Deep Learning for Acceleration of Spectrally-Sensitive MRI

Purpose: To speed up MRI image acquisition for the spectrally-selective Generation of Arbitrary Spectral Profiles (GASP) MRI pulse sequence developed by the Bangerter group. Specifically, deep learning will be used to generate fully-sampled image datasets for the GASP algorithm from under-sampled input datasets. Once trained, output from a fast acquisition that under-samples the required data can be fed to the algorithm to generate a complete GASP dataset.

Project Importance: GASP has the potential to minimize both cost and scan time, two limiting factors for spectral analysis in magnetic resonance imaging (MRI). Analyzing the best data acquisition for GASP will optimize how this is done. A deep learning algorithm to generate data points for the GASP algorithm will contribute to this potential.

Project Overview:

MRI is a highly-flexible medical imaging technique that, unlike X-ray, does not rely on ionizing radiation for image generation. MRI produces images with excellent soft tissue contrast, and modern MRI machines can achieve relatively high resolutions. It is largely noninvasive and generally considered safe for research subjects. It has become a great tool to visualize and study the human body, but the high-resolution 3D MRI scans increasingly used in both research and clinical practice suffer from long scan times, which makes them very expensive.

Balanced steady-state free precession (bSSFP) MRI is an imaging technique that yields images with high signal-to-noise ratio in a short amount of time, but suffers from bands of signal loss ("banding artifacts") due to high sensitivity to magnetic field variation.[1] These bands of null signal can make the scans unreadable, as pathology or important anatomic detail might be missing. The banding artifacts are a function of off-resonance frequency (caused by magnetic field inhomogeneities). To compensate for this, methods have been created to either reduce the appearance of banding artifacts or change the spectral profile of the acquired data to move the location of the banding artifacts and compensate for certain off-resonance frequencies.[2]

GASP is a technique recently developed by the Bangerter group to generate an arbitrary spectral profile for multiple-acquisition bSSFP. A spectral profile is a mathematical representation of the frequency response of signals acquired from the MRI scanner (i.e., the spectral profile tells us what the MR signal level is going to be at a given off-resonant frequency). Using multiple phase-cycled bSSFP acquisitions, the spectral profile of each acquisition can be manipulated in a predictable way. GASP then uses the set of shifted spectral profiles to generate an orthonormal basis from which one can approximate any arbitrary spectral profile for that data acquisition.[2] This means only a few scans are necessary to create different spectral contrast profiles and suppress unwanted off-resonant frequencies within image data. This is done by approximating features via a linear combination of basis vectors acquired from a few images. Increasing the number of terms in this basis expansion decreases the error of approximation.

GASP saves time and money in MRI by approximating data mathematically that would otherwise need to be acquired via further imaging. In order for this method to work, one must decrease the error of the mathematical approximation. However, to decrease the error more images are required for a better approximation. As the number of terms in the basis expansion increases, the error decreases at a diminishing rate. Thus, one must balance time and money spent on acquiring more data with the increased accuracy the data provides. My analysis of GASP will include adjusting imaging parameters (on both user-generated and in vivo data sets) and observing approximate error of the GASP algorithm. I will then utilize that information to determine the optimal number of terms for the basis expansion.

Once the parameters and number of images required is determined, I will further optimize GASP by creating a deep learning algorithm to generate extra terms for the basis expansion. By utilizing deep learning, one can teach a computer to develop an algorithm to generate extra terms based on the high level of mutual information between images. By feeding undersampled datasets as the input for the algorithm and giving it the expected fully sampled output, the algorithm can train itself to develop a complete output for a corresponding incomplete input. I will train it on many different spectral profiles and their corresponding outputs, so I can create an algorithm general enough to develop more terms for an orthonormal basis based on any spectral profiles given to it. This will allow the use of more terms in the basis expansion of the GASP algorithm without having to acquire more image data. Similar to the analysis of GASP, I will determine the optimal number of extra terms generated via deep learning by analyzing the effect the number of generated data points has on the error of approximation.

Thesis Committee:

Faculty Advisor: Dr. Neal Bangerter, PhD, Department of Electrical Engineering

Faculty Reader: Dr. David Wingate, PhD, Department of Computer Science

Department Honors Coordinator: Dr. Karl Warnick, PhD, Department of Electrical Engineering

Qualifications of Thesis Committee:

Dr. Neal Bangerter: I have worked in the Bangerter Biomedical Imaging Group here on campus for two years under the advisement of Professor Bangerter. He has many years of expertise in the fields of MRI and AI. Professor Bangerter received his PhD in Electrical Engineering from Stanford and now holds faculty positions at Imperial College London, Brigham Young University, and the University of Utah. He advised me on an abstract acceptance to the International Society for Magnetic Resonance in Medicine (ISMRM) annual conference: the premier international conference for MRI in both medicine and research. He continues to advise me on my current research projects and has extended experience advising many PhD candidates, Master's students, and undergraduate students in their research goals.

Dr. David Wingate: Dr. Wingate received a BS and MS in computer science from BYU and a PhD in computer science from the University of Michigan. He was a postdoc and research scientist at MIT with a joint appointment in the Laboratory for Information Decision Systems and the Computational Cognitive Science group. Before joining BYU, he was the director of Lyric Labs where he directed research at the intersection of hardware and machine learning. His current research interests include, among other things, the application of deep learning in robotics and medical imaging.

Project Timeline:

April 2019: Thesis Approval

April 2019 - September 2019: Analysis of GASP sequence

September 2019 - December 2019: Construction and analysis of neural network

November 2019: Abstract submission to annual ISMRM conference

January 2020 - February 2020: Finishing stages

March 2020: Defense of thesis

IRB approval:

This project will be completed under IRB F18329.

Funding:

$1000 funding from the Honors Program would be integral in affording scan time required to acquire data sets to analyze. Time on the MRI scanner is very expensive (ranging $150-$200 per hour). Further funding for the project will come from Professor Bangerter's research grants; however, this is difficult as he has just recently moved to Imperial College London. This has complicated funding for research projects in the United States. Receiving research funds from the Honors Program would significantly lessen the burden of obtaining funding to complete the project.

Culminating Experience:

The goal of the project is to share our findings to increase the usability of GASP in other research endeavors and lessen the time and money required for MRI research. To accomplish this we will submit an abstract the ISMRM annual conference in 2020. We will also submit our findings to be published in an academic journal.

References:

1. Bangerter, et al. “Analysis of Multiple-Acquisition SSFP”, Magnetic Resonance in Medicine, 2004
2. Mendoza, et al. “Generation of Arbitrary Spectral Profiles using Orthonormal Basis Combinations of bSSFP MRI”, Proceedings of ISMRM 26th Joint Annual Meeting (2018).