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REDEFINING RESOURCES

WHITE PAPER

Different stages for calibration of sensor-based CAAQMS

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Introduction

Sensor-based air quality monitoring systems have revolutionized the world of air pollution measurement technologies. They have evolved as a highly reliable and scalable solution for all real-time ambient air quality monitoring requirements. They provide high accuracy data at significantly low capital and operating cost. Their cost-effectiveness, portability and data accuracy make them an ideal choice for hyperlocal air quality monitoring. Such a network of densely placed monitors produces unprecedented details of air pollution exposure at human breathing level. Air pollution mitigation strategies rely on data provided by air quality monitors. Therefore, it is very much important and crucial that they provide highly accurate air quality measurements throughout their deployment.

Various factors affect data accuracy of air quality monitoring systems. Periodic calibration of monitors is carried out to ensure data quality of air pollution concentration measurement. This paper serves as a guide to understand calibration, its importance and various stages of it to achieve the highest level of data quality. It effectively addresses various questions related to calibration of air quality monitoring systems.

What is Calibration

Calibration is the process by which the performance of an air quality monitoring system is tested and the required corrections are made. All the sensors provide output in the form of a voltage signal. The calibration of monitors establishes the relationship between instrument response (in the form of output voltage signal) and known pollutant concentration. This signal response relationship is then used to convert sensor response to corresponding ambient pollutant concentration. The deployment of monitors in ambient conditions tends to incorporate various possibilities of error and data bias in the measurement. To meet data quality objectives, all the air quality monitoring systems have to be calibrated at regular intervals. Calibration process corrects and compensates for data drift/bias and keeps check on the linearity of instrument response.

Calibration of air quality monitoring systems is a scientific and systematic process. Fundamental factors that should be taken into consideration while carrying out calibration are as follows-

- Inherent stability / instability of monitoring systems under prevailing ambient conditions of humidity, temperature, atmospheric pressure, etc.
- Cost and time involved in carrying out calibration
- Data quality goals

Need Of Calibration

Instrument calibration is an integral part of operating any air quality monitoring site. It is vital for data quality assurance. Various factors of the ambient environment negatively influence the sensor's ability to accurately measure air pollutant concentration. Oizom's Whitepaper 3 explains the effect of such factors on data quality in detail. As a result, sensors may incur systematic errors such as data drift and bias by overestimating or underestimating the air pollutant concentration. These errors could be present in the form of unreasonable spikes, outliers, interference, unusual patterns, etc. Various statistical parameters and data quality check / assessment(QC/QA) techniques are used to identify the presence of such errors in concentration measurement. It signals the requirement of calibration of the air quality monitoring system.

A detailed explanation of the above mentioned statistical parameters and QA/QC techniques is provided in Oizom's Whitepaper 7.

It is recommended that every air quality monitoring system should be calibrated at least twice a year. However, at sites with high pollution load, the frequency should be at least once every 3 months. Routine calibration and maintenance should be scheduled in such a way that any associated data loss is evenly distributed. Also, care should be taken to avoid data loss during critical monitoring times. Apart from the routine calibration, calibration of air quality monitoring systems is recommended in the occurrence of the following events:

- Calibration upon initial deployment if required.
- Relocation of the air quality monitoring system
- Replacement of any sensors
- After any other services or repairs that might affect calibration
- Following any interruptions in operation for more than a few days indicating system malfunction.

Calibration of air quality monitoring systems significantly improves the quality of data. Accurate and reliable monitoring results are crucial to assess the health risk from pollution exposure. Such analyses provide a fundamental basis for policy formulations and air pollution mitigation strategies and for that accuracy of air quality data is a central tenet.

Stages of Calibration

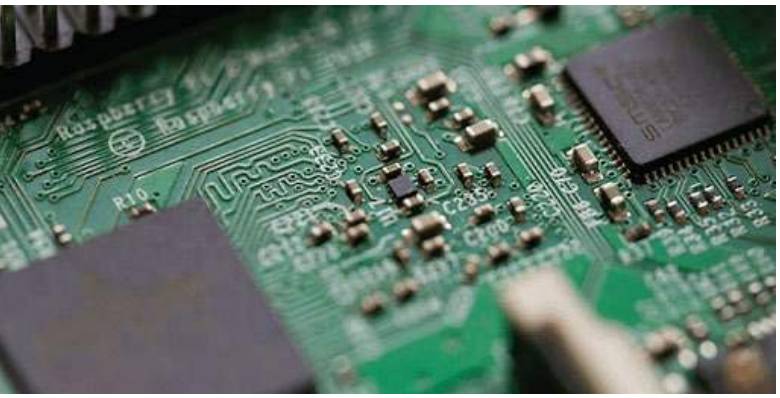
From sensor manufacturing to system assembly and field deployment, there are various possibilities of error introduction at each of these stages. To avoid that, the sensor is passed through rigorous calibration processes at all these stages. Sensor performance is checked, tested and corrected for errors in pollutant measurement. Various methods and techniques of system calibration at different stages can be broadly classified into two categories: Pre-deployment calibration and post-deployment calibration.

Pre-Deployment Calibration:
- Factory calibration at manufacturer's facility
- Reference gas calibration at a standardized laboratory
- Collocation against the reference station.

Post-Deployment Calibration:
- Spot Calibration
- Model / Mathematical Corrections

Sensor Calibration at Manufacturing Facility

Low-cost sensor-based monitors measure gaseous and particulate pollutants using different sensors such as Non-Dispersive Infrared (NDIR), Photoionization Detector (PID), Electrochemical sensors, and light scattering laser-based sensors. Each type of sensor has their own working principle. As a result, the signal response relationship with the pollutant concentration of each of these sensors is different. Also, the sensor response time and repeatability of a given measurement also vary with the sensor working principle. This may induce inherent data bias to sensor measurements. To avoid such measurement errors, all the sensors are calibrated individually at the sensor manufacturing facility. Each sensor is referenced against a standard response time curve to determine sensor performance. The operating range of sensors is also checked for various environmental factors like temperature and relative humidity. It is the first step in the whole life-cycle of calibrating air quality monitoring systems.



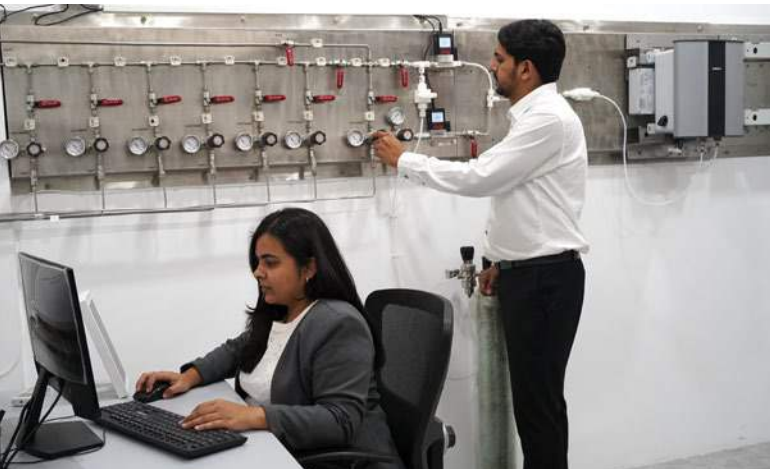
Calibration of the assembled air quality monitoring system

An air quality monitoring device consists of a variety of air pollutant measurement sensors. They are systematically placed in a device provided with the microclimatic conditions and power supply. Such an arrangement is designed to reduce the negative effects of the ambient environment on accurate measurement capability. This type of microclimatic conditions can only be provided in the active sampling based monitoring instruments such as Oizom's devices. All the assembled devices are passed through various laboratory tests to check for their precision and accuracy at Oizom. It is a pre-deployment calibration approach. At Oizom's laboratory, the overall accuracy of the devices is checked and improved to get better results. All the major parameters which the equipment is capable of monitoring are tested. During calibration, the device is exposed to a reference gas of known concentration under controlled microclimatic conditions. Initially, the device is exposed to clean air of "zero" concentration and gradually reference gas concentration is increased. Comparing the data at "zero" and higher concentrations allow the determination of how well the sensor repeats itself under various conditions. Multiple data points are generated in order to determine measurement bias, the deviation of the measured value from the "true" value of pollutant concentration. Here "true" value is the known concentration value of reference gas. Overall device performance is evaluated and necessary corrections are carried out. This is a holistic approach of calibration that ensures high quality of data is generated when multi-sensors are functioning together to measure various pollutants together.

Reference gas calibration at standardized laboratory

It is necessary that each ambient air quality monitoring device is well calibrated at highest possible standards before its deployment in the field. Calibration at a standardized laboratory ensures data accuracy and eliminates pollutant cross-sensitivity. Calibration processes are carried according to the scientific guidelines provided by various regulatory authorities such as US Environmental Protection Agencies (USEPA), Indian Central Pollution Control Board (CPCB), etc. All the Oizom equipments are calibrated at a NABL (National Accreditation Board for Testing and Calibration Laboratories)

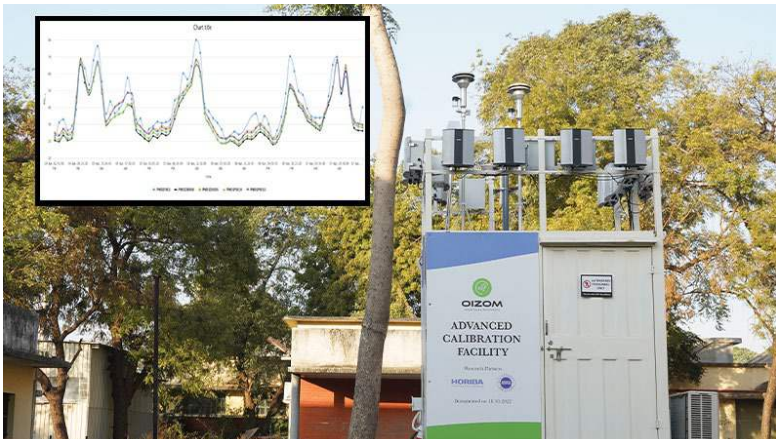
accredited laboratory for high data accuracy and precision standards. Gas calibration is done with pure air and standard calibration gas, at a high concentration range of 1-10 ppm and flow rate of 0.5 L/min. Such tests are repeated several times to ensure the highest level of data quality. The readings from the device are compared with the known concentration of the reference gas and the necessary corrections are made. Only those air quality monitors with benchmark performance in precision and accuracy are declared passed from the test to be deployed in the field.



Collocation against the reference stations

The environmental conditions are very different from the controlled climatic conditions in a laboratory where the device is calibrated until this stage. Various studies have found a change in sensor performance once the device is exposed to ambient conditions. It may cause erroneous and biased results even after it is calibrated in a laboratory with reference gas. It is highly recommended by USEPA to conduct a collocation study against a reference station to evaluate the sensor performance in ambient conditions. It can be conducted pre-deployment and post-deployment of the device. The device is placed along with a reference system to measure the same representative ambient air quality. A calibration curve is developed by creating a scatter plot comparing the results from the sensor-based device and the reference station. Various statistical analysis like the correlation test, standard deviation test, etc. are carried out to determine the sensor performance. The detailed guidelines to perform a collocation test is explained in OIZOM's Whitepaper 7 - Collocation study of Sensor Base CAAQMS with Reference Systems.

The calibration curve is prepared using a minimum of 1000 data points recorded by the sensor and reference stations. The averaging period of the data sets determines the time period required to record the 1000 data points. The averaging period and the pollutant concentration measuring are adjusted and synced between sensor-based devices and the reference station to record the concentration at the same time interval. The device is deployed at the selected location after the device is acclimatized in the ambient environment.



Post deployment collocation can be carried out in which the device is moved from its location to near a reference station and calibrated. The usual frequency of calibration is from 3 - 6 months but can also be conducted seasonally

based on the request of the user. If there is a hybrid air quality monitoring network where the reference station and the sensor-based monitor are located in the same vicinity, collocation can be conducted without relocating the sensor-based device. More information on hybrid air quality monitoring networks can be found in Oizom's Whitepaper 8 - Hybrid Air Quality Monitoring Network.

Spot Calibration

It may not be feasible to have a reference station present within the same proximity of the device to be calibrated. Moreover, the device cannot be calibrated at a reference station with varying meteorology and topography. Frequent transferring and relocating the monitor for collocation may incur extra cost and can damage the device. The collocation process also consumes much time and the device remains unfunctional during the entire process. Spot calibration can be carried out in such instances. A master device of Oizom that has recently undergone all the above-mentioned calibration process is deployed at the monitoring location. It is placed at the same location where the existing device is present. The device is retrofitted on the smart pole just below the device to be calibrated, keeping a minimum clearance of 1 meter. The master device can also be mounted on a mobile van and placed near the device to be calibrated. Minimum 150 data points are collected and compared with the results of the master device. The deviation in the results is flagged and corrected using appropriate mathematical and model formulations. In the case of large drifts in the data, the sensor is manually checked, cleaned, repaired and replaced if found necessary.

Spot calibration using Oizom's master device improves the efficiency of the device in a cost and time efficient manner. It eliminates the tedious process of relocating the device carried out during the collocation process. It is prescribed to conduct a spot calibration every 3 months with the cleaning of the device or every six months based on the request of the user. It serves as an effective alternative for the collocation against reference stations.

Oizom's Offerings

Oizom'd devices, Polludrone™, Odosense™, and Dustroid™ undergo each stage of calibration before deployment, ensuring highest data quality. Oizom's e-breathing technology enables on site calibration i.e. spot calibration. As the Oizom devices are active

sampling-based devices, the sensors are well protected under the main device body. It requires less frequent cleaning and calibration as compared to other passive sampling-based devices. The efficient mathematical model-based corrections provided by Oizom eliminates any drifts, bias, or outliers in the data. It also provides necessary corrections for different factors affecting the device performance such as temperature and humidity effects. Other devices can also be calibrated using a standard calibrated Oizom device.

References

[1] Air Sensor Guidebook, Environmental Protection Agency, United States. (USEPA)

[2] Good practice guide for air quality monitoring and data management, 2009, New Zealand Government.

About the Authors

Vrushank Vyas

Vrushank has 11 Years of experience in helping different industries in designing products with great usability and experience. He is leading a great team of Designers, Engineers, and Environment scientists at Oizom. He is always up for meaningful discussions in Air Quality.

Ayyan Karmakar

With an experience of more than 10 years promoting various Environmental Technologies, Ayyan Karmakar currently leads marketing at Oizom. He is an industry professional with core Environmental Engineering skills with a spirit of continuous learning.

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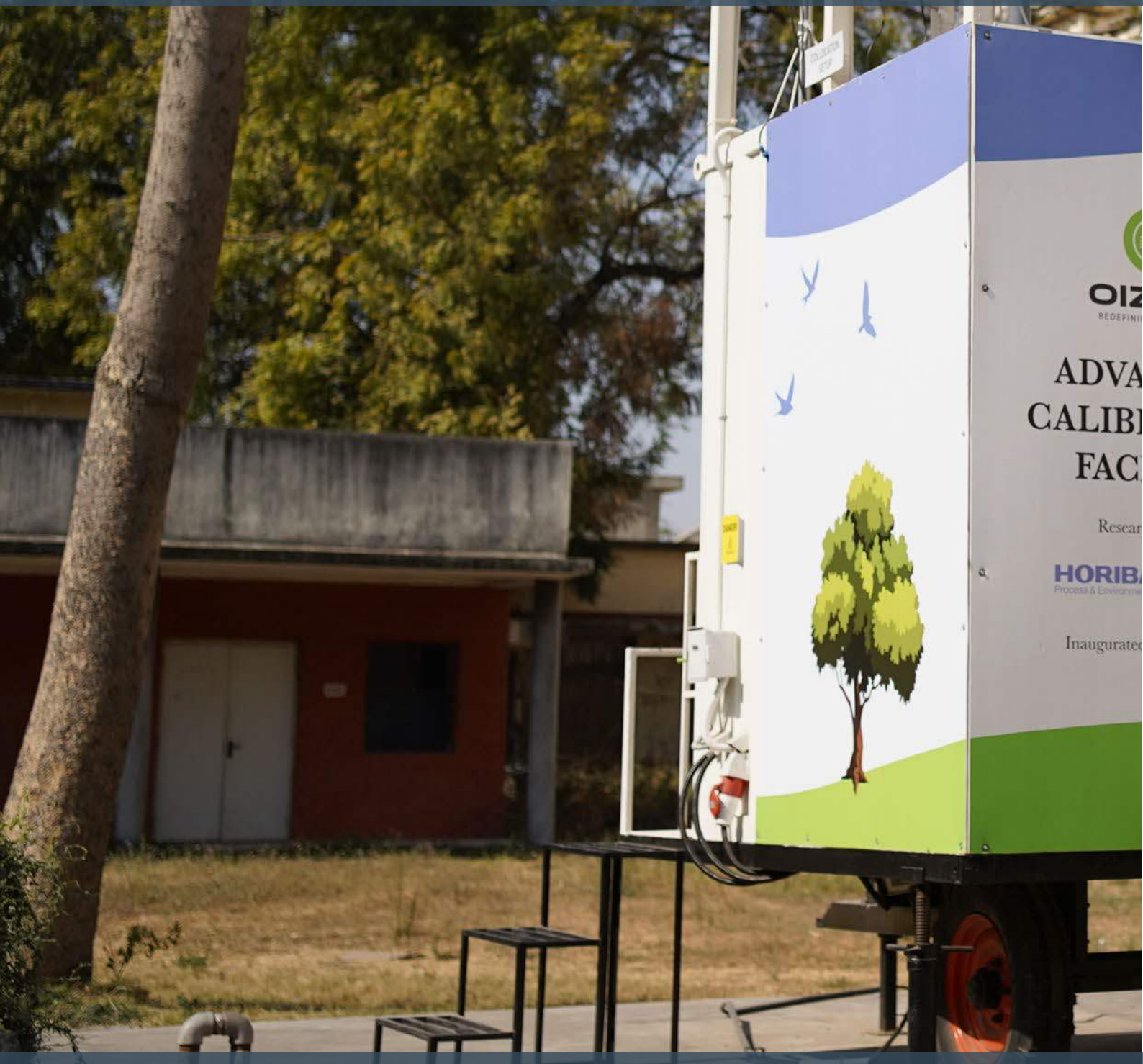

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