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Technique to Control and Minimize the Impact of Artifact and Optimize Parallel Imaging in 2DFT MRI

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This invention is intended to apply to conventional, two-dimensional fast Fourier transform MR imaging methods, although the principles will have application to other methods such as 3DFT, EPI, and other methods of filling K-Space. The following description assumes that the principles of MR imaging using the two dimensional Fourier transform [2DFT] method are well understood; background in this technique is readily available from a variety of sources.

SPECIFICATION

It is well known that most artifacts, including but not limited to phase ghosting, motion artifacts, flow artifacts, and Gibbs artifact manifest themselves primarily in the phase encoding direction of the 2DFT image; that is, the direction on the two dimensional image that is defined by the use of multiple phase encoding views during the acquisition of data by the system using the NMR phenomenon to form an image [the other, orthogonal direction is encoded using frequency encoding]. Normal functions of the modern MRI scanner allow the operator to select the direction in which the phase encode and frequency encode gradients are applied from the two primary directions of the image [as an example, in a conventional axial image, the operator may select to place the phase encode direction from the anterior to the posterior direction of the patient, making the phase encode artifacts appear horizontally (left-to right from the source of the artifact) in the image, or left to right direction, making the phase encode artifacts appear vertically (anterior to posterior from the source of the artifact) in the image.

There is a potential benefit from an ability to rotate the phase encode artifacts to any arbitrary angle, rather than only being able to select vertical [anterior/posterior in the axial image example], or horizontal [left/right in the axial image example for the orientation of the artifact. By selecting the phase encode direction to be defined as any arbitrary angle betwixt 0° and 180° in the reference coordinate system and the frequency encode direction at right angles to the phase encode direction [betwixt -90° and +90°], the phase encode artifacts can be directed in a manner causing the least impact on the readability and utility of the image by causing them to miss certain critical parts of the resulting image, and preventing the obscuring of the anatomy to be studied by the artifact.

In a similar manner, the use of parallel imaging methods that use phased array coils with multiple elements having unique sensitivity patterns exploits the sensitivity patterns to allow the unique filling of K-Space with fewer phase encode views by using the combined factors of the number of phase encode views and the coil sensitivity patterns. The combined coil sensitivity patterns and the reduced number of phase encode views enable the creation of a phase-encode data set using a fraction of the otherwise-needed phase encode views without using the coil sensitivity patterns to multiply the effective number of phase encode views. The phase-encode views must lie along the axis of optimal uniqueness of the phased array coil system's coil sensitivity patterns. These patterns may not be optimum in an arbitrary major-axis direction of the host MR system, so the optimization of the parallel imaging capability may call for the frequency and phase encode directions to be rotated to an arbitrary new orientation that may be at an angle to the system coordinate axes.

To accomplish the imaging, the resulting phase encode and frequency encode gradients will now have components of at least two of the three orthogonal Cartesian planes; in this example, the patient's Superior-Inferior direction is along the Z-Axis, his Left-Right lies along the X-Axis, and his Anterior-Posterior direction is in the Y-Axis direction. In an example of an axial image with a desired phase encode orientation of +45°, the slice select gradient in the Z-orientation is not impacted. The phase encode gradient [with a net direction of +45°] will consist of two components, one from the X-orientation, and one from the Y-orientation; each will have a magnitude of 0.707 of that of the same gradient with the phase encode direction completely in the X or Y direction. Similarly, the frequency encode gradient [orientation of +135° or -45°] will also consist of two components, one from the X-orientation, and one from the Y-orientation; each will again have a magnitude of 0.707 of that of the same gradient with the frequency encode direction completely in the Y or X direction.

The above gradients can be created by system software using a method similar to that used for oblique imaging, from an orientation input supplied by the operator. To maintain the square or rectangular field of view that is aligned with the major axes of the coordinate system of the scanner, use of this technique will require an overscan of the Cartesian coordinate dimensions by an amount dependent upon the selected angle for the phase encode direction [a maximum overscan of 41% may be needed].

The first two figures, Figure 1 and Figure 2, illustrate an artifact situation in a 2DFT image that cannot be avoided by either the default of the "Swap Phase-Frequency" options on a GEHC Signa MRI system. Figure 3 shows a rotation of the Phase and Frequency directions to avoid the illustrated artifact. Figure 4 shows the relocation of the artifacts to miss the image Region of Interest. Figure 5 shows a potential cropping of the image to save scan time.

The invention provides a tool to manage the position of artifacts in an image to minimize their impact on the utility of the image. It also provides a means to optimize the benefit of parallel imaging techniques when the optimum phase-encode orientation for the particular coil system in use does not lie exactly along one of the major coordinate system [gradient] axes of the host MRI system.

Shifting the effective orientation of the system gradients may not be obvious to someone, since the MR scanner does not routinely offer this ability. It may be a bit more obvious to someone who learned MRI in the early days, when Projection-Reconstruction was commonly used, rather than the Paul Lauterbur 2DFT method; however, I have not seen this idea advanced to date.

It is a modification of the 2DFT MRI imaging method as described by Dr. Paul Lauterbur. 2DFT is commonly used in essentially every MRI imaging system. The unique benefits to artifact management are achieved by adding a new variable and dimension to the 2DFT method. Its utility in parallel imaging employs the parallel imaging idea of using the coil element sensitivity patterns of phased array coil elements, but brings a new dimension to it by allowing the host system gradient coordinate system to be arbitrarily rotated to optimize the parallel imaging benefit.

The invention provides a means to control the orientation and position of artifacts from motion, flow, aliasing, and some other sources when performing 2DFT MR imaging. This is accomplished by rotating the coordinate system of the two 2DFT dimensions [phase and frequency] to an orientation that is not exactly aligned with the coordinate system defined by the host MRI system gradient fields.

In a similar vein, the invention provides a means to accomplish the same manipulation betwixt the positions of the unique field patterns of several coil elements in a phased array coil system and the coordinates of the system gradients to facilitate and/or optimize parallel imaging when the axes of the unique field patterns of the coil elements do not match the axes of the gradient system in the host MRI scanner.

The invention provides a means to rotate the coordinate system defining the two orientations of the frequency and phase directions in a 2DFT scan method when aligning the 2DFT axes with the axes of the host system gradient fields in any simple orientation till produces undesirable artifacts or aliases through the patient anatomy of interest.

Similarly, the invention provides a means to enable or optimize the parallel imaging of an MRI system using 2DFT image reconstruction, and the parallel imaging technique in which the coil elements provide uniqueness to an under-sampled phase-encode gradient direction in a 2DFT scan

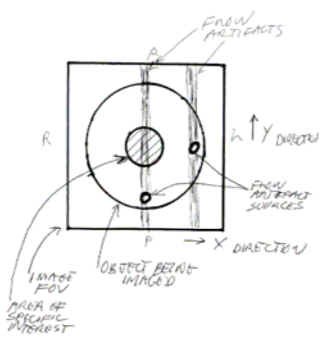

FIGURE 1 - FLOW ARTIFACT WITH PHASE A-P

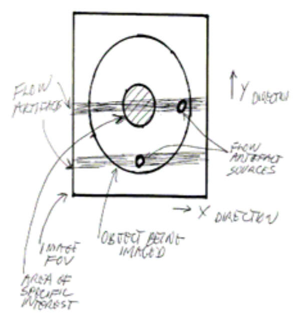

FIGURE 2 - FLOW ARTIFACT WITH PHASE L-R

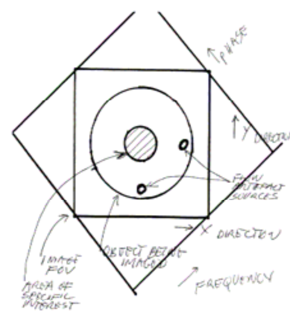

FIGURE 3 - FREQUENCY AND PHASE DIRECTION CHANGES USING CURRENT INVENTION

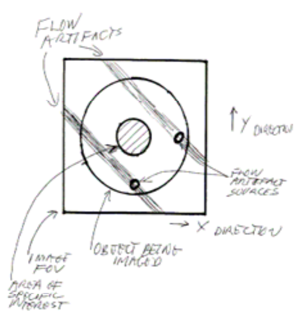

FIGURE 4 - FLOW ARTIFACTS MISS R.O.I. USING THE CURRENT INVENTION

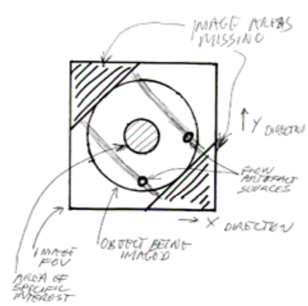

FIGURE 5 - IMAGE WITH REDUCTION IN NEEDED PHASE VIEWS TO SAVE TIME