

Recovery of Slice Rotations with the Stack Alignment Transform in Cardiac MR Series

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Displacement of individual slices in image stacks relative to each other is known as stack misalignment and it can occur in imaging modalities with discontinuous acquisition protocols. Stack misalignment in cardiac Magnetic Resonance (MR) cine series is caused by inconsistencies in breath-hold positions between slice acquisitions and depends on the ability of the patient to follow the instructions of the attending technician during the scan. Figure 1 shows a typical example of cine stack before and after misalignment correction.

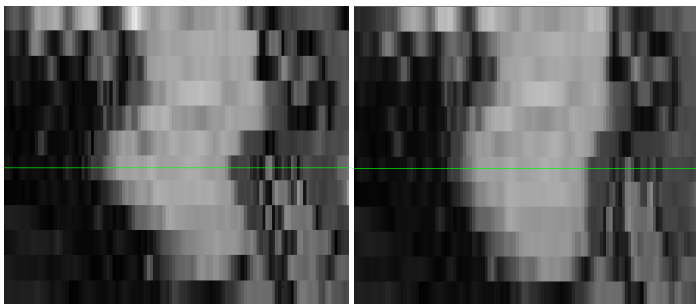


Figure 1: An example of misalignment and its correction: left ventricle (LV) in a cine stack reformatted to long-axis (LA) orientation before (left) and after (right) correction.

As with most registration applications the solutions to the problem of slice misalignment in image stacks rely on a reference image [2, 4]. However, as the authors in [1] observe, slice-to-volume registration can become an under-constrained problem due to the method's weakness which lies in the use of out-of-plane rotations. Slice displacements in cardiac cine stacks typically include translational and rotational components. Recovery of rotation in medial down to apical slices with the basic slice-to-volume registration may provide unreliable results because of rotational symmetry of the short-axis (SA) view of the LV.

This paper describes a novel method for correction of stack misalignment in cardiac cine series with recovery of the rotational component. The core of the presented method is a custom spatial transform, which improves the reliability of misalignment correction over the slice-by-slice correction approach because the image similarity metric for every iteration during optimisation is calculated on the whole image stack at once with all slice correction parameters contributing to the result.

The stack alignment transform parametrises separately the in-plane translation along the X and Y dimensions and rotation around a user-supplied centre of rotation for the individual slices independent of each other. In addition, the transform includes a parameter for global translation along the Z direction. For example, if the cine series consist of N slices, the transform is parametrised as $T = \{\{\theta_1, C_{x1}, C_{y1}, T_{x1}, T_{y1}\}, \dots, \{\theta_N, C_{xN}, C_{yN}, T_{xN}, T_{yN}\}, T_z\}$. The transform also includes a set of fixed parameters, which are used to calculate the relevant slice number and the corresponding subset of transform parameters for a point in 3D space. Fixed parameters include image origin, size and voxel spacing. Given a point $P = [x, y, z]$ in 3D space, the transformed point $P' = [x', y', z']$ is calculated in two steps as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos \theta_n & -\sin \theta_n \\ \sin \theta_n & \cos \theta_n \end{bmatrix} \cdot \begin{bmatrix} x - C_{xn} \\ y - C_{yn} \end{bmatrix} + \begin{bmatrix} T_{xn} + C_{xn} \\ T_{yn} + C_{yn} \end{bmatrix}, \quad z' = z + T_z \quad (1)$$

where n is an index into the Z dimension on the image grid, identifying the slice number, which point P falls into. The stack alignment transform deliberately avoids out-of-plane translations and rotations which otherwise

pose a problem for series reconstruction: both out-of-plane translations and rotations may result in the ‘‘holes’’ after the reconstruction.

Misalignment correction was evaluated for convergence reliability and accuracy. First, the transform was evaluated with a protocol of registration uncertainty measurement described in [5]. The protocol is designed for assessing the stability of registration in a large number of runs each with a known introduced misalignment; in this evaluation method the mean recovered transform is used as a pseudo-gold standard based on the assumption of a zero mean distribution of errors. The comparison of misalignment correction with stack alignment transform against the basic slice-by-slice correction provides evidence that the transform improves the robustness of misalignment correction. The second part of evaluation involved the measurement of registration accuracy on the basis of manually-defined contours treated as the gold-standard. In addition, this part of the evaluation was aimed at providing evidence to support the case for recovering the rotational component of slice displacement, as is shown in Figure 2; in our study about 25% of datasets contained visually-detectable rotation. The accuracy of contour match was calculated as the Hausdorff distance metric, which is used for determining the degree of similarity between two objects when superimposed on one another [3].

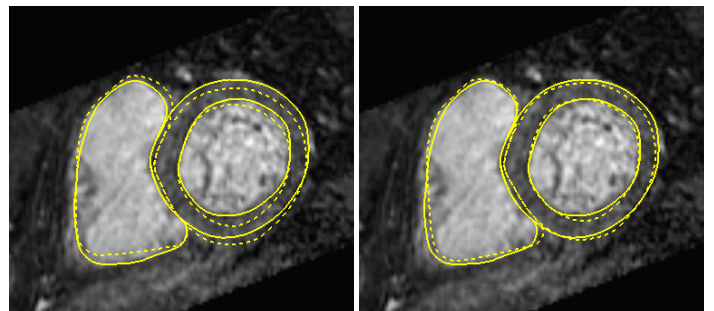


Figure 2: Improvement of correction accuracy gained through the recovery of slice rotation; moving contours (dashed line) after translation-only correction, superimposed on the fixed contours (solid line) shown in the context of the reference volume (left); moving contours after rotation and translation, superimposed on fixed contours (right).

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