Analysis and segmentation of low contrast images based on multiparameter topological resonance imaging method

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Abstract

A new method of low contrast images analysis and segmentation is outlined. The one has providers high sensitivity to detection of visually invisible low contrast areas and simultaneous stability to influence of local small brightness variations. . On base our experimental investigations it had been established importance virtual group-delay function (i.e. the new information characteristic) for tasks detection and segmentation low contrast fuzzy regions of analyzed images. Experiments were made with examples of real low contrast images: X-ray CT ,digital mammograms, and geophysical field images. For all situations there were obtained very good practical results.

1. INTRODUCTION

A problem detection and segmentation of low contrast regions of analyzed images is one of the most important and difficult in areas of remote sensing, medical diagnostics and nondestructive testing. There were used different approaches: brightness gamma correction, histogram equalization, pseudocolor coding, multiresolution analysis, hidden Markov random field method [1], fuzzy and self-organizing map clustering methods [2]. But all these methods for a lot of situations do not give positive results because the main problem of ones is necessity combination of visual analysis high sensitivity with simultaneous stability of segmentation procedure to small local brightness variations. For solving of these problems in application to low contrast image analysis there were develop some new approaches: virtual holographic interferometry imaging method [3] and method of virtual pseudocoherent complex wave field controlled inverse propagation [4].These methods are stable to influence of measurement noise and have high sensitivity to low contrast fuzzy areas detection, but the ones sometimes do not provide sufficient stability of segmentation procedure. In our paper [5] it was outlined a new approach, called as a multiparameter space-resonance imaging method. But the one was developed only for multispectral image analysis. As result, it does not give possibility for processing of ordinary images on base of that method.

The main aim of this paper is demonstration information possibilities of a new method low contrast image analysis. The one is possible to consider as generalization of the space-resonance imaging method on case of ordinary low contrast image analysis.

2. METHOD

For more detail analysis of the new approach peculiarities it is expedient to compare ones with algorithm of the space-resonance imaging method.

2.1 Space-resonance imaging method (SRIM)

The one consists of the following steps.

Virtual holographic interferometry transformation (VHIT) of all analyzed multispectral images. This step is needed for increasing of common analysis sensitivity. A mathematical description of VHIT is based on general principles of computer vision methods and presents nonlinear transformation on base superposition of an object virtual reflected coherent optical wave (for selected meaning of wavelength) with a reference one.

To every pixel (x, y) of analyzed multispectral image corresponds a virtual nonrecursive digital filter with transfer function

$$H_{(x,y)}(z) = H(z) = 1 + c_1 z^{-1} + ... + c_N z^{-N} \quad , \qquad (1)$$

where z is an operator of the Z - transformation; N is the number bands of analyzed multispectral image; c_k $(k = 1,..., N)$ is a complex brightness sequence, which is corresponded to pixel (x, y). A spectral characteristic of digital filter can be obtained from equation (1) on base substitution $z = \exp(j2\pi f)$, i.e.

$$H_{(x,y)}(f) = |H(f)| e^{-j\varphi(f)} , \qquad (2)$$

where $|H(f)|$ is a magnitude-frequency characteristic of digital filter and $\varphi(f)$ is a phase-frequency one. In our experiments these characteristics were calculated for

256 frequencies , because it corresponded to number gray levels of used PC monitor.

Because $\varphi(f)$ is defined only on interval $[-\pi \div \pi]$, it is much more convenient to analyze a continuous group delay function. The one is calculated on base phase function $\varphi(f)$ as

$$\tau(f) = -\frac{1}{2\pi}\frac{d\varphi(f)}{df}. \quad (3)$$

The main idea of SRIM is a direct analogy between $|H(f)|$ and $\tau(f)$ characteristics, and classical method of resonance measurements. It means, that information features of SRIM needed for analysis and segmentation low contrast multispectral image are extremum points of $|H(f)|$ and $\tau(f)$ characteristics.

We used eight features:

Visualization of magnitude-space resonance characteristics $p_{(v,y)} = \max|H_{(x,y)}(f)|$ and $f_{p(x,y)}$ corresponds to $p_{(x,y)}$.

Visualization of magnitude-space antiresonance characteristics $q_{(v,y)} = \min|H_{(x,y)}(f)|$ and $f_{q(x,y)}$ corresponds to $q_{(x,y)}$.

Visualization of group-delay resonance characteristics $pp_{(x,y)} = \max\{\tau(f)\}$ and $f_{pp(x,y)}$ corresponds to $pp_{(x,y)}$.

Visualization of group-delay antiresonance characteristics $qq_{(x,y)} = \min\{\tau(f)\}$ and $f_{qq(x,y)}$ corresponds to $qq_{(x,y)}$.

As it had been shown in paper [5], the method gives significant advantage in increasing sensitivity and space resolving power of low contrast multispectral image analysis in compare with known methods.

2.2 Topological resonance imaging method

The RSIM has two main practical problems: 1) it may be used only for processing of multispectral (multiparameter) images, i.e. the one can not be directly used for processing of ordinary images; 2) same difficulty presents and rational choice of virtual optical wavelength .

The new approach, named as topological resonance imaging method (TRIM), do not has these defects. In contradistinction to SRIM, the TRIM concludes the next different steps:

Forming moving window of size (3x3), which is scanning analyzed ordinary image. It allows to each pixel of image with coordinates, as example, (m,n) to compare a vector of coefficients $\bar{a}$

$$\bar{a} = \bar{a}(m,n) = [I(m-k, n-l); k,l = -1,0,1] \ ; \quad (4)$$

where $I(m,n)$ is brightness of analyzed image in point with coordinates (m,n).

To each vector $\bar{a}$ there is compare a complex analog $\bar{b}$, i.e.

$$\bar{b} = \bar{a} + j\,gradient(\bar{a}). \quad (5)$$

This operation promotes to increasing of further analysis sensitivity into the bounds of TRIM.

To each pixel (m,n) of analyzed image I there is compare a nonrecursive digital filter with transfer function $H(z)$ of nine degree with complex coefficients $\bar{b}_{(m,n)} = (b_1,...,b_9)$, i.e.

$$H(z) = 1 + b_1 z + ... + b_9 z^9 \ , \quad (6)$$

where z is an operator of the $Z-$transformation which characterized the order of complex coefficients sequence.

The further operations are similarity to the SRIM, but, in general, the TRIM has three differs from the SRIM:

1) The TRIM can be applied to ordinary low contrast image analysis and segmentation.

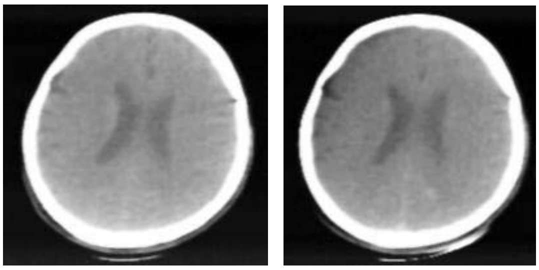
2) Using gradient mapping (5), instead of VHIT as in SRIM, providers simple meaning of complex transformation (5) and this gives, as it will be shown below, stability of segmentation procedure to influence small local brightness variations of analyzed images.

3) Resonance properties of spectral characteristic $H(z = -j2\pi f) = |H(f)|\exp(-j\phi(f))$ will be depended not only on values of complex coefficients $b_k, k = 1,...,9$, but and on mutual positions of the ones, i.e. actually on local topology of analyzed image. Namely this fact stipulated using name of the new method as the topological resonance imaging one.

3. EXPERIMENTAL INVESTIGATIONS

3.1 X-ray CT image processing

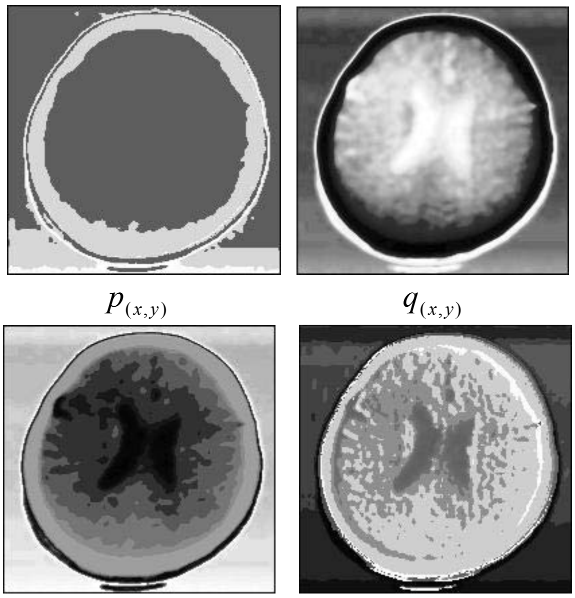
In fig.1 two low contrast medical images are presented. On the first of them (fig.1a) the gematoma is seen, but the area of its influence is invisible. The second image (fig.1b) was recorded after introduction to the same person a radiological contrast substance. It is seen that this operation gives a little real positive results for improvement of diagnostics.



a b

Fig.1. X-ray CT brain image: a – an original image; b – result after introduction of radiological contrast substance.

In fig.2 and fig.3 all eight characteristics of the TRIM in application to fig.1a are presented.



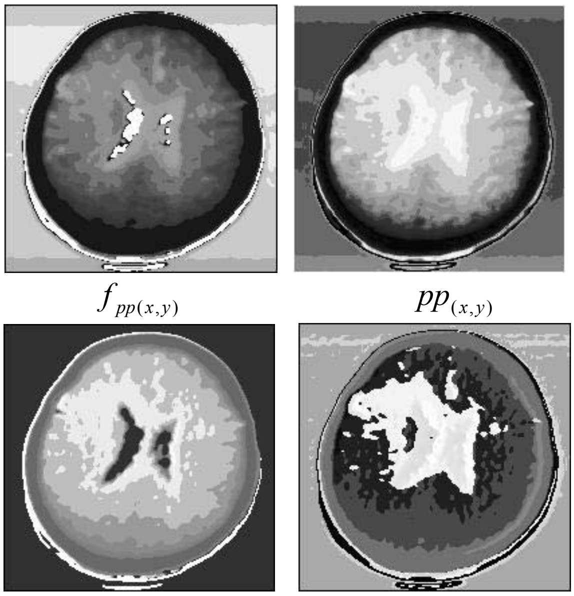
$p_{(x,y)}$ $q_{(x,y)}$

$f_{p(x,y)}$ $f_{q(x,y)}$

Fig.2. Magnitude-space resonance characteristics of original image (fig.1a)

From consideration of obtained results it is possible to make some important conclusions:

1. Magnitude-resonance characteristic $p_{(x,y)}$ is stable to influence of local brightness variations.
2. Anti-resonance frequency characteristic $f_{q(x,y)}$ is stable and sensitive to detection of the brain lesion area.



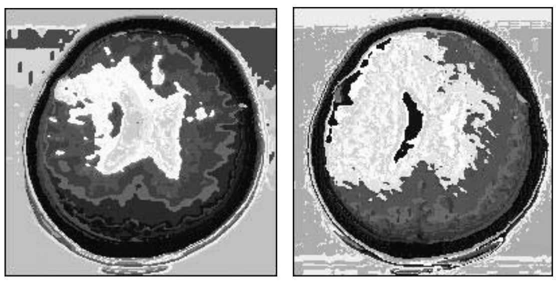
$f_{pp(x,y)}$ $pp_{(x,y)}$

$qq_{(x,y)}$ $f_{qq(x,y)}$

Fig.3. Group-delay resonance characteristics of original image (fig.1a).

3. Three group-delay resonance characteristics ($f_{pp(x,y)}$, $f_{qq(x,y)}$ and $qq_{(x,y)}$) are information for tasks of medical diagnostics. Especially impressive result to display $f_{qq(x,y)}$ characteristic from point of view localization of the lesion area.
4. As it is seen, there is no necessity for introduction of radiological contrast substance, because new information characteristics provide sufficient sensitivity to detection and segmentation all lesion areas.

Additional possibilities for further diagnostics improvement give a fusion of all eight TRIM characteristics into one resulting image on base using of self-organizing Kohonen maps. Obtained results are shown in fig.4. By the comparison of fig.4 with fig.1. it is especially to see all information advantages of the new method.



a b

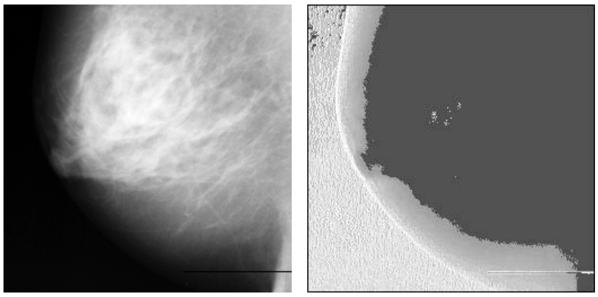
Fig.4. Results fusion TRIM characteristics into one image on base using of Kohonen self-organizing maps: a

– for original image (fig.1a); b - for image with contrast substance (fig.1b).

3.2 Mammogram image processing

Cancer breast diagnostics is basing on mammogram image analysis. Difficulties of such analysis are well known, and mainly connected with problems detection and classification of microcalcites at a more early stage. For this reason, investigation information possibilities of the new method on example of mammogram image presents particular interest.

Original image is shown in fig.5a. All known methods of mammogram image analysis had been used, but no one of them did not allow to detect invisible microcalcites. Magnitude-space resonance characteristics of the TRIM also did not solve this task, but using group-delay resonance characteristics of the one gave very good and unexpected result.



a b

Fig.5 Microcalcifications detection on base TRIM: a – original image; b - $f_{pp(x,y)}$.

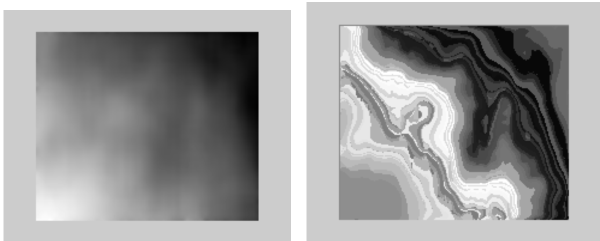
As it can be seen from consideration results in fig.5, using of group-delay resonance characteristics gave possibility to detect all invisible microcalcifications. In general, it allows to make one important conclusion: in practical situation it is possible to tune parameters of the TRIM such way, that some group-delay resonance characteristic will be sensitive to microcalcifications, and simultaneously the one will not be sensitive to space local brightness variations of surrounding normal tissue.

3.3Geophysical field image analysis

For a lot of situation, geophysical field image is presented a typical example of very low contrast one. The main problem of that image analysis is a selection of its anomalous areas or points, because there is nothing a priori to know about parameters the ones.

Two geophysical fields of different physical nature are shown in fig.6a,b. All measurements of the ones were made for one and the same area of Earth.

As it can be seen from consideration of obtained results in fig.6c,d, application of the TRIM allows to detect a lot of potentially important particularities of analyzed geophysical fields.



a b

Fig.6. Results fusion TRIM characteristics into one image on base using of Kohonen self-organizing map: a -– an original image of gravitation field; b -– obtained result.

4. CONCLUSIONS

1. Topological resonance imaging method presents a new tool for multiparameter analysis and fusion of ordinary low contrast images
2. The new method is unsupervised one and provides significant increasing in sensitivity and space resolving power of low contrast image segmentation.
3. The main result of our investigations is discovery information importance of the group-delay resonance characteristic for tasks of low contrast image analysis and segmentation.
4. The method has significant potential for its further information possibilities increasing on base optimal choice of the size and form of moving window.

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