Optimization of low cost gas sensor measurements using FIR filter approach.

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Abstract :
The monitoring of air quality nowadays, especially in urban areas, is of great importance due to the industrialization, transport and heating sources emissions. Government agencies and official research laboratories in each country develop air quality monitoring systems. Recently it has been observed that many citizens are involved in air quality improvement actions by developing low cost monitoring stations. The reliability and accuracy of low cost sensor measurements is still under investigation. In this frame and provided that the sources of errors in the collected data can be marginally predicted, several techniques are proposed to increase the validity of the sensors' collected data. In this work each sensor is treated and studied as a filter by applying prediction models on the measured quantities, correlated with reference values in order to optimize the measured values. This paper presents the results of applying the FIR filter approach as a prediction model, on the values of the low-cost air quality monitoring stations. The results show that the corrected data fit better with the corresponding data collected from reference equipment.

INTRODUCTION

The quality of the air is a constant object of monitoring in densely populated areas due to the impact on health and quality of life. As commercial air quality monitoring systems are overpriced there has been a movement from citizens to actively participate in air quality monitoring for the area where they live and work using low cost [1-3] air quality monitoring stations. The reliability and accuracy of the measured values from low cost systems are still under investigation while the low cost sensors technology is still improving. In this work an FIR filter is presented, to optimize measured values from low-cost gas sensors. A set of a low-cost air quality monitoring stations have been installed (**Figure 1**) at the facilities of the National Observatory of Athens (NOA) alongside commercial air quality monitoring systems in order to be calibrated. The low cost monitoring stations [4-6] were designed and implemented at the Electronic Devices and Materials Research Laboratory (EDML) at the University of West Attica.

The measured quantities from the low-cost monitoring stations are the:
- Barometric parameters
Temperature, Humidity, Barometric pressure
- Gases
Nitrogen dioxide (NO_2), Ozone (O_3)
- Particles
PM2.5

Figure 1. Low-cost air quality monitoring station installed on NOA

From the low-cost monitoring station, a measurement is conducted every ten seconds, the five minutes average values are transferred over from the cloud to the central station for further processing and visualization.

METHODOLOGY

An adaptive filter is used to estimate the system transfer function, according to the measurements from low cost sensor and reference sensor values, using the least mean squares (LMS) algorithm to identify the impulse response coefficients for each low-cost sensor. The convergence uses the impulse values and measurements from low-cost sensor values to extract the corrected low-cost sensor values.

- As a first step the low-cost sensor was treated as an adaptive FIR filter and its coefficients were determined [7]. This was conducted using the values of the low-cost sensor and the reference sensor.
- Sequentially the FIR filter, the coefficients and the measured values of the low-cost sensor were applied in a different time period aiming to get corrected gas concentration values (FIR).
- Both the collected and elaborated low cost sensor data were put in correlation to the corresponding reference sensor data in order to evaluate the performance of the FIR correction.

EXPERIMENTAL RESULTS

The study focuses on optimizing the gaseous pollutants measurements of low-cost sensors and specifically nitrogen dioxide (NO_2) and ozone (O_3) pollutants.
Two identical monitoring stations (N1 and N2) sere installed in February 2021, on the facilities of the National Observatory of Athens (Thisio area), Greece.
Two weeks data (1 March 2021 to 15 March 2021) were used to determine the FIR filter coefficients.
One month data (14 April 2021 to 14 May 2021) are shown in Figures 2 and 4 while their correlation with the corresponding data of the reference equipment is shown in Figures 3 and 5.
Figure 2 shows the concurrent data time-series of nitrogen dioxide (NO_2) of the low-cost sensors (N1, N2) and reference values. **Figure 3** shows the corresponding correlation plot. **Figure 4** shows the concurrent data time-series of ozone (O_3) of the low-cost sensors (N1, N2) and reference values. **Figure 5** shows the corresponding correlation plot.

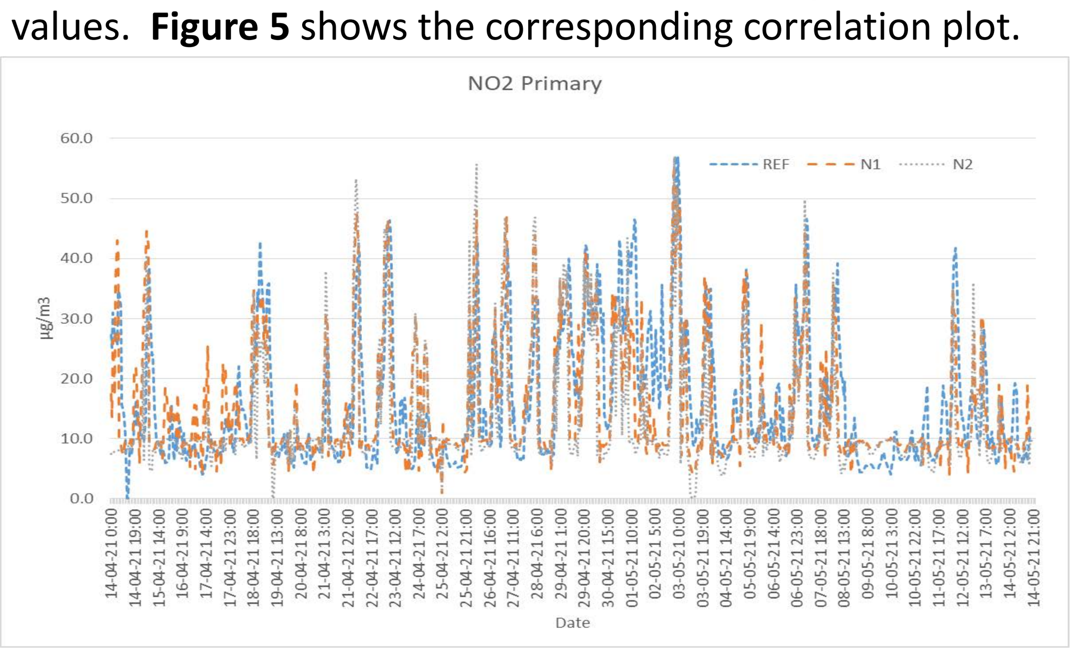

Figure 2. Time-series Nitrogen dioxide (NO_2) - Reference, Primary (low-cost sensors).

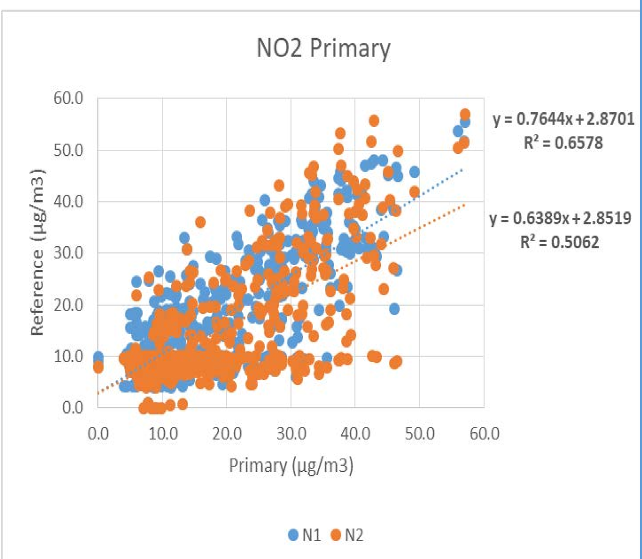

Figure 3. Nitrogen dioxide (NO_2) correlations Reference, Primary (low-cost sensors).

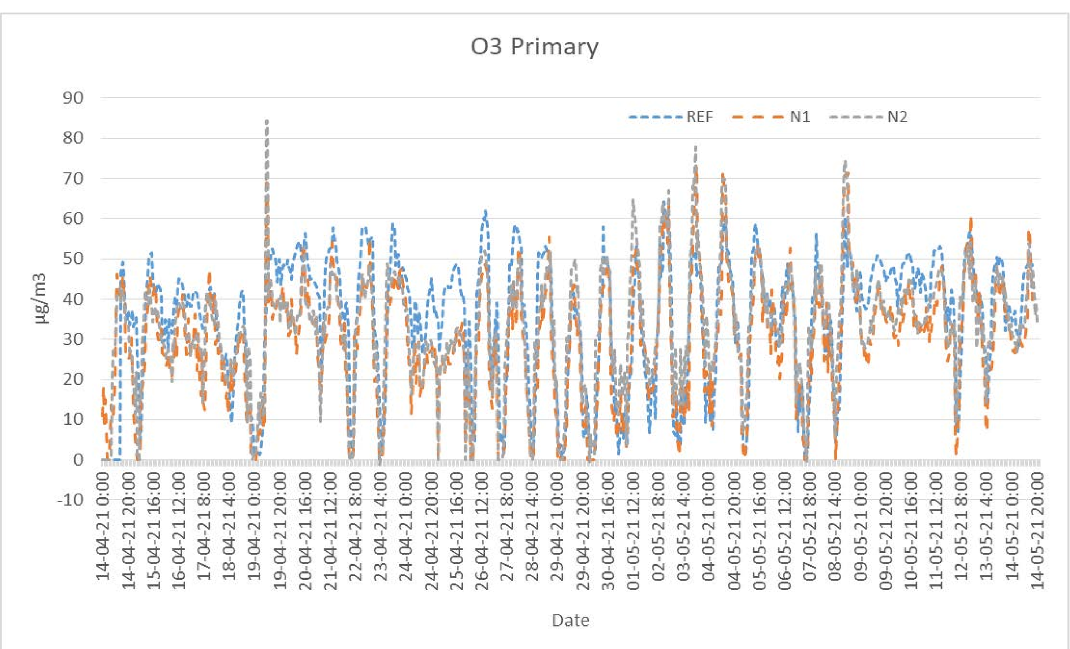

Figure 4. time-series Ozone (O_3) Reference, Primary (low-cost sensors).

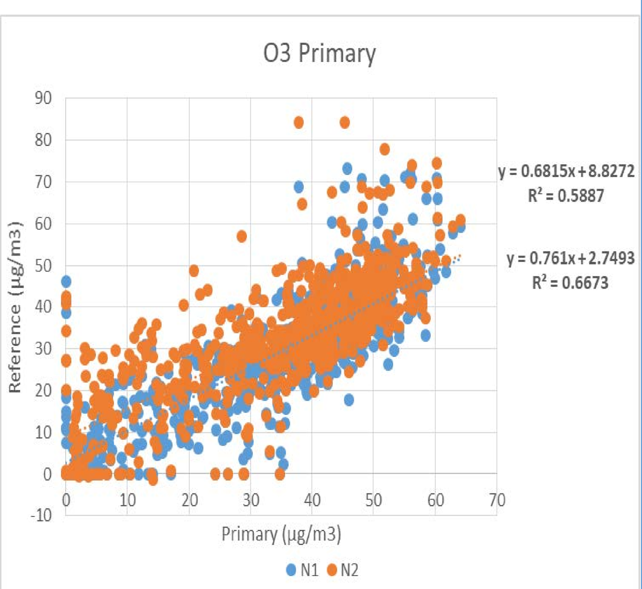

Figure 5. Ozone (O_3) correlations Reference, Primary (low-cost sensors).

The corresponding results after applying the FIR filter approach are presented in **Figures 6, 7, 8**, and **9**. **Figures 6** and **7** correspond to the nitrogen dioxide (NO_2) gas and **Figures 8** and **9** correspond to the ozone (O_3).

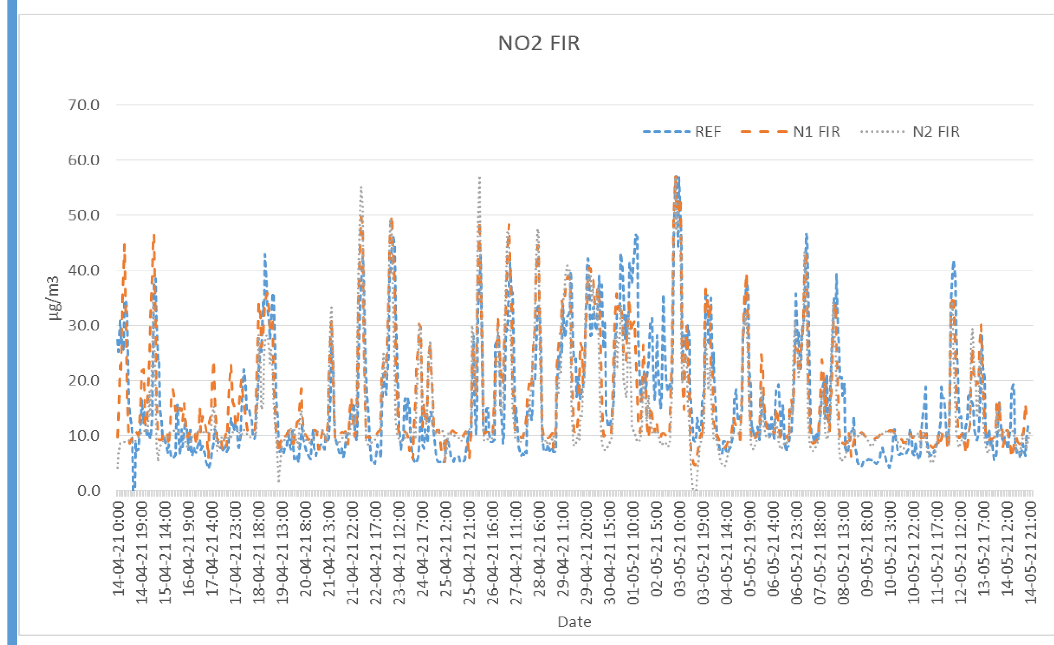

Figure 6. Time-series Nitrogen dioxide (NO_2) – Reference, Predicted (low-cost sensors).

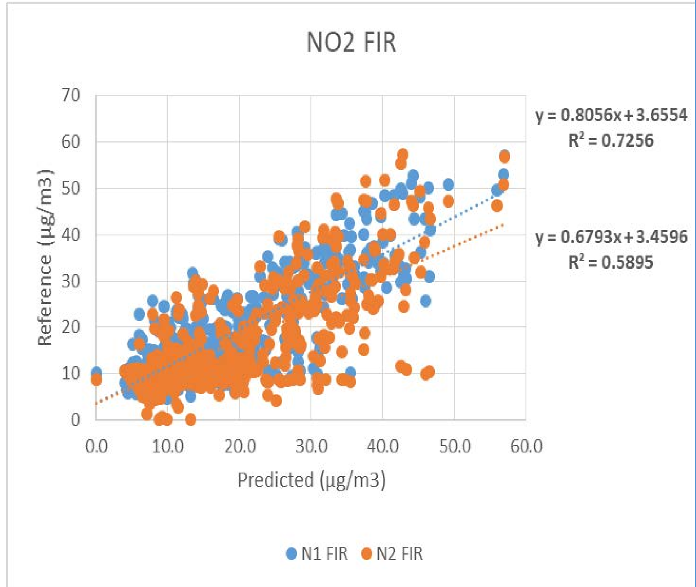

Figure 7. Nitrogen dioxide (NO_2) correlations, Reference, Predicted (low-cost sensors).

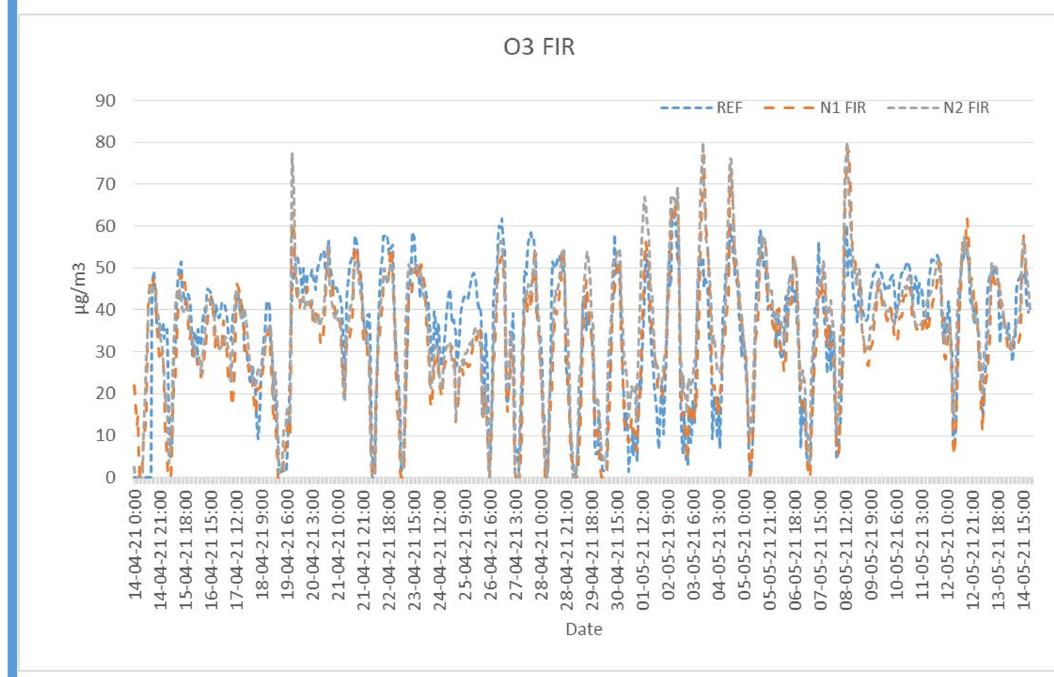

Figure 8. Time-series Ozone (O_3) – Reference, Predicted (low-cost sensors).

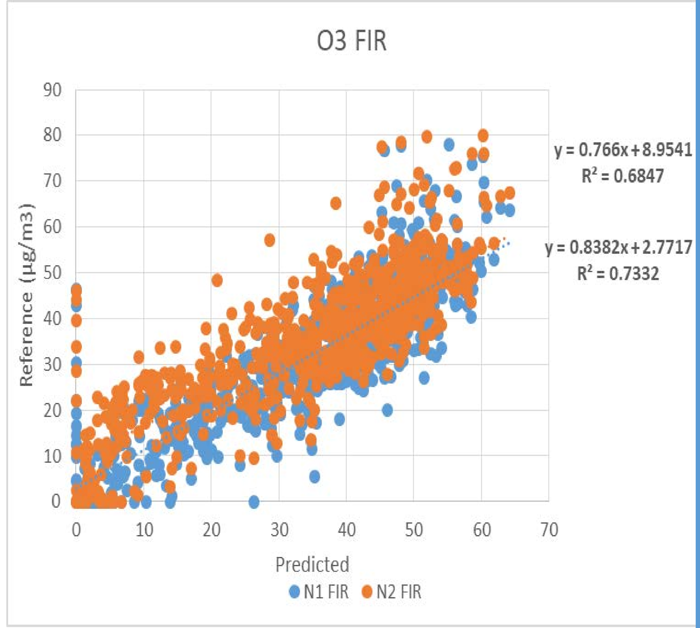

Figure 9. Ozone (O_3) correlations Reference, Predicted (low-cost sensors).

The evaluation of the predicted values in relation to the reference values is conducted by the application of the root mean square error (RMSE) method. Table 1 shows the RMSE values for both the installed low cost stations and both the measured gases.

Table 1. RMSE of primary – reference values and predicted – reference values

	N1 NO2	N2 NO2	N1 O3	N2 O3
Primary- Ref	0.401372	0.161503	0.200808	0.243823
Predicted-Ref	0.375625	0.120471	0.008367	0.040340

CONCLUSIONS

In this work, low cost sensors were used to implement NO_2 and O_3 gas monitoring stations and an attempt is made to optimize the measured values in order to improve the reliability and accuracy of the extracted results. The optimization is made by applying the FIR filter technique as a prediction model aiming to move the primary values closer to the reference instrument corresponding values. The degree of correlation (R^2) of the measured values in relation to the reference values ranged for nitrogen dioxide (NO_2) 0.50-0.65, while for ozone (O_3) 0.58-0.67. After the application of the FIR filter approach, the degree of correlation (R^2) of the predicted values in relation to the reference values ranged for nitrogen dioxide (NO_2) 0.59-0.72, while for ozone 0.68-0.73. The optimization of the measured values also appears from the application of the RMSE method, where the degree of RMSE appears smaller in the predicted values than in the measured values of each low-cost sensor. It can be straightforwardly concluded that the optimization of the measured values in low-cost sensors is feasible.

REFERENCES

[1] Y. Gao et al., "Mosaic: A low-cost mobile sensing system for urban air quality monitoring", IEEE INFOCOM 2016 - The 35th Annual IEEE International Conference on Computer Communications, 2016. Available: 10.1109/infocom.2016.7524478.
[2] W. Jiao et al., "Community Air Sensor Network (CAIRSENSE) project: evaluation of low-cost sensor performance in a suburban environment in the southeastern UnitedStates", Atmospheric Measurement Techniques, vol. 9, no. 11, pp. 5281-5292, 2016. Available: 10.5194/amt-9-5281-2016.
[3] SmartCitizen Smart Citizen Documentation. Available online: https://docs.smartcitizen.me/
[4] Migos, T.; Christakis, I.; Moutzouris, K.; Stavrakas, J. On the Evaluation of Low-Cost PM Sensors for Air Quality Estimation. In Proceedings of the 8th International Conference on Modern Circuits and Systems Technologies (MOCAST), Thessaloniki, Greece, May 2019; pp. 1–4.
[5] Christakis, I., Hloupis, G., Stavrakas, I. and Tsakiridis, O., 2020. Low cost sensor implementation and evaluation for measuring NO2 and O3 pollutants. 2020 9th International Conference on Modern Circuits and Systems Technologies (MOCAST), pp. 1-4.
[6] I. Christakis, G. Hloupis, O. Tsakiridis and I. Stavrakas, "Integrated open source air quality monitoring platform," *2022 11th International Conference on Modern Circuits and Systems Technologies (MOCAST)*, 2022, pp. 1-4, doi: 10.1109/MOCAST54814.2022.9837555.
[7] J. McClellan and T. Parks, "A unified approach to the design of optimum FIR linear-phase digital filters," in *IEEE Transactions on Circuit Theory*, vol. 20, no. 6, pp. 697-701, November 1973, doi: 10.1109/TCT.1973.1083764