Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol.44 No. 6 (2023)

A Telemetry System for Real-Time Air Quality and Noise Monitoring in Urban Areas Based on IoT Technology

Qashtalani Haramaini[1*], Dino Arla, Iwa Garniwa[2]

[1]*Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Indonesia*

PT PLN Persero, Indonesia

[2]*Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Indonesia*

Abstract

Large urban agglomerations inevitably lead to air pollution. The sustainable control and monitoring of air pollution have been lacking in many cities including air quality and noise information was difficult to be accessed by the citizens periodically. This paper aims to design an air quality and noise telemetry systembased on internet communicationwhich can record the measurement data into MySQL database and showing the data through a GUI in real time. The system was developed by using solar panel as a main power supply with Arduino Uno R3 as a microcontroller board, ENC28J60 as an ethernet module and various environmental sensors like MQ7 (CO gas), MQ131 (Ozone gas), KY-038 (Noise), Dust Sensor GP2Y1010AU0F (PM10) and DHT11 (Temperature and Humidity). The system has been tested through an in-field experimentation performed in different areas of Pontianak City. Electrical energy consumption was 78,49Wh in a day. According to the test results, the system could work properly for both hardware and software.

Keyword:*Telemetry***,** *Distributed Control System, Environmental Technology, Urban Sensing, Internet of Things*

Introduction

Air quality is a major concern for the public health, the environment and, ultimately, the economy of all the industrialized countries [1]. According to the latest urban air quality database in 2016, 98% of cities in developing countries do not meet WHO air quality guidelines due to the high population of motor vehicles, the rapid growth of industrial zones, manufacturing plants and the substantial urbanization. WHO also reported that in 2017 around 1,7 million children died each year as a result of air pollution exposure. Therefore, an accurate real-time monitoring of air quality in urban areas is esential to enable appropriate and timely public decisions and, ultimately, is extremely important for preserving the citizen's health. At present, air pollution concentrations are collected by environmental or government authorities using networks of fixed monitoring stations, equipped with large and expensive instruments specialised for measuring a number of pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), ozone (O_3) and particulate matter (PM) [2]. However, it is often difficult for citizens to obtain pollution data and the monitoring (although accurate) is limited to few specific areas also gathered measurements are sometimes not available to citizens. In addition, noise monitoring is a crucial parameter to control air pollution in the city [3] and it's also one parameter to make an efficient environmental monitoring system [4].

For all these reasons, implementation of a telemetry system is the best solution towards this problemin order to improve efficiency, ease supervision and real-time data acquisition for air quality and noise monitoring in urban areas. Along with the rapid technology of telemetry systems, there were so many methods and ways had been developing on the last decade. For instance, [5] used mobile laboratory to evaluate changes in on-road air pollutants during the Beijing 2008 Summer Olympics. Also in [6] used mobile monitoring platform to measure air pollutant levels in a near-highway urban area over a wide range of traffic and meteorological conditions. The utilization of mobile laboratory for air quality monitoring could not display the measurement data on timely based due to the complexity and required a high cost of investment, operation and maintenance of the stations.

Similarly, in [7-9] propose the used of Unmanned Aerial Vehicles (UAV) for air quality and meteorological measurements. The proposed system display data in real-time, but it could not operate automatically due to the human needs as an operator of the system. The measurement capability of the UAV also could not operate continuously because using a battery on its operation.

On the other way, air quality monitoring had been proposed by [10] using SMS Gateway on its communication methodfor monitoring air pollution in the traffic light intersection.This researchdoes not have an interactive user interface due to the measurement data had displayed on LCD and by SMS through the user's phone. Obviously, the used of SMS Gateway also needs high cost of its operation rather than used of internet communication method.

Conversely, the used of internet communication is the reliable and effective method to develop a real-time environmental monitoring especially for outdoor measurement. Currently, this method known as an Internet of Things (IoT) technology that allowed everyone can access the measurement data anywhere and anytime through their personal computer, laptop and smartphone. Several solutions to monitor the air pollution using the IoT technology have been proposed. For instance, [11] develop an air quality monitoring based on PIC 16F877A microcontroller with used in combination among SMS Gateway and internet as its communication of data transmission. The data measurement sent directly through GSM modem to the central server and display the data to the public based on visual basic application. The user interface design could not display in graphical format and visual basic also known as a desktop based platform so it was not reliable if it's used as a web based platform.

The development of environmental monitoring based on IoT technology is also proposed in [12] which developed a portable CO monitoring based on ARM LPC2148 microcontroller and MQ7 sensor. The system proposed a wireless technology usingZigBee module. ZigBee is a Wireless Personal Area Network (WPAN) which have a short range transmission (about 10 meters) and these module is also usually implemented for indoor measurement. Furthermore, ZigBee module had been designed to makedata transfer with a small capacity and worked for low level personal networking with transfer rate is 250 Kbps. This method also implemented in [13] which used ZigBee module as a wireless transceiver in its telemetry system.A similar approach is also followed in [14-17] where their research used wifi as its communication method to monitor environmental pollution such as CO gas and noise in outdoor location or industry scale. In fact, there were actually having not mentioned the user interface of their research.

Compared to the previously presented solutions, this paper proposethe used of IoT technology to develop a real-time environmental monitoring (*i.e.*, Carbon Monoxide, Ozone, Noise, PM10, Temperature, Humidity and Heat Index)which can record the measurement data into MySQL database and showing the data through a graphical format or Graphical User Interface (GUI). These systems can operate automatically and continuously usingsolar panel as a main power supply withArduino Uno R3 as a microcontroller board. The used of ENC28J60 as an ethernet module could make the data transmission of the system become more effective and efficient. For the reliability, low-cost environmental sensors such as MQ7 (CO gas), MQ131 (Ozone gas), KY-038 (Noise), Dust Sensor GP2Y1010AU0F (PM10) and DHT11 (Temperature and Humidity) had been implemented in this system. In addition, the results have been compared with the measuring instruments for each parameter and it has been tested through an in-field experimentation performed in different areas of Pontianak City. Eventually, the citizens can access the real-time air quality and noise information easily through their personal computer, laptop and smartphone, anywhere and anytime.

Method

As shown in Figure 1, a schematic diagram of the developed telemetric measurement system consisted two correlation parts based on the location which are measurement module and access module. Measurement module has several main functions such as to get the data through sensor circuits, to process the data through microcontroller and later on transmit the data through an ethernet module. While the access module is an enduser devices with internet connection which has a function to receive the measurement data from measurement module and displaying the data through a GUI in real time. The registered users can access the measurement data in GUI using a web based application through a web browser. The system design was divided into two parts, which are hardware and software. They are described in the following subsections.

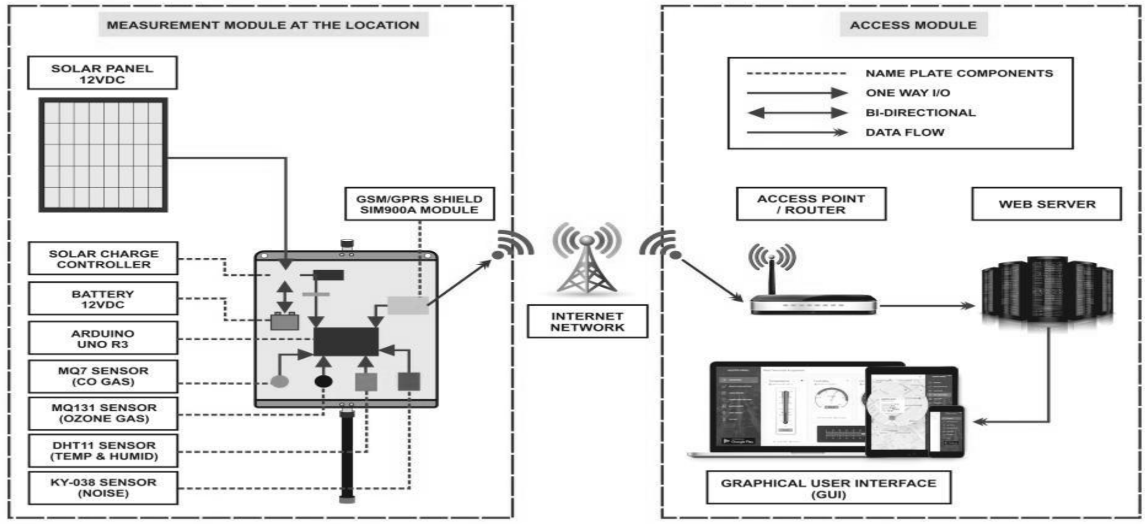


Figure 1. The schematic diagram of real-time air quality and noise monitoring

2.1. Hardware Design

The hardware design of this telemetry system consists of three main parts: power supply, control system components (i.e. controller, ethernet module and sensor) and telemetry casing. The main power supply of this system uses a solar panel and battery 12 Volt DC. It was controlled by solar charge controller which has a function to control direct current from solar panel to the load (Arduino Uno R3). Technically, the controller and sensor had a working voltage of 5 V so the system needed a voltage regulator IC Low-Dropout Regulator (LDO) with type LM2596. Figure 2 presents the circuit of solar power system.

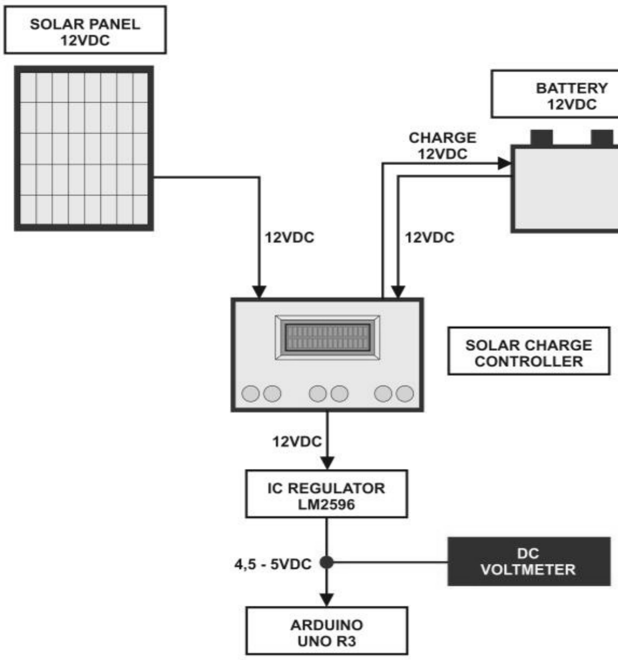
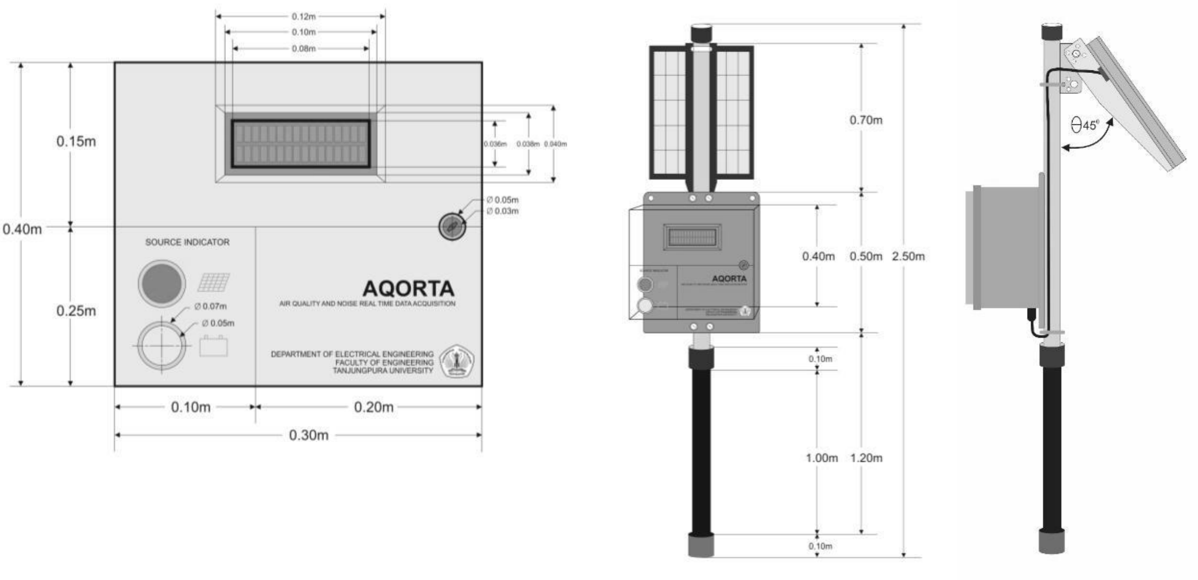


Figure 2. The circuit of solar power system

The control system components is the crucial components in this telemetry system which consists of controller, ethernet module and sensor. The controller uses an Arduino Uno R3 with arduino programming language using Arduino IDE Software. Arduino can exploiting some libraries provided by the producer to interface with controller, ethernet module and sensor. Communication between the controller and web server was designed by using microchip ENC28J60 as an ethernet module that allows TCP/IP and UDP/IP socket connections and HTTP/HTTPS communications. Microchip ENC28J60 is a slave device which can activate by connecting Port CS on microchip to the Port D10 (Slave Select) on Arduino. To accommodate data communication from Arduino to microchip, MOSI (Master Output Slave Input) or Port D11 on Arduino had connected to the Port SI on microchip. Conversely, MISO (Master Input Slave Output) or Port D12 on Arduino had connected to the Port SO on microchip in order to accommodate data communication from microchip to Arduino. Furthermore, SCK as a timer (clock) for Serial Peripheral Interface (SPI) was connected to the Port D13 on Arduino and Port INT was connected to the Port D2 on Arduino as an interrupt output pin which can handle interrupt function on the ethernet connectivity. Moreover, microchip ENC28J60 has a logic buffer circuit, wherein this circuit can change the high voltage of microchip (3,3 Volt DC) become the normal of high voltage (5 Volt DC).

The other control system component in this telemetry system is sensor. This research proposed five low-cost environmental sensors, i.e., MQ7 (CO gas), MQ131 (Ozone gas), KY-038 (Noise), Dust Sensor GP2Y1010AU0F (PM10) and DHT11 (Temperature and Humidity). MQ7, MQ131, KY-038 and Dust Sensor GP2Y1010AU0F sensor has an analog output signal, thus the analog to digital converter (ADC) is required. Arduino has an internal 10-bit ADC port so that this sensor was connected to that port. On the other hand, DHT11 sensor has an digital output signal. Hence, it was connected to the Port D5 on Arduino which would converted to temperature and humidity values by using DHT library packages according to the sensor datasheet.

This telemetry system was designed to implement in outdoor location, thus it needs a telemetry casing to protect the system from different kind of climate change. The telemetry casing has a height of 2,5 meter and it was integrated to solar panel holder which has a tilt angle of 45^o (the angle can be set). Figure 3a shows the box panel of telemetry casing with size of 0,4 x 0,3 meter, whereas Figure 3b shows the whole telemetry casing.



(a) (b)

Figure 3. (a) The box panel of telemetry casing; (b) The whole telemetry casing

2.2. Software Design

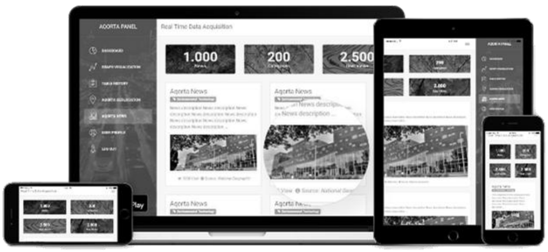
There are two main parts in software design, which are arduino and GUI-based website programming. On the arduino programming, the code was wrote on the arduino IDE software which is consisted the telemetry sensor libraries such as ethernet, MQ7, MQ131, KY-038, Dust Sensor Dust Sensor GP2Y1010AU0F and DHT11 library packages. There are three majorsteps on the arduino programming, i.e., initialization, setup and loop. All of the library packages, sensor pin, sensor variable, and Serial Peripheral Interface (SPI) were intialized on the initialization step. For the datacommunication through the internet connectivity, MAC and IP address were initialized on this step. On the setup step, Ethernet was configured by using Dynamic Host Configuration Protocol (DHCP). The parametersof the Ethernet configuration are local IP address, subnet mask, default gateway IP and DNS server IP. The delay time of this system is 5 seconds which is already configured on this step. The last step of the arduino programming is loop step. This step covered all of the main function of the telemetry system, i.e., all of the library checked list, data acquisition process of the sensor, data transformation to HTTP Post Request format and data sent to the database. All of the process on this step working continuously so it can be read by GUI in real time. The GUI was coded by using website programming method in a responsive and interactive design so the users can access the real time air quality and noise information easily through a web browser on their personal computer, laptop or smartphone.

(a) Dashboard

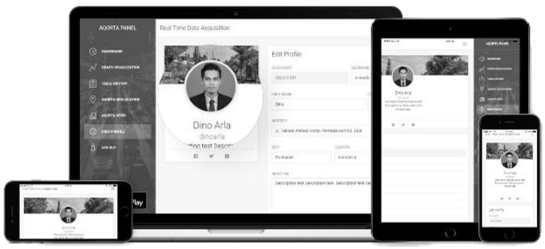
(b) Graph visualization

(c) Table history

(d) Geolocation



(e) Environment news



(f) User profile

Figure 4. Graphical User Interface (GUI) of telemetry system

As shown in Figure 4, the GUI of this telemetry system has 6 user-friendly features that have specific functions in accordance with the existing process. Dashboard interface as shown in Figure 4a is a main page of the GUI which are showing the measurement data every 5 seconds and visualized by using gauge indicators in a standard unit format of each paramater. For a noise display measurement in a decibel format, the calculation based on Decree of the Indonesia Minister of Environment Number: KEP-48/MENLH/11/1996 about Noise Level Standard as shown in equation 1:

$$L_{SM} = 10 \log {}^{1}/_{24} \{16x10^{0.1xL_S} + \cdots + 8x10^{0.1x(L_M+5)}\} dB (1)$$

where:

LSM = Equivalent Continuous Noise Level for a day and night (dB)

LS = Equivalent Continuous Noise Level for a day (dB)

LM = Equivalent Continuous Noise Level for a night (dB)

The second visualization of GUI in this telemetry system is graph visualization as shown in Figure 4b which are visualized by using line graph javascript library and updating the measurement data every 5 seconds. The record of the measurement data in this telemetry system can become enormous data in the future, therefore table history of the measurement data are extremely important and it was existed in the GUI as shown in Figure4c. This feature have a tracking and tracing system by using ajax programming method thus the users canobtain the measurement result by date or location with a single and simple click. Another feature of GUI is geolocation interface as shown in Figure 4d which are integrated to Google Maps API. This feature showing the measurement data by location of the installed telemetry (measurement module). Technically, the measurement range of the telemetry system is 100 meters, it will not cover all of place of the areas with a single measurement module. If this telemetry system subsequently implemented in urban areas, this feature are tremendous important for the whole measurement. Besides being a data monitoring and information system, this telemetry was also designed as an education tools which can educate the society with informative GUI about environment news on their neighborhood. This feature as shown in Figure 4e was similarly with a blog in several website which have been updated by the system administrator. The last feature of GUI is user profile interface as shown in Figure 4f, this feature only showing the registered user information for the validity purpose.

2.3. The Sensor Calibration Process of MQ7 Sensor

Sensor MQ7 for CO meter did not have conversion formula to convert the output voltage to measurement unit (ppm) on its datasheet. Hence it was necessary for these sensors to be calibrated. According to the datasheet of MQ7 sensor, the resistance ratio of the sensor (Rs/Ro) will be approach to 1 when concentration of the CO gas approach to 100 ppm. It can follow to the equation 2 which is used to get the Ro value because it did not have clearly stated on the datasheet:

$$100\ ppm\ CO = {}^{Rs}/_{Ro} = 1 \qquad (2)$$

The value of CO gas concentration on PPM units can be known by taking a few Rs data (the resistance of MQ7 sensor at various gas concentration level) and find the mathematic model by using regression line to any changes in CO gas concentration. The microcontroller read Rs value in ADC form then it processed simultaneously to get the Vout, Rl and Rs/Ro as shown in equation3 and 4:

$$Vout = \left({}^{R_L}/_{R_S} + R_L\right) x\ Vcc \qquad (3)$$

$$Rs = \left(Vcc\ x\ {}^{R_L}/_{Vout}\right) - R_L \qquad (4)$$

On the experimentation, range of measurement stated in 20 – 200 ppm of CO gas concentration in CO meter portableGas Leak Smartsensor serial AS8700A as a calibrator. A common source which produced CO gas is burnt paper. It was kept near the sensor placed in the test container. The data results shown in Table 1 as follows:

Table 1. The experiment results of MQ7 sensor (ADC) and calibrator (ppm)

No	Calibrator (ppm)	MQ7 (ADC)	V_{out} (Volt)	Rs (kΩ)	Rs/Ro
1	20	336,2	1,63	20,30	2,95
2	30	369,8	1,82	17,62	2,56
3	40	416,6	2,05	14,51	2,11
4	50	467,2	2,26	11,93	1,73
5	60	495,8	2,43	10,66	1,55
6	70	524,4	2,58	9,46	1,37

7	80	565,7	2,78	8,12	1,18
8	90	578,6	2,83	9,93	1,12
9	100	607,7	2,97	6,89	1
10	110	618,9	3,02	6,50	0,94
11	120	640,3	3,14	6,03	0,88
12	130	665,2	3,21	5,43	0,79
13	140	678,3	3,31	5,15	0,75
14	150	692,8	3,39	4,79	0,7
15	160	699,4	3,42	4,62	0,67
16	170	717,9	3,52	4,25	0,62
17	180	730,2	3,57	4,01	0,58
18	190	743,5	3,71	3,77	0,55
19	200	760,2	3,78	3,44	0,5

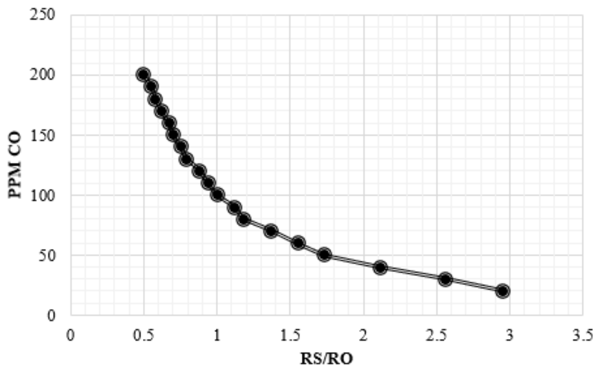


Figure 5. The correlation between PPM CO and Rs/Ro

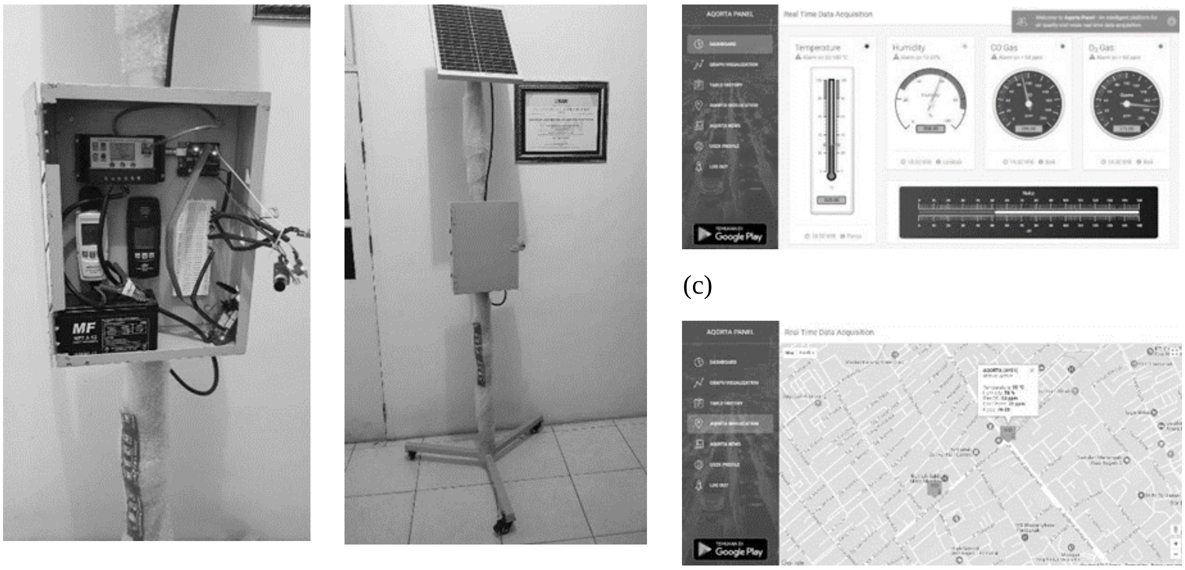
As shown in Figure 5, the correlation between ppm CO and Rs/Ro by using the regression (trendline) got the equation 5 with R square is 0,9867.

$$y = 96{,}311\, x^{-1{,}239} \qquad (5)$$

On the computation perspective, the trendline will be easier applied to the microcontroller. The equation 5 was used on the hardware code as an estimation of CO concentration in ppm unit.

Results And Analysis

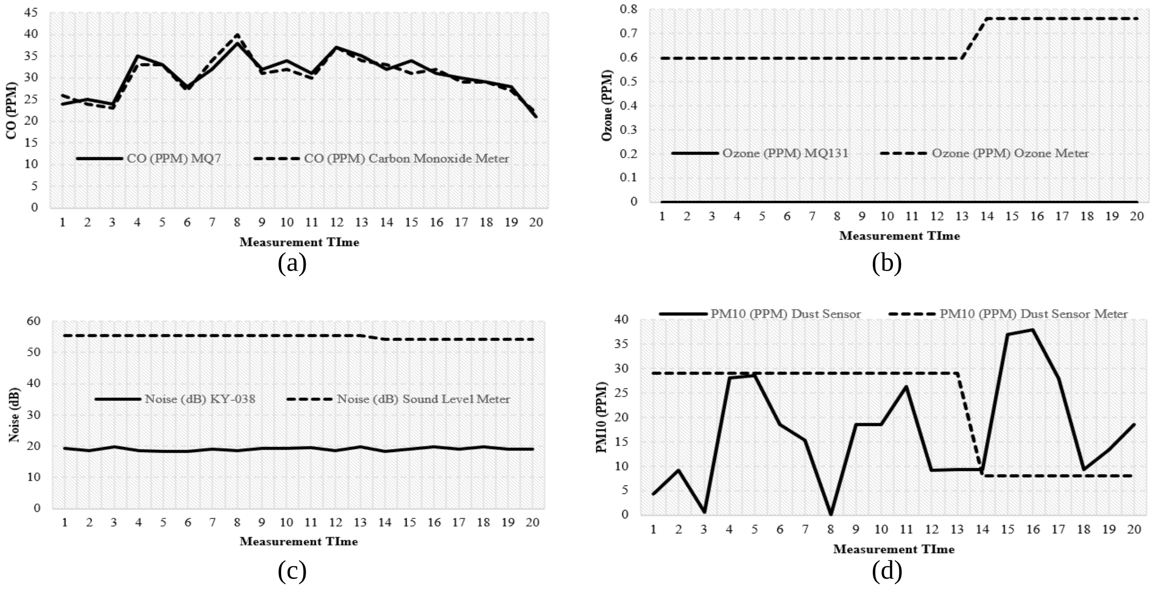
System-testing was carried out by comparing the sensor measurement value generated by the sensor measuring instrument for each parameter. There are CO meter portable Gas Leak Smartsensor serial AS8700A as thereference for MQ7, Ozone Meter digital American O_3serial DM502-O3 as the reference for MQ131, Sound Level Meter digitalDekkoserialFM7911Aas the reference for KY-038, Dust Sensor Meteras the reference for PM10 and Thermohygrometer digital as the referencefor DHT11. All of the references had installed on the inside of the telemetry casing as shown in Figure 6a, whereas Figure 6b shows the whole telemetry device. The dashboard GUI of the telemetry system was used for reading the measurement values from the measurement module at the installed location as shown in Figure6c, which is shows one result of the measurement activities and then it was compared with the references.

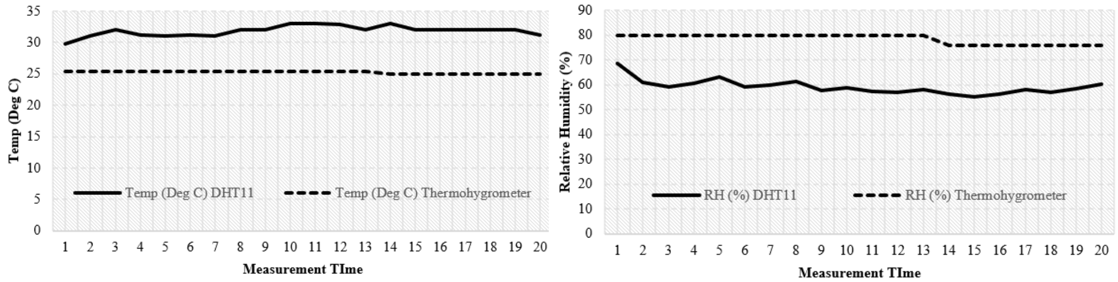


(a) (b) (c) (d)

Figure6.(a) Insidetelemetrydevicecasing;(b)Thewholetelemetrydevice;(c)Datareadingofthe telemetrysystem;(d)Locations oftheinstalledtelemetrydevices

In order to test and analyze the overall telemetry system, it was performed through an in-field experimentation in three different urban areas of Pontianak City (namely Zone A, Zone B and Zone C). The areas has different kind of traffic condition, situation and, hence, different expected pollution levels. Figure 6d shows the position on the map (geolocation GUI) of three installed telemetry system during the in-field experimentation. Zone A and Zone B is a traffic light intersection with heavy traffic intensity. The range among two zones are 500 meters. While Zone C has different situation of the other two zones because it was a diesel power plant on the center of Pontianak City and also it has a high pollution levels, including noise pollution and gas exposure. All three zones have good internet access with an average of statistics ping data is 23 ms out of 100 ping tests.Furthermore, the experimental results for each parameter of the telemetry system includingits performance in three zones were done by recording the measurement data in 1 hour as shown in Figure 7. According to the results, there is no measurement was missed, all of the measurement data had fully stored on the MySQL database every 5 seconds as it was configured on the arduino code. The trend line of the measurement data shows the similarity with small errors at some samples if it compared with the references.





(e) (f)

Figure 7. Experimental results compared with the references:

(a) CO in PPM; (b) Ozone in PPM; (c) Noise in dB; (d) PM10 in PPM; (e) Temperature in celcius degree; (f) Relative Humidity in percentage

Conclusion

The system has been tested through an in-field experimentation performed in different areas of Pontianak City. In the experiment with 20 data samples, the maximum error values of MQ7 sensor were 3 ppm and the minimum were 1 ppm. For KY-038 sensor, the maximum and minimum error values were 6 dB and 1 dB respectively. And dust sensor, the maximum and minimum error values were 5ppm and 8ppm respectively. The maximum and minimum temperature error values of DHT11 sensor were 0,8 ^{o}C and 0,1 ^{o}C respectively, while the maximum and minimum humidity error values were 1% respectively. Electrical energy consumption was 78,49 Wh in a day. According to the test results, the system could work properly for both hardware and software.

References

[1] Atmel Corporation , 2016. *8-bit AVR Microcontrollers ATmega328/P Datasheet Complete*, San Jose: Atmel Corporation.

[2] Badan Pengendalian Dampak Lingkungan, 1999. *Keputusan Kepala Badan Pengendalian Dampak Lingkungan Nomor: KEP-107/KABAPEDAL/11/1997 tentang Pedoman Teknis Perhitungan dan Pelaporan Serta Informasi Indeks Standar Pencemar Udara,* Jakarta: Badan Pengendalian Dampak Lingkungan (BAPEDAL).

[3] Badan Pusat Statistik, 2017. *Badan Pusat Statistik (BPS) Website.* [Online] Available at: https://www.bps.go.id/linkTableDinamis/view/id/1133 [Accessed 15 February 2017].

[4] Baranov, A. et al., 2015. *A Wireless Carbon Monoxide Sensor Node with Hybrid Power Supply*. Pisa, Italy, Institute of Electrical and Electronics Engineers, pp. 1019-1023.

[5] Baxter, R. & Bush, D., 2014. *Use of Small Unmanned Aerial Vehicles for Air Quality and Meteorological Measurements.* Valencia, T&B Systems, Inc.

[6] Brienza, S., Galli, A., Anastasi, G. & Bruschi, P., 2015. A Low-Cost Sensing System for Cooperative Air Quality Monitoring in Urban Areas. *Sensors,* Volume 15, pp. 12242-12259.

[7] Chaiwatpongsakorn, C., Lu, M., Keener, T. & Khang, S., 2014. The Deployment of Carbon Monoxide Wireless Sensor Network (CO-WSN) for Ambient Air Monitoring. *International Journal of Environmental Research and Public Health,* Volume 11, pp. 6246-6264.

[8] Dubey, A., Shamshad, M. & Patel, K., 2013. Design and Implementation of Pollution Monitoring and Recording System Using Microcontroller. *e-Journal of Science & Technology (e-JST),* pp. 17-26.

[9] Evangelatos, O. & Rolim, J., 2015. An Airborne Wireless Sensor System for Near-Real Time Air Pollution Monitoring. *Sensors & Transducers,* 189(6), pp. 12-21.

[10] Guthi, A., 2016. Implementation of an Efficient Noise and Air Pollution Monitoring System Using Internet of Things (IoT). *International Journal of Advanced Research in Computer and Communication Engineering,* 5(7), pp. 237-242.

[11] Kumar, P. et al., 2015. The rise of low-cost sensing for managing air pollution in cities. *Environment International,* pp. 199-205.

[12] Mazidi, M., Naimi, S. & Naimi, S., 2011. *The AVR Microcontroller and Embedded Systems Using Assembly and C.* New Jersey: Prentice Hall.

[13] Menteri Negara Lingkungan Hidup, 1996. *Keputusan Menteri Negara Lingkungan Hidup Nomor: KEP-48/MENLH/11/1996 tentang Baku Tingkat Kebisingan,* Jakarta: Kementerian Lingkungan Hidup Republik Indonesia.

[14] Microchip Technology Incorporated, 2008. *Microchip ENC28J60 Data Sheet Stand-Alone Ethernet Controller with SPI Interface,* U.S.A.: Microchip Technology Incorporated.

[15] Mohammad, A., 2016. Air Quality Monitoring System Using Wireless Sensor Node. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* 5(6), pp. 4865-4870.

[16] Mydlarz, C., Salamon, J. & Bello, J. P., 2016. The Implementation of Low-cost Urban Acoustic Monitoring Devices. *Journal of Applied Acoustics* , pp. 1-36.

[17] Padró-Martínez, L. T. et al., 2012. Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year. *Atmospheric Environment,* Volume 61, p. 253–264.

[18] Panjaitan, S., Fratama, N., Hartoyo, A. & Kurnianto, R., 2016. Telemonitoring Temperature and Humidity at Bio-energy Process using Smart Phones. *Telkomnika,* Volume 14, pp. 762-771.

[19] Republik Indonesia, 1999. *Peraturan Pemerintah Republik Indonesia Nomor 41 Tahun 1999 tentang Pengendalian Pencemaran Udara,* Jakarta: Republik Indonesia.

[20] Tan, B., Yuan, B. & Zhu, B., 2010. The Design of Ethernet Controller Interface Circuit Based on ENC28J60. *Proceedings of the Second International Symposium on Networking and Network Security,* pp. 35-38.

[21] Vidap, R. & Shahane, G., 2015. Development and Implementation of Arm Microcontroller Based CO Gas Monitoring System. *International Journal of Advances in Engineering & Technology,* 8(5), pp. 783-793.

[22] Villa, T. et al., 2016. An Overview of Small Unmanned Aerial Vehicles for Air Quality Measurements: Present Applications and Future Prospectives. *Sensors,* 16(1072).

[23] Wang, M. et al., 2009. Use of a mobile laboratory to evaluate changes in on-road air pollutants during the Beijing 2008 Summer Olympics. *Atmospheric Chemistry and Physics,* pp. 8247-8263.

[24] World Health Organization, 2014. *World Health Organization (WHO) Website.* [Online] Available at: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/ [Accessed 6 August 2016].

[25] Yang, J. et al., 2015. A Real-Time Monitoring System of Industry Carbon Monoxide Based on Wireless Sensor Networks. *Sensors,* pp. 29535-29546.