Improved Images emerge from the 4th Dimension

At the time of winning the CoSeC Impact Award (2021) Ryan Warr was a 3rd-year PhD student in the Henry Moseley X-ray Imaging Facility at the University of Manchester, where his research concerns the advancement of Spectral X-ray Computed Tomography imaging techniques. Ryan built on and developed existing imaging software to improve the quality of X-ray images by extracting the maximum amount of relevant information from poor quality images. The research aids the precise identification, visualisation and analysis of materials, enabling advanced imaging across fields including medical imaging, geology and security scanning.

Background

For many years, X-ray computed tomography (CT) has been used to non-destructively obtain insight into materials and objects, collecting sets of 2D images and recombining them to produce a detailed 3D map using a reconstruction algorithm. These techniques have been applied in a wide range of fields, including medical imaging, materials science, industrial testing, etc.

Conventionally, X-ray detectors produce 'black and white' images, where higher density objects (e.g. bone) will appear brighter than surrounding, lower density materials (fat, muscle). Where materials have similar density (e.g. soft tissue), however, the contrast between them, and hence structural detail, is poor. One way to address this is to use hyperspectral detectors.

On interacting with X-ray photons, every chemical element emits a unique, identifying spectral signal corresponding to a specific energy that can be used as an element's 'marker'.

With hyperspectral detectors, the exact energy of any markers can be precisely identified and used as fingerprints, confirming the presence and position of an element within the sample.

Hyperspectral tomography is a relatively new technology, and a number of challenges must still be overcome to optimize the data obtained from the imaging method.

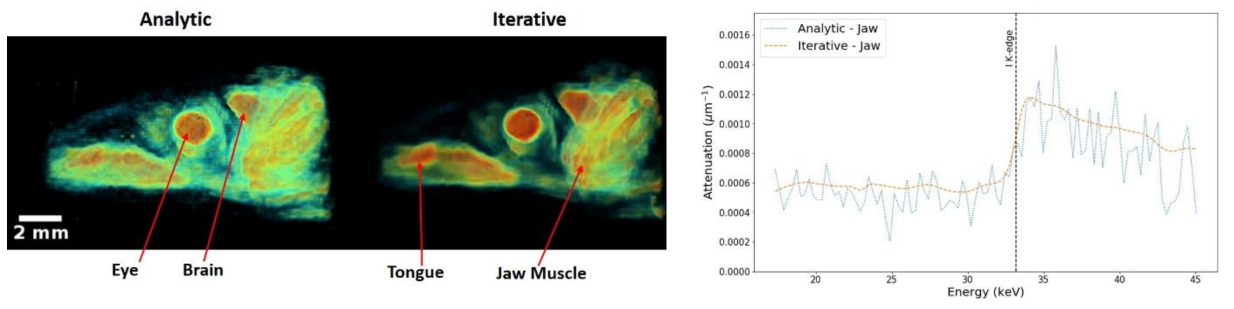
Challenges

Hyperspectral imaging unlocks access to an additional layer of energy-based information, yet current detector technology is still in its early stages. More demanding signal processing limits the amount of data we can collect during imaging. One may compensate for this by imaging for longer, but in some cases time or X-ray dose is restricted. The consequence is each image often suffers from poor signal-to-noise ratio, making structural features harder to distinguish. For spectral images, the unique energy markers may be hidden by noise, limiting the ability to map chemicals by their fingerprints. The correct choice of reconstruction algorithm is therefore crucial to counteract such issues and restore optimum image quality. Standard, analytic reconstruction methods typically fail to suppress high levels of noise. Advanced, iterative algorithms offer a solution but their availability is limited and inconsistent.

Therefore, it is essential to develop novel algorithms for optimum spatial and spectral image quality.

Ryan's role in addressing the challenges

Ryan has used the flexibility of the tomographic imaging open source software: Core Imaging Library (CIL), to create and test a novel, dedicated iterative reconstruction algorithm that can suppress noise and restore feature definition to key structures. With hyperspectral data, there are many similarities observed across the spatial and spectral dimensions. While this information cannot be utilised by analytic routines, an iterative algorithm can exploit such structural correlations to improve reconstruction quality. Ryan's PhD work involved the optimisation and application of the novel algorithm to reconstruct 4D (3D spatial + 1D spectral) datasets of stained biological specimens. The chemical agents used for staining are often low in concentration and inhomogeneously distributed, made worse in the case of noisy data. Novel iterative methods can successfully overcome such issues, enabling excellent characterisation and visualisation of chemically-stained soft tissue regions. The development of such algorithms to aid elemental analysis has the capability to improve the insight and understanding of samples within biology, geology and industrial testing.



Left: Noise reduction and improved chemical mapping of iodine stain in soft tissue using iterative method.
Right: Application of smoothing method to energy profile within jaw of sample, significantly reducing noise.

CoSeC's Impact

"Through CoSeC, my understanding of designing and optimising reconstruction algorithms has grown immensely by working closely with the CCPi. Being able to share and communicate new ideas through 'hackathon' and workshop sessions has vastly improved my theoretical knowledge and coding skills. I hope to continue my research in hyperspectral imaging and help to advance it across a wide range of applications, including geology, bio-imaging and non-destructive testing. As the imaging hardware, and software innovations such as CIL, continue to improve, I can only see hyperspectral imaging becoming more commonplace and I hope to be there when it does!"

Ryan Warr

CoSeC's network of supported communities enables invaluable opportunities to work across the Computational Collaborative Projects (CCPs) including CCPi - for Tomographic Imaging. CCPi aims to provide the UK tomography community with a toolbox of algorithms that increases the quality and level of information that can be extracted by computed tomography.

www.cosec.stfc.ac.uk

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Further information: An article was accepted for publication in September 2021, discussing the application of novel iterative algorithms to lab-based hyperspectral X-ray CT datasets.
Further papers describing the background and basic use of the CIL software (see https://www.ccpi.ac.uk/CIL)

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