Efficient trajectory design for measuring velocity distribution or spectra from MR Images

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Problem statement

Measuring velocity distribution or spectra for each voxel provides clinically useful information for several diseases (evaluation of vascular and valvular diseases, in cases of severe aortic stenosis, and flow through the mitra1 valve and in the pulmonary vein), and for highly pulsatile or turbulent flow.

Full velocity spectra can be obtained using Fourier Velocity Encoding, designing trajectories in the k_x-k_v space to cover a specific region of interest. This trajectory is generated using a two-shot readout bipolar gradient of uniform density [1]. It is also possible to do it with a one-shot bipolar gradient of uniform density [2] to reduce the readout time. Finally, a more efficient trajectory, in scan time and Field of View, can be designed employing variable density [3].

All these versions of the readout gradient are similar in their waveforms, and all of them assume that the gradient must be formed by repeated bipolar units. In this work we investigate novel shapes for the gradient, and k-space trajectories that optimizes the coverage of a region of interest. The resultant trajectory depends on the sequence parameters such as resolution in space and velocity (ROI in k-space), readout time, and FOV; and on hardware parameter: maximum gradient amplitude and slew rate.

Approach

The main constrain in the design of trajectories in the k_x-k_v space is the dependency between k_x and k_v, represented by the slope of the curve being time, $\partial k_v/\partial k_x = t$. This relationship results in a trajectory very sensitive to the time when the readout gradient is applied (a strong memory problem). This time dependency makes the design very complex, because the search space, formed by the values of the gradient for every unit of time, has a shape that changes along the time axis. In this work we propose a novel quasi-optimal heuristic for finding the gradient, as a practical way of solving an exponentially complex problem.

To circumvent the memory effect we structure the problem as a tree of decisions. Each level of the tree represents a discrete period of the readout time; the nodes in each level correspond to discrete positions in the k_x-k_v space. The different levels of the tree are connected with branches that represent trajectories to travel from a node in a specific time to another node in the next period of time. With this organization, each node is "memoryless" since it is not important what nodes where visited previously.

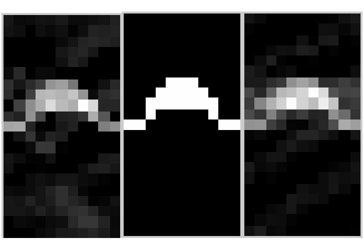
To discretize the problem we divide the gradient into discrete values in finite levels of amplitude that are connected with ramps (we use only three possible values: minimum and maximum amplitude and zero); then we create a large enough grid defined by nodes in the k_x-k_v space to see the evolution of the trajectory in time through these nodes. The decision tree is prune as follows: for every node we eliminate all branches that lead to unreachable nodes (because of amplitude and slew rate constrains).

To find an optimal path that covers the maximum percentage of the region of interest we perform two optimization heuristics: first backwards in time and second forward in time. In the backward optimization we mark each node with a number stating what is the maximum possible nodes belonging to the region of interest that can be visited starting from it. The nodes in the last level (the first in being processed) are filled with zero. This stage is ended when the algorithm reaches the first node, the origin of k-space. The marks of the nodes do not have information of how many times a particular node is visited. This is solved during the second pass which starts at the first node, origin, and makes its way forward in time choosing nodes that have maximum coverage. Once a node is chose it is marked as visited so it will not be counted again.

Results

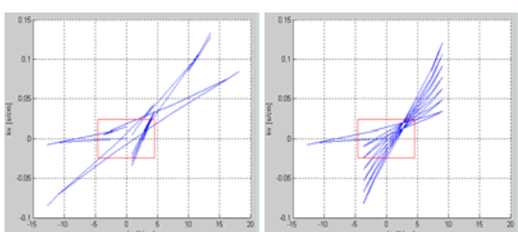
The proposed algorithm for designing k_x-k_v space trajectories was tested with simulations. The hardware parameters were: maximum gradient of 40 mT/m, slew rate of 150 T/m/s. The readout time was 16 ms; the phantom represents a flow with higher velocities in the center and a dispersion proportional to its mean, as shown in figure 1b (12.1 mm wide with a resolution of 1.1 mm, and with a maximum of 200 cm/s with a velocity resolution of 18.9 cm/s).

The trajectory we obtained with the proposed method covers 52.4% of the region of interest, compared to the 37.7% of the standard trajectory. The reconstruction of the phantom done with the two different trajectories is shown in figure 1. The trajectories are shown in figure 2 and the gradients that produce them in figure 3. Both reconstructions were done using the discrete inverse Fourier Transform of the collected samples. As expected, the reconstructed image with the new trajectory presents fewer artifacts in the region of interest, although there is a little aliasing left.



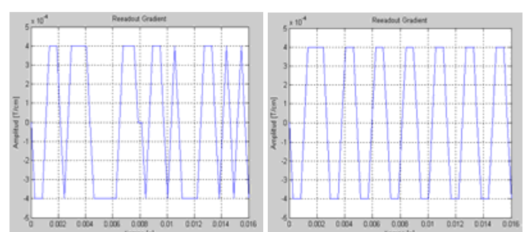
a) b) c)

Figure 1. Reconstructed images. a) Using optimized gradient. b) Original Image c) Using normal gradient.



a) b)

Figure 2. Trajectories in k_x-k_v space. a) Method trajectory b) Normal trajectory.



a) b)

Figure 3. Readout gradients. a) Optimized gradient b) Normal bipolar gradient

Conclusions

This work describes a novel method to find alternative readout gradients to maximize the coverage of a region of interest in k_x-k_v space. The method successfully produces trajectories that have better coverage under the same constrain that the regular bipolar gradient. We believe that the presented heuristic opens many practical possibilities for designing this kind of trajectories. There is space for improvement and for better results in increasing the discrete values for the gradient and for time. Since the regular trajectory is usually employed with a smaller first bipolar gradient to shift the readout in the k_x direction, for a more realistic comparison one would have to add extra possible values for the amplitude.

References

[1] Irarrazabal P, Hu BS, Pauly JM, Nishimura DG. Magn Reson Med 1993;30:207–212. [2] Luk Pat GT, Pauly, Hu BS, Nishimura DG. Magn Reson Med 1998; 40:603-613. [3] DiCarlo JC, Hargreaves BA, Nayak KS, Hu BS, Pauly JM, Nishimura DG. Magn Reson Med 2005;54:645–655.