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USE OF LOW-COST SENSORS, ATTACHED TO VESTS, TO MEASURE PARAMETERS OF ENVIRONMENTAL ISSUES BY SENDING DATA TO THE CLOUD

Pedro Antônio dos Santos Bhering
http://lattes.cnpq.br/1498063816913795

Rodrigo Marques de Oliveira
http://lattes.cnpq.br/3017579311577088

Abstract: This project aims to develop a low-cost device to monitor the quality of air, simultaneously measuring NH3, CO2, NO2, temperature, pressure and geographic coordinates, and sending this data to the cloud. Using the ESP8266 Node MCU WiFi module for its connectivity and versatility, the MICS-6814 sensor to detect gases, and the BME680 for meteorological variables, complemented by the NEO-6M V2 GPS for geolocation, this prototype allows real-time and cost-effective monitoring of pollution urban. The results indicate that the device was able to capture significant variations in pollutant concentrations in areas with different levels of traffic, demonstrating its effectiveness in identifying areas of potential risk to public health. This data is crucial for implementing more effective health and urban planning policies, emphasizing the importance of technological innovations to face environmental challenges and improve the quality of life in cities.

INTRODUCTION

As industrialization advances and the consumption of natural resources intensifies, monitoring air quality becomes a pressing concern, directly impacting public health. Daily activities, often intensified by the work role, contribute to environmental deterioration, resulting in exposure to dangerous air pollutants such as carbon monoxide (CO), carbon dioxide (CO2), ammonia (NH3), particulates and nitrogen dioxide (NO2) among others. These pollutants not only have the potential to cause respiratory and cognitive diseases, but also serious conditions such as Alzheimer's disease and cardiac impairment [1], [2], [3], [4].

In the context of the United States, for example, the impact of these pollutants is substantial, with estimates showing that deaths related to air quality in 2015 surpassed those caused by diabetes, influenza, kidney disease and suicide, reaching around 88 thousand deaths annually [1]. This reality highlights the need for effective and accessible monitoring of polluting gases, a challenge that has motivated the development of new technologies in several countries.

However, air quality monitoring is often limited by the lack of adequate equipment and the difficulty in disseminating understandable information to the non-expert public. In Brazil, for example, the lack of sufficient infrastructure to monitor and report on air quality increases the risk of pollution-related diseases, especially in areas with high traffic density or poorly ventilated places such as gyms [5], [3]. Furthermore, commercially available gas meters are generally expensive and specific, limiting their use to industrial applications.

This work proposes a low-cost prototype that simultaneously measures the concentration of NH3, CO2, NO2, temperature, pressure and geographic coordinates of the measurement point. The device not only provides numerical readings, but also sends them to the cloud and can be accessed remotely if deployed. The work did not make efforts, in this first stage, to calibrate the sensors, instead focusing on proposing a dynamic way of monitoring the aforementioned parameters and sending the data to the cloud.

MATERIALS AND METHODS

DESCRIPTION OF ESP8266- NODE-MCU

To read and send data to the cloud, the ESP8266 WiFi module was chosen Node MCU ESP-12 due to its versatility for connecting devices to a wireless network. This module is a WiFi-integrated microcontroller, which offers an excellent balance between cost and efficiency [6], [7].

The NodeMCU ESP-12 E is a development platform that incorporates the ESP8266 SoC, having considerable capabilities due to its compact and efficient design. This module includes a CH340 USB-serial interface, which simplifies programming through languages such as LUA or through the Arduino IDE, using a micro-USB connection for direct communication with the computer. Furthermore, the module is equipped with a built-in antenna, a 3.3V voltage regulator, and offers 11 I/O pins, along with an analog-to-digital converter, expanding the possibilities of use in different IoT applications [[8].

The ESP8266 is recognized for its ability to function as a WiFi serial bridge, allowing microcontrollers to access WiFi networks via the TCP/IP protocol integrated, which is essential for the transmission of collected environmental data. It can operate standalone or in conjunction with an external microcontroller, providing flexibility depending on project needs. This version was adopted due to its powerful processor and ability to directly integrate with sensors and other devices via GPIOs, minimizing the need for additional components and maximizing space in the rider's vest [8].

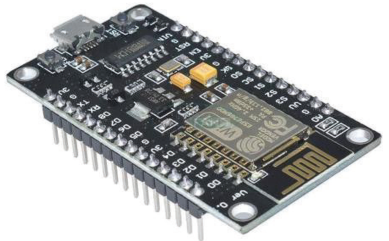

Figure 1: Photograph of the NODEMCU ESP8266 board.

Source: Own elaboration.

In addition to its technical specifications, the ESP8266 NodeMCU is widely supported by an active community of developers, who contribute a wide range of libraries and code examples.

This community provides a valuable resource for problem solving and continuous innovation, ensuring that the module remains a relevant choice for IoT projects, especially those focused on environmental monitoring in dynamic urban scenarios.

FEATURES OF THE MICS6814 SENSOR

The MICS-6814 is an advanced sensor designed for detecting and monitoring various gases present in the environment, essential for projects that require an accurate analysis of air quality. This module is particularly adapted to integrate with microcontroller platforms such as Arduino, Raspberry Pi and PIC, providing a versatile solution for real-time environmental monitoring.

It consists of three distinct gas detection elements, allowing simultaneous measurement of multiple gases with precision. Among those detectable are carbon monoxide (CO), nitrogen dioxide (NO2), ammonia (NH3), methane (CH4), propane (C3H8), ethanol (C2H5OH), hydrogen (H2), and iso-butane (C4H10). This capability makes the MICS-6814 an indispensable tool in industrial and urban applications where monitoring exposure to toxic gases is critical [2].

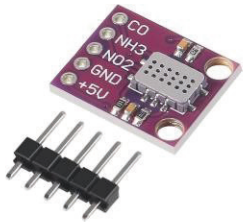

Figure 02: Photograph of the MICS6814 sensor.

Source: Own elaboration.

In technical terms, the sensor operates with a supply voltage of 4.9 to 5.1 VDC and can operate in extreme environmental conditions, with temperatures ranging from -30 to 85°C and relative humidity of 5 to 95% RH. The

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MICS-6814 design includes a diaphragm precision micromechanics and an integrated heating resistor upon which the gas detection layer is deposited, allowing a fast and accurate response to variations in gas levels [9]. The sensor's compact dimensions, measuring approximately 16.9 mm x 14.1 mm x 3.2 mm, along with its light weight (weighing just 1.5 g), make it easy to incorporate into portable systems, such as the motorcycle vest used in this project. These features make the MICS-6814 ideal for mobile applications where space and weight are critical considerations.

BME680 SENSOR SPECIFICATIONS

The BME680 sensor, developed by Bosch Sensortec, represents an integrated and highly efficient solution for environmental monitoring, combining the measurement of gases Volatile Organic Compounds (VOCs), atmospheric pressure, humidity and temperature in a single compact device. This sensor is widely recognized for its accuracy and linearity in measurements.

The BME680 is notable for its ability to detect a wide range of volatile organic compounds while measuring three environmental parameters that are critical with high precision: humidity with an accuracy of ±3%, atmospheric pressure with an accuracy of up to ±1 hPa, and temperature with an accuracy of ±1.0 °C. Due to its accuracy in measuring pressure, the sensor can also be used for altitude estimation with an accuracy of up to ±1 meter, which is especially useful for applications in indoor navigation and physical activity monitoring [10].

The sensor offers flexibility in terms of integration with various microcontrollers, supporting interfaces such as I2C, 3-wire SPI and 4-wire SPI. This versatility facilitates its adoption in various types of IoT projects, from simple Arduino-based systems to more complex applications involving single-board computers such as the Raspberry Pi. Its design includes protections against overvoltage, reverse polarity and signal conflicts on all signal pins, ensuring greater safety and durability in challenging environments. The sensor's compatibility with 3.3V and 5V microcontrollers, along with its breadboard-friendly 6-pin header and two mounting holes, makes the BME680 a practical and efficient choice for developers and researchers.

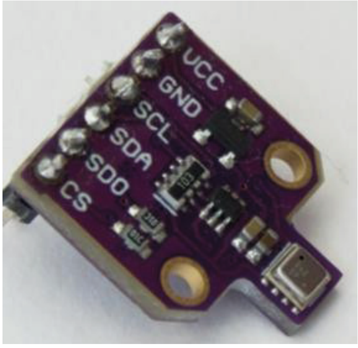

Figure 3: Photograph of the BME680 sensor:

Source: Own elaboration.

Typical applications of this sensor include air quality monitoring, home automation and control, weather forecasting, warning systems for high temperature and low humidity conditions, and other applications that require contextual awareness such as humidity detection and change, environment, vertical speed indication and internal navigation, among others.

USING THE NEO-6M V2 GPS MODULE

The NEO-6M V2 GPS module was chosen for this project due to its capability to provide accurate geolocation data, essential for the application of environmental monitoring on the move. This module is capable of transmitting detailed location information, including latitude, longitude, date, time, travel speed and altitude, facilitating accurate tracking of the device in different urban scenarios.

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It has great energy efficiency, operating with a supply voltage of5.0V and consuming only 22.0 μA, which makes it extremely suitable for long-term use in battery-powered devices, such as the motorcycle vest used in this study.

The ability to operate at low power consumption is crucial for mobile applications where energy saving and battery longevity are priorities [11], [12].

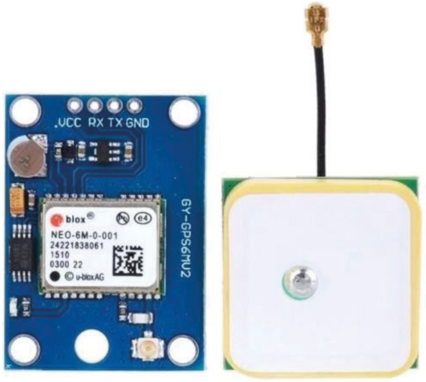

Figure 4: NEO-6M V2 GPS module.

Source: Own elaboration.

Communication with the GPS module is carried out via a TX/RX serial connection, requiring only two I/O pins, which significantly simplifies the integration of the module with a variety of microcontrollers used in the project, such as the ESP8266 and Arduino. This feature minimizes circuit complexity and maximizes overall design efficiency.

The NEO-6M V2 module not only provides accurate location data, but also provides information on the number of visible satellites, which can be useful in determining the accuracy of real-time location data. This data is essential for correlating environmental measurements collected with specific locations, allowing for a more detailed and contextualized analysis of pollutants and environmental conditions in the monitored urban areas if necessary.

MULTIPLEXER

In this project, the CD74HC4067 16-channel digital analog multiplexer was also used to expand the analog input capabilities of the ESP8266 microcontroller, which has only one ADC channel. The use of this component reduced the complexity of the circuit, reduced costs and optimized the use of space and energy, fundamental needs for projects like this work.

THE THINGSPEAK PLATFORM

ThingSpeak is an IoT analytics platform that plays a key role when there is a need for real-time data aggregation, visualization and analysis in the cloud. With its programming interface (API), it facilitates data storage and retrieval without the need for its own servers, integrating with MATLAB to enable complex data visualizations and processing directly in the cloud.

In this project, ThingSpeak centralizes data from multiple sensors attached to a motorcycle vest, including environmental data and geographic coordinates, which facilitates the correlation between environmental conditions and specific locations [13].

This real-time and remote analysis capability allows urban managers, researchers and health professionals to assess the quality of the urban environment and plan necessary interventions, improving quality of life and providing valuable data for environmental and public health studies.

METHODS AND RESULTS

This project used an integrated approach that combined hardware sensing, geolocation and wireless connectivity.

The prototype was built with two main types of sensors: the MICS6814 and the BME680. The MICS6814 is capable of detecting various gases, including NH3 and NO2, while the BME680 was used to measure

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meteorological variables such as temperature and humidity, essential for air quality analysis. For georeferencing, we chose to use the NEO-6M V2 GPS module, which provides precise location data, essential for associating air quality measurements with specific locations.

Initially, the use of Arduino was considered due to its ease of use and wide range of applications of documentation that is available. However, due to the need for a more compact solution with Wi-Fi connection capability, the ESP8266 module was selected. This microcontroller not only meets the size requirements, but also has built-in Wi-Fi functionality, allowing data to be transmitted directly to the internet without the need for additional hardware. The code sent to the ESP8266 contained information about the SSID and password of the wireless network created from the routing of a smartphone device.

The firmware required to operate the device was developed using the Arduino IDE, compatible with the ESP8266. The code was designed to initialize and read data from sensors at regular intervals, process it and send it to the cloud via Wi-Fi. To facilitate integration and data management, the ThingSpeak platform was used; chosen due to its ability to receive data transmitted via API, store this data in a dedicated channel and allow it to be viewed in real time.

The learning and initial tests were carried out in the laboratory on the IFMG campus, in Governador Valadares, MG. Below, a photo of the set under development at the headquarters of contacts. The circuit was powered by a lithium battery bank made up of two in series, both belonging to the 18650 model.

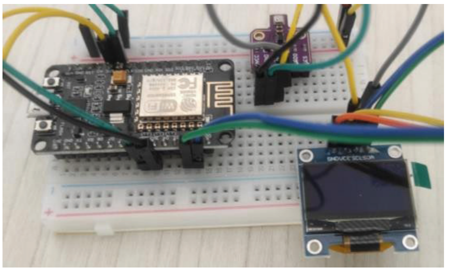

Figure 05: Tests being carried out in stages, using a small OLED screen (bottom right corner) for monitoring.

Source: Own elaboration.

Using the Creality brand 3D object printer existing on campus, and a case downloaded from the Thingverse website [14], the electronics can be packaged as shown in figure 06.

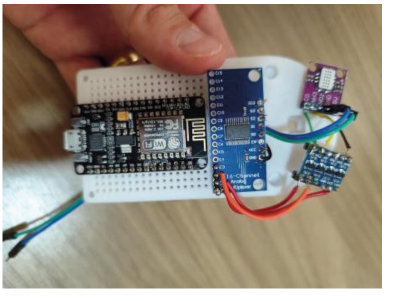

Figure 06: Organization of electronics in the case. The BME680 sensor and GPS module were not yet connected.

Source: Own elaboration.

The system was then attached to a motorcycle vest for testing in different urban conditions. The cyclist traveled several routes in the city, collecting data that was automatically sent to the *ThingSpeak* platform. This allowed remote and real-time monitoring of the environmental conditions encountered along the route, given that the prototype connected to the motorcyclist's smartphone, and sent the data to the *ThingSpeak*. It must be noted, however, that system calibration was not the subject of this project.

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Figure 07: Prototype sewn to the vest.
Source: Own elaboration.

The field test was carried out using the vest and circulating on city roads. One of these, Av. Minas Gerais, was chosen because it has a large circulation of motor vehicles throughout the day, presenting small traffic jams at peak times (when the population goes to or returns from work; school leaving; lunch time, to name a few). some).

Data was exported from ThingSpeak to Microsoft Excel for formatting convenience. The following graph shows the record for relative air humidity.

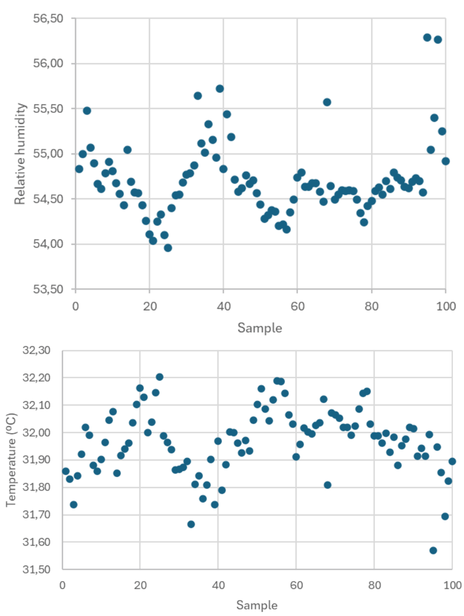

Figure 08: Values measured for relative air humidity and temperature, during cyclist movement on a busy road.
Source: Own elaboration.

No notable changes were observed when comparing the relative humidity and temperature between the roads with the highest concentration of vehicles and those with the lowest. It is noteworthy, however, that an average increase of close to 3% was observed in relative humidity for less busy roads, when close to green areas in the neighborhood.

It can be seen from the graphs above that there are maximum and minimum points. The first, reflect the moment when the cyclist stops due to traffic situations (closed traffic lights, situations where traffic is impossible, etc. At the maximum points, which appeared for both parameters, it was observed that the temperature was higher at the stopping points. A One hypothesis is that the convective heat due to the body of the person wearing the vest may have interfered in these points due to the lack of air circulation around the prototype, in addition to the reduction in the sensor's cooling. Relative air humidity dropped during these stops. Among the hypotheses raised, the following stand out: a) when it stops moving, the sensor could be exposed to a microsample of air with lower humidity, corroborated by b) the fact that the BME680 sensor shows heating. during operation. Therefore, when ventilation is reduced, the sensor could present a higher internal temperature, providing energy to water molecules and expelling them from nearby areas, leading to a drop in the value recorded for relative humidity. But the due cause needs to be studied.

The following graphs show an estimated concentration for three gases. The values on the ordinate axis represent the concentration of pollutants in ppm. These values were estimated in the code using the command gas value = map (gas value, 0, 1023, minimum_detection, maximum_detection). This command approximates the data read from the sensor, which ranges from 0 to 1023, for a detection range for the gas. This range was defined based on the technical specifications provided by the sensor datasheet, allowing a direct and simplified correlation between the sensor reading and the pollutant concentration in ppm.

Figure 09 shows the concentration of carbon monoxide in a 30-point section of the total record. The cut was made to show the oscillations obtained in relation to the graphic scale. This will be done next for NH3 and NO2.

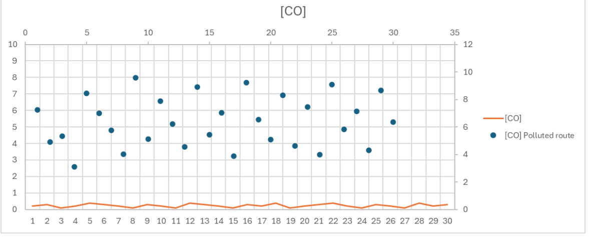

Figure 09: Carbon monoxide concentration on a lightly traveled road and another on a road with a large number of vehicles.

From the previous figure, a substantial change was observed in the concentration of carbon monoxide on roads with large vehicle traffic. Again, the absolute values were not considered as no type of calibration of the sensors was carried out.

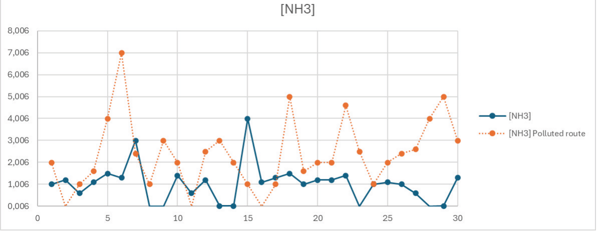

Figure 10: Ammonia concentration on a lightly traveled road and another on a road with large vehicle circulation.

Source: Own elaboration.

It can be seen from the previous figure that variations occurred in the values measured in busy roads in relation to those with little movement of motor vehicles. These higher values are expected mainly due to vehicular emissions, with incomplete combustion of fossil fuels being the main source of CO, while NH3 is released from catalytic decomposition in vehicular catalytic converters.

[15], [16]. It was observed that, although the two situations were different from the perspective of the values presented, they were nevertheless quite small even in the presence of a large circulation of vehicles.

Figure 11 shows the concentration of nitrogen dioxide obtained in a pathway that was very busy and in other areas not very busy.

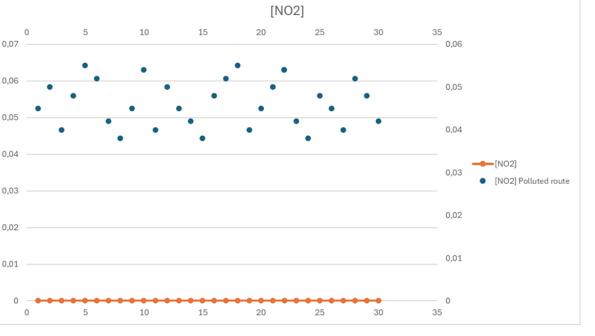

Figure 11: Nitrogen dioxide concentration on a lightly traveled road and another on a road with a lot of vehicle traffic.

Source: Own elaboration.

Measurements on streets with little traffic showed almost zero concentrations of NO_2, as adjusted by data. On busier roads, a significant increase in NO_2 concentrations was noted, indicating a large discrepancy in relation to less busy areas. This increase reflects higher emissions resulting from heavy traffic, highlighting the clear impact of vehicle density on air pollution in urban areas. [17], [18].

CONCLUSION

The development of this prototype demonstrated significant potential for cost-effective and effective monitoring of air quality in urban environments. The ability to simultaneously measure multiple pollutants, as well as climate and geographic variables, allows for a comprehensive understanding of environmental conditions in real time. However, some limitations have been identified that may affect the accuracy of measurements, such as the proximity of the sensors to the driver's body, which can lead to distorted readings due to body heat and airflow obstruction. Additionally, the loss of Wi-Fi connection in areas with high-rise buildings has presented challenges for continuous data transmission. Despite these challenges, fine adjustments to the programming code and better sensor positioning can minimize these interferences, increasing the system's accuracy and reliability.

This project highlights the importance of technological innovation in air quality management, proposing solutions that can be quickly adapted and implemented to improve public health.

However, to expand the effectiveness of this project, it is recommended that additional studies be carried out focused on sensor calibration. Robust calibration will allow the device to provide accurate measurements, which is essential for its application in scientific studies and public policy formulation. Furthermore, improving circuit stability and reducing prototype size are crucial steps towards its large-scale implementation, especially in portable devices for personal use in urban environments. The use of smaller shields can also be investigated to further optimize the design and functionality of the device. These improvements will not only increase the usability of the prototype, but will also contribute to its more effective integration into more robust environmental monitoring platforms. These suggestions represent valuable directions for future research and development, aiming to maximize the positive impact of this technology on society.

THANKS

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REFERENCES

[1] D. Brugge and K. J. Lane, " Fine particle air pollution is a public health emergency hiding in plain sight ," https://theconversation.com/fine-particle-air-pollution-is-a- public-health-emergency-hiding-in-plain-sight-106030.

[2] H. JARNSTROM, K. SAARELA, P. KALLIOKOSKI, and A. PASANEN, "Reference values for indoor air pollutant concentrations in new, residential buildings in Finland," *Atmos Environ*, vol. 40, no. 37, pp. 7178–7191, Dec. 2006, doi: 10.1016/j.atmosenv.2006.06.021.

[3] K. R. Bull and M. A. Sutton, "Critical loads and the relevance of ammonia to an effects-based nitrogen protocol," *Atmos Environ*, vol. 32, no. 3, pp. 565–572, Feb. 1998, doi: 10.1016/S1352-2310(97)00167-2.

[4] H. Suhendar, W. Indrasari, S. Ghina Muqita, and I. G. A. Isnaini, "Development of a Real-Time Gas Concentration Measurement System Using Internet of Things-Based Monitoring," *Spektra: Jurnal Fisika dan Aplikasinya*, vol. 9, no. 1, pp. 27–38, Apr. 2024, doi: 10.21009/SPEKTRA.091.03.

[5] "Exercise and air quality: 10 top tips," *Breathe*, vol. 11, no. 3, pp. 239–242, Sep. 2015, doi: 10.1183/20734735.ELF113.

[6] T. J. Saravanan, M. Mishra, A. D. Aherwar, and P. B. Lourenço, “Internet of things (IoT)- based structural health monitoring of laboratory-scale civil engineering structures,” *Innovative Infrastructure Solutions*, vol. 9, no. 4, p. 110, Apr. 2024, doi: 10.1007/s41062-024-01413-9.

[7] A. Kadu *et al.*, “Design and Development of Low Cost IoT Based Energy Optimising Meter for Home Application,” in *2024 International Conference on Emerging Smart Computing and Informatics (ESCI)*, IEEE, Mar. 2024, pp. 1–6. doi: 10.1109/ESCI59607.2024.10497360.

[8] V. Sajjan and P. Sharma, “Research on an iot based air pollution monitoring system,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 9 Special issue 2, 2019, doi: 10.35940/ijitee.I1116.0789S219.

[9] “The MiCS-6814 is a compact MOS sensor with three fully independent sensing elements on one package.,” *https://www.sgxsensortech.com/content/uploads/2015/02/1143_Datasheet-MiCS- c814-rev-8.pdf*, vol. 01. Amphenol SGX Sensortech, Corcelles-Cormondrèche, pp. 1–5.

[10] Bosch Sensortec, “BME680 Low power gas, pressure, temperature C humidity sensor,” Reutlingen, Jul. 2017.

[11] Eletrogate, “GPS Neo-6M com Arduino – Aprenda a Usar,” Eletrogate.

[12] Bernardo Guimarães Harduim Sant´Anna and Luiz Vinicius da Silva Cavalcanti, “Automação residencial com NodeMCU,” Universidade Federal Fluminense, Niterói, 2018.

[13] A. Hilary Kelechi *et al.*, “Design of a Low-Cost Air Quality Monitoring System Using Arduino and ThingSpeak,” *Computers, Materials & Continua*, vol. 70, no. 1, pp. 151– 169, 2022, doi: 10.32604/cmc.2022.019431.

[14] L. MakerBot Industries, “Ultimaker Thingiverse,” https://www.thingiverse.com/.

[15] I. Aravindaguru, C. Mathan, B. Sharmila, M. Nagarajapandian, and P. Veeramani, “Environmental Drones for Autonomous Air Pollution Investigation, Detection, and Remediation,” 2023, pp. 107–118. doi: 10.1007/978-981-99-5056-0_5.

[16] W. Pu *et al.*, “Mobile measurement background quantification methods for determining local traffic emissions and background source contributions to ammonia,” *Atmos Environ*, vol. 329, p. 120523, Jul. 2024, doi: 10.1016/j.atmosenv.2024.120523.

[17] I. Mavroidis and M. Ilia, “Trends of NOx, NO2 and O3 concentrations at three different types of air quality monitoring stations in Athens, Greece,” *Atmos Environ*, vol. 63, pp. 135–147, Dec. 2012, doi: 10.1016/j.atmosenv.2012.09.030.

[18] R. Purbakawaca, A. S. Yuwono, H. Alatas, and I. D. M. Subrata, “Low-cost nitrogen dioxide monitoring station based on metal oxide sensor and cellular network,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 1, p. 105, Apr. 2022, doi: 10.11591/ijeecs.v26.i1.pp105-115.