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CORRECTION OF INTENSITY INHOMOGENEITY IN MAGNETIC RESONANCE IMAGES USING RAMP FILTER

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ABSTRACT.

The paper deals with the problem of correcting the intensity non-uniformity in magnetic resonance images. This problem is due to the peculiarities of the imaging equipment, may be caused by magnetic coils, and other technical reasons. Bias field makes it difficult to recognize objects in images and make a correct diagnosis. In the paper, the method of removing such noise using ramp filter known also as the rho filter is considered. The numerical experiments on test images and real-world images of small animals are presented.

Keywords: Magnetic resonance imaging; Intensity inhomogeneity correction; Bias field; Ramp filter.

1. INTRODUCTION

The images produced by an MRI scanner are often subject to noise. These noises must be removed, since they significantly complicate the further process of classification and diagnosis. Interferences are divided into two large types - random and systematic. This division is quite arbitrary; there are also other specific interferences, for example, the anatomical and age characteristics of the patient, which are referred to as special interferences called patient noise.

Noise in MR images is caused by fluctuations in the magnetic field in the coil [1]. Various inhomogeneities associated with images include noise and shading artifact.

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High contrast and high spatial resolution are important parameters for all diagnostic tasks. A high signal-to-noise ratio is a must for image processing applications since most algorithms are sensitive to noise. This highlights the need to apply noise filtering to MR images to preserve fine image detail. The intensity value (from black to white) can vary within the same image texture. This is called the bias field. This is a low-frequency, smooth, unwanted signal that significantly darkens or brightens some areas of the MRI image. The displacement field is caused by unpredicted inhomogeneity in the magnetic field of the MRI machine. If the bias field is not corrected, image processing algorithms (such as segmentation and classification) will produce incorrect results. Therefore, a preprocessing step is necessary, although often in empirical way, to correct the influence of the bias field [2]. This paper examines the problem of improving the visual quality of images obtained in MRI scanners subject to systematic noise, namely, field shifts or brightness inhomogeneities in the images. The change in visual brightness of an MRI image caused by the displacement field can sometimes reach 30% distortion of normal image density.

Recent studies have proposed various methods for correcting the bias field, see review articles [2], [3]. Correction methods are mainly divided into two types: technical methods and digital post-processing techniques, according to different bias field sources. Engineering methods combat displacement fields caused by equipment and environmental conditions. Image post-processing techniques include methods for correcting the displacement field created by the shape, position and direction of the imaged object. They do not distinguish the source of the displacement field and are based only on the intensity of the MRI image and a priori knowledge of the scanned object. Processing strategies include techniques such as filtering approximation assumed shape of the displacement field [2], segmentation [4], [5], [6] and statistical approaches [7]. Although both hardware and digital methods have achieved good results in eliminating offset fields, they still have some disadvantages, including the need of modeling signal and displacement fields, manually setting parameters, optimizing testing methods, etc. Currently deep learning methods are widely used for overcome these shortcomings. For example, in the article [8] deep learning is used for correction of the field shift of magnetic resonance images of the brain. Currently, in tomography the task of developing methods and means for eliminating noise and image artifacts is still practically valuable and relevant. Our work considers the possibility of using for this purpose a rho filter, or a high-frequency filter, widely known and used in tomography [9], [10]. This tomographic filter corresponds to the imaging model in MRI scanners. The results of numerical experiments on model data and real MRI images are presented.

2. MATHEMATICAL MODEL OF DISTORTION

Two main artifacts are involved in the generation of noisy MR images: radiofrequency (RF) inhomogeneity and impulse noise. In the frequency domain, (RF)-inhomogeneity changes the low-frequency harmonics, and random impulse noise distorts high frequencies. In the spatial domain RF discontinuity is a multiplicative distortion, while impulse noise is additive. Based on the features described above, it is generally accepted model [1], [2], [3] looks like:

$$(1) \quad g(x, y) = f(x, y) \cdot b(x, y) + N(x, y).$$

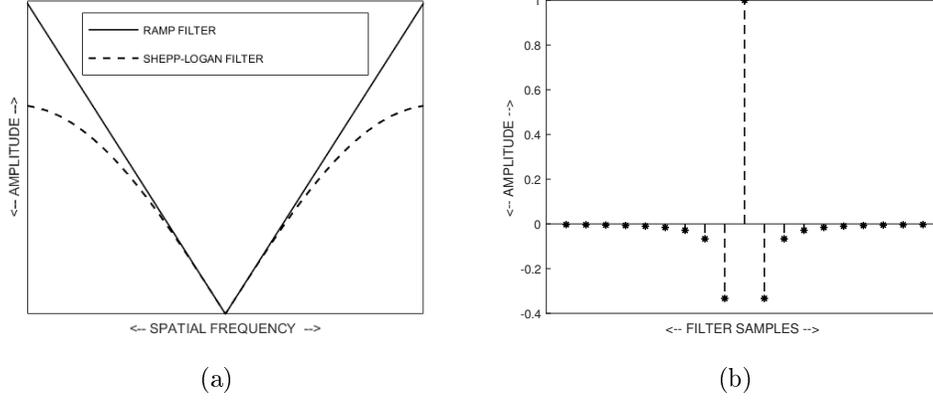


FIG. 1. Convolution Ramp Filter. In Fourier Space, filter has the form $|\rho|$. Maximum frequency must be truncated at some value r' . Filtering can be performed in Fourier (left) or spatial (right) domain.

The distorted image ($g(x, y)$) is obtained by the sum of noise ($N(x, y)$) and the original image ($f(x, y)$), multiplied by the RF inhomogeneity distortion ($b(x, y)$). Noise N can be suppressed using known noise removal filters such as anisotropic diffusion and others [4], [11]; Therefore, we assume that the problem of random impulse noise has already been solved and $g = f \cdot b$. By calculating the natural logarithm of both sides of the equation (1), we arrive at the additive model:

$$(2) \quad \ln(g) = \ln(f) + \ln(b)$$

Now the distortion $\ln(b)$ can be estimated by applying a low pass filter (LP), (*LowPass*) to $\ln(g)$:

$$(3) \quad \ln(b) = LP(\ln(g))$$

Substituting (3) into (2) we get:

$$(4) \quad \ln(g) = \ln(f^*) + LP(\ln(b))$$

Thus we obtain the following estimate of the undistorted logarithmic image:

$$(5) \quad \ln(f^*) = \ln(g) - LP(\ln(b))$$

To get the estimated reconstructed image, the $\exp()$ function applied to both sides of (5), yielding:

$$(6) \quad f^* = \exp(\ln(g) - LP(\ln(b)))$$

The filtering algorithm (1)-(5) can be implemented both in the image domain, and in the area of the Fourier transform. Unlike traditional displacement field removal algorithms based on signal models and a priori assumptions, in this article we focused on the ρ - filtering method, which does not use accurate modeling of signals and displacement fields and does not require significant parameter tuning [9], [10]. Convolution with a ramp filter can be performed in both the spatial domain and Fourier space.

The filter has the following form in the spatial domoin

$$(7) \quad \rho(n) = \begin{cases} \frac{1}{4\pi^2}, & \text{if } n = 0, \\ 0, & \text{if } n \text{ is even} \\ \frac{-1}{\pi^2 n^2 d^2}, & \text{if } n \text{ is odd,} \end{cases}$$

where d is the sample sampling step of the filter [10],[12].

We guess that the high-frequency filter would be helpful because the dark and light spots have a strong spectral component at which would be extinguished by a filter. The filter is sometimes called a ‘‘rho filter.’’ Unlike traditional displacement field removal algorithms based on signal models and a priori assumptions, the filtering ramp method does not require precise modeling of signals and displacement fields and does not require much parameter tuning.

The ramp filter is used in the filtered back projection method and is one of the main processing operators along with the Hilbert transform, which is mathematically justified in the theory of computational tomography. In our work we use this filter as a high-frequency filter since it is known from experience with the displacement field that this interference is low-frequency. Heuristic considerations for its use are motivated by the only a priori information about its smoothness and are confirmed by practice. Predict exact parameters cutting off low frequencies to isolate interference seems difficult at the moment. Therefore, we use a ramp filter, which preserves all frequencies except zero, thus acting more softly compared to bandpass filters, where suppression bands have to be sought selection method. This is caused by uncertainty in the nature of the displacement field, the parameters of which are unknown in advance. For example, the displacement field can be arbitrary (polynomial, exponential, linear, radially symmetric, etc.) and appear in any area of the image. Perhaps the ramp filter will find use in reconstructing the displacement field in a post-automatic mode, as is the case in the filtered back-projection method, where the search for better algorithms continues to improve the labor-intensive back-projection operator, but rho-filtering has long become a standard.

3. MODEL EXPERIMENTS

In the model experiments we used the Cameraman test image available in the MATLAB package and open image databases. This image has both large and small details and is often chosen for modeling in image recosntruction tasks. We have chosen two types of field bias. The first shades the image in columns linearly using the same formula for all image matrix columns, so that the bottom area of the image is heavily shaded, and the top part of the image is less shaded.

In Figure 2 (a) Test image of the size 256x256 is presented and column number 230 is highlighted. (b) Offset field - darkening with light top and increasing darkening in the lower part. (c) We model heterogeneity using the formula: $(c) = (a) \times (b)$, i.e. the image matrix of Fig. 2(c) is equal to the element-wise product of matrix Fig. 2 (a) and matrix in Fig.2 (b). (d) The result of applying the Ramp filter, in discrete form, known as the Shepp–Logan filter, is shown in image (c). There is an effect of general leveling of the background with approximately equal illumination of all areas of the test image without using information of type of distortion, in this case shown in Fig. 2(b).

In Fig. 3 (a) the columns number 230 of the test image in Fig. 3(a) and the unevenly darkened image by bias (Fig 3b) are presented; Fig. 3 (f) presents the

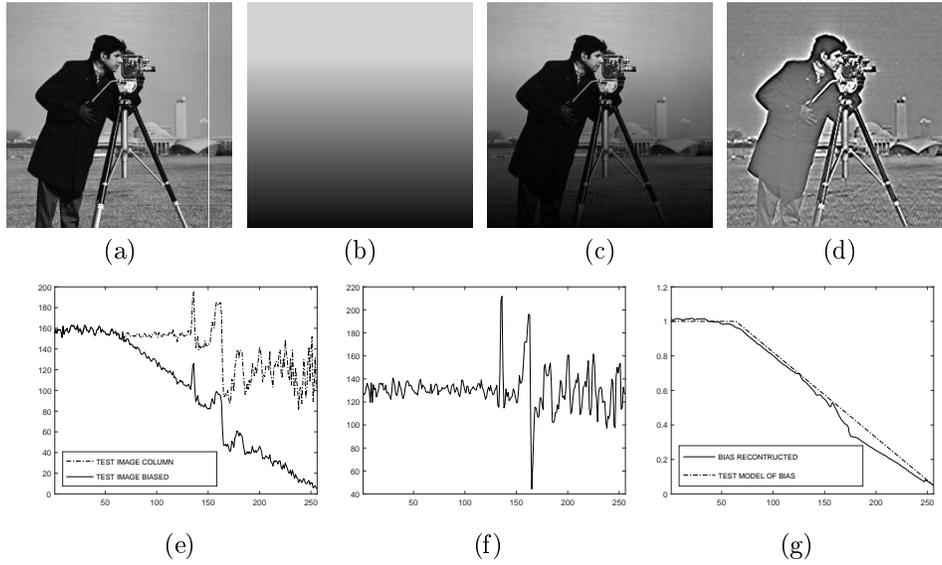


FIG. 2. (a) Original test image; (b) The image of linear bias field; (c) Corrupted image; (d) Reconstructed image; (e) Column number 230 of test image and corrupted by inhomogeneity; (f) Column 230 of filtered image; (g) Reconstructed bias field.

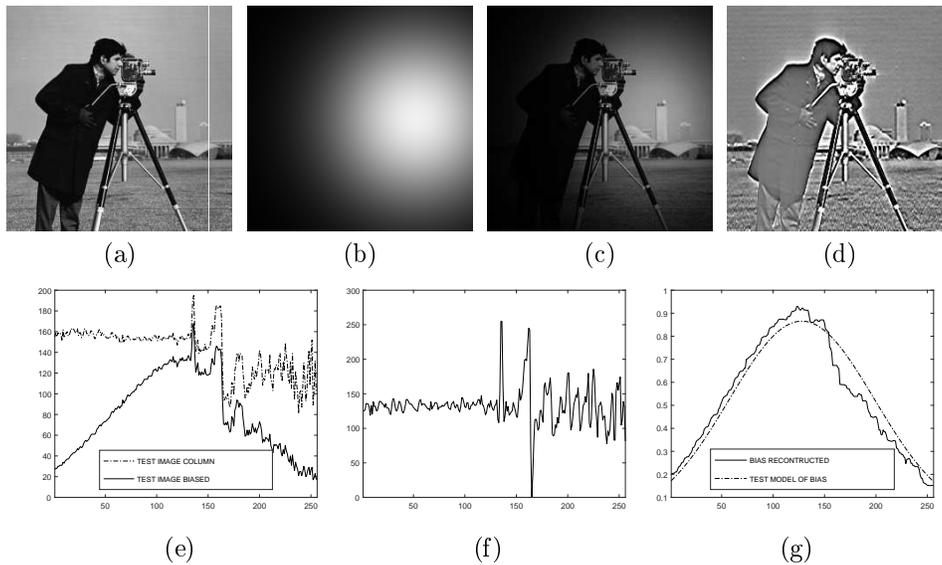


FIG. 3. (a) Test image; (b) Gaussian bias field; (c) Corrupted image multiplied by gaussian bias; (d) Filtered image; (e) Column number 230 of test image and corrupted by inhomogeneity; (f) Column 230 of filtered image; (g) Reconstructed bias field and test's column.

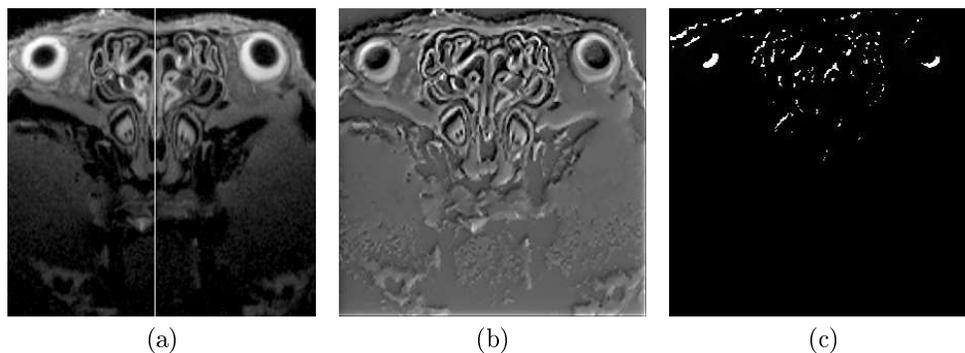


FIG. 4. (a) Original MRT scan of mouse. (b) The result of ramp filtering. (c) Bias field

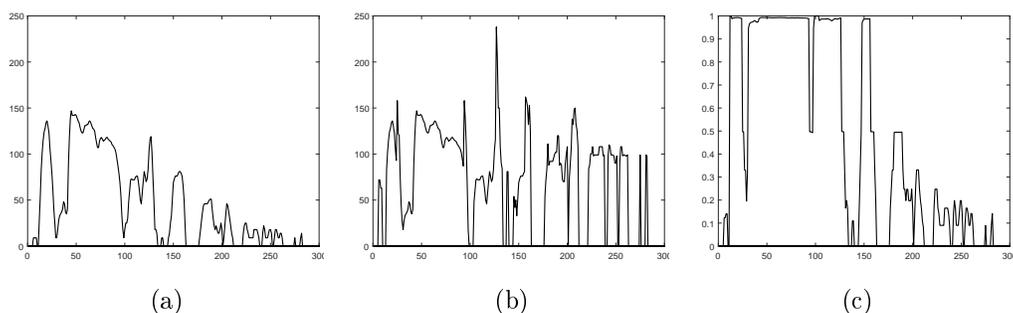


FIG. 5. (a) Original profile of central column of MRI mouse scan; (b) The result of inhomogeneity correction; (c) Bias filed constantly wise (in the left part) with nearly linear bias field in the right part.

column 230 of the image in Fig. 3 (d) – the result of filtering, where the background smoothing effect is noticeable. Fig. 3 (e) illustrates a comparison of the reconstruction of the multiplicative distortion obtained by element-by-element division of the image in Fig. 3(c) resulting the image matrix in Fig. 3(d). The displacement field—the darkening spreading radially from the center of brightness on the right side to the images—was able to be assessed visually quite accurately.

4. REAL-WORLD COMPUTER EXPERIMENT

The images (MRI tomograms of mouse head) are obtained on the biotomographic scanner BioSpec 117/16 USR. A methodology of the numerical experiment is the same as model computer tests .

In Figure 4. (a) 300x300 MRI image of a mouse head is presented. The offset field is a darkening with a light upper part of the image and a darkened lower part. In Figure 4 (b), the result of applying the Ramp filter, in discrete form known as the Shepp–Logan filter, to image (a) is shown. The effect of general leveling of the background with approximately the same illumination of all areas of a real MRI image is observed under conditions of an unknown type of distortion, in this partial case similar to quasi-linear behaviour.

5. CONCLUSION

Test model computer experiments and real reconstructions of MRI images allow us to conclude with cautious optimism that the ramp filter can be used in the task of background alignment. This is important for adequate use at the second stage of diagnostics, where corrected images with a leveled field of brightness can be used when applying methods and programs for recognizing abnormalities of the brain, joints and other organs. Aligning the bias will allow us to use the classical method of averages, as well as explore the possibilities of other approaches.

The model experiments carried out in this work achieve alignment of the linear and exponential (Gaussian blobs) field displacement functions. The purpose of the article is to develop an approximate method for removing image heterogeneity, with a minimum number of parameters for the operator. At the same time, we still need a method that really does a good job of leveling the background.

We found that a technological chain consisting of such components as rho filtering, sliding window smoothing, median filter and dynamic range stretching makes it possible to achieve equalization of the displacement field. The results obtained will allow further use of classification and recognition methods.

During MRI, due to factors such as non-uniform static magnetic field, eddy currents generated by the gradient field, and non-uniform sensitivity of the receiving coil, the MRI image will have non-uniform intensity. Correction of the displacement field is a component of a large technological chain, in which it plays the role of preprocessing for the subsequent successful application of methods of artificial intelligence, pattern recognition, classification, clustering and diagnostics.

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