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Dr. Eng. Helmy Fitriawan, S.T., M.Sc.
NIP. 197509282001121002

Megetahui,
Dekan Fakultas Teknik Unila

Prof. Ir. Suharno, M.Sc., Ph.D., IPU.
NIP. 196207171987031002

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Ketua LPPM Universitas Lampung

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# Embedded System for Temperature, Humidity and Gas Monitoring

**Helmy Fitriawan[1], Victor Farhan Wijaya[2], Sri Purwiyanti, Herlinawati[3]**

Department of Electrical Engineering, University of Lampung, Jl. Sumantri Brojonegoro No. 1, Bandar Lampung, 35145, Indonesia

**Abstract:** ***Air pollution is one of the environmental problems that must be solved. Heavy transportation and industrial activities may cause poor air quality and inhaling pollutants, such as CO and $CO_2$, for a long time may damage human health. Therefore, it is necessary to have an air quality monitoring system which gives information of hazardous gases concentration from time to time in certain area. This study aims to design and build a monitoring and measurement system for CO and $CO_2$ in the environment using wireless sensor network (WSN) with ZigBee based wireless network technology. The experimental results show the proposed system is able to provide the air quality monitoring in real time through WSN technology. In order to have accuracy measurement results, those sensors used in the developed system are compared and calibrated to reliable standard instruments. DHT 22 sensor works well as a sensor to read the temperature and humidity with an average error value of 0.14 °C and 0.1% RH, respectively. The MQ-7 gas sensor has an average error of 72,082 ppm and the MG811 gas sensor has an average error value of 281.36 ppm, both are compared to E4500-C standard instrument device.***

**Keywords:** gas monitoring, temperature, humidity, arduino, sensor

## 1. Introduction

The increase of the development of industry and technology has led to an increase the number of vehicles using fossil fuels. This causes the air we breathe to become polluted by exhaust gases from combustion. Air pollution is one of the environmental problems that must be solved [1]. There are several gases pollutants existed in the air, among them are carbon compounds such as CO (Carbon monoxide) and $CO_2$ (Carbon dioxide). These toxic gases can cause serious impact on human health and environment. For example, $CO_2$ gases can intrude the airways of the lungs and worsen those suffering from lung diseases. CO gases avoids the uptake of oxygen by the blood. This causes to a significant reduction in the supply oxygen to the heart, particularly in people suffering from heart diseases [2].

The air has a very important meaning in life and the existence of other living things. Air is a natural resource that must be protected for the lives of humans and other creatures. The pollutant gases are also produced in large quantities in industries. Therefore, these gases have to be monitored, whenever there is increase of their concentrations above the normal level then proper precaution should be taken. Hence, it is necessary to have an accurate air quality monitoring system. This system should have the facility to detect and quantify the toxic gases. The system also provides real time monitoring so that the information is given timely to avoid the endangering of human lives.

Recently, wireless sensor network (WSN) has been used in countless applications, such as home, industry, agriculture, health and medical, military, and environment [3]. Due to low power sensor, low cost embedded microcontroller and effective wireless communication technologies, WSN is applicable to collect and disseminate the environmental parameters, such as temperature, humidity, pressure, sound, vibration, and gas pollutant. WSN is a self-organizing multi hop network that consists of distributed sensors nodes deployed in a large range area [4]. These nodes are able to communicate and transmit or receive those sensing data. Hence, WSN has ability to sense physical parameters, data processing, and wireless communication at the same time. In the previous study, a prototype WSN for humidity and temperature monitoring is developed [5] and the analysis of its performance is reported [6].

This paper reports a study to design a system that can monitor several gases such as carbon dioxide, carbon monoxide, and monitor temperature and humidity in the environment wirelessly and real time. The system is modularity developed from an Arduino board, ZigBee based communication module, and low power temperature and humidity, and gases sensors.

## 2. Research Method

### 2.1 CO and $CO_2$

The environment is a unity of space with all things, power, circumstances, living things including humans and their behavior that affect nature itself, the survival of life, and the welfare of humans and other living things. Yet the environmental pollution in an urban area is still arising. Environmental pollution is the entry or inclusion of living things, energy substances, and / or other components into the environment, or changes in the environmental order by human activities or by natural processes. Consequently, the quality of the environment falls to a certain level that causes the environment to become less or unable to function in accordance with its designation.

On the basis of the form in which pollutants exist, pollutants are categorized as primary and secondary. The substances of primary pollutants are directly emitted from the source and remain in that form. Meanwhile, the substances of secondary pollutants are formed by chemical reaction between the primary pollutants and constituents of the environment. The main primary pollutants are carbon compounds such as CO and $CO_2$. CO is a colorless, odorless, tasteless gas mainly produced by the exhaust of industrial activities and the burning of transportation fuels. CO poisoning is caused by inhaling combustion fumes. When there is significant concentration of CO in the air get into the human respiratory system, the carbon monoxide will replace the oxygen in the body. This will prevents the oxygen to reach other parts of the body. This can lead to serious organ damage or even death. $CO_2$ is odorless at normally encountered concentrations, but at high concentrations it has a sharp and acidic odor. It is colorless gas that is heavier than air. In certain concentrations, $CO_2$ also gives bad impact to human health. High concentrations of $CO_2$ can cause asphyxiation quickly, without warning, regardless of the oxygen concentration.

### 2.2 Sensors

The system developed in this study is equipped with temperature, humidity, carbon monoxide and carbon dioxide gas sensors. Low cost digital DHT 22 sensor is used to read the temperature and humidity. It has range of temperature measurements from -40 to +80℃ with accuracy of about ±0.5$^o$C. Its humidity measuring range is from 0 to 100% RH with ±2-5% RH accuracy [7]. This sensor is classified as a component that has a very good level of stability and includes a temperature measuring resistive element (NTC).

In order to conduct gas measurements in the system, MQ-7 and MG-811 sensors are used. MQ-7 is a simple gas sensor to detect CO gas with range from 20 to 2000 ppm [8]. This sensor module is equipped with a potentiometer to adjust sensitivity and is usually used for home devices, industrial devices, measurement of pollutants on the road, or vehicles. The recommended environmental conditions for the use of this sensor are temperatures between -25 to 50$^0$C and humidity less than 95%. Another gas sensor is MG-811 is used to detect $CO_2$ [9]. This sensor has a heating coil component inside the Al2O3 ceramic pipe. The sensor structure consists of solid electrolytes and heaters. The electrolyte part is made of cations (Na+) which are between two electrodes arranged above the heater. This element functions as a $CO_2$ gas detector.

### 2.3 Arduino

Arduino Mega 2560 is used as the heart of the system. It is a microcontroller board based on the ATMega2560. It has 54 digital I/O pins (15 pins can be used as PWM outputs), 16 analog inputs, 4 UARTs, 16 MHz crystal oscillator, a USB connection, a power jack, a ICSP header and a reset button. The Arduino can be powered using the USB connection to the PC or with external power using AC-DC adapter or battery [10].

### 2.4 ZigBee Module

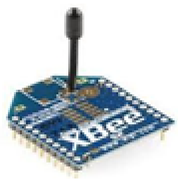

**Figure 1:** XBee S2

XBee S2 module, as shown in Figure 1, is used in the system for the communication task [11]. This module is suitable for low power and low cost wireless sensor network (WSN) applications with various topologies, i.e. peer to peer, star and mesh network topologies. It is operated based on the ZigBee communication protocol with 2.4 GHz frequency band and 250 Kbps data rate. The distance between communicated adjacent devices with XBee module in the line of sight outdoor deployment should not exceed 120 m. Meanwhile, in indoor deployment the distance is allowed no more than 40 m.

## 3. System Implementation

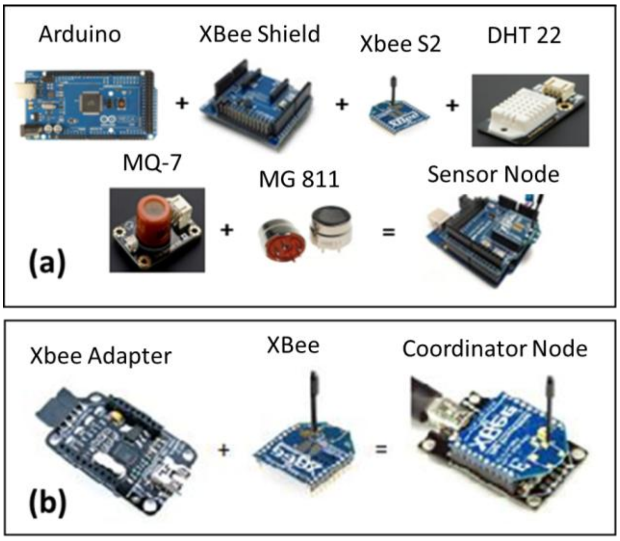


**Figure 2:** Hardware platforms for (a) Sensor Node, (b) Coordinator Node

In the implementation phase, the prototype system is developed in modular based. In modular based system, the prototype is designed by using independent component or module, where any of these modules can be changed or updated without affecting other modules connected to it. The developed system consists of two parts, one part is sensor node and the other part is coordinator node. The sensor node is developed from Arduino Mega module, XBee S2 module, DHT22 sensor, MQ-7 and MG 811 sensors which can be seen in Figure 2. (a). While for coordinator device consists of XBee adapter and XBee S2 which can be seen in Figure 2. (b).

XBee S2 module on the sensor node is configured to be the type of router or end device that serves to transmit data. Meanwhile, XBee S2 module on the coordinator is configured to be the type of coordinator that functions to receive data from the router or end device. Figure 3 shows the block diagram describing how the system is connected to transmit the data. The sensor node is used to measure temperature, humidity, CO and $CO_2$ gas concentrations in the environment where the sensor node is positioned. The measurement data is processed by the Arduino microcontroller and then sent to the coordinator via the XBee S2.

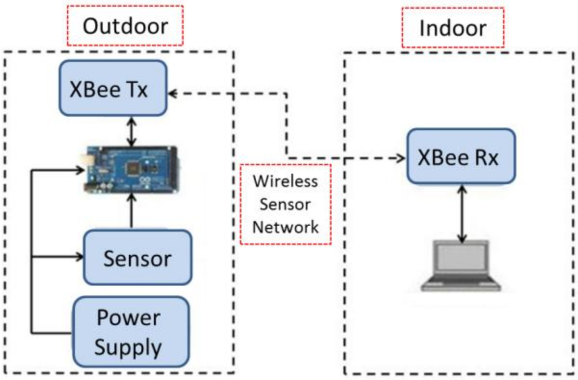


**Figure 3:** System Block Diagram

The overall working principle of the WSN starts from the formation of a network by XBee S2 telemetry. Formation of the XBee S2 telemetry network is carried out by setting the same PAN ID (Personal Area Network Identifier) for all XBee S2 telemetry used. Having the addressing each XBee S2 module, the communication process is able to perform. After the network is formed, the sensor node measures the temperature, humidity, gas concentrations in the environment where the sensor node is located. The measurement data will be processed by the Arduino microcontroller, then sent by XBee S2 to the coordinator. The coordinator receives the sensor measurement data using XBee S2 and XBee adapters. On the receiving side, the coordinator device is connected directly to the computer via a serial cable. The data received by the coordinator device is directly processed by the XAMPP software as a web server service provider to interface the WSN system monitoring in real time in the form of temperature, humidity, CO and $CO_2$ concentrations on the sensor node.

## 4. Results and Discussions

### 4.1 Temperature Sensor Testing

The temperature sensor testing method is carried out by comparing the measurement results by this sensor to those of temperature measurement instrument, Krisbow KW06-291. Both sensor and instrument are fetched near to the heating source. Table 1 show the results of measurements by the sensor and the instrument. The comparison shows the average error is only 0.14°C, therefore the DHT 22 is able to measure temperature appropriately.

**Table 1:** Temperature Sensor Testing Results

| No | Temperature Measurements (°C) | | Error (°C) |
|---|---|---|---|
| | DHT22 | KW 06-291 | |
| 1 | 35.1 | 35.0 | 0.1 |
| 2 | 35.1 | 35.0 | 0.1 |
| 3 | 35.2 | 35.1 | 0.1 |
| 4 | 35.3 | 35.2 | 0.1 |
| 5 | 35.4 | 35.3 | 0.1 |
| 6 | 35.7 | 35.5 | 0.2 |
| 7 | 36.2 | 36.1 | 0.1 |
| 8 | 37.2 | 37.0 | 0.2 |
| 9 | 37.3 | 37.1 | 0.2 |
| 10 | 37.3 | 37.1 | 0.2 |
| Average Error | | | 0.14 |

### 4.2 Humidity Sensor Testing

Humidity sensor testing is performed by placing water near the heater, as a result the water concentration is changing in the air. Then, the humidity sensor will sense the humidity condition near the water. The measurement results by the sensor are compared to those of humidity measurement instrument, Krisbow KW06-291. Humidity sensor testing results is shown in Table 2. The comparison shows there are no much difference from both measurements by the sensor and the instrument. The average error value obtained from the measurement test is only 0.1% RH. It conforms that the DHT 22 is also able to measure humidity properly.

**Table 2:** Humidity Sensor Testing Results

| No | Humidity Measurements (%RH) | | Error (%RH) |
|---|---|---|---|
| | DHT22 | KW 06-291 | |
| 1 | 75.2 | 75.2 | 0 |
| 2 | 75.2 | 75.2 | 0 |
| 3 | 75.3 | 75.3 | 0 |
| 4 | 76.3 | 76.3 | 0 |
| 5 | 76.4 | 76.4 | 0 |
| 6 | 76.5 | 76.5 | 0 |
| 7 | 77.2 | 77.2 | 0 |
| 8 | 77.5 | 77.3 | 0.2 |
| 9 | 77.8 | 77.5 | 0.3 |
| 10 | 78.1 | 77.6 | 0.5 |
| Average Error | | | 0.1 |

### 4.3 Carbon Monoxide Sensor Testing

The MQ-7 sensor is tested by sensing the exhaust gas released by the motorcycle. The sensor and the gas measurement instrument, E4500-C, are brought close to the motorcycle's muffler, and then measure the CO gas concentrations. The output of the sensor measurements is in the form of voltage value (volt) are compared to those of instrument's output which is in the form of gas concentration (ppm) as seen in Figure. 4.

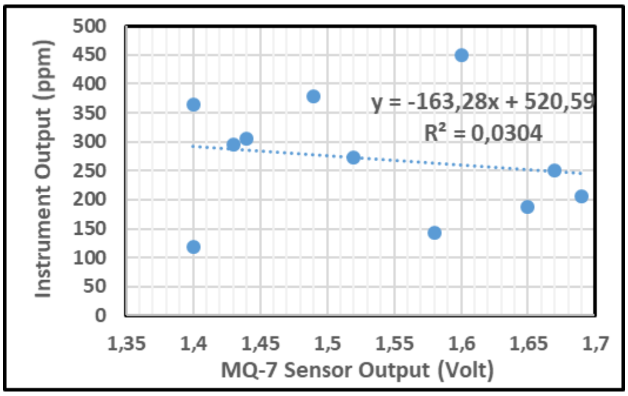


**Figure 4:** The comparison of MQ-7 sensor output with those of E4500-C instrument

It can be seen from the above figure the obtained voltage output is not linear with the increase in the amount of CO gas concentration measured by the standard insrtument device. Therefore, the linear regression approach is performed to model the relationship. The linear regression equation obtained is y = -163.28x + 520.59, meaning that the sensor output voltage is multiplied by the value of -163.28 + 520.59 to get the concentration value of the calibration gas. The calibration results obtained are summarized in Table 3. From the table it can bee seen that the average error is 72.082 ppm.

**Table 3:** MQ-7 Sensor Testing Results

| No | CO Concentrations (ppm) | | Error (ppm) |
|---|---|---|---|
| | MQ-7 | E4500-C | |
| 1 | 291.998 | 119 | 172.998 |
| 2 | 262.608 | 142 | 120.608 |
| 3 | 251.178 | 187 | 64.178 |
| 4 | 244.647 | 206 | 38.647 |
| 5 | 247.912 | 250 | 2.088 |
| 6 | 272.404 | 273 | 0.596 |
| 7 | 287.099 | 296 | 8.900 |
| 8 | 285.467 | 305 | 19.533 |
| 9 | 291.998 | 365 | 73.002 |
| 10 | 277.303 | 379 | 101.697 |
| 11 | 259.342 | 450 | 190.658 |
| Average Error | | | 72.082 |

### 4.4 Carbon Dioxide Sensor Testing

The assessment of MG811 sensor is carried out in the same technique as that of MQ-7 sensor. The MG811 sensor is tested by detecting the exhaust gas released by the motorcycle. The sensor and the gas measurement instrument, E4500-C, are brought close to the motorcycle's muffler, and then measure the $CO_2$ gas concentrations. The relationship between outputs read by the MG811 sensor and standard E type E4500-C instrument measuring instrument can be seen in Figure 5.

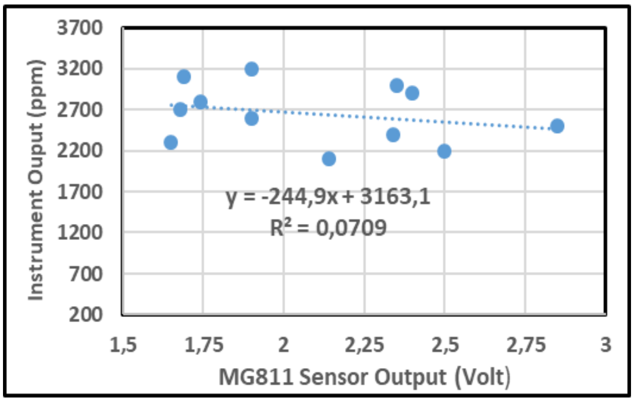


**Figure 5:** The comparison of MG811sensor output with those of E4500-C instrument

Based on the figure above it can be seen that the sensor voltage output values obtained is not linear with the increase of the amount of $CO_2$ gas concentration measured by the standard instrumnet device. Therefore, the linear regression approach is taken to obtain the relationship model. The linear regression equation obtained is y = -244,9x + 3163,1, meaning that the sensor output voltage is multiplied by the value of -244,9 + 3163,1 to get the concentration value of the calibration gas. The calibration results obtained are summarized in Table 4. From the table it can bee seen that the average error is 281.361 ppm.

**Table 4:** MG-811 Sensor Testing Results

| No | $CO_2$ Concentrations (ppm) | | Error (ppm) |
|---|---|---|---|
| | MQ-7 | E4500-C | |
| 1 | 2639.014 | 2100 | 539,014 |
| 2 | 2550.850 | 2200 | 350,850 |
| 3 | 2759.015 | 2300 | 459,015 |
| 4 | 2590.034 | 2400 | 190,034 |
| 5 | 2465.135 | 2500 | 34,865 |
| 6 | 2697.790 | 2600 | 97,790 |
| 7 | 2751.668 | 2700 | 51,668 |
| 8 | 2736.974 | 2800 | 63,026 |
| 9 | 2575.340 | 2900 | 324,660 |
| 10 | 2587.585 | 3000 | 412,415 |
| 11 | 2749.219 | 3100 | 350,781 |
| 12 | 2697,79 | 3200 | 502,210 |
| Average Error | | | 281,361 |

## 5. Conclusions

The development of prototype of Zigbee based WSN to monitor temperature, humidity, CO and CO2 gases is reported. In order to have accuracy measurement results, those sensors used in the developed system are calibrated to reliable standard instruments. DHT 22 sensor works well as a sensor to read the temperature and humidity with an average error value of 0.14 ℃ and 0.1% RH, respectively. The MQ-7 gas sensor has an average error of 72,082 ppm and the MG811 gas sensor has an average error value of 281.36 ppm, both are compared to E4500-C standard instrument device. It is concluded that the prototype system works well in terms of its functionality.



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## Author Profile

**Helmy Fitriawan** received the Bachelor of Engineering degree in Electrical Engineering from Institut Teknologi Bandung (Indonesia) in 1998. He obtained MSc and Doctor in Engineerings from University of Sheffield (UK) in 2000 and University of Kobe (Japan) in 2007, respectively. He is now senior lecturer in Department of Electrical Engineering in University of Lampung, Bandar Lampung, Indonesia, with specialization in electronics and data communications.

**Victor Farhan Wijaya** received the Bachelor degrees from Department of Electrical Engineering in University of Lampung, Indonesia, in 2016. During the study, his specialization was in electronics and control engineering.

**Sri Purwiyanti** received the Bachelor degrees in Electrical Engineering from Universitas Mercubuana (Indonesia) in 1996, Master degree from Universitas Gajah Mada (Indonesia) in 2000, and PhD degree from Universitas Indonesia (Indonesia) and Shizuoka University (Japan) in 2015. Currently She is working as a lecturer in the Department of Electrical Engineering, University of Lampung, Bandar Lampung, Indonesia.

**Herlinawati** received the Bachelor degree from Department of Electrical Engineering in Universitas Sriwijaya (Indonesia) in 1995. She also hold Master in Electrical Engineering from Institut Teknologi Bandung (Indonesia) in 2001. She is now senior lecturer in Department of Electrical Engineering in University of Lampung, Bandar Lampung, Indonesia.