k-space_masking_for_MRI_denoising

k-space based MRI image denoising (on the example of Agilent FID data).

1 Introduction

Raw MRI (Magnetic Resonance Imaging) data is stored in k-space. Each line of k-space represents a nuclear magnetic resonance (NMR) echo signal with the signal maximum located in the middle of the line. There is no NMR signal before the echo begins nor after the echo ends. The center of k-space hosts the strongest signals - the signal drops not only to the sides but generally towards the k-space edges (this is natural result of the physical nature of frequency and phase encoding in MRI experiment).

It is a fair assumption, that beyond some distance from the k-space center there is no usefull NMR data - just electric noise. Removing that 'empty' region results in excluding some noise from the resulting MRI image. It is worth remembering that electric noise covers all the k-space, so this technique would not remove all the noise.

It is also relevant that simple cutting out some region of k-space can cause artifacts on the reconstructed MRI image due to sudden signal zeroing. The solution to avoid the abovementioned artifacts is graduate dimming of the k-space until zero value is reached. The artifacts would not be a consideration if the software was used strictly for denoising purposes as numbers representing noise are generaly close to 0. The abovementioned solution was implemented in the code in case the script is ever used to intentionally remove some detail information. Every point in k-space represents a wave in the reconstructed image (i.e. a different spatial frequency at a different angle). The center of the k-space hosts low spatial frequencies (these data points in k-space translates only to large waves on the image - information about large areas of bright and dark, i.e. contrast information). The farther from the center the higher spatial frequency. This means that edges and detail information is located on the periphery of k-space and extensive exclusion of k-space edges will result in some real image details being lost.

2 The sample data

The data was acquired in the frame of the project described in the article "Alcohol-fixed specimens for high-contrast post-mortem MRI"([https://doi.org/10.1016/j.fri.2021.200449 (https://doi.org/10.1016/j.fri.2021.200449)](https://doi.org/10.1016/j.fri.2021.200449)). The specimen is one of the untreated mice.

MRI was performed at 17°C on a 9.4 T horizontal bore Agilent MRI scanner using a 40 mm diameter Agilent millipede coil for transmission and reception. The experiment was multi spin echo multi slice imaging (TR = 8s, TE = 7 ms, NE = 32). There were 12 spatial slices, each repeated for 32 different echo time values, resulting in total slice number of 384. Slice dimensions were 40 mm x 40 mm with slice thickness of 1 mm and data matrix size 128 x 128.

3 The software

For the code please see 'kspace_denoise.py' script file. The script contains 2 functions: 'kspace_denoise' for all the calculations and 'main' which provides input parameters for 'kspace_denoise' function, runs it and retrieves the results. It also creates global variables for the results to be available after the run completion.

3.1 Necessary python libraries:

- nmrglue,
- numpy,
- matplotlib,
- cv2.

3.2 Input parameters for 'kspace_denoise' function:

1. .fid folder location: **path** (string variable, e.g. "D:/mems_20190406_02.fid" or just "mems_20190406_02.fid" if located in one folder with the script),
2. total number of slices in the imaging experiment: **number_of_slices** (integer, e.g. 10)
3. selected slice number: **picked_slice** (integer, e.g. 5),
4. radius for k-space masking in pixels: **r** (integer, e.g. 56).

3.3 How kspace_denoise function works

The function starts with importing data from .fid folder specified in **path**. Single .fid file contains raw data for the whole imaging experiment, that can be multi-slice and/or multi-echo. The function needs **number_of_slices** to downsample the data to extracts k-space corresponding to the **picked_slice**.

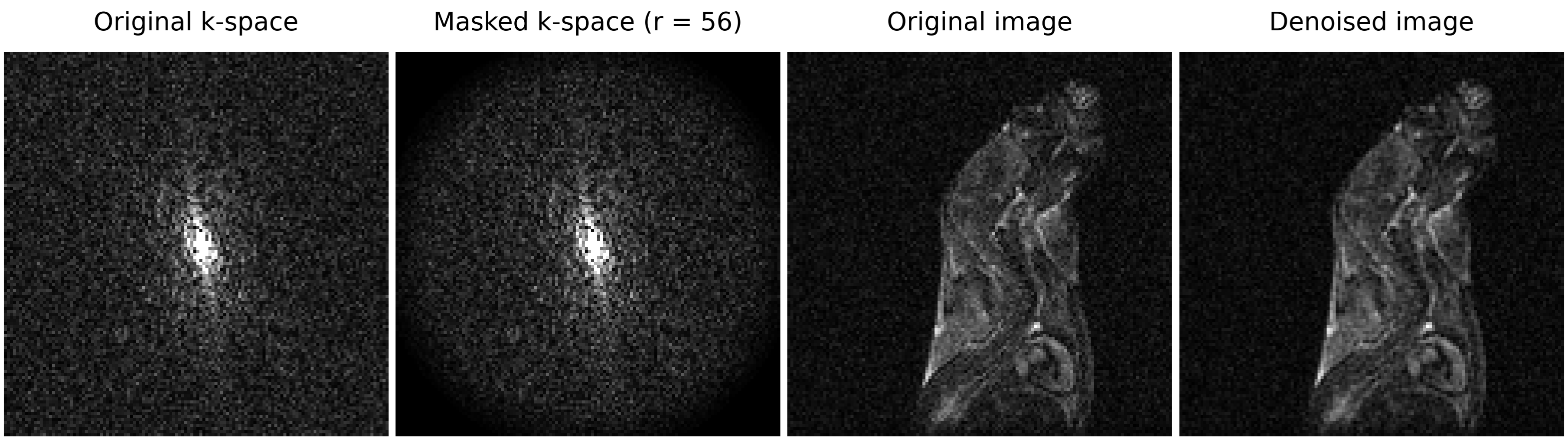
Subsequently, masked version of k-space is created by multiplying it by a mask gradually dimming the edges outside of the given radius **r**.

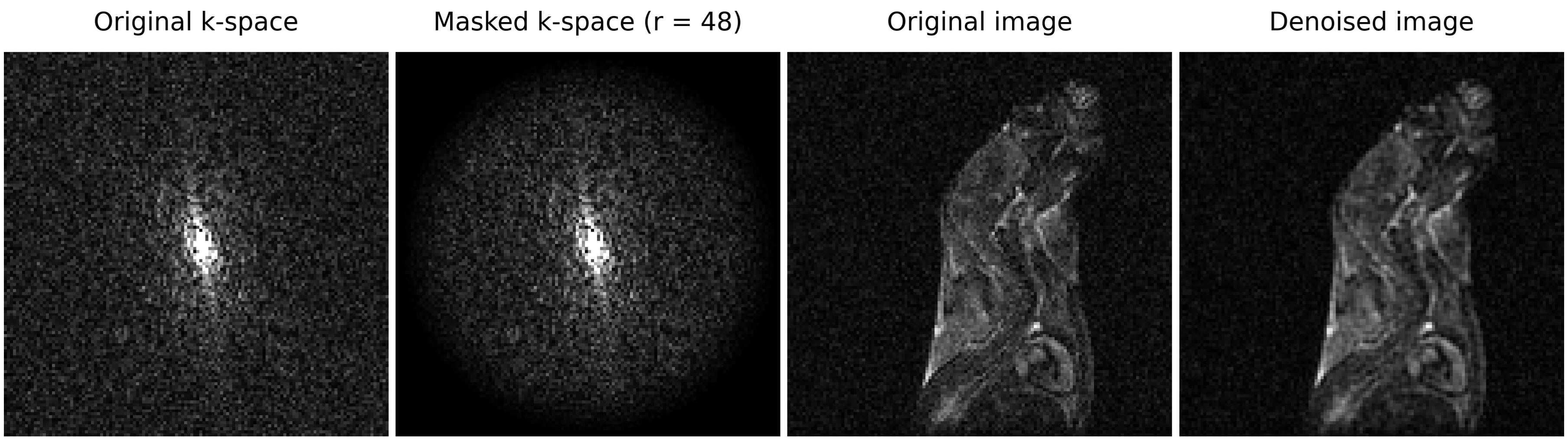
In the next step, MRI images are reconstructed, both from original k-space and masked k-space, using 2-dimensional Fast Fourier Transform (2D FFT).

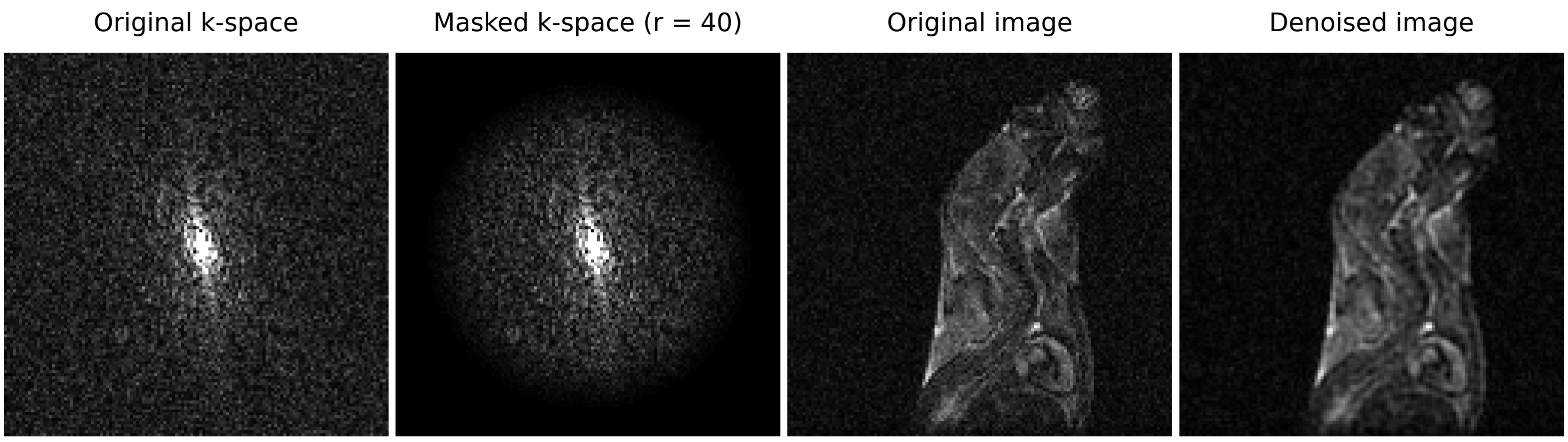
The results get sumarised in an illustration showing: the original k-space, the masked version of k-space, the original MRI image and the denoised MRI image. In the last step, the function returns the results in a form of 2 data arrays of complex numbers.

4 Results

The impact of **r** value on the denoised images is presented below.







5 Literature reference (for the sample data)

Beata Wereszczyńska, Alcohol-fixed specimens for high-contrast post-mortem MRI, Forensic Imaging, Volume 25, 2021, 200449, ISSN 2666-2256, https://doi.org/10.1016/j.fri.2021.200449 (https://doi.org/10.1016/j.fri.2021.200449). (https://www.sciencedirect.com/science/article/pii/S2666225621000208 (https://www.sciencedirect.com/science/article/pii/S2666225621000208))

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