CEOI 5th and 6th Open Calls
Final Review

The Ultra Compact Air Quality Mapper (UCAM)

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Project Introduction

The primary objective of the CEOI UCAM project:

- To investigate the feasibility of developing an ultra compact remote sensing instrument capable of enabling discrete wavelength retrievals of atmospheric nitrogen dioxide (NO_2) from a space borne platform

The societal and economic drivers for this concept are:

- Atmospheric NO_2 is one of many atmospheric pollutants prevalent in the urban atmosphere at ground level owing to its production via any combustion process, particularly ***internal combustion engines***, ***power plants*** and ***central heating***
- A day-to-day correlation has been found to exist between atmospheric NO_2 exposure and human mortality
- Increased sensitivity to already existing respiratory conditions in humans has been associated with NO_2 exposure through epidemiological studies
- Statistical enquiries have determined that the total cost to the UK economy of human exposure to NO_2 can be up to £20 billion per year

Project Introduction

The technical drivers for this concept are:

- The urban environment is where human NO_2 exposure is at its highest, yet knowledge of its concentrations at ground level are derived from very loosely constrained atmospheric models.
- Leicester is a well instrumented city compared to some, yet it only has **6** in-situ monitoring stations providing constraint to modelling activity covering approximately **100 km^2**.
- Conventional satellite data (OMI & GOME-2) are very sparse and unable to provide much support, with only ***2 or 3 overpasses*** over a particular city per day at fixed times, often ***obscured by cloud***, with ***>14km spatial resolution*** and ***relatively poor accuracy at ground level***.

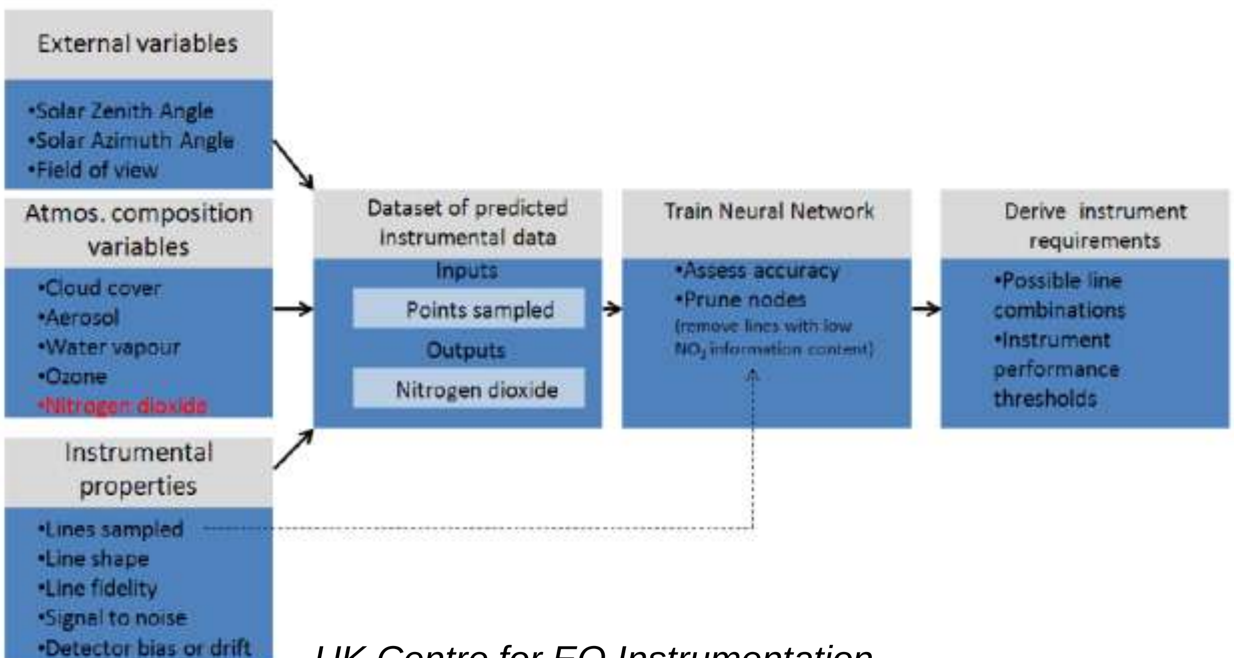
- To improve understanding of ground level NO_2 the atmospheric models require ***better constraint***.
- Amongst the options to achieve this improved constraint is the development of an instrument capable of retrieving atmospheric NO_2 using the least amount of information possible with the intention of ***minimising its size and mass***.
- An ultra compact, relatively cheap and therefore mass producible purpose built instrument could be piggy backed on satellites and installed on aircraft to observe the urban environment with improved temporal and spatial resolution.

UCAM ANN

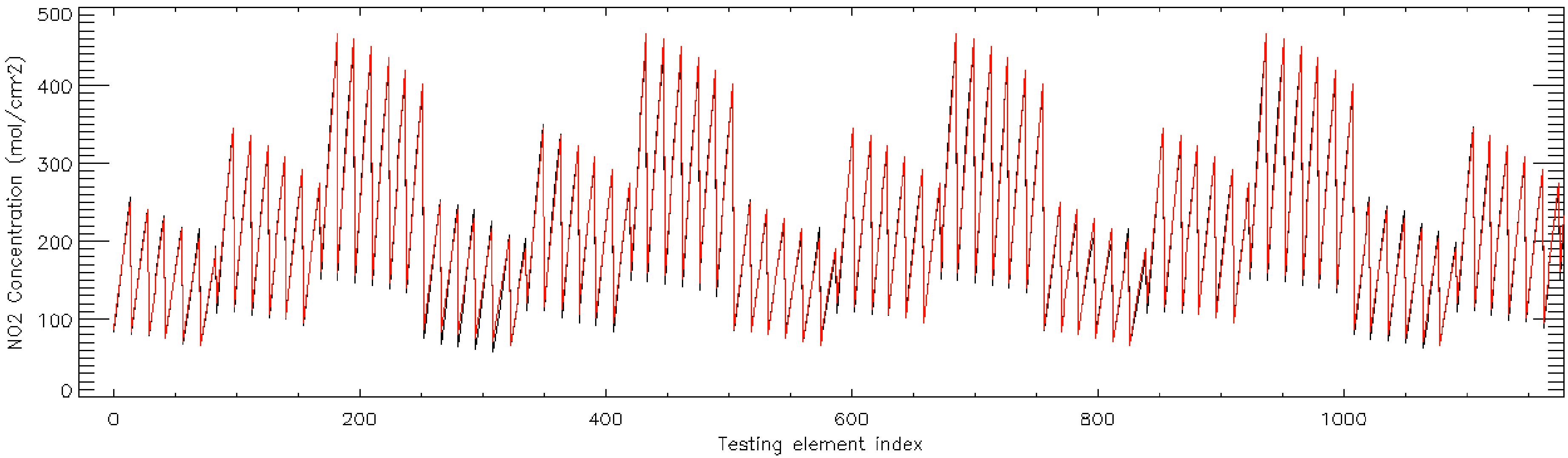
The discrete wavelength retrieval method adopted for UCAM was an artificial neural network. The arguments for using this approach are:

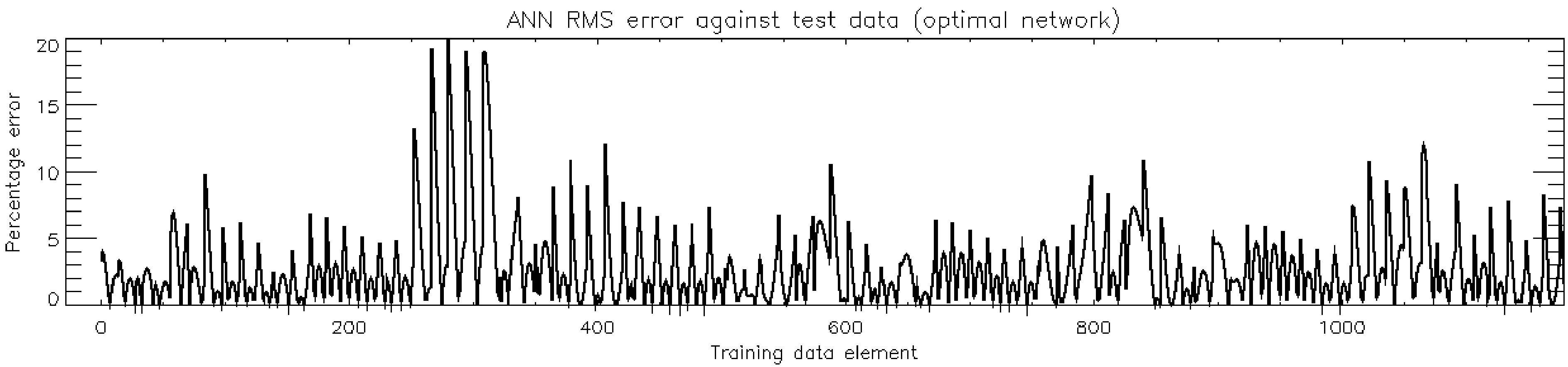
1. Very fast retrieval, enabling the possibility of a NRT operational algorithm
2. Can extract useful information from highly complex data if appropriately trained therefore has the potential to operate with the least amount of available data

The UCAM ANN architecture is as follows:

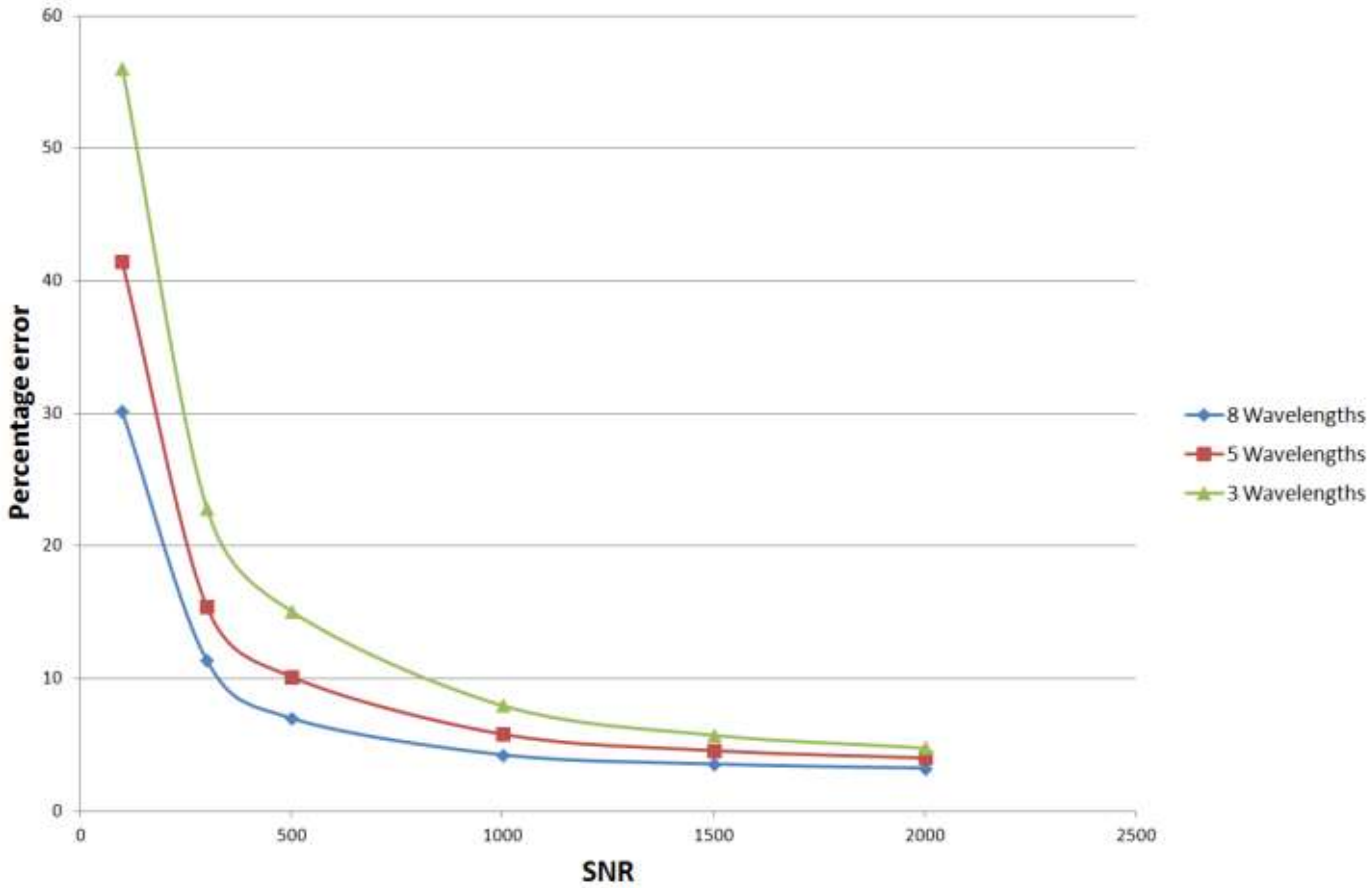


Network development and training





ANN Results



60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
Percentage error
SNR
8 Wavelengths
5 Wavelengths
3 Wavelengths

ANN Conclusions & Achievements

- Using a BP-MLP-ANN it has been demonstrated that discrete wavelength retrievals of NO_2 are possible using an ANN

- Early tests suggest fit errors of < 10% are achievable with an SNR of 500

- As a general rule more wavelengths = less noise sensitivity

- The network fit error was found to be independent of the complexity of the data set owing to the automatic network configuration optimisation algorithm employed for UCAM

Positioning achieved

- Work was presented at the Royal Society of Chemistry at the Air Quality Monitoring Conference, December 2012.
- Work to be presented at EGU in Vienna, April 2013
- Paper in preparation – Lawrence et al.
- Collaboration with SSTL, an already established working partnership further developed.
- Dialogue with Ocean Optics established for the development of a breadboard demonstrator of a terrestrial UCAM instrument – funding yet to be confirmed.

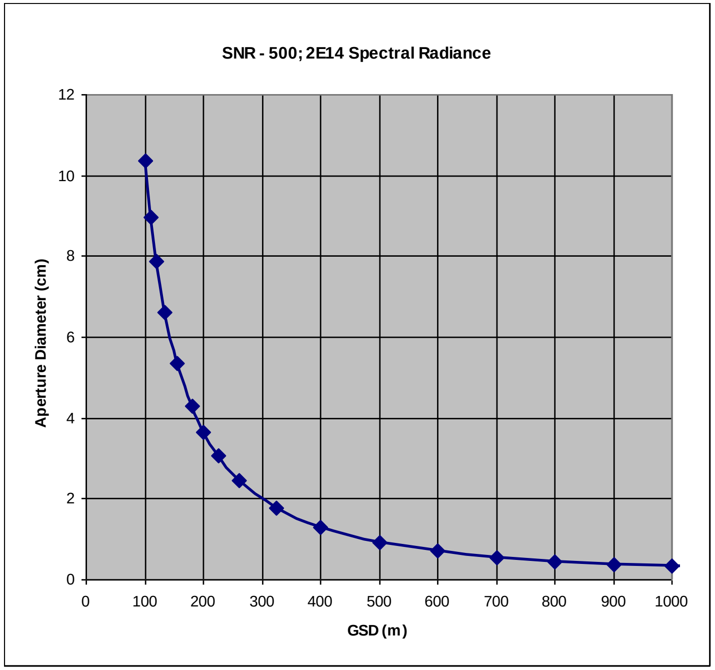
Roadmap

- UK capability and infrastructure created for discrete wavelength retrievals of atmospheric NO_2
- Discrete wavelength retrievals through the use of ANN’s can now be theoretically exploited for other gas phase species other than NO_2 at the University of Leicester.
- Improvement of the network training capability through a number of routes will be explored, including the use of a genetic algorithm
- A breadboard demonstrator will be built to provide an early example of a NRT terrestrial pollution monitor (possibly with Ocean Optics).

UCAM instrument investigations

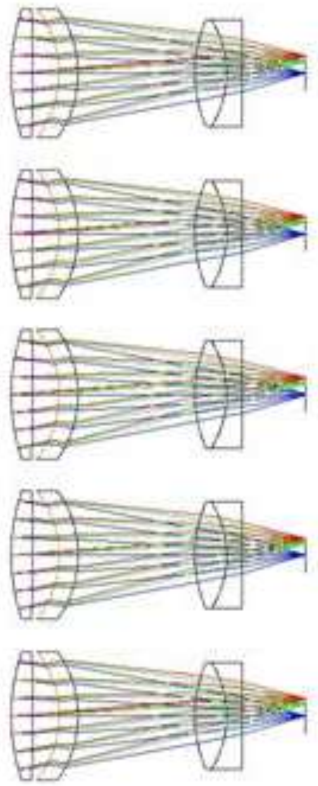
- Radiometric analysis
  - Target SNRs is 500 at typical Earth radiance
  - Can be achieved at 150m GSD with 20mm aperture
  - Not a severe driver

- Main problems for design:
  - **~0.2% relative accuracy between 3 to 8 spectral channels**
  - Detection-system response (offset and gain) drifts
    - Prefer to use a common detector
    - Ideally common optics
    - May need in-flight calibration
  - Spatially non-uniform ground reflectance
    - severe spatial registration between channels
  - Spectrally non-uniform ground reflectance (colour)
    - may require more than 8 channels to allow “pedestal” subtraction

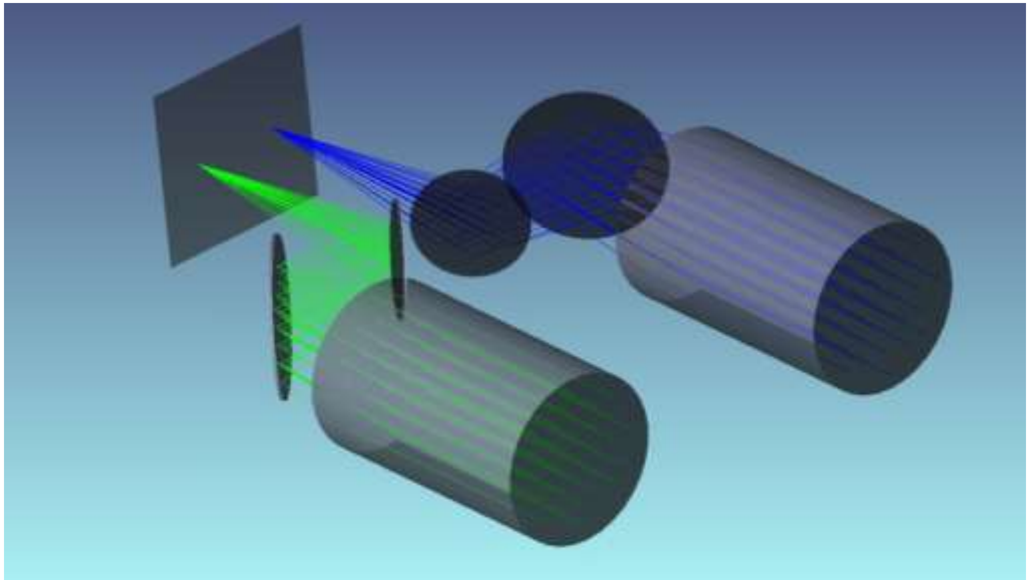


Filter solutions

- Simplest solution separate lenses imaging onto linear arrays give maximum relative-drift problems
- Filters for 1nm bands are likely to be expensive



- Imaging onto a single area-array detector reduces drift problems, but increases optics complexity



Imaging spectrometer option

- Eventually, we may prefer an imaging spectrometer solution
- Expensive grating etc, but avoids filter costs
- Uses a common area-array detector
- Can give very good registration (spatial and spectral)
- Able to read out large numbers of wavelengths: could be useful to investigate filter options