Оберемок Є., канд. фіз.-мат. наук,
каф. квантової радіофізики, факультет радіофізики, електроніки та комп'ютерних систем,
Київський національний університет імені Тараса Шевченка

СТРУКТУРА МАТРИЦІ МЮЛЛЕРА СЕРЕДОВИЩ З ОРТОГОНАЛЬНИМИ ПОЛЯРИЗАЦІЯМИ ВЛАСНИХ ХВИЛЬ

В роботі досліджено зв'язок між елементами матриці Мюллера однорідних анізотропних середовищ з ортогональними поляризаціями власних хвиль. Отримані співвідношення перевірено для випадку середовищ з простими та змішаними типами анізотропії. Встановлено, що ортогональність поляризацій власних хвиль зменшує кількість незалежних елементів матриці Мюллера до 12. Досліджено зв'язок між параметрами анізотропії такого типу середовищ та встановлено, що їх анізотропія може утворюватись поєднанням всіх чотирьох елементарних типів дихроїзму та двопроменезаломлення, проте, з обмеженим співвідношенням. Зокрема, показано, що за довільних значень дихроїзму, міри лінійного та циркулярного двопроменезаломлення можуть приймати тільки конкретні значення. З огляду на встановлену симетрію матриці Мюллера, вимірювання тільки необхідної кількості її елементів дозволяє скоротити час вимірювання зберігши або підвищивши точність.

Ключові слова: *Матриця Мюллера, ортогональність власних поляризацій, параметри анізотропії.*

Оберемок Е., канд. физ.-мат. наук,
каф. квантовой радиофизики, факультет радиофизики, электроники и компьютерных систем,
Киевский национальный университет имени Тараса Шевченко

СТРУКТУРА МАТРИЦЫ МЮЛЛЕРА СРЕД С ОРТОГОНАЛЬНЫМИ ПОЛЯРИЗАЦИЯМИ СОБСТВЕННЫХ ВОЛН

В работе исследована связь между элементами матрицы Мюллера однородных анизотропных сред с ортогональными поляризациями собственных волн. Полученные соотношения проверены для случая сред с простыми и смешанными типами анизотропии. Установлено, что ортогональность поляризаций собственных волн уменьшает число независимых элементов матрицы Мюллера до 12. Исследована связь между параметрами анизотропии такого типа сред и установлено, что их анизотропия может образовываться сочетанием всех четырех элементарных типов дихроизма и двулучепреломления, однако, с ограниченным соотношением. В частности, показано, что при произвольных значениях дихроизма, значения линейного и циркулярного двулучепреломления могут принимать только конкретные значения. Учитывая установленную симметрию матрицы Мюллера, измерения только необходимого количества ее элементов позволяет сократить время измерений, сохранив или повысив точность.

Ключевые слова: *Матрица Мюллера, ортогональность собственных поляризаций, параметры анизотропии.*

UDC 004.62

I. Shyian, post. grad. stud., G. Chuiko, Dr.Sci.,
A. Pavlenko, stud., Medical Systems and Devices Department,
Faculty of Ecology and Medical Sciences
Petro Mohyla Black Sea State University

DIGITAL PROCESSING OF MEDICAL IMAGE WITH MAPLE

Typical medical images are most often in gray scale and their matrices of pixel intensities are convenient for digital processing. Recent versions of popular computer mathematics system Maple have special program packages for this aim. We are going to illustrate the possibilities of these packages by example of usual medical image. Our case study presents the discrete dyadic wavelet analysis (DWT), block thresholding of detail coefficients and evaluations of quality for reconstructed image. We investigated in addition the dependences of quality parameters on the digital filters used within DWT procedure.

Keywords: *medical image, discrete wavelet analysis, dyadic decomposition, block thresholding, factors of image quality, image compression*

Introduction. Digital processing is important for many applications that involve huge data storage, transmission and retrieval such as for multimedia, documents, videoconferencing, and medical imaging. Uncompressed images require considerable storage capacity. The objective of image compression technique is to reduce redundancy of the image data in order to be able to store or transmit data in an efficient form. This results in the reduction of file size and allows more images to be stored in a given amount of disk or memory space [1].

Medical image compression may be based on wavelet decomposition. It can produce notably better medical image results compared to the compression results that are generated by Fourier transform based methods such as the discrete cosine transform (DCT) used by JPEG [6].

The aim of this paper is to illustrate how discrete dyadic wavelet analysis (DWT) and block thresholding may be applied in medical image compression to reduce the volume of data.

Experimental. If we consider the quadratic image with sizes $N \times N = 2^m$, we can get at least $m = 2\log_2 N$ consecutive Wavelet-Transformations (so called the scale levels). In practice, usually from two to six scale levels are enough for useful analysis [3]. We were starting with image size $N = 224$ and $m = 2$ (see Fig. 1).

a **b**

Fig. 1. A medical image before (A) and after processing (B)

Two-dimensional wavelet transform can be represented as a composition of one-dimensional wavelet decompositions in rows and columns of the matrix image.

Image after single-level wavelets transformation in rows and columns is divided into four frequency blocks with different interpretation (Fig. 2) [5]:

1. LL-blok is top left block of approximation coefficients, which were filtered out in the analysis (decomposition) with two low-pass filters. The block contains a copy of the primary image with half resolution.

2. HL/LH blocks, bottom left and top right blocks, contain the detail coefficients, which were filtered by a low pass filter and a high pass filter. Block LH contains vertical edges, while the block HL – horizontal edges of the image.

3. HH-block, lower left. It contains detail coefficients twice filtered by high pass filters. We can interpret this block as an area which contains the edges of the original image in the diagonal direction.

A large number of wavelet detail coefficients will be small in absolute value (module) after decomposition since the neighboring pixels of images have mostly similar intensity values. As a result, the only part of the wavelet coefficients, especially those that are located in the so-called block LL of upper scale, chiefly represents the energy of image.

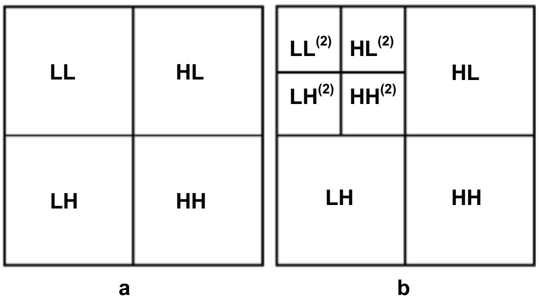

Fig. 2. Frequency blocks of wavelet coefficients for different numbers of levels of decomposition: A – single-level wavelet decomposition of the image; B – two-level (dyadic) wavelet decomposition

The following expression determines the image energy

$$E = \sum_{r=0}^{N-1}\sum_{c=0}^{N-1}\left(x_{r,c}\right)^2 \quad (1)$$

here $0 \le x_{r,c} \le 1$ is intensity of a pixel.

The usefulness of the DWT is the large number of zero (or close to zero) wavelet coefficients in the matrix of decomposition. Most of small wavelet-coefficients may be neglected by shrinking (replaced by zeros). Such a procedure is known as thresholding [3]. This last may deal either with every wavelet coefficient or with blocks of them. We used here the second kind of this procedure. If we are going to neglect all wavelet coefficients of so-called LH, HL and HH sub-matrices of decomposition matrix then the percent of these increases with the scale levels as [7]:

$$N(m) = 100 \cdot (1 - \frac{1}{2^{2m}}) \quad (2)$$

The percentage of negligible coefficients increases with the number of scale levels as it is evident from Figure 2.

Table 1 shows that for dyadic decomposition ($m = 2$) it gives 93.75 % of zeros in decomposition matrix.

Table **1**

Maximum percentage of zeros for thresholding of the matrix of wavelet coefficients depending on the number of the scale levels

the number of the scale levels (m)	1	2	3	4	5
percentage of zeros for thresholding (%)	75	93.75	98.44	99.61	99.90

Thus, only few percent of wavelet coefficients were in use for reconstruction of image (see Fig. 1B).

Figure 3 shows the intensity distribution of pixels on frequency blocks of wavelet coefficients for the two-level decomposition.

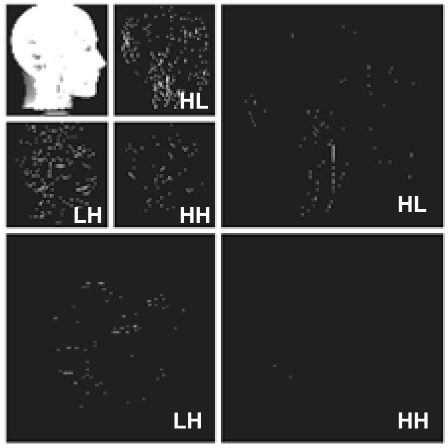

Fig. 3. Two-level refined from 93% of small detail coefficients image

Thus, there are only less then 7 % of non-zero wavelet coefficients, so the restored image will be significantly compressed. Such a radical reduction of information can be very useful in many cases, under condition that it is not accompanied by significant losses in image quality.

The evaluation of reconstructed image quality is possible with well-known factors: root of mean square error (rmse), peak signal to noise ratio (PSNR), entropy, coefficients of correlation between original and reconstructed images [2].

The root mean square error (rmse) measures the amount of change per pixel due to the processing. The rmse between a reference image and the compressed image is given by

$$rmse = \sqrt{mse} \quad (3)$$

Where *mse* is the mean square error

$$mse = \frac{\sum (r_{i,j} - s_{i,j})^2}{wh} \quad (4)$$

Here r, s are the reconstructed and source images, i, j range over all pixels, and w, h are the width and height [2, 8].

PSNR is most commonly used to measure the quality of reconstruction of compressed image. PSNR is usually expressed in terms of the logarithmic decibel scale.

$$PSNR = 10\log_{10}\left(\frac{peak^2}{mse}\right) \quad (5)$$

Where mse is the mean square error and $peak$ is the maximal intensity of a pixel in the image [2, 8]. For our evaluations $peak = 1$.

Entropy H is a scalar value representing the entropy of grayscale image. Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image.

The entropy of image is equal to

$$H = \sum_{i=1}^{M} p_i \log_2 p_i \quad (6)$$

Here M is number of equal intervals between boundary intensities 0 and 1 (normally $M = 256$).

Coefficients of correlation characterize correlation of pixels of original and reconstructed images [2].

The Table 2 presents these factors and their dependences on the length of digital filters of Symlet wavelet family. The Symlet wavelet family is one of the set of orthogonal wavelets offered by Maple. Symlets are also known as the Daubechies least asymmetric wavelets. Their construction is very similar to the Daubechies wavelets. The Symlet wavelet of size $2n$ has n vanishing moments.

Table 2

Factors of image quality vs. length of digital filters

Filter length	2	4	6	8	10	12
rmse	0.060	0.050	0.046	0.045	0.045	0.044
PSNR (dB)	24.45	26.07	26.66	26.90	26.91	27.05
Entropy (bit)	5.921	6.218	6.288	6.256	6.290	6.276
Correlation	0.981	0.987	0.989	0.989	0.989	0.990

Note: Entropy of original image is equal to 6.425877

Digital filters, more correctly the bank of digital filters (low-pass and high-pass), are main thing as for real DWT of image. You can know nothing about graphics of wavelet or its properties but you are able to make a DWT if you have a digital filter bank [7]. One can see that quality factors shown in Tabl. 2 are better for lengthier digital filters, nonetheless this gain is quite moderate. There should be found a compromise between the quality factors (longer filters) and the duration of computing (shorter filters).

One more problem is the optimal choice of wavelet family for decomposition. The Tabl.3 presents the collection of quality factors for different orthogonal wavelets with equal lengths ($n = 12$) of digital filters.

Table 3

Factors of image quality for different orthogonal wavelets

Wavelet families	Daubechies, 12	Coiflet, 12	Symlet, 12
rmse	0.045274	0.044845	0.044407
PSNR (dB)	26.882917	26.965637	27.05098
Entropy (bit)	6.334132	6.256444	6.276446
Correlation	0.989195	0.989403	0.989611

Now the reader can independently estimate the results of the switch from one family of orthogonal wavelets to another. This effect does not look extremely strong, from our point of view.

For processing images besides orthogonal wavelets are also widely used biorthogonal wavelets. The biorthogonal wavelets introduced by Cohen, Daubechies, and Feauveau contain in particular compactly supported biorthogonal spline wavelets with compactly supported duals. In biorthogonal wavelets, separate decomposition and reconstruction filters are defined and hence the responsibilities of analysis and synthesis are assigned to two different functions (in the biorthogonal case) as opposed to a single function in the orthonormal case [4].

The bank of wavelets of computer mathematics system Maple has the only biorthogonal wavelet Cohen-Daubechies-Feauveau (CDF) (9, 7) [8]. However, digital filters can be obtained by the algorithm outlined in the [7]. For processing we have chosen particularly biorthogonal spline (2, 2). Fig. 4, 5 shows the low-pass and the high-pass filters of biorthogonal spline (2, 2) for analysis and synthesis.

Table 4 displays evaluations of reconstructed image quality processed by orthogonal and biorthogonal wavelets with different number of digital filters.

As you see, biorthogonal wavelets have not advantages over orthogonal wavelets in this case.

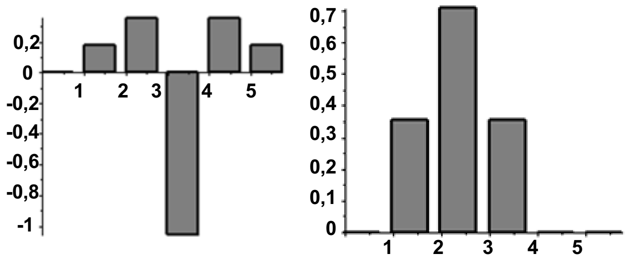

Fig. 4. Digital low-pass and high-pass filters of biorthogonal spline (2, 2) used for analysis

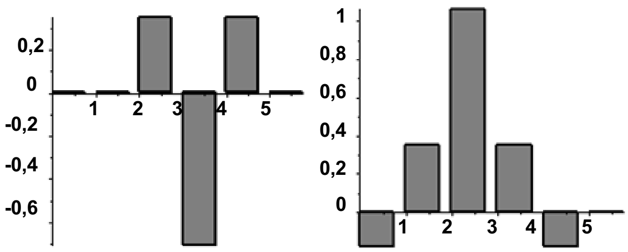

Fig. 5. Digital low-pass and high-pass filters of biorthogonal spline (2, 2) used for synthesis

Table 4

Comparison of factors of image quality for orthogonal and biorthogonal wavelets

Wavelet families	Orthogonal wavelets			Biorthogonal wavelets		
	Coiflet 12	Daubechies 12	Symlet 12	CDF 5/3	Biorthog. Spline 5/3	CDF 9/7
vanishing moments	6	6	6	2, 2	2, 2	4, 4
rmse	0,045	0,045	0,044	0,052	0,066	0,054
PSNR (dB)	26,97	26,88	27,05	25,71	23,65	25,34
Entropy (bit)	6,256	6,334	6,276	5,955	6,194	5,853
Correlation	0,989	0,989	0,990	0,986	0,977	0,985

Conclusions. Image compression and its clearing by method discrete wavelet transform can significantly reduce the size of a 2-D image (up to 6 times). Such a radical reduction of information can be very useful in many cases, under condition that it is not accompanied by significant losses in image quality.

Many scientists working in this field, are trying to find the optimal wavelet for image processing. However, the analysis showed that the reconstructed image quality parameters for different families of wavelets are almost indistinguishable. Besides, comparison of factors of image quality for orthogonal and biorthogonal wavelets shows, that biorthogonal wavelets have not advantages over orthogonal wavelets in our case study.

Research has shown that with increasing length of the digital filters factors of image quality are better. However, a compromise between quality factors (longer filters) and the computing duration (shorter filters) needs to be found.

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Шиян І., асп., Чуйко Г., д-р фіз.-мат. наук,
Павленко А., магістрант, каф. медичних приладів і систем, факультет еколого-медичних наук
Чорноморський державний університет імені Петра Могили

ЦИФРОВА ОБРОБКА МЕДИЧНИХ ЗОБРАЖЕНЬ ЗАСОБАМИ СКМ MAPLE

Більшість медичних зображень зазвичай представлені в сірих відтінках, а їх матриці інтенсивностей пікселів зручні для цифрової обробки. Останні версії популярної системи комп'ютерної математики Maple мають спеціальні програмні пакети для вирішення таких задач. В даній роботі проілюстровані можливості цих пакетів на прикладі типового медичного зображення. Для цифрової обробки зображення використовувалися засоби дискретного вейвлет-перетворення, процедури трешолдінгу (так званого "жорсткого порогу") та проводилася оцінка якості відновленого зображення. Крім того в роботі проведений аналіз залежності параметрів якості зображення від цифрових фільтрів, використовуваних у процедурі дискретного вейвлет-перетворення.

Ключові слова: *медичне зображення, дискретне вейвлет-перетворення, дворівневе розкладання, трешолдінг, параметри оцінки якості зображення.*

Шиян И., асп., Чуйко Г., д-р физ.-мат. наук,
Павленко А., магістрант, каф. медицинских приборов и систем, факультет эколого-медицинских наук,
Черноморский государственный университет имени Петра Могилы

ЦИФРОВАЯ ОБРАБОТКА МЕДИЦИНСКИХ ИЗОБРАЖЕНИЙ МЕТОДАМИ СКМ MAPLE

Большинство медицинских изображений обычно представлены в серых оттенках, а их матрицы интенсивностей пикселей удобны для цифровой обработки. Последние версии популярной системы компьютерной математики Maple имеют специальные программные пакеты для решения таких задач. В данной работе проиллюстрированы возможности этих пакетов на примере типового медицинского изображения. Для обработки изображений использовались средства дискретного вейвлет-преобразования, процедуры трешолдинга (так называемого "жесткого порога") и проводилась оценка качества восстановленного изображения. Кроме того, в работе проведен анализ зависимости параметров качества изображения от цифровых фильтров, используемых в процедуре дискретного вейвлет-преобразования.

Ключевые слова: *медицинское изображение, дискретное вейвлет-преобразование, двухуровневое разложение, трешолдинг, параметры оценки качества изображения.*

UDC 539.1

V. Iakovenko, Ph.D., High Energy Physics Department,
Kiev Institute for Nuclear Research, Cancer Center "Innovacia";
A. Kovalchuk, Chief engineer, V. Pugatch, Prof., O. Okrimenko,
Lead engineer, High Energy Physics Department, Kiev Institute for Nuclear Research;
I. Sorokin, Ph.D., High Energy Physics Department, Kiev Institute for Nuclear Research,
3GSI Helmholtz Centre for Heavy Ion Research; Y. Prezado, Ph.D., I. Martinez-Rovira, Ph.D.,
Department of Imaging and Modeling in Neurobiology and Oncology, CNRS, France;
A. Iliukhina, stud., Physical Faculty, Taras Shevchenko National University of Kyiv

METAL MICRO-DETECTORS FOR IMAGING AND BEAM PROFILE MONITORING IN RADIATION THERAPY

Metal micro-detector (MMD) has been developed at Kiev Institute for Nuclear Research (KINR). Physics and techniques of this detector applied for monitoring and imaging of charged particles beams are presented. To provide the precise beam profile monitoring a 128-channel X-Y MMD was produced. Test studies with this detector were performed for 20 MeV electrons (Cancer Center "Innovacia") and high energy hadrons (protons, ^{12}C-ions and ^{16}O-ions, Heidelberg Ion-Beam Therapy Center). Results of these studies are discussed in this work. The results of our studies suggest the possibility of MMD application in clinical practice.

Key words: *metal micro-detectors, beam profile monitoring, online dose monitoring, mini-beam radiation therapy.*

Introduction. The main goal of radiotherapy is to deposit a high dose of ionizing radiation in a tumor while keeping the absorbed dose in the surrounding healthy tissue at a tolerant level [1]. The monitoring of the beam position and absorbed dose are essential. Current developments in radiation therapy require non-destructive beam profile monitoring in real time, as beam diagnostics provides information on the status of the beam, monitoring of critical parameters and alarming in case of emergency. For low intensity beams a proper approach could be realized by using silicon micro-strip detectors. However, radiation hardness aspect makes this approach rather limited.

A Metal Foil Detector (MFD) technology developed at Kiev Institute for Nuclear Research makes possible the production of radiation hard monitoring devices that are able to take a challenge and fulfill the needs of modern radiotherapy.

The general physics and registration principles of the MFD are discussed in details elsewhere [2]. Charged particles (or photons) hitting the metal sensor-foil initiate Secondary Electron Emission at 10–50 nm surface layers. The charge generated in a sensor is measured by a sensitive Charge Integrator.

MFD technology was successfully explored for the design and production of a novel thin metal micro-strip beam profile monitors of charge particles and synchrotron radiation beams. Through an innovative plasma-chemistry etching process, thin (about 1 μm) metal micro-strips are aligned, without any other materials in the working area. The main advantages of MMD are: low thickness of detecting material; good position resolution (up to few μm); low operating voltage (~ 20 V); high radiation tolerance (at gigarads level). MMD were tested at the Minibeam Radiation Therapy (MBRT) setup (Bio-Medical Beamline