空气质量监测系统与多数据源：为胡志明市的城市空气质量建设

Cuong Pham-Quoc1,2*, Tran Ngoc Thinh1,2, Trong Nhan Le1,2, Phan Hien Vu2,3, Tan Long Le1,2, Kha Huynh Hoang1,2

1胡志明市理工大学（HCMUT），越南宁都区，越南
2越南国立大学—胡志明市大学，宁都区，越南
3国际大学—VNU-HCM，宁都区，越南

摘要

在这篇论文中，我们介绍了一种新型的空气质量监测系统，系统通过多个数据源为智慧城市建设提供服务。我们部署该系统在越南最大的城市之一，胡志明市。该系统使用我们传感器收集的数据和从遥感图像中提取的数据。此外，用户可以贡献一些数据，例如通过门户发布警报。通过传感器收集的数据，我们可以提供基本参数，用于计算空气质量指数（AQI）。而从遥感图像中提取的数据则有助于政府估算周围区域的AQI值，尽管这些信息不完全来自部署的传感器，但有助于我们迅速了解大区域的空气质量，同时成本较低。通过这些数据源，通知用户也可以帮助政府更快地应对空气污染问题。

通过实验，我们发现我们系统的误差（与商用设备的误差）不高于24%。对于传感器系统，当只使用900mW时，平均能耗较低。关键词：空气质量指数，空气污染，智能城市，细颗粒物，遥感图像

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1. 引言

世界卫生组织的统计显示，约有1260万人因不健康的生活环境而死亡[1]。在越南，这一数字约为52000人/年。因此，空气质量监测系统，特别是对大城市的空气质量监测，已经成为一项重要的需求，因为大城市的空气质量指数往往低于其他城市或农村地区。

虽然大城市的空气质量低于平均水平，但智能城市提供了许多好处。根据Smart City Tracker报告，2017年第三季度，全球已有超过400个智慧城市。除了智能交通和基于技术的智能应用外，智能城市和大城市的居民还需要有一个良好的空气质量，以支持健康的生活。

许多国家的政府已经建立了空气质量监测和空气质量预报系统。这些系统可以收集和预测有害气体的水平，如O3、NO2和PM2.5等。这些参数用于向政府和当地居民发出早期预警，以便他们对这些问题做出反应，如限制工厂的运行，禁止城市中心的车辆或使用绿色车辆[7]。
In Ho Chi Minh city (HCMC), although this is the biggest city in Vietnam with the highest population, there exist only a few of fixed air quality monitoring stations. According to these systems, the PM2.5 level in HCMC rises to the unhealthy level (25 µg/m³) [3]. Therefore, to provide people in HCMC a better life, air quality monitoring systems with multiple data sources as well as multiple parameters collected such as CO, CO2, temperature, or humidity level should be investigated.

In this paper, we present our hazardous monitoring system that uses multiple data sources including sensors, remote sensing images, and notifications from inhabitants to build an air quality monitoring system. The system can provide early alerts to both governors and inhabitants in HCMC to react quickly. Data collected in the system can be used for forecasting the AQI in the future.

The rest of the paper is organized as follows. Related work is presented in Section 2. Section 3 presents an overview of our system. We introduce our sensor nodes to sensing data as well as our remote image processing engine in Section 4. We provide values collected from the system and compare with values measured by commercial devices in Section 5. In section 6, we conclude our paper.

2. Related work

In both the literature and industry, there exist a number of air quality monitoring systems. However, these systems use either sensors for collecting parameters of AQI or remote sensing images for estimating AQI. In this work, we combine both techniques for our system so that they can compensate each other.

For the first approach, using sensors for calculating AQI, along with systems mentioned above, other systems can be counted as follows. One of the earlies systems in the world is GEMS/AIR – Global Environment Monitoring System built in Sweden for monitoring air quality as well as climate change [8]. According to the paper in of Kenneth L. Demerjian, in north America, there exist more than 4,000 monitoring stations controlled by the USA, Canada and Mexico for air quality sensing [8] In Asia countries, there also includes similar systems for monitoring AQI such as reported in [10][11].

For the second approach, using remote sensing image for estimating land surface temperature and PM2.5, there exists some publications in the literature in [12][13][14][15][16][17][18][19]. However, estimation of land surface temperature and fine particulate matter depends on current situation of the research locations such as building, grass, forest or lake. Therefore, we did our research for Ho Chi Minh city to build an estimation tool for these parameters reported in our previous work [20]. In this paper, we present the entire system where we combine both the above approach.

3. System overview

In this section, we present an overview of our system. Figure 1 illustrates the proposed system to monitor air quality for big cities using multiple data sources. As depicted in the figure, the system supports data from four different sources including:

- **Sensoring systems**: providing data collected by sensors. These sensors collect exactly values for different parameters at the sensor deployment positions. These values can be used to provide to governors and inhabitants as well as used to building estimation models for remote sensing images.
- **Server for remote sensing images processing**: automatically collecting and processing remote sensing images from satellites such as Landsat or MODIS. The results of this process are estimated values for PM2.5 and land surface temperature at locations inside the city. This engine is useful to estimate harmful parameters at locations without sensors. More details of the estimation models are presented in our previous work [20].
- **GUI and portal**: providing a portal to allow users to access data and notify any hazardous situations they can monitor manually. Of course, feedback from users needs to be double checked and granted by administrators or governors to become publicity.
- **Database systems**: storing raw and preprocessing data collected from three other sources for future purposes such as AI-based air pollution forecasting.

Finally, a cloud-based service is deployed to process data from different sources. However, due to different data structures of data sources (in data size, types, time stamp…), we need to build application programming interfaces (API) for integrating multiple data sources. Figure 2 illustrates the API architecture developed in the systems. These APIs follow the HTTP and REST standards so that other developers can easily connect to the system to develop other related applications.
4. System implementation

In this section, we present implementation of our system based on the proposed architecture in the previous section. We mainly focus and discuss the sensing systems and the cloud service.

4.1 Sensoring systems

In this work, we build our sensoring system with sensor nodes and gateway nodes. Sensor nodes directly collect different monitored values including levels of CO, CO2, temperature, PM2.5, and humidity. These values are sent directly to a gateway node via radio frequency (RF) signals, more precisely Long-Range RF (LoRa). Meanwhile, a gateway node collects data from a number of sensor nodes and sends to the cloud computing services through the internet (4G or wifi). This architecture reduces dependency to internet services compared to current monitoring systems in HCMC. Thanks to the LoRa technology, the distance between sensor nodes and the corresponding gateway node can be a few of kilometers. To secure the communication channel between the gateway node and the sensor nodes, we use AES128 [21] bit encoding for data communication.

To build the sensor nodes, we design and implement our boards which are equipped with a micro-controller, a LoRa module, sensors, and a power supply. Figure 3 presents the architecture of our sensor nodes. Figure 4 shows the printed circuit board layout of our sensor nodes.

Along with the sensor nodes, we also develop our gateway nodes with our self-design mainboard. The main functionality of the gateway nodes is to collect data from surrounding sensors nodes and send to the cloud computing services through the internet. Besides, to secure communication channels, AES encoding should be used. In our work, we use AES128 bit for encoding communication between the sensor nodes and the gateway nodes while AES256 for encoding communication between the gateway nodes and the cloud services.

To design and implement the mainboard, we choose the RK3128 processor with 4 ARM Cortex-A7MP Cores that can function at up to 1.3 GHz. Table 1 presents the main characteristics of the RK3128.

| Soc       | Rockchip RK3128 |
|-----------|-----------------|
| CPU       | ARM® Cortex™-A7 Quad-Core up to 1.3GHz |
| GPU       | ARM ® Mali - 400 MP2 Dual-core GPU, Support OpenGL ES1.1/2.0. Built-in high-performance 2D acceleration hardware |
| VPU       | The 1080P multi-format video decoding contains 1080P h.265 hardware decoding, 1080P video encoding, which supports h.264 format |
| PMU       | RK818 Power management unit |
| RAM       | Dual-Channel DDR3 (512mb/1GB/2GB Optional) |
| Storage   | High-Speed eMMC (4GB/8GB/16GB/32GB Optional) |
| Codec     | Integrated high quality Codec audio decoder |
| OS        | Android 4.4, 5.1, 7.1 / Android Things / Ubuntu 15.04 / Linux |
Power | Input Voltage 5V, Peak Current 2A

Figure 5 presents the architecture of the mainboard for gateway nodes. The RK3128 processor supports different I/O connections that can be extended for other applications in the future. Figure 6 shows the layout of the printed circuit board of the gateway node. Currently, the price for building a sensor node in this project is much cheaper than price of similar commercial products such as the Libelium-Aerostate AQI Solution Kit [22].

![Figure 5. The architecture of the mainboard for gateway nodes](image)

![Figure 6. PCB layout of the gateway mainboard](image)

4.2 Remote sensing images processing

In this work, along with data collected by sensors, we use remote sensing images (Landsat [22] and MODIS [23] images) for estimating AQI values (temperature and PM2.5) at areas without sensors. To build precise estimation models, values collected by sensors are used to calibrate values extracted from images. The processing steps as well as mathematic models to estimate values of land surface temperature and levels of PM2.5 are presented in our previous work [20].

4.3 Cloud services

The cloud services can be considered as the heart of the system when they connect all subsystems together. Figure 7 presents the three layers architecture of our cloud services.

- Data layer: including sensing and remote sensing images systems to collect air quality monitoring data. A service passively receives data sent from gateway nodes with values of CO, CO2, PM2.5, temperature, humidity. The other service connects to the remote sensing server to collect values of PM2.5 and land surface temperature extracted from remote sensing images.
- Cloud layer: functioning as the center management of the cloud services. Values collected from sensors and remote sensing images are processed at this layer to store in databases as well as to provide to users or governors. The layer is also responsible for managing users and monitoring the values to make alerts when needed.
- Application layer: including graphic user interfaces that allow users to access information processed by the system. The interfaces also help governors to handle the entire system through our configuration page where phone number and threshold of values can be configured. We also provide a portal at this layer to allow users to submit warning information they aware at their locations. The information then will be examined by administrators or governors before making publicity for inhabitants.

![Figure 7. The architecture of the cloud services](image)

4.4 Database systems

Figure 8 presents the architecture of our database systems. The processing is built on the Node.js technology allowing...
the system to process real-time event-oriented behaviors that are suitable for our air quality monitoring system.

The database system processing is designed according to MVC model (Model – View – Controller). The model helps the processing engine be maintained and expanded easily. The model partitions operations of the database systems processing into three different components, including Model, View, and Controller.

Model interacts with database management system (DBMS) to process and retrieve data. Model is executed under the controls of Controller. View is responsible for receiving and displaying information and interacting with users.

Figure 8. The architecture of database systems processing

5. System validation

To validate the proposed system, we conduct a number of tests to check values monitored by our sensing systems and other commercial devices. Tests to compare values extracted by the remote image processing system and values collected by our sensing system are also executed. In this section, we present the results of these validations.

5.1 Validation the sensing systems

To validate our sensing systems, we compare values collected from our sensor nodes and values measured by Tenmars commercial devices [24]. These devices are certified already and exported to many countries around the world. We collect data with different scenarios including peak hours. Table 2 presents our mean of errors when comparing our data and Tenmars data. According to the table, we obtained 0% error with levels of CO because in the normal conditions, there does not exist CO in the air. With particular matter values, PM2.5, we suffer from at most 23.08% error while less than 17.35%, 19.75% and 21.07% errors obtained for temperature, humidity, and CO2, respectively. The experimental results show that our sensing systems are reliable enough for monitoring air quality index in HCMC.

Table 2. Error when comparing our sensing system to commercial devices

| No. | PM2.5 | Temp. | Humidity | CO2 | CO |
|-----|-------|-------|----------|-----|----|
| 1   | 6.25  | 9.39  | 7.81     | 6.08| 0  |
| 2   | 12.5  | 9.68  | 4.76     | 12.28| 0 |
| 3   | 14.29 | 12.34 | 4.69     | 8.36| 0  |
| 4   | 13.33 | 9.09  | 6.25     | 9.97| 0  |
| 5   | 23.08 | 14.29 | 7.57     | 0   | 0  |
| 6   | 0     | 17.38 | 1.82     | 0.55| 0  |
| 7   | 18.82 | 13.29 | 1.85     | 7.49| 0  |
| 8   | 16.67 | 15.25 | 9.26     | 9.58| 0  |
| 9   | 16.67 | 8.01  | 5.45     | 8.31| 0  |
| 10  | 0     | 16.9  | 5.77     | 6.74| 0  |
| 11  | 0     | 12.43 | 3.85     | 9.26| 0  |
| 12  | 0     | 13.41 | 2       | 11.14| 0 |
| 13  | 0     | 11.35 | 6.76     | 8.8 | 0  |
| 14  | 16.67 | 11.11 | 8.75     | 6.18| 0  |
| 15  | 15.79 | 10.11 | 9.76     | 2.51| 0  |
| 16  | 13.33 | 5.66  | 15.66    | 7.76| 0  |
| 17  | 0     | 5.66  | 15.48    | 9.77| 0  |
| 18  | 0     | 9.09  | 14.12    | 13.02| 0 |
| 19  | 5.88  | 9.09  | 14.12    | 5.69| 0  |
| 20  | 7.69  | 8.75  | 12.94    | 3.99| 0  |
| 21  | 0     | 5.66  | 17.65    | 3.01| 0  |
| 22  | 9.09  | 5.66  | 17.65    | 2.56| 0  |
| 23  | 0     | 9.43  | 14.12    | 12.53| 0 |
| 24  | 0     | 9.43  | 12.79    | 5.42| 0  |
| 25  | 23.53 | 7.63  | 13.83    | 11.24| 0 |
| 26  | 5.56  | 1.82  | 19.75    | 7.4 | 0  |
| 27  | 5.56  | 1.75  | 16.44    | 6.38| 0  |
| 28  | 6.67  | 5.41  | 16.67    | 8.13| 0  |
| 29  | 5.88  | 3.33  | 16.9     | 5.24| 0  |
| 30  | 0     | 3.97  | 16.9     | 7.3 | 0  |
| 31  | 11.76 | 4.92  | 14.71    | 21.07| 0 |
| 32  | 21.05 | 5.84  | 14.71    | 6.08| 0  |

5.2 Validate the remote sensing images processing

To verify the remote sensing images processing, we compare values estimated by from remote sensing images and values collected by our sensing systems. Table 3 and Table 4 illustrate the errors of PM2.5 and land surface temperature comparison between the two methods. According to Table 3, we achieved at most 7.69% error for PM2.5 levels estimation. Error of land surface temperature values is at most 8.77%. With these errors, our remote sensing images processing can be used for estimating values of PM2.5 and land surface temperature in locations without sensors.

Table 3. Values of PM2.5 from images and from sensors

| Images | Date | PM2.5 | PM2.5 | Error |
|--------|------|-------|-------|-------|
|        |      |       |       |       |
Therefore, the system consumes in average 900mV.

Table 5 presents the values of current, and voltage used for our system in 5 different measurement times. According to the table, in average, we need the current of 176 mA and the power supply of 4.88V for the proposed system. Therefore, the system consumes in average 900mV.

Compared to other systems reported in the literature, our use is low-energy consumption.

Table 5. Results of current and voltage measurement

### 5.3 Energy consumption measurement

The model in Figure 9 is used to measure the current and the voltage used for our sensing system. In this model, “Load” means our system. We connect a one-ohm resistor serially with our system to calculate the current used by the system. Oscilloscope is used to measure voltage between A and B and then B and C. We supply a power of 5V for the entire system (U\textsubscript{AC} = 5V).

![Figure 9. Current used measurement model](image)

**Table 4. Values of land surface temperature from images and from sensors**

| Images  | Date      | Temp. \(^\circ\text{C}\) images | Temp. \(^\circ\text{C}\) sensors | Error |
|---------|-----------|---------------------------------|---------------------------------|-------|
| LANDSAT 8 | 14/04/2021 | 35.22                           | 33.1                            | 6.01% |
| LANDSAT 8 | 29/03/2021 | 34.28                           | 31.2                            | 8.75% |
| MODIS MOD11A2 | 17/04/2021 | 31.84                           | 30.4                            | 4.52% |
| MODIS MOD11A2 | 08/04/2021 | 28.50                           | 31.0                            | 8.77% |
| MODIS MOD11A2 | 31/03/2021 | 32.72                           | 34.1                            | 4.21% |

**Table 5. Results of current and voltage measurement**

| Time       | 1      | 2      | 3      | 4      | 5      | Average |
|------------|--------|--------|--------|--------|--------|---------|
| Current (mA)| 174    | 173    | 176    | 176    | 180    | 176     |
| Voltage (V) | 4.89   | 4.89   | 4.89   | 4.89   | 4.85   | 4.88    |

6. Conclusion

In this paper, we introduce our air quality monitor system with multiple data sources that can be applied in smart cities like Ho Chi Minh City. We use data collected from sensors and extracted from remote sensing images to monitor the quality index. We build our sensing systems with sensor nodes and gateway nodes. Based on values collected from sensors, we calibrate the remote sensing images processing models to estimate values of fine particulate matter and land surface temperature. The models can be used to evaluate air quality index in locations where we have not yet deployed sensing systems. To combine all components to a complete system, we build cloud services including APIs for collecting data as well as database for storing values. The cloud services also provide a graphic user interface portal for users and governors to explore the air quality index. The system is able to receive notifications from users when they aware any hazardous situations at their places. When compared with other commercial devices, values measured by our systems are different up to 24% at most for sensing while 9% at most with remote sensing images estimation. The proposed system is low-energy consumption when using only 900mW in average.

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**References**

[1] World Health Organization, “An estimated 12.6 million deaths each year are attributable to unhealthy environments,” [Online]. Available: https://www.who.int/news/item/15-03-2016-an-estimated-12-6-million-deaths-each-year-are-attributable-to-unhealthy-environments

[2] IHS Markit, “Smart Cities Project Database,” [Online]. Available: [https://technology.ihs.com/589696/smart-cities-project-database-q3-2017](https://technology.ihs.com/589696/smart-cities-project-database-q3-2017) [Accessed 6/1/2018]

[3] Huy, D.H., Chi, N.D.T., Phu, N.L.S., Hien, T.T, “Fine particulate matter (PM2.5) in Ho Chi Minh City: Analysis of the status and the temporal variation based on the continuous data from 2013-2017,” Science & Technology Development: Natural Sciences, 2018

[4] Manins, P., October 1999. Air Quality Forecasting for Australia’s Major Cities: 1st Progress Report; SB/1/40725.
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CSIRO Atmospheric Research, Aspendale, Australia. http://www.dar.csiro.au/publications/Manins_1999a.pdf

Pudykiewicz, J.A., Koziol, A.S., 2001. The application of Eulerian models for air quality prediction and the evaluation of emission control strategies in Canada. Int. J. Environ. Pollut. 16, 425-438.

U.S. EPA, 1999. Guideline for Developing an Ozone Forecasting Program. U.S. Environmental Protection Agency Rep. EPA-454/R-99e009, 88 pp. Available from: Office of Air Quality Planning and Standards, EPA, Research Triangle Park, NC 27711.

Wayland, R.A., White, J.E., Dickerson, P.G., Dye, T.S., 28-36, December 2002. Communicating real-time and forecasted air quality to the public. Environ. Manage.

Gwynne, M. D. (1982). "The global environment monitoring system (GEMS) of UNEP." Environmental Conservation 9(01): 35-41.

Demerjian, K.L (2000). “A review of national monitoring networks in North America.” Atmospheric Environment 34(12): 1861-1884.

Huy, D.H., Chi, N.D.T., Phu, N.L.S., Hien, T.T. Fine particulate matter (PM2.5) in Ho Chi Minh City: Analysis of the status and the temporal variation based on the continuous data from 2013-2017. Science & Technology Development: Natural Sciences, 2018.

Suzhou Air Quality Monitoring System, Online available at: http://www.sinoitaenvironment.org/ReadNewsex1.asp?NewsID=1896

D. A. Chu et al., “Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer (MODIS).” J. Geophys. Res. Atmos., vol. 108, no. D21, 2003.

J. Wang and S. A. Christopher, “Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implication for air quality studies,” Geophys. Res. Lett., vol. 30, no. 21, 2003.

J. Kloog, B. Ridgway, P. Koutrakis, B. A. Coull, and J. D. Schwartz, “Longand Short-Term Exposure to PM(2.5) and Mortality: Using Novel Exposure Models,” Epidemiology, vol. 24, no. 4, pp. 555–561, Jul. 2013. 156

H. J. Lee, Y. Liu, B. A. Coull, J. Schwartz, and P. Koutrakis, “A novel calibration approach of MODIS AOD data to predict PM2.5 concentrations,” Atmos. Chem. Phys., vol. 11, pp. 7991–8002, 2011.

Y. Liu, M. Franklin, R. Kahn, and P. Koutrakis, “Using aerosol optical thickness to predict ground-level PM2.5 concentrations in the St. Louis area: A comparison between MISR and MODIS,” Remote Sens. Environ., vol. 107, no. 1–2, pp. 33-44, 2007.

Y. Liu, P. Koutrakis, R. Kahn, S. Turqeyt, and R. M. Yantosca, “Estimating Fine Particulate Matter Component Concentrations and Size Distributions Using SatelliteRetrieved Fractional Aerosol Optical Depth: Part 1-Method Development,” J. Air Waste Manage. Assoc., vol. 57, pp. 1351–1359, 2007.

Z. Ma, X. Hu, L. Huang, J. Bi, and Y. Liu, “Estimating Ground-Level PM2.5 in China Using Satellite Remote Sensing,” vol. 48, no. 13, pp. 7436–7444, 2014.

J. S. Yang, Y. Q. Wang, and P. V August, “Estimation of land surface temperature using spatial interpolation and satellite-derived surface emissivity,” J. Environ. Informatics, vol. 4, pp. 37–44, 2004.

Vu P.H., Le TL., Pham-Quoc C. (2021) Estimating Land Surface Temperature from Landsat-8 Images Based on a Cloud-Based Automated Processing Service. In International Conference of Context-Aware Systems and Applications (ICCASA) 2020, Vietnam

Daemen, Joan; Rijmen, Vincent (March 9, 2003). “AES Proposal: Rijndael,” National Institute of Standards and Technology from the original on 5 March 2013, Retrieved 21 February 2021.

Libelium unites benefits of Smart Cities IoT solutions for air quality monitoring. Online: https://www.libelium.com/libeliumworld/libelium-unites-benefits-of-smart-cities-iot-solutions-for-air-quality-monitoring/

U. G. S. Department of the Interior, Landsat 8 Data Users Handbook.

NASA official https://earthdata.nasa.gov

Tenmars technology http://www.tenmars.com