Low rank Iterative infilling for Zero Echo-Time (ZTE) Imaging

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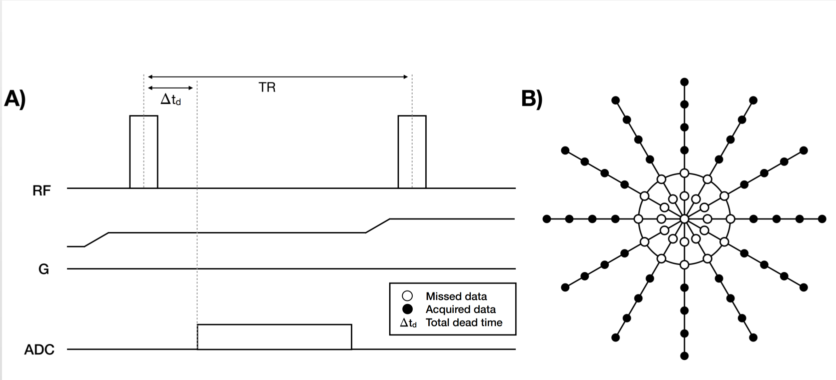
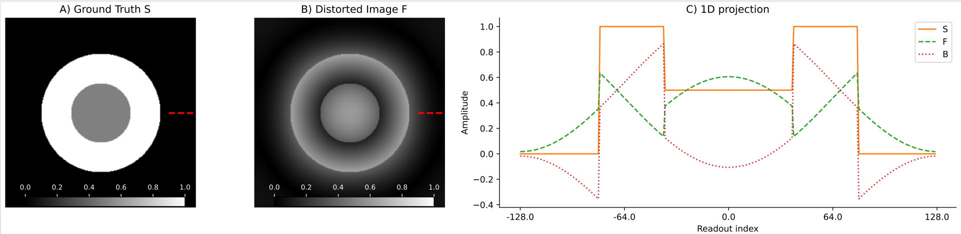
Introduction

- Zero Echo Time imaging (ZTE) can be used to image tissues with short and ultra-short transverse relaxation times
- The radiofrequency (RF) excitation is performed during spatial encoding, which leads to missing samples in the center of the k-space[1,2,3].
- The absence of the low-frequency Fourier coefficients translates, through Fourier transformation, into amplitude modulations within the image domain. This leads to a considerable reduction in image contrast.



Schematic of a ZTE sequence



Effects of the dead-time gap in ZTE imaging in the simulated spherical phantom.

1) Weiger 2012 2) Weiger 2019 3) Madio 1995

Background Information

- Sequence based methods
    - WASPI[1], PETRA[2], HIFY[3]
    - Separate acquisition
    - All these techniques introduce an non-ideal point spread function and potentially cause phase inconsistencies due to motion when combined with ZTE data.

- Reconstruction based methods
    - Algebraic[4], GRAPPA[5], CG-SENSE[5]
    - Proposed: The proposed method reformulates the in-filling of the missing samples as an inverse problem subject to low rank constrains.

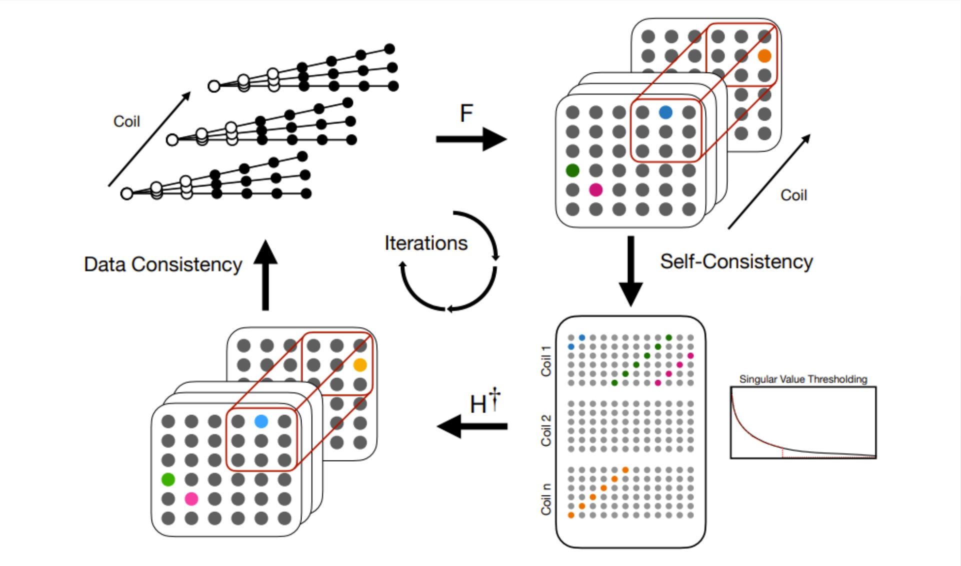
1) Wu 2007 2) Grodzki 2011 3) Froidevaux 2021 4) Kuethe 1999. 5) Wood2021

Theory

- Algebraic
  - Exploits the additional information from radial oversampling

- GRAPPA and SENSE
  - Exploits the additional information from multiple coils

- Low Rank
  - The proposed method recovers the missing data by enforcing self-consistency among neighboring K-space points in Cartesian space by minimizing the rank of the structured Hankel matrix.

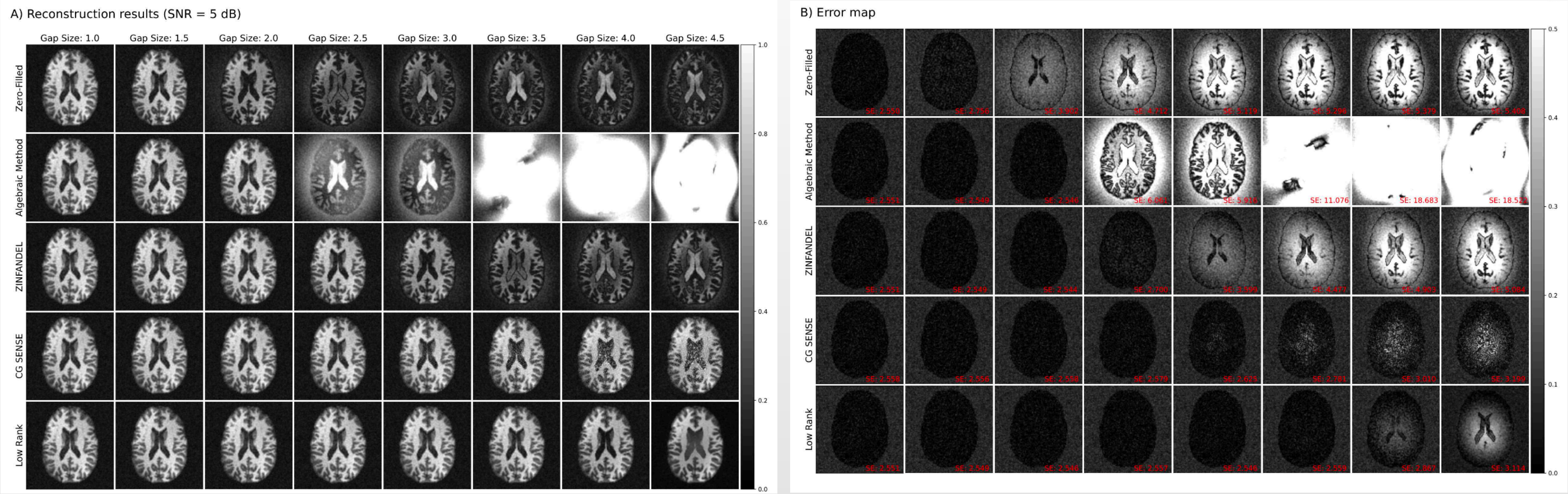


The flow chart of the proposed low rank reconstruction

Methods

- Simulation
  - The performance and robustness are evaluated through a comparative analysis that combines Monte Carlo simulations and data obtained from in vivo experiments.
  - The proposed method is tested for dead-time gaps ranging up to 4.5 Nyquist dwells, across SNR levels of 5, 10, 15, and 20 dB.
- In-vivo
  - The data was acquired on a 3.0 T scanner (Signa Premier XT, GE Healthcare, Waukesha, WI) using a 48 channel head-coil. Isotropic spatial resolution of 0.89 mm; Field-of-view of 235 mm. Flip angle of 1°; Readout bandwidth was set to +- 15.6 kHz, +- 20.8 kHz, +-31.25 kHz, +- 41.67 kHz, and +- 55.56 kHz with two times readout oversampling. Dead-time gap of 2, 2.5, 3, 3.5, and 4.5 Nyquist dwells are introduced under this setting, respectively.

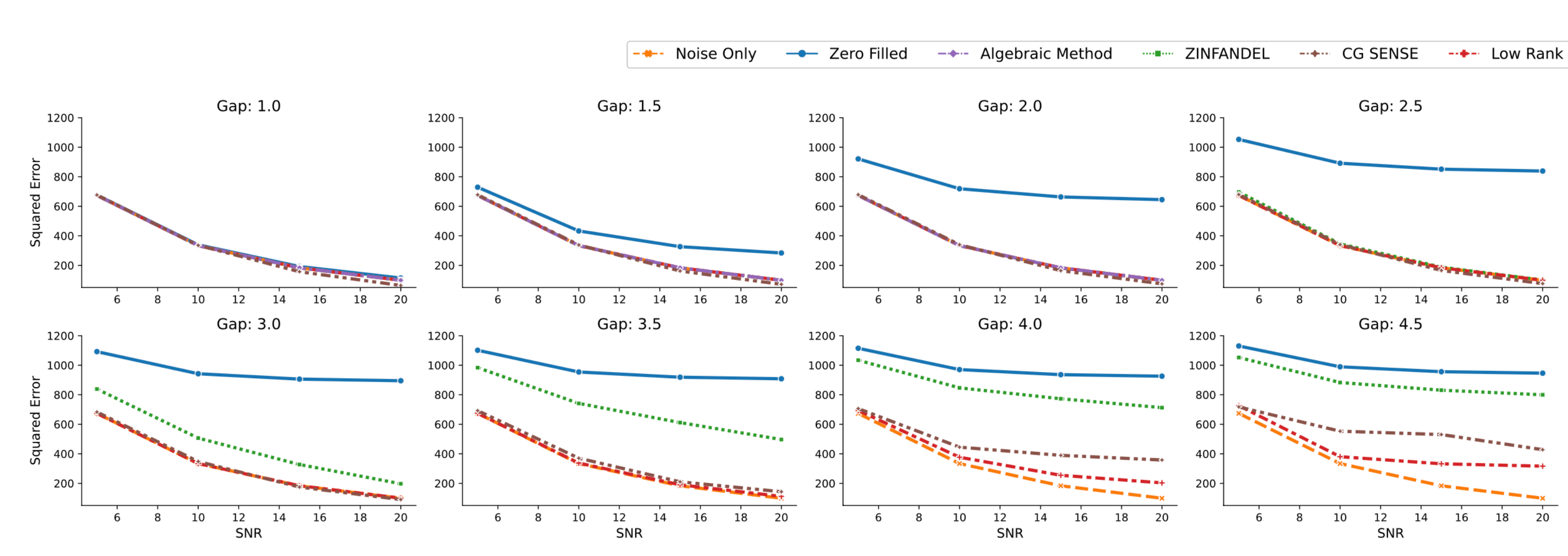
Results: simulation



An example of the digital brain simulations.

Low Rank method demonstrates superior results across all dead-time gaps compared to other methods at SNR = 5dB.

Results: simulation

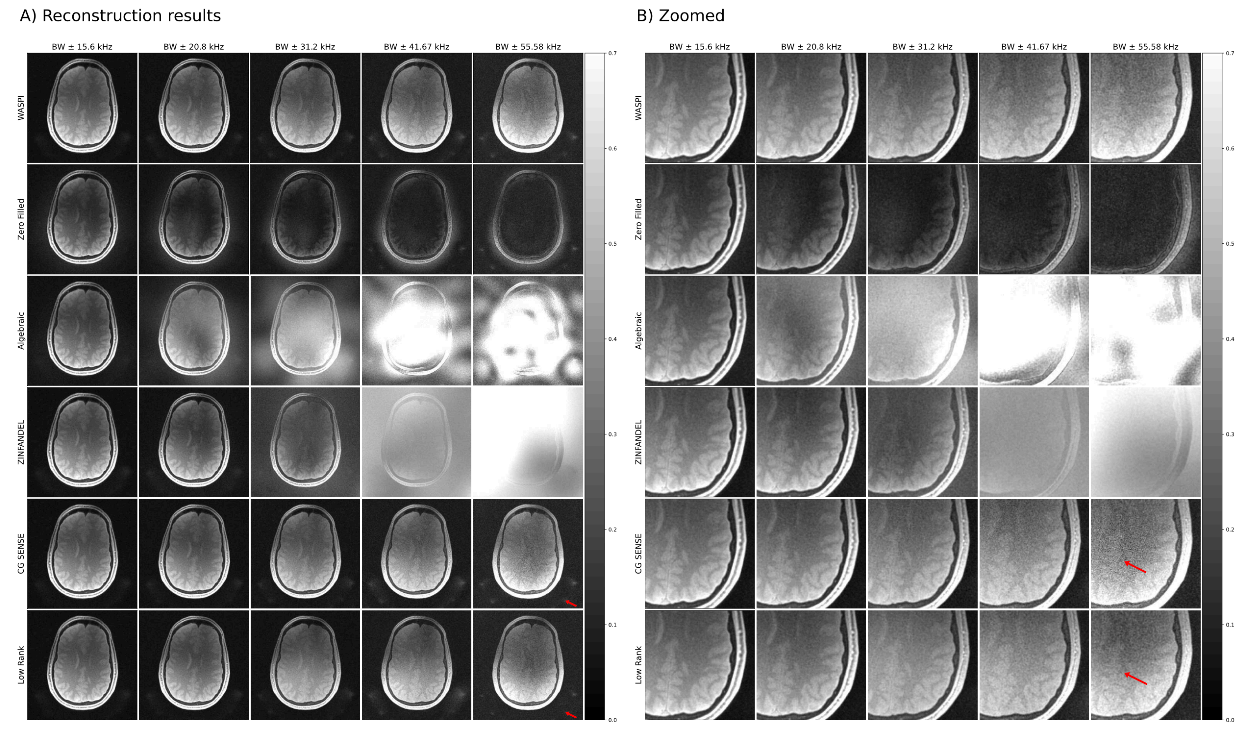


Quantitative analysis of the 3D brain simulation

Low Rank method demonstrates superior results

Results: in-vivo

Both the low rank and CG-SENSE methods are effective within a bandwidth of +- 41.67 kHz.



Reconstruction result with data collected using bi-directional radial sampling path for a normal volunteer.

Discussion

- Typically, conventional parallel imaging methods involve acquiring a fully sampled low-resolution signal in the center of k-space region. This signal is then utilized to estimate either the GRAPPA kernels or coil sensitivity profiles.
- However, within the ZTE acquisition, this low-resolution signal is inherently not present.
- Yet, we have shown that such problem can be solved much like conventional parallel imaging.
- The low-rank method proposed in this work employs both coil sensitivity information and a structured Hankel matrix, integrating the assumption that the solution lies within a low-rank subspace.

Conclusion

- We introduce a ZTE implicit data in-filling method based on low-rank reconstruction. This approach enables artifact-free reconstruction, without the need for gathering additional data. It demonstrated superior performance than the algebraic, ZINFANDEL, and the CG-SENSE method.

- It should be noted that when trying to recover data for applications that require more bandwidth, such as lung, significant difficulties remain. The use of CG-SENSE leads to significant noise amplifications, and the low-rank approach struggles to restore certain low-frequency components in the Fourier spectrum.