Motion Adaptive HYPR: an algorithm for dynamic imaging applications

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Introduction

Recently introduced HYPR [1] and HYPR LR [2] algorithms provide means for reconstructing images with high SNR and high spatial resolution from undersampled datasets with acceleration factors that were previously unattainable by existing techniques. It was demonstrated that the SNR and spatial resolution of HYPR images are determined primarily by the composite image used to constrain the reconstruction, thus, making a high quality composite image crucial for successful reconstruction. Typically, composite images are obtained from all or a significant portion of the data acquired during an exam to ensure sufficient sampling. However, in applications with significant motion, like cardiac imaging or catheter tracking, the combination of multiple time frames to form a well sampled composite image can degrade the temporal resolution of the resulting time frames. In this work, we present the Motion Adaptive HYPR algorithm (HYPR MA) that circumvents the problem of blurring due to motion and demonstrate applicability of the new algorithm to real-time cardiac imaging and MR catheter tracking.

Theory and Methods

In the conventional HYPR algorithm, the composite image used for the reconstruction of a given time frame has a fixed length; that is, a fixed number of time frames that were combined to obtain the composite image. The key element of the HYPR MA algorithm is the use of variable-length composite images that allow combining more time frames in the regions where no or little motion is present while adding up fewer time frames in the parts of the image that exhibit motion. To detect motion, time frames are subdivided spatially into local sub-regions. Typically, each sub-region is a square with a side of 1-8 pixels. Then, for a fixed frame, the average value of each sub-region in the given frame is compared with the average values of the corresponding sub-regions in all other frames in the time series. Sub-regions from the frames for which the difference falls below a pre-defined threshold are integrated in the composite image for the given time frame. This composite image is then used to constrain HYPR reconstruction to obtain the final image for the given time frame. The process is then repeated for each time frame in the series. Fig. 1 illustrates the procedure; colored sub-regions correspond to areas that were accepted by the motion threshold criteria and are therefore integrated into the composite image.

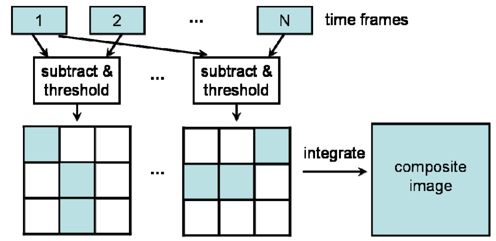

Figure 1. Formation of a composite image in HYPR MA

The number of frames included in each sub-region of the composite image depends on how much motion this portion of the anatomy undergoes as well as the level of thresholding. For the sub-regions where no or little motion is present, the composite image will comprise all time frames in the series, thus, reducing undersampling artifacts and increasing SNR in those sub-regions. Typically, the motion threshold is set to be 10-15% of the mean value of the time frame image. Such a choice of threshold guarantees that, save for the sub-regions with extreme motion, composite image will integrate at least several time frames, improving the overall image quality while preserving the temporal resolution of the dynamic portions of the image.

Results

We apply the HYPR MA algorithm to real-time cardiac imaging and MR catheter tracking. An additional benefit of the proposed algorithm for cardiac imaging is that it eliminates the need for ECG or a posteriori gating of the acquired data. A 2D SSFP real-time radial sequence was used to acquire short-axis time frames of cardiac function on a 1.5T Philips Achieva (Best, NL) using a 16 channel coil (Invivo Corporation, Pewaukee, WI). Scan parameters were: TR/TE/flip= 3.1/1.5/60^o, 300 mm FOV, 8 mm slice thickness, 160 x 26 projections. Radial acquisitions of consecutive time frames were scheduled using bit reversal ordering of 8 temporal interleaves. Time frame images reconstructed using the filtered backprojection (FBP) algorithm exhibit a high level of streak artifacts. If these images were used as input to HYPR MA, the streaks and their change in position between time frames could result in motion detection where no motion actually exists, producing composite images with streaks and low SNR level and ultimately degrading reconstructed image quality. To avoid this problem, we process the *k*-space data using parallel imaging and the McKinnon-Bates algorithm [3] to reduce the intensity of streaks and noise. To decrease the probability of falsely characterizing motion further, the resulting images are convolved with a small Gaussian smoothing kernel to mollify streaks even more before subjecting the images to HYPR MA processing. Fig.2 compares reconstruction results of a systolic frame using (a) FBP, (b) McKinnon-Bates, and (c) HYPR MA algorithms. The first two images suffer from low SNR and severe streak artifacts while the HYPR MA image remedies those problems without compromising temporal resolution due to the use of the variable length composite image. The number of time frames used for each pixel of the composite image for this frame is illustrated in Fig.2 (d).

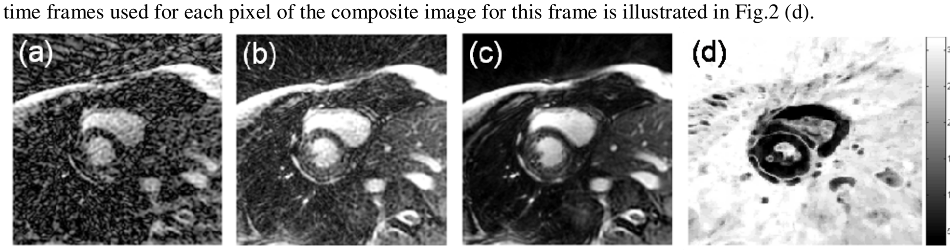

Figure 2. Systolic frame reconstructed by (a) FBP, (b) McKinnon-Bates, (c) HYPR MA; (d) shows the number of frames in the composite image for HYPR MA processing for the same frame.

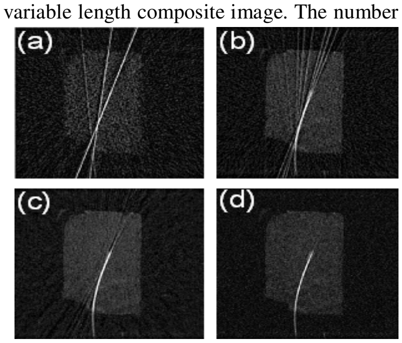

Figure 3. Catheter tracking images using (a) FBP, (b) HYPR LR and (c) HYPR MA. (d) shows the true image

In a phantom catheter tracking experiment, the need for high spatial and temporal resolution limits the number of projections that can be acquired in each time frame to 16. This represents an acceleration factor of 25 relative to the Nyquist criterion. As expected for such high level of undersampling, the FBP image (Fig.3a) contains a lot of streak artifacts that would prevent a radiologist from correctly identifying the catheter tip. Use of the HYPR LR algorithm with a 3-frame composite image improves image quality (Fig.3b), however, the streaks are not completely eliminated and location of the catheter tip is ambiguous due to spatial blurring of the composite image. This problem is solved by the HYPR MA algorithm (Fig.3c) that significantly reduces the appearance of streaks, improves SNR and correctly positions the catheter tip which can be verified by comparison to the fully sampled image (Fig.4d).

Conclusions

HYPR MA extends the previous advantages of HYPR to imaging applications that involve motion allowing for undersampling artifact reduction and SNR increase in accelerated MR imaging. Preliminary results suggest that HYPR MA holds high potential for cardiac function imaging and MR catheter tracking. Further investigation is needed to optimize the motion detection algorithm and sub-region sizes for each application.

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References

1. Mistretta CA *et al.* MRM 55: 30-40; 2006. **2**. Johnson KM *et al.* MRM 59: 456-462; 2008. **3**. Garden KL, Robb RA, IEEE Trans. Med.Imag MI-5: 233-239; 1986