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A Low-Cost Long Path DOAS system for Remote Monitoring of NO_2

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1. Introduction

Nitrogen dioxide (NO_2) is a major urban air pollutant produced by combustion emissions, especially from transport (Mucha et al., 2026). Long-Path Differential Optical Absorption Spectroscopy (LP-DOAS) is a well-established remote sensing technique which produces simultaneous measurements of multiple trace gases (Nasse et al., 2019). Typical LP–DOAS systems are bulky, with large primary telescope diameters of 30 cm or more. Such systems are expensive, undermining their suitability for routine air quality monitoring (Vita et al., 2014). LP-DOAS can also be used for tomographic studies of NO_2 (Pöhler, 2010), but cost and size constrain wider application of this methodology.

2. Aim and objectives

The aim of this study is to advance the use of **LP-DOAS** for remote monitoring of NO_2 in different urban settings, including in cities in low-income countries. The technical objectives are to develop a LP-DOAS system that:

- Is relatively **compact**
- Has a **moderate cost** (e.g., below €10,000)
- Achieves a detection limit below **2 ppbv** in **10 min**

3. Measurement Site

Figure 1: Satellite image of the study site in Cork showing visible light from the transmitter and receiver unit.

A 1.50 km LP-DOAS system with separate transmitter and receiver telescopes was set up on the western side of Cork city (pop. 210,000) in Ireland (Fig. 1). The transmitter and detector units were at heights of 20 m and 10 m, respectively.

4. System description

The system comprised a temperature-stabilised 0.8 W blue LED (peak wavelength at 431 nm), transmitting and receiving refracting telescopes with 5 cm diameter aperture, and Avantes spectrometer with a resolution of 0.66 nm. The transmitter and receiver units of the system were powered by 74 Wh powerbanks. The transmitter was placed indoors with light transmitted through a window. The receiver telescope and spectrometer were housed in an IP66 box to protect the detector and electronics.

Spectra were acquired every 6 s. A background spectrum was acquired every 10 min for a duration of 30 s by using a custom-made shutter to block the LED light. Background spectra were subtracted from the measured spectrum. Figure 4 shows a 6 s spectrum of the LED light spectrum measured by the detector after traversing the 1.5 km atmospheric path. This spectrum shows a strong signal for this measurement time and atmospheric pathlength, even for a DOAS system with a telescope diameter four times smaller than a small DOAS system (Kuriyama et al., 2010).

A gas cell in the light path inside the receiver telescope end could be filled with NO_2 to assess the system performance.

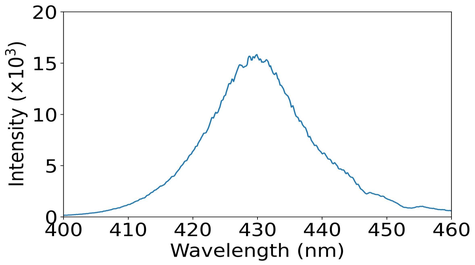

Figure 4: LED intensity spectrum observed over the 1.5 km atmospheric light path.

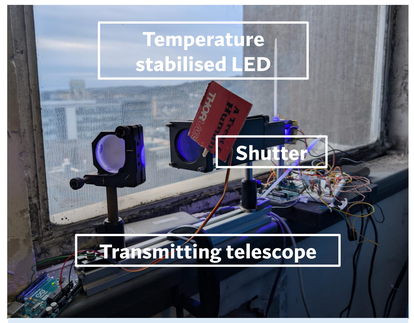

Figure 2: Photo of light transmitting telescope

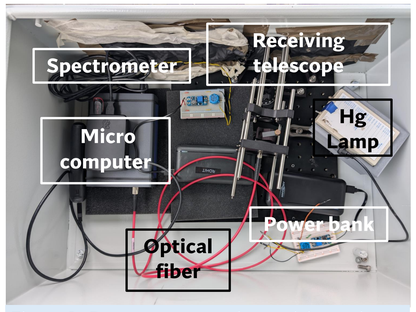

Figure 3: Detector setup at the receiving end

5. Results & Discussion

As the measurement site was 2.5 km away from the city center, levels of NO_2 were low. To demonstrate system performance with a strong NO_2 signature, NO_2 was added to the gas cell. Figure 5 shows the time profile of light intensity at 431 nm across the evening of 9 April 2026. The sudden drop in intensity at 20:10 is a result of the injection of NO_2 into the gas cell.

A spectral fit using DOASIS (Fig. 6) shows good agreement for NO_2 and minimal contribution of other interfering gases (Table 1). The DOAS fit settings for analysis are presented in Table 1. An initial column density equivalent to an average mixing ratio of 100 ppb was achieved, with gradual NO_2 diffusion out of the cell over a period of 8 hours.

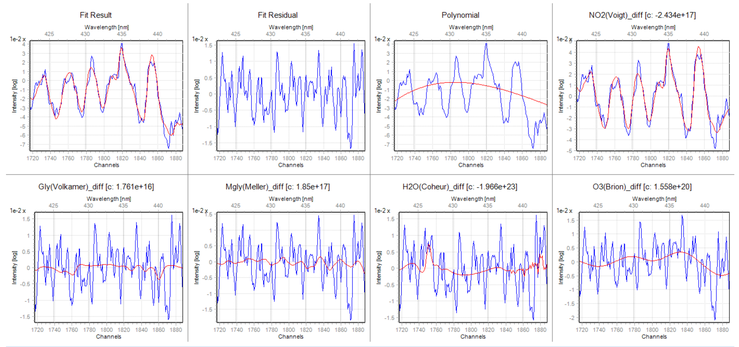

Figure 6: DOAS fitting results from DOASIS of NO_2 and other interfering gases.

The time dependence of the NO_2 mixing ratio from 10 min averaged spectra is shown in Fig. 7 with the fit uncertainty. The fit uncertainty was in the range of **0 – 4.1 ppb** with a mean value of **1.3 ppb**. Based on these values, the **detection limit** for the instrument was calculated to be in the range of **0 – 8 ppb** with a mean value of **2.5 ppb** (Kern et al., 2006). At 4:00 the concentration returned to zero after complete diffusion.

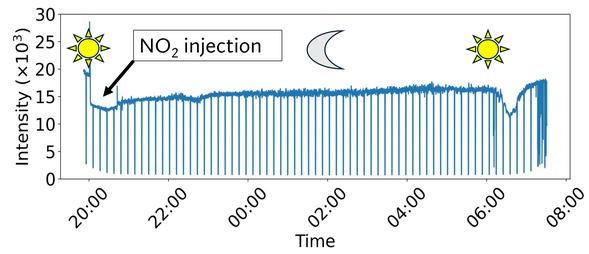

Figure 5: Time series of a single pixel light intensity level

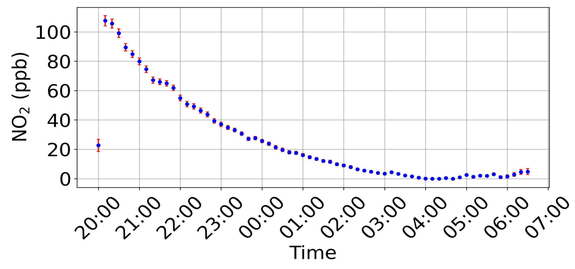

Figure 7: Time series of NO_2 concentration and fit uncertainty

FIT PARAMETERS	
Fit range	425 – 445 nm
Polynomial order	5
High pass filter	5000 iterations
Fitted references	NO_2, $C_2H_2O_2$, $C_3H_4O_2$, H_2O, O_3

Table 1: Fitting parameters for DOAS fitting

6. Conclusions

- A simple and relatively low–cost single-path DOAS system was developed for monitoring urban air quality.
- Demonstrated a DOAS system with the smallest diameter telescopes to our knowledge.
- An average detection limit of 2.5 ppb for NO_2 over 10 min was achieved
- This system performance could be suitable for ambient air quality monitoring in urban centres.

7. Future Work

Future work in this project aims to:

- Test the long-term performance of the instrument
- Apply the system in more polluted environments, including studies of vehicular emissions and shipping emissions
- Develop a folded path system configuration to capture a shortcut spectrum of the LED and improve the spectral fit.

8. References & Acknowledgement

Kern, Applicability of light-emitting diodes as light sources for active differential optical absorption spectroscopy measurements (2006)
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Pöhler, Determination of two dimensional trace gas distributions using tomographic LP- DOAS measurements in the city of Heidelberg, Germany (2010)
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