Infimal Convolution of Total Generalized Variation type functionals for highly accelerated reconstruction of dynamic MRI

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PURPOSE: Dynamic MRI (dMRI) is a highly interesting scenario that opens the possibility to study the time behaviour of dynamic processes within the human body. Important clinical applications are cardiac imaging, contrast-enhanced imaging and kinematic of joints and organs among others. High quality reconstructions for dMRI are in general complicated to achieve, as spatio-temporal resolution and SNR are restricted by data acquisition time constraints in relation to organ motion. dMRI draw a lot of benefit from parallel imaging (PI), temporal compressed sensing (CS) techniques ([1], [2]) and very recently from low rank and sparse matrix decomposition approaches ([3], [4]) exploiting predictable patterns of image time series. For dynamic imaging, we propose to extend the Total Generalized Variation (TGV) regularized reconstruction method of [5] for dynamic imaging via infimal convolution of two TGV functionals (ICTGV). ICTGV exploits the additional information of time correspondence between frames, i.e. allows to relax the piecewise smoothness assumption in space and time by assuming that the image sequence is piecewise smooth in space or time. The combination of suitably weighted TGV functionals via infimal convolution locally emphasizes one of these assumptions, thus is thought to yield good reconstruction of image sequences not only in areas that are piecewise smooth in space and time, but also in the two cases of either rapidly moving objects that are piecewise smooth in space or textured background regions. With that ICTGV allows to formulate a motion model that does not require explicit motion estimation.

METHODS: Fully sampled retrospective gated SSFP cardiac cine MRI data was acquired in breath-hold from a healthy volunteer on a whole-body 3T MRI scanner (Tim Trio, Siemens Healthcare). Imaging parameter were as follows: FOV 292 x 360 mm²), acquisition image matrix = 256 x 208, spatial resolution 1.4 x 1.4 mm², flip angle = 49°, TR/TE = 38.22/1.28 ms, receiver bandwidth = 1085 Hz/px and temporal resolution of 36.95 ms with 18 reconstructed cardiac phases. The raw data was retrospectively under-sampled by factors of 4, 8, 12 and 16 using a Cartesian lattice pattern as in [6]. Reconstruction quality was evaluated quantitatively calculating the mean-squared error to the fully sampled reference sum-of-squares reconstruction in a region-of-interest loosely encompassing the heart and visually displaying the time course of decisive line crossing the septum. Coil sensitivities were estimated from the subsampled data taking advantage of the stationary assumption. Numerical solution of the ICTGV algorithm employs a primal-dual extragradient algorithm [7].

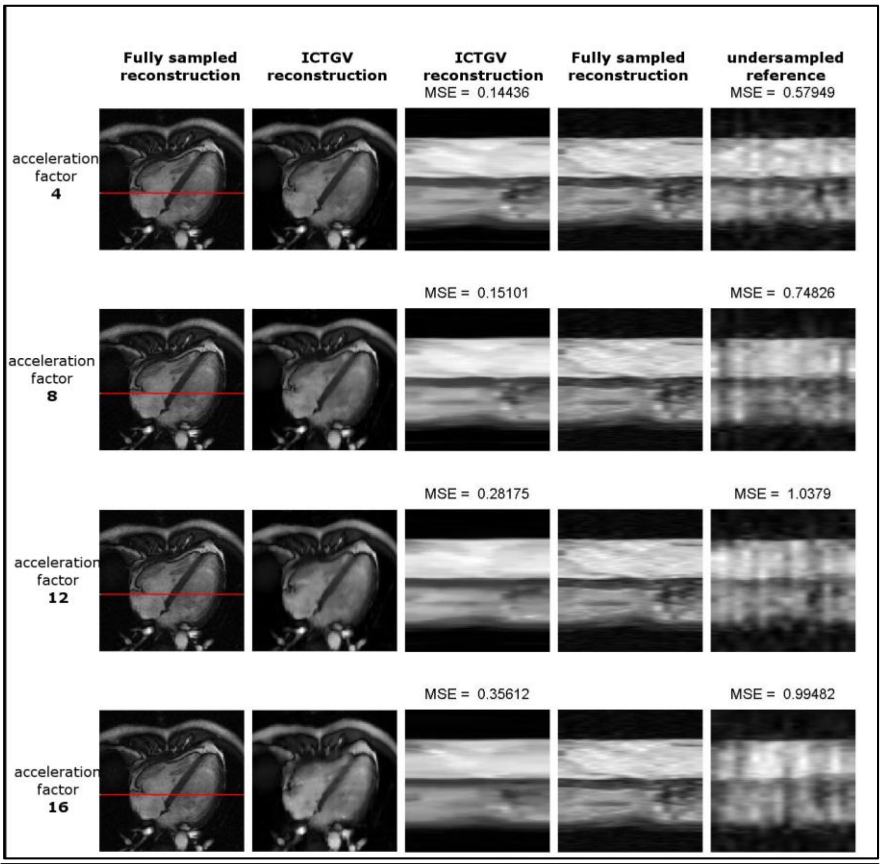

Fig 1: Results for different acceleration factors 4 (1st line) to 16 (4th line) are displayed together with a systolic timeframe of the fully sampled reference reconstruction (1st column) and ICTGV reconstruction (2nd column). The time-course of a slice crossing the septum (red) is displayed for ICTGV (3rd column, fully sampled reference (4th column) and under-sampled reference reconstruction (5th column) together with MSE.

RESULTS: Fig. 1 displays the results for ICTGV based reconstruction against the fully sampled reference and sum-of-squares reconstruction from under-sampled data for different acceleration factors. Up to acceleration factor 8, ICTGV yields a visually high quality reconstruction that is also reflected by a low MSE. Details like the papillary muscles can be observed quite well. For acceleration factor 12 details are still observable but already very smooth while lost for acceleration of 16.

DISCUSSION and CONCLUSION: The results show that our proposed method is able reconstruct highly under-sampled dynamic sequences employing a motion model based on smoothness assumptions in space and time. The reconstructions exhibit good spatio-temporal resolution and agreement with the fully sampled reference. The high acceleration rates, as exemplified for the case of cine cardiac MRI, permits the applicability to real time monitoring of any kind of physiological movements without restriction to in-plane motion. Great benefit for cardiovascular imaging lies in improved assessment of myocardial functions in real time with high temporal resolution. Furthermore ICTGV is not restricted to tailored sampling patterns and can also be adapted to non-Cartesian trajectories.

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