Real-time Geosensors for Air Quality Modelling

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1. Introduction

Historically much of the development of traffic systems has been focused on the reduction of vehicles delay and travel time on the road. This has allowed more capacity into the transport network which has led, in the last decades, to more vehicles on the road with severe impact on the environment and air quality.

In order to gain a clearer understanding of how road traffic has a direct impact on the air quality, Newcastle University, as part of the Newcastle University Integrated Database and Assessment Platform (*NUIDAP*, 2012), have integrated a number of raw and processed real-time data sources from meteorological, air quality and traffic sensors. Traffic controllers now have access to the location and values of pollutants and derived air quality metrics. Two test sites in UK at Medway in Kent and Newcastle upon Tyne have been used to validate the NUIDAP outputs supplied to Urban Traffic Control (UTC) centres.

2. Data Inputs

The traffic sensors are pre-existing sensors developed by UTMC and record data using a technique known as the Split Cycle Offset Optimisation Technique (SCOOT). These SCOOT (*How Scoot Works*, 2012) devices are designed to provide information on the physical layout of the road network and how the traffic signals control the individual traffic streams. This is to allow a quick and effective response to any changes in the current traffic situation. They work by detecting vehicles at the start of each approach to every controlled intersection. They then model the progression of the traffic from the detector through the stopline, taking into account the state of the signals and calculating any consequent queues. Whilst SCOOT's primary purpose is to provide information about traffic controls as a by-product these sensors also provide a measurement of the flow and occupancy. These measurements can be used to produce a more detailed model of the state of traffic.

The air quality sensors were originally developed as part of the *Mobile Environmental Sensor System Across Grid (MESSAGE)* (2006) project by researchers at Newcastle University. The sensors are designed from the ground up to be a low cost, low power consumption environmental quality monitoring devices that allows data to be recorded at a high spatial and temporal resolution and accessed in real-time (Neasham *et al.,* 2007). Meteorological data is provided by a small number of standard meteorological monitoring stations around the deployment.

To integrate the various data sources a spatially enabled PostgreSQL database is used as backend database. A sensor API has been developed for the air quality sensors as part of the MESSAGE project but for other real-time data streams a variety of solutions to parse and store the data have been developed using open source tools and technologies.

In addition to the real-time systems, the spatial location of sensors, a DEM and a 3D building height dataset are stored within NUIDAP. These facilitate the spatial display and analysis of the data and allow for offline processing and validation.

3. Data Services

Each data source has a custom interface that pushes the data into a database relation. These were developed as Windows services using Python. The services are independent of each other and this modular approach allows other data sources and new sensor streams to be incorporated and integrated into the NUIDAP architecture as they come on stream or as the underlying technology develops.

The subsystem for SCOOT data acquisition required the development of a number of Python components run as Windows services, the first being a forward proxy service. This forward proxy handles communication between the sensor data server on site and the remote NUIDAP server, via a TCP connection. The forward proxy handles loss and reinstatement of communication and buffers data flow. Furthermore, the forward proxy can be set up to push sensor data feeds to multiple IP addresses.

A further middleware component parses the forwarded message and writes the data to the NUIDAP database. It manages split data streams and other anomalies of the buffering and communication systems that underlie the SCOOT system. Figure 1 shows the SCOOT processing subsystem. Typically the sampling frequency of SCOOT is at ¼ second, but messages are created each cycle and/or every 5 minutes.

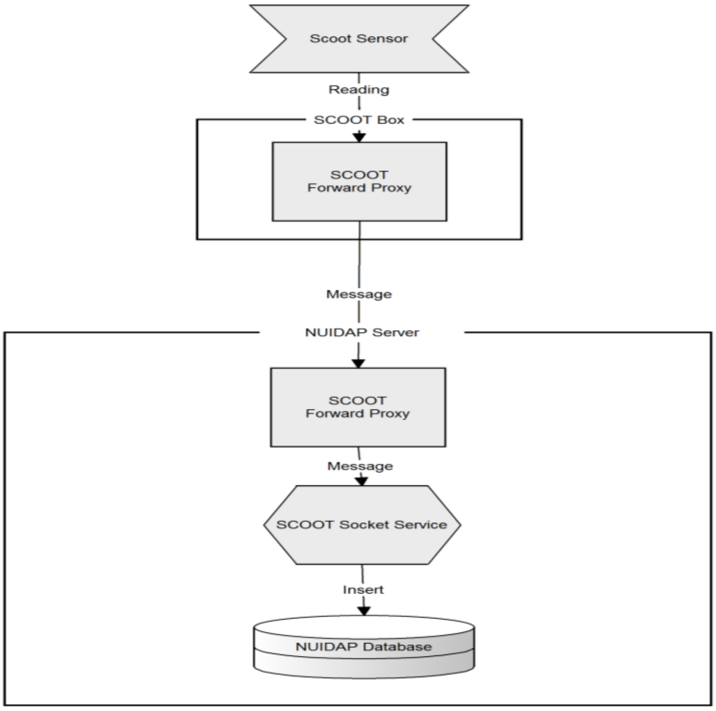


Figure 1: SCOOT Subsystem Architecture

The meteorological data has a much lower sampling frequency than other data streams, typically being updated each hour. The current met sensors deployed in the test sites at Medway and Newcastle record variables such as humidity, wind speed and temperature and provide an XML output that can be redirected to a remote FTP site. The meteorological data processing subsystem then pulls the XML documents from the remote site. A windows service parses the data for insertion into the NUIDAP database. Figure 2 shows an overview of the system.

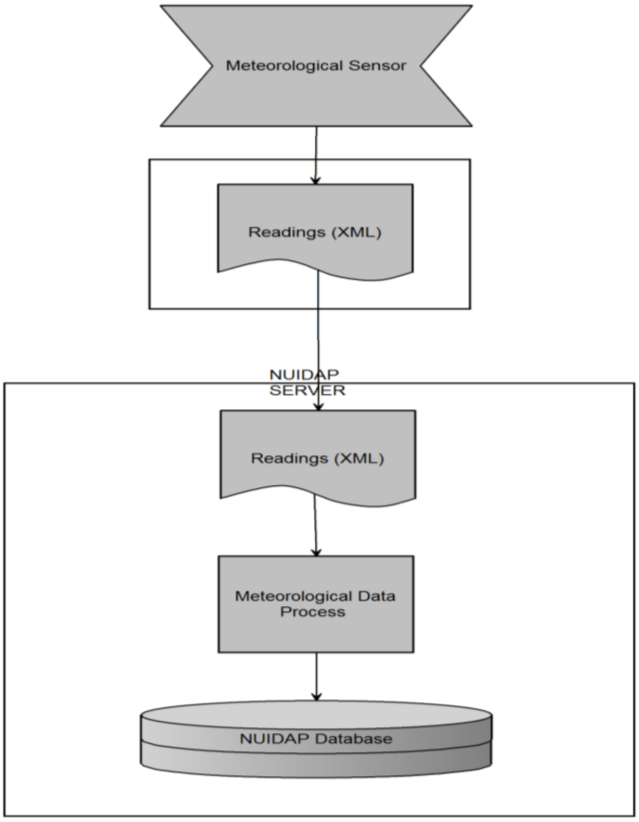


Figure 2: Met Data Subsystem Architecture

The air quality sensors data subsystem utilises a third party component developed by Envirowatch, the company that produces commercial versions of the air quality sensors, that pushes data into the NUIDAP database from a server located on the customer's network. All the data subsystems use validation data parameters stored in the NUIDAP system to check for outliers or erroneous data within the data streams. Data values that are outside the parameters are stored in the database but flagged as faulty or corrupt, and therefore, not used in subsequent processing.

The various sampling regimes, update frequency and communication latency issues of the sensor systems make integration of the raw sampled data problematic and thus a variety of systems were developed to parcel time across the sensor systems into five minute averages. Five minute averages were selected to balance the requirements of the traffic controller for frequent updates with the need to be able to aggregate sensor readings to a reasonable level to allow for a number of cycles and therefore smooth any anomalies.

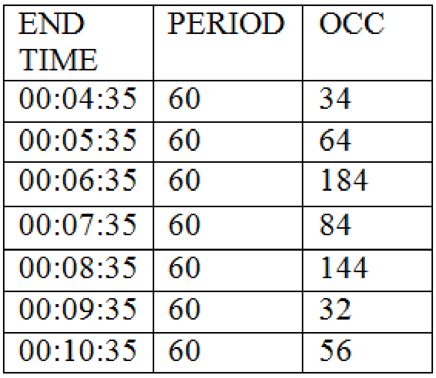
4. Processing services

The processing subsystems were developed as Python services and database triggers using PL/Python programming language. In order to calculate the five minute average of the mote data a python service was developed that queried the last five minutes of data for each sensor. A simple average calculation was then performed with the result written to a new relation. As this is calculated in real-time it is vital that the latency of the system is less than 5 minutes for each processing subsystem.

A similar service was developed in order to calculate 5 minute average for the SCOOT data. This service allowed for the fact some time period would run over the 5 minute average period and therefore the values would have to be proportionally split. For example the average OCC in table 1 for the time period 00:05:00 - 00:10:00 would be.

$$[((64*35)/60) + 184 + 84 + 144 + 32 + ((56*25)/60)]/300 = 504.667 / 300 = 1.68$$

Table 1: Example SCOOT average data



END TIME	PERIOD	OCC
00:04:35	60	34
00:05:35	60	64
00:06:35	60	184
00:07:35	60	84
00:08:35	60	144
00:09:35	60	32
00:10:35	60	56

For the meteorological data a database trigger is used to copy the relevant data into 5 minute averages. The five minute parcels are synchronised across all data services using network clocks.

Bell *et al.* (2011) sets out two algorithms, the first of which produces an estimate for the state of congestion at a SCOOT sensor given the values of flow and occupancy. This algorithm was developed into a database trigger producing real-time values of congestion for each sensor at each location. The congestion values were validated against security camera footage from the deployment sites to check that the algorithm related spatially and temporally to the expected traffic conditions.

This result, along with the traffic flow, speed and emissions factors (*NAEI Data Warehouse*, 2012) is then fed into a further algorithm which estimates the tail-pipe emissions of CO, Oxides of Nitrogen, NOx and particulate matter, PM_{10}, with diameter of 10microns or less for a sensor at a given time. This again was developed into a database trigger producing real-time results. These results are validated using data captured by the air quality sensors and *Automatic Urban and Rural Network (AURN)* (2012) (Bell *et al.*, 2012)

These results are again averaged over five minute periods using separate windows services thus providing output to the traffic controllers of real-time measured emissions, congestion and estimated tail pipe emissions at a sample rate of every five minutes allowing for the controllers to modify traffic flow to reduce potential air quality issues.

5. Modelling

Whilst NUIDAP provides traffic controllers with a real-time indication of congestion and emissions at each sensor as yet it does not provide real-time air quality measurements which require more detailed modelling. The NUIDAP system has been successfully integrated with the Operational Street Pollution Model (OSPM) developed by the National Environmental Research Institute of Denmark (Berkowicz *et al.*, 1997). The model is used for simulating the dispersion of air pollutants in streets surrounded by tall buildings on both sides. The basic model inputs from aggregated sensors and building height and footprint information are extracted from the NUIDAP system. (Figure 3);

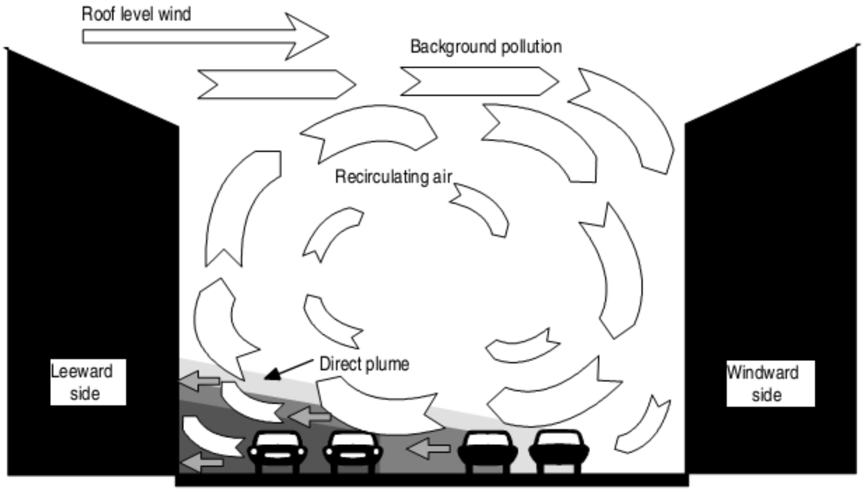


Figure 3: OSPM example (Berkowicz *et al.*, 1997)

Further developments will provide the ability to run air quality and dispersion models in near real-time integrating the sensor subsystems and the 3D geometry and DEM.

These developments will lead to a fully integrated near real-time system that has the ability to monitor the environment status of the network, characterise problems, explore strategies and assess their impact.

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Biography

Neil Harris is a recent graduate from the GIS programme at Newcastle University and is currently working as a research assistant/software developer in the Geospatial Engineering group.

Phil James is a Senior Lecturer in GIS. He is interested in applying spatial data and techniques to the solution of engineering problems and the integration of data using space and location as the key.

Dr Fabio Galatioto is Research Associate in Transport Modelling. His main research focus is network modelling and assignment (macro-simulation); traffic micro-simulation analysis; traffic emission and pollutant dispersion modelling; transport data collection and statistical analysis; Intelligent Transport Systems. He is author and co-author of more than 40 Journal and Conference papers.