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RESEARCH ARTICLE

The method of increasing the information content of microfocus X-ray images

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Abstract. A method for processing microfocus X-ray images is described. It is based on high-frequency filtration and morphological image processing, which increases the contrast of the X-ray details. One of the most informative X-ray techniques is microfocus X-ray. In some cases, microfocus X-ray images cannot be reliably analyzed due to the peculiarities of the shooting method. So, the main disadvantages of microfocus X-ray images are most often an uneven background, distorted brightness characteristics and the presence of noise. The proposed method for enhancing the contrast of fine image details is based on the idea of combining high-frequency filtering and morphological image processing. The method consists of the following steps: noise suppression in the image, high-frequency filtering, morphological image processing, obtaining the resulting image. As a result of applying the method, the brightness of the contours in the image is enhanced. In the resulting image, all objects will have double outlines. The method was tested in the processing of 50 chest radiographs of patients with various pathologies. Radiographs were performed at the Mariinsky Hospital of St. Petersburg using digital stationary and mobile X-ray machines. In most of the radiographs, it was possible to improve the images contrast, to highlight the objects boundaries. Besides, the method was applied in microfocus X-ray tomography to improve the information content of projection data and improve the reconstruction of the 3D image of the research object. In both the first and second cases, the method showed satisfactory results. The developed method makes it possible to significantly increase the information content of microfocus X-ray images. The obtained practical results make it possible to count on broad prospects for the method application, especially in microfocus X-ray.

Keywords: microfocus X-ray, digital image processing, image filtering

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НАУЧНАЯ СТАТЬЯ

Метод повышения информативности рентгеновских снимков

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Резюме. Описан основанный на высокочастотной фильтрации и морфологической обработке изображения метод обработки микрофокусных рентгеновских снимков, повышающий контраст деталей рентгенограммы. Одной из наиболее информативных методик рентгенографии является микрофокусная рентгенография. В ряде случаев микрофокусные рентгеновские изображения не могут быть достоверно проанализированы из-за особенностей способа съемки. Так, основными недостатками микрофокусных рентгеновских изображений чаще всего являются неравномерный фон, искаженные яркостные характеристики и наличие шумов. Предлагаемый метод повышения контраста мелких деталей изображения основан на идее сочетания высокочастотной фильтрации и морфологической обработки изображений. Метод состоит из следующих шагов: подавление шумов на изображении, высокочастотная фильтрация, морфологическая обработка изображения, получение результирующего изображения. В результате применения метода усиливается яркость контуров на изображении. На полученном изображении все объекты будут иметь двойные контуры. Метод был апробирован при обработке 50 рентгенограмм органов грудной клетки пациентов с разнообразной патологией. Рентгенограммы были выполнены в городской Мариинской больнице Санкт-Петербурга на цифровых стационарных и передвижных рентгеновских аппаратах. На большей части рентгенограмм удалось улучшить контраст снимков, выделить границы объектов. Также метод был применен в микрофокусной рентгеновской томографии для улучшения информативности проекционных данных и улучшения восстановления 3D-образа объекта исследования. Как для первого, так и для второго случаев метод показал удовлетворительные результаты. Разработанный метод позволяет существенно повысить информативность микрофокусных рентгеновских снимков. Полученные практические результаты позволяют рассчитывать на широкие перспективы применения метода, особенно в микрофокусной рентгенографии.

Ключевые слова: микрофокусная рентгенография, цифровая обработка изображений, фильтрация изображений

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INTRODUCTION

It is well known that X-ray radiography is a method for studying a research object using X-rays. One of the most informative techniques of its application is microfocus X-ray using radiation sources with focal spots less than 100 μm in size.

Using of these sources allows obtaining images with direct geometric (projection) magnification of the image by 5–20 times. Today, microfocus X-ray is widely used in medicine, in quality assessment of agricultural crops, and in nondestructive industrial control [1–6].

In some cases, however, microfocus X-ray images cannot be analyzed accurately due to the poor image quality. Thus, the main disadvantages of the microfocus X-ray images are most often the uneven background, distorted brightness characteristics, and the presence of noise. In some cases, the widely used contrast enhancement algorithms [4−10] may not allow increasing the contrast of X-ray images, while keeping the noise level at the acceptable level.

The developed method solves this problem by enhancing the contrast of the object structure details without a significant increase in the image noise.

METHOD FOR ENHANCING THE CONTRAST OF THE IMAGE FINE DETAILS

The proposed method for enhancing the contrast of the image fine details is based on the concept of combining high-pass filtering with morphological processing of images. The method consists of the following steps: suppression of the image noise, high-pass filtering, morphological processing of the image, and obtaining the resulting image.

In the paper, an adaptive median filter is used for noise reduction [4, 11].

High-pass filtering is performed by changing the Fourier image by multiplying it with the Gaussian high-pass filter (HPF) image.

The Gaussian filter is set in the frequency domain according to the following expression:

$$H(u,v) = 1 - \mathrm{e}^{-D^2(u,v)\,/\,2D_0^2},$$

where, D_0 stands for a given constant taking values greater than zero, while $D(u, v)$ is the distance in the frequency domain between point (u, v) and the origin of coordinates.

Thus, after this filter, low-frequency components are significantly attenuated in the image, while high-frequency components remain unchanged. In other words, the brightness of areas with slow changes in this parameter is significantly reduced, while the areas with sudden changes in brightness (object boundaries) remain unchanged.

The next step is morphological image processing [12]. A square-shaped structural element with the size of 9 pixels is used for morphologic expansion (dilatation). After this operation, the thickness of all objects in the image is increased by 2 pixels.

The expansion of image A by structural element B is denoted by $A \oplus B$ and is given by the following expression:

$$A \oplus B = \bigcup_{b \in B} A_b.$$

Structural element B is applied to all image pixels. Every time the origin of the structure element coordinates coincides with a single pixel, a carry and subsequent logical addition with corresponding image pixels is applied to the entire structural element.

In the next step, the image after HPF is multiplied by a constant (the value of the constant varies from 1.2 to 1.8, depending on the image brightness and contrast), and then the image obtained by morphological expansion and also multiplied by a constant is subtracted from it [13]. The resulting image is described by the following expression:

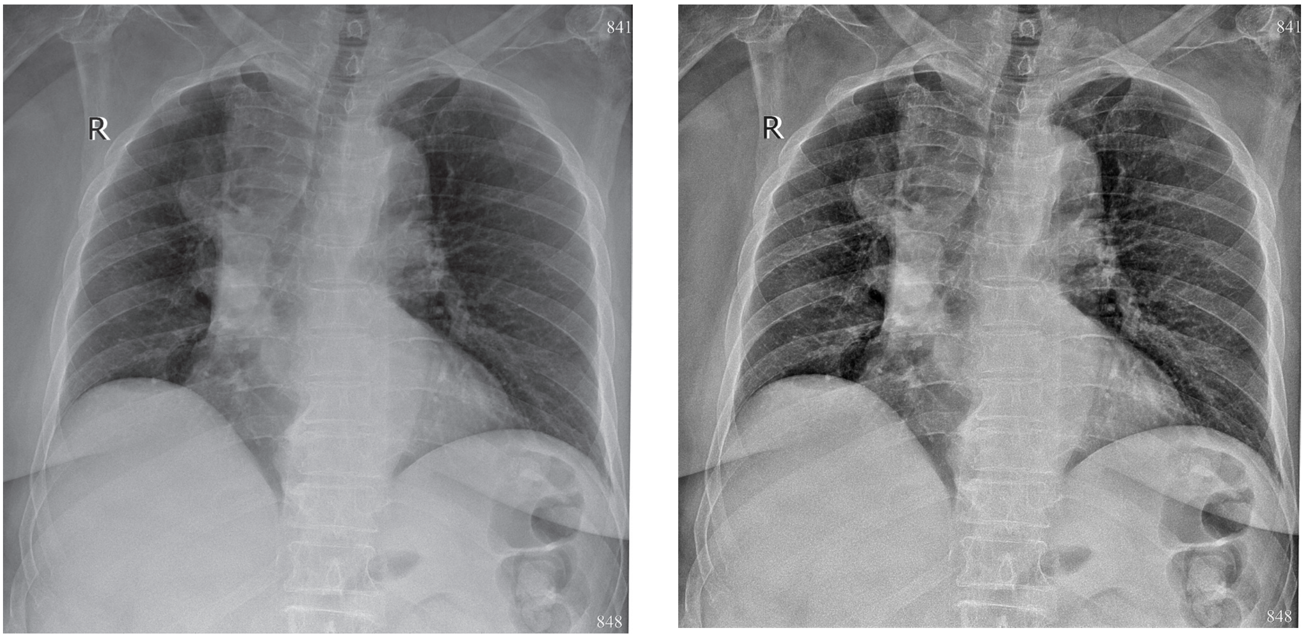
$$I_{\mathrm{res}} = I + I_{\mathrm{s}} \times C_1 - I_{\mathrm{m}} \times C_2,$$

where I is the original image; I_{s} is the image after high-pass filtering; C_1, C_2 are positive constants; I_{m} is the image obtained by morphological expansion.

This results in the brightness enhancement of contours in the image. In the resulting image, all objects have double contours; in case of the negative image (wherein denser structures have higher brightness), an inner contour which pixels have higher brightness than the object as well as an outer contour which pixels have lower brightness than the object appear [14, 15]. The algorithm for the positive image may be implemented in a similar way.

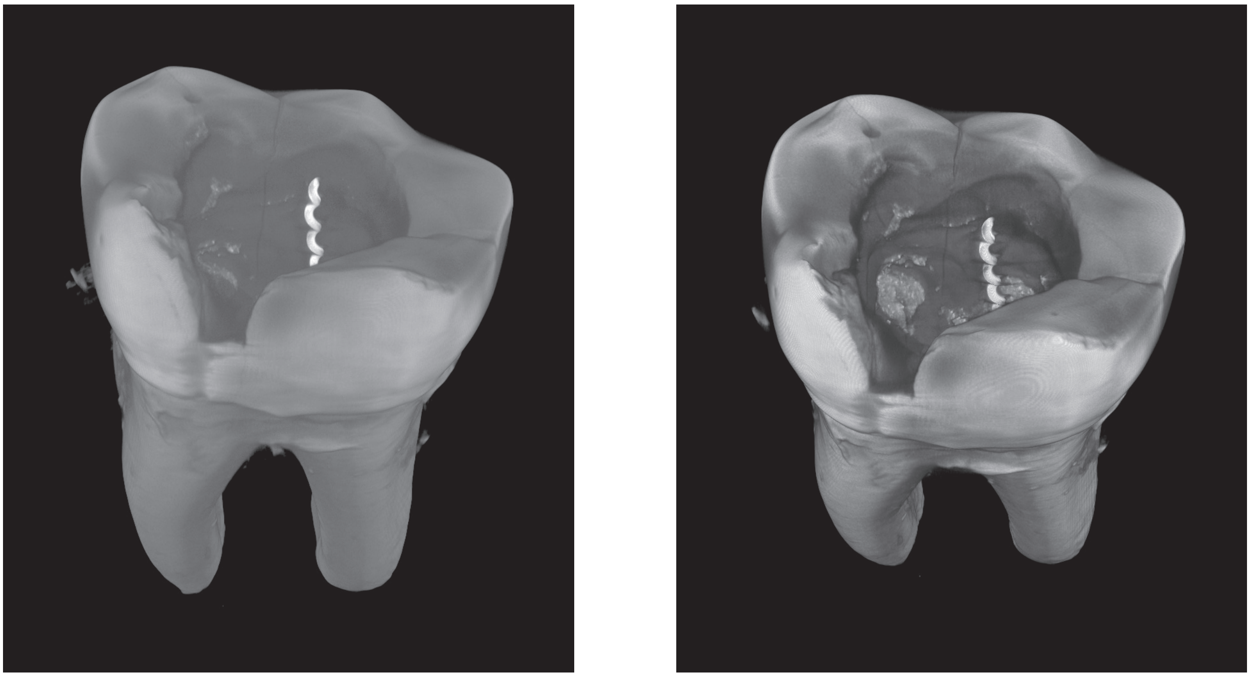
DISCUSSION

An example of the algorithm is illustrated in Fig. 1 showing chest X-rays before and after applying the method. The sharpness as well as the contrast of the image fine details enhance significantly. At the same time, there is no increase in the image noise, while the visual analysis becomes easier. Application of the proposed method allows detecting lung lesions more accurately.



(a) (b)

Fig. 1. Chest X-rays:
(a) before processing; (b) after processing



(a) (b)

Fig. 2. Recovered results of tomographic analysis of tooth specimens:
(a) before processing; (b) after processing

The method has been tested in processing 50 chest X-rays (CXRs) of patients with multiple pathologies. The CXRs have been done at the Mariinsky Municipal Hospital (Saint Petersburg, Russia) using the digital stationary and mobile X-ray machines. Digital processing of a series of X-ray images showing the extensive inhomogeneous opacification of both lungs by this method allows focalizing and identifying the following: circumscribed areas of the increased transparency, inhomogeneous thickening of the distorted lung pattern due to interstitial elements, inhomogeneous infiltration in lung tissue, and pleural effusion boundaries. In a series of X-ray images showing focal lung disease, the method allows visualizing clearly the boundaries of low-intensity foci identifying barely visible destruction sites in them. In CXRs of patients with COVID pneumonia, the postprocessing enhances the contrast and boundaries of polysegmental different-sized foci and infiltration sites. In CRSs of patients with traumatic injury to the chest organs, the method allows identifying barely visible signs of rib fracture, pneumomediastinum, and mantle pneumothorax.

The method has also been used in microfocus X-ray tomography for increasing the information content of projective data as well as for improving the recovery of the 3D image of the research object. The method gives satisfactory results for both the first and the second cases. The slices obtained with the use of the MRCT-04 microfocus X-ray tomograph in studying human tooth specimens have been used for analyzing tomographic data. The results of recovery without using the developed method are shown in Fig. 2a, while those of the recovery using the method are presented in Fig. 2b.

CONCLUSIONS

In the paper, the algorithmic support for the method of increasing the information content of X-ray images, first of all, the contrast, is considered. The method allows increasing the detection of low-contrast and fine details of the research object structure in its image significantly in a number of application areas for X-ray radiography.

Practical results allow expecting ample opportunities for applying the method, especially to microfocus X-ray radiography.

Authors' contribution. All authors equally contributed to the research work.

REFERENCES

1 Arkhipov M.V., Priyatkin N.S., Gusakova L.P., et al. X-ray computer methods for studying the structural integrity of seeds and their importance in modern seed science. *Tech. Phys*. 2019;64(4):582−592. https://doi.org/10.1134/S1063784219040030
2. Potrakhov N.N., Gryaznov A.Yu., Zhamova K.K., Bessonov V.B., Obodovskii A.V., Staroverov N.E., Kholopova E.D. Microfocus X-ray diagnostics in medicine: physical and technical features and modern device. *Biotekhnosfera*. 2015;5(41):55−63 (in Russ.).
3. Staroverov N.E., Gryaznov A.Y., Kholopova E.D. Digital x-ray image processing with using adaptive histogram equalization and adaptive background correction. *Biomedicine Radioengineering = Biomeditsinskaya radioelectronika*. 2018;5:56−58.
4. Staroverov N.E., Kholopova E.D., Gryaznov A.Yu., Zhamova K.K. The methods of processing of microfocus X-ray images. In: *2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering* (*EIConRus*). 2017, p. 745−747. https://doi.org/10.1109/EIConRus.2017.7910665
5. Mazurov A.I., Potrakhov N.N. Possibilities and limitations of microfocus radiography in medicine. *Biotekhnosfera*. 2010;4(10):20−23 (in Russ).
6. Gryaznov A.Yu., Potrakhov E.N., Potrakhov N.N. Portable unit for X-ray express quality food products. *Biotekhnosfera*. 2009;6(6):26−28 (in Russ.).
7. Stark J.A. Adaptive image contrast enhancement using generalizations of histogram equalization. *IEEE Trans. Image Process*. 2000;9(5):889−896. https://doi.org/10.1109/83.841534

СПИСОК ЛИТЕРАТУРЫ

1. Arkhipov M.V., Priyatkin N.S., Gusakova L.P., et al. X-ray computer methods for studying the structural integrity of seeds and their importance in modern seed science. *Tech. Phys*. 2019;64(4):582−592. https://doi.org/10.1134/S1063784219040030
2. Потрахов Н.Н., Грязнов А.Ю., Жамова К.К., Бессонов В.Б., Ободовский А.В., Староверов Н.Е., Холопова Е.Д. Микрофокусная рентгенография в медицине: физико-технические особенности и современные средства рентгенодиагностики. *Биотехносфера*. 2015;5(41):55−63.
3. Staroverov N.E., Gryaznov A.Y., Kholopova E.D. Digital x-ray image processing with using adaptive histogram equalization and adaptive background correction. *Biomedicine Radioengineering = Biomeditsinskaya radioelectronika*. 2018;5:56−58.
4. Staroverov N.E., Kholopova E.D., Gryaznov A.Yu., Zhamova K.K. The methods of processing of microfocus X-ray images. In: *2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*. 2017, p. 745−747. https://doi.org/10.1109/EIConRus.2017.7910665
5. Мазуров А.И., Потрахов Н.Н. Возможности и ограничения микрофокусной рентгенографии в медицине. *Биотехносфера*. 2010;4(10):20−23.
6. Грязнов А.Ю., Потрахов Е.Н., Потрахов Н.Н. Портативная установка для рентгеновского экспресс-контроля качества пищевой продукции. *Биотехносфера*. 2009;6(6):26−28.
7. Stark J.A. Adaptive image contrast enhancement using generalizations of histogram equalization. *IEEE Trans. Image Process*. 2000;9(5):889−896. https://doi.org/10.1109/83.841534

8. Mukhopadhyay S., Chanda B. A multiscale morphological approach to local contrast enhancement. *Signal Process*. 2000;80(4):685–696. https://doi.org/10.1016/S0165-1684(99)00161-9
9. Parihar A.S., Verma O.P., Khanna C. Fuzzy-contextual contrast enhancement. *IEEE Trans. Image Process*. 2017;26(4):1810–1819. https://doi.org/10.1109/TIP.2017.2665975
10. Pogany A., Gao D., Wilkins S.W. Contrast and resolution in imaging with a microfocus x-ray source. *Rev. Sci. Instrum*. 1997;68(7):2774–2782. https://doi.org/10.1063/1.1148194
11. Pizer S.M., Amburn E.P., Austin J.D., et al. Adaptive histogram equalization and its variations. *Comput. Vis. Graph. Image Process*. 1987;39(3):355–368. https://doi.org/10.1016/S0734-189X(87)80186-X
12. Vincent L. Morphological grayscale reconstructions in image analysis: Applications and efficient algorithms. *IEEE Trans. Image Process*. 1993;2(2):176–201. https://doi.org/10.1109/83.217222
13. Gryaznov A.Yu., Guk K.K., Staroverov N.E., Kholopova E.D. Method for sharpening and contrasting details of X-ray images. *Fizicheskie osnovy priborostroeniya = Physical Bases of Instrumentation*. 2019;8(4(34)):34–37 (in Russ.). https://doi.org/10.25210/jfop-1904-034037
14. Staroverov N.E., Gryaznov A.Yu., Potrakhov N.N., Kholopova E.D., Guk K.K. New methods of digital processing of microfocus X-ray images. *Biomed. Eng.* 2019;52:435–438. https://doi.org/10.1007/s10527-019-09864-6
[Staroverov N.E., Gryaznov A.Yu., Potrakhov N.N., Kholopova E.D., Guk K.K. New methods of digital processing of microfocus X-ray images. *Meditsinskaya tekhnika*. 2018;52(6):53–55 (in Russ.).]
15. Staroverov N.E., Gryaznov A.Y., Kholopova E.D., Guk K.K. Microelectronic devices digital X-ray image processing method development. *J. Phys.: Conf. Ser.* 2018;967(1):012016. https://doi.org/10.1088/1742-6596/967/1/012016

8. Mukhopadhyay S., Chanda B. A multiscale morphological approach to local contrast enhancement. *Signal Process*. 2000;80(4):685–696. https://doi.org/10.1016/S0165-1684(99)00161-9
9. Parihar A.S., Verma O.P., Khanna C. Fuzzy-contextual contrast enhancement. *IEEE Trans. Image Process*. 2017;26(4):1810–1819. https://doi.org/10.1109/TIP.2017.2665975
10. Pogany A., Gao D., Wilkins S.W. Contrast and resolution in imaging with a microfocus x-ray source. *Rev. Sci. Instrum*. 1997;68(7):2774–2782. https://doi.org/10.1063/1.1148194
11. Pizer S.M., Amburn E.P., Austin J.D., et al. Adaptive histogram equalization and its variations. *Comput. Vis. Graph. Image Process*. 1987;39(3):355–368. https://doi.org/10.1016/S0734-189X(87)80186-X
12. Vincent L. Morphological grayscale reconstructions in image analysis: Applications and efficient algorithms. *IEEE Trans. Image Process*. 1993;2(2):176–201. https://doi.org/10.1109/83.217222
13. Грязнов А.Ю., Гук К.К., Староверов Н.Е., Холопова Е.Д. Метод повышения резкости и контрастности деталей рентгеновских изображений. *Физические основы приборостроения*. 2019;8(4(34)):34–37. https://doi.org/10.25210/jfop-1904-034037
14. Староверов Н.Е., Грязнов А.Ю., Потрахов Н.Н., Холопова Е.Д., Гук К.К. Новые методы цифровой обработки микрофокусных рентгеновских изображений. *Медицинская техника*. 2018;52(6):53–55.
15. Staroverov N.E., Gryaznov A.Y., Kholopova E.D., Guk K.K. Microelectronic devices digital X-ray image processing method development. *J. Phys.: Conf. Ser.* 2018;967(1):012016. https://doi.org/10.1088/1742-6596/967/1/012016

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