EVALUATION OF ARIMA AND ANN STREAM ANALYTICS FOR AIR QUALITY MONITORING SYSTEM

NURMADIHA BINTI OSMAN

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

____

(Supervisor's Signature)

Full Name : IR. DR. MOHD FAIZAL BIN JAMLOS

Position : PROFESSOR

Date : 25 NOVEMBER 2021

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : NURMADIHA BINTI OSMAN

ID Number : MMH19002

Date : 24 NOVEMBER 2021

EVALUATION OF ARIMA AND ANN STREAM ANALYTICS FOR AIR QUALITY MONITORING SYSTEM

NURMADIHA BINTI OSMAN

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

College of Engineering

UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2021

ACKNOWLEDGEMENTS

Alhamdulillah, all praise be to Allah SWT, the Lord of the whole universe. May the peace and blessings of Allah be upon on the noblest of the Prophets and Messengers, our Prophet Muhammad SAW, and upon his family, and all his companions. I am thankful to Allah for the grace and guidance in completing this journey successfully. Thanks to everyone who has been of help and inspiration to me in my graduate work and I would like to thank them for their support. I offer my full-hearted apologies to anybody I ungratefully overlook from explicit mention.

First and foremost, I express my deep gratitude to my supervisor, Prof. Ir. Dr. Mohd Faizal Bin Jamlos, who helped in every step of the way and for the continuous support of my study, for his patience, motivation, and the untiring assistance. The help and support of all staff in the College of Engineering and Institute of Postgraduate Studies (IPS) at Universiti Malaysia Pahang, and especially to all my friends, have been invaluable. Not forget to En Azman M. Yusof from the Universiti Malaysia Perlis (UniMAP) for his guidance on sensors, python, and controllers, Dr. Junaida Binti Sulaiman from Faculty of Computing, UMP who thought me and other colleagues on Machine Learning Classification and Regression. My coach, Dr Hj Mohd Khairul Nizam Bin Zainan Nazri, for his guidance, motivations, and strategies in completing this wonderful journey. My helpful research teammate, Aidil Redza Khan Bin Mohamed Amer khan and Nur Syahirah Binti Mohd Sabli, my postgraduate friends Muhammad Aizzuddin Bin Abdullah, and Mohd Kamal Bin Kamarulzaman, for their valuable suggestions, recommendations, and opinions regarding the complications that I have faced along with this research study.

At last, and most importantly, with immense pleasure, I express my sincere indebtedness and appreciation to my family. Words cannot express how grateful I am to my father, Osman Bin Ismail, my mother, Rosmaniah Binti Mokhtar, my sisters, Nurdiyana, Nursyafira, and Nur Raihan, for their continual prayers, sacrifices, and moral support throughout my life. Without them, I would not have been able to achieve my goal.

ABSTRAK

Terdapat banyak sistem pengawasan alam sekitar yang tersedia di pasaran dengan teknologi yang diaktifkan oleh *Internet-of-Things (IoT)*. Walau bagaimanapun, sistem yang ada tidak dilengkapi dengan analisis data dalam talian. Sebilangan dari mereka menyediakan analisis tetapi dilakukan dalam ragam luar talian melalui perisian atau peranti pihak ketiga yang dikenali sebagai analisis kumpulan. Dari segi harga, sistem pengawasan yang ada sahaja mahal walaupun tidak ada yang dilengkapi dengan analisis aliran. Tesis ini membentangkan reka bentuk dan pengembangan sistem pengawasan kualiti udara yang tepat yang dilengkapi dengan analisis ramalan pembelajaran mesin aliran yang disebut *Smart Environmental System (SES)*. *SES* yang dibangunkan terbahagi kepada dua bahagian iaitu unit nod akhir dan unit get laluan. Unit nod akhir terdiri daripada pendera nitrogen dioksida *(NO_2)*, karbon monoksida *(CO)*, karbon dioxida *(CO_2)*, zarahan jirim 2.5 *($PM_{2.5}$)*, zarahan jirim 10 *(PM_{10})*, ozon (O_3), dan kelembapan suhu yang tertentukur yang disatukan dengan papan tunggal komputer *Raspberry Pi* dan modul pemancar julat jauh *LoRa*. Sementara itu unit get laluan terdiri daripada modul Raspberry Pi, penerima julat jauh *LoRa* dan 4G. Unit nod akhir memindahkan data secara wayarles ke unit get laluan melalui komunikasi julat jauh *LoRa*, dan unit get laluan menyimpan data dengan segera di *MySQL* yang dipasang di pelayan *Linux Apache MySQL PHP (LAMP)*. Penyiasatan untuk menilai ketepatan pendera dilakukan dengan membandingkan data yang dikumpulkan oleh *SES* dibandingkan dengan data dari Jabatan Alam Sekitar. Ralat peratusan ketepatan *SES* untuk pendera *CO, NO_2, O_3, PM_{10}*, adalah 5.1%, 7%, 6.1% dan 6% berbanding dengan DoE. Ketepatan pendera sedemikian boleh diterima dengan ketepatan dibawah daripada 10%. Setelah ketepatan disahkan, data yang disimpan dalam pangkalan data MySQL berjaya dieksport ke jadual *query* R di pelayan R dengan menggunakan atucara *dbGetQuery ( )*, diperiksa dan diselaraskan dengan pangkalan data *MySQL*. Diperhatikan bahawa data dalam *MySQL* berjaya dieksport ke jadual *query* R berdasarkan jumlah pemboleh ubah yang serupa antara kedua jadual tersebut. Data yang disimpan dalam jadual *query* bertindak sebagai input kepada algoritma analitik yang berjalan di pelayan R juga. Dalam tesis ini, dua algoritma telah dilaksanakan dan dibandingkan iaitu *Auto Regressive Integrated Moving Average (ARIMA)* dan *Artificial Neural Network (ANN)*. Telah dikenal pasti bahawa algoritma *ARIMA* mempunyai ketepatan ramalan yang lebih baik dengan peratusan 99.45%, 99.87%, 99.75%, 98.92% untuk *CO, NO_2, O_3,* dan *PM_{10}* melebihi algoritma *ANN*, dengan demikian, algoritma *ARIMA* dipilih sebagai algoritma analitik ramalan untuk *SES*. Setelah disematkan ke *SES*, prestasi algoritma *ARIMA* dinilai berdasarkan Kesalahan Peratusan Mutlak Rata-rata (PETA) dan Ketepatan Ramalan (PA). Diperhatikan bahawa ARIMA MAPE masing-masing adalah 1.64%, 9.67%, 9.59%, 7.09%, untuk CO, NO_2, O_3 dan PM_{10}, yang menyebabkan PA mencapai 96.78%, 90.33%, 90.41% dan 92.91%. Hasilnya membuktikan bahawa SES yang dicadangkan dapat meramalkan gas tersebut dengan tepat selama 24 jam ke depan melebihi ketepatan ramalan 90%. Dapat disimpulkan bahawa *SES* yang diusulkan dapat dilaksanakan sebagai masa depan untuk sistem Indeks Pencemaran Udara *(API)*.

ABSTRACT

There are many environmental monitoring systems available in the market with Internet-of-Things (IoT) enabled technology. However, the existing system is not equipped with online data analytics. Some of them provide analytics but are done in offline mode through third-party software or devices known as batch analytics. Pricewise, the existing monitoring system alone is expensive even though none of them are furnished with stream analytics. The thesis presents the design and development of an accurate air quality monitoring system equipped with streaming machine learning predictive analytics called Smart Environmental System (SES). The developed SES is divided into two sections End-Node Unit (ENU) and Gateway Unit (GWU). ENU consisted of calibrated sensors of NO_2, CO, CO_2, $PM_{2.5}$, PM_{10}, O_3, temperature humidity integrated with Raspberry Pi Single-Board Computer (SBC) and Long-Range (LoRa) Transmitter (Tx) module. Meanwhile, GWU consisted of Raspberry Pi SBC, LoRa Receiver (Rx) and 4G module. The ENU transferred the data wirelessly to the GWU through LoRa communication, and GWU stored the data immediately in MySQL, which was installed in the Linux Apache MySQL PHP (LAMP) server. Investigation on evaluating sensors' accuracy is executed by comparing the collected data by SES vs data from the Department of Environment (DoE). The SES's accuracy percentage error of CO, NO_2, O_3, PM_{10} are 5.1%, 7%, 6.1% and 6% correspondingly compared to DoE. Such accuracy of sensors is acceptable with an accuracy below 10%. Once accuracy has been validated, the data stored in MySQL database is successfully exported to the R query table in R-Server by using dbGetQuery() command, checked and aligned with the MySQL database. It is observed that the data in MySQL are successfully exported to the R query table based on the similar number of variables between those two tables. The data stored in the query table act as input to the analytics algorithm, which runs in R-server as well. In this thesis, two algorithms have been implemented and compared. Auto-Regressive Integrated Moving Average (ARIMA) and Artificial Neural Network (ANN). It is identified that ARIMA has better prediction accuracy (PA) percentage of 99.45%, 99.87%, 99.75%, 98.92% for CO, NO_2, O_3 and PM_{10} over ANN thus chosen as a predictive analytics algorithm for SES. Once embedded in SES, ARIMA performances are evaluated based on Mean Absolute Percentage Error (MAPE) and Prediction Accuracy (PA). It is observed that ARIMA MAPE is 1.64%,9.67%, 9.59%, 7.09%, for CO, NO_2, O_3 and PM_{10}, respectively which led PA to achieve 96.78%, 90.33%, 90.41% and 92.91% correspondingly. The results proved that the proposed SES is able to precisely predict those gases for the next 24 hours above the 90% prediction accuracy. It can be concluded the proposed SES could be implemented as a future for the Air Pollutant Index (API) system.

TABLE OF CONTENT

REFERENCES

Adiono, T., Fathany, M. Y., Fuada, S., Purwanda, I. G., & Feranti Anindya, S. (n.d.). A Portable Node of Humidity and Temperature Sensor for Indoor Environment Monitoring. *2018 3rd International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, 1–5.

Ahmed, M. M., Banu, S., & Paul, B. (2017). Real-time air quality monitoring system for Bangladesh's perspective based on Internet of Things. *2017 3rd International Conference on Electrical Information and Communication Technology (EICT)*, (December), 1–5. https://doi.org/10.1109/EICT.2017.8275161

Air Pollutant Index (API) | Department of Environment. (n.d.). Retrieved January 25, 2021, from https://www.doe.gov.my/portalv1/en/info-umum/english-air-pollutant-index-api/100

Air Quality Monitoring System - HORIBA. (n.d.). Retrieved March 1, 2021, from https://www.horiba.com/ru/process-environmental/products/system-engineering/air-quality-monitoring-system/

Air Quality Test Kit | Test Outdoor Air Pollution with our Air Quality Testing Kit | Aeroqual. (n.d.). Retrieved March 1, 2021, from https://www.aeroqual.com/product/outdoor-portable-monitor-starter-kit

Al-sarawi, S., Anbar, M., Alieyan, K., & Alzubaidi, M. (2017). Review, 685–690.

Ali, M. I., Ono, N., Kaysar, M., Shamszaman, Z. U., Pham, T. Le, Gao, F., … Mileo, A. (2017). Real-time data analytics and event detection for IoT-enabled communication systems. *Journal of Web Semantics*, *42*(July), 19–37. https://doi.org/10.1016/j.websem.2016.07.001

Alkandari, A. A., & Moein, S. (2018). Implementation of monitoring system for air quality using raspberry PI: Experimental study. *Indonesian Journal of Electrical Engineering and Computer Science*, *10*(1), 43–49. https://doi.org/10.11591/ijeecs.v10.i1.pp43-49

Ambient (outdoor) air quality and health. (n.d.). Retrieved June 13, 2019, from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Ayele, T. W. (2018). Air pollution monitoring and prediction using IoT. *2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT)*, (Icicct), 1741–1745. https://doi.org/10.1109/ICICCT.2018.8473272

Bai, L., Wang, J., Ma, X., & Lu, H. (2018). Air pollution forecasts: An overview. *International Journal of Environmental Research and Public Health*, *15*(4), 1–

44. https://doi.org/10.3390/ijerph15040780

Buratti, C., Conti, A., Dardari, D., & Verdone, R. (2009). An Overview on Wireless Sensor Networks Technology and, 6869–6896. https://doi.org/10.3390/s90906869

Carbon Dioxide Detection and Indoor Air Quality Control -- Occupational Health & Safety. (n.d.). Retrieved July 2, 2019, from https://ohsonline.com/articles/2016/04/01/carbon-dioxide-detection-and-indoor-air-quality-control.aspx

Choudhary, G., & Jain, A. K. (2016). Internet of Things: A survey on architecture, technologies, protocols and challenges. *2016 International Conference on Recent Advances and Innovations in Engineering, ICRAIE 2016*, 0–7. https://doi.org/10.1109/ICRAIE.2016.7939537

Collier-Oxandale, A., Feenstra, B., Papapostolou, V., Zhang, H., Kuang, M., Der Boghossian, B., & Polidori, A. (2020). Field and laboratory performance evaluations of 28 gas-phase air quality sensors by the AQ-SPEC program. *Atmospheric Environment*, *220*, 117092. https://doi.org/10.1016/j.atmosenv.2019.117092

Dobrea, M., Badicu, A., Barbu, M., Subea, O., Balanescu, M., Suciu, G., … Dobre, C. (2020). Machine Learning algorithms for air pollutants forecasting. *2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging, SIITME 2020 - Conference Proceedings*, 109–113. https://doi.org/10.1109/SIITME50350.2020.9292238

Ecotech – Environmental monitoring solutions. (n.d.). Retrieved March 1, 2021, from https://www.ecotech.com/

Fei, X., Shah, N., Verba, N., Chao, K. M., Sanchez-Anguix, V., Lewandowski, J., … Usman, Z. (2019). CPS data streams analytics based on machine learning for Cloud and Fog Computing: A survey. *Future Generation Computer Systems*, *90*, 435–450. https://doi.org/10.1016/j.future.2018.06.042

Huang, W. H., Lin, J. H., Weng, C. H., Hsu, C. W., & Yen, T. H. (2016). Environmental NO2 and CO Exposure: Ignored Factors Associated with Uremic Pruritus in Patients Undergoing Hemodialysis. *Scientific Reports*, *6*(August), 2–11. https://doi.org/10.1038/srep31168

IBM WebSphere Reviews: Pricing & Software Features 2020 - Financesonline.com. (n.d.). Retrieved March 14, 2021, from https://reviews.financesonline.com/p/ibm-webspehre/

IEEE. (1997). Telecommunications and information exchange Part 11 : Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. System.

Inside IoT network rollouts: LoRa, Sigfox and LTE-M. (n.d.). Retrieved March 5, 2019, from https://www.rcrwireless.com/20160715/internet-of-things/iot-network-rollouts-tag31-tag99

IoT Connectivity - Comparing NB-IoT, LTE-M, LoRa, SigFox, and other LPWAN Technologies | IoT For All. (n.d.). Retrieved March 5, 2019, from https://www.iotforall.com/iot-connectivity-comparison-lora-sigfox-rpma-lpwan-technologies/

Jacobson, M. Z. (2008). On the causal link between carbon dioxide and air pollution mortality. *Geophysical Research Letters*, *35*(3), L03809. https://doi.org/10.1029/2007GL031101

Jo, B. W., & Khan, R. M. A. (2018). An internet of things system for underground mine air quality pollutant prediction based on azure machine learning. *Sensors (Switzerland)*, *18*(4). https://doi.org/10.3390/s18040930

Kanchan, Gorai, A. K., & Goyal, P. (2015). A review on air quality indexing system. *Asian Journal of Atmospheric Environment*, *9*(2), 101–113. https://doi.org/10.5572/ajae.2015.9.2.101

Kasar, A. R., Khemnar, D. S., & Tembhurnikar, N. P. (2013). WSN Based Air Pollution Monitoring System. *International Journal of Science and Engineering Applications*, *2*(4), 55–59. https://doi.org/10.7753/ijsea0204.1001

Kim, S. H., Jeong, J. M., Hwang, M. T., & Kang, C. S. (2017). Development of an IoT-based atmospheric environment monitoring system. *International Conference on Information and Communication Technology Convergence: ICT Convergence Technologies Leading the Fourth Industrial Revolution, ICTC 2017*, *2017-Decem*, 861–863. https://doi.org/10.1109/ICTC.2017.8190799

Kumar, U., & Jain, V. K. (2010). ARIMA forecasting of ambient air pollutants (O 3, NO, NO 2 and CO). *Stochastic Environmental Research and Risk Assessment*, *24*(5), 751–760. https://doi.org/10.1007/s00477-009-0361-8

Kusrey, S., Rai, A., & Saxena, V. (Nigam). (2017). Zigbee Based Air Pollution Monitoring and Control System using WSN. *International Journal of Electronics and Communication Engineering*, *4*(6), 7–11. https://doi.org/10.14445/23488549/ijece-v4i6p103

Li, D., Bao, Z., & Yang, Y. (2016). Design of workshop environment monitoring system based on Internet of Things, 165–170. https://doi.org/10.1109/ISCID.2016.152

Li, L. N., Gong, X. P., Dai, L. C., & Zhan, X. H. (2013). The Regression Models of PM2.5 and Other Air Pollutants in Wuhan. *Advanced Materials Research*, *864–867*(December 2013), 1356–1359. https://doi.org/10.4028/www.scientific.net/amr.864-867.1356

Liang-Ying, Guo, Y. F., & Zhao-Wei. (2015). Greenhouse environment monitoring system design based on WSN and GPRS networks. *2015 IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems, IEEE-CYBER 2015*, 795–798. https://doi.org/10.1109/CYBER.2015.7288044

Mabahwi, N. A. B., Leh, O. L. H., & Omar, D. (2014). Human Health and Wellbeing: Human Health Effect of Air Pollution. *Procedia - Social and Behavioral Sciences*, *153*(October), 221–229. https://doi.org/10.1016/j.sbspro.2014.10.056

Mansour, S., Nasser, N., Karim, L., & Ali, A. (2014). Wireless sensor network-based air quality monitoring system. *2014 International Conference on Computing, Networking and Communications, ICNC 2014*, 545–550. https://doi.org/10.1109/ICCNC.2014.6785394

Martínez-España, R., Bueno-Crespo, A., Timón, I., Soto, J., Muñoz, A., & Cecilia, J. M. (2018). Air-pollution prediction in smart cities through machine learning methods: A case of study in Murcia, Spain. *Journal of Universal Computer Science*, *24*(3), 261–276.

Masih, A. (2018). Modelling the atmospheric concentration of carbon monoxide by using ensemble learning algorithms. *CEUR Workshop Proceedings*, *2298*.

Mokrani, H., Lounas, R., Bennai, M. T., Salhi, D. E., & Djerbi, R. (2019). Air quality monitoring using IoT: A survey. *Proceedings - 2019 IEEE International Conference on Smart Internet of Things, SmartIoT 2019*, 127–134. https://doi.org/10.1109/SmartIoT.2019.00028

Oracle. (2012). Oracle Technology Global Price List Software Investment Guide, 1–13. Retrieved from http://www.oracle.com/us/corporate/pricing/technology-price-list-070617.pdf

Pavani, M., & Rao, P. T. (2017). Urban Air Pollution Monitoring Using Wireless Sensor Networks : A Comprehensive Review, *9*(3), 439–449.

PM25 and PM10 on line air quality monitoring system. (n.d.). Retrieved March 1, 2021, from https://www.oty-detector.com/products/PM25-PM10-on-line-air-quality-monitoring-system.html

Porcino, D. (2003). Ultra-Wideband Radio Technology : Potential and Challenges Ahead, (July), 66–74.

Rahman, N. H. A., Lee, M. H., Latif, M. T., & Suhartono. (2013). Forecasting of air pollution index with artificial neural network. *Jurnal Teknologi (Sciences and Engineering)*, *63*(2), 59–64. https://doi.org/10.11113/jt.v63.1913

Rai, A., Saxena, V. N., & Kusrey, S. (2017). Zigbee Based Air Pollution Monitoring and Control System using WSN, *4*(6), 7–11.

Raju, V., Varma, A. S. N., & Raju, Y. S. (2018). An environmental pollution monitoring system using LORA. *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing, ICECDS 2017*, 3521–3526. https://doi.org/10.1109/ICECDS.2017.8390115

Ranjitha, B. P. (2015). Streaming Analytics over Real-Time Big Data, *15*(5).

Review: Zeus Web server - Linux.com. (n.d.). Retrieved March 15, 2021, from https://www.linux.com/news/review-zeus-web-server/

Saha, A. K., Sircar, S., Chatterjee, P., Dutta, S., Mitra, A., Chatterjee, A., … Saha, H. N. (2018). A raspberry Pi controlled cloud based air and sound pollution monitoring system with temperature and humidity sensing. *2018 IEEE 8th Annual Computing and Communication Workshop and Conference, CCWC 2018*, *2018-Janua*, 607–611. https://doi.org/10.1109/CCWC.2018.8301660

Scientific Facts on Air Pollution Nitrogen Dioxide. (n.d.). Retrieved July 27, 2019, from https://www.greenfacts.org/en/nitrogen-dioxide-no2/

Smart Environment | Libelium. (n.d.). Retrieved March 1, 2021, from https://www.libelium.com/smart-environment/#

Spachos, P., & Hatzinakos, D. (2016). Real-Time Indoor Carbon Dioxide Monitoring Through Cognitive Wireless Sensor Networks. *IEEE Sensors Journal*, *16*(2), 506–514. https://doi.org/10.1109/JSEN.2015.2479647

SQL Server 2019—Pricing | Microsoft. (n.d.). Retrieved March 15, 2021, from https://www.microsoft.com/en-us/sql-server/sql-server-2019-pricing#OneGDCWeb-ContentPlacementWithRichBlock-pp5ed24

Syafei, A. D., Fujiwara, A., & Zhang, J. (2015). Prediction Model of Air Pollutant Levels Using Linear Model with Component Analysis. *International Journal of Environmental Science and Development*, *6*(7), 519–525. https://doi.org/10.7763/ijesd.2015.v6.648

Tang, Q., Hess, P. G., Brown-Steiner, B., & Kinnison, D. E. (2013). Tropospheric ozone decrease due to the Mount Pinatubo eruption: Reduced stratospheric influx. *Geophysical Research Letters*, *40*(20), 5553–5558. https://doi.org/10.1002/2013GL056563

Thompson, J. E. (2016). Crowd-sourced air quality studies: A review of the literature & portable sensors. *Trends in Environmental Analytical Chemistry*, *11*, 23–34. https://doi.org/10.1016/j.teac.2016.06.001

Thu, M. Y., Htun, W., Aung, Y. L., Shwe, P. E. E., & Tun, N. M. (2019). Smart air quality monitoring system with LoRaWAN. *Proceedings - 2018 IEEE International Conference on Internet of Things and Intelligence System, IOTAIS 2018*, 10–15. https://doi.org/10.1109/IOTAIS.2018.8600904

Trevathan, J., & Johnstone, R. (n.d.). Smart Environmental Monitoring and Assessment Technologies (SEMAT)-A New Paradigm for Low-Cost, Remote Aquatic Environmental Monitoring. https://doi.org/10.3390/s18072248

Wang, S., Hou, Y., Gao, F., & Ji, X. (2017). A novel IoT access architecture for vehicle monitoring system. *2016 IEEE 3rd World Forum on Internet of Things, WF-IoT 2016*, 639–642. https://doi.org/10.1109/WF-IoT.2016.7845396

What are the differences between Raspberry Pi and Arduino? (n.d.). Retrieved June 17, 2021, from https://www.electronicshub.org/raspberry-pi-vs-arduino/

Xiaojun, C., Xianpeng, L., & Peng, X. (2015). IOT-based air pollution monitoring and forecasting system. *2015 International Conference on Computer and Computational Sciences, ICCCS 2015*, 257–260. https://doi.org/10.1109/ICCACS.2015.7361361

Yang, Z., & Wang, J. (2017). A new air quality monitoring and early warning system: Air quality assessment and air pollutant concentration prediction. *Environmental Research*, *158*(June), 105–117. https://doi.org/10.1016/j.envres.2017.06.002

Yi, W. Y., Lo, K. M., Mak, T., Leung, K. S., Leung, Y., & Meng, M. L. (2015). *A survey of wireless sensor network based air pollution monitoring systems*. *Sensors (Switzerland)* (Vol. 15). https://doi.org/10.3390/s151229859

Yin, J., & Harrison, R. M. (2008). Pragmatic mass closure study for PM1.0, PM2.5 and PM10 at roadside, urban background and rural sites. *Atmospheric Environment*, *42*(5), 980–988. https://doi.org/10.1016/j.atmosenv.2007.10.005

Yu, T. C., Lin, C. C., Chen, C. C., Lee, W. L., Lee, R. G., Tseng, C. H., & Liu, S. P. (2013). Wireless sensor networks for indoor air quality monitoring. *Medical Engineering and Physics*, *35*(2), 231–235. https://doi.org/10.1016/j.medengphy.2011.10.011

Zhang, H., & Srinivasan, R. (2020). A Systematic Review of Air Quality Sensors , Guidelines , and Measurement Studies for Indoor Air Quality Management.

Zhang, J., & Ding, W. (2017). Prediction of air pollutants concentration based on an extreme learning machine: The case of Hong Kong. *International Journal of Environmental Research and Public Health*, *14*(2), 1–19. https://doi.org/10.3390/ijerph14020114

Zheng, K., Zhao, S., Yang, Z., Xiong, X., & Xiang, W. (2016). Design and Implementation of LPWA-Based Air Quality Monitoring System. *IEEE Access*, *4*, 3238–3245. https://doi.org/10.1109/ACCESS.2016.2582153

Zhi, S., Wei, Y., Cao, Z., & Hou, C. (2017). Intelligent controlling of indoor air quality based on remote monitoring platform by considering building environment. *2017 4th International Conference on Systems and Informatics (ICSAI)*, (Icsai), 627–631. https://doi.org/10.1109/ICSAI.2017.8248365