IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Biophysics informed deep learning for MRI**	
Project Number	**IMURA0962**	
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Research Clusters:

Highlight which of the Academy's CLUSTERS this project will address?
*(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*

1	*Material Science/Engineering (including Nano, Metallurgy)*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*
3	*Math, CFD, Modelling, Manufacturing*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*
8	*HSS, Design, Management*

Research Themes:

Highlight which of the Academy's Theme(s) this project will address?
(Feel free to nominate more than one. For more information, see www.iitbmonash.org)

1	*Advanced computational engineering, simulation and manufacture*
2	*Infrastructure Engineering*
3	*Clean Energy*
4	*Water*
5	*Nanotechnology*
6	*Biotechnology and Stem Cell Research*
7	*Humanities and social sciences*
8	Design

The research problem

Understanding the living human body requires in-vivo visualisation and quantification of tissue microstructure, function and metabolism. Magnetic resonance imaging (MRI) is an important non-invasive biomedical imaging modality that underpins many breakthroughs in science, biology and medicine. Recent breakthroughs in machine learning especially deep learning has provided a unique opportunity for further improvement in medical imaging.

Recent deep learning based image reconstruction methods greatly improve image quality compared to existing methods [1][2][3][4]. This improvement is attributed to the ability of deep models to capture complex relationships between the acquired data and the physical quantity being imaged. However, current deep learning models show poor out-of-sample performance especially with limited training datasets and inconsistent data-acquisition protocols.

The number of model parameters for data processing in medical imaging increases exponentially from compressed sensing to more recent dictionary-based and deep learning models [5] The trend towards data-driven image reconstruction requires stabilisation and regularisation using physics-based prior knowledge during the image reconstruction as an inverse problem. A major goal of MRI research is to infer comprehensive physics-based models for image reconstruction and artefact removal. However, this is an intractable problem due to the high dimensionality of the parameter space.

This project aims to bridge the gap between physical models and deep learning models and to develop biophysics informed deep learning model for robust end to end signal processing in MRI. The project is generic in nature and will improve many applications in medical imaging such as functional neuroimaging [6][7][8], image segmentation [9][10], and design of optimal data acquisition [11].

The PhD candidate will plan her/his curriculum to satisfy all curriculum-related criteria specific to the Computer Science and Engineering (CSE) Department at IITB, in addition to criteria specific to the IITB-Monash Academy. The PhD candidate will need to fulfil the requirement of Monash University for PhD candidature. The student is required to travel to Australia to undertake a part of the research.

References:

[1] B. Zhu, J. Z. Liu, S. F. Cauley, B. R. Rosen, and M. S. Rosen, “Image reconstruction by domain-transform manifold learning,” *Nature*, 2018.

[2] K. Pawar, Z. Chen, N. J. Shah, and G. F. Egan, “A Deep Learning Framework for Transforming Image Reconstruction Into Pixel Classification,” *IEEE Access*, vol. 7, pp. 177690–177702, 2019.

[3] Pawar, K., Chen, Z., Shah, N.J., Egan, G.F., “Suppressing Motion Artefacts in MRI using an Inception-Resnet network with Motion Simulation Augmentation,” *NMR Biomed*, no. accepted, 2019.

[4] K. Pawar, Z. Chen, J. Seah, M. Law, T. Close, and G. Egan, “Clinical utility of deep learning motion correction for T1 weighted MPRAGE MR images,” *Eur. J. Radiol.*, 2020.

[5] V. P. Sudarshan, G. F. Egan, Z. Chen, and S. P. Awate, “Joint PET-MRI image reconstruction using a patch-based joint-dictionary prior,” *Med. Image Anal.*, 2020.

[6] S. D. Jamadar *et al.*, “Simultaneous task-based BOLD-fMRI and [18-F] FDG functional PET for measurement of neuronal metabolism in the human visual cortex,” *Neuroimage*, 2019.

[7] S. Li, S. D. Jamadar, P. G. D. Ward, M. Premaratne, G. F. Egan, and Z. Chen, “Analysis of continuous infusion functional PET (fPET) in the human brain,” *Neuroimage*, 2020.

[8] S. Li, S. D. Jamadar, P. G. D. Ward, G. F. Egan, and Z. Chen, “Estimation of simultaneous BOLD and dynamic FDG metabolic brain activations using a multimodality concatenated ICA (mcICA) method,” *Neuroimage*, 2021.

[9] A. Pozaruk *et al.*, “Augmented deep learning model for improved quantitative accuracy of MR-based PET attenuation correction in PSMA PET-MRI prostate imaging,” *Eur. J. Nucl. Med. Mol. Imaging*, 2021.

[10] K. Pawar, Z. Chen, N. J. Shah, and G. Egan, “Residual encoder and convolutional decoder neural network for glioma segmentation,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2018.

[11] K. Pawar, Z. Chen, J. Zhang, N. J. Shah, and G. F. Egan, “Application of compressed sensing using chirp encoded 3D GRE and MPRAGE sequences,” *Int. J. Imaging Syst. Technol.*, 2020.

Project aims

The overall objective of the project is to develop fast and robust end to end data processing methods for MRI, and specific aims are:

Aim 1: Development of biophysics informed deep learning model for end to end MR signal processing

Aim 2: Application of developed model in neuroimaging with quantitative improvements.

Expected outcomes

The expected outcomes include:
Outcome 1: Novel biophysics informed deep learning model for end-to-end MR signal processing.
Outcome 2: Applied developed model in neuroimaging with quantitative improvements.
Outcome 3: Publications resulting from the novel research at top-tier conferences and journals.

How will the project address the Goals of the above Themes?

The core aim of the project is in line with the above theme. The project will bring a new design and solution for medical imaging data acquisition and image reconstruction in a multi-disciplinary setting. The project will lead to clinical and scientific studies using medical imaging in human populations. The project involves medical image computing, machine learning, signal and image processing, and physics which falls in the areas of expertise of the Academy.

Potential RPCs from IITB and Monash

Prof Gary Egan is an international leading expert in neuroimaging and neuroscience. He has substantial experience in mentoring and also provide direct input into the project. Prof Egan is currently the director of Monash Biomedical Imaging.

Prof Meng Law is an international leading expert for AI in Radiology. He is currently the Head of Radiology Unit at the Alfred hospital and professor at Faculty of Medicine at Monash.

Capabilities and Degrees Required

The ideal candidate should have knowledge / skills in the following domains:

1. Machine learning
2. Medical image computing
3. Basic statistical modelling and inference, optimisation, linear algebra

Although not mandatory, candidates with experience in MR and/or PET imaging and experience in deep-neural-network based methods will be highly regarded.

Necessary Courses

Name three tentative courses relevant to the project that the student should complete during his/her coursework at IITB (the student will require to secure 8 point in these courses)

1. Medical Image Computing (CS 736)
2. Foundations of Machine Learning (CS 725) or equivalent
3. Some course focused on deep-learning based image/data analysis

Select up to **(4)** keywords from the Academy's approved keyword list **(available at http://www.iitbmonash.org/becoming-a-research-supervisor/)** relating to this project to make it easier for the students to apply.

Medical image computing; Machine learning; Medical imaging; Image processing; Computer vision