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CORRECTION OF THE INHOMOGENEITY OF THE BRIGHTNESS OF MAGNETIC RESONANCE IMAGES

МАГНИТТІК-РЕЗОНАНСТЫҚ БЕЙНЕЛЕРДІҢ ЖАРЫҚТАНДЫРУЫНЫҢ БІРКЕЛКІ ЕМЕСТІГІН ТҮЗЕТУ

КОРРЕКЦИЯ НЕОДНОРОДНОСТИ ЯРКОСТЕЙ МАГНИТНО-РЕЗОНАНСНЫХ ИЗОБРАЖЕНИЙ

Аңдатпа. *Мақалада магниттік-резонанстық медициналық суреттердегі қарқындылықтың біркелкі еместігін түзету мәселесі қарастырылады. Бұл мәселе визуализация жабдықтарының ерекшеліктеріне байланысты, магниттік орамалардың өрісті тіркеуінің тұрақсыздығы және тағы басқа техникалық себептерден туындауы мүмкін. Ауытқу өрісі суреттердегі нысандарды танудың сандық әдістерін қолдануды және дұрыс диагноз қоюды қиындатады. Жұмыста бұрмалаушы төмен жиілікті жүйелік компонентті алу үшін жоғары жиілікті сүзгіні (ро-сүзгі немесе ramp filter) қолдану ұсынылды. Нәтижелер модельдік мысалмен және биомединциналық МРТ-суреттерді нақты өңдеумен бейнеленеді.*

Түйін сөздер: *магнитті-резонансты томография, қарқындылықтың біркелкі еместігін түзету, ауытқу өрісі,бейнелерді сүзу.*

Аннотация. *В статье рассматривается проблема коррекции неравномерности интенсивности на магнитно-резонансных изображениях. Эта проблема связана с особенностями оборудования для визуализации, может быть вызвана нестабильностью регистрации поля магнитными катушками и другими техническими причинами. Поле смещения затрудняет применение цифровых методов распознавания объектов на изображениях и постановку правильного диагноза. В работе предложено применять высокочастотную фильтрацию (ро-фильтр, или ramp filter) для снятия искажающей низкочастотной систематической компоненты. Результаты иллюстрируются модельным примером и реальной обработкой биомедицинских МРТ-снимков.*

Ключевые слова: *магнитно-резонансная томография, коррекция неоднородности яркости, поле смещения, фильтрация изображений*.

Abstract. *The article deals with the problem of correcting the uneven intensity in magnetic resonance images. This problem is related to the features of the visualization equipment, may be caused by the instability of the field registration by magnetic coils and other technical reasons. The displacement field makes it difficult to use digital* *methods for recognizing objects in images and making a correct diagnosis. In this paper, it is proposed to use high-frequency filtering (rho filter, or ramp filter) to remove the distorting low-frequency systematic component. The results are illustrated by a model example and real processing of biomedical MRI images.*

Keywords: *magnetic resonance imaging, correction of brightness inhomogeneity, displacement field, image filtering.*

Introduction. Images obtained in an MRI scanner are subject to noise. These interferences need to be removed, as they significantly complicate the further process of classification, clustering and diagnosis. Interference is divided into two large types - random and systematic. This division is rather conditional, there are other specific interferences, for example, anatomical and age characteristics of the patient, which are attributed to special interferences called patient noise.

The fight against random interference has a long history in the theory and practice of signal processing, starting with the invention of radio in the early twentieth century and then with the advent of systems for transmitting and detecting audio, visual and multispectral information. Statistical methods of suppression of random interference have been developed and widely used. The theory of random noise is rich in mathematical models and well developed. Within the framework of this theory and practice, methods and algorithms for image reconstruction of computational tomography, stabilization and optimization of noise-resistant approaches of the theory of weakly conditioned and incorrect problems of mathematical physics have been applied.

Usually, the noise in MR images is caused by fluctuations in the magnetic field in the coil [1]. Various inhomogeneities associated with MR images include noise, shading artifact, and partial volume effect. The inhomogeneity of intensity occurs due to the irregularity of radio frequencies during data collection, which leads to a shading artifact [2]. When several types of fabrics or classes occupy the same voxel or pixel, this is called the partial volume effect. High contrast and high spatial resolution are mandatory depending on the type of diagnostic tasks. A high signal-to-noise ratio is a prerequisite for image processing applications, since most algorithms are sensitive to noise. This highlights the need to apply noise filtering on MR images to preserve the fine details of the image.

The intensity value (from black to white) can vary within the same fabric. This is called the displacement 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 the inhomogeneity of the magnetic field of the MRI machine. If the offset field is not corrected, image processing algorithms (for example, segmentation and classification) will give incorrect results. Before segmentation or classification, a preprocessing stage is necessary to correct the influence of the displacement field [3].

In this paper, we consider the task of improving the visual quality of images obtained in MRI scanners and subject to systematic interference, in particular, field displacement, or brightness inhomogeneities in the images. The change in the visual brightness of an MRI image caused by the displacement field can sometimes reach 30% distortion of the normal image density, which causes great difficulties for doctors when evaluating images when making a clinical diagnosis, and has an adverse effect on the possibilities of digital processing of medical images, such as segmentation, registration and quantification.

Currently, the task of developing methods and means of eliminating noise and image artifacts is still practically valuable and relevant in tomography [4], [5], [6]. The paper considers the possibility of using a RO filter, or a high-frequency filter, widely known and used in tomography [7]. This filter corresponds to the model of image formation in MRI scanners. The results of numerical experiments on model data and real MRI images are presented.

Problem statement. Almost all researchers in their work use a similar formulation of the problem and a model of interference formation of MRI images [3]. Two main artifacts distort the MRI image: radio frequency (RF) heterogeneity and pulse noise. In the frequency domain, (RF) inhomogeneity changes low-frequency harmonics, and random pulse noise distorts high frequencies. In the spatial domain, RF inhomogeneity is a multiplicative distortion, and pulse noise is additive. Based on the features described above, we can write the following interference model:

$$g = f \times b + N, \qquad (1)$$

The distorted image (g) is obtained by the sum of noise (N) and the original image (f) multiplied by the distortion (offset) of the RF inhomogeneity (b). Noise can be suppressed using known noise removal filters, such as anisotropic diffusion in [8]; therefore, it is assumed that the problem of random pulse the problem has already been solved [12], [13]. Only images f and b will be considered.

The algorithm for solving the problem. Calculating the natural logarithm of both parts of equation (1), we obtain an additive model:

$$\ln(g) = \ln(f) + \ln(b). \qquad (2)$$

Now the distortion of ln(b) can be estimated by applying a low-pass filter (LP), (Low Pass) for ln(g):

$$\ln(b) = LP(\ln(g)). \qquad (3)$$

Substituting (3) into (2) we get:

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

Thus, we get the following estimate of the undistorted logarithmic image:

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

To get the intended restored image, the exp () function is applied to both parts (5):

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

Numerical calculations. The filtering algorithm (1) - (6) can be implemented both in the image domain and in the Fourier transform domain. Unlike traditional algorithms for removing displacement fields based on signal models and a priori assumptions, we pay attention to the p-filtering method, which does not use accurate modeling of signals and displacement fields and does not require significant parameter tuning (Fig.1). The result of its action is similar to the effect of background alignment and the results are shown in Fig. 2, Fig. 3 and Fig.4.

Po – the filter (ramp filter) has the following form in the spatial domain

$$\rho(n) = \left\{ \begin{array}{c} \dfrac{1}{4\pi^2}, n = 0 \\ 0, n = 2, 4, \dots \\ \dfrac{-1}{\pi^2 n^2 d^2}, n = 1, 3, \dots \end{array} \right\}. \qquad (7)$$

d – is the sampling step of the filter samples [7].

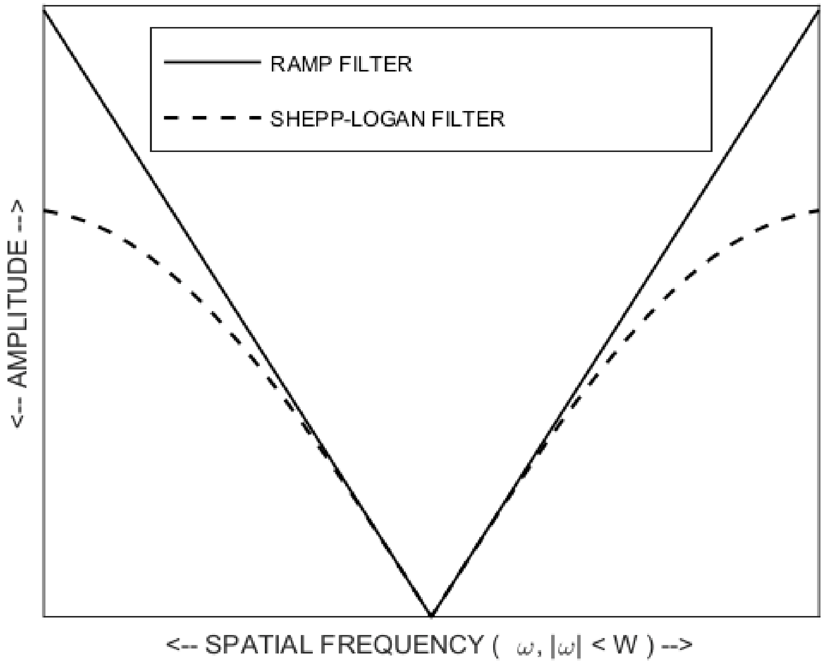


Figure 1. Ramp filter in the frequency domain, or in the Fourier space

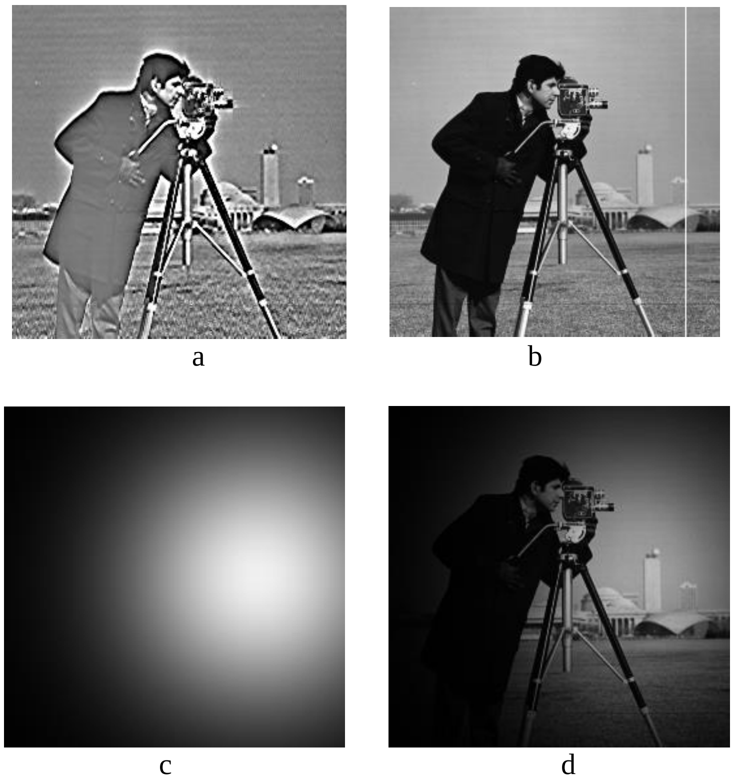
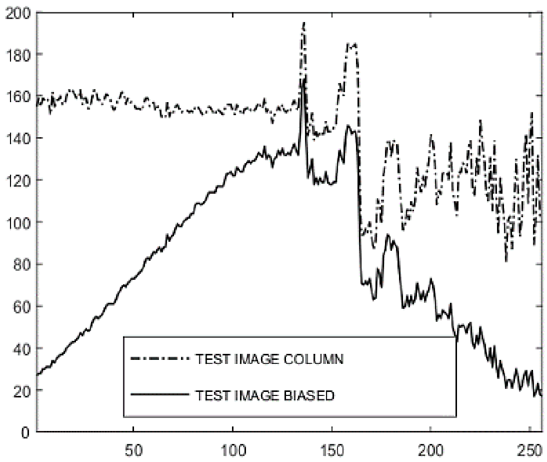


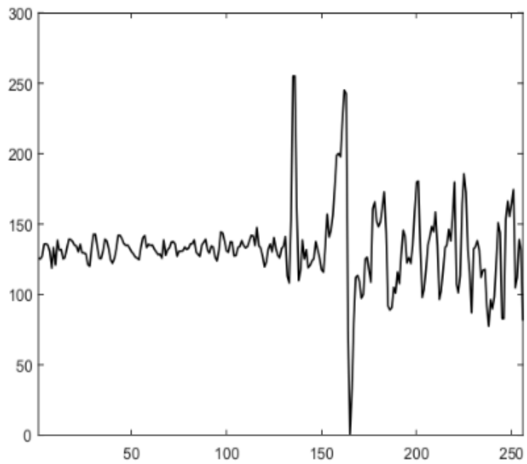
Figure 2. (a) The test image is 256x256; The column with the number 230 is highlighted.

(b) The offset field is darkening with a light central part of the spot on the right side (c)

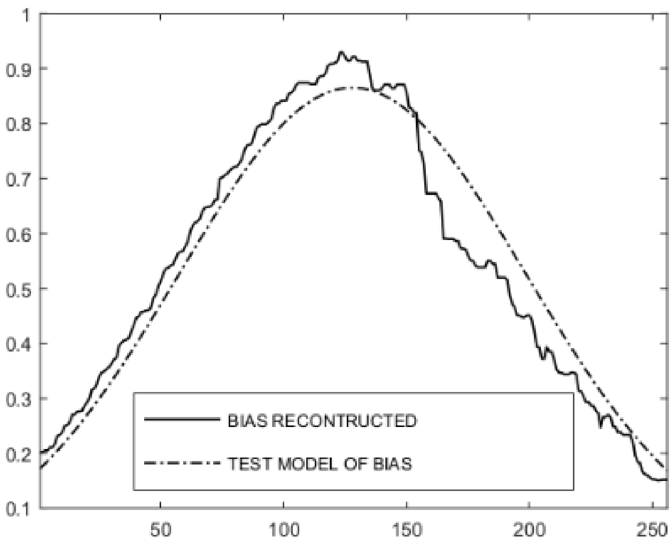
Modeling of inhomogeneity is performed according to the formula: (c) = (a)x(b), i.e., the image matrix of Figure 2 (c) is equal to the element product of matrix (a) by matrix (b). (d) The result of using a Ramp filter, in discrete form, known as the Schepp filter – Logan, to the image (c). There is an effect of general background alignment with approximately the same illumination of all areas of the test image under conditions of an unknown type of distortion, in this case shown in Fig. 2 (b).



a

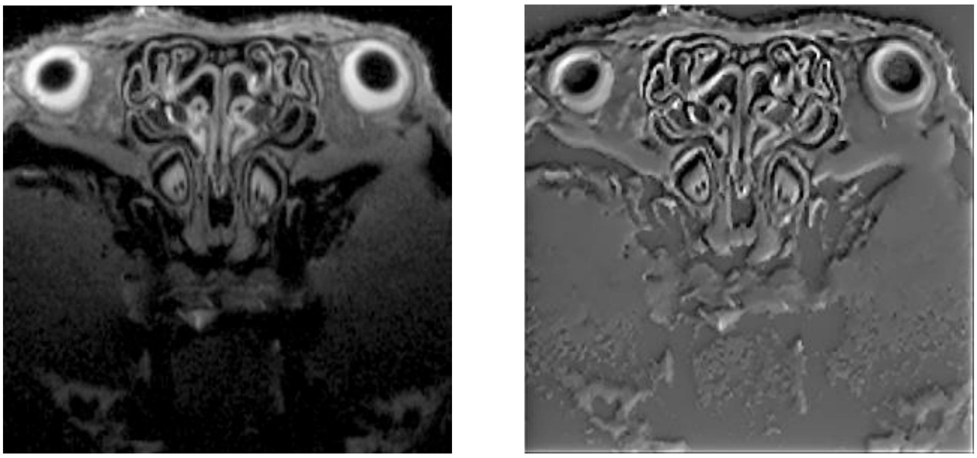


b



c

Figure 3. (a) Columns number 230 of the test image in Fig. 2 (a) and the unevenly darkened image in Fig. 2 (c); (b) Column 230 of the image in Fig. 2 (d) is the result of filtering, the effect of background alignment is noticeable. (c) Comparison of the reconstruction of the multiplicative distortion obtained by piecemeal division of the image in Figure 2 (c) by the image matrix in Figure 2 (d). The displacement field – the darkening spreading radially from the center of brightness in the right part to the sides, was able to estimate quite accurately



a b

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

The use of MRI in the diagnosis of the knee joint. Muscles, ligaments, cartilage and other articular structures are well visualized using MRI. In many cases, an MRI provides information about body structures that cannot be seen with an X-ray, ultrasound, or CT scan. Magnetic resonance imaging (MRI) of the knee is done to check the cause of unexplained knee pain or knee failure; looking for problems in the knee joint, such as arthritis, bone tumors, infections, or damage to the cartilage, menisci, ligaments, or tendons.

An MRI shows whether knee arthroscopy is necessary, and can also detect bone fractures when x-rays and other tests are inconclusive. MRI is performed more frequently than other tests to detect certain bone and joint problems [9], [10].

Osteoarthritis of the knee is one of the leading causes of chronic disability worldwide and represents a significant social and economic burden on health systems; therefore, it became necessary to develop methods for identifying patients at risk of developing osteoarthritis of the knee at an early stage. Standard MRI morphological sequences mainly focus on the changes seen in the advanced stages of osteoarthritis. However, they have low sensitivity to early subtle and potentially reversible changes in the degenerative process. In a review [11], the authors summarized the state of the art with respect to innovative quantitative MRI techniques that use objective and quantifiable biomarkers to detect subtle changes that occur in the early stages of osteoarthritis in the cartilage of the knee, before any morphological change occurs, and to identify potential effects on the brain. These new MRI imaging tools are believed to have great potential to improve the current standard of care, but further research is needed to remove limitations before these digital techniques can be reliably applied in research and clinical settings [14], [15], [16].

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 the dissertation, where corrected images with an equalized field of brightness can be used in the application of methods and programs for recognizing anomalies of the knee joint. We plan to use the K-means method, as well as explore the possibilities of other approaches.

The model experiments carried out in this paper achieve the alignment of the linear, quadratic and cubic field displacement functions. The purpose of the article is to develop an approximate method for removing the inhomogeneity of images, with a minimum number of parameters for the operator. At the same time, we need a method that aligns the background really well.

We found that the technological chain made up of components such as ro-filtering, sliding window smoothing, median filter and stretching of the dynamic range of brightness make it possible to obtain the alignment of the displacement field. The results obtained will allow further use of classification and recognition methods, for example, k-means.

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