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Robust Single Point Ultra Short Echo Time Water Fast Separation

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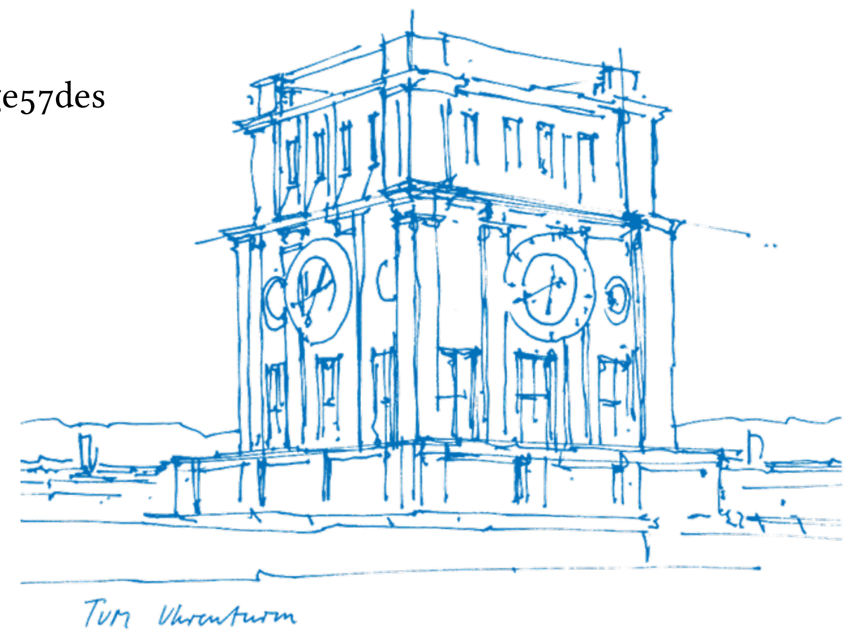

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ABSTRACT

Water–fat (WF) MRI is a set of techniques used in the assessment of metabolic dysfunction-related diseases. These techniques leverage the frequency shift between water and fat MR signals to separate them into two images, needing the acquisition of images at multiple echo times which extends the already prolonged MRI scan duration.

To shorten this acquisition time water-fat imaging has been combined with ultra-short echo time (UTE) techniques. The combination of these two methods are called UTE-Dixon imaging. These techniques have been used to suppress the fat signal in the MRI acquisitions and to determine tissue electron density properties. However, the need of two complex images to separate water and fat prolongs the scan time. A solution is to separate water and fat with the use of a single complex image instead of two, shortening scan time. This technique in combination with UTE acquisitions is called single-point UTE (sUTE) Dixon imaging. The use of a single image to separate water and fat introduces complexity to the problem, since some background phase contributions, coming from B_0 and B_1 field inhomogeneities cannot be implicitly deduced from only one echo. Hence, the problem becomes ill posed.

New techniques have arisen to tackle this problematic such as Kronthaler [citeKronthaler] with the use of a second order iterative optimization method (Gauss-Newton Method) with a smoothness constraint. Because the problem is ill posed initialization is necessary to ensure a proper convergence path and a better result of the water-fat separation.

This study aims to explore different methods to improve sUTE-Dixon imaging by addressing two different points:

1. Characteristics of background phase contributions and different approaches to modeling them.
2. How initialization techniques changes the behavior of the iterative optimization method results?.

We developed a sUTE-Dixon reconstruction framework based on the latest literature and integrated initialization techniques to further improve the method. This framework is used to compare reconstructions of different phantoms and anatomies with different hyper-parameters and initialization approaches.

Our findings reveal that initialization, not only prevents artifacts in reconstructed images but also significantly enhances the achievable water-fat separation quality. Additionally, we highlight two principal limitations of the current framework:

1. Its inability to accurately reconstruct water and fat at the anatomy/object edges.
2. Its sensitivity to mean phase shifts from the scan.

We have seen that computer programming is an art,
because it applies accumulated knowledge to the world,
because it requires skill and ingenuity, and especially
because it produces objects of beauty.

— **knuth:1974 [knuth:1974]**

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1 Members of GuIT (Gruppo Italiano Utilizzatori di TeX e LaTeX)

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Part I

INTRODUCTION TO WATER FAT SEPARATION IN MRI

1 INTRODUCTION

Magnetic Resonance Imaging (MRI) is a fundamental tool in radiology and biomedical research, offering capabilities for both anatomical and functional imaging. MRI excels in providing superior soft-tissue contrast compared to CT scans and delivers higher resolution images than ultrasound, all while being a generally safe method with infrequent occurrences of patient harm [3] and no exposure to ionizing radiation.

MRI operates based on the Nuclear Magnetic Resonance (NMR) phenomenon to create changes in magnetization that are detectable by its receiver systems. It achieves spatial localization by stimulating nuclear spins within an external magnetic field. By modifying the imaging sequences, MRI can manipulate spin systems to produce various contrasts, such as relaxation, proton density, diffusion, and phase contrasts. Beyond producing diagnostic-quality images, MRI can also be adapted for quantitative analysis, which has spurred developments in creating maps of tissue physical properties for quantitative clinical interpretations.[2]

Globally, over 25,000 MRI scanners are in use, supporting a wide range of diagnostic and therapeutic applications. In neuroimaging, MRI is crucial for distinguishing between gray and white matter, aiding in the diagnosis of conditions like dementia, Alzheimer's disease, demyelinating diseases, epilepsy, and anomalies in the brain and spinal cord. It also facilitates diffusion and functional imaging techniques that can map neuronal tracts and blood flow. Cardiovascular uses of MRI include examining the structure and function of the heart and assessing vascular diseases. In musculoskeletal imaging, MRI is used for evaluating joints, spine, soft tissue tumors, and muscle disorders. Additionally, MRI is employed in abdominal assessments for the liver, gastrointestinal tract, breasts, and prostate, particularly useful in detecting cysts, tumors, and other abnormalities. Functional imaging of metabolites through spectroscopy is also a capability of MRI. [1]

Part II

THEORY OF WATER FAT SEPARATION USING ULTRA SHORT ECHO TIME SEQUENCES

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2 EXAMPLES

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