Device benchmarking study

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All three of the device types deployed at scale for the project were assessed at UTS by a team from the Faculty of Engineering and IT, in collaboration with the Faculty of Science. An additional three air quality monitors that were not deployed for the project were also benchmarked to provide insight into comparative performance of the EMS. Using a custom-designed chamber to control environmental variables, the quality of data from each device was directly compared to data from a high-performance reference monitor. Device performance was also compared between devices allowing them to be ranked.

Three devices deployed at scale for the project (TULIP EMS; Netvox R712; DecentLab Temperature Sensor) were found to perform to a satisfactory or high standard across all parameters. This independent assessment supports their use in the project as devices that produce reliable and trusted data. The EMS performed best in its class for particulates and NO2, when compared to three other air quality monitors. It could not be compared to a CO or O_3 monitor.

Test chamber design
A test chamber was constructed using the design for a Continuous Mass Flow Reactor (CMFR) to enable introduction and thorough mixing of pollutants before emissions sampling, ensuring that reference monitors and IoT devices sampled precisely the same concentrations. The chamber had an interior volume of 308 litres and was lined with stainless steel to minimise chemical interference from chamber walls.

Image: The EMS mounted inside the test chamber. The perforated sheet separates the visible test section of the chamber from the mixing section behind.

Research Aims and outcomes:

1) Confirm that devices deployed for the project are fit for purpose
2) Determine how project devices perform against common commercially available competitors

Devices deployed for the project:

Manufacturer	Model	Measures	Measurement range	Measurement technique
The ARCS Group	Custom-designed Environmental Monitoring System (EMS)	$PM_{2.5}$ O_3 NO_2 CO Temperature and Relative humidity **Noise** **Location**	0-500 µg/m³ ($PM_{2.5}$) 0-1000 ppm (CO) 0-5 ppm (O_3) 0-5 ppm (NO_2) -40-80 °C (temperature) 0-100% (relative humidity)	Laser light scattering ($PM_{2.5}$; Plantower PMS7003 sensor) Electrochemical sensors (O_3 – SPEC 3SP_O3_5 sensor; NO_2 – SPEC 3SP_NO2_5F sensor; CO – 3SP_CO_1000 sensor) Electret microphone (noise) Capacitative type sensor (MaxDetect RHT03 sensor) Global Positioning System (location)
Decentlab	DL-SHT35-002	Temperature and Relative humidity	-40-125 ° C 0-100%	Band-gap temperature sensor Capactive type humidity sensor
Netvox	R712	Temperature and Relative humidity	-10-50 ° C 10-90%	Capactive type humidity sensor

Commercially available devices used for benchmarking comparison:

Manufacturer	Model	Measures	Measurement range	Measurement technique
Libelium	Smart Cities Pro	PM_1, $PM_{2.5}$, PM10 NO_2 **NO** **CO** Temperature, Relative humidity and pressure	10,000 particles/litre in 16 size bins (PM_1/$PM_{2.5}$/PM_{10}) 0-20 ppm (NO_2) 0-18 ppm (NO) 0-500 ppm (CO) -40-85 °C (temperature) 0-100% (relative humidity) 30-110 kPa (pressure)	Optical particle counter (Alphasense OPC N2) Electrochemical gas sensors Integrated environmental sensor (Bosch BME280)
GlobalSat	LS-113P	$PM_{2.5}$ Temperature and relative humidity	0-500 µg/m³ ($PM_{2.5}$) -40-125 °C (temperature) 0-95% (relative humidity)	Laser light scattering Complementary metal-oxide semiconductor
Aeroqual	AQY-1	$PM_{2.5}$ **O_3** **NO_2** Temperature and relative humidity **Dew point**	0-1000 µg/m³ 0-200 ppb 0-500 pbb -40-125 ° C 0-100% -30-50 ° C	Laser light scattering ($PM_{2.5}$) Gas sensitive semiconductor (O_3) Electrochemical sensor (NO_2)

Reference monitors:

Manufacturer	Model	Measures	Measurement range	Measurement resolution
TSI	8533 DustTrak	$PM_{2.5}$	0.001-150 mg/m^3	±0.1% of reading or 0.001 mg/m^3 whichever is great
Ecotech	EC9841AS	NO, NO_2	0-1000 ppm	2 ppb or 0.1% of reading whichever is greater
Ecotech	EC9830	CO	0-200 ppm	0.025 ppm or 0.1% of reading whichever is greater
Ecotech	Serinus 10	O_3	0-20 ppm	0.5 ppb or 0.2% of reading whichever is greater
TSI	VelociCalc Model 9565	Temperature, relative humidity and pressure	-10 – 60 °C 5-95 % 517.15-930.87 mm Hg	± 0.3 °C (temperature) ± 3% (relative humidity) ± 2% of reading (pressure)

Summary of findings:

Device	Aim	Parameter	Outcome
TULIP EMS	Confirm device performs to a minimum standard and is fit for purpose	Particulates	Confirmed
		NO2	Confirmed
		CO	Confirmed
		O3	Inconclusive (technical challenges with test equipment)
		Noise	Not part of scope
		Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Particulates	Best performer out of four devices assessed
		NO2	Best performer out of two devices assessed (EMS and Libelium)
		CO	Only device with CO sensor so could not be compared
		O3	Only device with O3 sensor. Could not be tested.
		Noise	Not part of scope
		Temperature	Best performer out of four devices assessed
		Humidity	Worst performer out of four devices assessed. Indicates potential design alteration required for EMS
DecentLab Temperature and Humidity monitor	Confirm device performs to a minimum standard and is fit for purpose	Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Temperature	Ranked last out of 4
		Humidity	Ranked 3 out of 4
Netvox R712 Temperature and Humidity monitor	Confirm device performs to a minimum standard and is fit for purpose	Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Temperature	Ranked 2 out of 4
		Humidity	Ranked 2 out of 4

Discussion points and caveats:

- Electrochemical cell technology is widely used in low cost gas sensing applications, and is known to cause issues such as batch-to-batch variability in sensor response (e.g. good results with one batch of sensors does not imply good performance with a new batch of sensors). An expanded study could compare the performance of a number of devices of each type.
- With PM sensors there are known problems with detecting higher concentrations related to the issue of coincidence corrections. At higher concentrations multiple particles can be present in the optical sensing chamber at a particular time and without the appropriate correction algorithm, improving the non-linear response of a sensor is not possible.
- Further work is required to investigate the sort of calibrations that could be applied in cases where sensor response is linear although with a systematic bias towards either over or underestimated concentrations.
- Further work is required to remove the likelihood of a low cost sensor reporting a negative concentration. This issue could be related to the zero calibration applied at the point of manufacturing.

The full study report can be accessed at: http://bit.ly/EMS_Benchmarking_Report