The Similarity-Based Navigator Echo (SIMNAV)

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INTRODUCTION: Conventional navigator techniques select data based on a minimum navigator displacement criterion. This reduces, but does not eliminate motion artifacts. In theory, the effects of motion could be eliminated completely by removing the navigator-determined displacement from the k-space data prior to image reconstruction. In practice, the improvement provided by such an approach is limited [1] because existing navigator techniques detect only rigid-body components of motion, while most anatomical motion contains non-rigid-body elements. The presence of non-rigid-body displacement is even more likely if the navigator is placed at a location remote from the anatomy of interest [2], as in cardiac imaging where diaphragmatic navigators are used.

In the present technique, navigator data is acquired directly from the anatomy of interest. Unlike conventional methods, the navigators are used to select specifically data that differs by only rigid-body displacements. This is accomplished by selecting data based on the relative *similarity*, rather than the relative *displacement* between navigators. Thus, even if the overall anatomical motion is non-rigid-body, the image formed from the subset of selected data can in theory be completely motion corrected with the appropriate linear k-space phase factors. In the present study, the similarity-based navigator (SIMNAV) technique is implemented in conjunction with a FIESTA sequence. The utility of this technique is demonstrated on non-ECG-gated, free-breathing cardiac imaging, and imaging of joint kinematics.

THEORY: In the SIMNAV technique, navigator data is obtained by acquiring a central k-space line periodically [3] (Fig. 1a). After Fourier transformation, 1D projections of the anatomy ($\equiv P_i(x)$; i = 1,…,n) are generated (Fig. 1b). A projection is chosen as a reference ($\equiv P_{ref}(x)$). The rigid-body displacement between P_{ref} and each of the P_i's is then calculated by finding the location Δx_i that maximizes a similarity metric ($\equiv C$):

$$C_i(\Delta x) = \left\| P_{ref}(x), P_i(x+\Delta x) \right\| \;;\quad i = 1,\ldots,n$$

In this study, a correlation similarity metric is used [4]. In conventional navigator techniques, data associated with a particular P_i is accepted if the calculated Δx_i is sufficiently small. However, if non-rigid-body motion is present, Δx_i may not describe accurately the true displacement. In the SIMNAV technique, data associated with a particular P_i is accepted only if its similarity metric, $C_i(\Delta x_i)$, is sufficiently large. Displacement itself plays no role in data selection. Ideally, this identifies a set of P_i's that are identical except for rigid-body displacements (Fig. 1c). These displacements can be corrected completely with linear k-space phase factors ($= e^{-i2\pi k_x \Delta x_i}$).

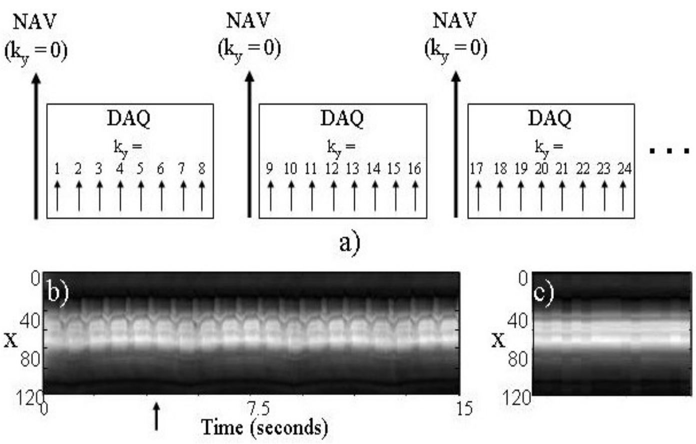

Figure 1: (a) SIMNAV timing diagram: k_y=0 lines are interspersed at regular intervals in the data acquisition. (b) 1D projections (P_0, P_1,…) of the heart generated from the k_y=0 lines as a function of time. The x direction is superior-inferior and the projection direction is medial-lateral. Note the cyclical behaviour due to cardiac and respiratory motion. (c) A set of projections selected from (b) with maximal similarity to a reference projection at time=4.4s (arrow in (b)). Note the displacement **(Δx_i)** *between some of the projections. These displacements are removed from the k-space data associated with each projection prior to image reconstruction.*

METHODS: A 2D FIESTA sequence with TR=4.6ms, $\theta=50^0$, matrix=128x128, FOV=26cm was used. A navigator (i.e. a k_y=0 line) was acquired after every 8 k-space lines (Fig. 1a). Data was acquired for a total of 30s to allow for a repeated sampling of the k-space data matrix. To form an image retrospectively at *any* time during the acquisition, a navigator acquired at that time was taken as a reference. The projection formed from this reference was then correlated with all of the other projections. A complete image was formed by selecting k-space data associated with projections that possessed maximal correlation (Fig. 1c). Residual displacement (if any) was then removed, and the image reconstructed. By using consecutive navigators as references and repeating the data selection procedure, dynamic movies with a temporal resolution of 8*TR (=37ms) were generated.

RESULTS: Figures 2a,b are non-ECG gated, free-breathing cardiac images in systole and diastole respectively. The sharp edges and lack of surrounding artifact indicate the effectiveness of motion compensation. All projections acquired in the first 12s were used as references. These were used to generate a total of 320 images with a temporal resolution of 37ms. Figure 2c indicates that correlation values of the projections in this data set ($C_i(\Delta x_i)$) are large (> 0.96). It can be shown [4] that correlation values in this range indicate that the projections are identical within noise. Residual displacements (Δx_i) up to 8mm were calculated for this data. These (rigid-body) displacements were removed prior to image reconstruction.

In another demonstration of the SIMNAV technique, images of the wrist were acquired during side-to-side motion. Figure 2d is an image acquired during ulnar, and Fig. 2e during radial deviation. The effectiveness of motion compensation is again demonstrated by the sharp edges, and minimal blurring.

DISCUSSION: The results of this study demonstrate that the SIMNAV technique is effective at imaging in the presence of complex, non-rigid-body motion. Analytically, the correlation data suggested that this approach is able to identify data that differs only by noise plus rigid-body displacements. This in theory allows for the complete elimination of interview motion artifacts (i.e. caused by motion between readout periods). Intraview motion artifacts (i.e. caused by motion during the readout) would remain. However, a more thorough verification of these postulates remains to be performed. More generally, to validate the utility of this technique, it will be essential to perform a comparison between similarity-selective and conventional displacement-selective navigator techniques. A final point to note is that, while the SIMNAV approach was implemented in conjunction with 2D FIESTA in this study, the same strategy could be applied to almost any other sequence (e.g. 3D FIESTA, spiral, EPI, PR, etc.). All that is required is a periodic acquisition of the central k-space line.

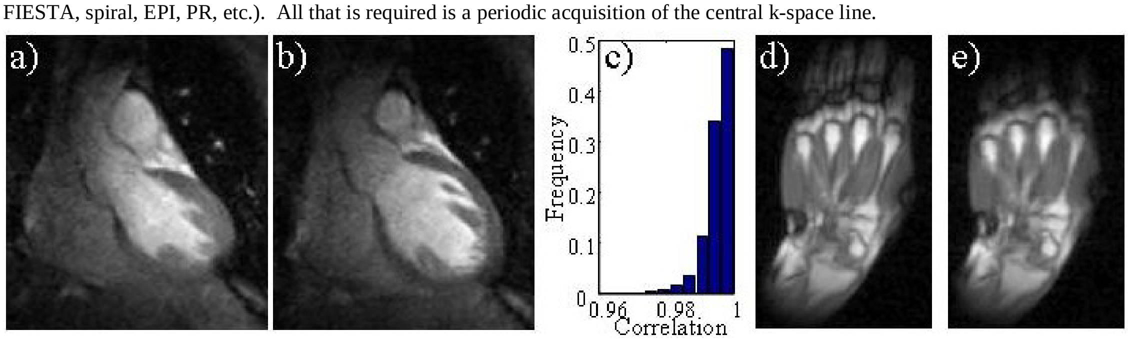

Figure 2: Non-ECG gated, free-breathing cardiac images in (a) systole and (b) diastole generated with the SIMNAV technique. A total of 320 images were generated with 37ms temporal resolution. (c) Histogram of correlation values of the projections used to generate all 320 images. (d), (e) SIMNAV images of the wrist acquired during side-to-side motion. For both heart and wrist images, the navigators consisted of projections along the horizontal direction.

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