Super-resolution reconstruction of 4D neonatal cardiac MRI using coupled dictionary learning

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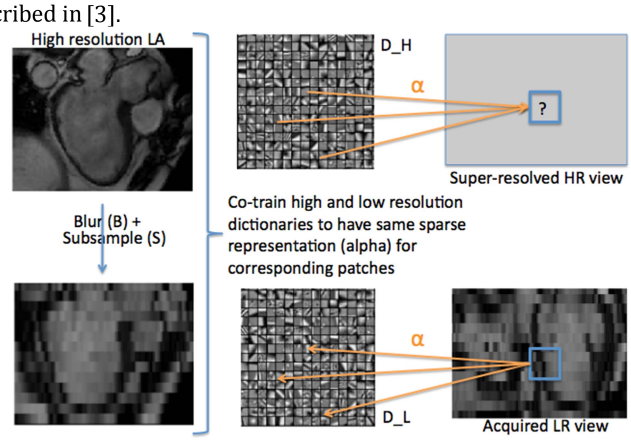
INTRODUCTION

Preterm birth affects around 10-12% of deliveries and its consequences contribute to significant individual, medical and social problems [1]. Evidence suggests that circulatory factors have an influence on the pathophysiological patterns of brain injury that lead to poor long-term outcome in preterm infants [2]. However neonatal cardiovascular physiology is currently poorly understood. The ability to obtain high-resolution neonatal cardiac MR images therefore has an important role in further understanding the circulatory system. However, the small size of the heart and unenforceable patient stillness or breath-holds makes high-resolution acquisitions difficult, and resolution enhancement of the resulting images is strongly motivated by both visualisation and analysis. Techniques have been developed to acquire anisotropic high-resolution 2D stacks [3]. In this work, we present a novel method for cardiac image super-resolution and apply it to such images in order to reconstruct spatially isotropic 4D cine MRI of the neonatal heart.

METHODS

Acquisition and subjects: 6 infants of corrected gestational ages 32-41 weeks and birth weights ranging from 1.4-4.1kg, were scanned. Data were acquired on a 3T Philips Achieva scanner, using an 8 channel (paediatric) receive coil. All infants were scanned un-sedated with routine monitoring using the feed and wrap technique; no respiratory compensation techniques were used. Balanced-SSFP cine acquisitions with retrospective cardiac gating providing 20 frames were acquired with resolution: 1x1mm, 10 x 4mm thick slices and adjusted slice overlap (0-1mm) to cover apex-base. Further details are described in [3].

Reconstruction: Resolution enhancement can be obtained by super-resolution reconstruction (SRR). Conventional SRR techniques generally focus on aligning multiple views of the same object. However, this requires sub-pixel alignment of these views, and the highly non-rigid motion in the cardiac cycle makes this hard to achieve. For this reason, standard interpolation is still commonly used to upsample MR images for visualisation and analysis. Instead, we propose the use of an *example-based* super-resolution method using coupled dictionary learning [4], which has previously been used to enhance the resolution of brain MRI [5]. This works by exploiting the data redundancy that occurs at an image patch level, when images are acquired to cover both the heart volume and the cardiac cycle. By moving to a patch scale, we are able to remove the need for any accurate alignment or registration. An illustration of the method is shown in the adjacent figure.



Coupled dictionary learning: To achieve the above, we construct high-resolution (HR) and low-resolution (LR) *dictionaries* using a given HR 2D view, which has been blurred and subsampled in accordance with scanner properties, to give corresponding HR and LR images. LR patches (p^L) are extracted from this training set and used to construct a LR dictionary (D^L) as well as a sparse code (α) that reconstructs each patch $D^L, \alpha = \min \sum_k \|p_k^L - D^L \alpha_k\|_2^2 \; s.t. \|\alpha\|_0 < \lambda$. This is then used, together with corresponding patches from the HR images (p^H), to construct a HR dictionary $D^H = \underline{p^H \alpha^T} (\underline{\alpha\alpha^T})^{-1}$ resulting in coupled HR and LR dictionaries. This method of co-training the dictionaries enforces a common relationship (α) between high- and low- resolution patch representations. These dictionaries are used to reconstruct the non-planar, LR view of a stack acquired orthogonal to the training stack. For example, to reconstruct the non-planar view of a short-axis (SA) stack, we also acquire an orthogonal long-axis (LA) stack to be used for training.

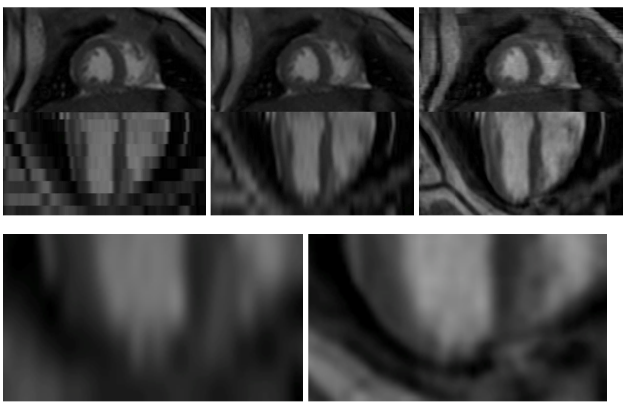


Figure 2: *Top row* (L-R): original stack acquistion, bicubic interpolation reconstruction, reconstruction using proposed method. *Second row*: Magnified region of interest around the apex for (L-R) bicubic interpolation and proposed method, respectively.

RESULTS: 15 validation datasets were created by downsampling HR 2D cine MRI to acquisition resolution. These were then upsampled using the method proposed and bicubic interpolation. Our method resulted in a reduction of the mean, mean squared reconstruction error by 52% over bicubic interpolation. For real data, images from 6 infants were super-resolved using the method proposed. Blind evaluation by clinical experts concluded that in all cases, reconstruction by the proposed method was preferable to bicubic interpolation. In particular, the apex of the heart was clearer and could be potentially be used more reliably in manual segmentation. Better definition between the myocardium and blood pool was also described. Fig. 2 shows a typical reconstruction of the non-planar view of a SA stack for one such example compared to bicubic interpolation.

CONCLUSION: We have presented a method for resolution enhancement of 4D cardiac MRI using coupled dictionary learning and applied this to the upsampling of neonatal cardiac images. We have shown improved results over standard interpolation techniques.

REFERENCES: [1] Martin et al. Pediatrics. 121:788-801, 2008. [2] Volpe et al. Ped. Res. 50:553-62, 2001. [3] Price et al. MRM 70:776-784, 2013. [4] Zeyde et al. SMIA Curves & Surfaces, 2012. [5] Rueda et al. MedIA 17(1):113-132, 2013.