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ANALYSIS OF MEDICAL IMAGES IN FREQUENCY AND SPACE-FREQUENCY DOMAINS

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1. Introduction

Relevancy of the work. Image processing is quickly developing branch of digital signal processing. Images as a convenient and human friendly information form are used in many fields of life and science including medicine. One of the aims of modern medicine are non-invasive ways of diagnostics. There are number of non-invasive methods used in medical diagnostics; among them methods with visualization capability are most relevant. These methods use ultrasound, X-rays either Nuclear Magnetic Resonance to visualize interior of human body. Methods with visualization capabilities are most important in the diagnostics of diseases of human brain. Diseases of the brain mostly develop as a result of contractions (stenosis) and dilatations (aneurysms) of blood vessels. When blood vessels have lesions then probability of brain stroke increases because of thrombosis either internal spill of blood. After the stroke has occurred it is essential to describe precisely the diagnosis. The first stage of diagnosis is localization which may be performed by Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). In the early stages of vessels diseases there is relevant Magnetic Resonance Angiography (MRA) diagnostics which allows to evaluate the lesions of blood vessels. The problem of stroke diagnosis encompasses visual analysis of multiple slices performed by trained radiology personnel. If there are signs of regions of diseases then it is necessary to evaluate its numerical characteristics that are critical in selection of proper treatment.

Images of CT and MRI are grayscale images and usually they are analyzed by radiologists on display either on transparency screen. Then objects in images are recognized by their properties like average luminosity of the region, localization, shape, dimensions, etc. The process of visual recognition is affected by many factors. The totality of factors determines uncertainties of diagnostics. More and more often there are used software utilities in the analysis of images which help to lower the uncertainties and speed up the analysis time. Computer software in comparison with traditional visual analysis has an advantage of more precise evaluation and calculation of image characteristics using full dynamic range and resolution of images. Applications of software cover automatic analysis of images, calculation of areas and volumes of lesions, determination of optimal treatment, planning or assisting in chirurgical operation, training of radiologists.

Formulation of the problem. In image processing and analysis there are used various mathematical approaches. Generally methods may be divided by the domain of processing into spatial methods and methods with coordinate transforms. The most important and actual are spectral transforms which convert image (spatial) domain into frequency or space-frequency domains. These kinds of transforms give an advantage in the analysis and evaluation of periodicity and stationarity of signals. Applications of spectral transforms in the processing of CT and MRI images are not investigated widely; there are open questions on how spectra may be adopted to enhance or segment the regions of stroke diseases.

In the doctoral dissertation there is analyzed the problem of medical image processing in the frequency and joint space-frequency domains with the aim of evaluation of capabilities of spectral methods. The solution of problem is based on developing of techniques and algorithms for detection of regions of diseases or other specific regions of images.

The aim and tasks of the work. The aim of the work is investigation of medical image processing and analysis using frequency and joint space-frequency domains and developing of algorithms suitable for segmentation of regions of diseases. The following tasks must be solved to achieve the purpose:

1. investigate particularities of spectra of CT images containing the region of ischemic brain stroke;
2. propose techniques for segmentation of region of ischemic brain stroke by using analysis of CT images in frequency and space-frequency domains;
3. create corresponding algorithms and experimentally investigate properties of the techniques;
4. create a technique and corresponding algorithm for the segmentation of regions of blood vessels in the MRA images;
5. analyze capabilities of application of spectral methods for the processing of images with periodic regions.

Scientific novelty and practical value of the dissertation. The following results were obtained during PhD studies which are relevant in the science of electrical engineering and electronics:

- Created techniques for segmentation of brain region and for calculation of quasi symmetry axis in CT images by using *Fourier* spectrum.
- Created technique and corresponding algorithm for the segmentation of region of ischemic brain stroke by using *Fourier* spectrum.
- Created technique and corresponding algorithm for the segmentation of region of ischemic brain stroke by using *Haar* wavelet spectrum.
- Proposed technique for the segmentation of regions of blood vessels in MRA images.
- Experimentally tested created algorithms and investigated their capabilities to analyze clinical images.

Proposed algorithms may be implemented into medical image processing software either into personal computers for the individual image analysis saving time of diagnostics.

Methodology of research. The following methods and techniques were used in the work: Fourier and wavelet spectrum analysis, processing in the frequency and space-frequency domains, elements of mathematical morphology and theory of sets, geometrical methods.

Presented for defence.

- Technique for segmentation of the region of brain in CT images using spectrum analysis.

- Technique for estimation of quasi symmetry axis based on Fourier spectrum analysis.
- Techniques for segmentation of the region of ischemic brain stroke in CT images based on *Fourier* and *Haar* wavelet spectra.
- Technique for segmentation of regions of blood vessels in MRA images based on wavelet spectrum.
- Experimental results of segmentation of regions of brain, ischemic brain stroke and blood vessels; results of estimation of quasi symmetry axis.

Approbation of the dissertation. The results of the work were discussed in nine scientific conferences in Lithuania and other countries. Nine articles are printed: one article is referred in ISI Master List database; two are referred in ISI Proceedings; two articles are cited in Inspec database, three articles are printed in reviewed conference proceedings; one article printed in other conference proceedings.

Structure of the dissertation. The dissertation manuscript is composed of six chapters; first one is Introduction, last one – General conclusions. Lists of references and author‘s publications are presented after conclusions.

The volume of the work is 110 pages without annexes; there are 39 formulas, 45 figures and two tables used. The list of references contains 96 records.

2. Content of the dissertation

Chapter 1. Introduction. Relevancy of the work, formulation of the problem, the purpose and tasks of the work, objects of defence and work approbation are presented in the chapter.

Chapter 2. Principles and methods of medical image analysis. The chapter is dedicated for review of brain diagnostic methods, principles of visual investigation of medical images, estimation of image characteristics of human brain. Attention is paid to *Fourier* and wavelet spectra applications.

Chapter 3. Analysis of Fourier spectrum of medical images. The chapter encompasses review of *Fourier* spectrum estimation and its relation with properties of image. Then it is proposed spectrum symmetry estimation technique which allows to calculate rotation angle of quasi symmetry axis of CT image. Results of estimation were compared with ellipse approximation and *falx cerebri* detection results. Also there are proposed two techniques for segmentation of brain area and for segmentation of the region of ischemic brain stroke based on the enhancement of low frequency components of spectrum and application of threshold function.

Segmentation of brain region. One of the aims of image preprocessing is detection of region of analysis. This is useful when image must be analyzed locally. In the case of CT there are regions in the slices which do not belong to the region of brain, e.g. regions corresponding to tissues of bones, fat, skin, eyes, etc. These regions may be eliminated by creating the mask of brain region. The advantage of using mask is dual: first, the number of analyzable points is reduced; second, reliability of further analysis stages is higher. There are two cases of brain region detection. In the first case (most usual) region of brain is single and completely surrounded by region of bone. In the second case there are multiple regions of brain which are (partially) surrounded by region of bone. Second case is more complicated because it leads to the solution of the following tasks: 1. it is necessary to detect from 1 to 3 regions of brain; 2. segments must not overlap with regions of skin, fat or eyes.

Detection of region of brain may be performed using proposed algorithm which consists of two stages: approximate segmentation stage and correction stage. An advantage of algorithm is its capability to detect region of brain in the first stage in the case of completely surrounded single region of brain. Second stage is required if region of brain is fragmented or has a contact with other similar regions.

An algorithm of the first stage is based on the fact that region of brain is a compact group of grey level pixels; the number of groups often is one however in complicated CT slices there may be up to three significant groups. The region of brain usually doesn't have direct connection with a region of background and luminosity variations in that region are lower in comparison with region of skin. These properties have a connection with amplitudes of low frequency components of Fourier spectrum; the bigger the group of grey pixels, the higher are amplitudes of low frequency components. Thus low pass filter may be used to enhance such groups of pixels. Another important fact is that amplitudes of spectrum components decrease according to exponent law when frequency rises. This means that pass-band of low pas filter must be very narrow. To obtain the mask of brain region a threshold function must be applied.

At the second stage image is divided into equaled size squares; then centers of squares are calculated; in the next step there are used only those centers whose squares overlap with mask from the first stage. From every selected point there are drawn radii with a given step of angle; only those squares which radii cross the region of bone are selected. Then it must be tested how many radii crossed the region of bone; if the number of radii is greater than threshold parameter then the region of square is transferred into initial mask. After all obtained initial mask is dilated by iterative region growing and evaluating ratio between mask perimeter in the region of bone and total perimeter of segment of mask. The maximum of this ratio corresponds to stop condition of iterative region growing.

It was experimentally evaluated an integral uncertainty of region growing which was calculated by adding over-grown and under-grown areas and dividing result by the area of region of brain. In the case of complicated CT images (total of 124) the integral uncertainty was lower than 20 % in 75 % of processed images.

The algorithms were implemented using fast calculation methods and total time of processing was in the range of one second on the modern PC.

Calculation of quasi-symmetry axis. In the analysis of CT images sometimes it is required to apply comparison techniques which are useful when object has some symmetry properties. The region of brain also has particular symmetry because hemispheres are similar by size and shape. This may be used to compare the regions of hemispheres and detect irregular or susceptible regions. For this purpose it is needed to estimate symmetry axis. However the regions of hemispheres are not ideally symmetrical by its nature and axis (as a straight line) may be evaluated only approximately. There are proposed three techniques of quasi symmetry axis calculation based on ellipse fitting, detection of region of *falx cerebri* and analysis of *Fourier* spectrum in polar coordinate system.

Special objects of human brain tomography images are head bones which are easily detectable in every slice as bright ring-shaped areas. It is able to approximate the bone region by using ellipse fitting algorithms based on optimization and clustering (voting) methods. In the result geometrical features of head bone as well as of brain area may be evaluated, for instance, symmetry axis, center, eccentricity. Ellipse fitting is also useful in identification of brain region because ellipse contour can separate brain from other tissues. Both optimization and clustering algorithms are suitable for analysis of computed tomography images if used together with special preprocessing. It was applied optimization method of least squares criterion. Appropriate results were obtained when images were preprocessed by applying threshold function and morphological filter of the biggest particle. From the class of clustering algorithms it was selected and implemented algorithm which uses 1D array-accumulator. It was noticed that clustering algorithms are not sensitive to extraneous points however processing speed is appropriate when the number of points does not exceed couple of hundreds. The speed requirement limits application of selected voting algorithm because region of bone consists of many thousands of points. Consequently it is needed to apply high ratio decimation techniques which have direct connection with the results of fitting. Optimization method of ellipse fitting with morphological filter was applied to CT slices of 18 patients (total 341 images). In every slice it was manually drawn reference axis and its parameters were compared with automatically fitted (major) axis of ellipse. Comparison results show that angle between real and modeled symmetry axes does not exceed 10 degrees in more than 60% of processed images and brain area was detected without deviations in more than 40% of analyzed slices. Uncertainty is related to eccentricity e of ellipse: if $e > 0,6$ then angle deviation drops under the limit of five degrees.

Another technique of quasi symmetry axis estimation is based on detection of region of *falx cerebri* which separates left and right hemispheres. This approach is more precise in comparison with geometrical methods since it tries to find physiological feature of the brain. From the other side the region of falx cerebri is detectable only in slices of head vertex. Temporal CT slices require other axis evaluation techniques either information obtained by processing vertex slices may be extended to other slices by approximation of plane.

Technique of detection of *falx cerebri* was implemented by calculation of center of mass, reduction of analysis region, detection of potential segments and noise filtering based on Hough principle. There were evaluated uncertainties of

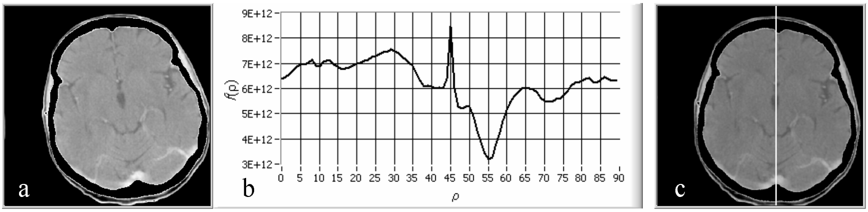

Fig 1. CT image with region of bone removed (a), function of spectrum symmetry estimation in polar coordinate system (b) and image rotated by degree corresponding to minimum of function (c)

axis detection. For this purpose there were taken total of 61 image of 9 patients and compared results of automatic and expert given symmetry axis. Statistical analysis of results show that maximum distance between axes in the region of brain do not exceed 9 pixels for more than half of processed slices, and 5 pixels for one third of processed slices. The speed of algorithm depends on the size of image and is in the range of couple seconds per slice using P4/2,4 GHz/256 MB machine.

Quasi symmetry axis may also be evaluated by *Fourier* spectrum analysis. The main idea is that spectrum of symmetrical object has symmetry with respect to line crossing zero frequency component and its direction corresponds to the angle of rotation of an object. The most appropriate way of finding spectrum symmetry line is based on conversion of *Fourier* spectrum into polar coordinate system. In polar coordinate system it is necessary to find angle which ensures division of spectrum into two “the most similar” parts. Least squares criterion was used as a similarity factor. Qualitative analysis of results showed that angle of rotation correlates with geometrical properties of bright objects of image. (Fig 1). If region of brain dominates over other regions and has symmetry features (bone region is eliminated) then symmetry estimation function $f(\rho)$ has clear minimum at the angle of rotation. When angle is known the image may be back rotated ensuring vertical position of quasi symmetry axis. If region of bone exists in the CT image then angle of rotation corresponds to the bone region since its luminosity is much higher in comparison to region of brain. If object in image is not symmetrical then spectrum symmetry estimation function has many minima with similar values.

Segmentation of region of ischemic brain stroke in CT images. It was created technique for segmentation of ischemic brain stroke in CT images using masking of usual dark regions of brain and applying low pass filtering. Experimental tests with standard size spectra corresponding to 512 $\times$ 512 CT images showed that data related with ischemic brain stroke is concentrated in narrow low frequency band limited to 20 $\times$ 20 size. However this band includes data about other common brain objects. The influence of them to detection of ischemic stroke may be decreased by using additional processing which is related with the following assumptions: 1. ischemic brain stroke is continuous, local spot, occupying 5–40 % of brain area; 2. brain contains some common objects that are considerably darker than ischemic

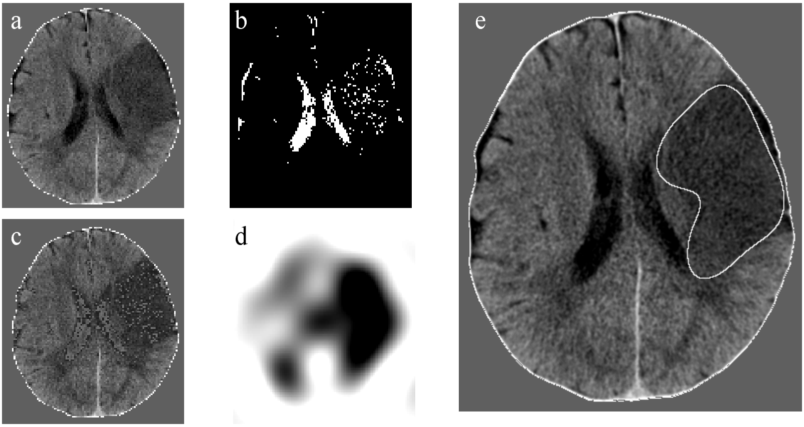

Fig 2. Intermediate results of detection of region of ischemic brain stroke

stroke region. The first assumption is related to the condition that ischemic brain stroke is concentrated in the lowest spatial frequency band. Second one is the basis of additional processing which may be performed by threshold function. The purpose of thresholding is to detect common dark brain objects except of ischemic stroke. Further detected objects may be multiplied by constant coefficient that moves dark objects to average level of the brain luminosity. This operation results in better concentration of low frequency components related with ischemic stroke.

Intermediate and final results of additional processing, filtering and thresholding are shown in the Fig 2. There are four main steps of the method. First, usual dark objects are detected (Fig 2, b), second, detected dark objects are lightened (Fig 2, c), third, image is low pass filtered (Fig 2, d) and the fourth, image is again thresholded to mark the ischemic stroke region (Fig 2, e). The tests were performed to more than 30 images with ischemic stroke and good visual results were obtained even for fixed threshold parameters. The biggest deviations were obtained only for images where mentioned assumptions are violated.

Chapter 4. Analysis of Haar wavelet spectrum of medical images. Principles of wavelet transform, its properties in 1D and 2D cases are analyzed in the chapter; also there are described created technique and algorithm for segmentation of region of ischemic brain stroke using *Haar* wavelet transform. The main advantage of wavelet transform in comparison with *Fourier* teansform is a capability to analyze images with non-homogenic regions without loosing the information about location of analysis.

Having the signal $x[k] = \{x_{,0}, x_{,1},..., x_{,N-1}\}$, where $N = 2^R$, R is positive integer number, the discrete wavelet spectrum $w_j[n]$ at scale j is defined as follows:

$$w_j[n] = 2^{j/2} \cdot \sum_{k=0}^{N-1} x[k]\psi[2^j k - n] . \qquad (1)$$

Here $\psi[\cdot]$ is a chosen discrete wavelet function, j is a scale, $j = 0, 1,\ldots, R-1$, n is a translation, $n = 0, 1, \ldots, 2^j - 1$, k is a signal sample number, $k = 0, 1,\ldots, N-1$. The formula (1) shows that wavelet spectrum has two parameters: scale and translation (shift), which correspond to frequency and time axes respectively. There is no need to analyze signal at every scale j, it may be done only up to certain scale J. Then non-decomposed part of the signal is expressed as a matrix of approximation coefficients calculated as follows:

$$c_J[n] = 2^{J/2} \cdot \sum_{k=0}^{N-1} x[k]\varphi[2^J k - n], \tag{2}$$

where $c_J[n]$ is an approximation coefficient, $\varphi[\cdot]$ is a discrete scale function. The simplicity of *Haar* wavelets allows using fast recursive transformation formulas printed below:

$$c_{j-1}[n] = \left(c_j[2n] + c_j[2n+1]\right)/\sqrt{2}, \tag{3a}$$

$$w_{j-1}[n] = \left(c_j[2n] - c_j[2n+1]\right)/\sqrt{2}. \tag{3b}$$

When starting the signal transformation it must be taken into account that $j = R$, $c_R[2n] = x[k]$ for $k = 0, 2,..., N-2$ and $c_R[2n+1] = x[k]$ for $k = 1, 3,..., N-1$. In this way transformation is calculated serially from the smallest scale $j = R$ up to the largest scale $j = 0$ (or until required scale J). Every recursion produces wavelet and approximation coefficients at the scale j and the obtained approximation coefficients are used in next recursions. The transformation is fast because every next recursion requires fewer calculations.

The same formulas (Eq. 3a, b) are acceptable for transformation of image using row-column algorithm. Often image wavelet coefficients are abbreviated as d coefficients and approximation coefficients are abbreviated as s because they are obtained by using *difference* and *sum* operations. In first stage, formulas (Eq. 3a, b) must be applied to rows obtaining two matrixes s_{j-1} and d_{j-1}. Then to each of them the same formulas must be applied repeatedly but this time for columns. After processing of matrix s_{j-1} there are obtained again two matrixes called ss_{j-1} and sd_{j-1}, respectively from d_{j-1} are obtained ds_{j-1} and dd_{j-1}. Consequently four different coefficient matrixes are obtained at every scale j: one approximation ss_{j-1} and three wavelet coefficient matrixes sd_{j-1}, ds_{j-1} and dd_{j-1}. Approximation matrix ss_{j-1} is suitable for next recursion and obtaining of larger scale wavelet coefficients.

Examination of wavelet matrixes at different scales proved that region of ischemic stroke corresponds to low frequency coefficients and most of interested information is concentrated in approximation matrixes. Even when primary image is transformed with 6 recursion steps (matrix size then is equaled to 8×8) the stroke region can be identified as couple of low intensity neighbor pixels in approximation matrix. Based on these observations the stroke region detection method was developed. The region of ischemic brain stroke in many cases is continuous localized spot with decreased brightness. These properties determine

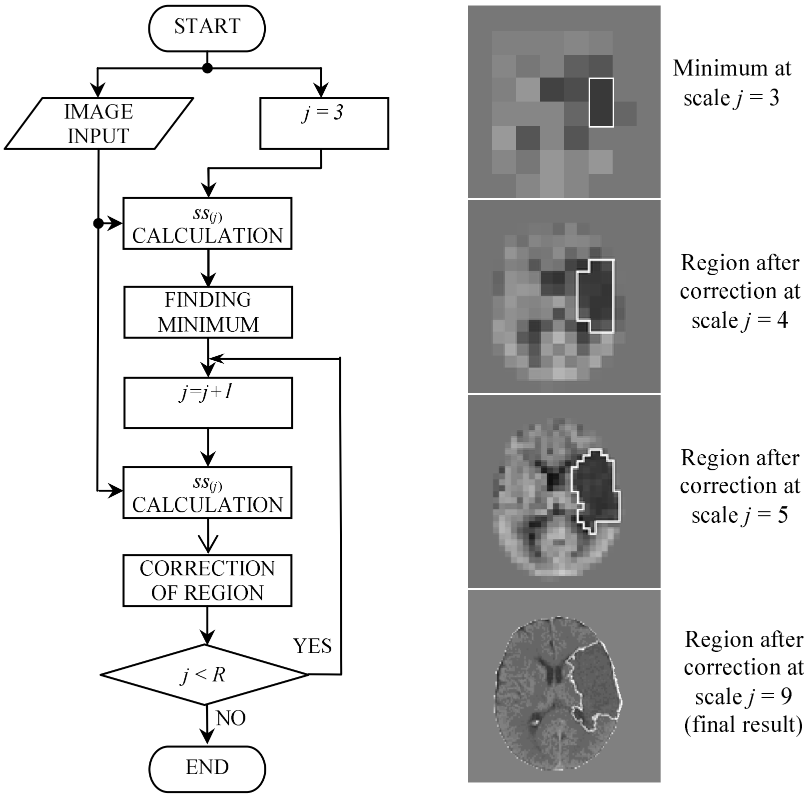

Fig 3. Generalized algorithm of detection of stroke region and the results of its application

the assumption that region may be simply filtered by low pass filter (LPF) and then marked by threshold function. However LPF affects the accuracy of detected region by smoothing it. The advantage of LPF is approximate but reliable localization of ischemic stroke region. In the simplest case region may be identified by finding the minimum of filtered image. The accuracy of region contour may be increased by extending pass-band of LPF but then increases the probability of detection of false (non ischemic stroke) regions. Thus the main idea of the algorithm is finding an approximate location of ischemic stroke region in filtered image and application of stepped correction of its contour by continuously increasing the pass-band of LPF. Stepped filtering is performed by calculating approximation coefficients of *Haar* wavelet transform (Eq. 3a, b).

Generalized flowchart of developed algorithm is shown in Fig 3. It starts from setting a scale variable j to 3, calculating matrix ss_3 and finding the minimum element. The largest scale is chosen equaled to 3 because then single element size is comparable with the dimensions of the area of stroke region. The larger scales as well as smaller are not appropriate because localization may be poor either minimum may jump to other conventional image objects. After finding the minimum element the scale coefficient j is incremented and approximation coefficients are obtained. Based on them the detected region (internal contour) and its neighbor pixels (external pixels) are checked at higher resolution and if neighbor pixels have similar brightness then they are connected to the region otherwise – rejected. In such a way stroke region contour is corrected by using erosion and dilation operations at every scale. Finally when j reaches R, correction stops and contour may be transferred into original image.

The above described algorithm was implemented in C language under Linux OS. The test results show that algorithm is suitable for automatic and accurate detection of ischemic brain stroke region in the cases when region is large in comparison with other usual dark brain image objects. Deviations of detection may be observed when region of stroke has contact with usual low density brain objects.

Chapter 5. Detection of non-stationary regions of images. Applications of *Fourier* and wavelet spectra for the analysis of images with periodic and non-homogenous regions are described in the chapter. The aim of analysis is segmentation of non-stationary regions of image. It was shown that *Fourier* spectrum is suitable for segmentation of periodic regions. Capabilities of segmentation of non-stationary fragments of image were investigated using wavelet spectrum.

Detection of periodic regions. Some kind of images contain periodic regions that may require enhancement or elimination. For this purpose periodic regions must be segmented. Periodicity features of image are easily detectable in spatial frequency domain by searching for peaks of amplitude. There are many ways of peak detection and one of them is threshold function. Detection of periodic regions requires several stages. At first, image must be transformed into frequency domain. Then frequency band of potential locations of peaks are defined. A threshold function is applied in the selected frequency band. The result of thresholding must be used as filter function which pass band corresponds to obtained segments. After that inverse Fourier transform is applied and image with enhanced periodic regions is obtained. Finally image must be segmented by using modulus or square function and applying another threshold function. The result is a mask of periodic regions.

Detection of periodicity perturbations. Detail analysis of perturbations of image periodicity may be performed after the periodic region of image is detected. For this purpose, opposite to classic Fourier transform, space-frequency representations if image are useful. Periodic regions of image are treated as stationary regions and their spectrum does not depend on location. However if periodicity has some deviations then it is required analysis tool capable to detect changes of spectrum at particular location. An appropriate tool is wavelet transform.

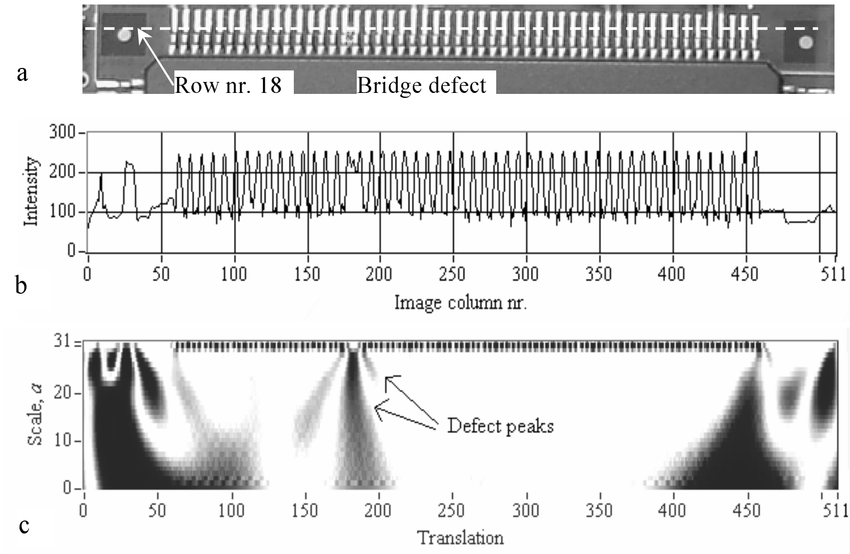

Fig 4. Image with periodic region (a), luminosity graph of single row of image (b) and MHAT wavelet spectrum of indicated graph (c)

In practice there are usually two types of wavelet transform: continuous (time) wavelet transform (CWT) and discrete wavelet transform (DWT). Both types are extendable from a one-dimensional to multidimensional case and implemented in a digital way. The main advantage of CWT is the possibility to analyze signals at arbitrary scales and locations; however, its computation is highly redundant and time consuming. DWT uses orthogonal basis functions for signal decomposition and its computation is very fast and non-redundant.

The capability to detect periodicity perturbations using wavelet analysis is illustrated in Fig 4. There is shown an example of an image taken from real printed circuit board (PCB) photo which contains region of soldered pins together with some neighbor area. Intensity graph of row nr.18 and its wavelet spectrum using Mexican Hat (MHAT) CWT are also shown in the figure. As was expected the intensity graph in the region of interest is periodic if analyzed perpendicular to pins. The bridge (or solder ball) defect causes the disappearance of the peak between columns No.175 and No. 190.

The MHAT CWT representation shown in Fig 4, c was calculated in 32 different scales. A translation factor in the given example is equaled to the number of samples of the row. The main difference in the sense of translation is that *Haar* DWT uses a non-overlapping analysis window and the CWT uses overlapping windows which increase the information redundancy in the wavelet spectrum. From the other side CWT spectrum is smoother and allows to detect periodicity perturbations more precisely in comparison with DWT. Similar conclusions are valid in the case of 2D analysis of PCB photos.

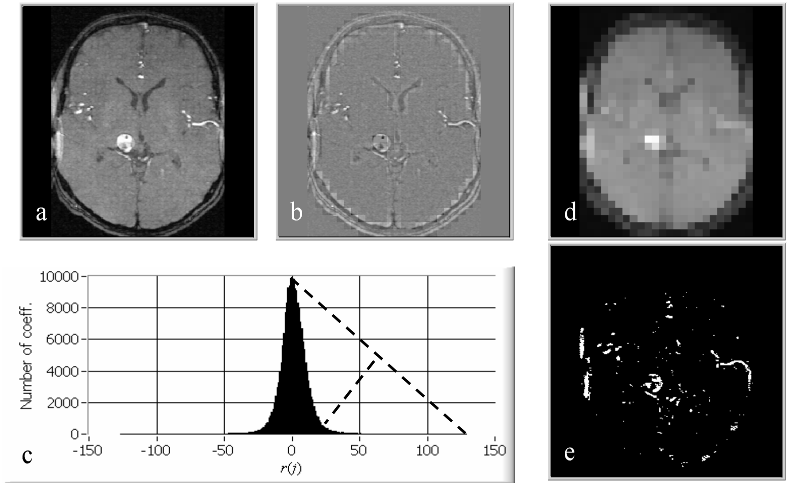

Fig 5. MRA image (a), reconstruction image $r_{(j)}$ (b) and its histogram (c), image of approximation coefficients (d) and automatically segmented regions of blood vessels (e)

Detection of non-stationary regions in non-periodic background. An important stage of MRA image analysis is detection of regions of blood vessels. Detection of blood vessels is relevant in the diagnostics of brain diseases like aneurysm. If MRA images were obtained in TOF mode then regions of blood vessels are observed as bright spots in the homogenous background of region of brain. Thus regions of blood vessels may be interpreted as non-stationary regions of image. Regions of vessels correspond to high values of pixel intensity however threshold function not always is suitable for their segmentation because of image intensity gradient, noise, artifacts, and variability of histogram modes.

Proposed technique of segmentation is based on the analysis of *Haar* wavelet spectrum. Wavelet coefficients at fixed scale may be generalized using synthesis equation and expressed through images of reconstruction $r_{(j)p,\,q}$:

$$r_{(j)\,p,q} = (-1)^p sd_{(j)\,p,q} + (-1)^q ds_{(j)\,p,q} + (-1)^{p+q} dd_{(j)\,p,q}\,, \quad (4)$$

where $p = m\mathrm{div}2^{R-j}$, $q = n\mathrm{div}2^{R-j}$, $j = 0...R-1$; $m, n \in [0, N-1]$. Analysis of reconstruction images (Fig 5, b) proved that regions of blood vessels correspond to particular distribution of reconstruction coefficients by the scale axis. The reconstruction coefficients of blood vessels are usually positive and much bigger with comparison to homogenous areas of image. Segments of blood vessels are obtained by thresholding of reconstruction images with respect to image of approximation coefficients (Fig 5, c and d). This technique of segmentation also detects non stationary regions near the corners of region of brain (Fig 5, e); they may be removed if segmentation of brain region is applied prior to detecting of blood vessels. An advantage of proposed technique with comparison to global threshold function is lower level of segments related with noise.

3. General conclusions

1. The aim of dissertation was to create and investigate image processing techniques suitable for detection of regions of ischemic brain stroke and blood vessels in medical images. Review of the references gave an idea that goal may be reached by analysis of images in frequency and space-frequency domains. The main results are the following:

2. Created technique for segmentation of region of brain in CT images suitable for the cases where region of brain is single or fragmented; the basis of technique is low pass filtering procedure followed by region growing; In the case of complicated CT images (total of 124) the integral uncertainty was lower than 20 % in 75 % of processed images.

3. Proposed three techniques for estimation of quasi symmetry axis of human brain in CT images based on ellipse fitting, detection of region of *falx cerebri* and evaluation of symmetry of *Fourier* spectrum; experimental tests proved that angle between expert defined axis and major axis of fitted ellipse does not exceed 10 degrees in more than 60 % of processed images (total 341 images); detection of *falx cerebri* is useful in the case of analysis of CT slices of vertex level; evaluation of the symmetry of *Fourier* spectrum allows to calculate angle of rotation of image under analysis.

4. Created technique for segmentation of region of ischemic brain stroke in CT images based on connection between region of stroke and low frequency components of *Fourier* spectrum; technique is adopted for segmentation of relatively large regions of brain stroke occupying more than 10 % of brain area; the size of target region is related with the bandwidth parameter of low pass filter; it was implemented algorithm of the technique and satisfied results of segmentation were obtained when masking of usual dark objects in the brain image is used.

5. Investigated principles of *Haar* wavelet transform and connection between region of brain stroke and wavelet coefficients.

6. Created technique and algorithm for segmentation of region of ischemic brain stroke in CT images using approximation coefficients of *Haar* wavelet transform at different scales; technique is based on approximate detection of region of stroke at large scale and series of correction procedures at finer scales; technique performed well when stroke region is relatively large and isolated from other usual objects of the brain with similar average luminosity. The processing time of single slice is only fraction of one second.

7. Analyzed images with periodic regions; it was proposed the way of filter construction in frequency domain suitable for segmentation of periodic regions; periodicity perturbations were investigated using wavelet transform; it was shown that continuous wavelet transform may be used for more precise detection of non-stationary signal or image fragments in comparison with discrete wavelet transform.

8. Created technique of segmentation of blood vessels in MRA images based on analysis of *Haar* wavelet spectrum; it was investigated that regions of blood vessels may be treated as non-stationary regions corresponding to large wavelet coefficients at particular scales; thresholding of generalized wavelet coefficients over the scale axis leads to segmentation of regions of blood vessels.

List of publications on the topic of the dissertation

Article included in the list of the Institute of Scientific Information (ISI):

ŽITKEVIČIUS, E.; MARTAVIČIUS, R. Image wavelet transform for PCB soldering's quality evaluation. A Collection of Papers from the 1st International Conference: Mechatronic systems and materials, Vilnius, Lithuania, 20-23 October 2005. Trans Tech Publications: Solid State Phenomena. ISSN 1012-0394, 2006, Vol. 113, p 85–90. http://www.ttp.net/3-908451-21-3.html

Articles referred as ISI Proceedings:

1. ŽITKEVIČIUS, E.; MARTAVIČIUS, R. Detection of human brain ischemic stroke region by computed tomography image spectrum. BEC 2004: proceedings of the 9th Biennial Baltic Electronics Conference, Tallinn University of Technology. October 3-6, 2004, Tallinn, Estonia. ISBN 9985-59-462-2, p. 169–170.
2. GRIGAITIS, D.; ŽITKEVIČIUS, E.; UŠINSKAS, A. Determination of symmetry axis on human brain CT image. BEC 2004: proceedings of the 9th Biennial Baltic Electronics Conference, Tallinn University of Technology October 3-6, 2004, Estonia. ISBN 9985-59-462-2, p. 165–168.

Articles quoted in Inspec database:

1. ŽITKEVIČIUS, E.; MARTAVIČIUS, R. Time-frequency approach for human brain ischemic stroke region detection in ct images. Electronics and Electrical Engineering. ISSN 1392-1215. 2005, No. 5(61), p. 61–66 (in Lithuanian).
2. MIKELAITIS, V.; MARTAVIČIUS, R.; ŽITKEVIČIUS, E. Wavelet analysis of human brain ct images with ischemic stroke region. Electronics and Electrical Engineering. ISSN 1392-1215. 2005, No. 8(64), p. 73–78 (in Lithuanian).

Other publications in conference proceedings:

1. GRIGAITIS, D.; KIRVAITIS, R.; ŽITKEVIČIUS, E.; MEILŪNAS, M. On optimization of region growing procedure for complex CT images. 10th International Conference Mathematical Modelling and Analysis and 2nd International

Conference Computational Methods in Applied Mathematics. June 1–5, 2005, Trakai, Lithuania: proceedings. ISBN 9986-05-924-0, 2005, p. 395–402.

2. GRIGAITIS, D.; KIRVAITIS, R.; ŽITKEVIČIUS, E.; MEILŪNAS, M. An algorithm of automatic human brain identification in complex ct images. VI International Workshop for candidates for a doctor's degree OWD'2005 under the auspices of deans of electrical, electronic and computer science faculties of engineering. Vol. 21. ISBN 83-922242-0-5. Gliwice: Faculty of Electrical Engineering Silesian University of technology, 2005, p. 23–26.

3. ŽITKEVIČIUS, E.; MARTAVIČIUS, R. Ellipse fitting in the analysis of human brain computed tomography images. Biomedical engineering: conference proceedings. October 27–28, 2005. ISBN 9955-09-950-X, 2005, p. 252–255 (in Lithuanian).

4. ŽITKEVIČIUS, E. Application of spectral analysis for medical signals. Proceedings of 7th conference of junior scientists "Lithuania without science – Lithuania without future". Electronics and electrotechnics. March 19, 2004. Vilnius. ISBN 9986-05-803-1, 2004, p. 10–15 (in Lithuanian).

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Medicininių vaizdų analizė ir tyrimas spektriniais metodais

Darbo aktualumas. Vaizdų apdorojimas yra sparčiai besivystanti skaitmeninių signalų apdorojimo kryptis. Vaizdai, kaip geriausiai žmogui suvokiama informacijos forma, yra plačiai naudojami įvairiose srityse, tame tarpe medicinoje. Vienas svarbiausių šiuolaikinės medicininės diagnostikos principų yra kuo mažiau įtakoti žmogaus organizmą tyrimų metu, todėl svarbią vietą tarp tyrimo metodų užima neinvaziniai vidinių organų vizualizavimo metodai. Pagrindiniai iš jų yra ultragarsinis tyrimas, kompiuterinės tomografijos (KT) bei branduolių magnetinio rezonanso (MR) tyrimai.

Žmogaus smegenų ligų diagnostikoje reikia taikyti ypač tikslius ir patikimus tyrimus. Dažnai šiam tikslui tinka tik KT ir MR tyrimai, kurie leidžia identifikuoti bei lokalizuoti tam tikras ligas. Pagrindinės smegenų ligos yra susijusios su kraujo apytakos sutrikimais. Esant susiaurėjusioms kraujagyslėms arba susidarius aneurizmai, išauga tikimybė susirgti smegenų insultu.

Įvykus smegenų insultui, būtina tiksliai nustatyti diagnozę. Pirmas diagnostikos etapas yra lokalizacija, kurios rezultatai suteikia daug informacijos kitiems etapams. Lokalizacijos etape pagrindiniai tyrimai yra KT (bazinis) arba MRT (papildomas).

Problemos formulavimas. Žmogaus galvos KT bei MR vaizdus analizuoja apmokyti diagnostikos specialistai – radiologai. Vaizdai, kuriuos turi analizuoti radiologas, yra pilkieji vaizdai, pateikiami monitoriuje arba skaidrėse. Juose tiriami objektai yra atpažįstami pagal tam tikrų vaizdo sričių pilkumo lygį, išsidėstymą, formą, dydį ir kitus požymius. Atpažinimo procesui turi įtakos eilė veiksnių, kurių visuma lemia diagnostines neapibrėžtis. Jų sumažinimui bei diagnostikos paspartinimui vis plačiau taikoma pagalbinė kompiuterinė programinė įranga, kuri, be to, suteikia daug papildomų trimačio vizualizavimo ir skaičiavimo galimybių. Kompiuterinė vaizdų analizė, skirtingai nuo vizualiojo tyrimo, leidžia efektyviau išnaudoti medicininių vaizdų skaisčio dinaminį diapazoną, skiriamąją gebą ir įvertinti įvairius vaizdo ar jo sričių parametrus bei charakteristikas.

Pagalbinė medicininių vaizdų apdorojimo programinė įranga turi keletą aktualių taikymų. Pirma, ji leidžia tiksliau nei vizualiuoju būdu nustatyti tam tikrų patologijų kontūrus, skerspjūvius, tūrius, matmenis ir kitus skaitinius parametrus. Antra, kompiuterinė analizė padeda tiksliau parinkti gydymą, efektyviau pasiruošti intervencinei operacijai ar net asistuoti jos metu.

Vaizdų apdorojime bei analizėje taikomi patys įvairiausi matematiniai metodai. Metodų įvairovę lemia tai, kad vaizdai yra plačiai taikomi įvairiose srityse ir jie yra labai įvairūs pagal savo turinį, tipus, savybes ir t. t. Dažnai iškeltam tikslui pasiekti tinka aibė metodų. Metodo taikymo efektyvumas priklauso nuo vertinimo kriterijų, metodo galimybių ir jų panaudojimo konkrečiam uždaviniui spręsti. Vaizdų apdorojimo metodus galima suskirstyti į erdvinius (laikinius) ir metodus su koordinačių transformacijomis. Didelę dalį sudaro erdviniai metodai, kuriuose veiksmai atliekami su vaizdų taškų koordinatėmis ir jų skaisčio reikšmėmis, todėl tarpiniuose apdorojimo etapuose išlaikoma ta pati vaizdo koordinačių sistema. Metoduose su transformacijomis vaizdas transformuojamas į kitą koordinačių sistemą, kurioje jis apdorojamas ar analizuojamas ir, jeigu reikia, transformuojamas atgal į pradinę koordinačių sistemą. Svarbią transformacijų grupę sudaro spektriniai metodai, kuriuose vaizdas transformuojamas į dažninį spektrą (DS) arba erdvinį dažninį spektrą (EDS). Vaizdų arba signalų perskaičiavimas į dažnio arba erdvės dažnio sistemą suteikia papildomų galimybių, analizuojant ir įvertinant signalų periodiškumo bei nestacionarumo savybes. DS ir EDS taikymas medicininių vaizdų apdorojime ir analizėje kol kas nėra gerai ištirtas, šiuolaikinėje literatūroje maža žinių apie tai, kaip šiuos metodus taikyti KT ir MR vaizdų apdorojime, smegenų ligų lokalizacijos uždaviniuose.

Disertacijoje nagrinėjama dažninių ir erdvinių dažninių spektrų taikymo medicininių vaizdų apdorojime problemą, siekiant atskleisti jų teikiamas apdorojimo galimybes. Problemos sprendimas yra grindžiamas spektrų taikymo metodikomis ir algoritmais, skirtais ligų sričių arba kitų specifinių sričių aptikimui klinikiniuose KT ir MRT vaizduose.

Tyrimų objektas. Darbo tyrimų objektai yra žmogaus galvos kompiuterinės tomogramos, magnetinio rezonanso angiogramos, dirbtiniai (testiniai) vaizdai, nemedicininiai vaizdai, turintys periodinių sričių.

Darbo tikslas. Šio darbo tikslas yra ištirti medicininių vaizdų analizės ir apdorojimo galimybes, taikant dažninius ir erdvinius dažninius spektrus, bei sudaryti algoritmus, skirtus ligų sričių ar kitų specifinių vaizdo sričių segmentavimui.

Darbo uždaviniai. Darbo tikslui pasiekti darbe reikia spręsti šiuos uždavinius:

1. ištirti kompiuterinių tomogramų su insulto sritimi bei magnetinio rezonanso angiogramų su kraujagyslių pėdsakais spektrų savybes;
2. pasiūlyti išeminio insulto srities aptikimo metodikas kompiuterinėse tomogramose, pagrįstas dažninio bei erdvinio dažninio spektrų analize;
3. sukurti pasiūlytų metodikų įgyvendinimo algoritmus ir eksperimentiškai patikrinti jų galimybes;
4. sudaryti arterijų pėdsakų segmentavimo magnetinio rezonanso angiogramose metodiką ir jos įgyvendinimo algoritmą;
5. išanalizuoti spektrinių metodų taikymo galimybes, analizuojant vaizdus su periodinėmis sritimis.

Tyrimų metodai. Darbe panaudoti klasikinės spektrinės bei vilnelių analizės metodai, vaizdų apdorojimas dažnio ir erdvės dažnio srityse, matematinės morfologijos ir aibių teorijos elementai, geometriniai metodai.

Mokslinis darbo naujumas. Rengiant disertaciją buvo gauti šie elektros ir elektronikos inžinerijos mokslui nauji rezultatai:

- Sudarytos metodikos, aprašančios smegenų srities išskyrimą, panaudojant *Furje* spektrą.

- Pasiūlyta metodika ir jos algoritmas išeminio insulto srities aptikimui, panaudojant *Furje* spektrą ir papildomą apdorojimą.
- Sukurta metodika ir algoritmas išeminio insulto srities aptikimui taikant *Haaro* vilnelių aproksimacijos koeficientus.
- Pasiūlyta metodika kraujagyslių pėdsakų sričių aptikimui magnetinio rezonanso angiogramose.
- Eksperimentiškai ištirti sukurti algoritmai ir parodytos jų galimybės, apdorojant klinikinius vaizdus.

Gynimui teikiama.

- Galvos smegenų srities kompiuterinėse tomogramose identifikavimo metodika, taikant spektrinius metodus.
- Smegenų didžiųjų pusrutulių kvazisimetrijos ašies skaičiavimo metodika, pagrįsta vaizdo *Furje* spektro analize.
- Išeminio insulto srities aptikimo galvos kompiuterinėse tomogramose metodikos, panaudojant vaizdo *Furje* ir *Haaro* vilnelių transformacijas.
- Kraujagyslių pėdsakų aptikimo galvos magnetinio rezonanso angiogramose metodika, panaudojant vilnelių spektrą.
- Eksperimentiniai galvos smegenų srities, kvazisimetrijos ašies, išeminio insulto srities, kraujagyslių pėdsakų aptikimo rezultatai.

Darbo rezultatų aprobavimas. Darbo rezultatai buvo paskelbti devyniose mokslinėse konferencijose Lietuvoje bei užsienyje. Disertacijos tematika yra atspausdinti 9 moksliniai straipsniai: vienas – straipsnių rinkinyje, įtrauktame į ISI sąrašą; du konferencijų medžiagoje, referuotoje ISI duomenų bazėje; du – respublikiniame žurnale, cituojamame Inspec duomenų bazėje, trys – recenzuojamose tarptautinių konferencijų medžiagose, vienas – respublikinės konferencijos medžiagoje.

Disertacijos struktūra. Disertaciją sudaro šeši skyriai, iš kurių pirmasis yra įvadas, o paskutinysis – apibendrinimas. Darbo apimtis yra 110 puslapių, tekste panaudotos 39 numeruotos formulės, 45 paveikslai ir 2 lentelės. Rašant disertaciją buvo remtasi 96 literatūros šaltiniais.

Pirmajame skyriuje aptartas darbo aktualumas, sprendžiama problema, suformuluotas darbo tikslas, uždaviniai, apibendrinta tyrimų metodika, darbo aprobavimas bei pateikta darbo struktūra.

Antrajame skyriuje apžvelgiami žmogaus smegenų tyrimo metodai, aptariami medicininių vaizdų vizualinės analizės principai bei nagrinėjami smegenų vaizdų parametrų skaičiavimo metodai.

Trečiajame skyriuje pateikiama vaizdo *Furje* spektro skaičiavimo metodika, spektro parametrų skaičiavimas, jų ryšys su vaizdo parametrais. Analizuojant spektrą, sudarytos smegenų kvazisimetrijos ašies kampo radimo, smegenų srities bei insulto srities segmentavimo metodikos.

Ketvirtajame skyriuje nagrinėjami vilnelių transformacijos principai, taikant diskrečiąją *Haaro* vilnelę. Parodytos *Haaro* vilnelės transformacijos ypatybės, analizuojant pavienę vaizdo eilutę bei visą vaizdą. Sudaryta metodika bei algoritmas, leidžiantis segmentuoti insulto sritį kompiuterinių tomogramų vaizduose.

Penktajame skyriuje nagrinėjami *Furje* ir vilnelių transformacijų taikymai vaizdams su periodinėmis ir neperiodinėmis sritimis, siekiant aptikti juose nestacionariuosius vaizdo fragmentus. Čia įrodoma, kad *Furje* spektras tinka periodinių sričių segmentavimui, siekiant išskirti analizės sritį. Taip pat ištirtos nestacionariųjų fragmentų aptikimo galimybės, analizuojant magnetinio rezonanso angiogramų bei vaizdų su periodinėmis sritimis vilnelių spektrus.

Rezultatų apibendrinimas. Disertacijoje buvo siekiama sukurti ir ištirti vaizdų tyrimo metodikas, tinkančias išeminio insulto bei kraujagyslių sričių aptikimui medicininiuose vaizduose. Darbo metu gauti šie rezultatai:

1. Sudarytas metodas, leidžiantis segmentuoti smegenų sritį kompiuterinėse tomogramose, kai ji yra tolydi arba fragmentuota; metodikos pagrindą sudaro spektro žemojo dažnio dedamųjų filtravimas ir srities tikslinimas auginimo būdu.
2. Pasiūlytos trys metodikos, skirtos apskaičiuoti smegenų pusrutulių skiriamajai linijai (kvazisimetrijos ašiai), pagrįstos aproksimacija elipse, pjautuvo srities aptikimu bei *Furje* spektro simetrijos įvertinimu; metodų taikymai parodė, kad aproksimacija elipse leidžia apskaičiuoti kvazisimetrijos ašį su nuokrypiu iki 10° daugiau nei 60 % nagrinėtų vaizdų; pjautuvo srities aptikimo metodas leidžia tiksliai apskaičiuoti ašį, kai apdorojami viršugalvio pjūvių vaizdai; spektro simetrijos įvertinimo rezultatai priklauso nuo apdorojamo vaizdo charakteristikų ir gali būti praktiškai pritaikyti, kai žinoma, kokio tomogramos objekto simetrijos savybes siekiama apskaičiuoti.
3. Sudaryta metodika išeminio insulto sričiai pažymėti kompiuterinės tomografijos vaizduose, pagrįsta šios srities sąryšiu su *Furje* spektro žemojo dažnio dedamosiomis; metodika pritaikyta insulto sritims, užimančioms palyginti didelę smegenų srities dalį ir besiskiriančioms nuo įprastinių smegenų sričių; metodikai patikrinti sudarytas algoritmas, kurio taikymo rezultatai rodo, kad insulto sritį įmanoma tiksliai pažymėti, jeigu prieš tai vaizde yra panaikinamos įprastinės mažo skaisčio smegenų sritys.
4. Ištirti *Haaro* vilnelių vaizdų transformacijos principai; parodytos greitosios vilnelių transformacijos savybės ir jų sąryšis su išeminio insulto sritimi tomogramoje.
5. Sukurta metodika ir algoritmas, skirtas išeminio insulto srities aptikimui kompiuterinėse tomogramose, taikant *Haaro* vilnelių aproksimacijos koeficientų analizę įvairiuose masteliuose; metodo pagrindą sudaro apytikslis srities aptikimas žemojo dažnio filtru apdorotuose vaizduose ir palaipsninis jos tikslinimas, pereinant prie smulkiųjų mastelių; metodika pasiteisino, kai insulto sritis yra izoliuota nuo įprastinių tamsių smegenų sričių ir yra palyginti didelė.
6. Analizuoti vaizdai, turintys periodines vaizdo sritis; siekiant aptikti periodines vaizdo sritis ir jų fragmentus, kuriuose periodiškumas yra sutrikęs, buvo pritaikyti *Furje* ir vilnelių spektrai; parodyta, kad tolydžioji vilnelių transformacija lyginant su diskrečiąja, leidžia tiksliau lokalizuoti periodiškumo nuokrypius.

7. Sudaryta metodika kraujagyslių sričių aptikimui magnetinio rezonanso angiogramose, pagrįsta *Haaro* vilnelių spektro analize; parodyta, kad kraujagyslių sritys smegenų srities fone atsispindi kaip nestacionarūs vaizdo fragmentai, kuriuos atitinka palyginti dideli vilnelių koeficientai.

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ANALYSIS OF MEDICAL IMAGES IN FREQUENCY AND SPACE-FREQUENCY DOMAINS

Summary of Doctoral Dissertation
Technological Sciences, Electrical Engineering and Electronics (01T)

Evaras ŽITKEVIČIUS
MEDICININIŲ VAIZDŲ ANALIZĖ IR TYRIMAS SPEKTRINIAIS METODAIS

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