

DERINGING OF MRI MEDICAL IMAGES*

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A no-reference method to detect and suppress ringing effect in MRI images is suggested. The ringing detection method is based on finding the area where ringing effect is likely to appear and calculating the ratio of average edge-normal and edge-tangential derivatives moduli in this area. The area consists of pixels with the certain distance to basic edges — sharp edges that are distant from other edges. The proposed ringing suppression method is based on the projection onto the set of images with bounded total variation with ringing level control.

Keywords: Gibbs phenomenon, ringing effect, magnetic resonance imaging.

Introduction

Magnetic resonance imaging (MRI) is a noninvasive medical image technique to visualize internal structures of the human body.

Many different artifacts can occur during magnetic resonance imaging (MRI), some affecting the diagnostic quality, while others may be confused with pathology. There are three main sources of artifacts [1]:

1. Artifacts caused by motion of a patient, different flows within the body or metal objects.

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2. Artifacts introduced by hardware: radiofrequency quadrature, inhomogeneity, noise, external magnetic field inhomogeneity, gradient field artifacts.

3. Artifacts added by software signal processing algorithms during data sampling: chemical shift artifact, partial volume artifacts, wrap-around artifacts and Gibbs phenomenon (ringing artifact, truncation artifact).

In this work, we consider the problem of ringing effect detection and reduction in MRI images.

In MRI the data is measured in k-space (Fourier transform values). In practice, a limited number of phase-encoded signals are often acquired in order to minimize the duration of measurements and to maintain adequate signal to noise ratio. This results in the truncation of the k-space data. After applying inverse Fourier transform, the frequency truncated data results in image with limited resolution and ringing effect near sharp edges.

Ringing reduction methods were developed to suppress this effect. These methods include Gegenbauer reconstruction, regularization methods [2], wavelet shrinkage methods [3], Bayesian approaches [4].

The problem of ringing detection in MRI is not studied well. Most of ringing detection algorithms are focused on the detection of ringing artifacts produced by specific image processing or compression methods like JPEG-2000 [5, 6].

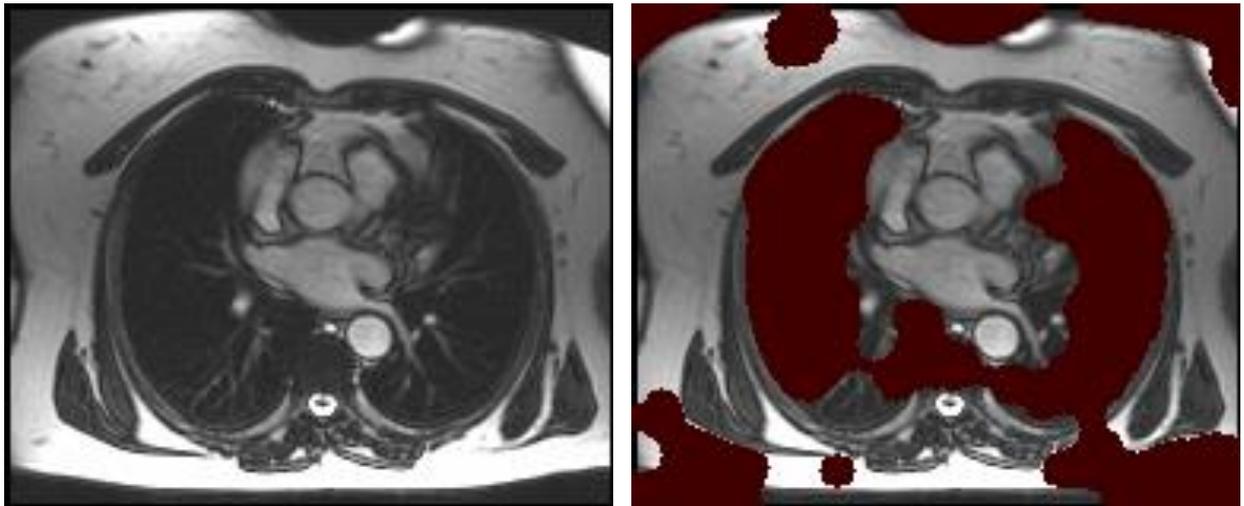
Finding ringing regions

Before performing ringing detection, we find the regions where ringing effect may appear in MRI images.

Ringing effect usually appears near sharp edges distant from other edges which we call basic edges [7, 8]. But the area of possible ringing effect should be refined for MRI images. For example, object boundary is detected as the basic edge, but ringing effect does not appear in black area outside the object.

We use the following algorithm to find the areas for ringing detection:

1. Preprocessing step. This step includes eliminating solid dark or white areas from the further analysis. It is performed by finding pixels with the intensity less than I_{\min} and the intensity greater than I_{\max} and applying morphological opening and closing to the obtained set of pixels. We use $I_{\min} = 64$, $I_{\max} = 192$ and the radius of morphological operations equals to 5 pixels. An example of finding working area is shown in Fig. 1.



a) source image

b) working area

Fig. 1. Finding working area for ringing detection.

The area not suitable for ringing estimation is marked by dark color on the right image.

2. Edge width estimation. Before detecting the level of ringing effect, the width of a single ringing oscillation d should be estimated. We use the algorithm from [7] to estimate it.

3. Basic edges detection. Basic edges are sharp edges distant from other edges. These edges are the most suitable for ringing effect detection because ringing oscillations produced these edges do not interfere with ringing oscillations from another edges.

This step consists of the following substeps:

a) Edge detection, which is performed by Canny edge detector;

b) Edge masking — omitting the edges which have the edge with higher gradient value nearby [9]. We check the conditions

$$g_{i_0, j_0} > \max_{i, j} g_{i, j} \varphi((i - i_0)^2 + (j - j_0)^2),$$

$$g_{i_0, j_0} > g_{\min},$$
(1)

where $g_{i, j}$ is the gradient modulus in the pixel (i, j) , and set to zero the values g_{i_0, j_0} for all points where these conditions are not both true. The second condition is used to remove edges with too low gradient value. The function $\varphi(x)$ is chosen as

$$\varphi(x) = \frac{1}{2} e^{-\frac{x^2}{2d^2}}.$$

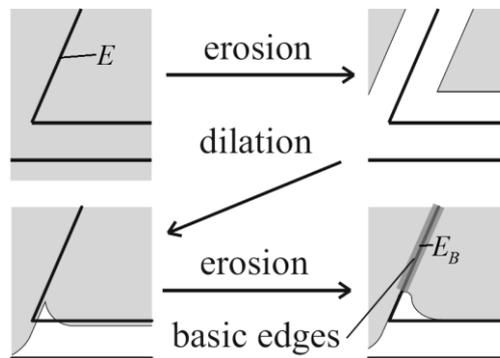
c) Finding edges with the distance to other edges greater than R .

This is implemented by morphological methods: the non-edge area is eroded with circular structural element with the radius $R/2$, then dilated with the same elements with radius $R/2 + \varepsilon$, where $\varepsilon = 2$ pixels, then the obtained area is eroded with circular element with the radius 2ε . The intersection of the obtained area with the edge detection result is the basic edges mask.

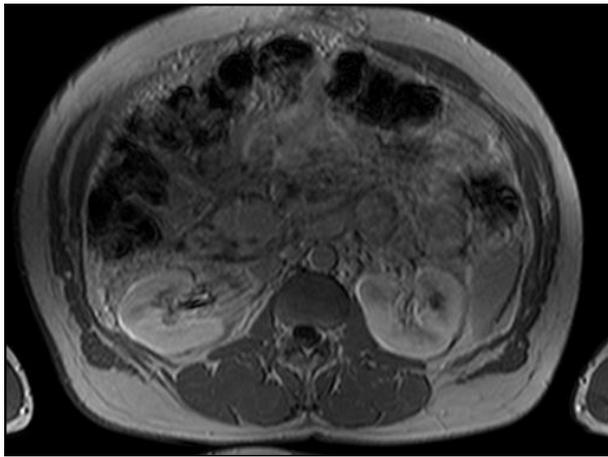
We choose the value R equals to $3d$ — three ringing oscillations.

4. Finding basic edges area. Using Euclidean Distance Transform (EDT) algorithm [10], we find the distance from every pixel to the nearest edge and to the nearest basic edge. Next we find the basic edges area — the set of pixels for which the nearest edge is the basic edge.

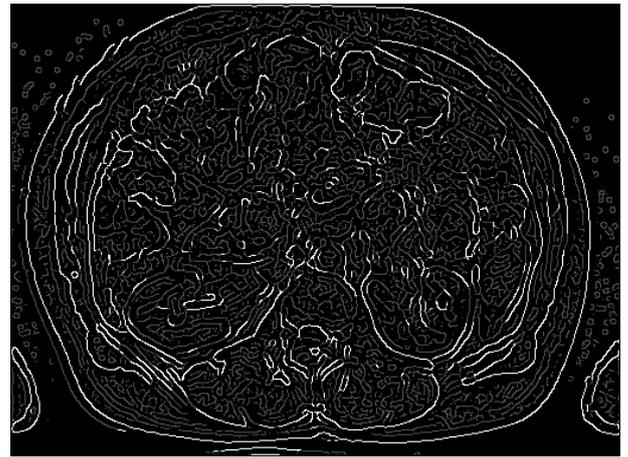
The example of basic edges detection is shown in Fig. 2.



a) morphological method of basic edges detection



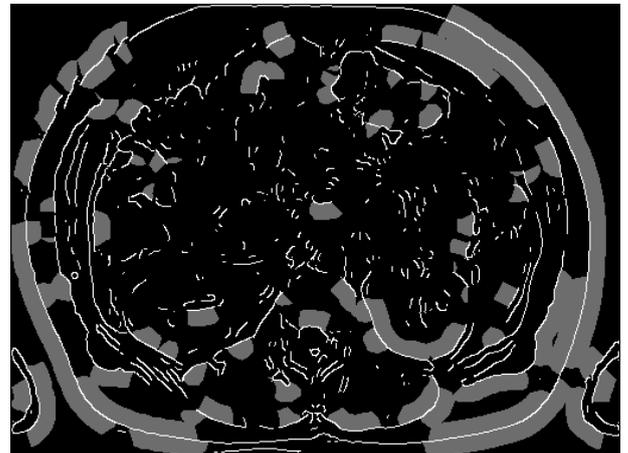
b) source image



c) edge detection and edge masking: white edges are non-masked edges, gray edges are masked edges (1)



d) basic edges detection: white edges are basic edges



e) basic edges area detection: gray area is basic edges area

Fig. 2. The illustration to the basic edges detection algorithm.

Ringling detection

To detect the presence of ringing effect and to estimate its level, we use the total variation analysis. In [11] the connection between image total variation and ringing effect was shown. High values of total variation may be the indicator of the presence of ringing effect.

Instead of taking individual edge profiles [7, 8] we propose an integral approach for ringing level estimation.

Ringling oscillations are located tangential to the edge producing them. So we can assume that for the edge neighborhood the average modulus of directional derivatives tV (tangential variation) with the direction tangential to edge direction will be smaller than the average modulus of directional derivatives nV (normal variation) with the direction normal to edge direction.

To calculate tV and nV for the whole image, we use the following algorithm:

1. Take the subset of basic edges area with the distance to the nearest basic edge between d and αd where α controls the maximal number of considered ringling oscillations. We use $\alpha = 3$.

2. Extract from the obtained set too dark and too light areas calculated in the preprocessing step.

3. For every pixel of the obtained set find the direction of ringling oscillations and calculate normal and tangential variations. To estimate the direction of ringling oscillations, we find the nearest edge pixel using EDT algorithm and calculate gradient direction in the found pixel.

4. Calculate average tV and nV values and find the ratio $R_v = nV/tV$. We use this value as the indicator of presence of ringling effect. If the ratio is close to 1, we assume that there is no ringling effect. If this value is significantly greater than 1, we assume that there is ringling effect.

Image may be corrupted by noise which makes a great influence to variation values. To reduce the effect of noise, we analyze variation values for the image blurred by Gauss filter with the radius $\sigma = kd$. Parameter k is chosen to keep ringling oscillations but to suppress noise. By taking different images with ringling effect and with different noise level, we found that good results are obtained using $k = 0.25$.

Ringling suppression

To suppress the ringing effect in MRI images, we use projection onto convex sets (POCS) approach:

$$z_q = \arg \min_{z \in M_q} \|z - z_0\|_2, \quad (2)$$

where z_0 is the input image with ringing effect, z_q is the result image and the set M_q is the set of images with bounded total variation:

$$M_q = \{z : \|z\|_V \leq q \|z_0\|_V\},$$

$$\|z\|_V = \sum_{i,j} |\nabla z_{i,j}|.$$

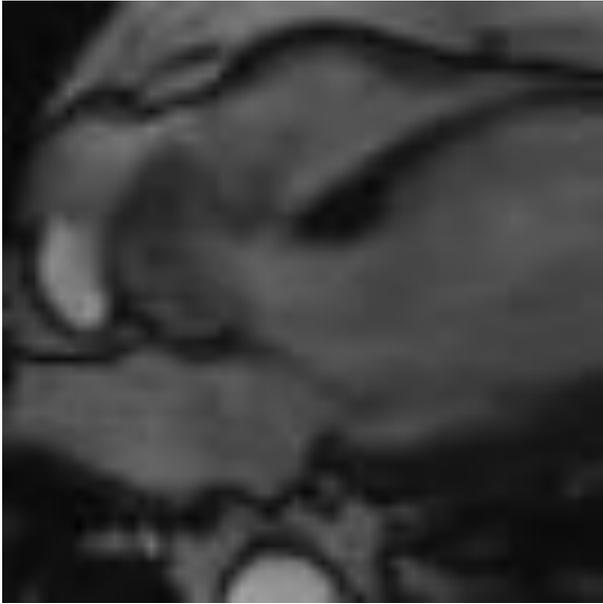
Parameter $q : 0 < q \leq 1$ controls the ringing suppression level. Higher values result in less ringing suppression.

Results

We have tested the proposed method on real MRI images with ringing effect and on MRI images with manually added ringing effect.

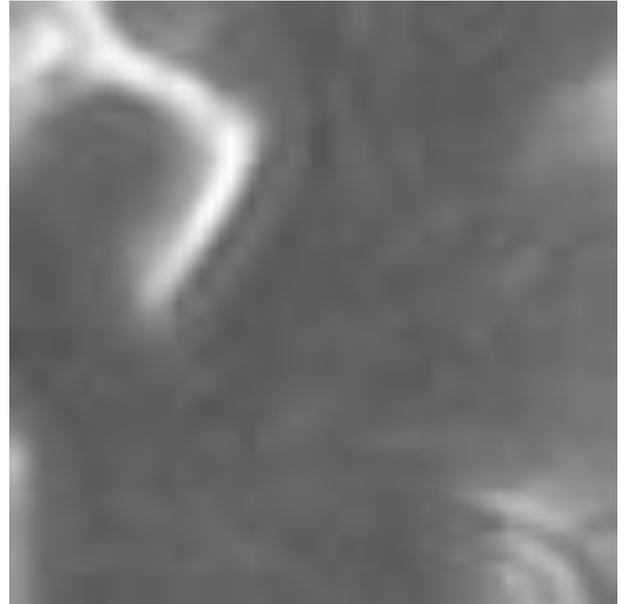
Ringing effect was modeled by truncation high-frequency coefficients in Fourier transform.

The results are shown on MRI images fragments in Fig. 3.



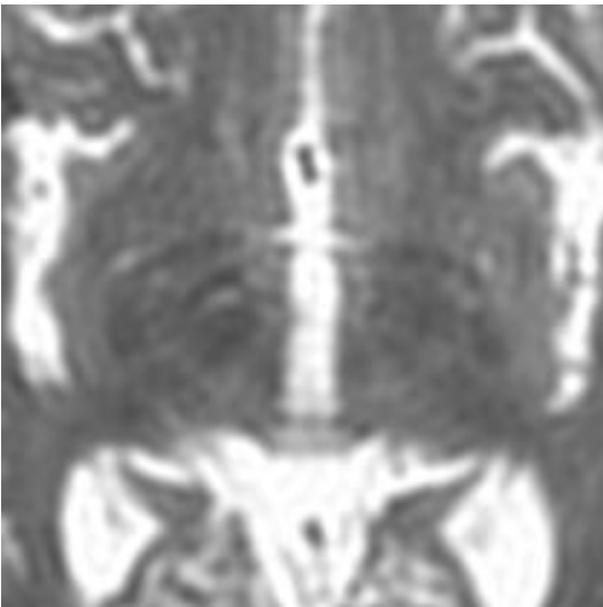
a) image without ringing effect and its fragment,

$$R_v = 0.93.$$



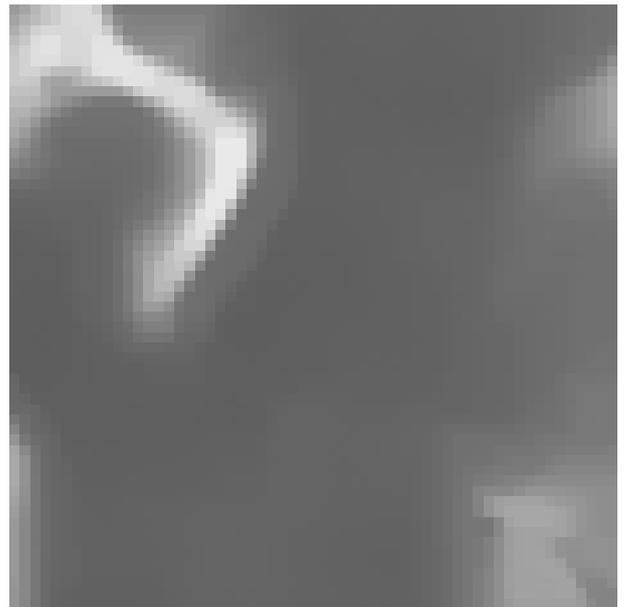
b) image with real ringing effect and its

fragment, $R_v = 1.86$.



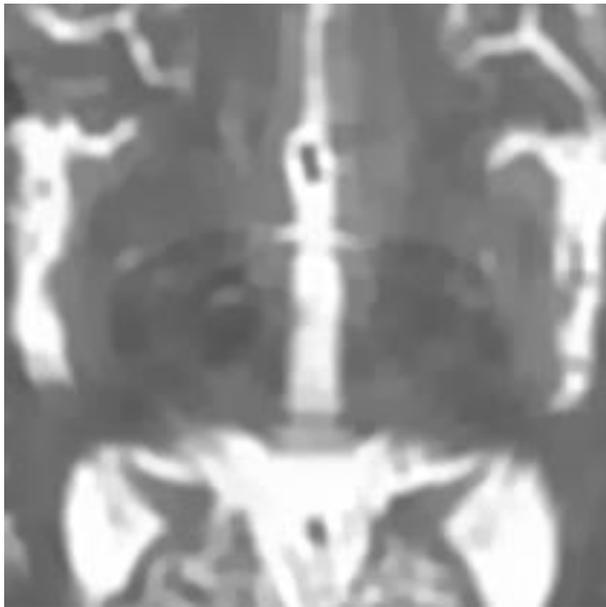
c) image with generated ringing effect and its

fragment, $R_v = 2$.



d) the result of ringing suppression (2) for the

image b), $q = 0.7$, $R_v = 0.95$.



e) the result of ringing suppression (2) for the image c), $q = 0.7$, $R_v = 1.05$.

Fig. 3. The results of ringing detection and suppression in MRI images.

Conclusion

The no-reference method to detect and suppress ringing effect in MRI images has been developed. The method is based on the analysis of the ratio of average directional derivative modules in area where ringing effect usually appears — near sharp edges distant from other edges. Ringing suppression is based on the projection onto the set of images with bounded total variation with the control of ringing level. The effectiveness of the proposed method was tested on real and synthetic data.

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