IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Machine learning based MRI and PET imaging**	
Project Number	**IMURA0882**	
Monash Main Supervisor (Name, Email Id, Phone)	Dr Zhaolin Chen zhaolin.chen@monash.edu	*Full name, Email*
Monash Co-supervisor(s) (Name, Email Id, Phone)	Dr Mehrtash Harandi mehrtash.harandi@monash.edu	
Monash Head of Dept/Centre (Name,Email)	Prof Tom Drummond tom.drummond@monash.edu	*Full name, email*
Monash Department:	Department of Electrical and Computer Systems Engineering	
Monash ADGR (Name,Email)	Associate Dean of Research Training Faculty of Engineering Prof Emanuele Viterbo Emanuele.Viterbo@monash.edu	*Full name, email*
IITB Main Supervisor (Name, Email Id, Phone)	Prof. Suyash P. Awate suyash@cse.iitb.ac.in https://www.cse.iitb.ac.in/~suyash	*Full name, Email*
IITB Co-supervisor(s) (Name, Email Id, Phone)		*Full name, Email*
IITB Head of Dept (Name, Email, Phone)	Prof. Umesh Bellur umesh@cse.iitb.ac.in	*Full name, email*
IITB Department:	Computer Science and Engineering (CSE) Department	

Research Clusters:

Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*		**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	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Advanced computational engineering, simulation and manufacture*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Infrastructure Engineering*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Water*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Nanotechnology*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Biotechnology and Stem Cell Research*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*	7	*Humanities and social sciences*
8	*HSS, Design, Management*	8	Design

The research problem

Background and research problem

Recently, a major development in Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) has been the fusion of the two methodologies into one hybrid MR-PET instrument capable of simultaneous measurement of both datasets [1]. The objective of this development is to enable acquisition and reconstruction of MR and PET; such an instrument opens up highly novel opportunities for fundamental research as well as for diagnostic imaging applications.

Simultaneously acquired MR-PET opens a new door to study of brain functions in a truly multi-parametric setting. The combination of two modalities offers new methods of imaging and the ability to make new discoveries of brain functions. For example, a recently published study in rats used simultaneous fluorodeoxyglucose (18F-FDG) PET and BOLD fMRI revealed complementary information and reported novel neuroscience findings [2]. Another recent study shows dynamic PET can be useful in measuring brain dynamic FDG metabolic changes using a paradigm similar to that of an fMRI experiment [3]. However, although the MR-PET are acquired simultaneously, little has been done to optimise the data acquisition and image reconstruction for both MRI and PET targeted towards specific clinical and scientific studies in human cohorts.

Machine learning has been applied in medical image analysis for various tasks such as image segmentation, image quality enhancement, and image reconstruction, demonstrating promising results [4,5,6,7,8]. This project aims to apply machine learning algorithms to model the fundamental data acquisition and image reconstruction process of MRI and PET. One outcome of this project will be fast and optimised data acquisition and image reconstruction for MR-PET. Another outcome of this project will be the application of existing and novel machine-learning methods towards novel clinical and scientific studies in human cohorts.

Research Project

The project comprises two main cores. One core of the project is to develop deep learning algorithms that are informed by models of the data acquisition processes of both MR and PET systems for accurate estimation of tissue properties. Another core of the project is to apply existing and novel machine-learning methods for clinical and scientific studies in human cohorts.

The MR acquisition process can be modelled as

$$\boldsymbol{S} = (\boldsymbol{E} + \boldsymbol{\Delta E})(\boldsymbol{C} + \boldsymbol{\Delta C})\boldsymbol{P} + \boldsymbol{N}$$

where $\underline{\boldsymbol{S}}$ is the acquired MR data, $\underline{\boldsymbol{C}}$ and $\underline{\Delta \boldsymbol{C}}$ are MR receive coil sensitivities and associated uncertainty

terms, $\boldsymbol{E}$ and $\Delta\boldsymbol{E}$ are encoding matrix and gradient error matrix, $\boldsymbol{N}$ is noise term, and $\boldsymbol{P}$ is the object being imaged.

The PET observable counts, y, are independent Poisson distributed random variables with

$$y \sim Poisson\left(\sum_{s} a_{ts}x_s\right)$$

where x_s is isotope concentration at the voxel location s, and t is a detector pair. The data model (probability density) is

$$p(y|x) = \prod_{t} \frac{\left(\sum a_{ts}x_s\right)^{y_t} \exp\left(-\sum a_{ts}x_s\right)}{y_t!}$$

The weight coefficient a_{ts} represents probability that an emission from voxel s is detected in projection t. Once the model is established, tissue biophysical property as a function of (p, x) can be estimated and classified.

Experimental analysis and validation of the developed algorithms will be performed using the imaging facility at Monash Biomedical Imaging, start with existing MR-PET datasets and later using newer datasets targeted towards specific clinical and scientific studies.

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 research.

References:

1. Chen, Z., et al. Human Brain Mapping, 2018. 39(12).
2. Wehrl, H.F., et al., Nat Med, 2013. **19**(9): p. 1184-9.
3. Jamadar, S., et al., NeuroImage, 2019.
4. Awate, S.P., et al., Medical Image Analysis, 2019, 55: 181-196.
5. Upadhyay, U., et al., IEEE ISBI 2019, pp. 1372-1376.
6. Shah, M.P., et al., MICCAI 2018, pp. 379-387.
7. Sudarshan, V.P., et al., MICCAI 2018, pp. 338-346.
8. Sudarshan, V.P., et al., Medical Image Analysis, doi.org/10.1016/j.media.2020.101669

Project aims

The overall objective of the project is to develop fast and robust MR and PET image reconstruction methods, and specific aims are:

1. Development of simulation models for MR data acquisition and reconstruction process
2. Development of existing and novel machine learning algorithms, including deep learning, to parameterise the models, starting with existing large datasets of clinical MR-PET images at Monash Biomedical Imaging
3. Experiment design of train datasets: (a) simulation; (b) in-vivo datasets towards clinical and scientific studies in human cohorts
4. Application of machine learning and deep learning algorithms to MR and PET imaging experiments
5. Clinical and scientific studies in human cohorts using MR-PET imaging coupled with existing and novel methods in machine learning and deep learning

Expected outcomes

The overall outcome of the project will be a framework for MRI and PET data acquisition and image reconstruction. The framework will be validated in in-vivo datasets

1. Developed a framework of machine learning and deep learning methods for MRI and PET data acquisition and image reconstruction
2. Validated results in both simulation and in-vivo datasets
3. Application of the developed methods in MR-PET experiments
4. Clinical and scientific studies in human cohorts using MR-PET imaging coupled with existing and novel methods in machine learning and deep learning

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

Advanced computational engineering, simulation and manufacture

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

Capabilities and Degrees Required

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

1. Image processing
2. Machine learning
3. Medical image computing
4. Basic statistical modelling and inference, optimisation, linear algebra
5. Code development and data analysis
6. Desirable background: Computer Science and Engineering, Electrical engineering

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

Potential Collaborators

Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.

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; Medical imaging; Image processing; Signal processing; Machine learning; Biomedical Engineering;