Contrast Enhanced Image Registration using Kullbach-Leibler Assisted Image Matching and Patching (KLAMP)

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Introduction: Contrast Enhanced MRI data consists of frames acquired before and after contrast injection with large changes in pixel intensity values between images. These changes are difficult to correctly deal with in image alignment algorithms and enhancing features may be seen to incorrectly shrink after image registration. Dispersion in the joint image histograms is the result of both contrast change and motion artefact. Minimisation of this dispersion, for instance, by maximisation of mutual information [1] may cause mis-registration of enhancing features. If there are features in the joint image histogram between pre and post enhancement images that are due to enhancement processes, then we can seek to minimise those changes by comparison with a joint image histogram containing only motion artefact dispersion. Work related to intensity alteration has been produced by [2]. The authors sought a functional multiplicative relationship between intensities in two images in order to correct for intensity biases in the MRI acquisition in order to improve segmentation techniques. These authors seek to reduce the influence of large local contrast variations on image registration.

Method: We describe the joint image histogram (normalised so that it may be considered a probability distribution of intensity values) of two pre-enhancement images, $\mathbf{A}_{pre1}$ and $\mathbf{A}_{pre2}$ as JIH($\mathbf{A}_{pre1}$, $\mathbf{A}_{pre2}$). Similarly, we consider the normalised joint image histogram between a pre-enhancement image, $\mathbf{A}_{pre1}$ and a post enhancement image, $\mathbf{A}_{post1}$, multiplied by a pixel mask, **M** giving JIH($\mathbf{A}_{pre1}$,$\mathbf{M}$*$\mathbf{A}_{post1}$) We optimise the mask **M** so that the divergence between the pre and post joint image histograms, as measured by the Kullbach-Leibler divergence (KLD), is minimised. The mask can be found using an automatic method inspecting the small change in KLD brought about by removing that pixel in a method comparable to [4]. For an enhancing image, masking pixels that are enhancing prevents their impact on the formation of image force gradients such as those used in fluid registration. In this sense our pre-enhancement histogram is a training histogram used to modify the enhancement histogram so that it can be used for motion correction. JIH($\mathbf{A}_{pre1}$, $\mathbf{A}_{pre2}$) should contain dispersion typical of the motion between two images and should therefore be calculated between pre-enhancement images only. Any dispersion in this joint image histogram can be considered to be motion related. JIH($\mathbf{A}_{pre1}$,$\mathbf{A}_{post1}$) contains dispersion due to both motion and enhancement, both of which are minimised during conventional registration.

If registration were carried out between the pre-enhancement image and the masked post-enhancement image, we would still have spurious force gradients at the mask boundaries. To reduce this effect it is necessary to calculate a patch to fill the gap produced by the mask. For each masked pixel, we replace it with the image intensity with the highest probability, given the joint image histogram formed by JIH($A_{\mathbf{pre1}}$,M*$A_{\mathbf{post1}}$).

Results: Figure 1 demonstrates the described masking and patching method and the effect on the image registration force gradients when registering the float image to the anchor image. The example float and anchor images are selected from a real DCE-MRI dataset containing motion. Local force gradients are calculated by consideration of maximising the Normalised Mutual Information as shown in [3]. Force gradients for the registration of the unmodified post-enhancement image to the pre-enhancement image are wrong (top row): there are pinching force gradients on both the aorta and the left-ventricle/ascending aorta. These effects are reduced or removed using masking and patching in (bottom row). In the masked and patched method we maintain the force gradients correcting respiratory medial-lateral abdominal wall movement and superior-inferior liver/diaphragm displacement but have removed false force gradients associated with the enhancing features.

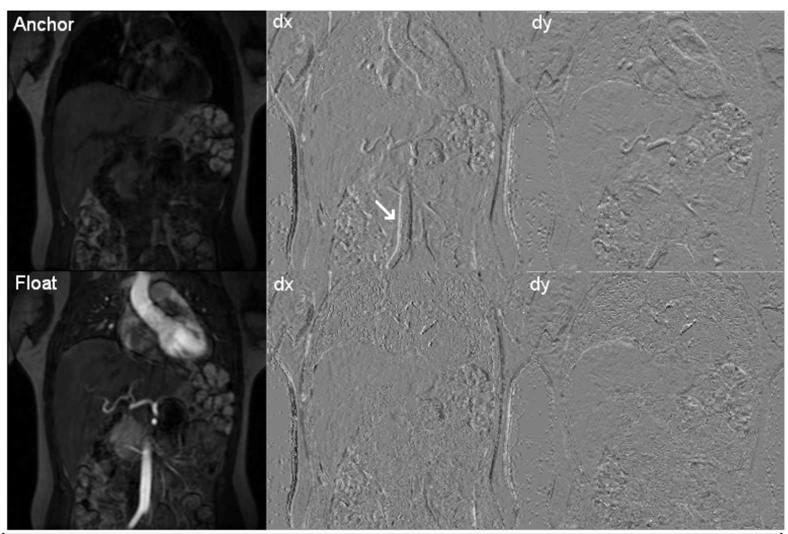

Fig 1) Demonstration of force gradient correction when registering *float* to *anchor*. Top row: Unmodified force gradients used to drive fluid registration (note pinching of aorta). Bottom row: KLAMP corrected force gradients.

Conclusion: This work has shown the theoretical benefit of contrast-enhancement masking and patching on the formation of image registration driving force gradients. The suppression of force gradients formed by enhancing features reduces the risk of mis-registration in these areas and this is of importance in subsequent analysis of contrast enhanced data.

[1] Viola & Wells. Alignment by Maximization of Mutual Information, *International Journal of Computer Vision,* **1997***, 24*, 137–154.
[2] Weisenfeld, N. & Warfield, S. Normalization of joint image-intensity statistics in MRI using the KL divergence *ISBI 2004,* 2004*, 1*, 101-104.
[3] Crum, W.R. *et al*. Information theoretic similarity measures in non-rigid registration. *Inf Process Med Imaging,* **2003***, 18*, 378-387