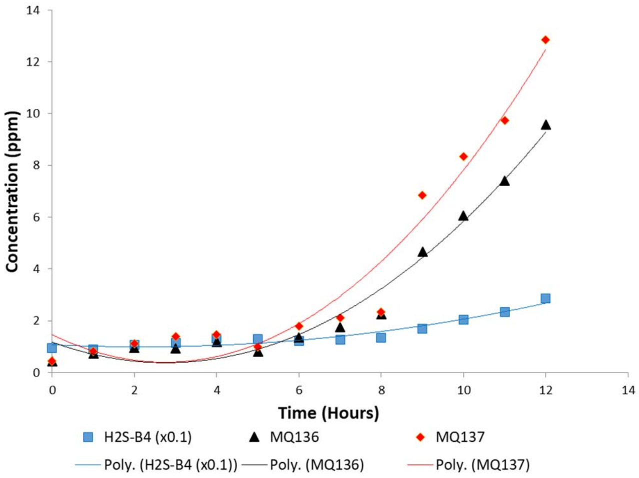

Fig. 8. The response of the gas sensors to a fish sample.

TABLE I. Response of gas sensors on the fresh fish.

Gas Concentration (ppm)		
H2S-B4	MQ-136	MQ-137
0.093	0.5	0.51
0.082	0.44	0.47
0.146	0.5	0.52
0.066	0.32	0.33
0.093	0.41	0.45
0.071	0.4	0.42
0.061	0.28	0.41
0.082	0.34	0.38
0.08	0.4	0.39
0.075	0.44	0.51

TABLE II. Response of gas sensors on the half-fresh fish.

Gas Concentration (ppm)		
H2S-B4	MQ-136	MQ-137
0.112	1.6	3.23
0.125	1.4	1.75
0.177	1.79	1.88
0.115	1.25	1.33
0.087	0.74	0.79
0.082	0.74	0.78
0.109	0.88	1.11
0.07	0.74	0.98
0.1	0.81	1.52
0.091	1.1	1.37

TABLE III. Response of gas sensors on the rotten fish.

Gas Concentration (ppm)		
H2S-B4	MQ-136	MQ-137
0.25	4.64	7.82
0.32	14.45	20.21
0.36	13.52	16.21
0.24	7.21	8.61
0.267	8.12	11.41
0.16	4.02	8.56
0.322	3.18	12.28
0.232	3.42	5.08
0.23	3.24	5.52
0.25	6.36	7.16

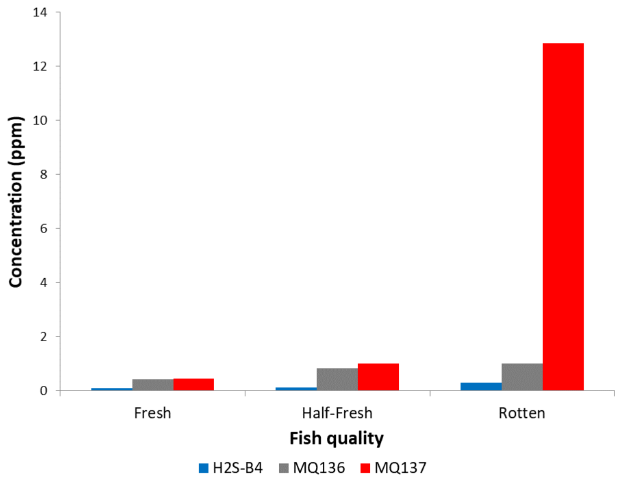

Fig. 9. The patterns of gas sensor array responses to fish quality.

The learning process on the Neural Network uses 30 fish quality data. This process is performed on a computer with an iteration of 250 epochs which produces an error of 0.01, as shown in Fig. 10. The last weight and bias values are used by the Neural Network algorithm which is implemented in the Arduino Due microcontroller.

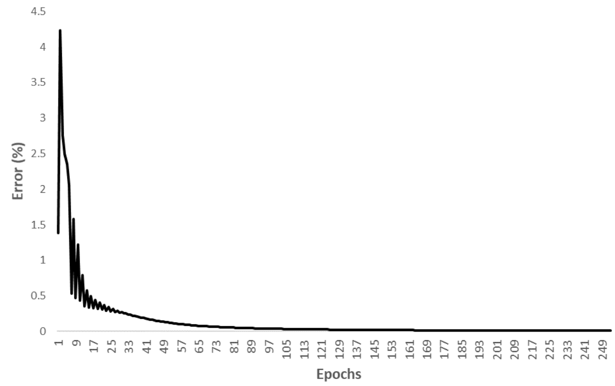

Fig. 10. The error rate in the learning process of the Neural Network.

TABLE IV. FISH QUALITY RECOGNITION BY THE NEURAL NETWORK.

No	Fish Quality	Classification
1	Fresh	Half-Fresh
2	Fresh	Fresh
3	Fresh	Fresh
4	Fresh	Half-Fresh
5	Fresh	Fresh
6	Half-Fresh	Rotten
7	Half-Fresh	Half-Fresh
8	Half-Fresh	Half-Fresh
9	Half-Fresh	Half-Fresh
10	Half-Fresh	Half-Fresh
11	Rotten	Rotten
12	Rotten	Rotten
13	Rotten	Rotten
14	Rotten	Rotten
15	Rotten	Rotten

The validation process uses 15 fish quality data that are not included in the learning process. Table IV shows that this system can recognize the fish quality including fresh, half-fresh, and rotten with a success rate of 80%. This system can be applied in the food industry where this method has a fast response and non-destructive manner [10].

IV. CONCLUSION

This study has developed a tool for recognition of the fish quality using an electrochemical gas sensor array and a Neural Network algorithm. The electrochemical gas sensor consists of amperometric type (H2S-B4) and conductometric type (MQ-136, and MQ-137). The 16-bit ADC ADS1115 module is used to convert an analog sensor signal into digital data. This sensor data is then fed to the Neural Network algorithm which is implemented in the Arduino Due microcontroller. The experimental results show that fish quality produces a different sensor response. The more fish decay, the greater the sensor response. This system can recognize the fish quality including fresh, half-fresh, and rotten with a success rate of 80%.

REFERENCES

[1] SNI 01-2729.1-2006. Spesifikasi Ikan Segar. BSN, 2006.

[2] B. Ray, Fundamental food microbiology, 3rd ed. Boca Raton: CRC Press, 2004.

[3] A. Pacquit, J. Frisby, D. Diamond, K.T. Lau, A. Farrell, B. Quilty, D. Diamond, “Development of a smart packaging for the monitoring of fish spoilage”, Food Chem., vol. 102, no. 2, pp. 466–470, 2007.

[4] B. Doujaiji, J. A. Al-Tawfiq, “Hydrogen Sulfide Exposure in an Adult Male”, Ann. Saudi Med., vol. 30, no. 1, 2010, pp. 76–80.

[5] Muhammad Rivai, Tasripan, “Fuel Qualification Using Quartz Sensors”, ARPN Journal of Engineering and Applied Sciences, Vol. 10, No. 16, 2015, pp. 6737-6743.

[6] Hari Agus Sujono, Muhammad Rivai, “Vapor Identification System Using Quartz Resonator Sensor Array And Support Vector Machine”, ARPN Journal of Engineering and Applied Sciences, Vol. 9, No. 12, 2014, pp.2426-2430.

[7] Muhammad Rivai, Achmad Arifin, Eva Inaiyah Agustin, “Mixed Vapour Identification Using Partition Column-QCMs and Artificial Neural Network”, International Conference on Information, Communication Technology and System, 2016, pp. 172-177.

[8] Anifatul Faricha, Suwito, Muhammad Rivai, M.A. Nanda, Djoko Purwanto, Rizki Anhar R.P., “Design of Electronic Nose System Using Gas Chromatography Principle and Surface Acoustic Wave Sensor”, Telkomnika, Vol.16, No.4, 2018, pp. 1458-1467.

[9] Muhammad Rivai, Eddy Lybrech Talakua, “The Implementation of Preconcentrator in Electronic Nose System to Identify Low Concentration of Vapors Using Neural Network Method”, International Conference on Information, Communication Technology and System, Surabaya, 2014, pp. 31-36

[10] G. Olafsdottir, P. Nesvadba, C.D. Natale, M. Careche, “Multisensor for fish quality determination”, Trends Food Sci. Technol., vol. 15, no. 2, 2004, pp. 86–93.

[11] N. Hasan, N. Ejaz, W. Ejaz, H. Kim, “Meat and Fish Freshness Inspection System Based on Odor Sensing”, Sensors, vol. 12, no. 11, 2012, pp. 15542–15557.

[12] Z. Jun, L. XiaoYu, W. Wei, Z. Zhu, Z. Wei, and X. Wu, “Determination Freshwater Fish Freshness with Gas Sensor Array”, World Congress on Computer Science and Information Engineering, 2009, pp. 221–224.

[13] D.A. Jiménez, G.D. Díaz, M.C.B. López, M.J.L. Castañón, A.J.M. Ordieres, P.T. Blanco, “Molecularly Imprinted Electrochemical Sensors,” in *Molecularly Imprinted Sensors*, Elsevier, 2012, pp. 1–34.

[14] Alphasense, Appl. Note 104, pp.1-4.

[15] E. Prasojo, “Design of H_2S Gas Control System in Biogas Purification using Water Scrubber System based Microcontroller ATmega128”, A.Md.T. thesis, Dept. Inst. Eng., ITS, Surabaya, Indonesia, 2017.

[16] S.A. Humaid, and M.T. Jamal, “The Effect of Storage Temperature (4°C, 15°C and 25°C) on The Shelf Life of Whole Marine Fish (Rastrelliger kanagurta)”, IOSR Journal of Environmental Science, Toxicology and Food Technology, 2014, pp. 46-51.