Accelerated MRA

Julia Velikina, PhD
Department of Medical Physics
University of Wisconsin - Madison
Madison, WI USA
Email: velikina@wisc.edu

This talk is aimed at both physicists and clinicians, who are interested in recent developments in accelerated imaging and their applicability to angiographic MR imaging.

Magnetic Resonance Angiography (MRA) is an attractive non-invasive imaging choice that has shown utility in visualizing vasculature and blood haemodynamics. MRA is general term comprising a number of imaging techniques, including both single image and time-resolved imaging with or without the use of contrast agents. While many of MRA techniques may benefit from increased spatial and/or temporal resolution, time-resolved contrast-enhanced (CE) imaging often is in a particular need of acceleration. Indeed, in many diseases useful information can be gleaned from separate images of arterial and venous enhancement, hence rapid passage of contrast puts a bound on the acquisition time of a single frame, depending on application. For instance, such pathologies as intracranial arterial-venous malformations may require temporal resolution on the order of 0.5 - 1 s [1], while imaging of upper and lower extremities would benefit from 3-7 second frames [2]. At the same time, inherently low speed of MR acquisitions limits the number of k-space samples that can be acquired within a given time period. This duality creates a typical for MRA need for a tradeoff between spatial resolution/coverage on one hand and temporal resolution on the other hand. An attempt to maintain both high spatial and temporal resolution inevitably leads to the need to reconstruct images from incomplete data. Since conventional reconstruction from undersampled data produces aliased images and SNR degradation, a number of advanced imaging techniques have been proposed to deal with this problem.

The required acceleration can be achieved on either acquisition side (e.g., by using efficient non-Cartesian trajectories [3-5] or specialized Cartesian acquisitions [6-8]) or reconstruction side (e.g. by using constrained reconstruction). Often, the two are developed jointly to maximize the benefits. MRA may offer unique sources of prior knowledge that may serve as a basis for acceleration. For example, a singular advantage of many MRA methods is sparsity of the image content, which is reached by special processing, such as mask subtraction in CE MRA [9,10] or complex difference processing in phase contrast imaging [11-13]. In such images, only a small portion of image pixels are bright (vessels) and the remaining pixels, representing background and/or stationary tissues, have values that are zero or insignificant. A benign behavior of the point spread function for many projection reconstruction-inspired trajectories (i.e., VIPR [5] or CAPR [6]) induces incoherent, dispersed aliasing artifacts in images with significant spatial sparsity, thereby allowing for some acceleration via solely k-space undersampling. However, for larger accelerations, even these artifacts become significant enough to cause noticeable degradation of SNR and spatial resolution to compromise diagnostic image quality, and further improvements require modified image reconstruction. One of the popular ways to improve image quality in time-resolved imaging is to use view-sharing, which is achieved by filling in the unsampled positions in k-space by the data acquired in the neighboring frames. Commonly, low frequency information is updated more often, while high frequency information is sampled less often. We will discuss several established view-sharing approaches such as keyhole method [14], tornado filter [5], TRICKS [11], or TWIST[15].

The use of view-sharing in conjunction with regular linear reconstruction inevitably widens the impulse response function, which leads to modification of temporal waveforms [16], usually, in the form of smoothing out. The severity of this distortion depends on the level of acceleration and, hence, the necessary amount of view-sharing. Additionally, view-sharing may create extraneous temporal correlations between images in a time series, which may be tolerable in some applications but undesirable in others. However, the existing true correlations between images in a series may be used to design a regularized reconstruction approach, which would allow a higher degree of acceleration without negatively affecting temporal dynamics. We will discuss several non-linear techniques, which utilize spatio-temporal correlations in reconstruction algorithm design. In particular, we will look at applications of regularized reconstruction methods (including compressed sensing approaches), which exploit joint sparsity in *k-t* or *x-f* space [17-20]. We will also consider a different type of constrained reconstruction, namely, HYPR algorithms [21-24], which utilizes spatial sparsity through the use of multiplicative constraint. We will discuss achievable acceleration factors and sources of potential error in applications of these techniques, as well as the issue of temporal resolution of such methods. The latter question does not have a straightforward solution since for nonlinear algorithms there is no direct relationship between temporal footprint and actual temporal resolution, unlike in the case of linear reconstruction. Therefore, true temporal resolution of each method needs to be determined experimentally or a non-linear analogue of an impulse response function needs to be introduced.

In the end, we will summarize the discussed techniques, accelerations achievable with them and potential drawbacks/inaccuracies to make it easier to decide which technique may be more suitable for a particular angiographic application.

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