CORRECTING SURFACE COIL INTENSITY INHOMOGENEITY IMPROVES QUANTITATIVE ANALYSIS OF CARDIAC MAGNETIC RESONANCE IMAGES

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ABSTRACT

Quantitative analysis of cardiac magnetic resonance (MR) images is important in bringing objectivity in diagnosis of myocardial abnormalities. Prior to quantitative analysis, it is necessary to correct signal intensity inhomogeneity due to the non-uniform surface coil sensitivity profile. We present a method using non-rigid body image warping and polynomial function fitting to correct this intensity bias on imperfectly registered cardiac MR images. The method was validated on normal human MR images and significantly reduced signal variation from 20.0% to 3.9% in regions of normal myocardium. In MR images of acute myocardial infarction in dogs, signal intensity analysis detected edematous myocardium as 35.9% brighter than normal myocardium on T2-weighted images (p=0.002) while control regions of interest on PD-weighted images were uniform within 2.2% (p=NS). The proposed approach effectively corrected surface coil related signal intensity inhomogeneity in imperfect datasets and allowed confident detection of subtle pathophysiological abnormalities.

***Index Terms*:** biomedical image processing, magnetic resonance imaging, cardiovascular system

INTRODUCTION

Quantitative analysis of cardiac magnetic resonance (MR) images has gained increasing importance in diagnosis of myocardial abnormalities since it allows for objective and unique assessment of disease. The use of surface coil arrays in cardiac MR imaging provides superior myocardial signal-to-noise ratio (SNR) than using the body coil due to their proximity to the heart for receiving the MR signal [1]. However, such phased arrays have inherent inhomogeneous sensitivity profiles and the SNR strongly depends on the distance of the tissue from the surface coil. This can potentially result in unwanted masking of pathophysiological findings in the images. Thus, it is necessary to correct the surface coil intensity profile for quantitative assessment of cardiac MR images [2]. This surface coil intensity correction should also be beneficial for qualitative interpretation of the images.

A number of surface coil intensity correction methods for MR images have been proposed. In general, the majority of these methods were developed for the application in brain or muscular-skeletal imaging where the surface coil is adjacent to the organ of interest. With an increased geometrical distance between the heart and the surface coil in cardiac imaging, correction of the surface coil sensitivity profile is further complicated by broader changes of signal intensity gradients due to distinct anatomical tissues such as the chest wall, lung air, myocardium and liver. Thus there is a need for methods that are tailored to account for the unique signal intensity distribution and anatomical geometry in cardiac MR imaging to correct the surface coil intensity inhomogeneity.

METHODS

In this study we present a post-hoc method using image segmentation and registration to estimate and correct the surface coil intensity profile for cardiac MR images. Multi-contrast T2-weighted and proton density (PD)-weighted images that maybe close but not exactly in the same locations were used. Signal intensity inhomogeneity in T2-weighted images was corrected based on the surface coil intensity profile estimated from the PD-weighted images. Signal intensity variation and contrast measurement within the myocardial region of interest is compared using the proposed method.

The method includes a series of image post-processing steps to estimate the surface coil sensitivity profile for nonlinear signal intensity correction. First, a short-axis stack of PD-weighted MR images were used to estimate the signal intensity profile at different imaging locations. Figure-1a shows a PD-weighted canine image acquired with a gradient echo sequence at a small flip angle. Since the proton density of different tissues does not vary much, the signal intensity variation in the image is dominated mostly by the inhomogeneous surface coil reception. Figure-1b shows a T2-weighted canine image corresponding to the PD image in Figure-1a. The slice location is not exactly the same and there is a noticeable displacement between the PD and T2 images since they were acquired about an hour apart. A non-rigid body image registration was used to correct this geometric displacement. This was implemented by having the user select corresponding anatomical landmarks on both PD and T2 images (Figure-1c and Figure-1d) for a thin plate spline warping. The deformed PD image (Figure-1e) is a better match to the target T2 image (Figure-1b) than before the warping (Figure-1a).

A high order polynomial function fitting which combines a hierarchical region weighting scheme was used to approximate the surface coil intensity profile from the deformed PD image. In order to weight the polynomial fitting more to the heart than the surrounding tissues, a higher density of sampling was used inside the heart to further constrain the fitting (Figure-1f). The region of the heart was manually defined by tracing the epicardial surface. The lower density of sampling was used outside the heart and in the background noise area. The body and background regions were automatically segmented by intensity thresholding. Next, a fifth-order 2D polynomial least square fitting was used to estimate the signal intensity bias field (Figure-1g). This 5th order polynomial fitting was selected to minimize imperfect surface coil signal intensity fitting at the edges of the epicardium near the lungs since the abrupt transition in proton density at these regions is a high-order form and critical to cardiac applications. The estimated signal intensity bias field was used for correcting the T2-weighted image by dividing the T2 image with the intensity bias field (Figure-1h).

To assess the performance of the method, normal human and pathophysiological canine T2-weighted cardiac MR images were acquired with a Siemens 1.5T scanner using an 8-element phased-array surface coil. All animals underwent left anterior descending coronary artery occlusion to induce acute myocardial infarction [3]. Short-axis stacks of T2-weighted images were acquired 6-8 hours after reperfusion to visualize the myocardial water content and edema. Elevated signal intensity within the myocardial wall was evidence of edema secondary to myocardial infarction. Signal intensity and contrast measurement from the different myocardial regions of interest were measured in all images before and after using the proposed method. Contrast was calculated as a ratio (%) of (mean intensity of "bright" pixels – mean intensity of "dark" pixels) / (mean intensity of "dark" pixels).

RESULTS

To evaluate the efficacy of the image warping step in the proposed method, Figure-2 shows the T2-weighted canine image divided by the PD-weighted image before and after the image warping. The arrows in Figure-2a point to a severe intensity artifact in the myocardium as a result of T2 and PD image mis-registration. (Myocardium above the arrows should be dark, not bright). These artifacts are suppressed after the image warping in Figure-2b.

To validate the results of the method, myocardial signal intensity variation was measured on normal human T2-weighted images between the anterior and posterior left ventricular walls where contrast is expected to be 1 in the normal myocardium. Contrast averaged 20.0±2.8% before the intensity correction and decreased to 3.9±1.7% after the correction (n=6).

To assess the applicability of the proposed method for correcting a volumetric dataset, Figure-3 shows a short-axis stack of the T2-weighted canine images after the signal intensity correction. For the group data overall, average myocardial signal intensity of anterior and posterior walls on the PD-weighted canine images was uniform within 2.2% of variation after the correction (p=NS, n=45, Figure-4a). When applied the method to T2-weighted images of acute myocardial infarction, the myocardial signal intensity of anterior edematous wall was approximately 35.9% brighter than the posterior normal wall (p=0.002, n=45, Figure-4b) and consistent with the expected physiological differences in water content associated with acute myocardial infarction.

DISCUSSION

When surface coil arrays are used in cardiac MR imaging, the inhomogeneous coil sensitivity profile can be steep and appears as signal intensity gradients. The severe and abrupt transitions in proton density between myocardium and lung pose a challenge for modeling the surface coil intensity variation. The problem is further complicated by endogenous contrast between fat, water, and air in non-proton weighted images. We present a systematic approach using a multi-contrast MR dataset which allows for correcting surface coil related signal intensity inhomogeneity in imperfect cardiac images. Application of the correction method was demonstrated with quantitative analysis of T2-weighted images using the surface coil intensity profile estimated from the PD-weighted images.

In the proposed method, we used non-rigid body image warping to correct for the mis-registration of PD-weighted and T2-weighted MR images that occurred at different geometrical locations and perhaps during different cardiac phases. A high order polynomial intensity surface fitting which combines a hierarchical regional weighting scheme was employed to estimate the signal intensity bias field and avoid unwanted intensity artifacts at edges with abrupt transitions in proton density.

Preliminary results from normal human and infarcted canine T2-weighted images show the proposed method can retrospectively correct surface coil intensity inhomogeneity in volumetric datasets. It worked well in differentiating the subtle T2 signal intensity differences associated with acute myocardial infarction. In particular, edge artifacts were largely eliminated with this method compared with rigid, simple correction schemes. This method could be applied to other cardiac MR images such as gadolinium enhanced T1-weighted imaging to improve quantitative assessment of myocardial viability or perfusion.

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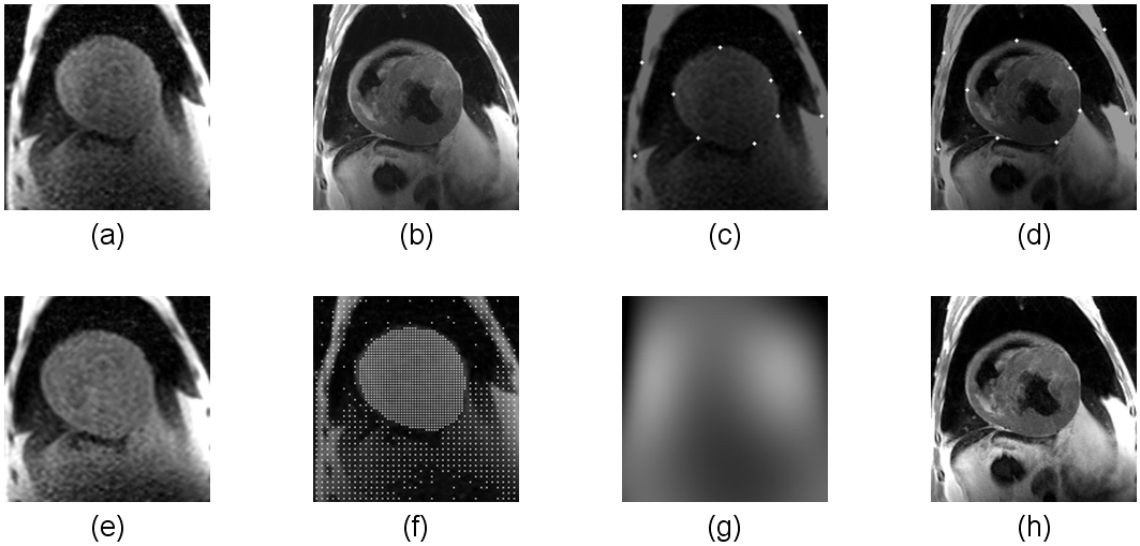
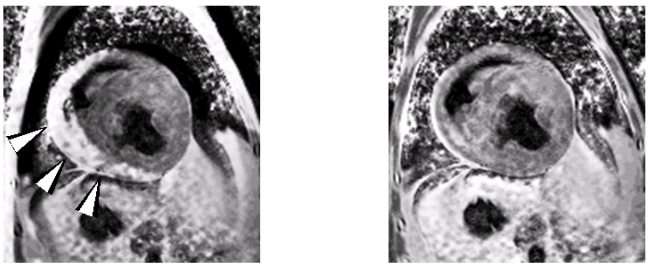


Figure-1. Intermediate results of the multi-contrast surface coil intensity correction method.



(a) (b)

Figure-2. T2-weighted image divided by deformed PD-weighted image in (b) shows mis-registered myocardial intensity artifacts (arrows in a) is suppressed after the image warping.

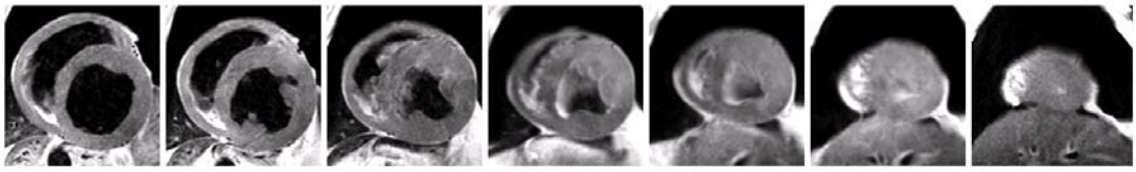


Figure-3. A short-axis stack of T2-weighted images after surface coil intensity correction.

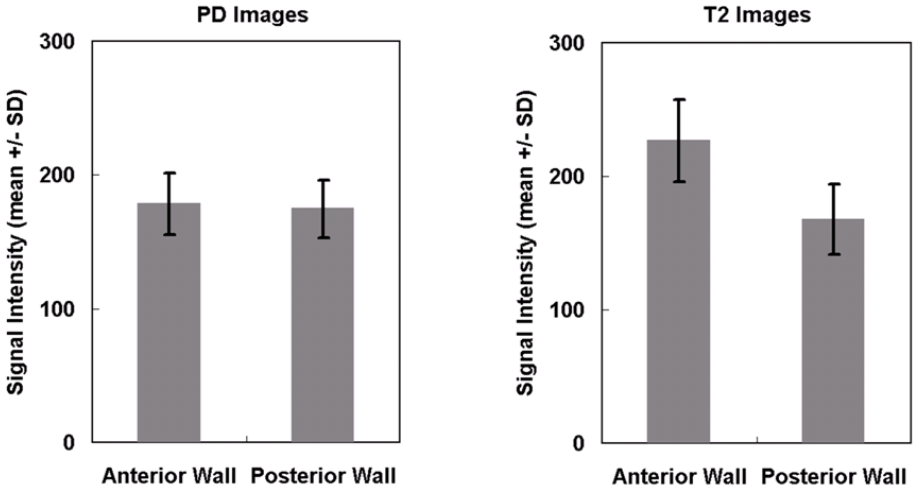


Figure-4. (a) Myocardial signal intensity of anterior and posterior walls on PD-weighted images was uniform after the correction (p=NS). (b) The signal intensity difference between edematous and normal myocardium was much larger than the residual errors after the correction (p=0.002).