UAV-Powered DOAS Tomography

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Abstract

Project ATMOS was a Portuguese initiative for a smart and mobile atmospheric monitoring platform.

Air Pollution is one the most important concerns of the modern world, especially in Western countries. For some decades now, increases in atmospheric pollutants concentration have been unequivocally linked with an increase in mortality and morbidity numbers, as well as in the number of hospital visits. DOAS tomography is a relatively new field of study with an enormous potential for atmospheric pollutant monitoring, since it can inherently map their concentration in a two- or three-dimensional way.

This paper aims to present the feasibility of a UAV-assembled tomographic DOAS apparatus, in the form of a numerical simulation tool that paves the way towards a physical implementation of the final system. On board computers and flight controllers ensure that the device describes a pre-programmed trajectory that facilitates the construction of several fan beam arrays by pointing the optical assembly towards predetermined directions. The resulting projections can then be reconstructed through several mathematical algorithms, of which we present three examples.

Our simulations have shown that it is possible to make accurate reconstructions if projection intervals are kept to a maximum of 3 degrees.

Keywords: DOAS tomography, atmospheric monitoring, pollutant mapping

CONTEXT

This project was born from the ATmosphere MOnitoring System (ATMOS) project, which was a Portuguese EU funded project that aimed to develop a miniaturised spectroscopy system for atmospheric analysis and trace gas mapping using Differential Optical Absorption Spectroscopy (DOAS), with tomographic capabilities. FCT NOVA participated in this project as part of a consortium which also included Compta, one of the oldest IT groups in Portugal. The ATMOS project required the development of an actual physical system, but before that stage is reached, it became necessary to develop a simulation software platform. This simulating application had to be designed while taking the ATMOS project's specifications into account: simulations had to be like what the project's final intended capabilities will allow. This paper details the application of artificial light to our previously developed natural light Differential Optical Absorption Spectroscopy (DOAS)(Platt & Stutz, 2007) Tomography UAV simulation platform.

INTRODUCTION

Air Pollution (AP) is a very important topic of discussion in the current days, with scientists and researchers around the globe being very aware of the potential effects it can have on the health of individuals and populations across all ecosystems. After climate change (one of the largest capital threats to life on Earth, perhaps just behind nuclear apocalypse), AP is the biggest environmental concern for Europeans, and Europe's single largest environmental health hazard. It has also been established by many authors as a major cause of premature death, cardiopulmonary disease onset and hospital visits. The growing concerns about Air Pollution and its effects on human health and the world in general is an indication for the importance of measuring it correctly and with detail. The diversity of its effects and the sheer number of variables that need to be considered establish the problem of AP as one that can only be effectively tackled if approached intelligently, highlighting the need for smart devices for the measuring and monitoring atmospheric pollutants (EEA, 2016; Ghorani-Azam, Riahi-Zanjani, & Balali-Mood, 2016; Kampa & Castanas, 2008; Vallero, 2014).

DOAS tomography is one way to achieve this. This relatively new field of study has an inherent capability to perform two or three dimensional mappings for the concentration of several trace gases with clinical significance (EEA, 2016; Pundt, 2006). Compared to traditional mapping methods, such as in-situ monitor placement, the technique is much easier to deploy (only one sensor vs tens of sensors), can require much less infrastructure and requires less maintenance. Historically, and although there are not many instances of its application, DOAS tomography has been successfully deployed for measurements in heavily polluted scenarios, such as a busy motorway or a refinery (Laepple, Knab, Mettendorf, & Pundt, 2004; Mettendorf, Hartl, & Pundt, 2006; Stutz et al., 2016). However, one thing that is common in all tomographic DOAS applications is their lack of mobility, and in many cases also require the construction of dedicated infrastructure. These limitations are important, because they hinder the “real life” deployment of tomographic air pollution monitoring systems, restricting them to research applications.

METHODS AND INTENDED OUTCOMES

This paper presents one of our attempts in mitigating this problem, in numerical simulation form. We have designed a UAV-ready DOAS system, which will be fitted with a flight controller that enables the device to describe a carefully planned circular trajectory, planned for spectral projection gathering. An artificial light source has numerous advantages over a natural one, such as a better knowledge of the measured light and the ability to work during the night, which could be interesting in some cases. To test the feasibility of such system, and how it would be able to perform actual reconstructions, we have chosen to write a numerical simulation tool that enabled us to determine the system's requirements before committing to the device’s physical construction.

Our simulation tool was written using Python and its numerical library, NumPy. It defines a two-dimensional circular Region of Interest (ROI) of 1 km diameter, discretised in a 10m pixel grid (100 by 100 pixels total grid). Spectral acquisitions pointing inwards with reference to the trajectory circle and describing a fan beam geometry assembly were acquired with angular intervals which were always the same, and equal to the angular variation between rays in each fan. Using two phantoms, we have reconstructed the image from the simulated projections using three different algorithms: FBP, SART and MLEM (Defrise, Kinahan, & Michel, 2005; Herman, 2009; Kak & Slaney, 2001).

We have considered two types of error estimation, on the geometric and reconstruction levels. Geometric errors are important during the calculation of projection data. They are introduced into the simulation by means of a Monte Carlo approach, in which the software considers the standard deviation to be the expected hardware error, provided by the manufacturer or described in the literature. Simulated projections are therefore different from their “nominal” value, according to this process. Post reconstruction, we illustrate the errors in two ways. The first is using a graphical representation of the errors (as an image) for each reconstruction process (see Figure 1). The other is by applying the normalized root mean squared error formula, using the squared sum of the phantom (acting as ground truth) as normalization factor. Errors for FBP and SART can be seen in Table 1.

In our previous efforts using a natural light simulation, all algorithms were able to reconstruct the intended images (the phantoms) with the simulated projection information, although visible limitations were identified regarding projection intervals (above 3 degrees, reconstruction degradation was clear). Despite the tomographic approach being very similar, we expect this new effort to behave slightly better, due to our using of an artificial light spectrum.

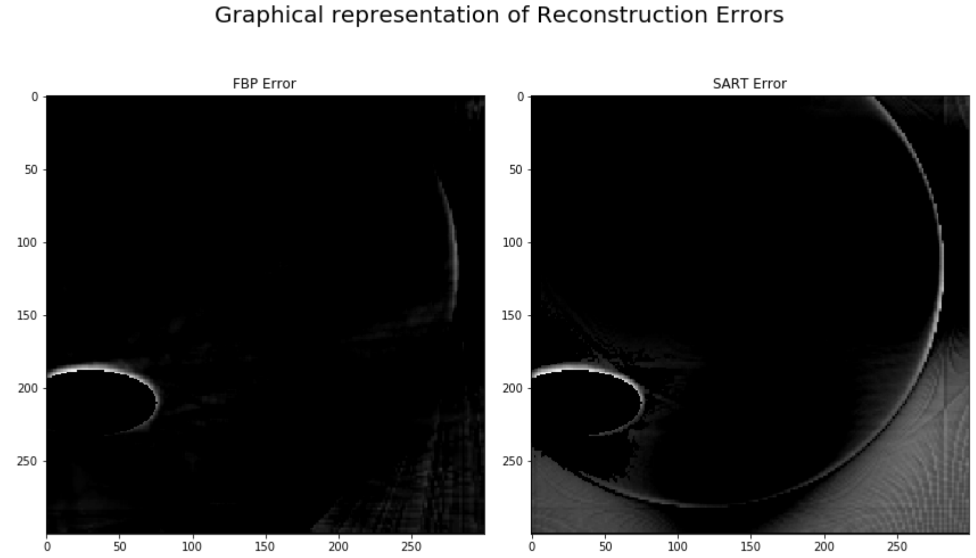

Figure 1 Graphical representation of reconstruction errors. These two images are the matrices of the absolute differences between the original phantom and the reconstruction.

Table 1 Normalised Root Mean Squared Errors (NRMSE) for SART and FBP Reconstruction.

NRMSE	
FBP	*SART*
0.89	0.88

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