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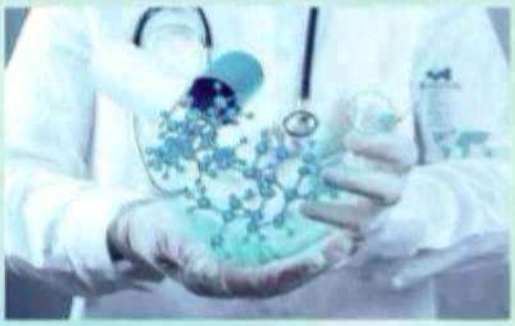

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AUTOMATED DETERMINATION OF SPERMATOZOA VITALITY BASED ON DIGITAL ALGORITHMS OF COLOR SIGNAL PROCESSING

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✓ ***Resume***

This article investigates the structure and practical implementation of a digital color signal processing algorithm utilizing the Daubechies wavelet, with specific applications in andrology and reproductive medicine. Color signals employed to assess spermatozoa vitality served as the primary experimental subject. Evaluation of sperm vitality represents a critical parameter in semen analysis, providing essential information regarding male fertility, defined as the ability to fertilize an oocyte. The proposed algorithm facilitated microscopic registration of color signals from cells, focusing on spermatozoa stained with specialized staining techniques. To estimate error, the absolute error of the Daubechies wavelet relative to the actual signal was calculated using results obtained through the Python programming language.

Keywords: male infertility, sperm vitality, spermogram, wavelet transform, interpolation, interpolation error, Daubechies wavelet, absolute error.

АВТОМАТИЗИРОВАННОЕ ОПРЕДЕЛЕНИЕ ЖИЗНЕСПОСОБНОСТИ СПЕРМАТОЗОИДОВ НА ОСНОВЕ АЛГОРИТМОВ ЦИФРОВОЙ ОБРАБОТКИ ЦВЕТОВЫХ СИГНАЛОВ

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✓ ***Резюме***

В статье отражены структура и практическое применение в андрологии и репродуктологии алгоритма цифровой обработки цветовых сигналов в вейвлете Добеши. В качестве объекта для экспериментальной оценки были использованы цветовые сигналы, позволяющие определять жизнеспособность сперматозоидов. Оценка жизнеспособности сперматозоидов представляет собой один из значимых параметров спермограммы, позволяющий делать соответствующие выводы относительно мужской фертильности – способности к оплодотворению и зачатию детей. В соответствии с предложенным алгоритмом осуществлялась микроскопическая регистрация цветовых сигналов от клеток – определённым образом окрашенных сперматозоидов. При оценке ошибки абсолютная ошибка вейвлета Добеши по отношению к реальному сигналу давалась на основе результата, полученного в среде языка программирования Python.

Ключевые слова: мужское бесплодие, жизнеспособность сперматозоидов, спермограмма, вейвлет-преобразование, интерполяция, ошибка интерполяции, вейвлет Добеши, абсолютная ошибка.

RANGLI SIGNALLARNI RAQAMLI QAYTA ISHLASH ALGORITMLARI ASOSIDA SPERMATOZOIDLAR HAYOTIYLIGINI AVTOMATLASHTIRILGAN TARZDA ANIQLASH

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✓ ***Resume***

Ushbu maqolada andrologiya va reproduktiv tibbiyotda Dobeshi veyvletiga asoslangan rangli signallarni raqamli qayta ishlash algoritmining tuzilishi va amaliy qo'llanilishi tasvirlangan. Eksperimental baholash obyekti sifatida spermatozoidlarning hayotiyligini aniqlash uchun ishlatiladigan rangli signallar ishlatilgan. Spermatozoidlar hayotiyligini baholash spermogrammaning muhim parametri bo'lib, erkaklarning fertilligi to'grisida xulosalar chiqarish imkonini beradi. Taklif qilingan algoritm hujayralardan, xususan, ranglangan spermatozoidlardan olingan rangli signallarini mikroskopik ravishda qayd etish uchun ishlatilgan. Xatolikni baholash uchun Dobeshi veyvletining haqiqiy signalga nisbatan mutlaq xatosi Python dasturlash tilida olingan natijadan foydalanib hisoblab chiqilgan.

Kalit so'zlar: erkaklar bepushtligi, spermatozoidlar hayotiyligi spermogramma, wavelet transformatsiyasi, interpolatsiya, interpolatsiya xatosi, Dobeshi veyvleti, mutlaq xato.

Relevance

Digital one- and two-dimensional medical data analysis software utilizing wave-based techniques can accelerate the identification of specific pathological abnormalities, broaden the range of the examined population, and enhance opportunities for early disease diagnosis. These advancements are particularly relevant to contemporary medicine, especially within clinical disciplines such as andrology and reproductology [4,5].

The assessment of spermatozoa vitality is a crucial parameter in the diagnosis of male fertility and is routinely conducted in andrological laboratories and medical institutions specializing in IVF (in vitro fertilization) technologies. Spermatozoa vitality is typically evaluated by measuring membrane integrity and can be assessed in all ejaculates. However, this assessment is not necessary when at least 40% of spermatozoa demonstrate motility. In samples with reduced motility, the vitality test is essential for distinguishing between immotile dead sperm and immotile live sperm [2,6].

Assessment of spermatozoa vitality relies on the presence of an intact cell membrane, which distinguishes live from dead cells. The integrity of the cell membrane is evaluated using specific dyes. When membrane integrity is compromised, the dye penetrates and stains the cell, indicating a dead cell. Conversely, an intact cell membrane prevents dye entry, resulting in an unstained, viable cell. Eosin-nigrosin staining is commonly employed for this purpose, although eosin staining alone is also utilized. In the two-step technique, eosin is added for 30 seconds, followed by nigrosin, or a pre-mixed combination of both dyes may be applied simultaneously (one-step technique). As an alternative to dye exclusion, the hypo-osmotic swelling test may be used to assess vitality. This test is used when staining of spermatozoa must be avoided, e.g. when choosing spermatozoa for intracytoplasmic sperm injection (ICSI). The hypo-osmotic swelling test presumes that only cells with intact membranes (live cells) can swell in hypotonic solutions. Spermatozoa with intact membranes swell within 5 minutes in hypo-osmotic medium, and all flagellar shapes are stabilized by 30 minutes [6].

Cell counting is typically performed manually with a laboratory calculator [5]. This process is time-consuming and can lead to fatigue among medical personnel. Human involvement introduces potential errors in laboratory counting, making the elimination of such issues a pressing concern [7].

The implementation of automated systems for the calculation and analysis of medical signals enhances both efficiency and accuracy. Specifically, the development of mathematical models, algorithms, and software utilizing Coiflet waves has enabled highly accurate calculations and significant time savings.

The aim of the study is to investigate the automated determination of sperm viability based on digital color signal processing algorithms.

Materials and methods

1. Extent of research on the problem.

The development of one- and two-variable wave models and digital signal processing algorithms has been extensively addressed in the global scientific literature, including research conducted in Uzbekistan. Notable contributions to digital signal processing in wave models have been made by international researchers such as A. Haar, I. Daubechies, R. Coifman, Yu.S. Zavyalov, V. Michael, and G. Strang. In Uzbekistan, significant research on digital signal and image processing modeling has been conducted by M.M. Musaev, K.N. Zaynidinov, J. Jurayev, U.R. Khamdamov, and others [7,8,9].

The application of similar algorithms for assessing sperm vitality was initiated and implemented at the Department of Urology, Samarkand State Medical University, and the private medical clinic "Euromedik." Supporting documentation includes Implementation Certificate No. 1 dated November 21, 2023, and Rationalization Proposal No. 1935 dated May 14, 2024 (authors: R.R. Gafarov, L.Ya. Khuramov, Sh.U. Urakov).

2. Methods of sperm processing and spermatozoa staining

Sperm vitality was assessed using the eosin-nigrosin staining method, a one-step technique that employs an eosin-nigrosin suspension. This procedure is detailed in the 6th edition of the World Health Organization (WHO) laboratory manual for the examination and processing of human semen. In this method, eosin penetrates non-viable spermatozoa, staining them red or dark pink, while viable spermatozoa remain unstained. Nigrosin serves as a contrast dye, providing a dark background that enhances visualization of unstained live spermatozoa. Semen is classified as normal if the proportion of viable spermatozoa is at least 58%. A diagnosis of necrozoospermia is made when fewer than 58% of spermatozoa are viable. During eosin-nigrosin staining, a minimum of 200 spermatozoa are counted to determine the ratio of live to dead cells [1,3].

3. A model for analyzing one- and two-wave signals based on a Coiflet wavelet

Ψ(x) of the function zero moments smoothing in the function *J* increase in value with $Q_{j,k} = (\mathrm{f}, \Psi_{j,k})$ wavelet of the function coefficients decreases and the function becomes well approximated (smooth). However, this hello $P_{j,k} = (\mathrm{f}, \varphi_{j,k})$ scaling of the function does not belong to the coefficients. If it is required to satisfy the following zero moments (1):

$$\int_{-\infty}^{\infty} x^k \, \varphi(x)dx \; = 0, k = 1, \dots, N-1 \; (1)$$

In this case, we can apply the expansion theorem according to the Taylor formula, we give the expansion of the function f(x) according to the Taylor formula as follows (2)

$$f(x) = f(x_0) + f(x_0)(x - x_0) + \cdots + \frac{f^{N-1}(X_0)}{(N-1)!}(x - x_0)^{N-1} + g(x)(x - x_0)^{N-1} \; (2)$$

$\varphi_{j,k}$ function x_0 point around (1) according to the formula we get (3)

$$P_{j,k} = \left(f, \varphi_{j,k}\right) = \left(f\ (\mathrm{x}_0), \varphi_{\mathrm{j,k}}\right) + g(x)\ (x - x_0)^{N-1}, \varphi_{j,k})) \approx$$

$$\int_R f(x_0)\sqrt{2^j}\ \varphi\left(2^j x - k\right)dx = f(x_0)\sqrt{2^j}\int_R \varphi\left(2^j x - k\right)dx = \frac{1}{\sqrt{2^j}} f(x_0)$$

The last one we $\int_{-\infty}^{\infty} \varphi(\mathrm{x})\mathrm{dx} = 1$ consider that in equality.

Suppose f(x) is a vector function x_0=0 is pointed around. In that case $\varphi_{j,k} = \sqrt{2^j}\,\varphi(2^j x - k)$function $x_{j,k}$= $\frac{k}{2^j}$ around $f(x)$ to the fuction 2^jwill be smoother.

P = $_{j,k}f, \varphi_{j,k}(f, \varphi_{j,k})$ the coefficient of the scaling function to find for $x_0 = x_{j,k}$, k=$\frac{k}{2^j}$ pointed around that is necessary to the Taylor series spread. In that case $f(x)$ smoothing function j for (4) we have the approximate equality.

$$P_{j,k} = \left(f, \varphi_{j,k}\right) \approx \frac{1}{2^j}(f\ (2^{-J}\ k)\ (4)$$

low transmitter scaling function coefficient $f(x)$ function to choose provides an efficient way to switch. That's why for Ψ(x) wave function will also have zero moments and a function f(x). From here the following compact carrier Ψ(x)and $f\,(x)$ functions is determined. For this, the following equations (5) and (6) must be presented:

$$\int_{-\infty}^{\infty} x^k\,\varphi(x)dx\ = 0, k = 1, \dots, N-1\ (5)$$

$$\int_{-\infty}^{\infty} \varphi(x)dx\ = 1,\ \int_{-\infty}^{\infty} \varphi(x)dx = 0, k = 1, \dots\ N-1\ (6)$$

Equations (5) and (6) denote N number of coiflet waves of order N.

Now we write the scaling and wave equation to construct the Coiflet wavelet

$$\Psi(x) = \sum_r s(r)\ \sqrt{2\varphi(2x-r)}\ (14)$$

$$\varphi\,(x) = \sum_r e(r)\ \sqrt{2\varphi(2x-r)}$$

Here
x - time parameter.

Ψ(x)- at x- time wave is used to analyze and synthesize high-frequency values of the input signal

$\varphi\,(x)$ - at x- time scaling is used for analysis and synthesis of low-frequency values of the input signal

$s(r)$ - Wave of the function filter coefficients

$e(r)$ - Scaling of the function filter coefficients

The scaling function requires the following condition (15)

$$\varphi\,(x) = \begin{cases} 1\ if\ \frac{r}{2} \le \mathrm{x}\ <\ \frac{1+r}{2} \\ 0\ if\ >\frac{r}{2}\ x\ or\ x\ \ge\ \frac{1+r}{2} \end{cases};\ \mathrm{r} = 0,1\dots,\ \mathrm{N\text{-}1}\ (15)$$

(14) in view Ψ(x), $\varphi\,(x)$ -x in time we give the equation of the wave and scaling functions, we get N=6, this coiflet means 6 coefficients.

$\psi(t)$=$e_0\sqrt{2}\varphi(2t) + e_1\sqrt{2}\varphi(2t-1) + e_2\sqrt{2}\varphi(2t-2) + e_3\sqrt{2}\varphi(2t-3) + e_4\sqrt{2}\varphi(2t-4) + e_5\sqrt{2}\varphi(2t-5)$ (16)

$\varphi(t)$=$s_0\sqrt{2}\varphi(2t) + s_1\sqrt{2}\varphi(2t-1) + s_2\sqrt{2}\varphi(2t-2) + s_3\sqrt{2}\varphi(2t-3) + s_4\sqrt{2}\varphi(2t-4) + s_5\sqrt{2}\varphi(2t-5)$ *(16)*

of the form from equality wave $s(r)$ and scaling $e(r)$ the coefficients of the functions are determined as follows

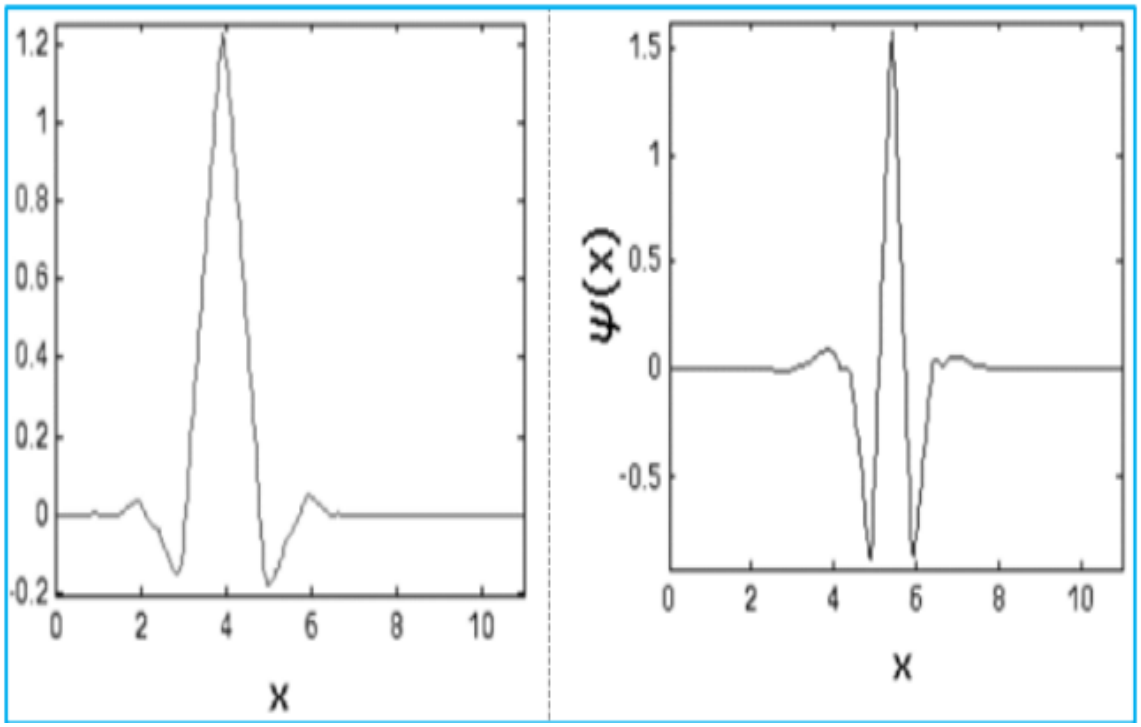
$s(r) = (-1)^r \cdot e[N-1-r]$; $e(r) = (-1)^r \cdot s[N-1-r]\ (-1)^{N-1}$ (17)

Here
N is the number of coefficients

s(r)- coiflets for scaling filter coefficient of the function

e(r)- coiflets for wave filter coefficient of the function

H_0 in appearance polynomial obtained using wavelet functions N = 2 are called tiered Coiflets (Figure 1).



(17) the coefficients of the scaling function Coif6 were determined from the equation (18)

$$s_0 = \frac{1-\sqrt{7}}{16\sqrt{2}};\ s_1 = \frac{5+\sqrt{7}}{16\sqrt{2}};\ s_2 = \frac{14+2\sqrt{7}}{16\sqrt{2}};\ s_3 = \frac{14-2\sqrt{7}}{16\sqrt{2}};\ s_4 = \frac{1-\sqrt{7}}{16\sqrt{2}};\ s_5 = \frac{-3+\sqrt{7}}{16\sqrt{2}} \quad (18)$$

The coefficients of the wave function coif6 are found based on the scaling function and it takes the following values:

$$e_0 = s_5 = \frac{-3+\sqrt{7}}{16\sqrt{2}};\ e_1 = -s_4 = \frac{-1+\sqrt{7}}{16\sqrt{2}};\ e_2 = s_3 = \frac{14-2\sqrt{7}}{16\sqrt{2}};$$

$$e_3 = -s_2 = \frac{-14-2\sqrt{7}}{16\sqrt{2}}\ e_4 = -s_2 = \frac{1-\sqrt{7}}{16\sqrt{2}}\ e_5 = -s_0\ \frac{-3+\sqrt{7}}{16\sqrt{2}} \quad (19)$$

Results. Digital processing and determination of spermatozoa vitality based on Coiflet wavelet imaging provided in laboratory conditions is presented below (Fig. 2).

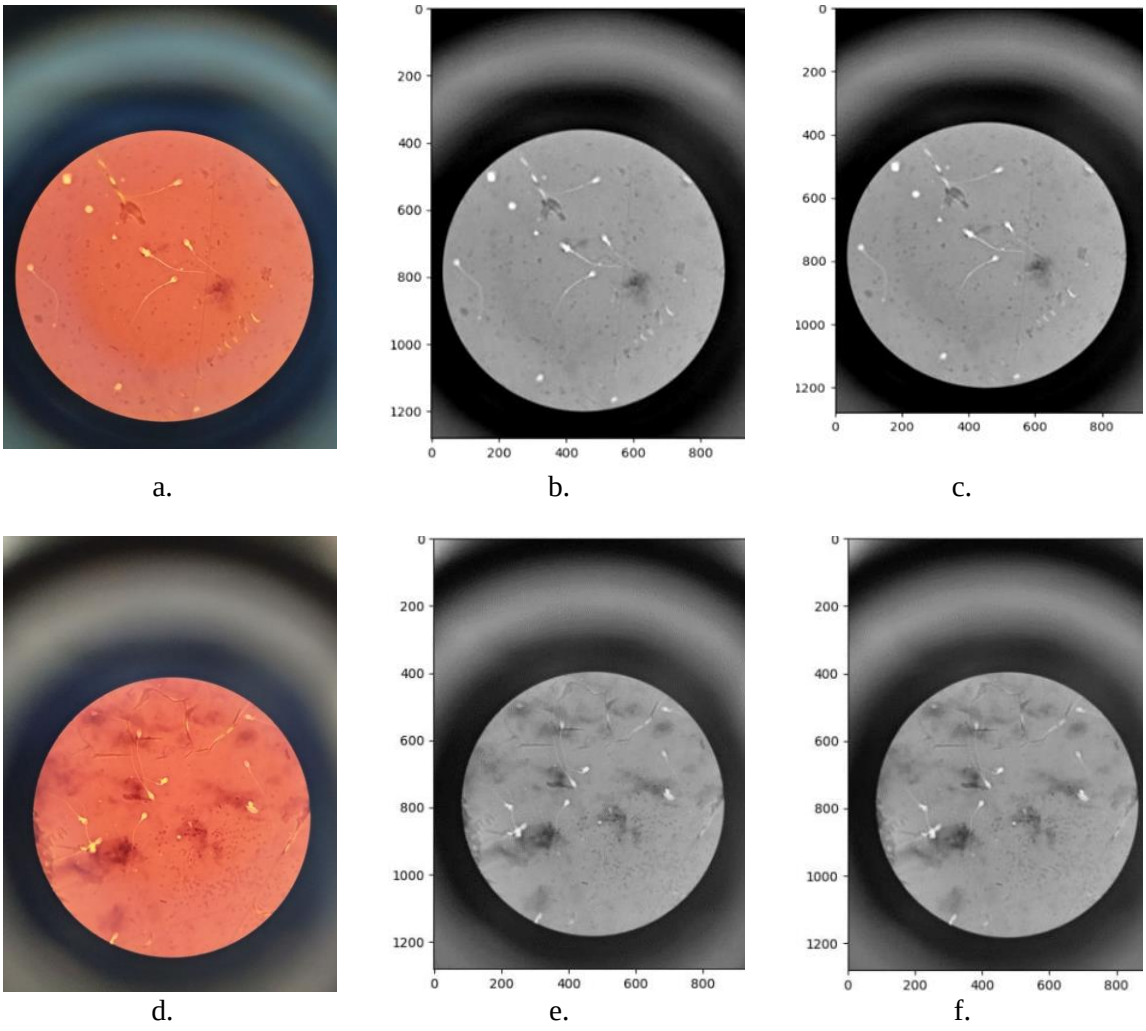


Figure 2. a,d - initial color image; b,e - initial monochrome image; c,f - reconstructed image.

Evaluation. Spermatozoa have been taken as an experiment, spermogram of the image high-order Gaussian noises were used in the evaluation. The quality indicator of the digitally processed image compared to the restored image is measured by the peak signal-to-noise ratio (PSNR) equation (20) and the result is measured in decibels (dB) in Table 1:

Table 1. PSNR and the size of the reconstructed image using various Haar, Daubechies and Coiflet wavelets.

Type of Wavelets	*a
PSNR (dB)	31.23
Size (kilobytes)	37.2

**a - Coiflet*

Table 1 shows the numerical analysis results of the Coiflet wavelet when the threshold of the semen analysis image is 4 and 4.

Conclusions

This research investigates the digital processing of color signals to determine spermatozoa vitality. The methodology utilizes the Coiflet wavelet, a specific type of wavelet known for its high accuracy and efficiency. Microscopic images of spermatozoa obtained from patients with various andrological pathologies were collected under laboratory conditions and processed to remove both artificial and

natural redundancies. Preliminary results indicate that spermatozoa vitality can be determined with approximately 94% accuracy.

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