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Technology hybridization for real time particulate matter monitoring

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Abstract While the monitoring and management of air pollution remains a challenge at a regional level, it also becomes more and more sensitive at very local scale. Both, as hot spot sources, can be very localized, but vulnerable population (in schools, hospital…) due to fluidic effect, especially in cities with tall buildings, can lead to very significant disparities in local pollution levels.

For all those reasons, accurate real time measurements of local pollution is increasingly of interest for all stakeholders. So far, no satisfactory solution (microsensors, modeling...) has proven both reliable and affordable on its own as an alternative to reference analyzers. The solution can thus only come from an appropriate combination of various technologies and algorithms.

This paper presents and shows the benefit of an innovative approach to combine well known dust air quality monitoring proven equivalent method, such as beta attenuation and indicative sensors based on light scattering as a first step to allow wider hybrid networks over particulate matter monitoring and extend it to other parameters such as gases (SO2, NO2...), which would provide simultaneously a cost effective, reliable, and hyperlocal solution especially when combined to mathematical modelling software.

Keywords: PM_{10}, $PM_{2.5}$, monitoring, air quality, micro-sensors, MP101M, hybridization.

1. Introduction:

Generally, air quality monitoring made by compact micro-sensors are qualified as indicative in comparison to reference or equivalent measurement, achieved by certified analyzers.

While the complementarity of those two approaches seem obvious, practical implementation falls short of any success up to now, with some cities using in parallel reliable reference network with a limited number of location and a network of micro-stations with a more questionable accuracy.

Effective combination of those two elements is a critical step to help cities across their problematic and, their inhabitants, to better monitor, understand, and thus improve the air quality of their city detection capabilities. A dedicated studies mixing both type of approaches was thus set up to analyze the possibilities of closer interaction between the two types of monitors.

Air pollution event in Hanoi

2. Materials and methods

Air quality solution, including MP101M certified beta attenuation monitor for PM_{10} and $PM_{2.5}$ and micro-sensors using light scattering were installed in Hanoi city Vietnam, both with collocated and separated locations.

AQMS station, Donre, Hanoi

Cairnet station installed in Hanoi

Cairnet® stations network are innovative tools that enable the real-time monitoring of the critical parameters related to air quality, as well as the corresponding impact on the surrounding community.
Up to 6 parameters are measured with one completely autonomous station, thanks to miniature cost-effective sensors based on electrochemical with amperometric detection (for gases) and light scattering optical device (for dust) developed to continuously monitor SO_2, CO, O_3, NO_2, PM_{10} and $PM_{2.5}$. This study was conducted using a new generation of optical sensors for the particulates matter (Cairsens PM) that includes, among other improvement, a heating function activated when relative humidity goes over 60% to minimize its impact on the intensity of the light scattered by the particles.
Those sensors have been deployed alongside several reference stations, using MP101M, EU and US EPA approved beta attenuation monitor for PM_{10} and $PM_{2.5}$ measurement. The same equipment was used for initial reference in France.

MP101 reference analyzers for PM10 and PM2,5, Donre, Hanoi

Some sensors have been deployed together with the certified analyzers and then switched to more remote locations, while others were always deployed at remote distance in the city. One site has been used as a reference station for the study. It was based on the roof of the DONRE building and indicated as S01. Positions of the other sites are indicated by their distance from S01 in table 1.

No.	Station	Site	Location	Type of station	Period	Note
1	Hang Dau	116	Police headquarters of Hang Ma Ward	Trafic	11/01/2020 – 11/06/2021	Co-located with Site S01
					11/07/2020 – 01/25/2021	7.3 km away from the Site S01
2	Hoan Kiem	122	Police Headquarters of Hoan Kiem District	Urban	11/1/2020 - 1/25/2021	5.5 km away from the Site S01
3	Kim Lien	119	Kim Lien Kindergarten, No. 19 Hoang Tich Tri Street	Urban	11/01/2020 – 01/19/2021	3.9 km away from the Site S01
					01/20/2021 - 01/25/2021	Co-located with Site S01
4	My Dinh	110	People's Committee of My Dinh Ward I	Urban	11/1/2020 - 1/25/2021	3 km away from the Site S01
5	Pham Van Dong	107	Hanoi Center for Natural Resources and Environment Monitoring and Analysis, 36A Pham Van Dong	Trafic	11/27/2020 – 12/29/2020	Co-located with Site S01
					11/01/2020 – 11/26/2020 and 12/30/2020 – 01/25/2021	3.2 km away from the Site S01
6	Thanh Cong	101	The roof of management Ho Thanh Cong	Trafic	11/1/2020 - 01/25/2021	1.5 km away from the Site S01
7	Tan Mai	113	People's Committee of Hoang Van Thu Ward, Hoang Mai District	Urban	11/1/2020 - 01/25/2021	6.4 km away from the Site S01
8	Tay Mo	104	People's Committee of Tay Mo Ward, Nam Tu Liem District	Suburban	11/1/2020 - 01/25/2021	5.4 km away from the Site S01

Table 1: schedule of microsensors localization and distance from S01

3. Results and discussion

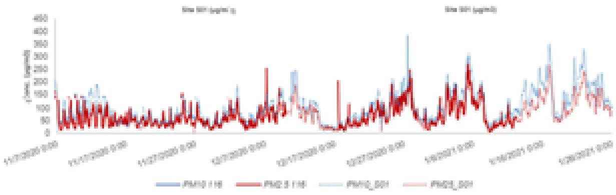
Impact of sensor correction

First, result was related to the performances of the Cairsens PM on their own, especially in a very humid climate such as Hanoi city. Those conditions and main parameters levels are summarized in table 2.

	PM10	PM2.5	HUMIDITY	TEMPERATURE
	(µg/m3)	(µg/m3)	(%)	(°C)
COLLECTION RATE	74%	74%	70%	70%
MEAN	87.0	69.1	66.9	21.8
MEDIAN	73.1	57.3	68.0	21.7
MAX	349.9	280.3	96.0	37.0
MIN	8.3	5.5	23.6	10.6

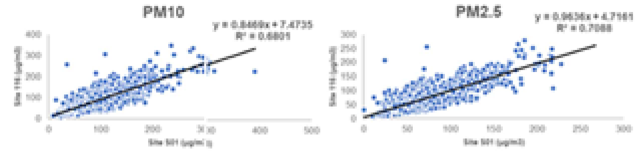
Table 2: local conditions

Results are summarized on hereafter graph 1:



Graph 1: general results of sensor 116 collocated with S01

The general trend looks reliable with a good correlation, especially compared with previous generation of sensors that did not included moisture management functions. This improvement avoid peaks during high humidity events. Global uncertainty calculation is shown on graph 2 below:



Graph 2: correlation of sensor 116 collocated with S01

Correlation (R^2) are respectively 0,68 for PM_{10} and 0,71 for $PM_{2.5}$, demonstrating that the Cairsens PM is already a good "indicative" sensor for those two parameters, even in such atmospheric conditions.

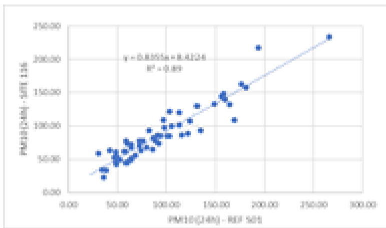
Global correlation results are given in table 3 below:

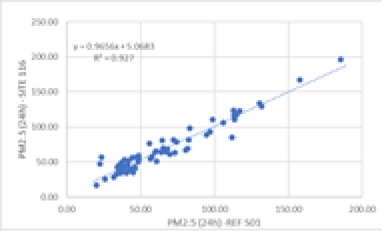
No.	Station	Site	Type of station	Distance	PM10 (R^2)	PM2.5 (R^2)
5	Pham Van Dong	107	Trafic	**Same location**	**0.72**	**0.71**
				3.2 km	0.62	0.57
3	Kim Lien	119	Urban	**Same location**	**0.63**	**0.68**
				3.9 km	-	-
1	Hang Dau	116	Trafic	**Same location**	**0.81**	**0.8**
				7.3km	0.68	0.71
6	Thanh Cong	101	Traffic	1.5km	-	-
4	My Dinh	110	Urban	3 km	0.72	0.72
8	Tay Mo	104	Suburban	5.4 km	0.73	0.76
2	Hoan Kiem	122	Urban	5.5 km	0.69	0.7
7	Tan Mai	113	Urban	6.4 km	0.61	0.63

Table 3: general results for Cairsens PM without correction

But the objective of this combination is to bring the correlation even higher using certified analyzers as a reference in real time data management system. This combination could be achieved using ENVEA XR™ air quality data management system that collects the concentrations generated by both micro-sensors and approved analyzers, together with other data such as location and meteorological data. This system would allow for a real time adjustment. The first correction was decided to be done using a fixed formula, made by comparing sensor and reference analyzer on a different site and different climate (Poissy, France).

The use of all this formula allows an additional step of correction, and provides the result shown in below graph 3:





Graph 3: general results of sensor 116 collocated with S01 after correction.

Correlation (R^2) are respectively 0,89 for PM10 and 0,93 for $PM_{2.5}$.
The same method was applied on all the sensors without concern for colocation, the complete table of results is shown in table4 below:

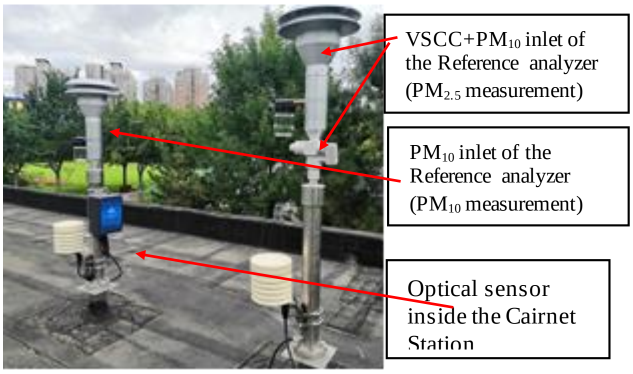
		Slope	Offset	R²
Site 116 (7,3km REF S01 - 07/11 au 25/01)	PM10 (24H)	0,84	8,42	0,89
	PM2.5 (24H)	0,97	5,07	0,93
Site 122 (5,5km de REF S01 - 01/11 au 25/01	PM10 (24H)	0,94	4,70	0,88
	PM2.5 (24H)	1,07	2,43	0,90
Site 119 (sur site REF S01 - 20/01 au 25/01)	PM10 (24H)	missing data		
	PM2.5 (24H)			
Site 110 (3km de REF S01- 01/11 au 25/01)	PM10 (24H)	0,91	-1,16	0,94
	PM2.5 (24H)	0,92	-4,25	0,94
Site 107 (sur site REF S01- 27/11 au 29/12)	PM10 (24H)	0,93	3,86	0,91
	PM2.5 (24H)	1,08	4,50	0,94
Site 113 (6.4km de REF S01 - 01/11 au 25/01	PM10 (24H)	1,02	0,62	0,84
	PM2.5 (24H)	1,12	-0,78	0,85
Site 104 (5.4km de REF S01 - 01/11 au 25/01	PM10 (24H)	0,92	1,94	0,90
	PM2.5 (24H)	0,98	0,57	0,91

Table 4: general results of corrected micro-sensors

Comparison of R² in tables 3 and 4 show that higher values are obtained within the proposed method.
It must be noted that some communication issues prevented the complete collection of data for site 119, thus correlation could not be calculated accurately and was not included in the result table.

Real time Vs pre factory adjustment

A parallel experiment was done using the same equipment in Beijing (Huajiadi, Chaoyang district), P.R of China, to expose it to a widely different kind of climate.

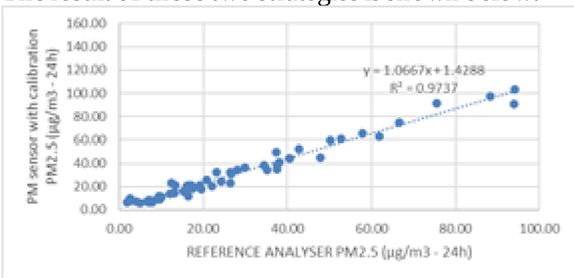


For this location, the purpose was to compare a real time adjustment of PM_{10} and $PM_{2.5}$ concentrations with and without a pre factory adjustment. Measurements were recorded from Nov. 1st 2020 to Jan. 1st 2021, to cover a wider range of atmospheric conditions. Effective range of temperature and humidity covered were as follow:

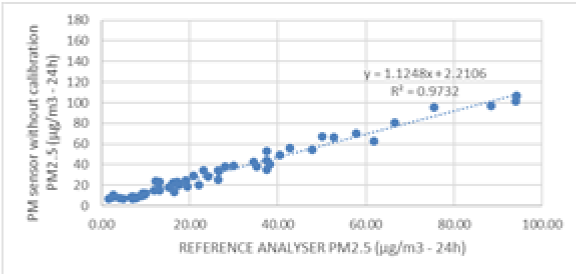
	Lower value (1h average)	Higher value (1h average)
temperature	-1,2°C	23,5°C
humidity	8%	97%

The data logger system allowed to register raw data, and thus to perform two kinds of correction, one based on a comparison performed in factory with a reference analyzer, and the second without such setting, but in both cases using the reference analyzer on site in real time for adjustment.

The result of these two strategies is shown below:



Graph 4: correlation with factory calibration



Graph 4: correlation without factory calibration

Both methods can achieve an excellent correlation factor (>0,97), but the one without factory calibration displays higher correction parameters (y=1,1248x+2,2106, compared to y=1,0667x+1,4288); showing that the recalibration from the beta gauge is more important. A slope factor lower than 1,1 is for example a criteria to pass certification such as US-EPA.

Conclusion

The article demonstrates that factory calibration is a key step to ensure proper use of micro-sensors in either standalone (micro-sensors only) or hybrid networks (sensors + certified analyzer).
In the case of hybrid networks, this calibration could be combined with on-site real time adjustment, but would reduce the scale of this adjustment, increasing the value of each location measurement.
Next step would be to add such kind of real time adjustment using certified analyzers that are not in the same location, but it will not be possible without either a micro-sensor collocated as a sample or hypothesis of the impact model, otherwise, if the only assumption is that micro-sensors should be close to the reference station nearby, it would remove any benefit of having more measurement locations.

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