Low Cost Sensor Network for Indoor Air Quality Monitoring in Residential Houses: Lab and Indoor Tests of Two PM Sensors

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Abstract

Purpose / Context – The purpose of our work is to investigate: a) the sensor responses of the two different low-cost PM sensors to concrete dust and indoor environment and activities; b) the evaluation of the measuring performance of two low-cost PM sensors and their potential application in indoor air quality monitoring.

Methodology / Approach – The chamber and indoor tests of Sharp sensor GP2Y1010AU0F (Sharp sensor) and Shinyei sensor PPD42NS (Shinyei sensor) were conducted. Otherwise, the sensor board of Sharp and Shinyei sensors was located in the indoor environment for over 24 h.

Results – Lab and indoor tests of the Sharp sensor and Shinyei sensor were conducted and they showed a good agreement with the reference instruments (DustTrak and AirBeam) and respond quickly to the concrete dust concentration change above 50 μg/m^3 as well as repond well to cooking activity when locating in the indoor environment.

Key Findings / Implications – The Sharp sensor and Shinyei sensor were all able to detect $PM_{2.5}$ in the chamber test and indoor environment. However their ability to monitoring PM concentration in ambient concentrations (around 10~20 μg/m^3) still need further validation and improvement.

Originality –The collected data of indoor air quality and environmental parameters will also be a reference to adjust the HVAC system and energy use based on individual’s behaviour. The lab and indoor tests of these two PM sensors are the first step to put the low cost sensors into practice.

Keywords - indoor environment quality; sensor network; indoor/outdoor relationship; indoor air quality monitoring; low cost PM sensor

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1. Introduction

Indoor air quality has become a hot issue since the modern building and houses are more airtight and space saving which are not good for air circulation and exchanging. Otherwise, people are spending a large percentage of them daily time in indoor environment. Indoor air contaminants can affect the occupant's health, comfort and then influence their working performances and may be related to Sick Building Syndrome (SBS) and Building Related Illness (BRI) (Zampolli, Elmi et al. 2004, Kim, Jung et al. 2010, Saad, Saad et al. 2013).

Among various air pollutants in indoor environment, particulate matter (PM) has been a crucial role in air pollution since it poses adverse impact on human health and living environment (Ashmore and Dimitroulopoulou 2009). A large number of researches have been done on PM pollution (Agus, Young et al. 2007, Morawska, Johnson et al. 2009, Buonanno, Marini et al. 2012, Snyder, Watkins et al. 2013), however, the state of the art monitoring tequeniques are always being bulky, complicated, expensive and time consuming, the promising sensing technologies of PM are effective tool to be utilized in the air pollution monitoring area.

There are a few kinds of PM sensor monitor available in the market. The DC1100 Pro Air Quality (Dylos) is a Laser Particle Counter with two different size ranges. The small channel (0.5> Micron) can detect bacteria and mold. The Large channel (2.5> micron) is able to detect dust and pollen and it costs 290 USD (http://www.howmuchsnow.com/arduino/airquality/grovedust/). Other PM measuring devices such as AirBeam, AirBot, Air Quality Egg and Electronic Nose Sensor are available in the market or under developing (http://www.treehugger.com/clean-technology/environmental-sensors.html). Several dust sensing projects has been done (Holstius, Pillarisetti et al. 2014, Austin, Novosselov et al. 2015, Wang, Li et al. 2015), however few of them were investigated in the real indoor environment. In order to investigate the performance of the low-cost PM sensor and its ability to measure the PM concentration in the air, a series of measurements of sensors were conducted in the chamber together with the DustTrak and indoor environment (a living room of a typical house) together with Airbeam.

The aim of the job is to investigate: a) the sensor responses of the two different low-cost PM sensors to concrete dust and indoor environment and activities; b) the evaluation of the measuring performance of two low-cost PM sensors and their potential application in indoor air quality monitoring.

2. Methodology

2.1 PM Sensors

The low-cost PM sensors investigated were Sharp dust sensor GP2Y1010AU0F (Sharp sensor) and Shinyei PPD42NS dust sensor (Shinyei sensor). These two sensors are all working by light scattering but they varied in details. And the price of them are around USD10 and easy available in the market.

The Detecting principle of Sharp sensor is that the light emitter (Light Emitting Diode) and the light detector (Photodiode) are spotted with a lens and a slit. When dust and/or cigarette smoke exists inside of it, the light from light emitter is refracted by particles and the amount of scattered light is detected (Budde, El Masri et al. 2013). Current in proportion to amount of the detected light comes out from the detector and the device makes analog voltage output (Pulse output) after the amplifier circuit amplifies the current from the detector (KHADEM and SGÂRCIU 2014). The Shinyei sensor is working by that an light beam provided by the infrared led and the light scattered by particles at a forward angle of about 45° is picked up by photodiode, a lens in front of the photodiode focuses into a detection region in the air flow and close to the LED light portal (Allen , Austin, Novosselov et al. 2015). The Shinyei particle sensor PPD4NS is used to create Digital (Lo Pulse) output to Particulate Matters (PM). Lo Pulse Occupancy time (LPO time) is in proportion to PM concentration. The air sample is drawing by a heater resistor. The minimum detectable particle size is approximately 1μm with a detectable range of concentration of 0~28,000 pcs/liter (KHADEM and SGÂRCIU 2014).

During the test period, 4 Sharp sensors and 4 Shinyei sensors were assembled on one board as shown in Figure 1 and the Sharp and Shinyei sensors read and store PM concentration outputs at 1-s intervals.

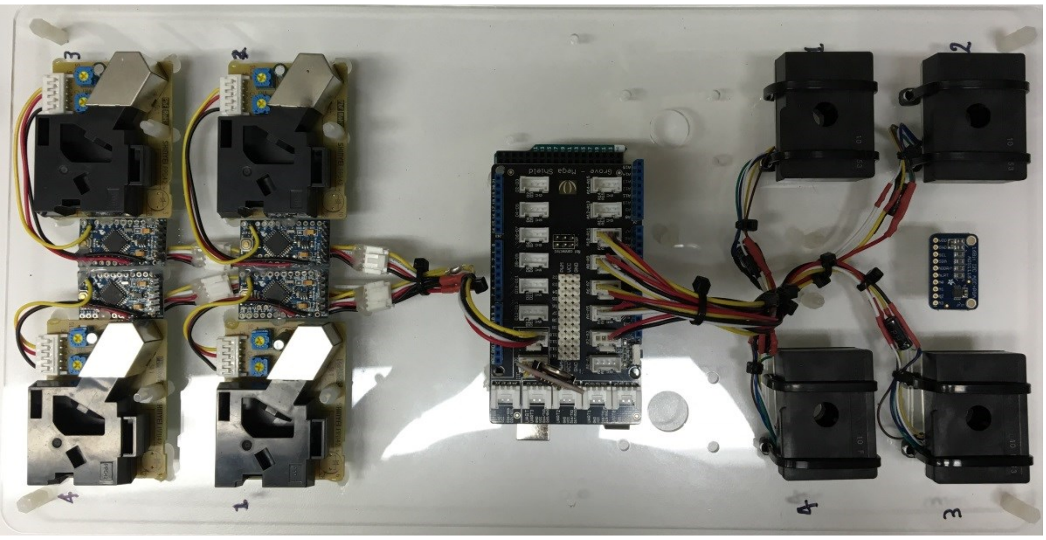

Figure 1 Sensor board architecture (left: 4 Shinyei sensors, right: 4 Sharp sensors)

2.2 DustTrak

DustTrk Aerosol Monitors are battery-operated, data-logging, light-scattering laser photometers which can simultaneously measure both mass and size fraction in real-time. It can measure PM1, PM2.5, Respirable, PM10, and Total PM size fractions. The detecting particle size range is 0.1 to 15 μm and the Aerosol Concentration Range is 0.001 to 150 mg/m^3 (DustTrak-DRX aerosol monitor datasheet).

2.3 AirBeam

AirBeam is a wearable air monitor that maps, graphs, and crowdsources your pollution exposures in real-time via the AirCasting Android app (http://www.takingspace.org/aircasting/airbeam/). It uses a Shinyei PPD60PV sensor as the sensing element and measures $PM_{2.5}$ at 5-min intervals. In the indoor test, we use the Airbeam data as a reference to see the indoor $PM_{2.5}$ concentration variation.

2.4 Testing procedures

The sensor board of 4 Sharp and 4 Shinyei sensors were first tested in the chamber together with DustTrak. The concrete dust was blow into the chamber to test the sensor responses.The DustTrak were fitted with a $PM_{2.5}$ filter and the measuring time was set to 5 s. The timeline of chamber test are listed in Table 1.

Table 1 Timeline and activities in lab test.

Time	Activities
13:04:06	Start (in the chamber) with DustTrak and fan on
13:08:45	Blow the Concrete dust
13:39:40	Vacuum on to decrease the aerosol concentration
13:47:35	Turn off the fan
14:42	Stop

Later, the sensor board of 4 Sharp and 4 Shinyei sensors were put in the living room of a house together with Airbeam for over 24 h. During the measuring time, the house was occupied by two persons with normal daily activities such as cleaning, washing and cooking. The timeline for the Indoor test are listed in Table 2.

Table 2 Timeline and activities in indoor test.

Time	Activities
21/05/2016 16:10	Start together with Airbeam
16:45-20:~(no exact time)	Cooking and eating
20:~-22:~ (no exact time)	One person in the living room
22:~- 22/05/2016 12:00	No one in the living room
12:00-14:00	Cooking
14:00-16:35	One person in the living room
16:35-17:00	bake + fry+eating
18:07	Stop test

3. Results and discussion

3.1 Chamber test with concrete dust

Figure 2 presented the response of DustTrak and Sharp and Shinyei sensors to concrete dust in a Chamber environment. As it was depicted in Figure 2 (a), the sharp sensors are sensitive to concrete dust and respond quickly to concrete dust. Otherwise, the 4 Sharp sensors are in good agreement with each other and respond quickly to a concrete dust concentration increasing.

As from Figure 2 (b), it is obvious that the Shinyei sensors are also able to detect the concentration variation of concrete dust as the sensors output decreasing together with the DustTrak readings. However, the sensors outputs keep stable after the DustTrak readings went down to 50 $\mu g/m^3$ and these may indicate the detection size range of both two kinds of sensors are lower than the DustTrak. Otherwise, the Shinyei sensor 1 and 3 were not sensitive and sensor outputs always became 0 when the dust concentration are very low. The variability (called “noise”) in the Shinyei outputs are much bigger compare with the Sharp sensors.

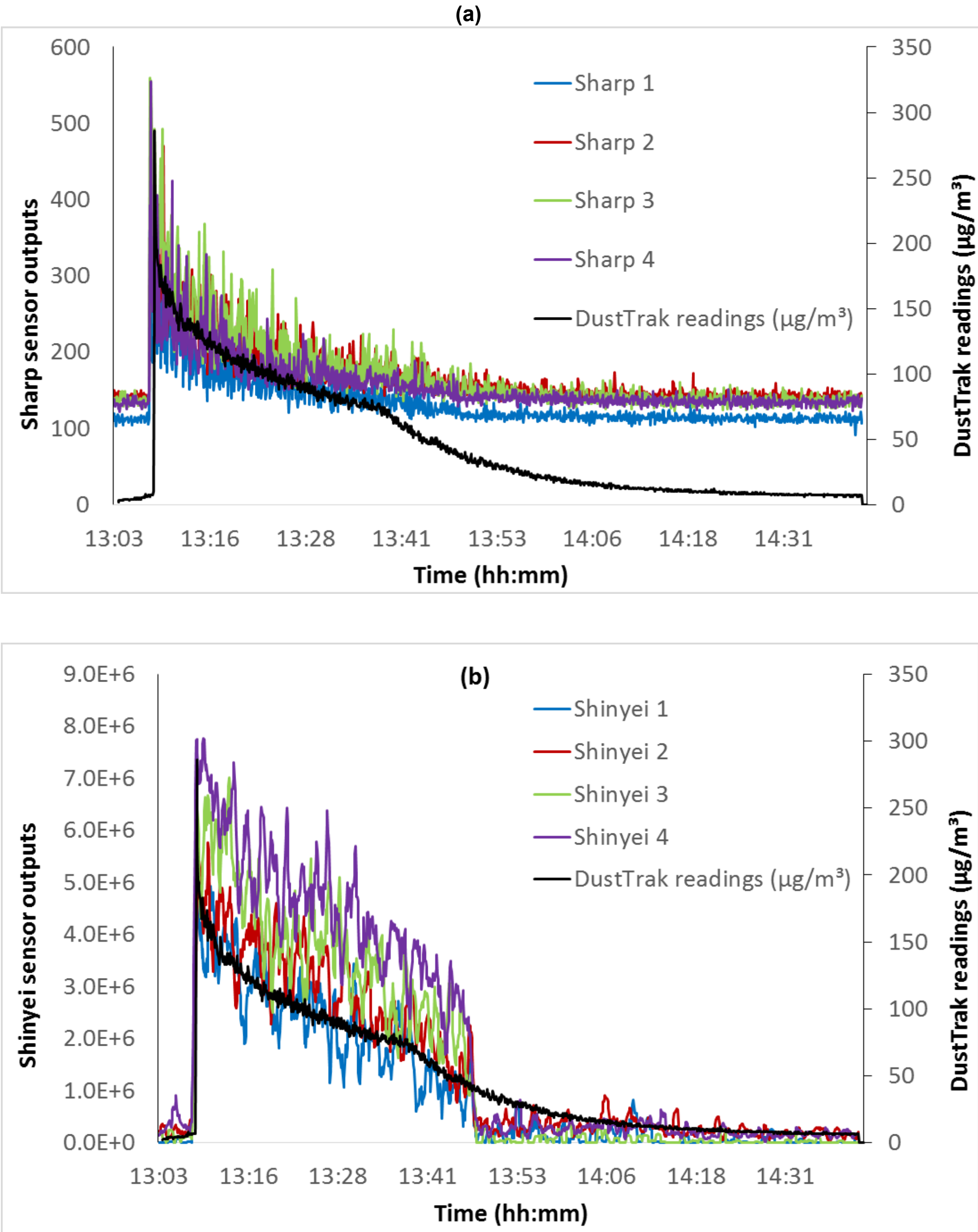

Figure 2 Time series of DustTrak readings with sharp (a) and shinyei (b) sensor output in Chamber test.

From Fig.3 (a), the linearity between Sharp outputs and DustTrak reading were good (R^2=0.58-0.67), and the Sharp sensor outputs ranges were very small while the DustTrak readings were below 50 µg/m^3. As it was presented in Figure 3 (b), the linearity between Shinyei outputs and DustTrak readings were high (R^2=0.89-0.91), but sensor outputs were stable and close to 0 when the DustTrak readings are below 50 µg/m^3.

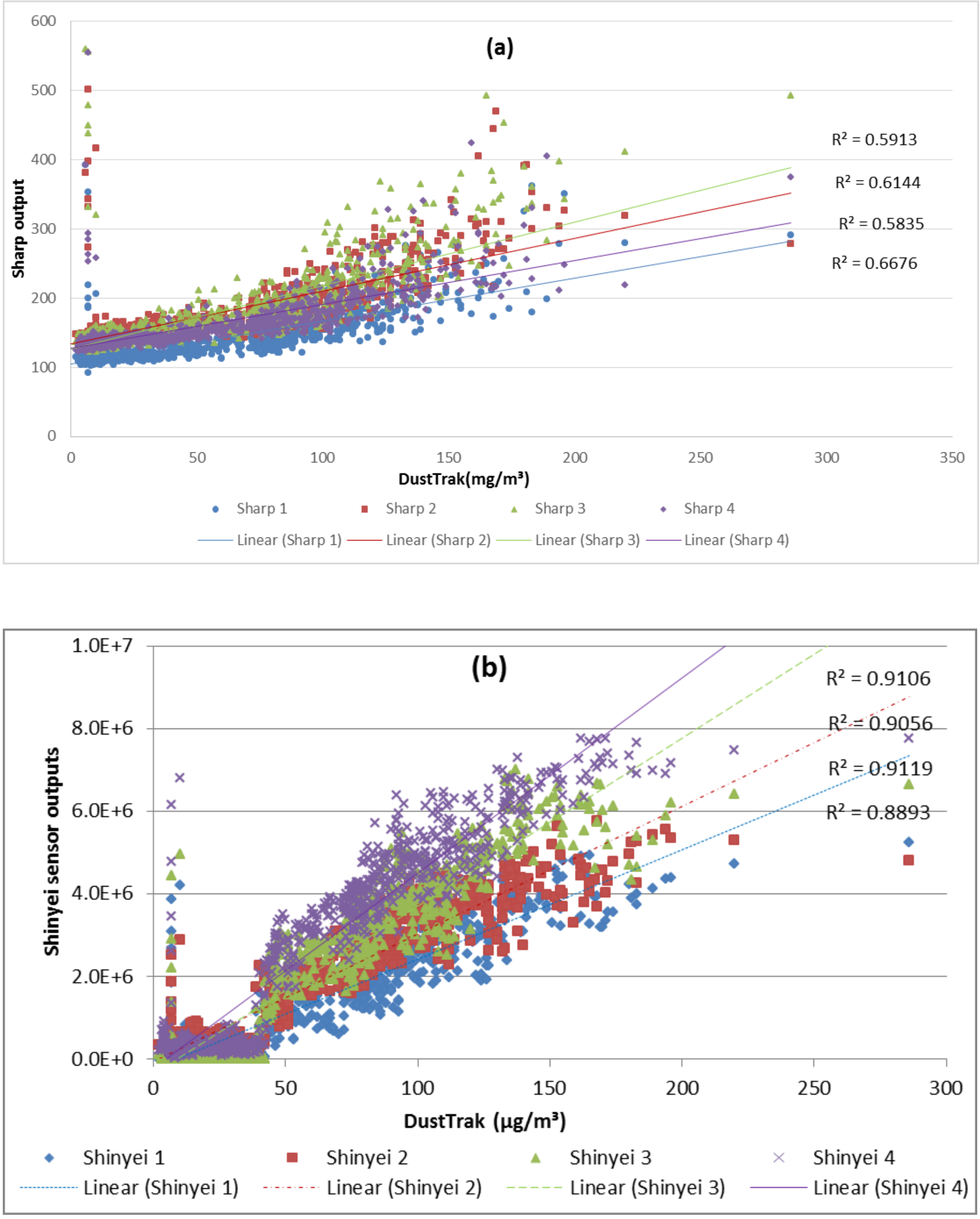

Figure 3 Linearity of DustTrak readings vs sharp (a) and shinyei (b) sensor output in chamber test

3.2 Indoor test

Because the values of AirBeam are $PM_{2.5}$ concentration in every 5 minutes. To plot, the average of every 5 minutes of the Sharp and Shinyei sensors outputs have been calculated. As it was shown in Figure 4 (a), Sharp sensors outputs increased and have peaks at 5 pm of both two day because of cooking activities. The same trend was found in AirBeam data. These demonstrated that the Sharp sensors can reponse to $PM_{2.5}$ concetration changes due to indoor activities. From Figure 4 (b), the Shinyei sensors were presenting small peak values at 5 pm of both day, it was illustrated that the Shinyei sensors can respond to cooking emissions. However, the Shinyei outputs were varied greatly during daytime (9 am to 3 pm) of the second day. It was later analyzed and found to be caused by the strong sunlight shining on the sensor board through the window. And both Sharp and Shinyei sensors outputs settled down at night (from 10 pm-9 am the next day) when no one are walking around or occupied in the living room.

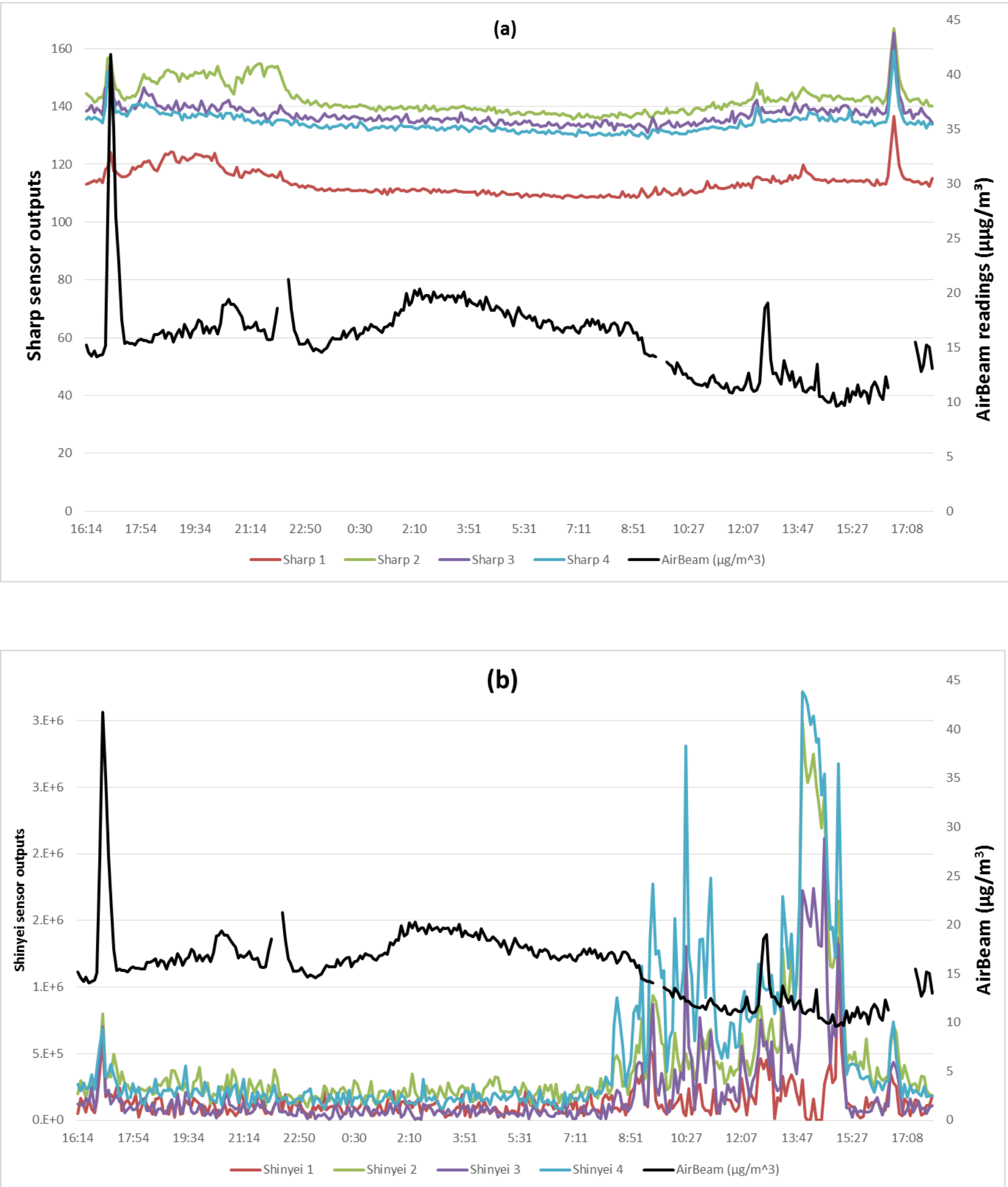

Figure 4 Time series of Airbeam readings with sharp (a) and shinyei (b) sensor output in indoor test

4. Conclusion

The low-cost Sharp and Shinyei PM sensors were evaluated in the lab and indoor environment. The Chamber tests indicate that both Sharp and Shinyei sensors respond to particles concentration > 50 μg/m^3 and they respond in line with the DustTrak but the responses of unfiltered signals are noisy. Otherwise, the problem of both sensors is that whether they are able to detect $PM_{2.5}$ at a low concentration range need to be validated and strengthened.

Some measures will be applied in the future work to reduce the noisy and imporove the sensitivity of sensors. The first step will be increasing the measuring time intevals of both sensors to every 30 s or every 5 min or even longer. The second way is to cover the sensor board with light-proof materials to prevent the influence of light. Later a fan can be added to both sensors to increase the PM concentration rather than the passive measuring of Sharp sensors or relying on the resistor heater in the Shinyei sensors.

Since only a small part of work has been done, the future work will be foucus on the calibration of the PM sensors and their practical application in residential houses. The multiple parameters including temperature, humidity, and light intensity on PM sensor performance need to be conducted and validated. Besides, other reference PM measuring methods such as SMPS, TEOM, APS will be used to calibrate sensor performance.The low cost PM and gas sensor will be used inside the houses as well as outdoors to quantify the levels of the indoor air pollutants and the relationship between indoor and outdoor pollutants.

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