EDIF: Towards a digital twin for transport – sensor catalogue executive summary

Introduction

The relatively recent development of the Internet of Things (IoT), cheap and ubiquitous communications and the miniaturisation of sensing technologies has resulted in the increasing availability and deployment of environmental and infrastructure sensing in our cities and regions. Sensors can be used to measure a wide range or urban metrics and can range in price from £10s to £100000s. IoT sensors typically are self-powered, provide data in real-time (or near real-time), monitor continuously and can be categorised as big data; providing data at high volumes, at high velocity (e.g. every second, or every minute) and across a variety of urban metrics.

The Urban Observatory (UO) Programme (funded by BEIS, managed by UKRI) was established to develop smart city infrastructure at scale through the deployment of in-situ sensor networks in our cities. It has sought to develop appropriate data management, data access and metadata protocols and to widen our understanding of the potential application, uses and limitations of these networks for urban management, planning, forecasting and decision making, addressing some of the challenges we face in our cities and regions (air quality, climate change mitigation and adaptation, transition to a low carbon economy etc.).

Type	Measures	Indicative Purchase Cost	Indicative Lifespan
Air quality IoT	CO, pressure, temperature, humidity, particle count, NO, NO2, PM1, PM2.5, PM10, PM4, O3, sound/	£500-9000	1-5years
Air Quality (Precision)	NO, NO2, PM1, PM2.5, PM4, PM10, Ozone, NO, NO2	£30000~£100000	3-7 years
Traffic Measurements (ANPR, CCTV)	journey time, plates in, plates out, plates matching, bus count, car count, cycle count, motorcycle count, van count, truck count, vehicle count	£1000+	5-15 years
CCTV pedestrian counts	pedestrian count, pedestrian vectors	£1000~£2500	2-5 years
Weather monitoring	air temperature, relative humidity, air pressure, precipitation, wind, dew point, sunshine hours, solar radiation, rainfall	£450-5000	3-5 years
Infrastructure monitoring	road surface temperature	£1300	3-5 years
Noise monitoring	Outdoor noise	£450-5000	5 years

Table 1: Summary of sensor measurements. Costs are for initial purchase not lifetime costs. Costs do not include maintenance annual fees, processing and data transmission and are not indicative of total life-cycle costs.

Nomenclature of IoT Sensors

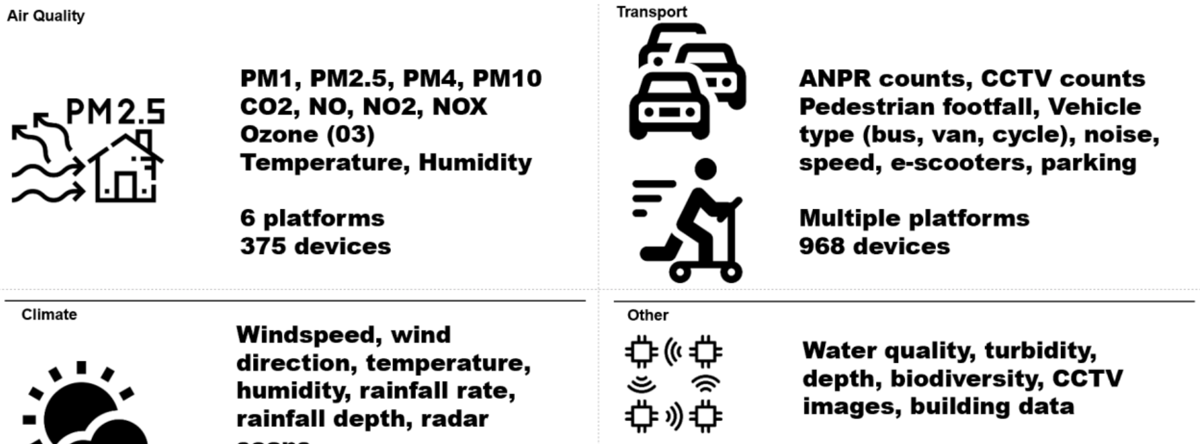
Typically, an IoT sensor does not sense a single phenomenon. For example, a weather station sensor will have onboard sensors that measure temperature, humidity, wind speed, wind direction etc. An **observation** is a measurement of a single phenomenon in space and time from a single sensor stream. A **sensor stream** is a continuous stream of observations from a sensor device. A **sensor device** is a physical sensor that measures one (but typically more than one) phenomenon. A **sensor broker** is a collection of sensor devices that share similarities (eg. devices from a particular manufacturer) and access protocols. These definitions are further extended in the catalogue for data access and organisation purposes. (See Definitions)

Communication protocols

IoT sensors rely on ubiquitous communication networks for the transmission of data. UO sensors use a large number of communication protocols to transmit data for onward processing and storage. The majority of devices use 3g/4g/5g technology to transmit data packets. These protocols support relatively high bandwidth devices (such as video streams) and can update frequently. Increasingly sensors are using IoT specific communication protocols including LoraWAN and NBIoT (Narrowband IoT). These networks are cheaper and easier to establish but are not suitable for high bandwidth applications. Wifi is now rarely (if ever) used for data communications. Sensor devices may transmit data continuously (e.g. CCTV video), but typically they report periodically with cycles ranging from 1 minute to 15 minutes per observation.

Sensor Types and volumes

The UOs have deployed large numbers of standalone sensing devices, but also operate as a clearing house for 3rd party sensor data that is collected through embedded IoT devices deployed for operational reasons. For instance, data is collated from local authority ANPR (Automatic Number Plate Recognition) devices and from live GPS tracks on buses. These sensing devices are deployed and managed operationally by public and private bodies, but real-time feeds are made available to the UOs. The UOs collate and manage three broad types of sensors: (1) deployed standalone IoT sensor devices e.g. air quality sensing devices (2) embedded IoT devices operated by 3rd parties e.g, ANPR counts and (3) sensing devices that require further processing for data extraction e.g. CCTV. The range of potential sensing devices is enormous, but the majority of urban sensing focuses on mobility or mobility related metrics. Figure 1 below summarises the range of metrics and data volumes.



Urban Observatory	No. Live Sensor streams	Av. no. Records Per Day	Total no. Records Ever
Birmingham	605	147,288	162,000,000
Manchester	4411	998,379	402,576,140
Newcastle	1722	967,000	2,284,270,579
Total	6738	-	2,848,846,719

Figure 1 Summary of current UO data holdings and examples of sensor types

Sensor applications
The applications of sensor devices are broad but can be summarised as:

1. Used to **measure trends** especially long- and medium-term trends. Long baselines of data are critical to understanding change against the background noise of a city.
2. Lower cost, and smaller size, enables sensors to be used **to increase geographical coverage** of measurements e.g. to measure air quality in the suburbs or throughout a network.
3. IoT sensors are used to carry out **place-based experiments** to understand the impact of change at high spatial and temporal resolution e.g. to accompany new infrastructure (e.g. a new road) or policy change (LTNs, ULEZ, pedestrianisation). Sensors can be moved relatively easily to carry out multiple campaigns.
4. To provide **continuous monitoring across multiple phenomena** to quantify the impact of policy changes and to **capture unintended consequences** (e.g. displacement activity such as rat-running).
5. To provide unprecedented amounts of data to improve and support new **modelling and predictive analytics** such as AI leading to Digital Twins
6. To provide **operational intelligence** for automated and human-in-the-loop systems such as traffic management, crowd control, automatic signalling.

Sensor Metadata
The variety of sensing platforms, devices and observations requires careful thought to capture the necessary information related to an observation. For example NO2 (Nitrogen Dioxide, a critical contaminant from combustion engines) can be measured by a £200 IoT sensor or a full calibrated DEFRA approved £100,000 sensor. These measurements differ in accuracy and reliability and therefore how they should be used and reported. Metadata must address quality and potential usage applications to ensure that the data is fit for purpose. (See Metadata report for further details).

Sensor Issues
IoT sensing is relatively new and currently is a largely unregulated space and as such care must be taken when analysing data or purchasing equipment. As sensors are deployed in the wild they suffer mechanical and electrical breakdown, communication issues and degradation. Increasingly data is seen as a saleable commodity and can be locked into proprietary systems. The UOs propose an open, scalable and federated solution to enable data for all and the public good.

Update Strategy
This sensor catalogue should be updated biannually but should be used in conjunction with other metadata to ascertain stream health.