Journal of Theoretical and Applied Information Technology
15th February 2018. Vol.96. No 3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A STUDY ON THE DETECTION OF MALFUNCTION OF GAS SENSOR IN INDOOR USING REGRESSION ANALYSIS

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ABSTRACT

As the industry enters the modern world, the chemical industry is growing in scale. As a result, the handling of chemicals is increasing and the risks are increasing. In particular, there is always the problem of the occurrence of chemical accidents due to the failure of control or management. To prevent this, a disaster detection system using sensors is actively under study. However, the gas sensor among the disaster detection sensors is malfunction due to the influence of the temperature and the humidity. Therefore, in this paper, we analyze the data of temperature sensor, humidity sensor data, and gas sensor data collected in indoor to prevent this. After confirming the correlation between the data, we calculate the regression equation that can express the sample data by calculating the coefficient of determination through regression analysis. Based on this, we propose a method to detect the malfunction by constructing an environment that can compare and analyze the data of the actual gas sensor with the data through the regression equation.

Keywords: *Gas Sensor, Bigdata, Regression analysis, Correlation*

1. INTRODUCTION

With the rapid development of the industry as it enters the modern society, the research content given to researchers is rapidly changing. Among them, the chemical industry is directly or indirectly related to almost all industries, and also occupies a very large proportion in industrial scale. According to the American Chemical Society (ACS), about 246,000 chemicals are commercially available worldwide. In Korea, 40,731 kinds of chemical substances are circulated and about 400 new chemical substances are newly entering the Korean market every year. Chemicals are used not only in our life necessities, but also in semiconductors, electrical and electronics, automobile and aerospace industries. In recent years, it has become a must in various high-tech industries such as Information Technology, BT (biotechnology) and NT It is used as a raw material or base material[1]. For example, the automotive industry, which has become the center of the machinery industry, is now increasingly dependent on the chemical industry after it has gone through electronics. Therefore, the development of the chemical industry and the increase of the chemical distribution greatly contribute to the development of the national industry, but there are many risks such as the chemical accident caused by the failure of management and control. In particular, the electric and electronics industries such as semiconductors are experiencing a significant increase in the risk of chemical spills due to the increase in the demand for various new chemical substances with high chemical use and harmful risks due to rapid development [2,3].

When handling chemicals and using many kinds of materials, the complexity of the process and equipment, and proper process safety management are not achieved, the risk becomes doubled[4]. Most of the chemical plants and chemical handling processes are composed of the equipment industry, in which highly complex and intensive technology processes are continuously running. Thus, in the event of a major industrial accident, such as fire, explosion or leakage, not only one accident will cause huge human and material loss, but also pollutes the environment or damage the local residents[5].

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Disaster detection sensors used for this purpose play an essential role in disaster detection. However, since the monitoring system based on the sensor depends on the human resources, the performance of the system may be degraded depending on the condition of the operator [6]. In addition, occasional sensor faults can lead to malfunctions or improper control operations by mis-communicating operating conditions or incorrectly performing the control system. Therefore, although a procedure of periodically checking and correcting is performed, this method is impossible to deal with the malfunction of the sensor immediately[7]. Therefore, it is necessary to study how to continually grasp malfunctions online and cope with them promptly. This will also be useful in managing and maintaining an accident.

Among the disaster detection sensors, gas sensors used for fire detection are influenced by temperature and humidity (hereinafter referred to as environment). Therefore, malfunction may occur due to environmental changes. At present, the development of sensors that minimize these effects is ongoing, but it is impossible to develop gas sensors that are fundamentally unaffected by the environment. [8].

Therefore, in this paper, statistical analysis is performed using open source R, analyze the correlation between collecting temperature sensor, humidity sensor (hereinafter, environmental sensor) data and gas sensor data. And apply regression analysis to check the dependency between data based on this. Through this, research is carried out to detect the malfunction of the gas sensor. In the case of gas sensors, it is used to detect fire or gas leaks in chemical laboratories. The results of this study can be used to detect the malfunction of the gas sensor not only in the laboratory, but also in other places in the chemical industry.

2. *RELATED WORK*

2.1 IoT(Internet of Thing)

Recently, research on safety related information service using object-based internet sensor has been actively conducted to prepare countermeasures against disaster situations [9]. IoT communication research using MQTT or CoAP protocol is also being actively conducted [10], and researches are being conducted to detect instantly when a fire occurs by applying Internet technology to implement Raspberry pie [11]. In this paper, propose a method to detect the malfunction of the sensor in advance. To do this, collect and analyze data on gas concentration with changes in temperature and humidity. Through this, it is possible to detect the malfunction of the gas sensor data and minimize the safety accidents that may occur.

2.2 R

It is an object-oriented programming language for statistical analysis and visualization. It is an open source program that has the advantage of adding multiple packages or extending functions. In the analysis of the national climate data using the open source R statistical package, statistical analysis using R was performed to analyze the national climate data [12], but in this paper, the correlation between the gas sensor and the environmental sensor Data analysis was conducted.

2.3 Concept of Correlation Analysis

Correlation analysis is a means of objectively and clearly recognizing the relationship between two variables. If you want to know the correlation between two variables, you can analyze Pearson correlation coefficient, Sperman correlation coefficient, Sperman correlation coefficient, and Kendall tau as necessary. The Pearson correlation coefficient is used when both variables are continuous variables, and the partial correlation coefficient is used by obtaining partial correlation coefficients of various orders when there are control variables. We calculate the correlation between Spearman correlation coefficient and Kendall's tau order scale parameter.

The Pearson correlation is a measure of the correlation originally designed by Pearon and is called a Pearson correlation or simple correlation. There are various correlation coefficients, but in general, correlation coefficient means the Pearson correlation coefficient. The Pearson correlation coefficient is called r and the correlation coefficient r is calculated by the following equation (1) with dependent variable (y) and independent variable (x) [13].

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (1)$$

The range of correlation coefficient r in the population distribution between two variables is shown in Equation (2).

$$-1.0 \le r \le +1.0 \quad (2)$$

Correlation analysis is classified into Pearson correlation analysis, which does not control the second variable depending on whether the third variable is controlled, and partial correlation analysis, which controls the third variable. The variables used in this paper use Pearson correlation analysis because they do not control the third variable with the data collected by the sensor.

2.3.1 Correlation Coefficient and Correlation

When the correlation coefficient r is within the range of -1.0 <r <0, it is called a negative correlation and when the correlation coefficient r is within the range of 0 <r <+ 1.0, it is called a positive correlation. Figure 1 shows an example of correlation and Pearson correlation coefficient r is defined as Table 1 below [14].

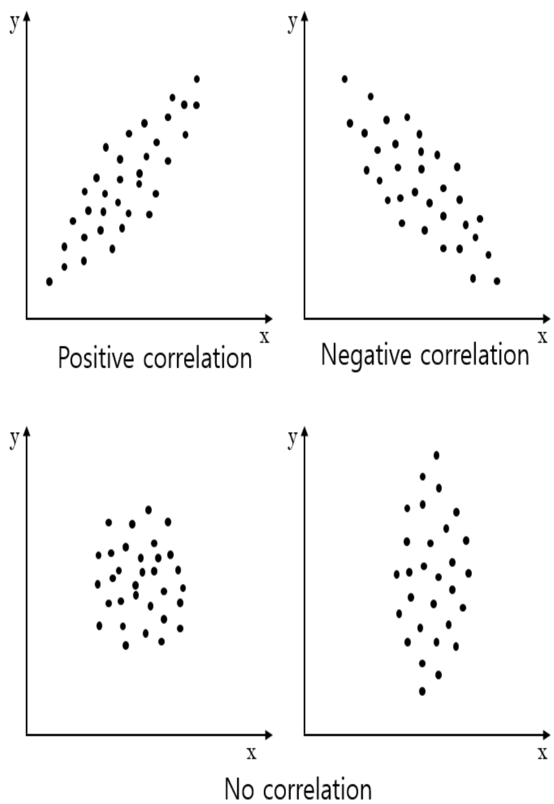

Figure 1: Correlation Diagram

Table 1. Correlation by correlation coefficient

$0.7 \leq r < 1.0$	Positive Correlation & Very relevant
$0.4 \leq r < 0.7$	Positive Correlation & Relevant
$0.2 \leq r < 0.4$	Positive Correlation & Somewhat relevant
$0.0 \leq r < 0.2$	Positive Correlation & Irrelevant
$-0.2 < r \leq 0.0$	Negative Correlation & Irrelevant
$-0.2 < r \leq -0.4$	Negative Correlation & Somewhat relevant
$-0.7 < r \leq -0.4$	Negative Correlation & Relevant
$-1.0 < r \leq -0.7$	Negative Correlation & Very relevant

2.4 Concept of Regression Analysis

Correlation analysis only confirms whether there is a linear relationship between two variables. Regression analysis, on the other hand, is a method of assessing and assessing the relevance of each observed or given variable. Statistically, it is a method to find the linear relationship expressing the correlation between the independent variable and the dependent variable and the analytical method to measure the fitness of the obtained model. The analysis of the relationship between one independent variable and one dependent variable is called simple regression analysis and the analysis of the relationship between several independent variables and one dependent variable is called multiple regression analysis do. In addition, when a variable measured by a nominal scale or a sequence scale is used as an independent variable, it is called a dummy variable regression indicated by a binary variable. In addition, it is divided into linear regression analysis and nonlinear regression analysis according to the relationship between independent variables and dependent variables[15].

2.4.1 Simple Linear Regression Analysis

The main purpose of linear regression analysis is to explain the relationship between independent variables and dependent variables or to predict output values for new cases. Simple regression analysis, which is one of them, is a function that explains one dependent variable Y by one independent variable X, and the basic formula is shown in Equation (3).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$Y = \alpha + \beta X + £ \quad (3)$$

In this equation, α and β are regression coefficients. £ is the difference between the value of the actual dependent variable and the value of the predicted dependent variable of any independent variable, which is called the residual or noise and is not accounted for by the regression coefficient. α is the slice value when X is 0 and β is the slope value of the regression line affecting the dependent variance of the population. The reason for including the residues in the regression model is that of the first missing variables other than X. The second is the observation error of the variables and finally the error that occurs when the linear relationship is not clear [16].

2.4.2 Multiple Linear Regression Analysis

The basic concept of the multiple linear regression analysis is the same as the simple linear regression analysis, except that two or more independent variables are used. By using several independent variables, the prediction ability can be increased. This model is used to fit the linear relationship between the quantitative dependent variable Y and the independent variables X_1, X_2, ..., X_k. The basic model of the multi-linear regression analysis with independent variables k is shown in the following equation (4).

$$Y = \alpha + \beta_0 X_0 + \beta_1 X_1 + \ldots + \beta_k X_k + £ \quad (4)$$

In this equation, α, β_0, β_1, …, β_k, are regression coefficients, and the residual ε is the error that occurs when measuring Y [17].

2.4.3 Definition of Regression Coefficients and Decision Coefficients

When the regression coefficient has the same independent variable and the range of the dependent variable, the larger the slope, the greater the variation of the dependent variable with the independent variable. That is, the larger the slope, the more sensitive the value changes.

The coefficient of determination is the amount of change explained for the total amount of change, that is, the relative proportion of the sum of squares explained by the regression equation. It is represented by R^2 (squared multiple correlation) and is an index indicating how the independent variables explain the dependent variable to be. In particular, the coefficient of determination in the multivariate regression model does not show the explanatory power of each independent variable for the dependent variable but the explanatory power of all independent variables. The value of the coefficient of determination is between 0 and 1, and the higher the correlation between the dependent variable and the independent variable, the closer to 1. In other words, a regression model with a value of R^2 close to zero has a lower usefulness, while a value of R^2 has a high usefulness of a regression model. The multiple regression analysis uses an adjusted coefficient of determination (R^{2a}) rather than a simple regression [14].

3. SYSTEM MODEL AND METHODS

3.1 System model

The system model for recognizing the malfunction of the gas sensor proposed in this paper is shown in Figure 2. The data is collected by the gateway through the sensor, corrected to an appropriate value by error correction, and then transmitted to the main server for storage. And we analyzed the correlation between stored gas sensor and temperature sensor data and designed a system that can apply regression analysis.

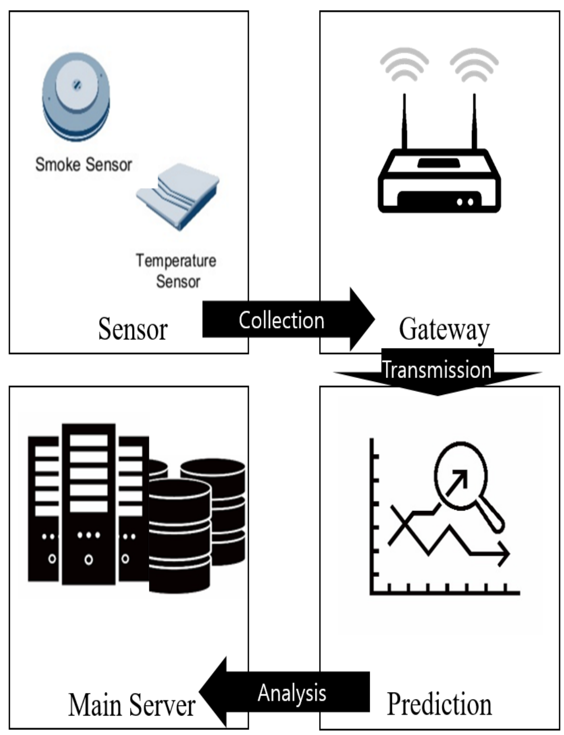

Figure 2: Data transmission system

3.1.1 Experimental environment

In this paper, have studied the gas sensor and environmental sensor data [18] collected from the Bioengineering Institute of San Diego,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

California, USA, which is similar to the system model presented above. This data was collected in an indoor environment where the gas concentration remains unchanged and only changes in temperature and humidity.

3.1.2 Data Refining

The collected data is in the form of csv and excel files that can be easily analyzed and conveniently found. Raw data is unprocessed computer data and is stored in time series and can be briefly represented in Table 2 and Figure 3. In this paper, data correlation and regression analysis between gas sensor and environmental sensor are aimed. Therefore, it is necessary to delete the unnecessary data in accordance with the purpose of analysis and to align the environmental sensor data with the different gas sensors.

Table 2. Examples of raw data

	First data	Second data	…
Time	0.000199	0.000477	…
First Gas sensor	13.007100	13.008400	…
Second Gas Sensor	10.611700	10.612300	…
Third Gas Sensor	10.632900	10.632900	…
Fourth Gas Sensor	11.944100	11.944500	…
Temperature	25.586800	25.588000	…
Humidity	58.894500	58.904400	…

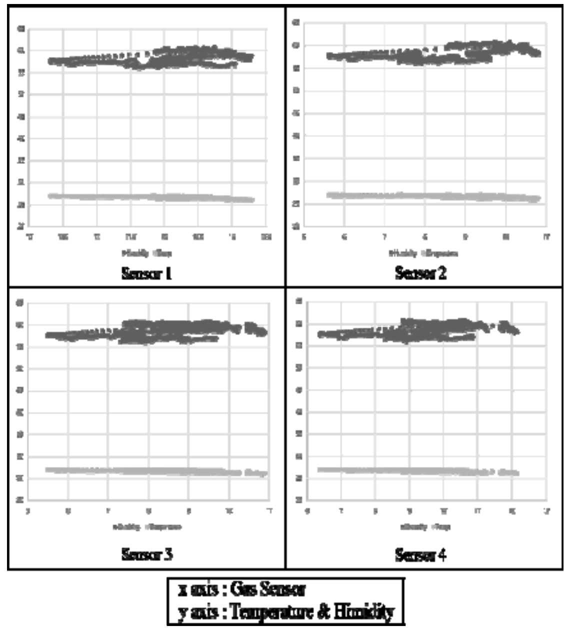

Figure 3: Data distribution of humidity and temperature for each sensor

3.2 Data Correlation Analysis

In order to confirm that the environmental sensor affects the data of the gas sensor, it must be verified whether the gas sensor and the environmental sensor are correlated or not. Therefore, in this paper, the correlation analysis between the environmental sensor and the gas sensor is performed before the regression analysis.

3.2.1 Correlation Analysis between Temperature Sensor and Gas Sensor

In order to analyze the correlation between the gas sensor and the environmental sensor, the r coefficient is calculated by substituting in equation (1). The results are shown in Table 3.

Table 3. R coefficient of each sensor according to temperature

	Temperature Sensor
Gas Sensor 1	-0.8120951
Gas Sensor2	-0.7953799
Gas Sensor3	-0.860681
Gas Sensor4	-0.8600337

As shown in Table 3, the gas sensor data changes according to the temperature sensor data, and it can be confirmed that the Correlation diagram between the two data is negative correlation by the r coefficient. This means that as the value of the temperature sensor data increases, the value of the gas sensor data decreases. That is, it can be seen that as the temperature increases, the resistance of the gas sensor that senses the gas increases, and the data value of the gas sensor decreases relatively. Since the absolute value of the r coefficient is 0.7 or more in all four sensors, the correlation between the gas sensor and the temperature is high. The correlation diagram visualizing the correlation between the temperature sensor and the gas sensor is shown in Figure 4.

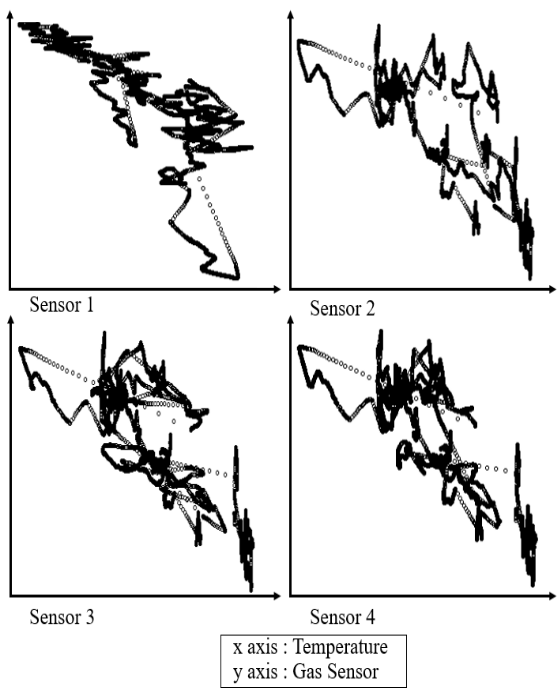

Figure 4: Correlation diagram between temperature sensor and gas sensor data

The x-axis portion of Figure 4 is the temperature sensor data and the y-axis portion is the data of the gas sensor. It is possible to visually confirm that the two data have a negative correlation.

3.2.2 Correlation analysis between humidity sensor and gas sensor data

In order to analyze the correlation between the gas sensor and the environmental sensor, the r coefficient is calculated by substituting in equation (1). The results are shown in Table 4.

Table 4. R coefficient of each sensor according to humidity

	Humidity Sensor
Gas Sensor 1	0.2659616
Gas Sensor2	0.5484825
Gas Sensor3	0.3550670
Gas Sensor4	0.3566585

It can be confirmed that there is a positive correlation with the temperature sensor data. In the case of the humidity sensor, the absolute value of the correlation coefficient is generally low, and the value of 0.5484825 from the sensor 2 is the highest value. It has a value between 0.2 and 0.4 as a whole and does not have a high correlation with the gas sensor data like the temperature sensor data, and has a little correlation. It can be confirmed that the gas sensor is more affected by temperature than humidity. The correlation diagram visualizing the correlation between the humidity sensor and the gas sensor is shown in Figure 5.

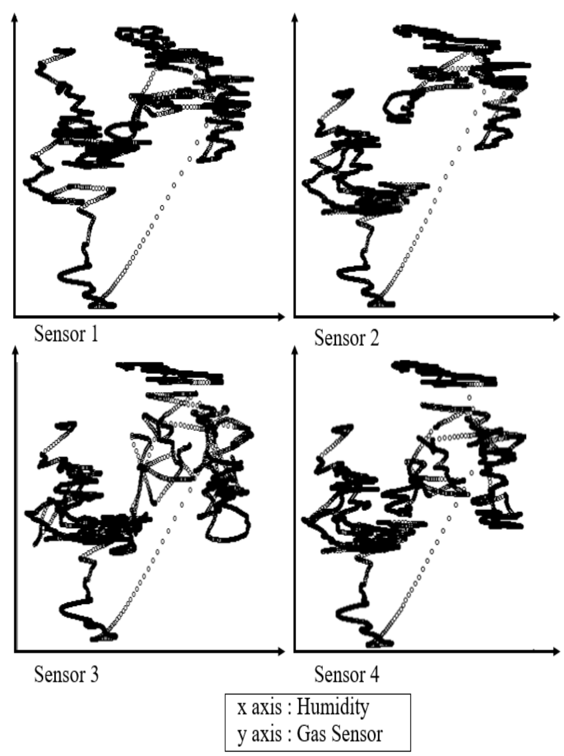

Figure 5: Correlation diagram between humidity sensor and gas sensor data

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The x-axis portion of Figure 5 is the humidity sensor data and the y-axis portion is the data of the gas sensor. It can be visually confirmed that both data have a positive correlation, and it is found that they are weakly related to the temperature sensor.

3.3 Data Regression Analysis

It is confirmed that the gas sensor data value, which is a dependent variable, is influenced by the environmental sensor data as an independent variable. This time, we try to calculate the regression equation of two data through regression analysis. The temperature sensor and the humidity sensor data have different correlations with the gas sensor. Therefore, after regression analysis of temperature sensor data, humidity sensor data, environmental sensor data and gas sensor data, the overall results were compared and analyzed

3.3.1 Temperature sensor and gas sensor data regression analysis

It is confirmed earlier that the gas sensor data value, which is a dependent variable, is affected by the independent temperature sensor data. This time, we try to calculate the regression equation of two data through regression analysis. First, regression analysis was performed using temperature sensor data with high correlation and four gas sensor data. The results are shown in Table 5.

Table 5. Regression equation of temperature sensor and gas sensor and determination coefficient

	Regression equation	Determination coefficient
Gas Sensor 1	y = -1.82t+60.66	0.6595
Gas Sensor 2	y = -3.735t+108.060	0.6326
Gas Sensor 3	y = -4.21t+120.42	0.7406
Gas Sensor 4	y = -4.461t+128.206	0.7397

Table 5 shows the regression equation and the coefficient of determination. Where it is the value of the independent temperature sensor and y is the value of the dependent gas sensor. In the regression equation of sensor 3, the slope -4.21 indicates the degree of change of the independent variable and the dependent variable by the regression coefficient. The coefficient of determination 0.7406 of Sensor 3 is a measure of how many percent of the sample data used in the regression analysis is explained by the derived regression equation. The determination coefficient of the gas sensor and the temperature sensor is 0.7406, and 74.06% of the sample data can be interpreted as a regression equation. In other words, the correlation between two variables is high and it is confirmed that this regression equation is highly fit.

Figure 6 shows the Correlation diagram and the regression equation between the gas sensor and the temperature sensor in one figure. It can be seen that the data is distributed around the regression equation as a whole. In particular, when the sensor 3 having the highest determination coefficient is seen, it can be confirmed that the data is highly distributed around the regression equation.

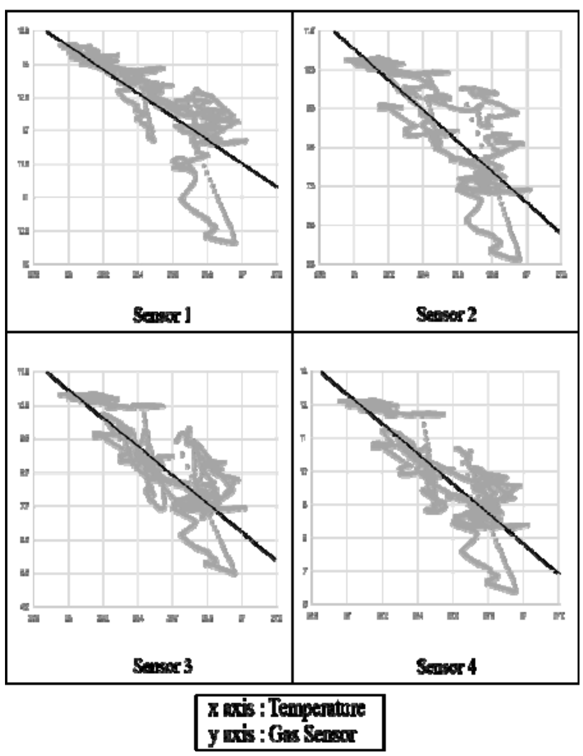

Figure 6: Correlation diagram and regression equation between temperature sensor and gas sensor

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.3.2 Humidity sensor and gas sensor data regression analysis

The gas sensor data value, which is a dependent variable, is affected less by the independent humidity sensor data. This time, we try to calculate the regression equation of two data through regression analysis. Regression analysis was performed using the humidity sensor data and the four gas sensor data. The results are shown in Table 6.

Table 6 shows the regression equation and the coefficient of determination. Where h is the value of the humidity sensor as an independent variable and y is the value of the gas sensor as a dependent variable. It can be confirmed that the value of the coefficient of determination is low as a whole, and the highest value is the value 0.3008 of the sensor 2. This means that the sample data of the humidity sensor and the gas sensor 2 can be interpreted only in a regression equation of 30.08%. When we look at the slope of the regression equation, it can be confirmed that the overall is low, and the sensitivity of the humidity sensor and the temperature sensor is low. As a result, it can be confirmed that the correlation between the two variables, that is, the compatibility is low.

Table 6. Regression equation of humidity sensor and gas sensor and determination coefficient

	Regression equation	Determination coefficient
Gas Sensor 1	$y = 0.1407h + 4.2829$	0.07074
Gas Sensor 2	$y = 0.6083h - 26.2173$	0.3008
Gas Sensor 3	$y = 0.4102h - 14.9238$	0.1261
Gas Sensor 4	$y = 0.436h - 15.3411$	0.1272

Figure 7 shows the Correlation diagram and the regression equation between the gas sensor and the humidity sensor. Since the regression coefficient is low, it can be confirmed that the distribution of data is small around the regression equation when compared with the temperature sensor. In the case of sensor 4, which has the highest regression coefficient, it can be seen that the data are relatively distributed near the regression equation when compared with the remaining three sensors.

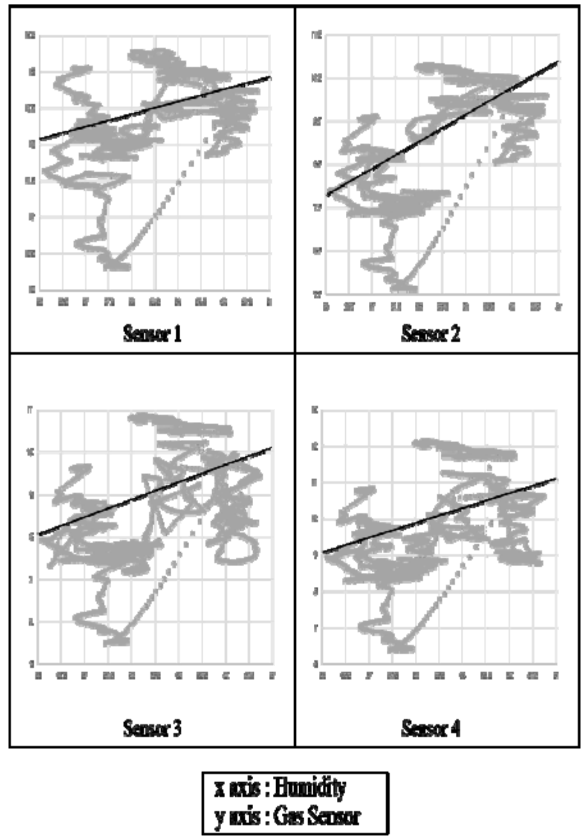

Figure 7: Correlation diagram and regression equation between humidity sensor and gas sensor

3.3.3 Environmental sensor and gas sensor data regression analysis

In the previous passage, the regression analysis was performed by applying the temperature sensor and the humidity sensor as one independent variable and the gas sensor data as the dependent variable. In the case of the temperature sensor, the regression equation of the regression analysis can be interpreted up to 74.06% of the sample. On the other hand, in the case of the humidity sensor, the regression equation could only interpret a maximum of 30.08% of the sample. This is because the correlation of the humidity sensor is lower than that of the temperature sensor. In order to increase the fitness of the regression equation, regression analysis was performed by combining the data with high correlation and the data with low correlation. In other words, the regression analysis of the data of the environmental sensor and the gas sensor predicted that the fitness of the regression equation would increase. Table 7 shows the results of regression analysis.

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Table 7. Regression equation and determination coefficient of environmental sensor and gas sensor

	Regression equation	Determination coefficient
Gas Sensor 1	y = -1.84135t - 0.01445h+62.07807	0.6601
Gas Sensor 2	y = -3.2266t + 0.3363h + 75.0583	0.7129
Gas Sensor 3	y = -4.1137t + 0.0635h + 114.1934	0.7433
Gas Sensor 4	y = -4.35504 + 0.06985 + 121.35237	0.7425

Table 7 shows the results of the regression analysis of the environmental sensor and the gas sensor. Regression analysis of environmental sensor and gas sensor is multiple regression analysis, so modified coefficient of determination is applied unlike previous two regression analysis. Where t and h are the values of the independent temperature sensors and humidity sensors, respectively, and y is the value of the gas sensor, the dependent variable. The modified coefficient of determination of sensor 3 is the largest at 0.7433, and this regression equation can interpret 74.33% of the sample data. Compared with Table 4, the coefficient of determination increased slightly, and the value of sensor 2, which had a high correlation with the humidity sensor, increased the greatest. As a result of the regression analysis using only the temperature sensor, only the 63.26% of the sample data could be interpreted as a result of the regression analysis with the environmental sensor. As a result, it was confirmed that the regression equation can interpret 71.29% of the sample data can do.

4. CONCLUSION

In this paper, data analysis is performed to detect malfunction of gas sensor. Data were collected from data collected in environments with the same gas concentration and only changes in temperature and humidity. As a result of the experiment, it was confirmed that the gas concentration data change according to the change of the environment even though the same gas concentration. Therefore, correlation analysis was performed to analyze the correlation between data.

As a result of correlation analysis with temperature sensor data, the absolute correlation coefficients of all four gas sensors were 0.7 or more and the average value was -0.8320292. This indicates that they have a high correlation and a negative correlation. Therefore, the higher the temperature, the more likely it would have a negative impact on the gas sensor data. On the other hand, as a result of the correlation analysis with the humidity sensor data, the absolute values of the four correlation coefficients of the gas sensor were all below 0.7 and the average value was 0.3815424. Overall, it showed a low correlation with temperature sensor data and had a positive correlation.

Based on the correlation analysis, the regression equation and the coefficient of determination were calculated by regression analysis of the temperature sensor and the gas sensor data. As a result, the regression equation showed that the sample data can be interpreted with an average of about 69.25%. On the other hand, the regression equation and the coefficient of determination were calculated by regression analysis of the humidity sensor and the gas sensor data. As a result, the regression equation was able to interpret the sample data with an average of 15.62% of the four sensors, which is lower than the temperature sensor. n this paper, we will work to improve the fitness of the regression equation to explain the sample data. If regression analysis is performed by combining data with a low correlation and high correlation, it is expected that the fitness of the regression equation will increase a little more. Therefore, regression, analysis of environmental sensor and gas sensor data was performed.

Regression analysis of environmental sensor was compared with regression analysis of temperature sensor which had higher correlation than humidity sensor. Figure 8 shows the rate of increase of conformity value.

Regression analysis showed that the sample data can be interpreted with an average of 71.47% of the four sensors. Compared with the regression analysis of the temperature sensor data, it increased by 2.22%, indicating that the usefulness in interpreting the sample data was slightly increased. Based on these results, it is possible to suggest a method to minimize the sensing error and malfunction of the sensor by studying the algorithm that can correct the value of the gas sensor data.

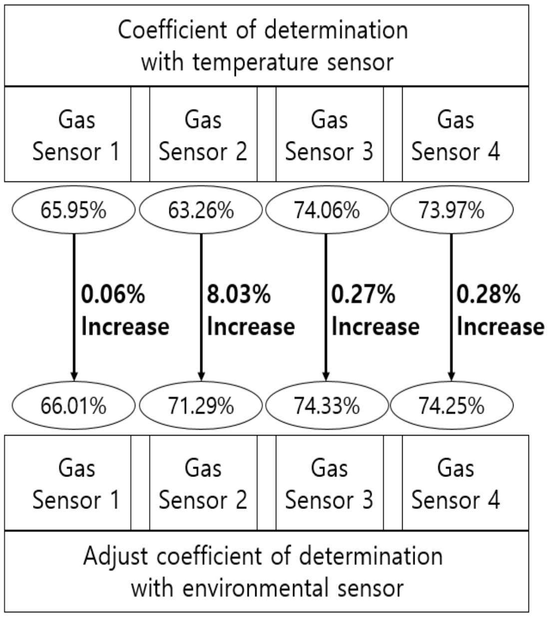

Figure8: Fitness increase numerical value

However, considering the average value of the regression equation, it is difficult to completely detect the malfunction of the gas sensor because the environmental sensor data can only analyze the gas sensor data by about 70%. In the future, we will carry out research to detect the malfunction of the gas sensor by using the data of the humidity sensor as well as the temperature sensor. And we study algorithms that increase the accuracy of gas sensor measurement data based on the regression equation of integrated data. Through this, it is expected that the false alarm due to the malfunction of the gas sensor will be reduced, and more precise gas detection will be possible. And if precise gas management is performed not only in the laboratory, but also in the home, the chemical plant, and the public place, it will be very helpful for safety management.

ACKNOWLEDGMENTS: This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2017R1D1A3B03036130).

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