Pulseq Rocks - 2023-34 Reproducibility Challenge:

Open-Source, Cross-Platform Workflow for MRI Data Acquisition and Image Reconstruction Based on the Pulseq Framework

Qingping Chen

Division of Medical Physics, Dept. Of Radiology,
University Medical Center Freiburg, Germany

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Reproducibility Team Challenge

Pulseq Rocks Team

- **Team name:** *Pulseq Rocks*
- **Original author sub-team members:**
  - *Qingping Chen*, *Frank Zijlstra*, *Patrick Hucker*, *Sebastian Littin*, and *Maxim Zaitsev*, from University Medical Center Freiburg, Germany
- **Replicator sub-team members:**
  - *Amaya Murguia*, *Andrea Jacobson*, *David Frey*, *Scott Peltier*, and *Jon-Fredrik Nielsen*, from University of Michigan (UoM), USA
  - *Pengcheng Xu* and *Berkin Bilgic*, from Massachusetts General Hospital (MGH), USA

Reproducibility Team Challenge

Reproducibility Task

- **Title of abstract that was replicated:**
  - "*Open-Source, Cross-Platform Workflow for MRI Data Acquisition and Image Reconstruction Based on the Pulseq Framework*" (program number: 6708, ISMRM 2024)
- ***Goal:*** to replicate the open-source, cross-platform, easy-to-learn data acquisition and image reconstruction workflow (Fig.1) on Siemens and General Electric (GE) magnetic resonance scanners

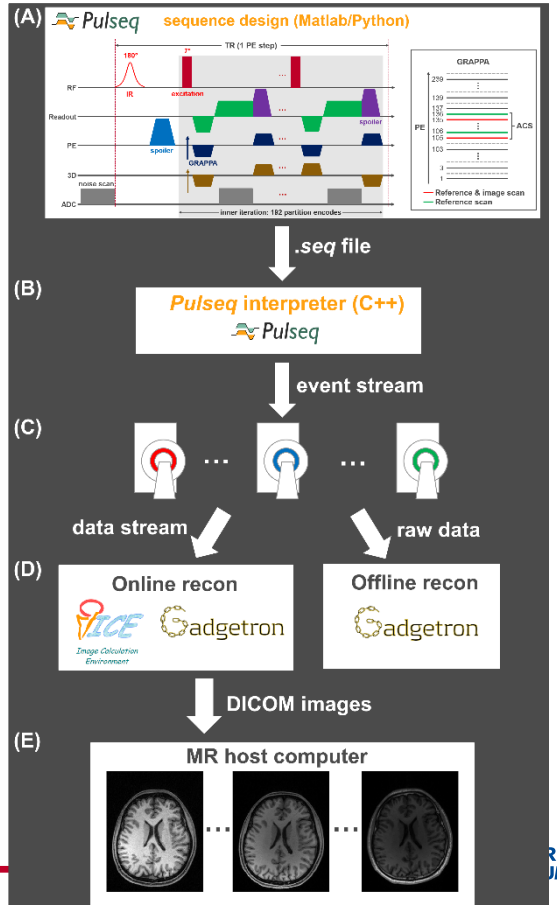


Figure 1 Workflow

Measurements

Scanners

- **University Medical Center Freiburg:**
  - Siemens Cima.X 3T scanner (version: XA61A, 20-channel coil)
  - Siemens Prisma 3T scanner (version: XA60A, 20-channel coil)
  - Siemens Trio 3T scanner (version: VB19A, 12-channel coil)
- **Massachusetts General Hospital:**
  - Siemens Prisma 3T scanner (version: XA30A, 20-channel coil)
- **University of Michigan:**
  - GE SIGNA UHP 3T scanner (32-channel coil)

Measurements

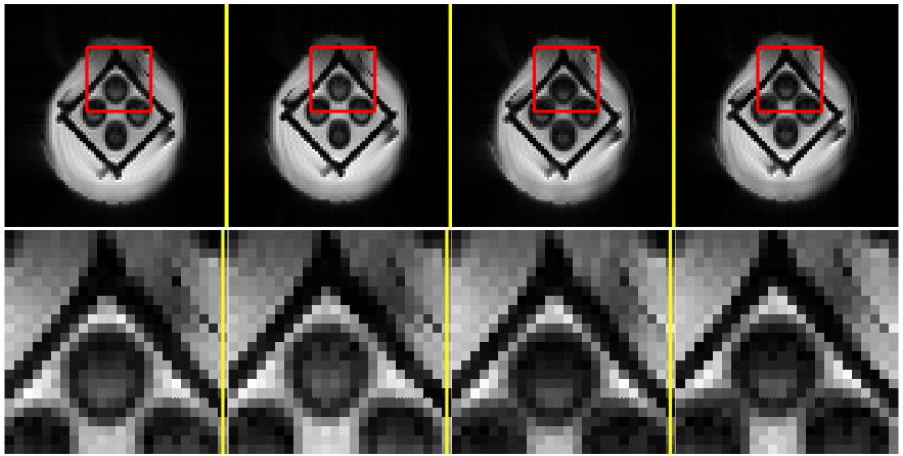
Data Acquisition and Image Reconstruction

- **Objects:** a phantom and the brain of a healthy volunteer
- **Data acquisition (sequences):**
  - Vendor-based and Pulseq-based 3D MPRAGE sequences with GRAPPA acceleration and noise scan
  - Vendor-based and Pulseq-based 2D multi-slice EPI sequences with ramp sampling and a three-echo navigator
- **Image reconstruction:**
  - Offline Gadgetron (Hansen et al., MRM, 2013; Xue et al., MRM, 2015) reconstruction for GE Pulseq-based data and Siemens vendor-based and Pulseq-based data
  - Online “Image Calculation Environment” (ICE) reconstruction on Siemens scanners for Siemens-based and Pulseq-based sequences
  - Online reconstruction on a GE scanner for GE-based sequences

Results

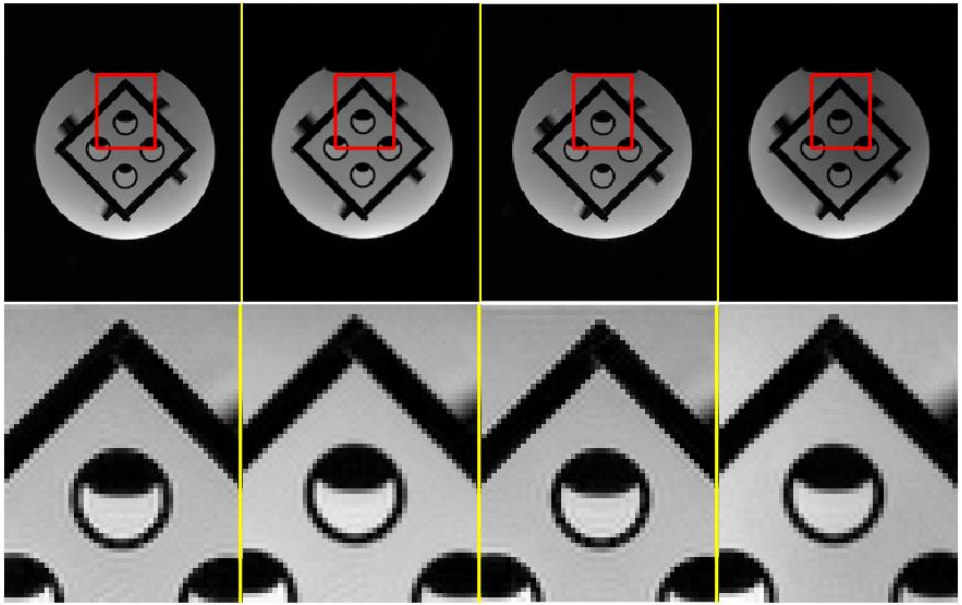
Freiburg – phantom on Siemens Cima.X 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



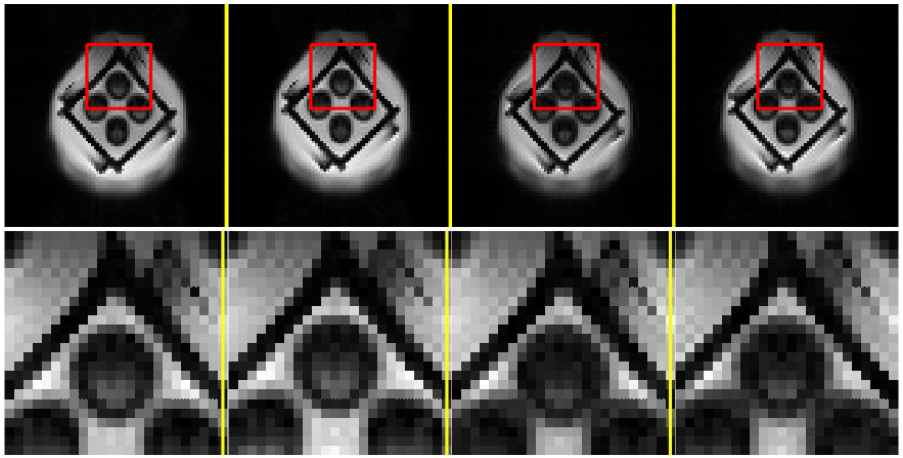
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

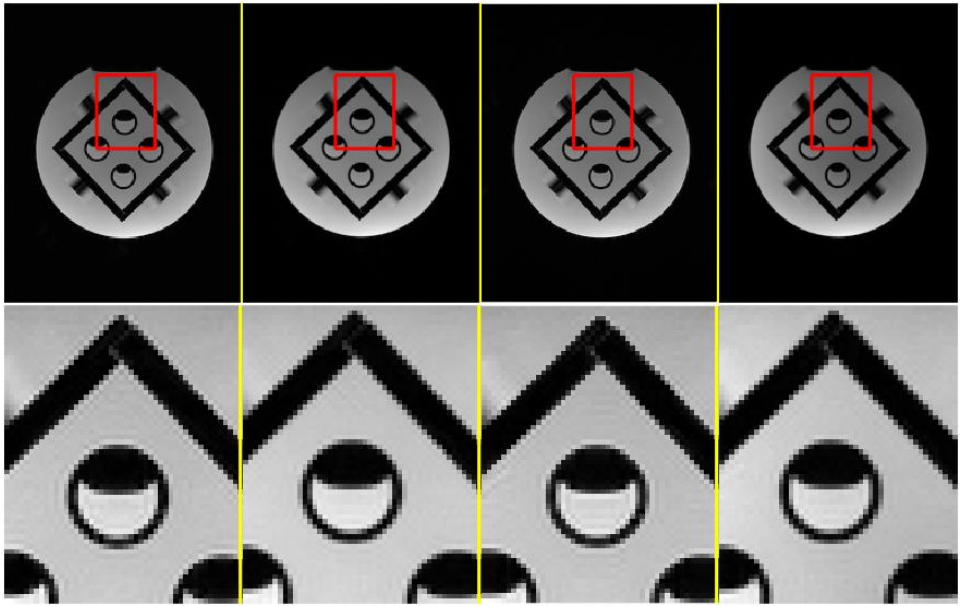
Freiburg – phantom on Siemens Prisma 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



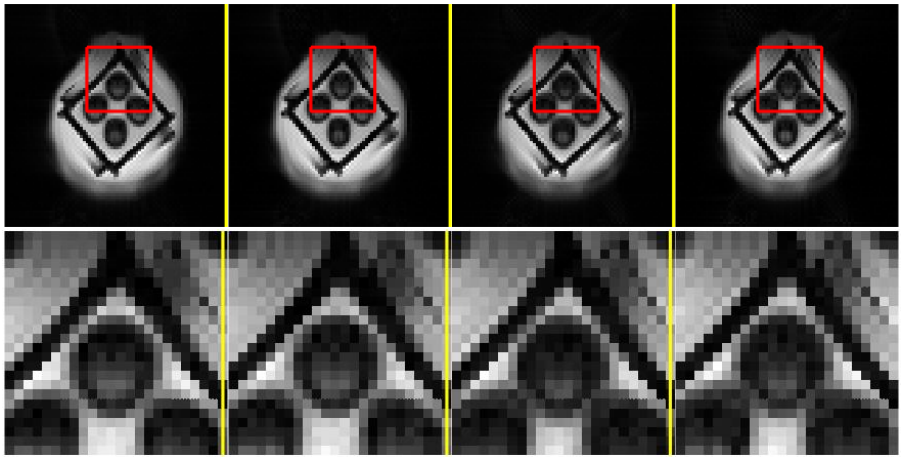
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

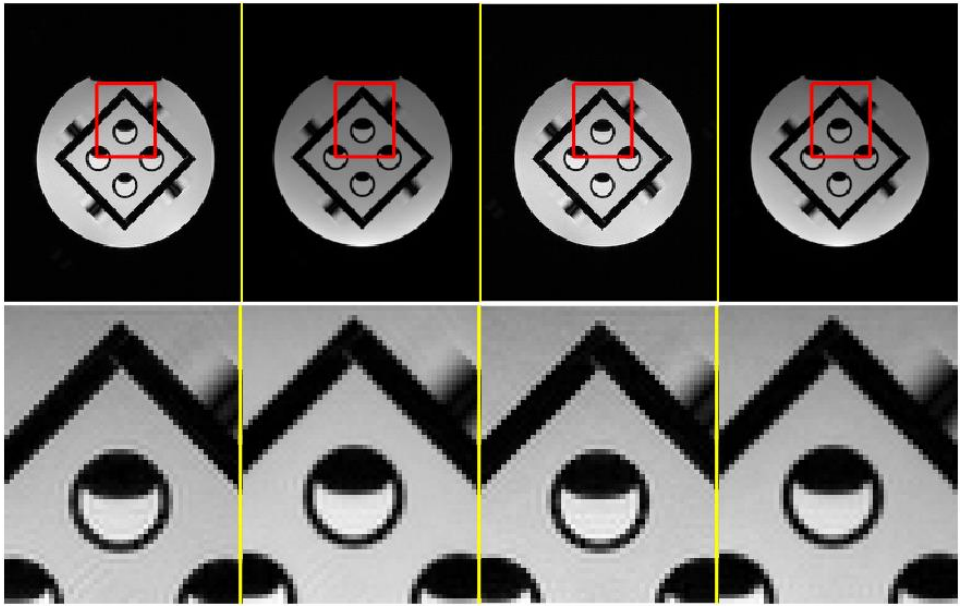
Freiburg – phantom on Siemens Trio 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



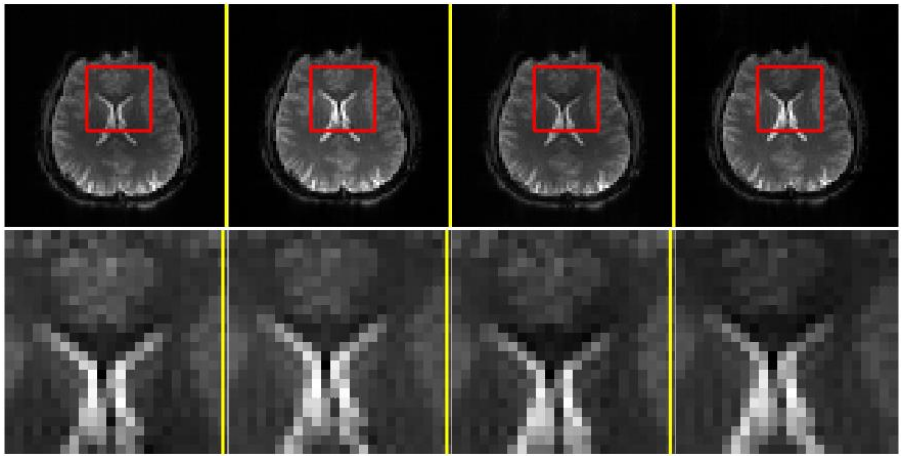
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

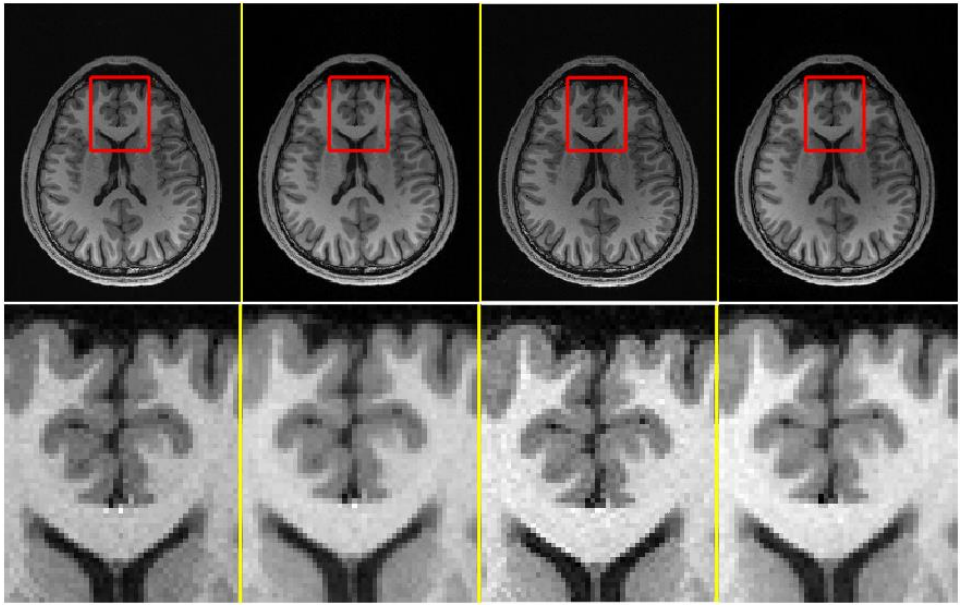
Freiburg – in vivo on Siemens Cima.X 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



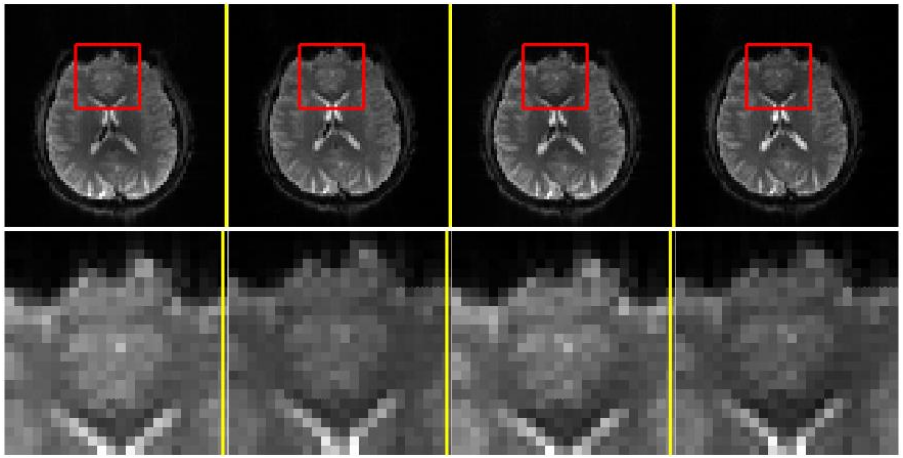
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

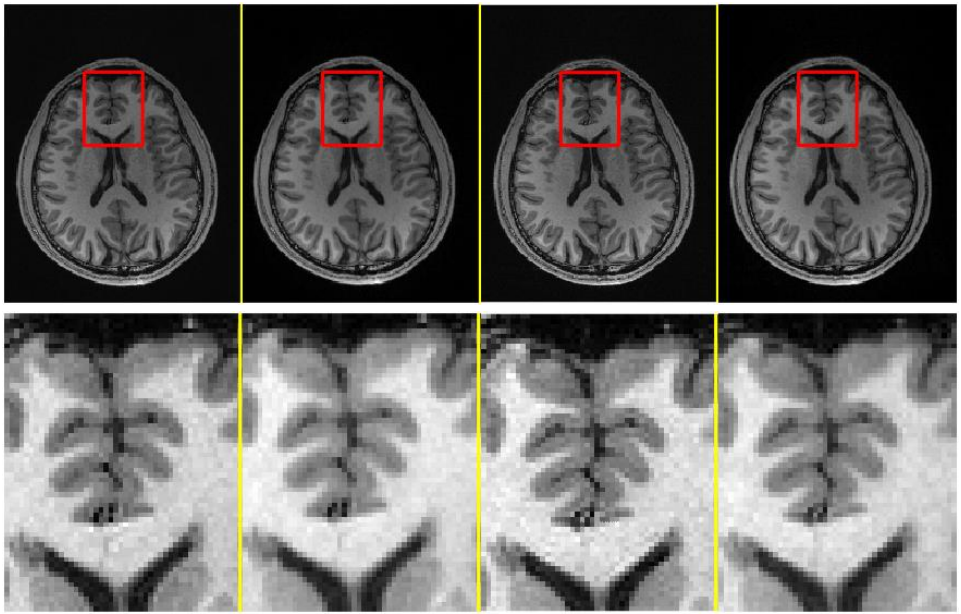
Freiburg – in vivo on Siemens Prisma 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



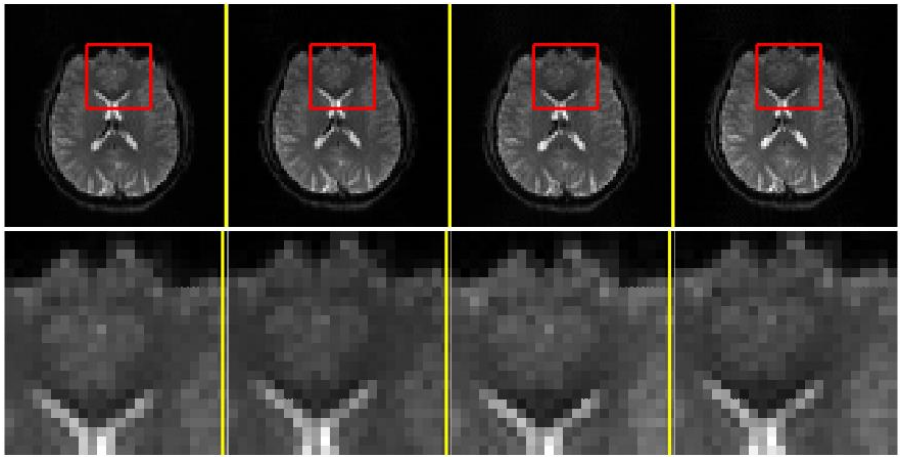
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

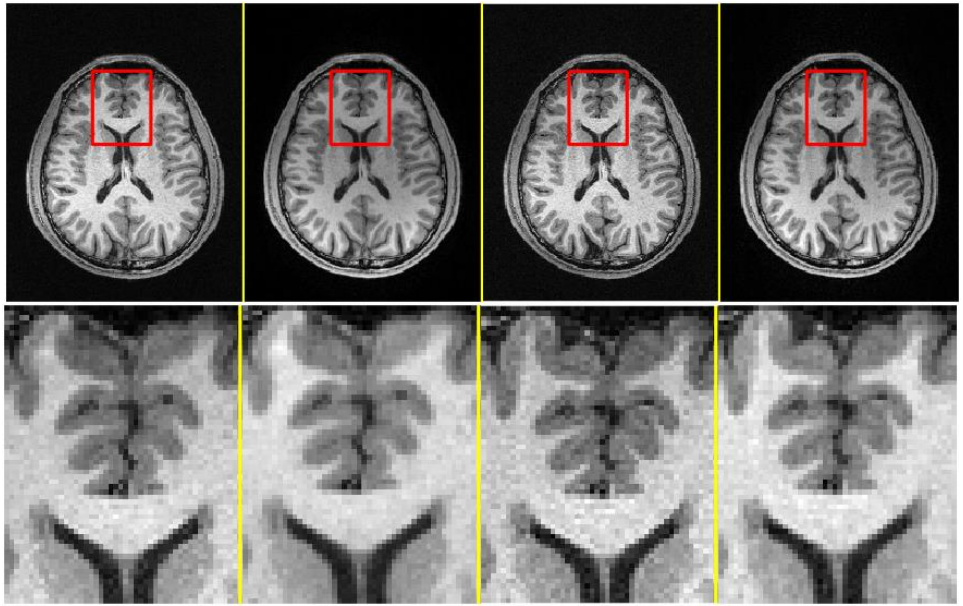
Freiburg – in vivo on Siemens Trio 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



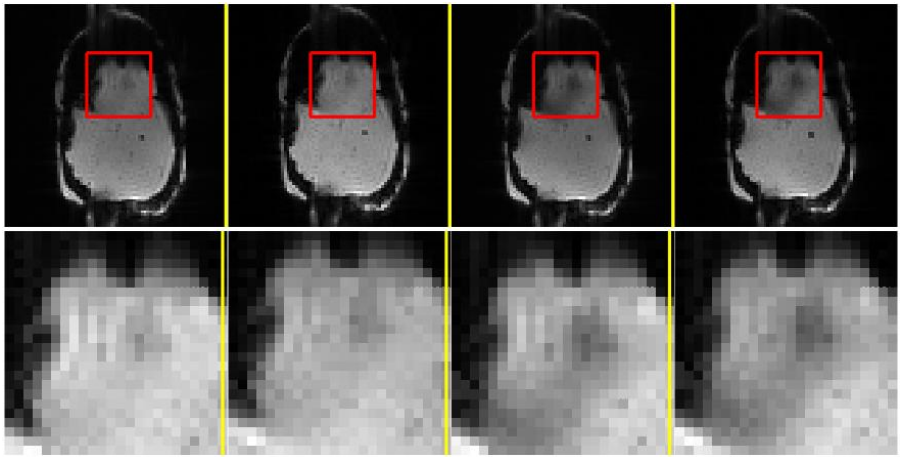
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

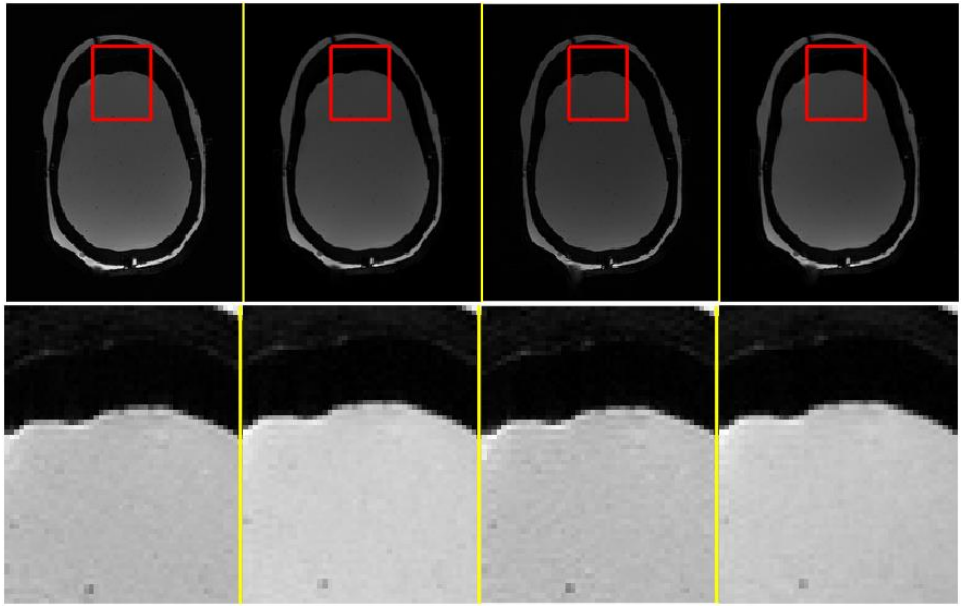
MGH – phantom on Siemens Prisma 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



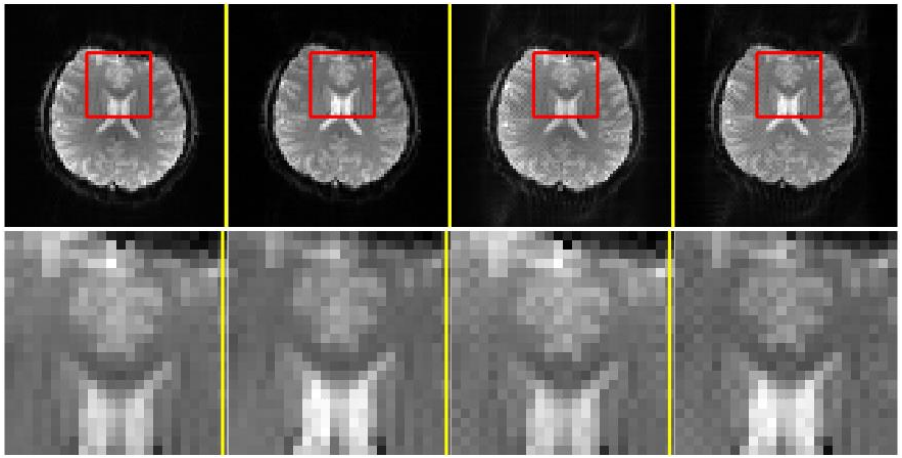
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

Results

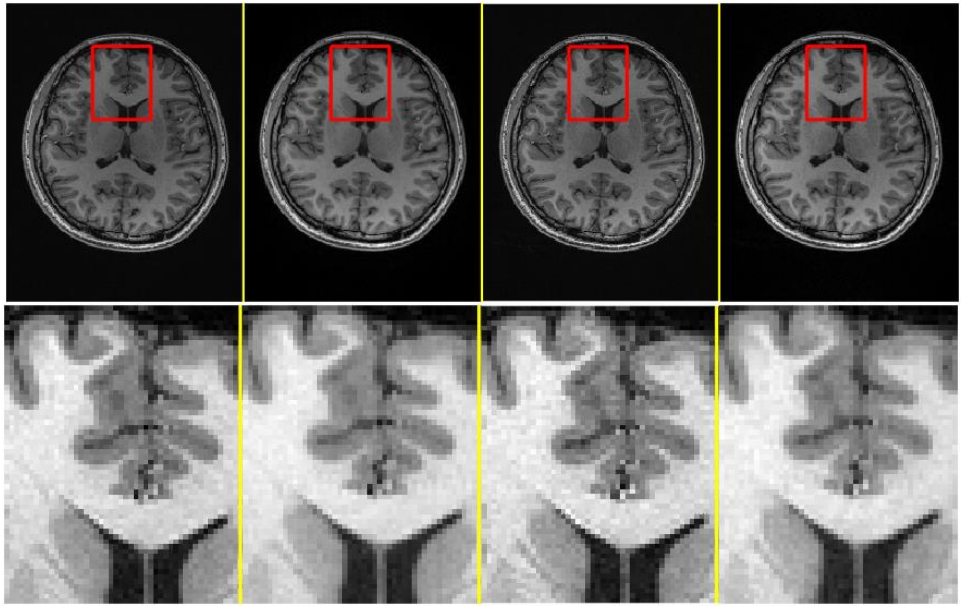
MGH – in vivo on Siemens Prisma 3T

EPI



Product+ICE Product+GT Pulseq+ICE Pulseq+GT

MPRAGE



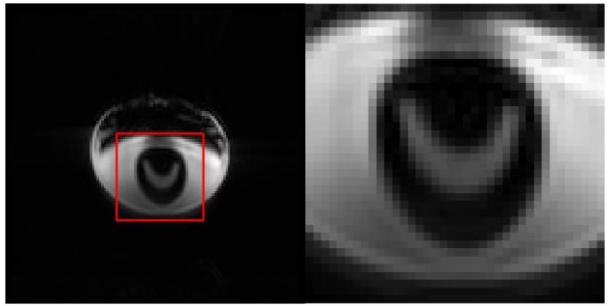
Product+ICE Product+GT Pulseq+ICE Pulseq+GT

*GT = Gadgetron, Product = vendor-based sequence

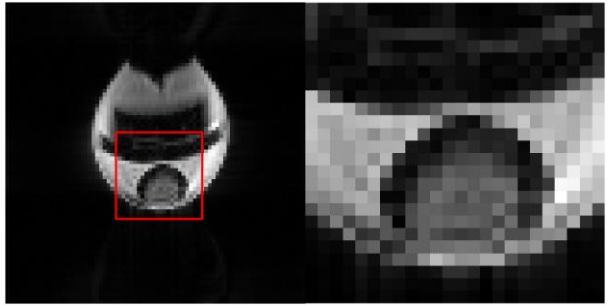
Results

UoM – phantom on GE 3T

EPI

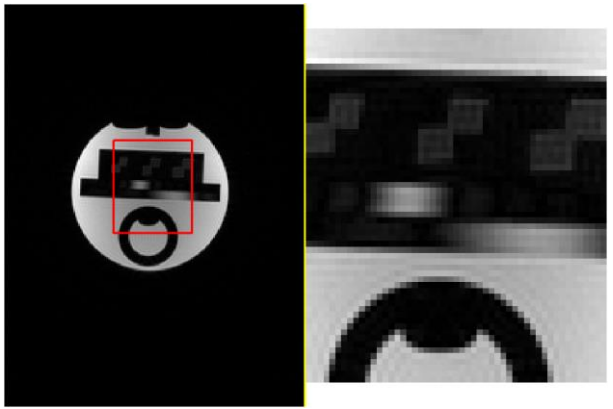


GE-provided EPI + GE onlineRecon (128*128*48)

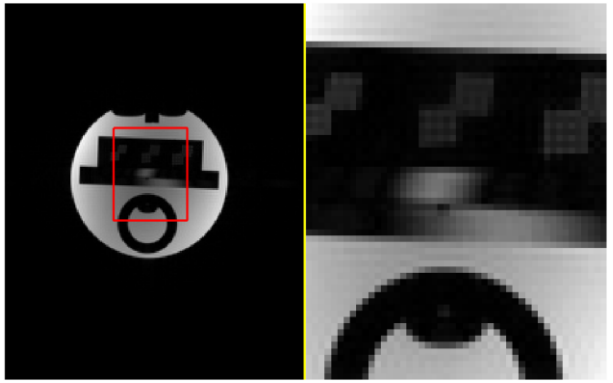


Pulseq-based EPI + Gadgetron (80*80*48)

MPRAGE



GE-provided MPRAGE + GE onlineRecon (256*256*192)

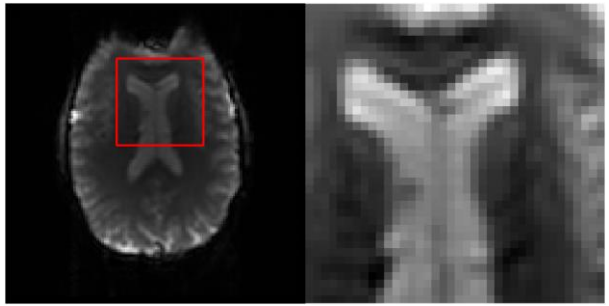


Pulseq-based MPRAGE + Gadgetron (256*240*192)

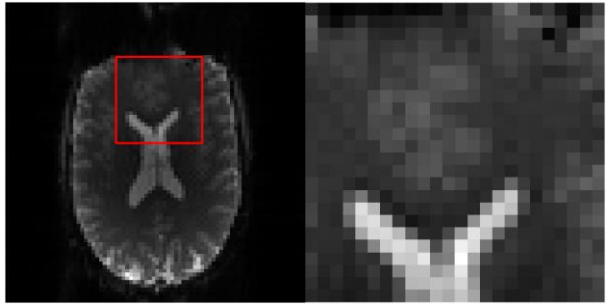
Results

UoM – in vivo on GE 3T

EPI

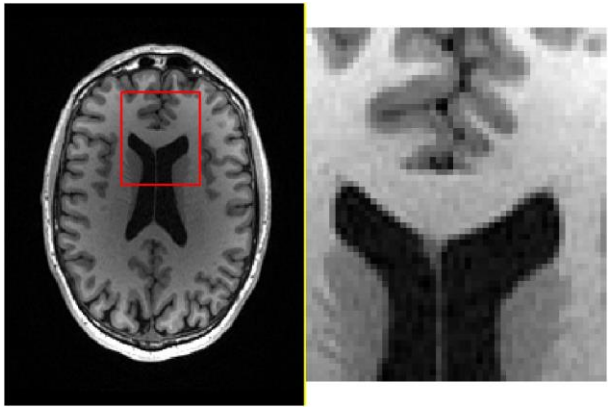


GE-provided EPI + GE onlineRecon (128*128*48)

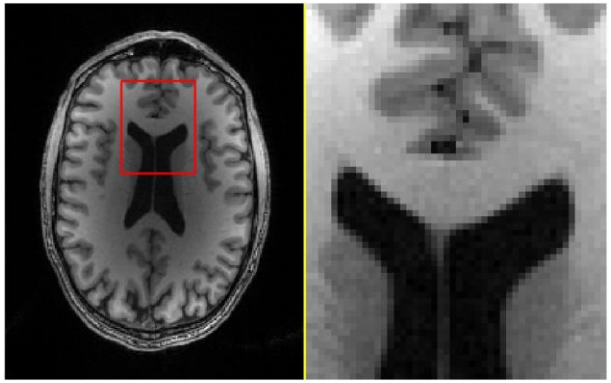


Pulseq-based EPI + Gadgetron (80*80*48)

MPRAGE



GE-provided MPRAGE + GE onlineRecon (256*256*192)



Pulseq-based MPRAGE + Gadgetron (256*240*192)

Discussion

Data Acquisition

- On Siemens, replication of the workflow is straightforward and easy to learn. With the Pulseq interpreter installed on the Siemens scanner, the MGH sub-team was able to execute the identical MPRAGE and EPI sequences using the provided *.seq* files.
- On GE, an additional step is required for the replication - the provided *.seq* files need to be converted to *.tar* files that can be run on a GE scanner using TOPPE (Nielsen & Noll, MRM, 2018) software. With the TOPPE interpreter installed on the GE scanner, the UoM group was able to perform the identical EPI sequence. Due to hardware limitations, the noise scan of the MPRAGE sequence must be moved from the beginning to the end of the data acquisition, which, nevertheless, has little effect on the reconstructed images.
- Pulseq only specifies the behavior of gradient, RF, and ADC events during data acquisition. In addition to these events, the reconstructed image quality might be affected by operator-specific factors, such as FFT scaling factors, shimming, FOV positioning, receiver gain, image scaling factor, etc. A standard operating procedure could further enhance the harmonization of data acquisition.

Discussion

Image Reconstruction

- The MGH sub-team was able to perform ICE online reconstruction for both MPRAGE and EPI sequences on a Siemens scanner.
- In addition, the MGH group was able to convert the Pulseq Siemens raw data to ISMRMRD data (Inati et al., MRM, 2017) and perform Gadgetron offline reconstruction in a Docker image without a long learning curve.
- Likewise, the UoM group was able to convert the Pulseq GE raw data to ISMRMRD data and perform Gadgetron offline reconstruction in a Docker image.
- The current Gadgetron version does not support ISMRMRD conversion of the Numaris X Siemens data. We had to convert the product Siemens XA data to ISMRMRD data manually.

Discussion

Image Assessment

- **University Medical Center Freiburg:**
  - For both MPRAGE and EPI on a phantom and a human brain, Gadgetron has comparable reconstruction performance to ICE, and the images acquired with Pulseq sequences align with corresponding product sequences across the three very different Siemens scanner systems.
- **Massachusetts General Hospital:**
  - The MGH group successfully demonstrated the feasibility of harmonizing data acquisition and image reconstruction on a Siemens scanner in a different center.
  - The MPRAGE images have comparable quality between Product (ICE) and Pulseq (Gadgetron) on both a phantom and a human brain. However, the Pulseq-based EPI images have slightly more artifacts than the product-based images, which might be due to inappropriate parameter settings (e.g. FFT scaling factor, receiver gain, etc) and remains to be further investigated in the near future.
- **University of Michigan:**
  - The UoM group successfully demonstrated the feasibility of harmonizing data acquisition and image reconstruction across vendors using Pulseq and Gadgetron.
  - The phantom and in vivo results show that the Pulseq-based MPRAGE and EPI sequences produce image quality comparable to the closely matched vendor-based sequences.

Conclusion

- We successfully establish an efficient, open-source, easy-to-learn MRI data acquisition and image reconstruction workflow based on Pulseq and Gadgetron and validate it for MPRAGE and EPI protocols.
- The reproducibility challenge study demonstrates that it is feasible to use this workflow to harmonize data acquisition and image reconstruction across scanner system versions, centers, and vendors.
- The preliminary results indicate that this workflow has excellent potential to enhance efficiency, transparency, and reproducibility for data acquisition and reconstruction in large-scale MRI studies.

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pypulseq Python

TOPPE

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