The Maxwell Advanced Technology Fund Postgraduate Scholarships

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The University of Edinburgh firmly believes that education is one of the most powerful tools for transforming lives and we are committed to attracting outstanding students irrespective of their financial or personal circumstances.

The support provided by the Maxwell Advanced Technology Fund Postgraduate Scholarships has contributed directly to attracting outstanding students to the Institute of Digital Communications at the University, helping us maintain our place at the cutting-edge of research and innovation in this critical area.

Our postgraduate students have all been affected by the closure of the University, due to COVID-19, but we are delighted that Robert has continued his research without missing a beat. He continues to impress his colleagues and supervisor alike, and is currently writing up his first major publication on his PhD research.

Robert has provided a comprehensive report on his progress, which we introduce with an update from his supervisor, Dr Nick Polydorides.

Progress report from Dr Nick Polydorides, Head of Institute for Digital Communications, School of Engineering

Robert's project is perhaps among the very few that have not been impacted that much by the pandemic, although not having been able to communicate in person, or travel to conferences, has had an effect. I believe he made the right choice to remain in Edinburgh at the start of the first lock down, and, although this comes with a number of challenges, he has managed to establish some form of daily routine and progress his research according to plan. Two of my other PhD students have withdrawn, as they left Edinburgh and were unable to access the necessary conditions to continue their studies.

As I mentioned in last year’s report, I thoroughly enjoy working with Robert: he is just so inspiring and his ideas are fresh and exciting. We communicate via Skype and Teams once every two weeks or so, but tend to text quite a lot in between to discuss our projects. Some of these video calls could easily run to four or five hours, but they never felt boring, anything but. This year I also had to redesign my course (in Engineering maths) and, as Robert is a mathematician, I consulted him a number of times to ask his opinion on how I planned to present the topics and on choosing the right questions for the exercises etc. He was always willing to help and proof read my material.

Turning to our own project, Robert is now in the late stages of writing up his first major publication on his PhD research. This will probably be a pair of publications, as the material is in excess of 40 pages. The submission of these drafts will be before the end of May. We are now looking for a company/lab with an optics competence to help us demonstrate our methods with real measurements, but, as you will understand, experimental work has been severely affected by the pandemic, and most of these labs are still not operational.

Robert and I are also working on a variation of his project (led by me) on randomised algorithms for real-time, in-situ computation (destined for smart manufacturing plants). This is progressing well, and I expect a publication to be submitted this side of the summer.

Closing, I would like to highlight that a research proposal is to be submitted to ESPRC as soon as Robert's papers are out, to take this research further and maximise its impact. I have asked Robert to help with the write up, as part of his academic training. I am also expecting two summer interns, PhD students from the school of Mathematics, to come and work with us over a 6-month period on projects related to Robert's research.

Progress report from Robert Lung, Institute for Digital Communications, School of Engineering

Optical remote sensing of gas dispersion: From chemical hazard assessment to greenhouse gas monitoring.

1 The project's vision

This thesis sets to investigate the problem of real-time detection and concentration imaging of hazardous chemicals dispersed in the atmosphere. The aim of the project is to develop and analyse methodologies equipped for imaging gas plumes of interest in near real-time, even in congested urban conditions, and with extremely weak signals, none of which is possible with the current state of the art, despite the fact that it uses measurements from commercial off-the-shelf instruments.

This timely information will be critical in responding quickly to accidental leaks or terrorism acts in order to protect people against chemical hazard exposure. Aside tracking the plume and its concentration the method can trace its origins and future trajectory according to the landscape and wind information to provide early warnings and crucial information to first responders in their assessment of the incident. In addition, the methods are suitable in environmental monitoring and in particular quantifying greenhouse gas emissions from industrial plants.

The success of the project will bring a step change in the image performance of Lidar-based gas tomography both in terms of temporal and spatial resolution. The proposed system supersedes the state-of-the-art in gas detection and imaging in that (i) it can resolve the location(s) and history of the release by backtracking in time, (ii) it can quantitatively image in three dimensions the concentration of the gases, and (iii) it can predict the future profiles and trajectory by forward tracking in time.

To make time resolved absorption measurements useful for real-time applications this project will consider a different approach to the reconstruction process alongside the option of incorporating off-beam photons from wider fields-of-view that have undergone multiple scattering. Aside yielding more credible imaging, the proposed approach can improve signal quality and thereby make the acquisition process far more efficient.

2 Key ideas and methods

Differential absorption lidar (DIAL) systems that operate on two adjustable wavelengths have been used for determining the concentration of gases in the atmosphere or the release rate of gaseous plumes [RGI+11, IRG+17]. These methods are particularly suitable for cluttered environments since they are based on absorption which makes them robust against potentially interfering scattering media. Although in principle these optical imaging methods have the potential to provide a fairly accurate spatial concentration profile for a given gas of interest, the obtained signals are typically extremely weak resulting in noisy low-photon count data. The acquisition process therefore requires a significant amount of temporal averaging which makes it prohibitively slow for applications necessitating real-time information.

Our approach is unique in that we adopt a more application specific view of the optical measurement and reconstruction problem by coupling the measurements with an atmospheric dispersion model. Instead of regarding DIAL data as (local) concentration measurements we recover three-dimensional concentration profiles implicitly through a dispersion process. The approach, which combines optical models from radiative transport theory [AS09] with plume dispersion dynamics [Sto11] exploits the structure of the atmospheric structure of atmospheric plumes to alleviate the ill-posedness of the imaging problem. This allows to locate sources as well as track the further movement of the plume as this information is directly related to the reconstructed dispersion parameters.

In order to properly address these tasks, it is often necessary for a 3-dimensional region to be analysed, e.g. when the location of the gas might be unknown or even its presence is questionable. If such a question was to be answered with conventional methods one would effectively first solve a three-dimensional imaging problem in order to obtain local gas concentrations [Stu10]. These, however, can only be as accurate as the time resolved optical measurement corresponding to the location of interest allows. The ill-posedness of 1 this problem makes it virtually impossible to solve in the presence of significant measurement noise and the substantial amount of temporal averaging needed in order to obtain signals of sufficient quality would render the approach prohibitively slow.

Consequently, state-of-the-art approaches based on optical data are limited to scanning spatially restricted regions such as lines or cross-sections which puts them in a similar position as point concentration measurements with regard to their ability of plume location and tracking. A clear limitation presented by any approach that utilises spatially sparse measurements is that, regardless of their accuracy, they can only detect objects if (or once) they are near the measurement location.

On the other hand, some questions, such as whether there is a significant amount of gas, could be answered by spatially averaging a noise corrupted measurement, e.g. the optical data, and thereby improving its quality. Although spatial information is lost, such a globally averaged measurement would be sensitive to a gas anywhere in the domain.

This observation suggests that certain aspects of the concentration profile can be recovered even when the measurement data is corrupted by a significant amount of noise. Unlike general 3D image reconstruction problems that often have between 104 and 106 unknowns, we seek to only reconstruct a small amount of parameters corresponding to dispersion related quantities.

By leveraging this physical prior knowledge and reducing the concentration profile to its most essential aspects we are able to utilise spatially unrestricted noisy measurements which is something that, to the best of our knowledge, state-of-the-art DIAL methods are unable to do. In this respect our initial results on the sketching computational expensive models have shown great promise [LWKP20].

Additionally, the method retains interpretability of the reconstructed quantities which provide answers to questions regarding the origin and future behaviour of the gas that may be of even greater interest than the concentration profile itself.

3 Anticipated impact of the project

The goal of this research is to develop an optical remote sensing and imaging method based on absorption measurements that has the capability to compute three-dimensional concentration profiles as well as physically meaningful dispersion related quantities in essentially real-time.

As such it will provide information that is unobtainable through any of the existing approaches and can further aid in finding the right course of action when it comes to first-responses after accidents or attacks involving dangerous gases. The approach can be used in any scenario where a reasonably accurate dispersion model is available to describe the image, and thus we expect the impact to be most significant in surveillance applications where a gas is supposed to be detected and possibly located, making it necessary to scan a large region, as indeed in environmental metrology applications where the source of the plume is known and the objective is to estimate the flux of the emission of various chemicals present in the plumes.

4. Acknowledgements

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