The Outdoor Dust Information Node - ODIN

Development and first tests

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The large gradients in air quality expected in urban areas place a significant challenge to standard measurement technologies. Small, low-cost instrumentation has been developing fast in recent years. Here we present the first version of the Outdoor Dust Information Node (ODIN) developed by NIWA. The results of field tests indicate that the ODIN is able to capture more than 90% of the variability in $PM_{2.5}$ in a wood-smoke impacted site but further tests are required in order to generalize those results.

Keywords: *Dust, Low-cost sensor, Instrument development, Calibration.*

Introduction

Urban air pollution has been linked to more than 7 million premature deaths a year worldwide. However, most of the available studies in air pollution rely on a sparse network of measurement sites in urban areas and have trouble resolving the large gradients in concentrations expected in urban areas[4]. One of the main reasons for the sparseness of the networks is the significant cost of the sensors but over the past few years, advances in miniaturization and mass production have enabled the development of low-cost sensors that have sparked a number of citizen science initiatives ([2, 5, 9, 3]). However one of the first issues that these projects find is the quality of the data obtained and the need for some level of calibration of the units.

NIWA has made some progress in this area with the development of the Particles, Activity and Context Monitoring Autonomous Node (PACMAN) for indoor exposure studies [8]. To complement the PACMAN, it was necessary to count with an instrument to describe the outdoor air quality as one of the questions is often about the

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impact of infiltration on the indoor environment. In this work we present the results of the first field tests of the Outdoor Dust Information Node (ODIN) in terms of its performance against compliance-level instrumentation.

Methods

ODIN

The ODIN was developed starting from the same base as the PACMAN [8] in terms of hardware and firmware, building as much as possible on the existing open source hardware and software tools available. The components of the unit are:

- **Dust sensor**. To benefit from the PACMAN development, the same component used in PACMAN was used here, namely the Sharp Optical Dust Sensor GP2Y1010AU0F[1].
- **Temperature and relative humidity**. From previous tests [8] we have identified that the response of the PACMAN's dust sensor has a dependency with ambient temperature and given that the measurement principle is light scatter, we expect that relative humidity also influences the measurements and therefore included the HUMID temperature-humidity sensor from Freetronics[2].
- **Microcontroler**. To benefit from the PACMAN development, the same component was used, namely Sparkfun's Arduino Pro Mini based on the ATMega328 microcontroller[3].
- **Memory**. A 2GB μSD card is used to log the dust, tempreature and relative humidity data. Adafruit's μSD card adapter board[4] was used to interface with the microcontroller.
- **Clock**. Because the microcontroller does not have an internal real time clock, an external component was needed. The DS3231 based temperature compensated RTC Chronodot v2.0[5] was used to keep track of time.
- **Power**. A lithium ion polymer battery pack delivers the power required for the unit.

To maximise the battery life, the sensor only logs once per minute in a separate file for each day. The details of the firmware can be obtained elsewhere[7]

[1] `http://www.sharpsde.com/optoelectronics/sensors/air-sensors` accessed 2014-07-07
[2] `http://www.freetronics.com/collections/modules/products/humidity-and-temperature-sensor-module` accessed 2014-07-07
[3] `https://www.sparkfun.com/products/11113` accessed 2014-07-07
[4] `http://www.adafruit.com/products/254` accessed 2014-07-07
[5] `http://docs.macetech.com/doku.php/chronodot_v2.0` accessed 2014-07-07

Deployment

In this study, we used the first prototype of the Outdoor Dust Information Node labelled **ODIN_01**. Environment Canterbury[6] provided us access to their air quality monitoring site at St Albans (Coles Place) and the **ODIN_01** was deployed there between the 15^{th} of May and the 3^{rd} of June 2014 with a pause between the 22^{nd} and the 24^{th} of May. The data for this deployment can be found elsewhere[6]

Figure 1: Deployment of ODIN_01 at ECan's air quality monitoring site.

Auxiliary data

Data for the standard air quality monitoring station was obtained from ECan's data catalogue[7] and it included PM_{10} and $PM_{2.5}$ measured by TEOM-FDMS, wind speed, direction and air temperature[1].

Regression analysis

According to previous analyses of PACMAN data[8], it is expected that the response of the ODIN depends on the ambient temperature and relative humidity. In this analysis,

[6] http://ecan.govt.nz
[7] http://data.ecan.govt.nz/Catalogue/Method?MethodId=29 accessed 2014-07-07

a linear relationship is proposed:

$$Dust_{calibrated} = A * Dust_{raw} + B * Temperature_{ODIN} + C * RH_{ODIN} + D \quad (1)$$

In order to obtain the parameters A, B, C and D, a multi-linear regression was performed between the ODIN data and the data from the TEOM-FDMS. The data was further separated into daytime and nighttime to explore the variability in the regression coefficients throughout the day.

Results

Raw ODIN output

Figure 2 shows that the raw **uncorrected** data from ODIN does not capture the observed features of the PM_{10} or $PM_{2.5}$ time series.

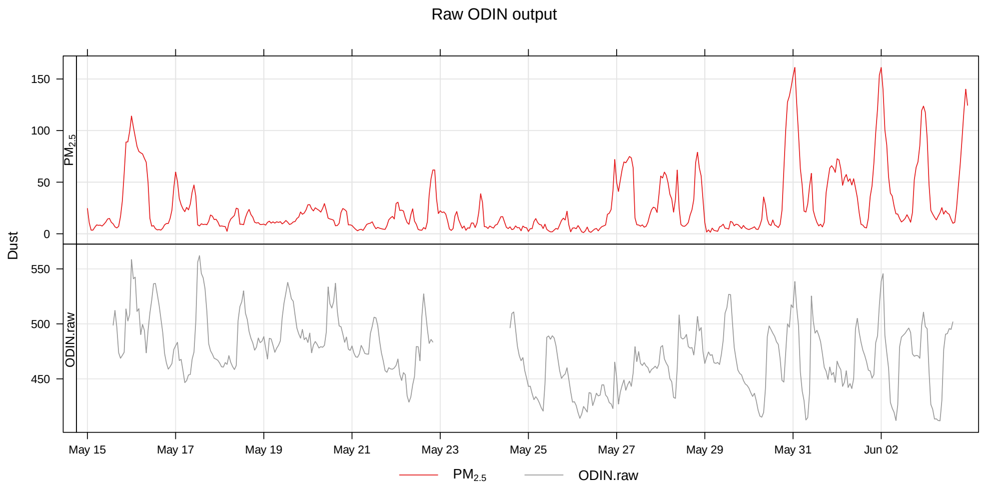

Figure 2: Comparison between the raw output from ODIN (top plot), PM_{10} (middle plot) and $PM_{2.5}$ (bottom plot). Note that all three plots have been normalised by their respective means in order to highlight the patterns rather than the absolute concentrations.

Calibrated data

By performing the linear regression indicated earlier we were able to determine the values of the coefficients for the whole time series, for the daylight data (from 08:10 to 18:00) and for the nighttime data (from 18:10 to 08:00). Table 1 shows that the linear regression gives high correlation coefficients for the *all day* and *nighttime*. During

Table 1: Calibration coefficients for ODIN separated by time of day. Daytime is used here from 09:00 to 18:00 and nighttime is used here from 19:00 to 08:00. The error estimates correspond to the 95% confidence interval.

Coefficient	Full time series	Daytime	Nighttime
Raw dust	0.91 ± 0.05	0.33 ± 0.11	1.01 ± 0.05
Temperature	-5.51 ± 0.25	-2.30 ± 0.73	-5.62 ± 0.27
RH	-1.03 ± 0.12	-0.29 ± 0.23	-1.04 ± 0.17
Intercept	-284.94 ± 23.71	-96.01 ± 41.61	-331.66 ± 27.92
Adjusted R^2 (model fitting)	0.84	0.28	0.90

daytime, the model fit is not as good as reflected both by the low correlation coefficient (¡30%) and large confidence intervals. Particularly interesting is the significant increase in the size of the confidence interval for **RH** from 10% for the night data to almost 80% for daytime. This may indicate that relative humidity only plays a significant role during nighttime. This was expected because at RH above a certain level, its effects on aerosol growth are more evident.

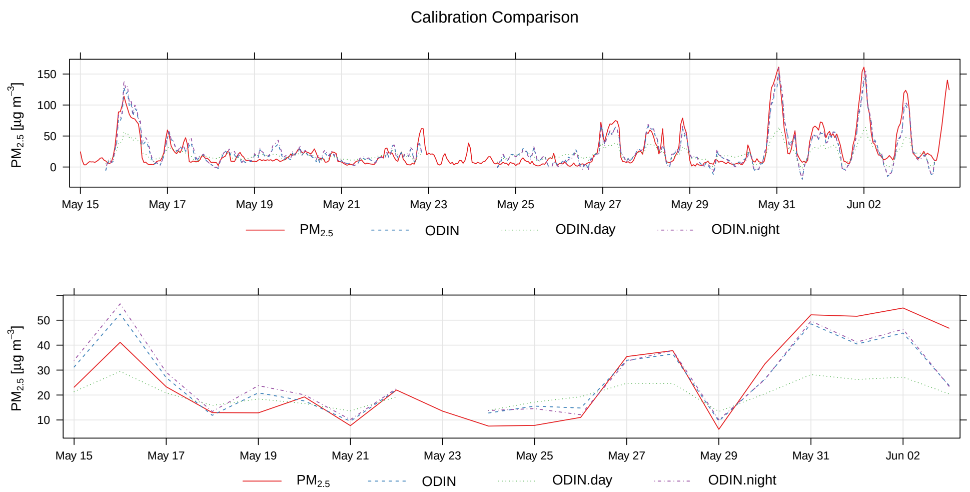

Figure 3: Hourly (top) and daily (bottom) time series of calibrated ODIN data together with FDMS $PM_{2.5}$ concentrations.

Figure 3 shows the time series of the calibrated ODIN data according to the three sets of parameters in Table 1. Comparing the raw data in Figure 2 it is clear that the temperature and relative humidity corrections managed to extract $PM_{2.5}$ concentrations from the ODIN dust signal. In fact, the ODIN data is able to reproduce all major features of the PM2.5 time series both in one and 24 hour scales.

Conclusions

The small, low-cost dust sensor ODIN has been shown to be able to capture most of the features of the $PM_{2.5}$ time series in a wood-smoke impacted area.

The ODIN seems to perform better during nighttime which may be related to both the levels of dust observed at night and the kind of emission source dominant during these periods.

The impact of relative humidity on the ODIN's performance seems to be more significant during nighttime but more tests are required capturing more varied conditions.

Future work

The next steps in understanding the response of the ODIN to urban aerosols are to explore the inter-instrument variability and the transferability of calibration coefficients. This will be done with data currently being captured in Auckland and Christchurch and it is expected to generate results by winter 2015.

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Supporting material

The computer code used to generate the plots and results in this manuscript can be found here: `https://github.com/guolivar/ODIN_anzaw2014/tree/v1.0`

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