DEPLOYMENT OF MOBILE AND FIXED AIR SENSOR PLATFORMS IN THE CITY OF FLORIANÓPOLIS, BRAZIL: PRELIMINARY RESULTS

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1. INTRODUCTION

The problem of local representativeness of air quality data is an issue for government offices and environmental agencies. The insufficiency of relevant information may result in a deficient estimation of air pollution and on the implementation of ineffective air quality management policies. This topic is especially relevant in Brazil, where regulatory monitoring is still limited (Oyama and Zamboni 2017). The high costs of the certified stations and their maintenance, as well as the lack of qualified staff, hamper the deployment of spatially broader and denser monitoring networks. However, alternatives have been introduced into the air quality monitoring domain with the rise of low-cost sensing for managing air pollution (Kumar et al. 2015).

According to Emily Snyder and contributors (2013), the air quality monitoring has experienced a paradigm shift in the way data are collected. The authors affirm that the recent advances in electrical engineering "provide opportunities to enhance a range of existing air pollution monitoring capabilities and perhaps provide avenues to new air monitoring applications" (Snyder et al. 2013). This shift has been possible due to a set of relatively new monitors commonly known as low-cost air quality sensors. Such devices have valuable defining features, like smaller dimensions, lower weight, lower power consumption, and easiness of use, that differentiate them from the traditional monitoring methods (Lewis et al. 2018), and present them as a promising alternative for monitoring air pollution, especially for developing countries. However, the reliability of these sensors is still a question, and the influence of environmental conditions, cross-sensitivity and long-term performance requires further investigation.

In this work, we present the preliminary results of deploying two prototypes of air sensor platforms in the city of Florianópolis, Brazil. The sensor nodes were developed at the Laboratory of Air Quality Control, at the Federal University of Santa Catarina. One prototype, installed at a fixed site, features a set of Alphasense and SPEC sensors. The other one, which was used for mobile monitoring, only utilizes SPEC sensors for registering the air quality readings.

In the discussion bellow, we address the following questions: i) What is the correlation between the responses of sensors from different manufacturers (SPEC and Alphasense) for the same pollutant? ii) What is the effect of the relative humidity on the sensors' responses? iii) Are the sensors able to detect daily and weekly variations on traffic patterns, and to differentiate the level of pollution at specific locations and hours of the day? To answer those, the outputs of the SPEC and Alphasense sensors, installed in the static node, are compared between each other. The output of the mobile node, on the other hand, is compared to the output of a Sniffer 4D V1 multi-gas detector from Shenzhen Soarability Technologies Co., Ltd.

2. METHODS AND MATERIALS

2.1 Low-cost sensors prototypes for air quality monitoring

The basic structure of the sensor prototypes consists of an Arduino Mega microcontroller platform, an array of electrochemical gas sensors,

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a micro SD card for data storage, and an ESP8266 module for Wi-Fi communication. Both devices measure gaseous pollutants that are regulated by the Brazilian environmental laws, i.e.: Carbon Monoxide, Nitrogen Dioxide, Ozone, and Sulfur Dioxide. Each node uses screen-printed electrochemical gas sensors for IoT from SPEC Sensors that connect to a UART port over an RS485 bus. These sensors provide digital readings with the concentration values in parts-per-billion, the ambient relative humidity and the temperature.

For timing and geolocation, the mobile device uses the GY-NEO6MV2 GPS module. The fixed node, on the other hand, uses a Real-Time Clock for timing. Besides the aforementioned sensors, the fixed node also includes five Alphasense B4 series electrochemical transducers, sensitive to the same gases, as well as to hydrogen sulfide.

2.2 Deployment of fixed and mobile nodes

We deployed the static node at a meteorological measuring site within the University campus, close to a street with a regular and frequent flow of heavy vehicles, like buses for public transport. It is worth mentioning that the period of data gathering corresponds to the corona-virus outbreak in Brazil. Thus, public transport within the city was considerably reduced for some periods; anthropogenic activities decreased, in general.

The static node collected air pollution measurements in two periods of approximately three months each. The first one spanned from March 14 to May 26. During this initial period, the instrument was powered with a solar panel and a 12 V battery for power storage. During the second period (July 14 to September 3), the node was directly connected to the power network. The instrument recorded the concentration values of Carbon Monoxide measured by a CO-B4 Alphasense sensor, and a DGS-CO 968-034 from SPEC Sensors, as well as the value of the ambient relative humidity.

For mobile measurements, we used the mobile prototype and a Sniffer 4D version 1 from Shenzhen Soarability Technologies Co., Ltd., which uses Alphasense electrochemical sensors. Air quality readings were performed on three streets with medium traffic, as well as on residential areas, from Monday to Sunday during a period of four weeks. The measuring campaigns were accomplished in three different times of the day that better capture the daily traffic pattern, i.e.: 07H00 – 10H00 (intense traffic), 14H00 – 16H00 (quiet traffic), and 17H00 – 19H00 (intense traffic). The mobile prototype recorded the concentration values of Carbon Monoxide and relative humidity measured by a SPEC DGS-CO 968-034. The output of this sensor was then compared with the readings from the Sniffer 4D for the same pollutant.

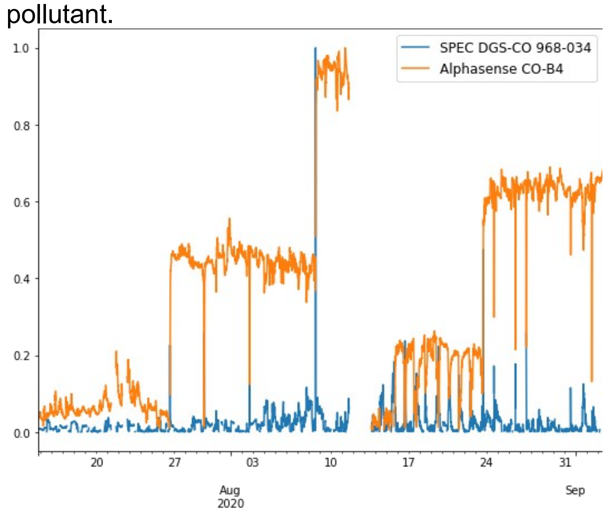


Fig. 1. Normalized time series of sensors outputs (July 14, 2020 – September 3, 2020).

3. RESULTS

The results obtained from the responses of the Carbon Monoxide sensors of both the fixed and mobile nodes are presented bellow. For the static node, we focus on the period from March 14th to May 26th, when we consider that the data collected was more useful to our purposes. The reason for this decision is that during the second campaign of measurements, as shown in Figure 1, the Alphasense sensors suffered from repeated baseline drifts and spikes, related, apparently, to peak values on the concentration captured by the SPEC Sensor. That effect may have been caused by energy fluctuations or by actual high pollution events, but, for the purposes of this work, it will not be considered on the analysis.

3.1 Fixed node

The Figure 2 shows the responses of the SPEC sensor for Carbon Monoxide, the DGS-CO 968-034, and the Alphasense CO-B4. As can be observed, the absolute level of response of the SPEC sensor was between 6 to 8 times higher than Alphasense's. The scatter plot of Figure 3 indicates that the responses of the CO sensors were poorly correlated. The Spearman and Kendall correlation coefficients for both variables were -0.07 and -0.04 respectively (see Table 1), which corroborates the hypothesis of a low correlation between the responses of the carbon monoxide sensors.

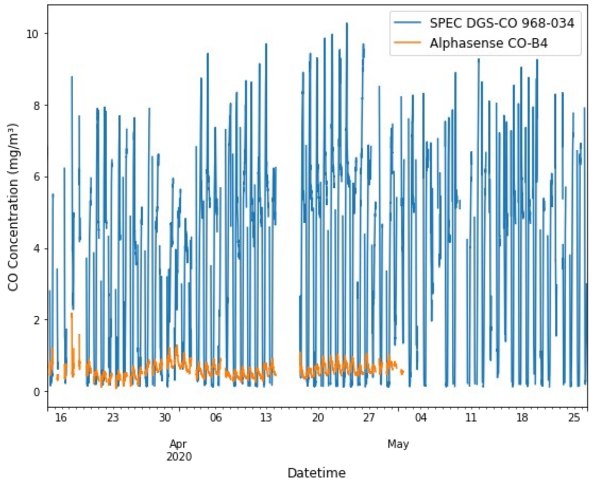


Fig. 2. Time series of sensors outputs (March 14, 2020 – May 26, 2020).

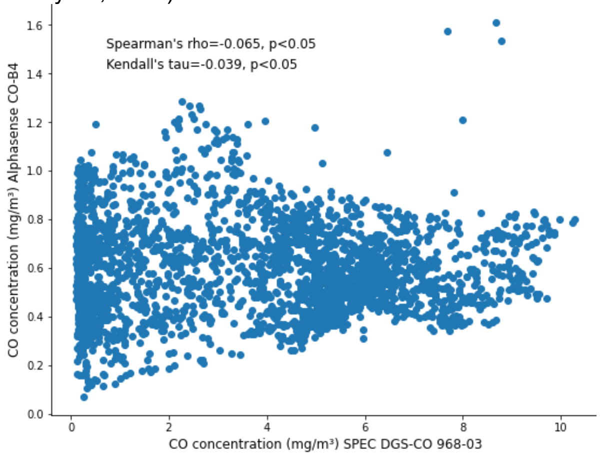


Fig. 3. Alphasense CO-B4 vs. SPEC DGS-CO 968-034 (March 14, 2020 – May 26, 2020).

Figure 4 illustrates the daily behavior of the outputs of the carbon monoxide sensors and the relative humidity along the entire period. For comparison, the data was hourly aggregated. In those graphs it is visible the similarity between the daily patterns of both the relative humidity and the response of the SPEC sensor. The output of the Alphasense sensor, on the other hand, reveals an increase in the level of response during the hours of more intense traffic activity. That suggests that CO-B4 was responsive to variations in the traffic intensity, and that its correlation with the relative humidity was lower than the correlation of the SPEC sensor.

The scatter plot of Figure 5 reinforces the supposition of a high correlation between the response of the SPEC sensor and the relative humidity. Spearman and Kendall coefficients between both variables were 0.5 and 0.4, respectively, which corroborates the hypothesis of a high correlation between the variables (also see Table 1).

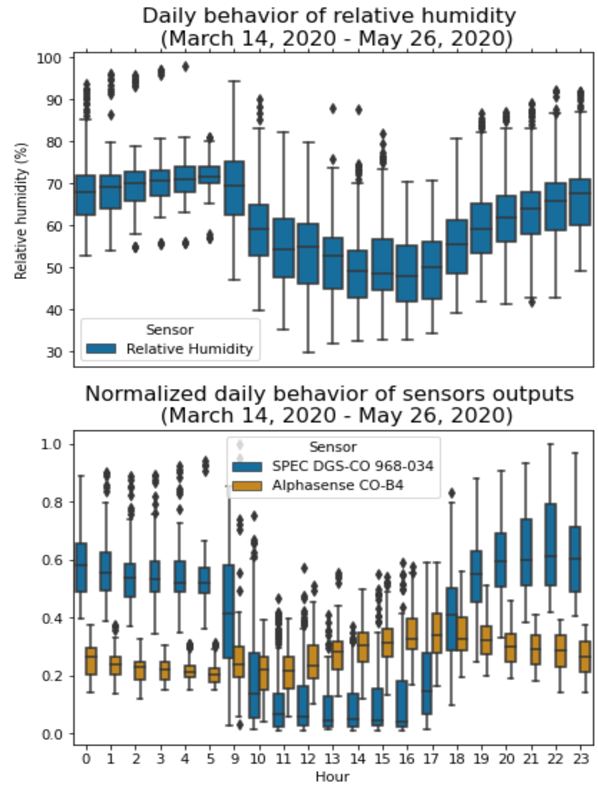


Fig. 4. Daily behavior of the relative humidity and the carbon monoxide sensor's outputs

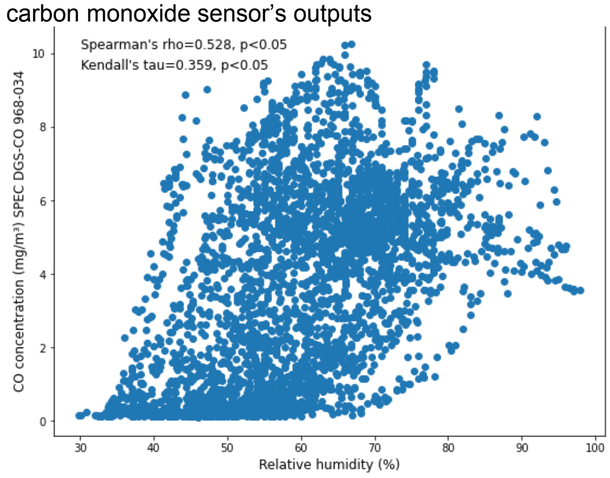


Fig. 5. SPEC DGS-CO 968-034 vs. Relative Humidity (March 14, 2020 – May 26, 2020).

The correlation between the output of the Alphasense CO-B4 and the relative humidity was low compared to SPEC. As shown in Table 1, Spearman and Kendall coefficients were both approximately -0.1. Figure 6 shows the scatter plot of the CO-B4 sensor response and the relative humidity.

Table 1. Correlation coefficients between variables

	Spearman coefficient	Kendall coefficient
Alphasense CO-B4 vs. SPEC DGS-CO 968-034	-0.07 ($p < 0.05$)	-0.04 ($p < 0.05$)
SPEC DGS-CO 968-034 vs. Relative Humidity	0.53 ($p < 0.05$)	0.36 ($p < 0.05$)
Alphasense CO-B4 vs. Relative Humidity	-0.12 ($p < 0.05$)	-0.08 ($p < 0.05$)
Alphasense CO-B4 vs. SPEC DGS-CO 968-034 (trends)	-0.002 ($p < 0.05$)	0.008 ($p < 0.05$)
SPEC DGS-CO 968-034 vs. Relative Humidity (trends)	-0.08 ($p < 0.05$)	-0.05 ($p < 0.05$)

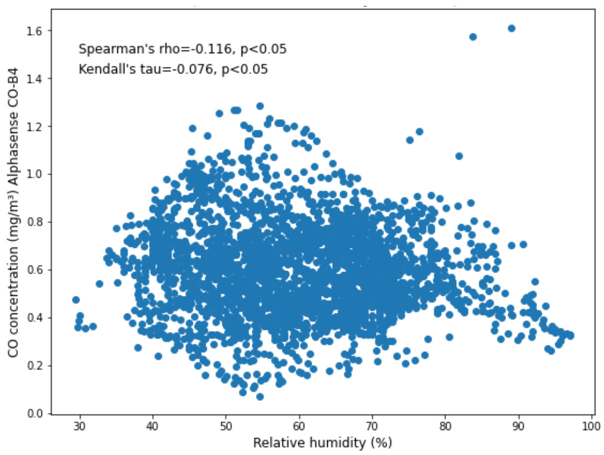


Fig. 6. Alphasense CO-B4 vs. Relative Humidity (March 14, 2020 – May 26, 2020).

In order to check the correlation between the long-term trends of the responses, we removed their daily seasonal component. As before, both CO sensors were found poorly correlated, with Spearman and Kendall coefficients of, respectively, -0.002 ($p < 0.05$) and 0.008 ($p < 0.05$), as shown in Table 1.

The weekly behavior of the sensors' responses was also analyzed using the extracted trends. Figure 7 shows box-plots of the normalized readings of the sensors grouped by days of the week. As can be observed, the median value of the SPEC sensor output remained practically constant throughout the week. In contrast, the Alphasense sensor recorded greater variation in the median concentration; with the highest median value on Wednesdays and the lowest on Saturdays. Also, the median concentration values of the Alphasense's output, and its variability, were lower on weekends compared to the majority of the weekdays. This behavior has a correspondence with the weekly traffic pattern of the city, that has a less intense anthropogenic activity during weekends.

We also checked the level of correlation between the trend of the relative humidity and the trend of the SPEC sensor's response. As shown in Table 1, Spearman and Kendall coefficients were approximately -0.1, which indicates a low correlation. This suggests that the main influence on the response of the SPEC sensor was the daily variation of the relative humidity, and that long-term slower fluctuations of that variable had little effect on the sensor's response.

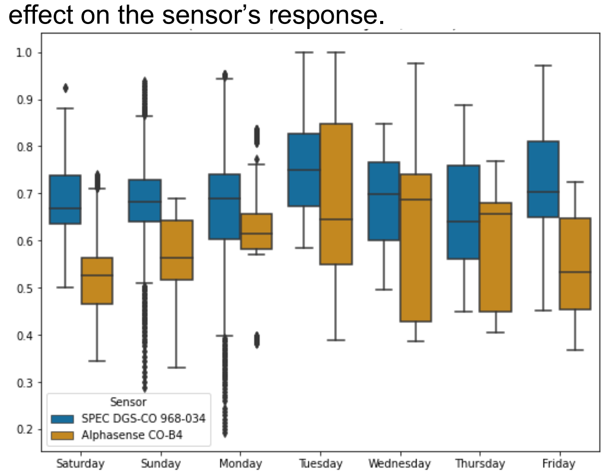
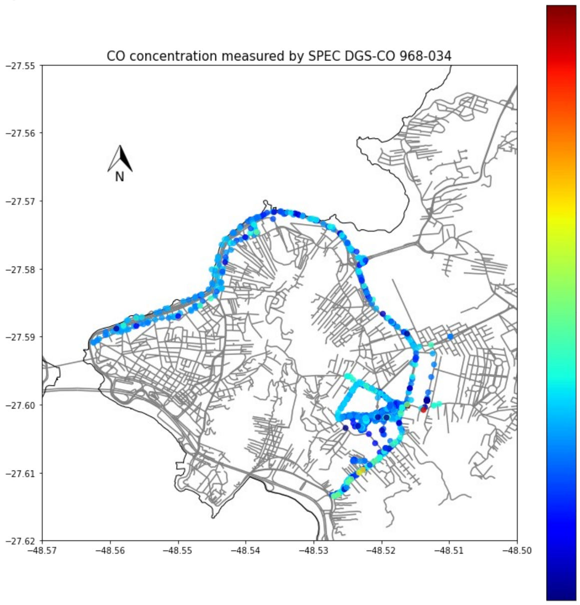


Fig. 7. Normalized weekly behavior of sensors trends (March 14, 2020 – May 26, 2020).

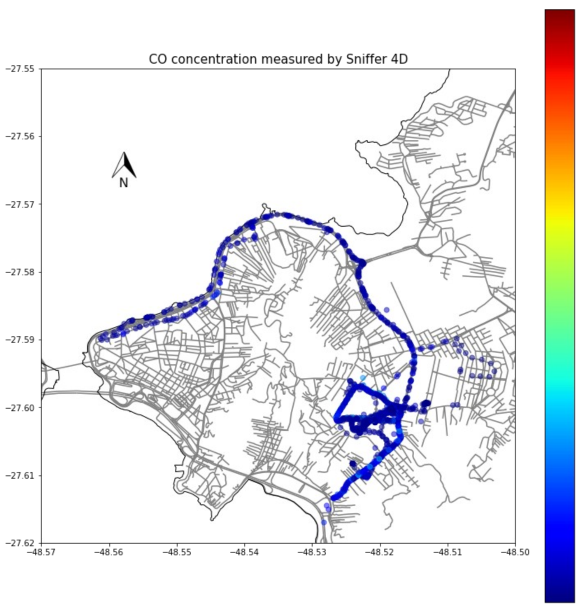
3.2 Mobile node

Figures 8a and 8b show maps of the carbon monoxide concentration measured on three streets with medium traffic and in residential areas. The maps contain the readings of the SPEC DGS-CO 968-034 sensor, used for mobile monitoring, and the Sniffer 4D. It can be observed from those figures, that the absolute values of the SPEC sensor, were higher than the Sniffer 4D. This corresponds to the results obtained for the static node.

Figure 9 uses box-plots to compare the readings taken on streets and in residential areas. The median values of the concentration levels recorded on both scenarios were close. This behavior is observed on both devices (our prototype and the Sniffer 4D). However, higher values and greater dispersion are found on streets. The behavior of the mobile devices, despite their visible differences in absolute values, was similar, with higher readings and greater dispersion on streets than in residential areas.



a)



b)

Fig. 8. Carbon Monoxide concentration maps using: a) the laboratory prototype and b) the Sniffer 4D.

The results of comparing the readings taken on weekdays and weekends on streets are shown as box-plots in Figure 10. The streets monitored usually have more intense traffic during weekdays. However, the devices did not detect considerable differences. The highest readings of both sensors were obtained during weekends, but the SPEC sensor registered values above 6 mg/m^3 more frequently during weekdays. In addition to this, the median values of the concentration levels recorded on both scenarios were close.

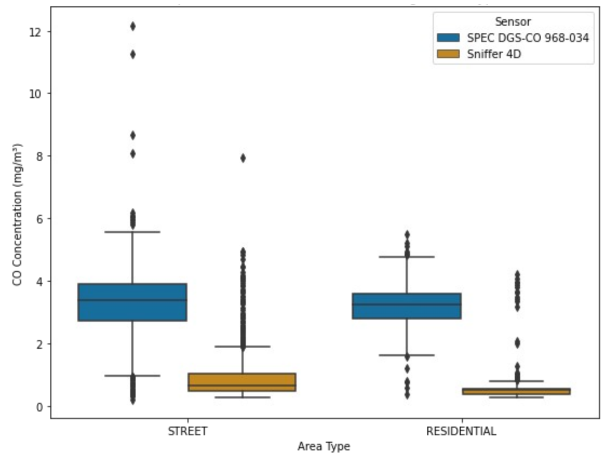


Fig. 9. Box-plots of Carbon Monoxide concentrations according to area type.

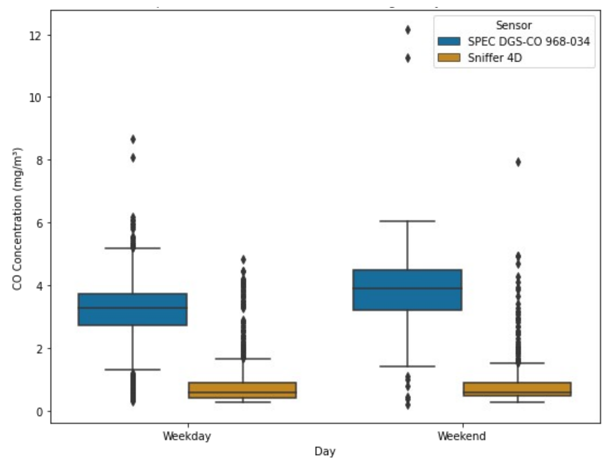


Fig. 10. Box-plots of Carbon Monoxide concentrations according to day of the week.

The clearest difference between scenarios was observed in the traffic intensity variation during the day. Higher concentrations were obtained during rush hours. However, since rush hours correspond to sunrise and sunset, when relative humidity increases, its influence on the readings was verified.

From Figure 11, we observe that both the relative humidity and the output of the SPEC sensor featured higher values during the rush hours. On the other hand, the median value of the Sniffer 4D didn't show a significant difference between rush and quiet hours. This leads us to suppose that the increase in the output of the SPEC sensor was indeed due to the increase in relative humidity, and not on carbon monoxide concentration.

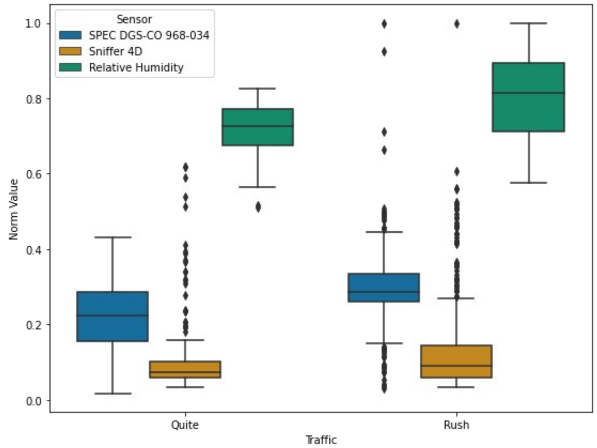


Fig. 11. Box-plots with the normalized values of Carbon Monoxide concentrations and the relative humidity according to day of the week.

4. CONCLUSION

In conclusion, we observed that the responses from Alphasense and SPEC sensors had a low correlation. In the fixed node, the Alphasense CO-B4 sensor detected higher concentrations during rush hours which wasn't the case for the SPEC sensor. Also, the correlation observed between the responses of the SPEC sensor and the relative humidity indicates that the daily variation of this environmental variable was the main driver for the responses of the sensor. The results also indicate that the long term variation of the relative humidity had little influence on the performance of the SPEC sensor. The Alphasense CO-B4, on the other hand, showed a very low correlation with relative humidity.

The trends of the responses from Alphasense and SPEC sensors also showed a low correlation. The weekly behavior of the CO-B4 indicated some differentiation between the readings taken on weekdays and those taken during the weekend, which was not the case for the SPEC sensor. The results obtained lead us to suppose that, under the conditions of these experiments and for the hardware configuration that we implemented, the DGS-CO 968-034, compared to the CO-B4, wasn't sensitive to the ambient air concentration level of carbon monoxide to which both sensors were exposed.

Regarding the mobile node, no considerable difference was perceived between readings taken on different areas or days of the weeks. Our prototype showed higher values in rush hours but very likely this was a result of the influence of the relative humidity.

The air sensors systems developed for the purposes of this work are still in its prototype phase and require further enhancements and assessment, especially in regards to laboratory calibrations, in-field co-location with regulatory monitoring stations, and long term performance. The results point to some problems on the sensor platforms that require improvement, like noise, strong dependence on environmental variables and lack of sensitivity.

These platforms have the potential to increase the spatial and temporal resolution of monitoring networks in the city, as well as to open the way to new monitoring services and applications such as the creation of air pollution maps, the detection of hot-spots in the city, citizen science and education on air pollution topics, assessment of personal exposure to gas contaminants and evaluation of the impacts that the performance of physical activities on polluted environments has on human health.

5. REFERENCES

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