

Artifact-Free MR Fluoroscopic Coronary Image Combination with the Correlation Coefficient Technique

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Introduction: A method has been recently developed for combining MR fluoroscopic coronary images for the purpose of improved SNR [1]. In this technique, displacement of the artery is determined in each image frame through a template matching technique. After correcting for displacement, frames are then combined to form a high-SNR composite image. A problem is that, while gross anatomical displacement between frames can be corrected, morphological changes in the coronary anatomy itself are ignored. Consequently, inter-frame anatomical deformation could introduce substantial artifact into the composite image. In practice, an attempt is made to minimize this problem by selecting only those images whose (pre-correction) displacement is less than some specified tolerance. The underlying assumption in this approach is that, less displacement implies greater the similarity between the images. In this abstract, the correlation coefficient (CC) template matching algorithm[2] will be used to provide a direct measure of similarity between images. We hypothesize that the CC algorithm is capable of generating a higher-SNR artifact-free composite image than the displacement tolerance technique.

Theory: The CC technique for image combination is described as follows: A single image from a fluoroscopic series is chosen. A subregion of the image containing the coronary artery of interest is saved as the template (Fig. 2a). Displacement is determined by identifying the location in each image that best matches the template. The "best match" is defined as the location in the image that maximizes the CC ($\equiv r_{max}$) between the image and template. While the *location* of r_{max} provides the displacement of the image relative to the template, the *value* of r_{max} indicates the similarity between the two; the larger r_{max} , the greater the similarity (up to a maximum of unity for identity). Therefore, instead of deciding which images to include based on a specified distance tolerance, the present technique will make the decision based on whether or not the image r_{max} exceeds a minimum CC value.

The selection of the maximum distance tolerance or the minimum CC value depends on how much artifact is tolerable in the composite image. The artifact in the composite image can be determined by examining the SNR (SNR_{comp}). If n images included in the composite image are identical except for noise, then SNR_{comp} should increase by a factor of \sqrt{n} relative to the SNR in the initial template image (SNR_{temp}). However, if the images contain structural differences, the signal will not add up to n times the template signal (noise will still increase by \sqrt{n} as before). Therefore, SNR will increase by a factor different from \sqrt{n} . The artifact-to-noise (ANR) ratio in the composite image is thus given by: $ANR = |\sqrt{n}SNR_{temp} - SNR_{comp}|$. To produce an artifact-free composite image, artifact should not be visible to an observer. According to Rose's criterion, structure in an image will be discernible if $SNR \geq 5$. Therefore, the minimum allowable CC value or maximum distance tolerance should be set such that: $ANR \leq 5$.

Methods: MR spiral fluoroscopic series of images (30s) were acquired of the RCA. Composite images were formed from n component images. The n components selected were the fluoroscopic frames possessing either the n largest r_{max} values, or the n minimum displacements. Selected images were corrected for bias, gain, and displacement before combination. To calculate SNR_{comp} , signal was measured as the mean signal in the template region and noise was measured in the background.

Results and Discussion: Fig. 1 plots the results of image combination for various numbers of images. As n increases, ANR (Fig. 1b) increases since smaller CC values and larger displacements are included in the composite image (Fig 1c). For a given n , Fig. 1b indicates that the CC algorithm produces composite images with less artifact than the displacement approach. This is particularly apparent for large n . Fig. 1b also implies that, to produce artifact-free images, the displacement technique can only include at most 31 images while the CC technique can utilize 42.

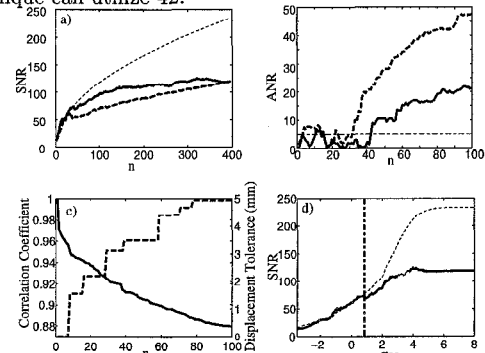


Figure 1: (a) $\sqrt{n}SNR_{temp}$ (dotted line), SNR_{comp} from CC algorithm (solid line), and SNR_{comp} from displacement tolerance (dashed line) vs. n . (b) ANR vs. n . Rose's criterion is indicated by the horizontal line. (c) Minimum CC values and displacement tolerances (in mm) vs. n . (d) $\sqrt{n}SNR_{temp}$, SNR_{comp} vs. minimum CC value plotted in terms of the number of $-\sigma_{CC}$'s away from μ_{CC} . Horizontal line indicates the CC value satisfying Rose's criterion.

Figure. 2b is the artifact-free composite image formed with the CC algorithm. In the composite image, SNR is increased with no visible artifact inside the template region. However, significant artifact exists outside the template region (e.g. false narrowing of coronary root). To obtain a high quality image of the entire artery, a series of templates could be used along the vessel. If the minimum CC value is extended substantially beyond the Rose criterion, Fig. 2c shows that significant artifact in the form of vessel blurring will be observed.

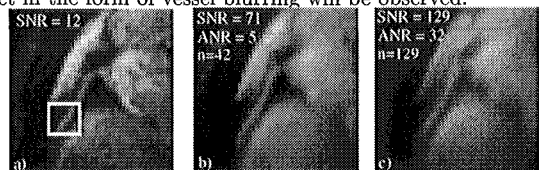


Figure 2: (a) Original image containing template (white rectangle). (b) Artifact-free composite image produced from the CC technique. (c) Composite image produced with the CC technique extended beyond Rose's criterion

To interpret the above results, consider the probability density function (PDF) of the CC in the presence of noise[3]. From the PDF, the mean (μ_{CC}) and standard deviation (σ_{CC}) of the CC can be found. Fig. 1d indicates that Rose's criterion corresponds to a minimum CC value of $\approx \mu_{CC} - \sigma_{CC}$. This implies that images included in the composite image are only those that are similar to the template within the limits of noise.

[1] Hardy, C., et al., *Proc., 6th ISMRM*, 22, 1998.

[2] Sussman, M.S., et al., *Proc., 7th ISMRM*, 2003, 1999.

[3] von Mises, R., *Math. Theory of Prob. and Stat.*, 1938

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