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Abstract

Particles in the air with volume ≤ 2.5 μm³ have been classified as carcinogenic by the World Health Organization (WHO). Therefore, rapid monitoring systems are crucial to obtain information about particulate matter (PM) concentrations and make this information publicly available. Supported by WHO criteria, this text focuses on the development of a field-portable cost-effective platform for rapid monitoring, data acquisition of particulate matter (PM_{10} and $PM_{2.5}$) and measurements of environmental variables (relative air humidity and temperature) at the micrometeorological level, in addition to providing access via the Internet of Thing (IoT). The platform was tested, as well as validating its results when compared to those made available at the National Meteorology Institute-INMET (Instituto Nacional de Meteorologia). Based on this technology, tests and measurements have been performed in the local presence of the population and vehicle traffic, in order to identify the concentrations of PM in public places. Between the results obtained, the device recorded higher temperature and low humidity, at 12 noon, and the average hourly reached 175.3 μg/m³ (PM_{10}) and 164.2 μg/m³ ($PM_{2.5}$), which means a warning sign. This computational platform would be useful for cost-effective and rapid quantification of PM density, even in the field and resource-poor settings.

Keywords: Air-quality monitoring; Embedded system; Particulate matter.

1. Introduction

The air is an essential resource and indispensable for all living beings. With technological development, there was an increase in quantitative population in line with the increased demand for natural resources, attempting to satisfy human consumption [1]. This has generated tremendous pressure on the ecosystem, leading to unprecedented impacts worldwide. Among the varieties of other problems, air pollution has drawn attention due to the harmful effects on the environment and health-related to Particulate Matter (PM) [2]. PM can be defined as a mechanism for mixing solid and liquid particles of organic and inorganic substances in the atmosphere. PM is often referred to as aerosol, aero colloid or particles which include dust, ash, smoke, fog, pollen and marine sprays. In this respect, the most worrying pollutants for public health are PM, i.e., nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO) [3].

Particle air pollution is formed by solid and liquid particles dispersed in the air [4]. These PMs may have adverse health effects over time, depending on particle size and concentration in the atmosphere. The smaller the particle, the higher the damage to human health, being associated with numerous diseases due to its small size [5]. These PM may originate from natural as well as anthropogenic sources and are classified according to their aerodynamic diameter. Particulate material with diameter 2.5µm < PM_{10} ≤ 10 µm is known as gross inhalable, usually barred in the upper respiratory tract. The other range of PM is breathable or thin inhalable, with aerodynamic diameter $PM_{2.5}$ (0.1µm > PM ≤ 2.5µm). Air quality data are essential, considering human actions on the environment. This information contributes to the creation and development of policies for the control, use of natural resources and the improvement of current technologies to the reduction of atmospheric emissions [6].

Nowadays, there is various types of equipment involving the monitoring of environmental variables, but most of them are imported and have a high financial cost, which discourages their use in various applications. Thus, the development of low-cost technologies and open technologies are significant for conducting microscale studies and enabling the monitoring of environmental variables in locations not monitored by financially accessible sensors [7]. The use of wireless and integrated circuit sensors and microprocessors has stimulated the creation of smart sensor networks that operate remotely and autonomously, facilitating the collection of environmental data [8]. Therefore, this work aims to present the development of a pollutant monitoring platform to contribute to the expansion of solutions to air quality issues.

2. Background of the Study

The quantification of pollutants gives the level of air pollution in the atmosphere. Consequently, the choice of air quality parameters was established in the practical order, limited according to their importance and universality of pollutants as broader indicators of air quality (SO_2, NO_2, CO, O_3, PM). Some of these gases and particles were chosen as indicators because they are often linked with adverse effects on the environment and health [9].

Carbon monoxide (CO) is considered a pollutant that is present everywhere in the urban environment, is characterized by an odorless and colorless gas, formed mainly in the burning process, and one of its sources is in emissions from the combustion of engines. The importance of CO monitoring is essential because of its potential for harmfulness and abundance in the air [3]. The health-related effects of CO range from the subtlest effects such as behavioral swings to death. These damages are caused due to the high affinity of CO gas to hemoglobin, consequently causing a deficiency in oxygen transport to organs [10].

Nitrogen is one of the most abundant gases in the atmosphere. Associated with this, other elements are belonging to the nitrogen cycle, such as nitrogen oxides and human actions in industry, mainly in agriculture, which favors the increase of nitrogen compounds in the atmosphere, causing changes in the natural oxygen cycle. In urban centers, nitrogen dioxide (NO_2) is considered one of the primary pollutants; it is directly related to the production of ozone gas (O_3) and the formation of acid rain and directly influences the global climate [3]. The process of NO_2 emissions comes from both anthropic and natural sources. Natural sources emit the most NO_2 to the atmosphere, but direct emissions of this gas are relatively low. Nitric oxide, due to its rapid oxidation, is one of the main sources of NO_2 gas. Nitric oxide has as main natural sources the edaphic microorganism activities. In urban centers, the main source is the burning of all types of fuels. The effects of nitrogen dioxide on human health may occur in respiratory and allergic problems and lung problems [11].

There are several natural sources of SO_2 emissions, such as volcanoes, marine aerosols, and organic decomposition and by anthropogenic sources such as the burning of fossil fuels from petroleum and coal, accounting for about 95% of air emissions. When in the atmosphere, it forms various reactions with other compounds, forming small sulfate particles contributing to the formation of secondary particulate material. Sulfur dioxide has high water solubility, the reaction of this gas in the presence of water vapor forms sulfuric acid (H_2SO_3) and in the presence of oxygen is rapidly oxidized to sulfuric acid, characterizing it as one of the acid rain precursors, as well as NO_2 [12]. Exposure to sulfur with a concentration of 0.19 particles per million (PPM) and an average of 24 hours of exposure with high particle concentrations is capable of causing irreversible effects on living beings. Sulfuric acid and sulfides affect sensory and respiratory functions, in some cases aggravating the crises of people with asthma problems. In vegetation, the presence of high concentrations of SO_2 directly affects the photosynthesis capacity [13].

Ozone gas is formed secondarily in the lower atmosphere from another NO_2 pollutant by photochemical reaction with oxygen and solar radiation. When formed in the troposphere (lower layer of the atmosphere), it is highly toxic. The effects of ozone in high concentrations cause eye irritation, headaches, nausea, among other effects related to the form and time of exposure to gas. Besides, ozone is harmful to plant metabolism [14]. The prevention of harmful effects on health goes by indicating the primary atmospheric contaminants and establishing minimum safe levels, promoting the protection of the human quality of life. From these levels, the air quality standards are established numerically [15].

The first interventions on air pollutant issues took place in the 1950s, in the United States, through the Air Pollution Control Act 1955, becoming a milestone in the world's environmental legislation. In 1963 a federal law entitled Clean Air Act created for air protection commissioned the United States Environmental Protection Agency (USEPA) to determine national air quality standards NAAQS - National Ambient Air Quality Standards. In 1970 the USEPA stood out for being a pioneer in monitoring air sampling, which was the basis for the Brazilian legislation. So, split its standards in primary and secondary. The first standards were created to promote the protection of public health, drawing attention to the most vulnerable population such as children, elderly, and sick respiratory. Secondary standards aimed at protection against damage to animals, crops and materials [16]. Table 1 presents these values.

Table 1 - Air Quality Standards adopted by the US Environmental Protection Agency.

POLLUTANT	DIAMETER	PRIMARY/SECONDARY	AVERAGE TIME	LEVEL µG/M³
PARTICULATE MATTER (PM)	$PM_{2,5}$	Primary	1 year	12
		Secondary	1 year	15
		Primary and secondary	24 hours	35
	PM_{10}	Primary and secondary	24 hours	150

Source: Adapted from USEPA.

Although WHO standards have global application, the setting of individual country standards should be under their specificities, with each country having the autonomy to define its values according to its economic and technological circumstances. Table 2 shows the particulate matter concentration patterns [17].

Table 2 - WHO recommended global concentrations.

POLLUTANT	DIAMETER	AVERAGE TIME	LEVEL (μG/M³)
PARTICULATE MATTER (PM)	$PM_{2,5}$	24 hours	25
		1 year	10
	PM_{10}	24 hours	50
		1 year	20

Source: WHO [17].

WHO [3] also includes provisional targets for pollutant concentration in addition to the general guideline. These provisional values correspond to intermediate concentrations, aiming to promote continuous compliance with the final recommendations. If these intermediate objectives are met, the risks related to PM can be considerably reduced [18]. Table 3 shows the values of interim targets with their benefits to be achieved.

Table 3. Intermediate Standard IS and Final Standard FS, annual average values.

PHASE	PM_{10} (μG/M³)	$PM_{2.5}$ (μG/M³)	INDICATED LEVELS
IS-1	70	35	15% higher risk of mortality compared to FS
IS-2	50	25	6% risk reduction in premature deaths compared to SI-1 (2% to 11%)
IS-3	30	15	Risk reduction by 6% mortality compared to SI-2 (2% to 11%)
FS	20	10	Low mortality

Source: WHO [17].

.Some PM are dark and large enough which can be seen with the naked eye, others are so small that they can only be detected by electron microscopy [19]. As an example of the intense dispersal of organic PM released into the atmosphere are the Amazon forest fires, which occurred due to the poor environmental management of the Brazilian government. Soot plumes from forest burning can be carried thousands of miles away from the outbreaks. As a result, last August 19, 2019, the country's largest city, Sao Paulo, received a plume of smoke and soot in gigantic proportions (Figure 1). This phenomenon what was called as "the day that became night" when São Paulo's skies, 3 pm afternoon suddenly turned black was close to 500 μg/m³ ($PM_{2.5}$) [20].

Figure 1. São Paulo on the day that became night.
Source: O GLOBO [26].

As an explanation, the interactions of aerosol particles with solar radiation directly affected the reflection and absorption properties of surface light. In addition to acting as a condensation nucleus, therefore delaying precipitation and providing the formation of soot-contaminated giant clouds [21]. This soot is known as Black Carbon, which has a high capacity to absorb radiation. These PMS are due to biomass combustion, which mainly emits $PM_{2.5}$ mode particles [22].

The thick plume of PM was detected by the CPTEC/INPE satellite responsible for monitoring the transport of pollutants emitted by burning in South America using the CATT-BRAMS model (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System) [23]. Based on these monitoring results, it was possible to detect the river of smoke from thousands of kilometers, favored by the weather conditions (Figure 2).

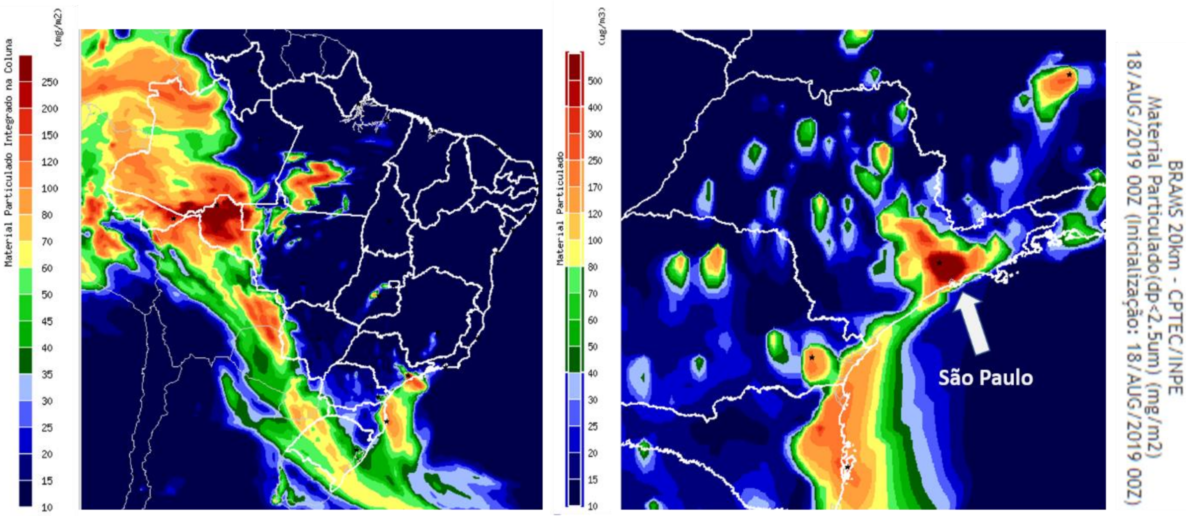

Figure 2. $PM_{2.5}$ particle plume detected by CETEC.
Source: CPTEC/INPE [23].

3. The Embedded Computing System

This text describes the specifications of the sensors used, including the auxiliary components of data processing and storage, as well as the procedures followed to perform the testbed. For this, five steps must be considered, namely: Assembly of the electronic circuit; Arrangement of sensors in the shelter; Programming and implementation of algorithms; Measurement and data collection (testbed). Likewise, this monitoring platform is intended for the acquisition and storage of PM, temperature and relative air humidity data at the micro-meteorological level, *in situ*. Next, tests were made at the bus stop, located in front of the Federal Rural University of Amazonia - UFRA.

The components used for mounting the platform were: ESP8266 NodeMCU Wifi Module, Shield SD card, Real-Time Clock RTC DS3231, Sensor SDS011, Sensor BME280. NodeMCU (Node Microcontroller Unit) is an IoT-based development coupled with an ESP8266 WiFi chip. This Wifi module, through its configuration, can provide embedded system IoT communication signals via the digital cloud. Therefore, an enabled user on the Internet network can remotely access information about quality conditions in the environment.

The embedded system has both hardware and development of free software. The ESP8866 chip attached to the embedded ships has all devices of a computer: CPU, RAM, Wifi, and even the Linux operating system. Besides these advantages, they are related to low cost and low power consumption. The NodeMcu project can be an add-on for the Arduino IDE that allows programming the ESP8266 using the Arduino IDE and its programming language, and therefore, to connect and control compatible sensors. Due to the small size, this work used a base that expands the connection capacity of the module pins, in order to facilitate the connection of the components. So, all components have been powered on and operated by NodeMcu.

The SD card module communicates with NodeMcu via the serial peripheral interface (SPI) communication protocol, which is a data protocol used by the microcontroller. NodeMcu connections with the Shield SD card were inserted into an 8 gigabyte FAT32 formatted memory card for storing the monitored data. This allows continuously to record the incoming data from the sensors, and when they are downloaded to a computer for processing and graphing.

The DS3231 Real Time Clock (RTC) or low-cost real-time clock is an electronic component capable of forthcoming information such as date and time. A lithium battery is attached to the component, ensuring data reliability even in the absence of external power supply. To record the time of data collection, this module was used to inform the date, time, and minutes of the data collection, creating an internal datalogger to storage data. Diffusion conditions can influence high concentrations of PM and this, in turn, is altered by climate variables that include humidity, temperature, wind and precipitation [24]. For this purpose, the BME-280 sensor was used to measure ambient temperature and relative humidity, which is ideal for applications in which the project requires reduced size dimensions and low power consumption. Furthermore, it can measure humidity in the range of 0 to 100% with an accuracy of 0.008%, atmospheric pressure from 0 to 1100hPa barometric range with an accuracy of ±1Pa and temperature in the range -40 to 85ºC with the fast response time.

The SDS011 sensor uses the laser diffraction principle, and this technique is widely used for particle size evaluation. This sensor operates by light scattering which will be induced when particles pass through its detection area, generating fluctuations in light intensity. These fluctuations are transformed into electrical signals that will later be amplified and processed. This method facilitates data collection due to high sample throughput and instant response. The SDS011 sensor officially registers PM_{10} and $PM_{2.5}$ enabling to detect concentrations of 0 µg/m^3 to 999 µg/m^3. The manufacturer specifies that its relative maximum error is ±15%. Else then, its operating scheme begins with air entering through a circular opening that is channeled to a detection area where a beam of light strikes particles. Given this, light scattered is detected by a photoconductor. Therefore, the circuit was assembled and ready for running tests (Figure 3).

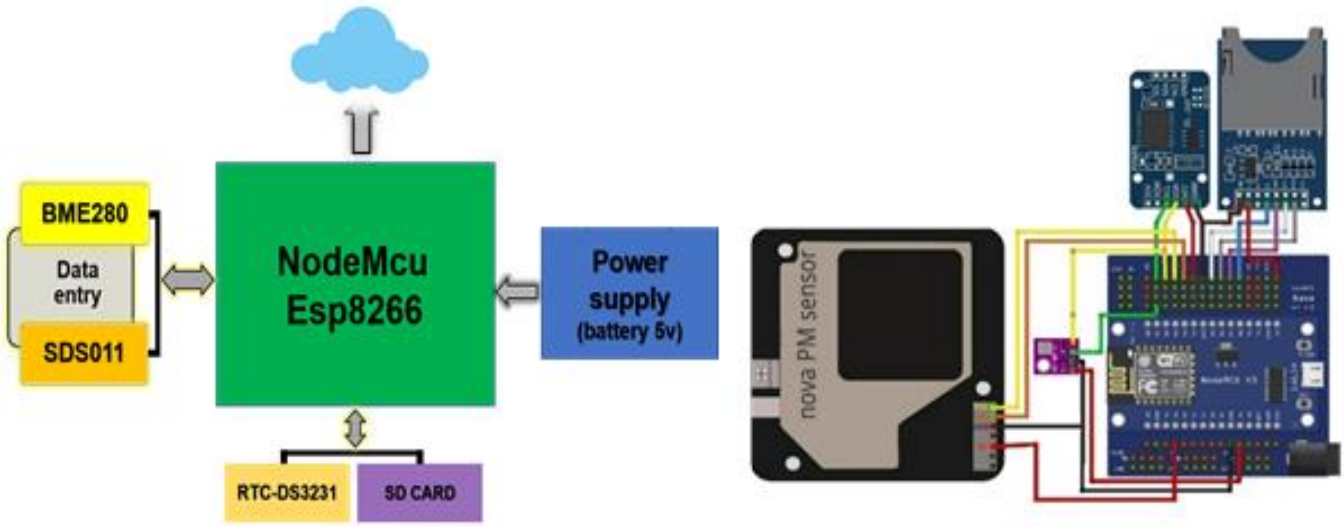

Figure 3. Block diagram.

From the prototyping of the circuit, a case was adapted to measure the arrangement of sensors and components. The arrangement of the sensors was made according to the manufacturer's recommendations. However, other components were organized according to the ease of connection of the components (Figure 4).

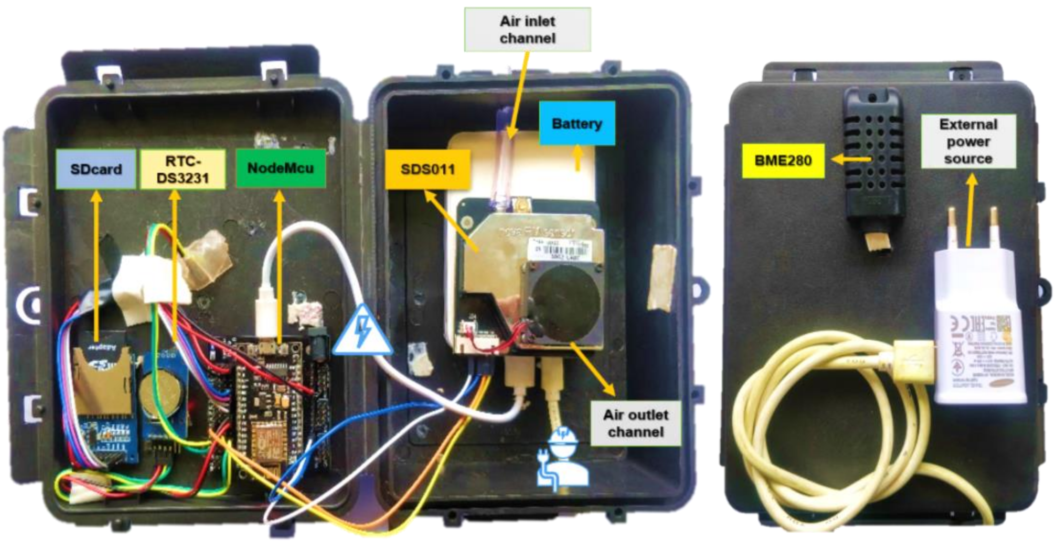

Figure 4. Platform prototype.

Finally, the chosen place to the experiment is in UFRA, located in Belém (state of Pará, northern Brazil), latitude 1°27'30.26"S and longitude 48°26'12.08"W, at an altitude of 15 m above sea level. It is noteworthy that Belém has an equatorial climate, the average annual rainfall of 2537 mm, and the average temperature is 26.4 °C [25]. The annual average high temperatures favor high convection and unstable air that provide the formation of convective clouds. Strong convection, instability and high humidity contribute to convective cloud formation, resulting in a high incidence of precipitation [25]. Subjected to these weather conditions, the platform was programmed to get and store data every 10 seconds, with a total of 6 collections per minute. As an experiment, the platform was coupled to the data collection point, about 1.20 m from the floor and remained collecting data for 11 hours, from 7 am to 6 pm due to crowding of passengers (Figure 5).

Figure 5. Image of the experiment and its respective location.

4. Results and Discussion

The testbed lasted approximately 11 hours (6:58 am to 6:02 pm), resulting in 3980 data collected. In the first 2 hours of monitoring, the concentration values for PM_{10} and $PM_{2.5}$ were 109.5 µg/m^3 and 37.2 µg/m^3, respectively, both measured at 7:10 am (Figure 6). The environment at 6:58 am when the measurements began presented gross concentrations of 39.8 µg/m^3 PM_{10} and 19.8 µg/m^3 $PM_{2.5}$. These variations indicate the beginning of a high flow due to the activities of passers-by and the constant traffic of public collectives, acting as a source of PM.

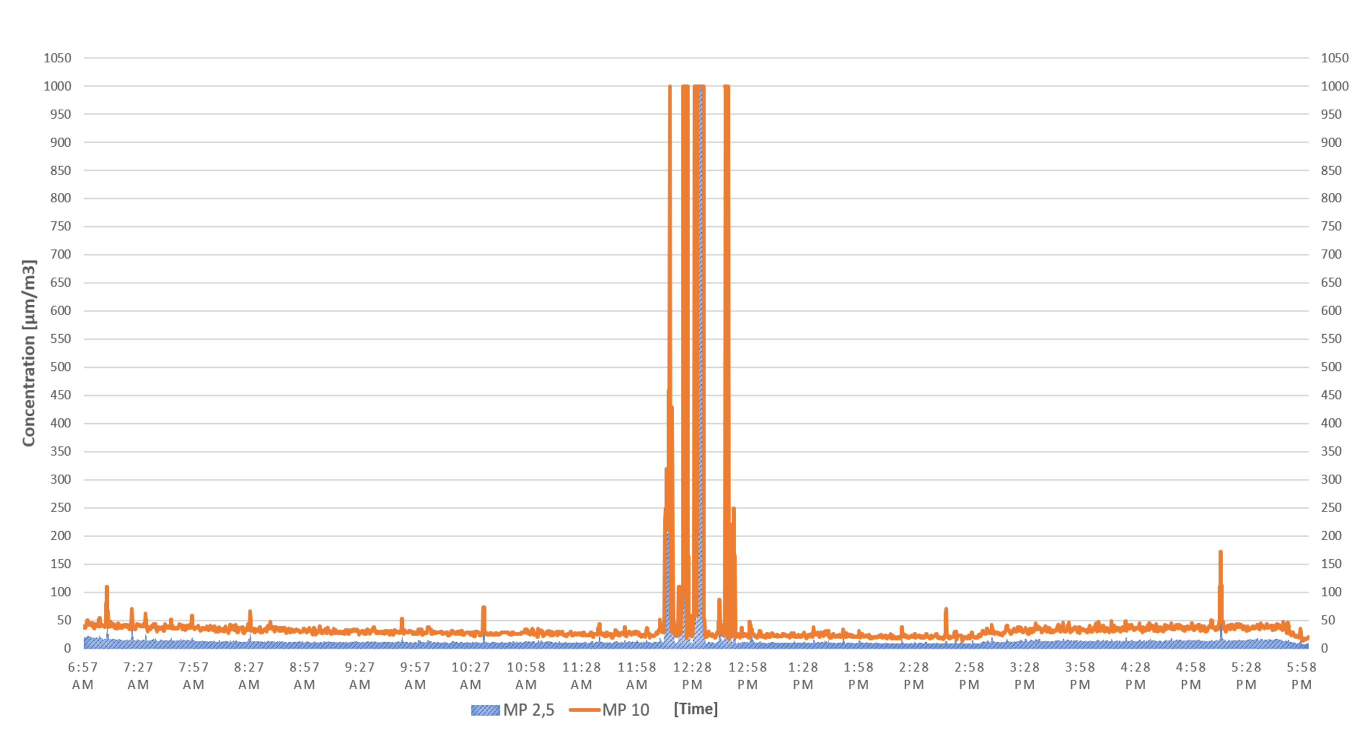

Figure 6. Particle volume (µm^3).

Average hourly concentrations decreased over time in the morning ranging from 40.7 µg/m^3 at 7 am to 26.5 µg/m^3 at 11 AM PM_{10} and from 16.37 µg/m^3 at 7 am to 11.3 µg/m^3 at 11 am $PM_{2.5}$. Both results showed the same trend and this trend results from the attenuation of dust suspension and vehicle combustion. At 12 noon, PM concentrations increased abruptly reaching the maximum detection capacity of the SDS011 sensor (999.9 µg/m^3 PM_{10} and $PM_{2.5}$). Nevertheless, these values are generally considered to be saturated values as they reach the upper limit of sensor detection. The average hourly for this event reached 175.3 µg/m^3 and 164.2 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. Therefore, the hypothesis of suddenly high values goes beyond vehicular traffic as a source of emission, but also the substantial permanence of people at the bus stop, which commonly prevents the circulation of wind, increasing the residence time of high concentrations of PM at noon This event was detected 46 times, distributed within 1 hour. These values coincide with the time of the highest inflow and outflow from UFRA. In the forthcoming process over the next 2 hours, so there was a decrease to 87% of average hourly, ranging from PM_{10} (23.3 µg/m^3 to 21.68 µg/m^3) to $PM_{2.5}$ (10.58 µg/m^3 to 9.69 µg/m^3).

Throughout the entire experiment period, at 3 pm the values increased as the traffic increased, registering concentrations of 172.1µg/m^3 and 65.4 µg/m^3 at 5:14 pm to PM_{10} and $PM_{2.5}$, respectively. The maximum and minimum temperature values monitored by the sensors were higher since the beginning of the measurements, with a minimum temperature of 29.08 °C and a maximum of 31.5 °C. While the INMET station had a minimum value of 24.6 °C and a maximum of 24.8 °C for the same time, only at 5 pm, the minimum sensor temperature was below that of INMET, as shown in Figure 7.

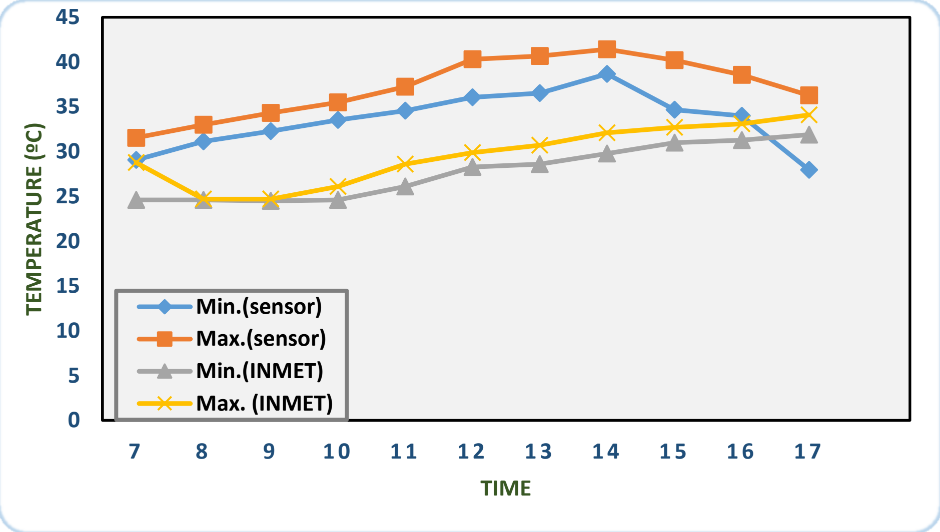

Figure 7. Comparison of temperature values between the Sensor and INMET station.

The difference between platform values and INMET station during monitoring is due to the sensitivity of the BME280 sensor to the effects of microclimate, because own the short distance from the paved surface and the sensor, contributing to the temperature rise at the bus stop. Under these circumstances, it should be observed that INMET stations do not have any obstacles or people within a 30 m radius, to avoid noise in the data. For instance, a different condition from the sensor which has been maintained at a bus stop. Therefore, the maximum and minimum relative air humidity data recorded in the embedded system were lower than the INMET stations, since the temperature detected at the bus stop was higher, influencing the disruption of water molecules present in the air, resulting in at an attenuated humidity (Figure 8).

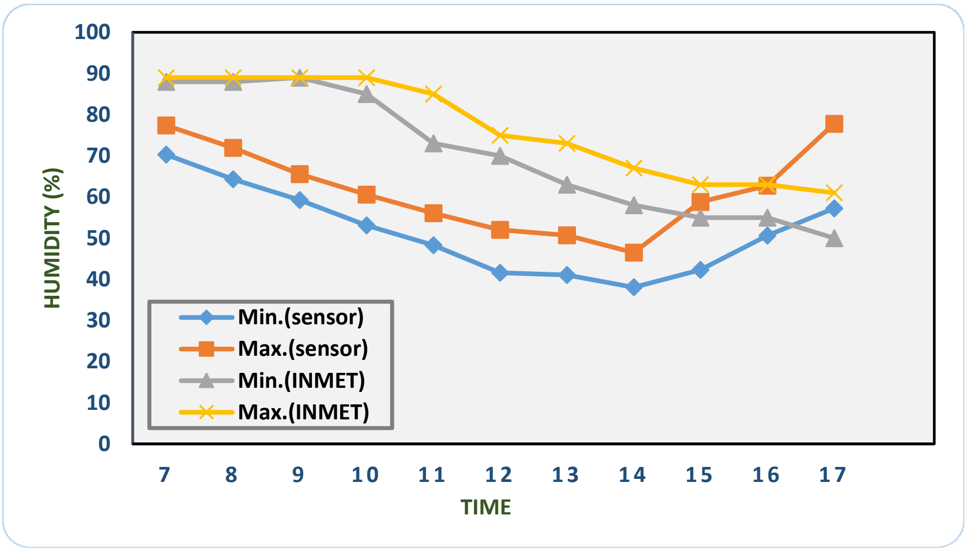

Figure 8. Comparison of relative air humidity values between the Sensor and the INMET station.

In the measurements made by the monitoring platform, the humidity value at 7 AM was 70.29% minimum and 77% maximum. The INMET station had a minimum humidity of 88% and a maximum of 89%. So only at 5 PM, the platform humidity was higher than the INMET station. The data obtained by the sensors are represented in microscale because it is of atmospheric conditions and events less than 1 kilometer and less than 1 hour. Table 4 shows measures of central tendency and standard deviation, as well as maximum and minimum values resulting from all testbed measurements at the UFRA bus stop for PM, temperature and humidity.

Table 4. Key monitoring values.

Parameter	Average	Median	Minimum	Maximum
$PM_{2.5}$	26,24	12	7	999,9
PM_{10}	44,11	30,2	13,1	999,9
T (°C)	35,31	35,21	27,97	41,43
H (%)	56,77	56,25	38,04	81,85

Source: The Authors.

The average data represents the distribution center. Therefore, the average and the median, they measured the central tendency of the collected results and were directly affected by PM peaks, which represent atypical values called outliers. These results indicate the importance of using alternative solutions for monitoring air quality, temperature and humidity in urban environments. The variation along the PM, in the observed place, evidenced a relationship with the arrival and departure flow of people at 7 am, 12 am and 5 pm; consequently, there was also a higher flow of vehicles in the locality, which contributes significantly as a source of emission. Particles due to combustion and dust lifting.

5. Conclusions

This article has been presented a portable and cost-effective PM detecting, measurements of environmental variables (relative air humidity and temperature) at the micrometeorological level. In addition to access signal via IoT, the module containing an embedded computational system consists of a field-portable device weighing 600 g, which allows easy installation in places containing crowding of passengers and vehicle traffic in public environments. The proposed device can be used in urban or rural places that present natural or anthropogenic sources of PM, which may cause a health risk through inhalation. Furthermore, the test performance of the device was validated by measuring climatic variables, when compared results with those available, and a close correlation was shown. Considering the aspects of utilization to air sampling by the computer system, the results were in agreement with the verified situations. We hope that the contribution of this platform might be considered useful in order to a wide range of applications in air quality management and improvement of life in the most impoverished areas.

6. References

[1] C.L.M. BOUROTTE, O.R. SANCHEZ-CCOYLLO, M.C. FORTI, and A.J. MELFI, “Chemical composition of atmospheric particulate matter soluble fraction and meteorological variables in São Paulo state, Brazil,” Brazilian Journal of Meteorology, 2011, pp. 419–432.

[2] S. VEDAL, B. HAN, J. XU, A. SZPIRO, and Z. BAI, “Design of an Air Pollution Monitoring Campaign in Beijing for Application to Cohort Health Studies,” International Journal of Environmental Research and Public Health, 2017, pp.1580-1589.

[3] WORLD HEALTH ORGANIZATION, Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide, WHO Press, Genova, 2005, pp. 1-20.

[4] D. YOUNAN, A.J. PETKUS, K.F. WIDAMAN, X.W., R. CASANOVA, M.A ESPELAND, M. GATZ, V.W. HENDERSON, J.E. MANSON, S.R. RAPP, B.C. SACHS, M.L. SERRE, S.A. GAUSSOIN, R. BARNARD, S. SALDANA, W. VIZUETE, D P. BEAVERS, J.A. SALINAS, H.C. CHUI, S.M. RESNICK, S.A. SHUMAKER, and J.C. CHEN, “Particulate matter and episodic memory decline mediated by early neuroanatomic biomarkers of Alzheimer’s disease,” Journal of Neurology, 2019, pp 1-14.

[5] J.H. PARK, OH S.J., and LEE J.H., “Effects of particulate matter on healthy human skin: a panel study using a smartphone application measuring daily skin condition,” Journal of The European Academy of Dermatology and Venereology, 2019, pp. 1363-1368.

[6] Y. WU, A. SHILEDAR, Y. LI, Y. LI, J. WONG, S. FENG, X. CHEN, C. CHEN, K. JIN, S. JANAMIAN, Z. YANG, Z.S. BALLARD, Z. GÖRÖCS, A. FEIZI, and A. OZCAN, “Air quality monitoring using mobile microscopy and machine learning,” Light: Science & Applications, 2017, e17046.

[7] O.A. CHASE, A.N. CARVALHO, E.S.S. ANDRADE, C.T. COSTA JUNIOR, and J.F. ALMEIDA, “Environmental Measurement Technology: An approach to the Amazonian environment,” IEEE Latin America Transactions, 2018, pp. 1036-1041.

[8] R.A. KHAN, A.K. PATHAN, “The state-of-the-art wireless body area sensor networks: A survey,” International Journal of Distributed Sensor Networks, 2018, pp. 1-8.

[9] CETESB - STATE ENVIRONMENTAL COMPANY OF SAO PAULO, Air quality in the state of Sao Paulo, Port press, 2018, pp. 1-210.

[10] I. BLUMENTHAL, “Carbon monoxide poisoning,” Journal of the Royal Society of Medicine, 2001, pp. 270-272.

[11] M.A. ARBEXI, U.P. SANTOS, L.C. MARTINS, P.H.N. SALDIVA, L.A.A. PEREIRA, and A.L.F. BRAGA, “Air pollution and the respiratory system,” The Brazilian Journal of Pulmonology, 2012, pp. 643-655.

[12] J. BAHINO, V. YOBOUÉ, C. GALY-LACAUX, M, ADON, A. AKPO, S. KEITA, C. LIOUSSE, E. GARDRAT, C. CHIRON, M. OSSOHOU, S. GNAMIEN, and J. DJOSSOU, “A pilot study of gaseous pollutants’ measurement (NO2, SO2, NH3, HNO3 and O3) in Abidjan, Côte d’Ivoire: contribution to an overview of gaseous pollution in African cities,” Atmospheric Chemistry and Physics, pp. 5173-5198.

[13] S. MUNEER, T.H. KIM, B.C. CHOI, B S. LEE, and J. H. LEE,” Effect of CO, NOx and SO2 on ROS production, photosynthesis and ascorbate–glutathione pathway to induce *Fragaria annasa* as a hyperaccumulator,” Redox Biology, 2014, pp. 91-98.

[14] G. JI-XI, Z. LIN-BO, S. JIAN-MIN, and C. HONG-FA, “Effects of ozone on plant metabolism,” Journal of Ecology and Rural Environment, 1996, pp. 42-46.

[15] Eduardo S., K.B. CUNHA, A.L. FERREIRA, and A. ZAMBONI, Air quality standards: comparative experience Brazil, USA and European Union, Institute of Energy and Environment, São Paulo, 2012, pp. 1-81.

[16] Vormittag, E.M.P.A, R.R. COSTA, A.A. BRAGA, M. MIRANDA, N.C. NASCIMENTO, and P.H.N. SALDIVA, Air quality monitoring in Brazil, Health and Sustainability Institute, São Paulo, 2014, pp. 1-99.

[17] WORLD HEALTH ORGANIZATION, “7 million premature deaths annually linked to air pollution,” Air Quality. Climate Change, 2014, pp. 53–59.

[18] CONAMA - BRAZILIAN NATIONAL ENVIRONMENTAL COUNCIL, Resolution 491, Publication DOU, Brasília, 2018, pp. 155-156.

[19] ALVES C., “Atmospheric aerosols: Historical perspective, sources, chemical formation processes and organic composition” New Chemistry, 2005, pp. 859-870.

[20] MOREIRA M., and TOLEDO K., “Satellites show burning smoke river over Sao Paulo: Clouds formed in the Amazon, Bolivia and Paraguay and turned night into the São Paulo city,” Folha de São Paulo. São Paulo, 2019, pp. 1-1.

[21] P. ARTAXO, P.H. OLIVEIRA, L.L. LARA, T.M. PAULIQUEVIS, L.V. RIZZO, C. PIRES JUNIOR, M. A. PAIXÃO, K.M. LONGO, S. FREITAS, and A.L. CORREIA, “Climate effects of aerosol particles from biogenic and biomass burning emissions in the Amazon basin,” Brazilian Journal of Meteorology, 2006, pp. 168-22.

[22] PMBC - BRAZILIAN CLIMATE CHANGE PANEL, Climate change and cities, special report of the Brazilian panel on climate change [RIBEIRO S.K., and SANTOS A.S. (Eds.)], COPPE - UFRJ, Rio de Janeiro, 2016, pp. 1- 116.

[23] INPE - BRAZILIAN NATIONAL INSTITUTE FOR SPACE RESEARCH, Monitoring the transport of biomass burning and anthropogenic pollution in South America, INPE Publisher, São José dos Campos - São Paulo, 2019, pp. 1-13.

[24] Hernandez, G., Berry, T-A., Wallis, S.L., & Poyner, D., Temperature and humidity effects on particulate matter concentrations in a sub-tropical climate during winter [Juan L. (Ed.)], Proceedings of International Conference of the Environment, Chemistry and Biology – ICECB, 2017, pp. 41-49.

[25] EMBRAPA - BRAZILIAN MINISTRY OF AGRICULTURE LIVESTOCK AND SUPPLY, Climate Aspects of Belém in the Last One Hundred Years [T. BASTOS, N. PACHECO, D. NECHET, T. SÁ (Eds)], EMBRAPA Digital publishing, Belém, 2002, pp. 1-31.

[26] O GLOBO, Nuvem carregada com ventos úmidos faz 'dia virar noite' em São Paulo, 2019. Available in: https://oglobo.globo.com/brasil/nuvem-carregada-com-ventos-umidos-faz-dia-virar-noite-em-sao-paulo-23888276.