Performance Evaluation of IoT Sensors in Urban Air Quality Monitoring: Insights from the IoT Sensor Performance Test

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Abstract: The use of Internet of Things (IoT) sensors has increased the accuracy and efficiency of urban air quality monitoring. This study evaluates the performance of IoT sensors under various conditions to provide insights into their applicability, accuracy, and dependability. IoT sensors are installed under controlled settings in a series of experiments to assess their performance. The experiments focus on different aspects of sensor performance, such as sensor positioning, ambient conditions, and data transmission techniques. The results highlight the significance of environmental factors and the importance of sensor calibration in improving air quality measurement accuracy.

Keywords: Urban air quality, IoT sensors, Sensor calibration, Environmental conditions, Data transmission

1 Introduction

There are significant ramifications of this study for several parties. The findings may be utilized by urban planners and legislators in drafting policies. Environmental legislation, public health interventions, and policy formulation are directly impacted by the accuracy and dependability of air quality data collected by Internet of Things sensors. Comprehensive performance studies of these sensors are essential given their growing importance. These evaluations must include data transmission techniques, environmental influences, sensor positioning, and calibration. The information produced will have a significant impact on informed choices on environmental policies and air quality management. A better understanding of these issues will aid urban planners and legislators in making well-informed decisions on the efficacy of IoT sensors in monitoring urban air quality.

1 Goals of the Research

- The goals of this paper are to evaluate the performance of IoT sensors in urban air quality monitoring, ultimately leading to more accurate and dependable air quality measurement.
- The study compares the performance of IoT sensors with traditional methods to determine the potential benefits of using IoT sensors.
- The research examines the influence of various factors on sensor performance, such as environmental conditions and data transmission techniques.
- The study aims to provide insights into the applicability, accuracy, and dependability of IoT sensors for urban air quality monitoring.

2 Significance

The significance of this study lies in its potential to improve air quality monitoring and management. The findings can be utilized by urban planners and legislators in drafting policies and implementing effective strategies to monitor urban air quality. The results will also have implications for environmental legislation, public health interventions, and policy formulation. The study highlights the importance of sensor calibration in improving air quality measurement accuracy.

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2 REVIEW OF LITERATURE

1 Using IoT sensors to monitor urban air quality

A vital component of Internet of Things sensor networks is data transfer. For analysis and decision making, sensor data must be sent to central repositories. There are differences in the data loss, latency, and dependability offered by different transmission methodologies. The choice of methodology is crucial to guaranteeing that the information gathered by sensors gets to its destinations in a reliable and timely manner.

2 Obstacles in the Monitoring of Urban Air Quality

Putting IoT sensors in urban settings is another important factor to take into account. It is possible to place sensors either inside or outside buildings. Sensor performance can vary depending on the environment, and the impact of sensor position and variability of data on sensor component longevity. It is crucial to comprehend how these environmental factors affect sensor data in order to ensure the accuracy of the information.

3 The Impact of Environmental Factors on Sensor Performance

Environmental effects, sensor position, and affordable solutions. To fully realize the promise of these technologies, however, issues with sensor calibration, calibration procedures and methods are thus essential to guaranteeing accurate data on air quality. Accurate and ongoing sensor calibration is one major obstacle. Measurement accuracy and consistency over time are crucial. A key technical advancement that makes it possible to monitor air quality indicators including particulate matter, volatile organic compounds (VOCs), and other gas pollutants effectively and in real time is the Internet of Things (IoT) sensor. These sensors provide scalable, remote, and reasonably priced data collecting capabilities. As a result, there has been a significant change in the way we approach sensor component longevity. It is crucial to comprehend how these environmental factors affect sensor data in order to ensure the accuracy of the information.

4 Positioning of Sensors and Variability of Data

Sensor reaction times, and calibration status are among the information gathered. The unpredictability of data on air quality may be greatly impacted by the positioning of sensors. For example, owing to differences in pollution sources and circumstances, measurements from interior and outside sensors may vary. It is essential to comprehend how sensor location affects data accuracy in order to properly build network mission systems, including Wi-Fi, cellular networks, and LoRaWAN. Selecting the right data transmission methodology is used in this work to thoroughly assess IoT sensor performance in the context of gas sensors and result in inaccurate measurements. Elevated relative humidity may have an impact on sensor component longevity. It is crucial to comprehend how these environmental factors affect sensor data in order to ensure the accuracy of the information.

5 Reliability of Data Transmission Methodologies

Data Gathering

1) First Experiment: Quantitative Sensor Calibration

- Procedure: A controlled environment is used to put the sensors and monitor the quality of the air. Whereas uncalibrated sensors provide data without correction, calibrated sensors undergo testing against reference standards. Measurements of air quality, such as particulate matter (PM), volatile organic compounds (VOCs), and other gas pollutants, are taken.

- Participants: Fifty Internet of Things (IoT) sensors are chosen for this experiment, each having a distinct calibration state (calibrated or uncalibrated).

- Results: The first experiment aimed to determine the reliability of data transmission methodologies by comparing the performance of calibrated and uncalibrated sensors in controlled environments.

2 Data Gathering

- Design of Research

- Participants: The participants in this study are fifty Internet of Things (IoT) sensors, each with a distinct calibration state (calibrated or uncalibrated).

- Procedure: The sensors are placed in a controlled environment, and their performance is monitored. Uncalibrated sensors provide data without correction, whereas calibrated sensors undergo testing against reference standards.

- Results: The findings of the first experiment highlight the importance of sensor calibration in ensuring accurate and reliable data transmission. It is crucial to comprehend how these environmental factors affect sensor data in order to ensure the accuracy of the information.
2) Experiment 2: Quantitative Environmental Conditions

- Participants: This experiment makes use of fifty IoT sensors.
- Method: The sensors are exposed to a range of environmental factors, such as humidity and temperature. Sensors are positioned in environments with strict constraints. Temperature, humidity, sensor response times, and air quality measures are all tracked.

3) Experiment 3: Quantitative Sensor Placement

- Participants: Forty Internet of Things (IoT) sensors will be installed in various urban areas, both indoor and outdoor, as part of this project.
- Method: To monitor air quality, sensors are positioned both inside and outside in critical locations. Sensor reaction times, sensor positioning, and interior and outdoor air quality are all measured and recorded.

4) Experiment 4: Quantitative Data Transmission

- Participants: For this experiment, a set of 70 Internet of Things sensors is used, each of which uses a different data transmission technique (cellular or Wi-Fi).
- Process: Sensors are installed in cities and set up to transmit data using certain protocols. Sensor response times, latency, and data loss percentages are all measured and recorded.

Statistical analysis will be performed on the quantitative data that was gathered from the studies. The data will be summarized using descriptive statistics, such as means, standard deviations, and frequency distributions. Regression analysis, ANOVA, and t-tests are examples of inferential statistics that will be used to evaluate significant differences and correlations between variables. Thematic analysis will be used to the qualitative data. A qualitative analysis will be conducted to look for patterns, trends, and any problems in the sensor data, which includes the calibration status, ambient conditions, sensor location, and data transmission techniques. This study's approach combines qualitative analysis and quantitative trials to assess IoT sensor performance in urban air quality monitoring in a comprehensive way. It focuses on data transmission techniques, sensor positioning, ambient factors, and sensor calibration. Enhancing air quality assessment and decision-making, the data gathered and examined in these trials will provide important insights on the dependability and precision of IoT sensors in urban air quality monitoring.

4 RESULT AND ANALYSIS

1 First Experiment: Sensor Adjustment

- IoT sensors were assessed in this experiment in two calibration states: calibrated and uncalibrated. The objective was to comprehend how sensor calibration affects reaction times and accuracy in air quality measurements.

1) First Outcome: Accuracy of Air Quality Measurement vs Calibration Status

- The average measurement error of air quality for the calibrated sensors was 4.3%, but the uncalibrated sensors showed an error of 8.5%.
- There was a statistically significant difference (p < 0.05) between the two groups according to a paired t-test.
- When compared to uncalibrated sensors, the calibrated sensors yielded substantially more accurate readings of the air quality.

2) Result 2: Sensor Response Time against Calibration Status

- The average reaction time of calibrated sensors was 2.2 seconds, but the response time of uncalibrated sensors was 2.8 seconds.
- A statistically significant difference (p < 0.05) was found using a t-test.
- Faster responses from calibrated sensors showed a useful benefit.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sensor Calibration</th>
<th>Air Quality Measurement Error (%)</th>
<th>Sensor Response Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calibrated</td>
<td>5.2</td>
<td>2.4</td>
</tr>
<tr>
<td>2</td>
<td>Uncalibrated</td>
<td>8.7</td>
<td>2.9</td>
</tr>
<tr>
<td>3</td>
<td>Calibrated</td>
<td>4.1</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>Uncalibrated</td>
<td>10.2</td>
<td>3.1</td>
</tr>
<tr>
<td>5</td>
<td>Calibrated</td>
<td>6.3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

| TABLE I. Sensor Calibration and Air Quality Measurements |
Environmental Conditions in Experiment No. 2

This experiment evaluated the effects of humidity and temperature on the accuracy and reaction time of IoT sensor data.

- The accuracy of the sensor increased with temperature. The average inaccuracy of the sensors was 3.6% at higher temperatures and 5.2% at lower temperatures.
- Temperature had a substantial impact on sensor accuracy, according to a one-way ANOVA (p < 0.05).
- High humidity levels led to quicker sensor performance. The average reaction time was 2.7 seconds in low humidity and 2.3 seconds in high humidity.
- A statistically significant difference was shown using a t-test (p < 0.05).

**TABLE II.** Environmental Conditions

<table>
<thead>
<tr>
<th>Participant</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
<th>Sensor Data Accuracy (%)</th>
<th>Sensor Response Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>50</td>
<td>3.5</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>60</td>
<td>4.2</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>70</td>
<td>4.8</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>40</td>
<td>3.1</td>
<td>2.1</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>55</td>
<td>3.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>

![Fig. 1. Sensor Calibration](image1)

![Fig. 2. Environmental Conditions](image2)
4 Experiment 3: Positioning the Sensor

This experiment investigated how the positioning of sensors—indoor or outdoor—affects the data on air quality.

- The average air quality index (AQI) for sensors put outside was 60, but the AQI for sensors placed inside was 45.
- The AQI variance was statistically significant (p < 0.05) between indoor and outdoor settings.
- Discussion: Because there were no sources of outside pollution, inside sensors showed lower AQI readings. The findings highlight how crucial it is to take location into account when analyzing data on air quality.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sensor Placement</th>
<th>Indoor Air Quality (AQI)</th>
<th>Outdoor Air Quality (AQI)</th>
<th>Air Quality Data Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indoor</td>
<td>45</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Outdoor</td>
<td>60</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Indoor</td>
<td>42</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Outdoor</td>
<td>57</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Indoor</td>
<td>44</td>
<td>53</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Sensor Placement

5 Experiment 4: Transmission of Data

The last experiment compared Wi-Fi and cellular choices for data transfer.

- Sensors that sent data using cellular networks lost an average of 2.5% of their data, compared to 1.8% for sensors that used WiFi.
- A statistically significant difference (p < 0.05) was found using a t-test.
- The average delay for sensors that sent data over cellular networks was 0.8 seconds, while the average latency for sensors that used WiFi was 0.6 seconds.
- There was a statistically significant difference in latency (p < 0.05).

<table>
<thead>
<tr>
<th>Participant</th>
<th>Data Transmission</th>
<th>Data Loss (%)</th>
<th>Latency (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cellular</td>
<td>2.5</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>WiFi</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>Cellular</td>
<td>3.1</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>WiFi</td>
<td>2.2</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>Cellular</td>
<td>2.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>
The findings show that when compared to cellular transmission, Wi-Fi transmission delivers reduced latency and less data loss. Nonetheless, variables like power consumption and network accessibility should be taken into account while selecting a transmission method.

5 CONCLUSION

The results of these tests provide important light on how well Internet of Things sensors work when monitoring urban air quality. The need of frequent calibration was shown by the much greater accuracy and quicker reaction times of calibrated sensors. Temperature and humidity are two environmental parameters that affect sensor accuracy and reaction times. Therefore, while interpreting data, these elements must be carefully taken into account. The location of sensors, whether outside or within, significantly affected the data on air quality, highlighting the need of careful sensor deployment.

Finally, data communication techniques like Wi-Fi provided benefits including reduced latency and data loss, highlighting how crucial it is to choose the right transmission technology. This study offers useful insights into IoT sensor performance, which helps to improve urban air quality monitoring tactics. These findings may help academics, urban planners, and policymakers make better judgments and maximize the usage of IoT sensors in air quality monitoring, which will eventually improve environmental management and public health.

6 REFERENCE


