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# Very Low-Cost, Internet of Things (IoT) Air Quality Monitoring Platform

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A B S T R A C T

Every year millions of people die prematurely due to air pollution. Many deaths occurred in cities, where fumes from vehicles, factories, and power plants filled the air with noxious particles and gases. The COVID-19 pandemic has also created a new awareness about the importance of monitoring air quality in the atmosphere and indoors. However, the available data are not widely accessible to the general public and are explicitly restricted for organizational use due to high costs. The research aims to develop a low-cost air quality monitoring device with parameters NOx, SOx, CO, $O_3$, $PM_{2.5}$, temperature, and humidity. The Air Quality Monitoring Prototype (AQMP) prototype was developed using an Internet of Things (IoT) solution based on low-cost sensors with a low-cost, low-energy, open-source Arduino system. Data is recorded every minute and stored in a database for parameters NOx, SOx, CO, $O_3$, $PM_{2.5}$, temperature, and humidity. Data communication is carried out via the cloud and displayed on smartphones and the web. The stages of work are carried out by designing systems, determining and constructing hardware, installing software, and testing. The test results show that the AQMP can operate and detect all parameters. Comparisons were made with data from the Environment Service of Bandar Lampung City, and the results showed an accuracy rate above 95%. This research has proven that low-cost air quality monitoring device can be developed with IoT. This research simultaneously supports the concept of "Going Green" to maintain a healthy and clean environment for present and future generations



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A B S T R A K

Setiap tahunnya jutaan orang meninggal sebelum waktunya akibat pencemaran udara, terutama ini terjadi di perkotaan. Pandemi COVID-19 juga telah memunculkan kesadaran baru tentang pentingnya pemantauan kualitas udara di atmosfer maupun dalam ruangan. Namun, data yang tersedia tidak dapat diakses secara luas untuk masyarakat umum dan dibatasi secara khusus untuk penggunaan organisasi karena biaya tinggi. Penelitian bertujuan mengembangkan alat pemantau kualitas udara berbiaya rendah, dengan parameter NOx, SOx, CO, $O_3$, $PM_{2.5}$, suhu dan kelembaban. Prototipe perangkat pemantau kualitas udara (Air Quality Monitoring Prototype/AQMP) dikembangkan menggunakan Internet of Things (IoT), berdasarkan sensor berbiaya rendah, dengan sistem Arduino yang berbiaya rendah, minim energi, dan bersifat terbuka. Perekaman data dilakukan setiap menit dan tersimpan dalam database untuk semua parameter. Komunikasi data dilakukan melalui cloud, dan ditampilkan pada smartphone maupun web. Tahapan pekerjaan dilakukan dengan perancangan sistem, penentuan dan konstruksi hardware, penanaman software, dan pengujian. Hasil uji coba didapatkan bahwa AQMP dapat beroperasi dan mampu mendeteksi keseluruhan parameter. Perbandingan dilakukan dengan data Dinas Lingkungan Hidup Kota Bandar Lampung, hasilnya menunjukkan tingkat akurasi di atas 95%, sehingga layak untuk digunakan. Penelitian ini telah membuktikan bahwa alat pemantau kualitas udara berbiaya rendah dapat dikembangkan dengan IoT, dan memberikan hasil yang akurat. Penelitian ini sekaligus mendukung konsep "Going Green" untuk mempertahankan lingkungan yang sehat dan bersih untuk generasi sekarang dan mendatang.



## INTRODUCTION

Air is an environmental factor that plays an essential role in life; therefore, it must always be maintained and monitored (Abidin & Artauli Hasibuan, 2019; Darmawan, 2018; Handayani & Mamurotun, 2019; Kurniawati, ;Nurullita, 2017). Air pollution can cause damage to ecosystems through the mechanism of acid rain (Abidin & Artauli Hasibuan, 2019; Goodarzi, 2006; Khairina, 2019; Kurniawati, ;Nurullita, 2017; Margahayu & S, 2015; Rodríguez-Cotto et al., 2013; Sánchez, Cohim, & Kalid, 2015), contribute to global warming and climate change (Rosenfeld & Feng, 2011), and disrupt human health (Ismiyati, Marlita, & Saidah, 2014; Sánchez et al., 2015).

According to WHO (2022), around seven million people die prematurely every year due to air pollution, especially in urban areas. Health problems related to air pollution include cardiovascular disease, stroke, urology, pneumonia, asbestosis, silicosis, pneumoconiosis, obstructive pulmonary, cancer, and neurological disorders (Balakrishnan, 2018; Kim, 2017; McCunney, Morfeld, & Payne, 2009; Ostro et al., 2010; Rosenfeld & Feng, 2011; Trigunarso, Yushananta, & Ainin, 2018; Valavanidis, Fiotakis, & Vlachogianni, 2008; WHO, 2021; Wu et al., 2013). Air pollution is mainly caused by traffic and industry (Aikawa, Kajino, Hiraki, & Mukai, 2014; Amodio et al., 2014; Leong, Chong, Poh, Hermawan, & Talei, 2017; Morselli, Olivieri, Brusori, & Passarini, 2003; Ostro et al., 2010; Pudasainee, Seo, Sung, Jang, & Gupta, 2017; Rokhim, 2017; Sánchez et al., 2015; Warsono et al., 2021; WHO, 2022, 2021; Wu et al., 2013; Yushananta, 2021).

The COVID-19 pandemic has also created a new awareness about the importance of monitoring air quality in the atmosphere and indoors and the availability of public data. Several recent studies explicitly explain the relationship between air quality parameters and the spread of COVID-19, namely $PM_{2.5}$, $O_3$, $NO_2$, $SO_2$, temperature, humidity, air pressure, and wind speed (Adam, Tran, & Balasubramanian, 2021; Agarwal et al., 2021; Asyary & Veruswati, 2020; Lorenzo, Tam, & Seow, 2021; Sangkham, Thongtip, & Vongruang, 2021; Skirienė & Stasiškienė, 2021; Tosepu et al., 2020; Warsono et al., 2021). Air quality monitoring aims to control pollution and its effects inside and outside buildings (Bappenas, 2011; Myles Allen, 2018; Strange & Bayley, 2008; WHO, 2021). However, the available data are not widely accessible to the general public and are explicitly restricted for organizational use due to high costs (Wall, McCullagh, Cleland, & Bond, 2021). Until now, Indonesia, through the Ministry of Environment and Forestry, has only 26 air quality monitoring stations spread across several major cities (Chaniago & Zahara, 2020).

One technology that can be developed for measuring air quality is the Internet of Things (IoT). IoT is a new concept to expand the benefits of internet connectivity. This technology provides low-cost, real-time solution capabilities that can provide large amounts of quantitative data (Aamer, Mumtaz, Anwar, & Poslad, 2018; Ahmed, Banu, & Paul, 2017; Esquiagola, Manini, Aikawa, Yoshioka, & Zuffo, 2018; Likuisa, 2019; Marques & Pitarma, 2019; Tapashetti, Vegiraju, & Ogunfunmi, 2016; Wall et al., 2021; Yushananta, Putri, Widyawati, & Sari, 2022). The research aims to develop a low-cost air monitoring device prototype, using the expansion of the benefits of the Internet of Things (IoT).

## METHODS

The air monitoring device prototype (Air Quality Monitoring Prototype/AQMP) was developed with the expansion of the benefits of the Internet of Things (IoT). All materials (sensors and microcontroller) were obtained from general electronic and robotic materials sellers. Two types of microcontrollers were used in the research, namely ATmega2560-16AU and ESP-32. Meanwhile, the sensors used were MICS-6814, MQ136, MQ131, DHT11, DSM501A, Photorest GY-30 BH1750, Raindrop Module.

The research was carried out in four stages of activity, namely: 1) designing the IoT system, to plan the entire IoT system to be developed, including the output of the system; 2) determination and assembly of hardware, to select and determine the appropriate hardware for the system being developed; 3) embedding software, designing work programs on the system; and 4) testing, to determine the performance of AQMP.

The MICS-6814 sensor (CO, $NO_2$ uses a voltage of 6 V and the detection range for CO ranges from 1-1000 ppm, and $NO_2$ ranges from 0.05-10 ppm. The MQ136 sensor is used to monitor $SO_2$ levels, with a voltage of 5 V and a detection range of 1-100 ppm. The MQ131 sensor is used to monitor $O_3$ levels in the air with a detection capability of 0.01-2 ppm, using a voltage of 5 V. The $PM_{2.5}$ sensor is used in the proposed system to measure particles in the environment. The DSM501A sensor is used to measure the concentration of small particles with a diameter of less than 2.5 microns. This sensor uses a voltage of 5 V and is able to detect $PM_{2.5}$ in the range 0-1.4 mg/$M^3$.

The DHT11 sensor is used to detect humidity and air temperature. This sensor uses a voltage of 3.3-6 V, with the ability to detect humidity 0-100%, and temperature -40-80 $^0$C. This study also used the Photorest GY-30 BH1750 sensor to detect dark or light weather conditions, as well as the Raindrop Module sensor to obtain rain or dry information. Both sensors use a voltage of 5 V.

## RESULTS AND DISCUSSION

Research has succeeded in developing a low-cost prototype of an air monitoring device (Air Quality Monitoring Prototype/AQMP), using the expansion of the benefits of the Internet of Things (IoT). To achieve cost-effectiveness, low-cost sensors and a low-cost Arduino system are used, with minimal energy, and are open. Data is recorded every minute and stored in a database for parameters $NO_2$, $SO_2$, CO, $O_3$, $PM_{25}$, temperature, and


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humidity. Data communication is carried out via the cloud and is displayed (interface) on a smartphone or PC.

*IoT system design*

The AQMP is designed (Figure 1) to simultaneously measure air quality and weather, using some detection components (sensors) managed by a microcontroller chip. Furthermore, data is sent by the Wi-Fi and cellular modules, and data communication is in the cloud system so that it can be received and allows for remote control and online data access. The sensor periodically (units of minutes) monitors the air quality and sends it; the data can be monitored and accessed without limits using a smartphone or PC with internet.

The device is also designed with a datalogger in mind, making it possible to save every data. The systems used are Arduino Mega and ESP-32, with low-cost considerations, the ability to process data from multiple sensors, and are open.

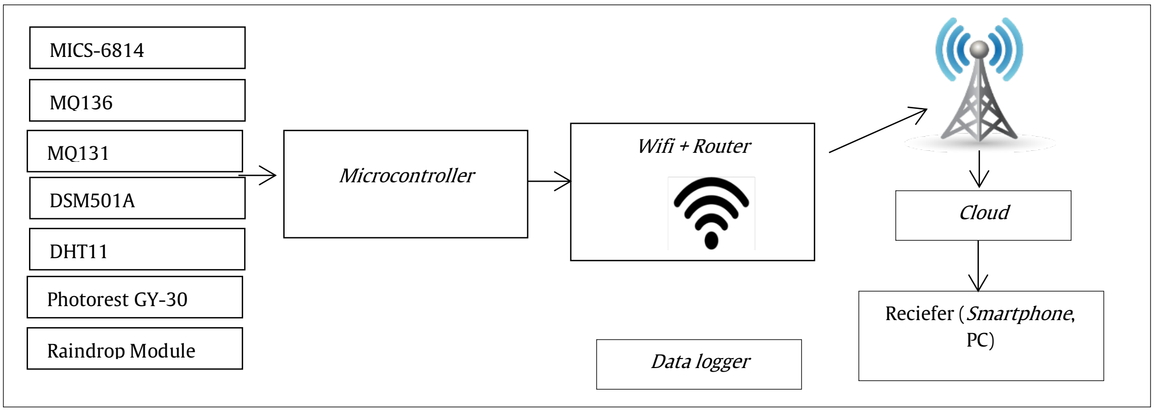


**Figure 1. IoT system architecture**

*Hardware*

About 16 materials were used during the research (Table 1), grouped into sensor modules, microcontrollers, accessories, and connectors. The entire sensor is connected via cable with the microcontroller at 5 volts supplied by the adapter.

The device detects air quality parameters ($NO_2$, $SO_2$, CO, $O_3$, $PM_{2.5}$, temperature, and humidity) in the environment. This device uses seven sensors, namely sensors MICS-6814, MQ135, MQ136, MQ131, DHT11, DSM501A, Photorest GY-30 BH1750, Raindrop Module. The sensor is connected to a microcontroller (Arduino ATmega 2560-16AU) at an output voltage of 5V. The processed data is sent via the GSM SIM900A module to the Thinger.ESP-32 cloud system, displayed via a smartphone or PC via the internet network. Data storage using the Mini Data Logger module in minutes.

**Table 1.**
**Materials used in the development of AQMP**

| No | Material | Description |
|---|---|---|
| 1 | *ATmega2560-16AU* | *Microcontroller*/mikroprosesor |
| 2 | *ESP-32* | *Microcontroller cloud* |
| 3 | *MICS-6814* | CO, $NO_2$ sensor |
| 4 | *MQ136* | $SO_2$ sensor |
| 5 | *MQ131* | $O_3$ sensor |
| 6 | *DHT11* | Temperature and Humidity sensor |
| 7 | *DSM501A* | $PM_{2,5}$ sensor |
| 8 | *Photorest GY-30 BH1750* | Dark and light sensor |
| 9 | *Raindrop Module* | Rain sensor |
| 10 | *GSM SIM900A Module* | Data sending to cloud system |
| 11 | *TFT LCD 2.4* | LCD Screen |
| 12 | *Mini Data Logger module* | Data storage system |

**Figure 3. AQMP hardware**

*Software*

The software design is implemented in two parts: acquiring front-end display data with the appropriate software and selecting software considering the low cost, minimal energy, and open (open-source). The program used in AQMP is Arduino for data acquisition using C/C++ language and Thinger-ESP32 for front-end display analysis.

The data acquisition software checks the sensor every five seconds, then saves the sensor data to an SD card and a MySQL database on the Thinger.io server. In addition, all data collected from sensors is entered into the MySQL database through prepared statements. This approach adds security to web applications by separating queries from data so that the data submitted cannot be used to change how queries are executed, thereby preventing injection attacks.

```
#define THINGER_SERIAL_DEBUG
#include "ThingerESP32.h"
#include "arduino_secrets.h"
ThingerESP32 thing(USERNAME, DEVICE_ID, DEVICE_CREDENTIAL);

#include <SPI.h>
#include <LiquidCrystal.h>
#include <SD.h>
#include <Keypad.h>


#define pinco   60
#define pinso   57
#define pinno   58
#define pinnh3  59
#define pino3   56
#define pindebu 55
#define ledpin  35

//keypad
const byte ROWS = 4;
const byte COLS = 4;
char hexaKeys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'}
};
byte rowPins[ROWS] = {15, 2, 3, 13};
byte colPins[COLS] = {12, 14, 27, 17};
Keypad customKeypad = Keypad( makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);
//keypad
```

```
//SD-Card
const int chipSelect = 53;
File dataFile;
//SD-Card


float resdebu;
float resco;
float resno;
float resso;
float resdht;
float resnh3;
float reso3;
float ppmco;
float ppmdebu;
float ppmno;
float ppmso;
float ppmo3;
float ppmnh3;
float xco;
float xdebu;

void setup() {
 Serial.begin (115200);
 lcd.begin();
 SD.begin(chipSelect);
 pinMode (ledpin, OUTPUT);
 digitalWrite (ledpin, HIGH);
 thing.add_wifi(SSID, SSID_PASSWORD);
 do {
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("M-SD Tidak ada");
 }while(!SD.begin(chipSelect));
```

**Figure 4. Softeware *AQMP***

*Trial*

The test was carried out to determine the AQMP's ability to detect air quality parameters, compared to the results of standard measurement device, namely the AQMS (Air Quality Monitoring System) owned by the Environment Service of Bandar Lampung City. The test was carried out on 10 measurements.

**Table 2.**
The accuracy of AQMP result

| Test | Standard device *(AQMS)* | Protype device *(AQMP)* | Deviation (AQMS-AQMP) | Error (%) |
|---|---|---|---|---|
| $PM_{2.5}$ (µg/M³) | 3 .4 | 3 .3 | 0 .1 | 2 .941 |
| $SO_2$ (µg/M³) | 42 .8 | 43 .9 | 0 .1 | 0 .234 |
| CO (µg/M³) | 2091 | 2090 | 1 .2 | 0 .057 |
| $O_3$ (µg/M³) | 43 .9 | 43 .8 | 0 .1 | 0 .228 |
| $NO_2$ (µg/M³) | 33 .7 | 33 .6 | 0 .1 | 0 .297 |

Table 2 shows that the average total $PM_{2.5}$ parameter measurement results with AQMS and AQMP were 3.4 µg/$M^3$ and 3.3 µg/$M^3$, so the AQMP error rate was only 2.941%. In the SO2 test, the measurement results obtained were 42 .8 µg/$M^3$ and 43.9 µg/$M^3$, so the AQMP error rate is 0.234%. CO measurement results, the average measurement results are 2091 µg/$M^3$ and 2090 µg/$M^3$, so the AQMP error is 0.057%.

In the O3 measurement, the average AQMS and AQMP were 43.9 µg/$M^3$ and 43.8 µg/$M^3$, AQMP error rate of 0.228%. At the same time, the NO2 measurement results were 33.7 µg/$M^3$ and 33.6 µg/$M^3$, an AQMP error of 0.297%. The results of this test show that the error rate is still far below 5%. The percentage of sensor measurement error of less than 5% indicates the device is feasible to use (Junaidi & Prabowo, 2018).

## CONCLUSIONS AND SUGGESTIONS

This research has proven that low-cost air quality monitoring device can be developed with IoT and provide accurate results. This research simultaneously supports the concept of "Going Green" to maintain a healthy and clean environment for present and future generations.

## ETHICAL CONSIDERATIONS

### Funding Statement.

The authors did not receive support from any organization for the submitted work.

### Conflict of Interest Statement

The authors declared that they have no conflict of interests.

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