Small data logger development for particulate matter measurement
Mahidol University: Salaya campus

Varong Boonchirdchoo and Sureerat Thongpradpha
Faculty of Environment and Resource Studies, IT section.

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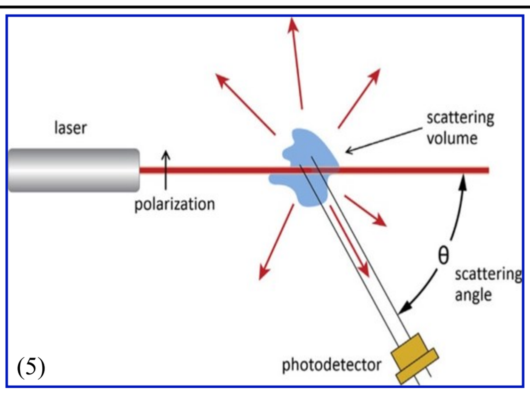
Introduction

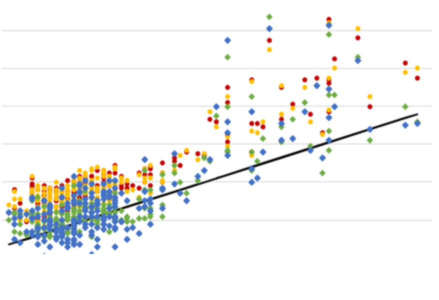
- Maintaining ambient air quality at an appropriate level is a great challenge that our society is facing. Most of the pollutants produced by human activities are particulate matter (PM), especially $PM_{2.5}$ (1), which cause a lot of health effects, such as respiratory illness and cardiomegaly (2)(3)(4).
- There is a high demand for a $PM_{2.5}$ instrument with accuracy and precision, but most of products are expensive, this limits their availability for research use.
- The lack of $PM_{2.5}$ instrument causes a small area gap that creates miscalculations to occur when modeling or interpolating within spatial analysis.
- A widely available low-cost PM sensor that uses light scattering techniques has been developed to supplement the air quality stations.

What is Light scattering?



- Light scattering is a light dispersion that reflect a light of a light scattering of an accumulated particle or a single particle.
- The scatter light is detected by a photometer as an electric pulse and its height of pulse is determined as the particles size.
- The number of pulses by area within time interval is determined by the particles mass concentration .
- The light source is a Laser or Infrared LED with a wavelength around 700 - 900 nm.
- The photometer can be placed at any angle to the light beam such as 15, 30, 45, 60 or 90 degrees.
- The high relative humidity remains the influence factor that has affected to the measurement performance by this technique.

Questions



- How long the low-cost sensors can operate wherever in an ambient environment?
- How is the low-cost sensors accuracy and precision?
- What is the limitation of the detection of low-cost sensors?
- Can the low-cost sensor be used for monitoring $PM_{2.5}$?

Materials and Method

- The PlanTower PMS5003 and the Nova-Fitness SDS021 were selected to evaluate their performance.
- Certified instrument were Teledyne Beta Plus 620 and BAM 1020.
- Microsoft R open 3.53 and Microsoft Excel 2013 were the analyst tool.
- Electronic tool was Fluke 73ii and Hantek digital oscilloscope DSO5102P.
- Relative standard deviation (RSD) was used to test the precision of low-cost sensors assembly that brought by different production batch.
- Linear regression (LR) and Maximin criterion were the tool to reveal the limit of detection (LOD). The seven levels of $PM_{2.5}$ classified as Lv1: 0-15, Lv2: > 15-30, Lv3: > 30-45, Lv4: > 45-60, Lv5: > 60-75, Lv6: > 75-90 and Lv7: > 90.
- The hygroscopic growth rate (HGR) and hygroscopic growth factor (GF) were used to estimate the values of $PM_{2.5}$ that effected by high relative humidity.
- LR was replaced by Polynomial 4th order (Poly4-R) in the order to match up with the $PM_{2.5}$ data patterns.
- Relative error (RE), root mean square error (RMSE) and r-square (R^2) were used as tools to observe an error of low-cost sensor detection which was drifting away from the value of the certified instrument.

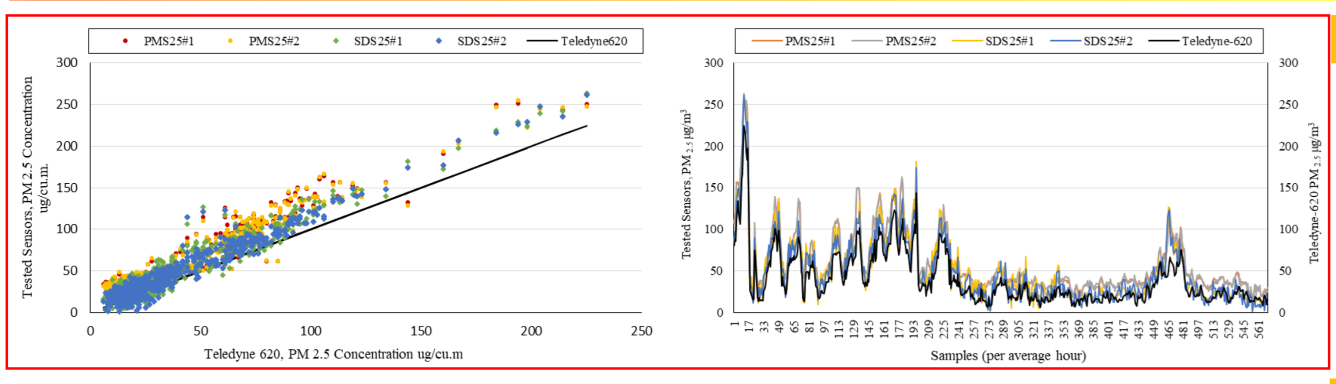


Fig.1

RE	Un-fixed				Petters and Kreidenweis				Crilley			
	PMS#1	PMS#2	SDS#1	SDS#2	PMS#1	PMS#2	SDS#1	SDS#2	PMS#1	PMS#2	SDS#1	SDS#2
BAM-1020	228.14	229.35	139.39	104.28	151.68	153.11	99.29	69.08	110.96	112.23	98.25	76.63
Teledybe-620	198.20	194.83	75.73	98.31	129.26	126.74	54.37	76.90	76.69	77.92	57.44	70.73

Fig.2

R^2	Linear Regression				Polynomial 4th Regression				R^2 residual			
Un-fixed data	PMS#1	PMS#2	SDS#1	SDS#2	PMS#1	PMS#2	SDS#1	SDS#2	PMS#1	PMS#2	SDS#1	SDS#2
BAM1020	0.9415	0.9391	0.9420	0.9732	0.9489	0.9454	0.9470	0.9753	0.0074	0.0063	0.0050	0.0021
TeleDyne 620	0.8296	0.8168	0.7203	0.6480	0.8665	0.8533	0.7978	0.7501	0.0369	0.0365	0.0775	0.1021
	Petters and Kreidenweis											
BAM1020	0.9188	0.9160	0.9065	0.9452	0.9329	0.9299	0.9209	0.9528	0.0141	0.0139	0.0144	0.0076
TeleDyne 620	0.8581	0.8462	0.7648	0.6940	0.8800	0.8688	0.8079	0.7588	0.0219	0.0226	0.0431	0.0648
	Crilley											
BAM1020	0.8236	0.8197	0.8060	0.8536	0.8405	0.8373	0.8290	0.8752	0.0169	0.0176	0.0230	0.0216
TeleDyne 620	0.8265	0.8171	0.7735	0.7109	0.8550	0.8463	0.8053	0.7501	0.0285	0.0292	0.0318	0.0392

Fig.3

RMSE and R^2										
PMS5003					SDS021					REF. Overall
Raw+LR	RMSE	20.0374	R^2	0.9275	Raw+LR	RMSE	15.4507	R^2	0.9272	
Fixed+LR		12.7963		0.9225	Fixed+LR		10.6043		0.9017	
Fixed+Po4		8.3116		0.9357	Fixed+Po4		9.2557		0.9187	

Fig.4

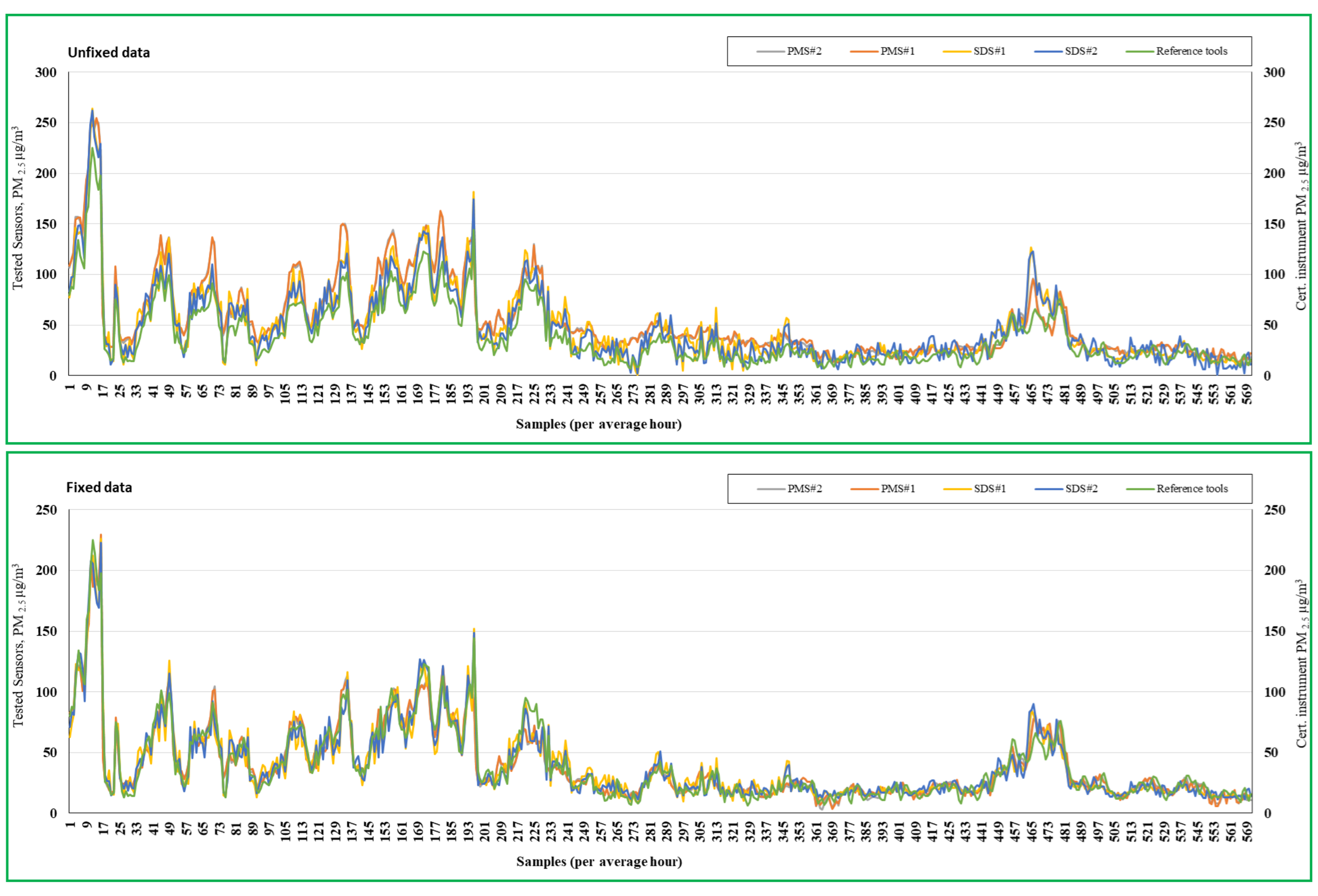


Fig.5

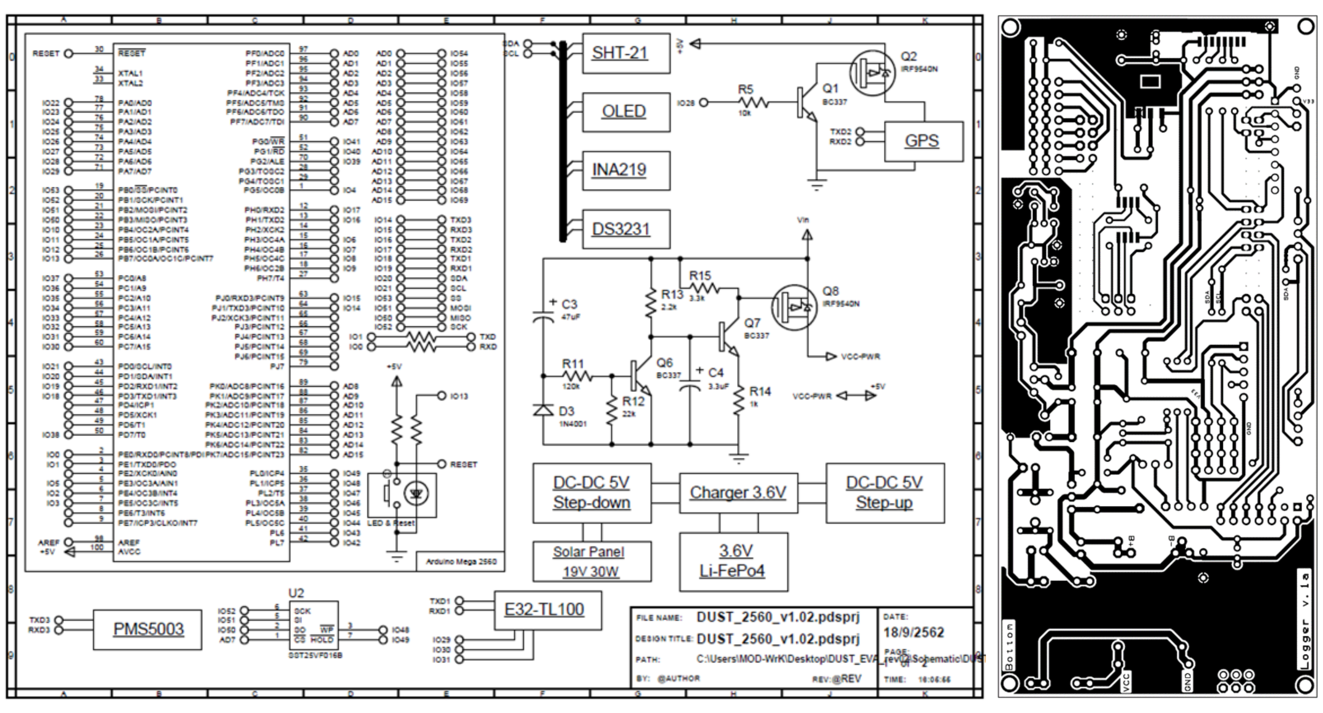


Fig.6

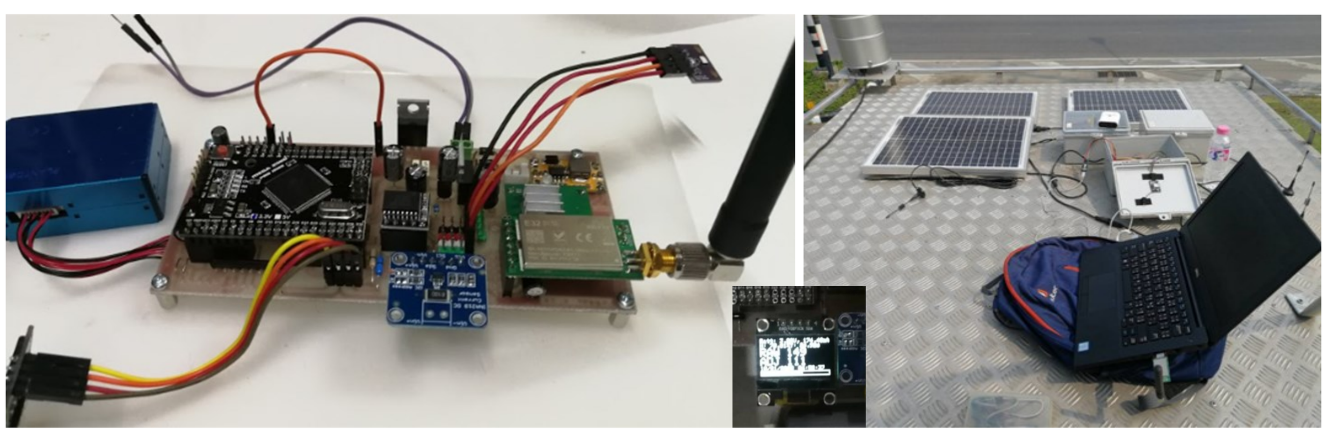


Fig.7

Results

- There was no fault with the tested sensors for 3½ weeks. (fig.1)
- RSD shows the PMS5003 assembly processes was more precise than SDS021 with < 0.5% deviation.

	PMS#1	PMS#2	Diff	SDS#1	SDS#2	Diff	BAM1020
SD	42.99	42.87		42.08	41.74		36.55
RSD	59.2%	59.0%	**0.2%**	65.6%	67.8%	**2.2%**	72.0%

	PMS#1	PMS#2	Diff	SDS#1	SDS#2	Diff	TYDN620
STD	18.87	18.75		19.74	20.57		13.62
RSD	45.4%	45.5%	**0.1%**	68.1%	71.3%	**3.2%**	59.2%

- R^2 of the PMS5003's LOD was 15µg/m³ as shown in the maximin criterion table.

	PMS#1	PMS#2	SDS#1	SDS#2	max	min
L7	0.8630	0.8581	0.9579	0.9788	0.9788	
L6	0.1906	0.1535	0.3480	0.5837	0.5837	**0.5837**
L5	0.1468	0.1422	0.0671	0.0942	0.1468	**0.1468**
L4	0.2331	0.2249	0.0020	0.0307	0.2331	**0.1468**
L3	0.4329	0.4416	0.2343	0.3603	0.4416	**0.2331**
L2	0.3610	0.2828	0.2092	0.1945	0.3610	**0.3610**
L1	0.0017	0.0024	0.0203	0.0222	0.0222	**0.0222**

- The RE of sensors was in a fig.2, the Crilley model (6) could correct the drifted data higher than Petters model (7). Furthermore, the high relative humidity influence was the major role to worsen the sensors detecting performance.
- As replacement of LR with Poly4-R, had a potential to improve the performance of sensors. The result shows R^2 was higher than LR with both of the models as fig.3.
- R^2 and RMSE also insisted the Poly4-R was the best over the LR with low data deviation (RE analyzed in fig.2) and got a higher R^2 as fig.4.
- The result in fig.5 was derived from Petters model and Poly4-R to estimate $PM_{2.5}$ that compared with the $PM_{2.5}$ of the certified instrument.
- The developed station (fig.6) was based on C programming for ATMEGA 2560 through avr-gcc version 8 complier. The final prototype was the fig.7.
- The second test were held in November to December 2019. (Lowest section)
- The sample test was on 9 January 2020 at 16:07 which outside the research. The station's $PM_{2.5}$ was 48µg/m³ without the correction processes. When this value passed through the developed method, the expectation would be 34.09µg/m³ which slightly varied from 36.84µg/m³ of the certified instrument.

Conclusions

PMS5003 can be used to monitor $PM_{2.5}$ level in an ambient environment. Its result correlated with the certified instrument as statistical significance. Because of R^2 gave 0.9357 or 93.5%, was an accordance with the Polynomial 4th order regression analysis model and RMSE was 8.3116. That referred to the discrepancy between the low-cost sensors and the certified instrument was around ±8.3116µg/m³.

$$Y' = -0.000000433x_i^4 + 0.0001836x_i^3 - 0.0242x_i^2 + 2.1x_i - 25.6,\ x_i >= 15.2$$

In addition the above formula, the lowest x is 15.2 which is the corresponding LOD of PMS5003 that is 15µg/m³. While the sensor reads $PM_{2.5}$ below 15.2µg/m³, the corrected $PM_{2.5}$ will be negative value. Also x_i must calculated by Petters model through hygroscopic growth factor (GF) as formula $x_i = Sensor_{readvalue} / GF$.

Literature cited

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The second test was on 23 Nov 2019 to 23 Dec 2019. R^2 = 0.8941, RMSE = 6.9786, mean absolute error (MAE) = 5.1268, Overall RE = 149.89