A New Class of Encoding Techniques using a Transmit Array: Illustration with Cylindrical Encoding

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Introduction

In nearly all magnetic resonance imaging (MRI) applications, gradient coils are used for data encoding. Although an arbitrarily oriented slice can be selected, gradient coils limit the field-of-view (FOV) to a rectangular region and the slice to a plane. However, in a considerable fraction of MRI applications, the region of interest (ROI) is merely a portion of the selected slice. Hence, all the FOV needs to be imaged. Because the gradients encode all the FOV data producing uniform pixels, either the resolution of the ROI has to be decreased or the total imaging time has to be increased. Although using multi-dimensional pulses, a certain region can be excited and the FOV can be decreased, due to the fact that the FOV needs to be rectangular, this method is useful if the ROI is rectangular too. If the ROI is convex, or encloses a region which is not of interest, the efficiency is still low.

In this paper we propose a novel encoding scheme that can excite arbitrarily shaped slices, so that the requirement of getting unnecessary data from outside the ROI is eliminated. The proposed method uses RF pulses to encode the data instead of gradient coils [1], and hence the FOV is not limited to be a rectangular region and the slice can be selected arbitrarily instead of being planar.

Theory

Multi-dimensional pulses have been studied for more than ten years and it is shown that they can effectively excite only a specified portion of the subject to be imaged [2,3]. However, performing the data encoding using gradient coils yields uniform pixel sizes, and a rectangular FOV. This leads to data encoding and reception for the regions that are not of interest. By using two RF transmit coils having different sensitivity profiles, and applying 180-degree pulses, a phase deposition on the spins can be obtained, which we called cylindrical encoding [4]. When a 180-degree pulse is applied on a spin from a transmit coil, the spin is rotated by twice the angle between the spin and the field of the coil, towards the field. Hence, if the angle between the spin and the field is initially α, the final angle is $-\alpha$. If two 180-degree pulses are applied, this process reverses, and the spin ends up at its initial position. However, if another 180-degree pulse is applied in between from another coil, which has a field direction having an angle of β with the field of the first coil, the spin is rotated by an angle of 2β with respect to its initial position after the three 180-pulses. If the second coil's field has a different and unique angle with respect to the first coil at any location, then with each couple of 180-degree pulses, there will be a unique phase deposition on the spins, which is the idea behind cylindrical encoding [4,5]. This way, encoding is accomplished without any gradient coils; however it should be guaranteed that the rotation angle that the pulses produce is 180-degrees at the excited regions, which can be accomplished by using adiabatic pulses [6]. The proposed method excites the ROI with a thickness corresponding to the desired slice thickness, and employs cylindrical encoding to receive the required data without any gradient coils. In case a rectangular FOV exists in one direction of the ROI, gradient coils can be used, although they are not necessary for the method to work.

Methods

In this study, birdcage coil is assumed as the transmit coil. For obtaining two different phase profiles as mentioned in the theory section, m=1 mode, which has a uniform phase distribution in the slice, and m=2 mode, which has a direction that varies linearly with the angle in the transverse plane (φ), are used [7]. To excite both modes, either two conventional birdcage coils tuned to different modes and connected to different transmit channels, or a microstrip (TEM) birdcage coil with multi-transmit channels can be used.

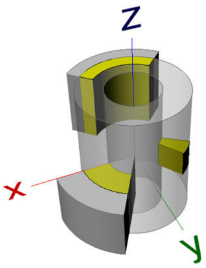

Figure 1: The object used for the simulations. The cylindrical shell shows the slice. Yellow regions indicate the regions in the slice.

The multi-dimensional excitation is designed to excite a ring region in the axial plane with a radius of 3 cm and a thickness of 2cm, which corresponds to slice selection along the radial direction; and encoding along the circumferential direction and the z-axis are achieved with cylindrical encoding and a readout gradient, respectively. Hence, the method corresponds to selecting a cylindrical shell with a thickness of 2cm, and unwrapping it in the sense that the resulting image is with respect to φ and z. Imaging of three objects which have different lengths, angular spreads, and radial thicknesses (Fig. 1) is simulated. Figure 2 shows the theoretically calculated image on the left and the obtained simulation image on the right. It can be seen that the images are in good agreement, although in the simulation, the excitation pattern is designed for only 32x32 pixels on the axial plane, which introduces sampling artifacts and hence some error.

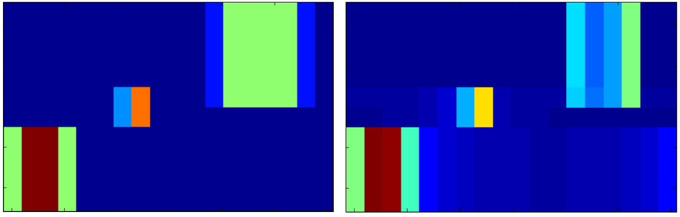

Figure 2: Simulation results for the geometry shown in Fig. 1. Left: Ideal image. Right: Simulation. The horizontal axis is the angle φ where the vertical axis is z. Magnitudes are in the same scale.

The method is implemented as an imaging sequence. BIR-4 is used as the adiabatic pulse algorithm [8]. Figure 3 shows the designed pulse sequence where RF$_a$ is the 2D excitation, RF$_b$ is the m=2 mode adiabatic and RF$_c$ is the m=1 mode 180-degree pulses. As m=1 mode is highly uniform [7] in the axial plane, the RF$_c$ pulse does not need to be adiabatic. Furthermore, as there is no slice selection, RF$_c$ can be a hard-pulse. G$_x$ and G$_y$ trace the excitation k-space and G$_z$ is the readout gradient.

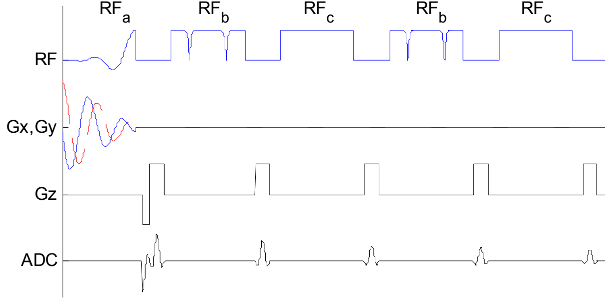

Figure 3: Imaging sequence showing the applied gradients and RF pulses. Readout occurs when G$_z$ is positive.

Conclusion

A new class of encoding techniques is proposed, which uses multi-dimensional pulses for arbitrary slice selection, and RF pulses for data encoding. Gradient coils can be implemented in the method, if the ROI is rectangular in one direction. Furthermore, with the proposed method, multiple slices in the radial direction can be obtained with radial encoding methods that are already present in the cylindrical encoding algorithm used in this article. The method can be implemented either with a transmit array or a single transmit channel if a switching hardware is used. A special case, for which the slice is a cylindrical shell with a pre-determined thickness, is simulated and implemented as an imaging sequence. After production of the transmit coils, the method will be implemented in a Siemens 3T Trio system with a transmit array.

The method eliminates the need to obtain the data of the regions that are not of interest by encoding only the data in the region of interest. Furthermore, arbitrary shaped slices can be imaged; hence the constraints of planar slices and rectangular FOVs are eliminated.

References: [1] A. A. Maudsley, Mag Reson Med 3,768-777 (1986) [2] J. Pauly et. al., Mag Reson Med 29:2 – 6 (1993) [3] G. Morrell et. al., Mag Reson Med 37:378-386 (1997) [4] E. Atalar, O Ocali, U.S. Patent #6,031,375 [5] S. King, J. Sharp, Published U.S. Patent Application #60/924195 [6] C. J. Hardy, et. al., J Mag Reson 66:470-482 (1986) [7] V. Alagappan et. al, Mag Reson Med 57:1148–1158 (2007) [8] R. S. Staewen et. al., Investigative Radiology, 25: 559-567 (1990)