Local feature-preserving selection of kernel size for unwrapping of high-resolution phase images

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Introduction

The recent introduction of whole body ultra high field MRI has put emphasis on the use of phase imaging [1] and its extensions, such as Susceptibility Weighted Imaging (SWI) [2], in order to visualize structures that are difficult to observe in the regular magnitude images. One of the main difficulties of phase imaging is the post-processing involved to remove the unwanted abrupt phase variations, also called phase wraps, caused by local magnetic field variations. The goal of a phase unwrapping algorithm is two-fold: it should remove the phase wraps while preserving the underlying local phase features. Whereas it is relatively easy to assess the quality of phase wraps removal, it is difficult to have an objective view on whether the features of interest are preserved or not. We investigated that latter aspect, i.e. the preservation of local features in the context of unwrapping MR phase images of the brain.

Material and Method

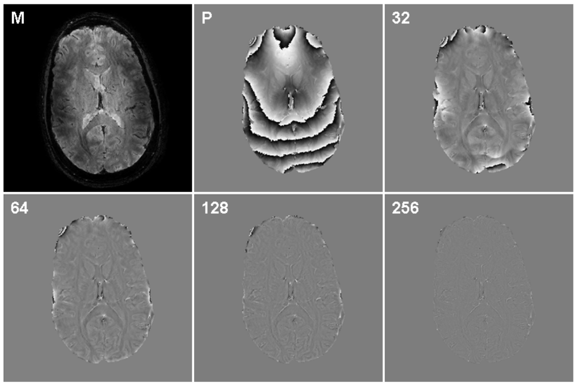

Figure1 Example of high field MR data unwrapped using different kernel sizes. M and P correspond to respectively the magnitude and original wrapped phase image.

Data were acquired on healthy volunteers using a 7 Tesla Philips Achieva MRI scanner with a 16 channel receive head coil (Nova Medical). The pulse sequence was a spoiled 3D flow compensated gradient-echo sequence with a FOV of 220x180 mm, matrix size 880x720 with an echo time of 19 ms, a repetition time of 32 ms with 120 slices of 0.7 mm thickness (over-contiguous sampling). Parallel imaging was used with a SENSE factor of 3, resulting in a total acquisition time of 7.5 minutes.

Data were subsequently unwrapped using the algorithm described in [3]. It consists of removing the phase wraps by means of high-pass filtering of the data within the k-space. In this method, a single variable is involved, the size of the filtering kernel. This size has to be chosen as the best trade-off between wraps removal (the larger the kernel, the better the removal) and underlying phase features preservation (the larger the kernel, the less remaining features), as shown in Fig. 1.

We propose to select the optimal kernel size parameter based on two informational content-based performance criteria. The first criterion is the Shannon entropy of the unwrapped data, providing information about the level of local details left in the unwrapped image. This parameter should be maximized as a function of kernel size. The second criterion is the Shannon entropy of the difference between the original and the unwrapped data, which is highly sensitive to the presence of phase wraps. It is hypothesized that with increasing kernel size, due to the finite number of wraps, this parameter will reach a steady state once all wraps are removed.

Results and Discussion

Figure 1 shows that, as expected, an increase in filtering kernel size leads to a decrease in the number of wraps, but also to a decrease in the local informational content of the unwrapped images. As a result, one can deduce that, qualitatively, the optimal kernel size should be situated between 32 and 64 pixels.

Figure 2 shows the evolution of our proposed two criteria with the filtering kernel size. The Shannon entropy of the unwrapped data first increases, reaching its maximum for a kernel size of 32 pixels, and subsequently decreases. This behavior can be explained by the removal of wraps, leading to an increase in local information, followed by the removal of local features as the filtering kernel comprises more and more high spatial frequencies. The second criterion shows a sharp decrease for kernel sizes between 16 and 64 pixels followed by a plateau ranging from 64 to 512 pixels. That trend can be explained, as mentioned before, by the removal of phase wraps. Indeed, Figure 1 shows that some phase wraps can be observed with a kernel size of 32 pixels, but none with kernel sizes of 64 and above. From those observations, one would suggest to use in that particular case a kernel size of 64 pixels.

Based on the detailed views presented in Figure 3, one can confirm the previous observations that too large a kernel leads to the loss of the local features observable in the original phase image. Moreover, the kernel size of 64 pixels appears to be the best for those acquisitions as the local features appear more clearly.

Conclusion

We have proposed two information-based criteria to select the optimal kernel size for unwrapping high resolution anatomical phase images by means of a k-space filtering-based algorithm. Shannon entropy of the unwrapped image allows avoiding over-unwrapping of the data whereas the entropy of the difference between the original and unwrapped data ensures a complete unwrapping. Results of the presented method could be applied to maximize the information gained with phase imaging.

References: [1] J.H. Duyn et al, Proc. Nat. Acad. Sci. 2007, 104:11796-11801.
[2] E.M. Haacke et al, Magn. Reson. Med. 2004, 52:612-618.
[3] Y. Wang et al, J. Magn. Reson. Imaging 2000, 12:661-670.

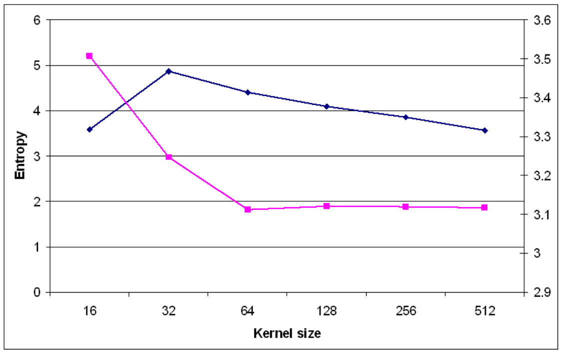

Figure 2 Evolution of the two proposed criteria with the filtering kernel size. The wraps removal criterion is plotted in pink while the local detail criterion is plotted in dark blue.

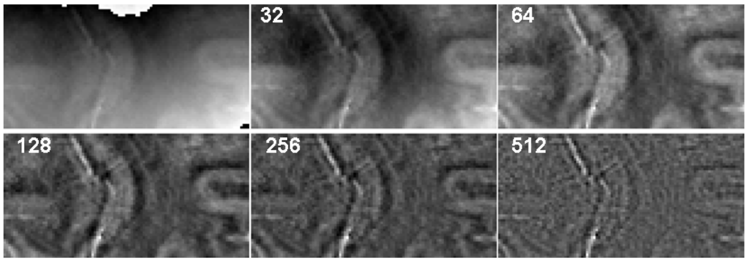

Figure 3 Detailed views of the original wrapped phase image (top left) and the unwrapped phase obtained using kernels of size 32, 64, 128, 256 and 512 respectively.