Accelerate Free Breathing Cardiac Cine Imaging with Propeller and GRAPPA

Tsung-Lun Wu[1], Ching-Lung Cheng[2], Ming-Ting Wu[3,4], Ming-Long Wu[1,2], and Tzu-Cheng Chao[1,2]

[1]Department of Computer Science and Information Engineering, National Cheng-Kung University, Tainan, Taiwan, [2]Institute of Medical Informatics, National Cheng-Kung University, Tainan, Taiwan, [3]Department of Radiology, Kaohsiung Veterans General Hospital, Kaohsiung, Taiwan, [4]School of Medicine, National Yang-Ming University, Taipei, Taiwan

Target Audience: Researchers or clinicians who are interested in self-gated free breathing cardiac imaging.

Introduction

Cardiac CINE imaging is a useful tool in routine exam to monitor cardiac function. Conventional CINE imaging requires accurate ECG gating and respiratory control to prevent from motion artifacts. Typically, the scanned subject will need to hold the breath for around 15 seconds for each scanned slice. In the case that a subject fails to cooperate with breathing control during the scan or has weak ECG signals, image quality could be degraded. Recently a free breathing method was proposed to improve cardiac CINE imaging utilizing PROPELLER[1] acquisition and image based self-gating strategy[2]. It was noticed that in order to achieve proper temporal resolution, each PROPELLER segment (blade) is allowed to contain only a small number of phase encoding lines potentially leading to insufficient spatial resolution for motion discrimination. In addition, as each blade covers only a small k-space region, it requires more blades for a full k-space resulting in long scan times. Seeing that both high temporal resolution and wide blade acquisitions are necessary in the dynamic self-gating PROPELLER imaging, an acceleration strategy should be able to satisfy these requirements. The presented work combined a parallel imaging strategy, Generalized Autocalibrating Partially Parallel Acquisition (GRAPPA)[3], to accelerate the existing free breathing dynamic PROPELLER imaging so as to capture a larger extent of a single blade while retaining the temporal resolution. Therefore, the proposed strategy is expected to achieve better gating accuracy and reduction in scan time.

Material and Methods

Two volunteer experiments were scanned on a 3.0T magnet (GE Discovery MR750, Milwaukee, WI). A dynamic PROPELLER acquisition was implemented in a "Balanced Steady State Free Precession" sequence with no ECG or respiratory gating. The matrix size of each blade was 256 x 32, and therefore a minimum of 12 blades with 15^0 degree separation will be required to cover a fully sample k-space. Five 5-mm short-axis slices were imaged for each subject with following parameters: FOV of 38cm, TR of 3.5 ms, TE of 1.5 ms and flip angle of 45^0. The dynamic scheme acquires a number of continuous samples (expressed as blade series hereafter) at each blade angle before switching to the next phase encoding direction. The first volunteer underwent with a fully sampled free breathing dynamic PROPELLER acquisition with 70 frames sampled for each blade series (temporal resolution: 112 ms; scan time: 101s/slice). For validation purpose, some of the phase-encoding lines from the data were discarded to simulate the accelerated GRAPPA acquisition. The acceleration scheme utilized two fold undersampling plus two additional autocalibration lines to acquire a total of 18 phase encoding lines for a blade. The experiment on the second volunteer directly utilized the proposed GRAPPA accelerated dynamic PROPELLER imaging (temporal resolution: 63ms) at two different conditions: 20 frames for each blade series with 17s breath-hold scans per slice and 70 frames for each blade series with 57s free breathing scans per slice respectively.

In the reconstruction of free breathing data, each blade is firstly recovered by GRAPPA then regridded to proper Cartesian k-space location followed by Fourier transformation to image domain as a low resolution blade image. The gating process starts with the first blade series (0^0) to distinguish breathing phase using respiratory trace method proposed in Ref[2]. Then the frames of a full cardiac cycle identified at end-expiration are extracted as a template series to differentiate motion status of the other blade images. With respect to cardiac gating, a region of interest (ROI) of each blade image located at left ventricle is selected to perform cross correlation with the signals in the same ROI on the template series. A blade image is identified to be in a cardiac phase the same as the template with which it is most correlated. Subsequently, the signals inside the entire FOV of each cardiac-gated blade image are again cross correlated to the corresponding template blade for final respiratory tracking. The blade image of each blade series that best resembles the template at a given cardiac phase will be regarded as being scanned at the same cardiac and respiratory motion status as the template and will be used for final PROPELLER reconstruction. This gating strategy ensures the k-space of each cardiac phase will be fully covered with minimal motion artifact.

Fig. 1. Free Breathing Experiment

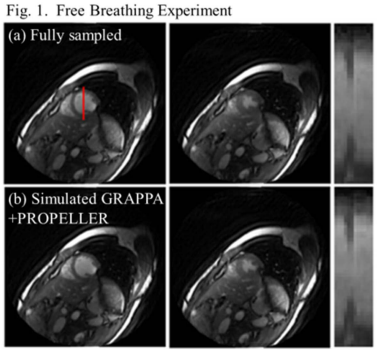

Fig. 2. GRAPPA + PROPELLER Experiment

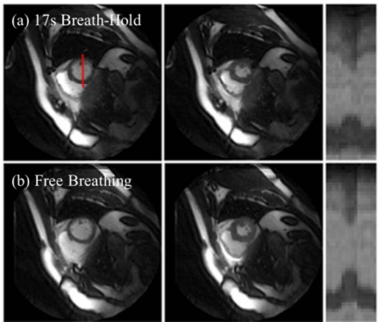

Table 1. Contrast Measure (mm^{-1})

Subject 1 Fully Sampled	0.353 ± 0.108
Subject 1 GRAPPA+PROPELLER	0.346 ± 0.075
Subject 2 17s Breath-hold	0.389 ± 0.093
Subject 2 Free Breathing	0.374 ± 0.063

Results

The reconstructed images at both diastole and systole and the time series from the highlighted ROI are shown in Figs. 1 and 2. The reconstructed images from simulated undersampling (Fig. 1(b)) retain similar dynamic properties and image quality to its fully sampled version (Fig. 1(a)). The result in Fig. 1(b) still sustains similar signal to noise ratio due to the densely sample around central k-space in PROPELLER imaging. The data series in Fig. 2 have more cardiac phases resolved than that in Fig. 1 thanks to the acceleration strategy to increase temporal resolution. No significant respiratory artifact is found around the thoracic cage with free breathing acquisition in Fig. 2(b) comparing to the breath controlled result in Fig. 2(a). In addition, streaking artifact or residual aliasing was hardly noticed in each frame image shown in Fig. 2. An edge sharpness index[4] was defined by the inverse of the distance between the 20% to 80% signal intensity levels on the selected ROI to measure the contrast change between blood pool and myocardium. The statistics of the contrast within the ROI over the time series of each experiment is listed in Table 1. The result shows that alteration in contrast due to different acquisition strategies is relatively small comparing to the variation caused by cardiac motion.

Discussion

In the self-gated dynamic PROPELLER imaging, reconstruction quality highly relies on the quality of each blade image. Blade images having higher spatial resolution are preferred to achieve better gating accuracy while temporal resolution becomes a tradeoff. If higher temporal resolution is of interest, fewer phase encoding lines would be acquired in a single blade leading to lower spatial resolution for self-gating and more blades required to reconstruct an image. With the combination of GRAPPA, each blade of dynamic PROPELLER scan could simultaneously meet the requirements in spatial and temporal resolution. The results suggest that the present work has potential to accomplish free breathing and self-gating cardiac CINE images with good quality in shorter scan time.

Conclusion

A strategy combining parallel imaging and PROPELLER acquisition is proposed to reduce scan time for free breathing cardiac CINE imaging.

Reference

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