Accelerating Cardiac MRI with Inline Generative AI and Open Recon

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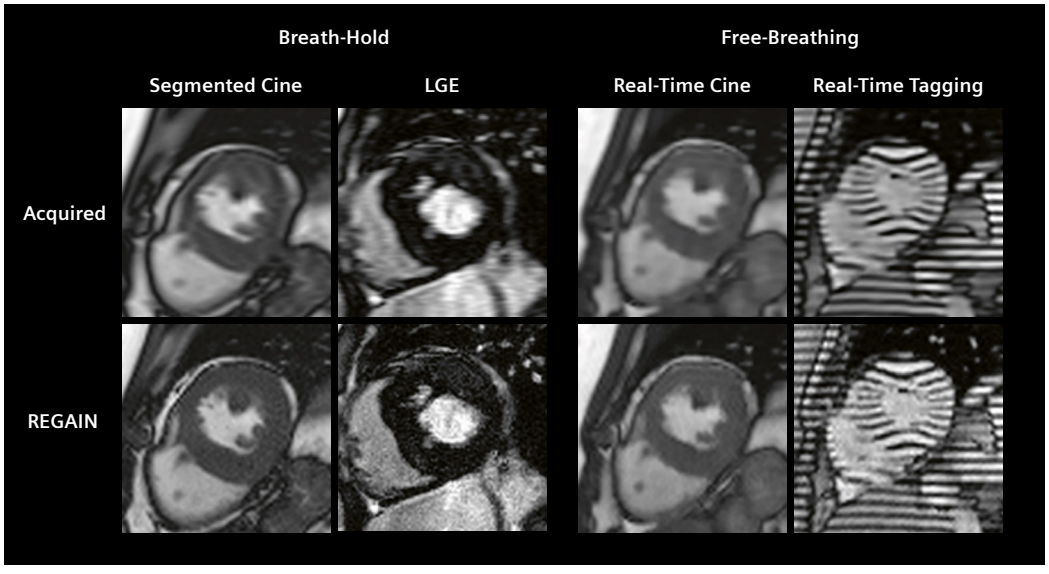
Introduction

Cardiac MRI protocols often require challenging breath-holds, and the resulting motion artifacts can compromise imaging quality. Compressed Sensing (CS) can significantly shorten scan times compared to traditional parallel imaging but has limitations in both image quality and reconstruction time. AI-based techniques can further increase imaging efficiency [1]; however, seamlessly integrating these approaches into daily practice can pose challenges due to the substantial effort required for on-scanner implementation in vendor software environments. We recently proposed a generative AI-based model for resolution enhancement [2] that can be readily deployed using the Open Recon[1] platform (Siemens Healthineers, Erlangen, Germany) to provide fully automated inline integration without any modification to product sequences. The resolution enhancement generative adversarial inline neural network (REGAIN) is trained on cardiac cine images and has been successfully applied to both reduce breath-hold duration and enable free-breathing real-time imaging across multiple cardiac MRI applications (Fig. 1).

REGAIN acceleration

For the REGAIN acquisition, *k*-space is undersampled using existing uniform or non-uniform acceleration techniques, such as GRAPPA or CS. In addition, the operator prescribes a reduced spatial resolution along the phase-encoding direction to further reduce scan time. GRAPPA or CS is applied normally to estimate missing *k*-space lines and is zero-padded in the phase-encoding direction prior to inverse Fourier transform to reconstruct an anisotropic



1 Acquired low-resolution data and AI-based resolution enhancement (REGAIN) using a pre-trained model based on seg mented cine images. REGAIN enables shorter breath-holds in segmented ECG-gated cine and LGE sequences, and free-breathing real-time cine and tagging images with high temporal resolution.

[1]*Open Recon is to add clinical reconstructions to the system, if signed and released for clinical use by SHS. Any other recon used e.g., by researchers is automatically labeled not for diagnostic use, which may require observation of national regulations.*

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low-resolution image with a matrix size corresponding to the desired high-resolution image. REGAIN subsequently restores the image sharpness of the reconstructed low-resolution images.

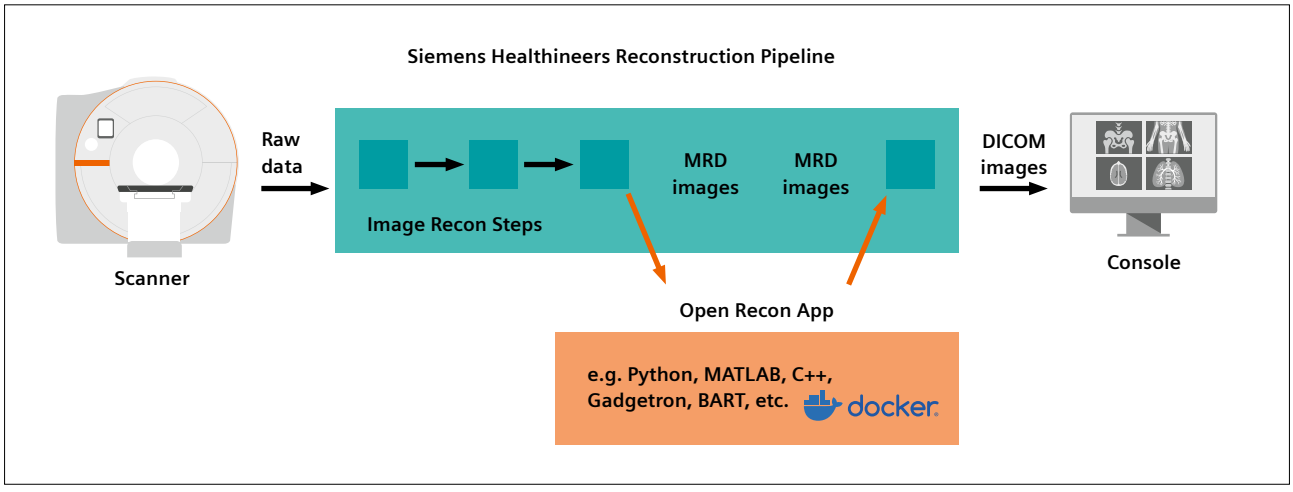
The REGAIN model was trained on retrospectively collected GRAPPA-accelerated, ECG-gated segmented bSSFP cine MRI from 1,616 patients with various cardiovascular indications [2]. Training data consisted of pairs of high resolution and low-resolution images, synthesized by discarding the outer phase-encoding lines. The generator is trained to sharpen the low-resolution image, while the discriminator estimates the probability that an image reconstructed from full *k*-space data appears "more realistic" than the resolution-enhanced image, to produce generated images that mimic true high-resolution images. REGAIN is implemented in Python using PyTorch (the Linux Foundation, San Francisco, CA, USA) and is open source: https://github.com/HMS-CardiacMR/REGAIN.

This proposed resolution enhancement model was validated on cine images prospectively collected from 126 patients and 55 healthy subjects. For ECG-gated segmented cine, REGAIN reduced the number of breath-holds required compared with GRAPPA parallel imaging (3.7 ± 1.0 vs 11.2 ± 1.4), while achieving similar diagnostic quality scores and excellent agreement for left ventricular function, volume, and strain measurements. Combining REGAIN with CS-facilitated 16-fold acceleration, enabling free-breathing real-time cine with $(1.8\ mm)^2$ in-plane spatial resolution, and 28 ms temporal resolution, with rapid inline image reconstruction [2]. The previously trained REGAIN model has also been successfully applied to enable highly accelerated real-time tagging to quantify myocardial deformation in response to physiological exercise in both healthy subjects and patients [3]. Most recently, REGAIN has also been applied without modification to reduce breath-hold duration in inversion-recovery 2D late gadolinium enhancement (LGE) acquisition (6 seconds vs. 16 seconds with GRAPPA acceleration) [4] and to improve image sharpness and quality of single-beat 2D LGE acquired with 4.7-fold acceleration [5].

Open Recon platform

The Open Recon platform is designed to provide a generalized interface for deploying advanced image reconstruction and analysis algorithms directly on the scanner with inline integration. Open Recon extends the existing reconstruction pipeline of Siemens Healthineers by either adding a third-party algorithm at the end of pipeline ("image to image") or replacing the Fourier transform ("raw-to-complex image") (Fig. 2). Data processed by the Open Recon application are converted to DICOM and displayed on the scanner, facilitating seamless integration. Open Recon processing can be selected for any sequence protocol through a customizable parameter card on the user interface, allowing developer-defined parameters to be adjusted for each acquisition for additional control of the processing pipeline.

Third-party algorithms may be implemented in any desired programming language and can communicate via the standardized open-source ISMRM raw data (MRD) format. Open Recon applications are packaged as Docker containers, which provide a consistent and isolated environment that can be deployed directly on the scanner's existing computer and enable unrestricted use of common software libraries. Open Recon apps are independent of the scanner software version, enabling the same application to be distributed to a fleet of scanners with Open Recon functionality.



2 Conceptual overview of the Open Recon platform for image-to-image workflows.

Innovating with Open Recon

The inline integration of the REGAIN algorithm with Open Recon enables fully automated reconstruction with low latency. The immediate availability of reconstructed images on the scanner console streamlines the workflow, allowing the AI-based resolution enhancement to be run routinely. The packaging of Open Recon apps, such as REGAIN, as independent Docker containers simplifies deployment and sharing with other sites. In particular, the software independence of Open Recon apps may help facilitate multi-center clinical trials, potentially accelerating the validation of AI-based methods and enabling quicker translation of these research applications. Integration with Open Recon increases the accessibility of REGAIN as a promising AI-based resolution enhancement method for improving cardiac MRI by simplifying deployment, thereby enabling widespread distribution and further research studies.

References

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