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Optical methods of measuring the hair diameter

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Abstract

When dealing with various tasks of medicine, in mathematical modelling of processes in the human body, it is necessary to know the physical parameters of biological tissues. In cosmetology and dermatology, these are the physical properties of hair – diameter, density, heat capacity, thermal conductivity, and optical parameters. Existing methods can solve the problem of measuring these parameters, but as a rule, they take a great deal of time and resources. Therefore, the purpose of this paper is to develop and study fast and cheap optical methods for measuring the diameter of a human hair using computer methods for processing the results of the experiment.

Several methods for measuring the diameter of a human hair have been studied. The hair diameter was measured by analysing the pattern of laser scattering and using a microscope with a digital attachment and an eyepiece micrometer. Measurements by diffraction methods are consistent with each other within the limits of errors. Measurements using PAINT program are a little more accurate (the average error is 0.7 μm) than using MATHCAD program (the average error is 1.3 μm). Measurements using MATHCAD program are more complicated. Therefore, of the two remaining methods, the first one is preferable. Measurements using a microscope require more manual work; especially focus adjustment, which, with a large magnification of the lens (20x – 40x), is a time-consuming operation. The measurement error (1 μm) is comparable with the error of diffraction methods. Thus, of the four methods considered, the diffraction method with the processing results using PAINT program, which is included with all versions of Microsoft Windows system, has the greatest advantages, in contrast to the paid MATHCAD program, which has be installed on a computer.

Keywords: hair; diameter; measurement; optical methods; computer processing.

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Introduction

When dealing with various tasks in biology and medicine, the mathematical modelling and methods of computer processing of experimental data are currently used. To develop mathematical models describing the propagation of light in biological tissues, it is necessary to know their optical parameters, which characterize light absorption and scattering. For example, the use of lasers in cosmetology and dermatology is gaining more and more popularity, which raises the problem of determining the optimal parameters for the effect of laser radiation on human hair. This, in turn, requires the development of fast and cheap means of controlling the optical characteristics of the hair [1–4]. This paper describes the use of computer mathematical methods for determining the parameters of human hair, in particular, measuring its diameter.

In Fig. 1 the structure of the hair is shown.

The outermost part of the hair (cuticle) is a dense covering formed by flat cells overlapping in layers like in a tiled roof. The cells are arranged in 6–9 layers. They consist of keratin and proteolipids, which form a hydrophobic hair coating and contain horn substances that provide mechanical protection to the inner layers. The organic components of the cuticle are fats, proteins, and wax-like substances that provide the hair with elasticity and gloss. The condition of

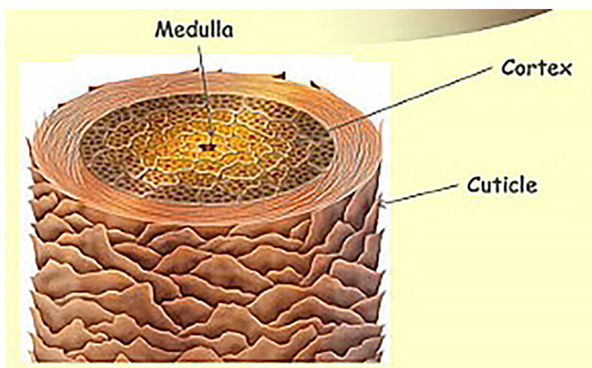
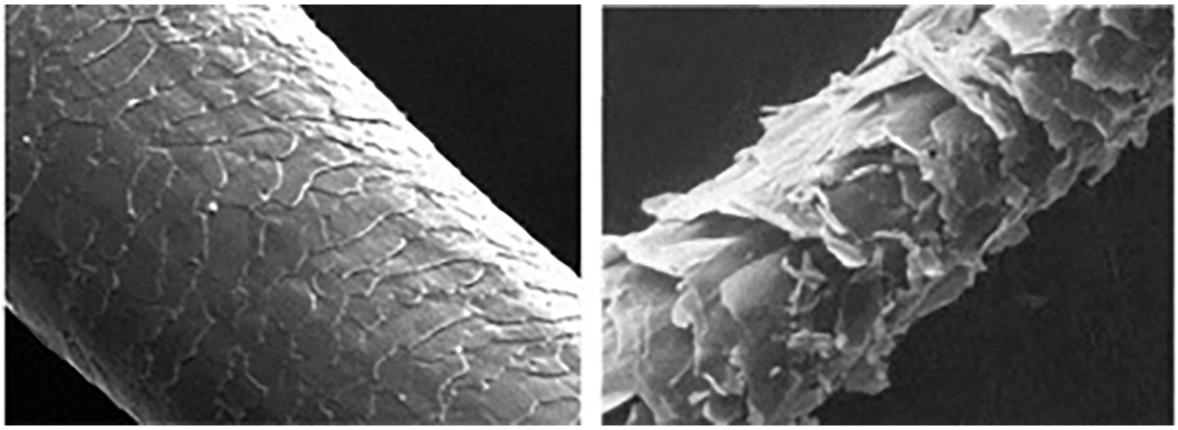


Fig. 1. Hair structure



a *b*

Fig. 2. Healthy (*a*) and unhealthy (*b*) hair

the cuticle is an important diagnostic feature. In cases of many diseases, it is impaired, because a sufficient amount of vitamins and other substances ceases to flow to their inner and outer layers. In this case, the outer cells die off, and the surface of the hair loses its smooth structure (Fig. 2).

The condition of the outer surface of the hair strongly influences its light absorption and scattering.

The inner part of the hair (cortex) is formed by keratinized fibres surrounded by the cells responsible for hair metabolism and morphology. The cortex accounts for approximately 90% of the hair mass. It contains melanin granules.

Hair colour is determined by the concentration and type of melanin:

– eumelanin, which colours hair black and brown;

– pheomelanin, which makes hair fair.

In grey hair, melanin disappears because it stops being synthesized in hair follicles, and the amount of hydrogen peroxide in them sharply increases. That is, natural hair discolouration is due to the same reagent that helps women become fair-haired. A large number of air cells appear at the same time, which also makes hair fair.

Thus:

- the light absorption in hair is determined by the amount and type of melanin it contains [5];
- light scattering is determined by keratin scales of the cuticle and melanin granules in the cortex [6].

In grey hair, light scattering also occurs on air bubbles inside the hair that are formed as a result of the destruction of melanin granules.

By measuring the scattering diagram and factors of light absorption and scattering, the medical condition of the hair can be determined.

Proposed methods

The diameter of a human hair ranges from 50 to 300 microns. It can be measured with a mechanical micrometer. However, since the graduation of an ordinary micrometer is 10 microns, the error in measuring the diameter of a thin hair is large – about 10%. Therefore, it is advisable to use measurement methods like microscopy or methods based on light diffraction.

1. Diffraction method

A block diagram of the experimental setup for measuring the diameter of a hair is shown in Fig. 3.

The radiation of laser 1 is directed to the hair under consideration 2. The diffraction pattern 4 of the light scattered by the hair is observed on screen 3. It is a series of alternating light and dark areas situated symmetrically on both sides of the central spot.

A photo of the diffraction pattern of an 18-year-old brown hair (sample 11), taken with a digital camera, is shown in Fig. 4. At the bottom of the photo, there is a scale bar.

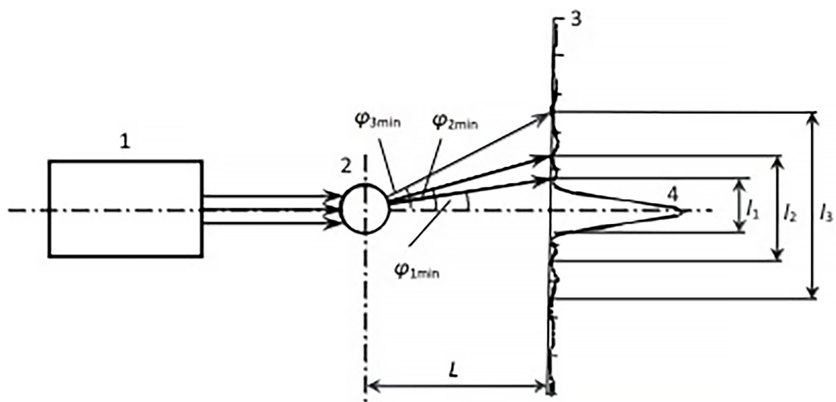


Fig. 3. Block diagram of the experimental setup: 1 – laser, 2 – hair, 3 – screen, 4– diffraction pattern

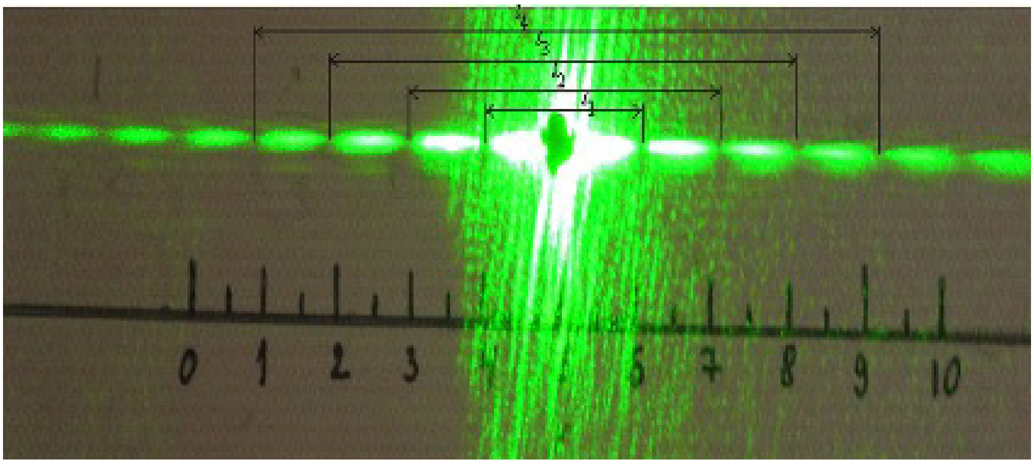


Fig. 4. Diffraction of laser radiation on the hair

It is known from the theory of diffraction that the diameter of a cylinder can be calculated by the formula

$$d = \frac{k\lambda}{\varphi_{k\,\min}}, \qquad (1)$$

where λ is the laser radiation wavelength, k is the order of the diffraction minimum, and $\varphi_{k\min}$ is the angle of the diffraction minimum of the order of k.

Angles $\varphi_{k\min}$ are calculated by the formula:

$$tg(\varphi_{k\,\min}) = \frac{l_k}{2L}, \qquad (2)$$

where L is the distance from the hair to the screen, l_k are the distances between symmetric minima of the order of k (they are shown in Fig. 4 – l_1, l_2, l_3, l_4).

Diffraction patterns were processed in two ways:

– using PAINT program;

– using MATHCAD program.

1.1. *Processing measurement results with PAINT program*

1. The diffraction pattern is placed in the PAINT window. The horizontal coordinates of the cursor are determined at the beginning and at the end of the scale of 100 mm long.

2. The number of pixels, which fit within the length of 1 mm, is determined.

3. The coordinates of the minima of the diffraction pattern are determined, and the distances l_1, l_2, l_3, etc. are measured.

4. According to formulae (1) and (2), the values of the hair diameters d_1, d_2, d_3, etc., corresponding to the values of l_1, l_2, l_3, etc. are calculated.

5. The value of measurement error Δd is found according to the rules for processing the results of a number of measurements.

As a result of the diffraction pattern processing shown in Fig. 4, we obtain:

$$d = 72.0 \pm 0.2 \ \mu\text{m}.$$

1.2. *Processing measurement results with MATHCAD program*

1. The pattern and graphs of the scale bar and diffraction maxima and minima are shown in Fig. 5.

2. The TRACE command determines the horizontal coordinates of two adjacent minima on the “Scale” graph, separated at the distance of 10 mm from each other, and calculates the number of pixels at 1 mm interval.

3. The “Diffraction pattern” graph contains the distances l_1, l_2, l_3, etc. in pixels and in millimetres.

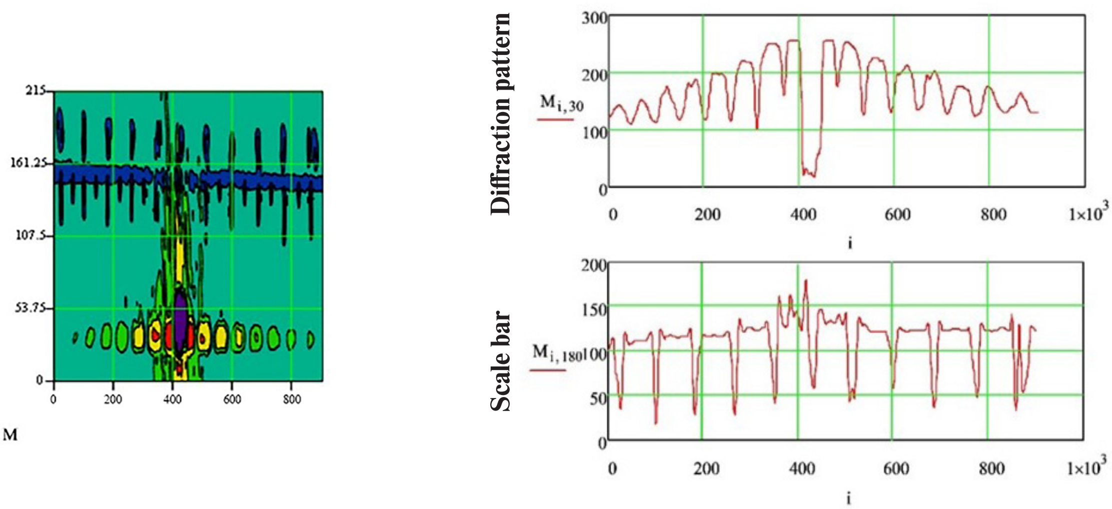


Fig. 5. Window of MATHCAD program

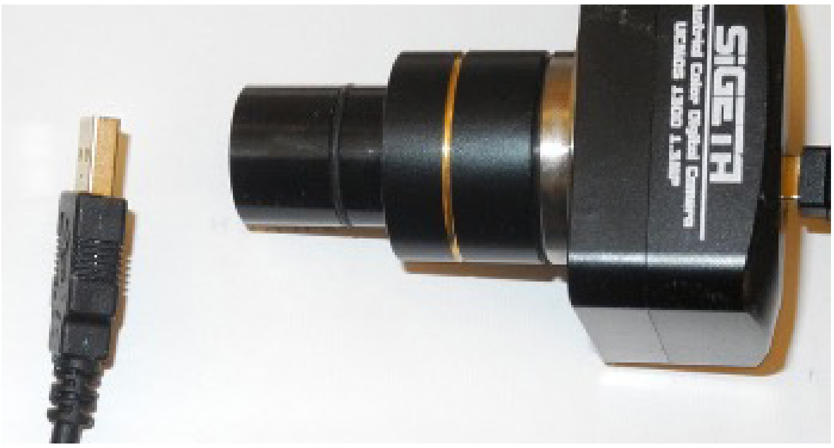


Fig. 6. USB attachment to the microscope

4. According to formulae (1) and (2), the values of the hair diameters d_1, d_2, d_3, etc., corresponding to the values of l_1, l_2, l_3, etc. are calculated.

5. The value of measurement error Δd is estimated.

The results of the pattern processing shown in Fig. 5 are as follows:

$$d = 72 \pm 1\ \mu\text{m}.$$

These results are consistent with the results shown above, but the measurement error is somewhat greater.

2. Microscopy method

2.1. ***Measurements using a microscope and digital attachment***

An optical biological microscope with lens of 10x, 20x and 40x magnification was used. The digital attachment **Sigeta UCMOS 1300** (Fig. 6) allows obtaining a digital image of an object and write it into the computer memory.

The photos of two hair samples and a scale bar with the graduation of 10 μm are shown in Fig. 7.

Using PAINT program, the pixel graduation of the scale bar was determined, and the hair diameter was calculated using a method similar to that described in paragraph 1.1:

$$d = 70 \pm 1\ \mu\text{m}.$$

2.2. ***Measurements using a microscope and eyepiece micrometer***

The eyepiece micrometer MOB-1-15x (Fig. 8) has a scale, the graduation of which depends on the magnification of the lens. With a 20x magnification lens, the value of one division on the scale is approximately 0.5 μm. The micrometer was accurately calibrated using the scale shown in Fig. 7.

The diameter of the hair, which was analysed by the previous methods (sample 11), turned out to be equal

$$d = 74 \pm 1\ \mu\text{m}.$$

The errors of both measurement methods with a microscope are determined by the scale graduation and are approximately ± 1 μm.

Results and discussion

For the experiments, hair samples of two 18- and 45-year-old brown-haired people, an 18-year-old fair-haired girl, an 18-year-old dark-haired girl, an 11-year-old red-haired girl and a 79-year-old grey-haired man.

The results of the measurements by four methods are shown in Table 1.

The diffraction measurements are consistent with each other within the error limits. Measurements

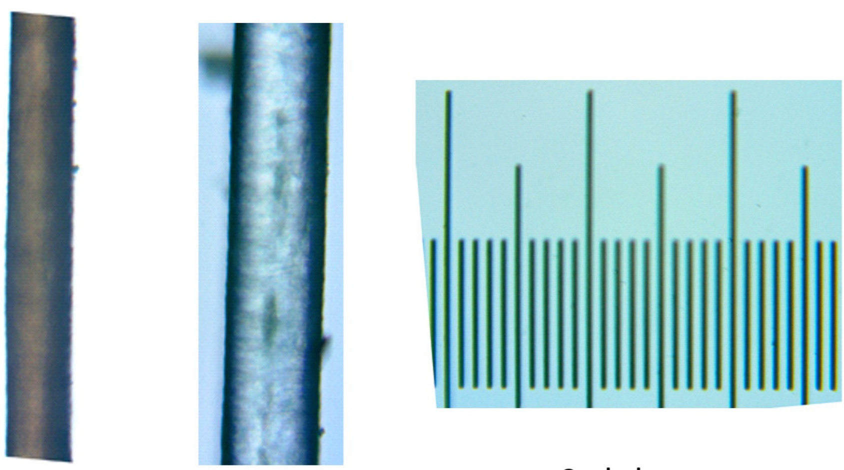


Fig. 7. Photomicrograph of hair

Fig. 8. The eyepiece micrometer

using PAINT program are somewhat more accurate (the average error value is 0.7 µm) than using MATHCAD program (the average error value is 1.3 µm). Measurements with MATHCAD are more complicated. Therefore, of the two methods, the first one is preferred.

Measurements using a microscope require more manual work; especially focus adjustment, which, with a large magnification of the lens (20x – 40x), is a time-consuming operation. This is a distinct disadvantage of such methods. The measurement error is comparable to the error of diffraction methods.

Table 1 shows that some results of the measurements with a microscope are very different from the results obtained by diffraction methods. This may be due to the difficulty of focusing the lens on an object comparable in size to the depth of the lens focus.

Conclusions

1. Methods for measuring the diameter of fine fibres, in particular, the diameter of human hair, have been studied.

Measurements by diffraction methods are consistent with each other within the error limits. Measurements using PAINT program are somewhat more accurate (the average error value is 0.7 µm) than using MATHCAD program (the average error value

Table 1

Hair Diameter Measurement Results

Sample	Sample characteristic	Diameter, micron			
		Diffraction method		Microscope	
		PAINT	MATHCAD	USB attachment SIGETA	Eyepiece micrometer MOB-1-15x
11	Dark-haired boy, 18 years old	72.0±0.2	72.0±1.0	70.0±1.0	74.0±1.0
12	Fair-haired girl, 18 years old	91.0±1.0	93.0±2.0	99.0±1.0	100.0±1.0
15	Dark-haired girl, 18 years old	96.0±1.0	95.0±1.0	96.0±1.0	85.0±1.0
16	Red-haired girl, 11 years old	46.0±1.0	46.0±1.0	48.0±1.0	57.0±1.0
17	Grey-haired man, 79 years old	62.0±1.0	61.0±1.0	61.0±1.0	54.0±1.0
18	Dark-haired man, 46 years old	54.3±1.0	55.0±1.0	52.0±1.0	43.0±1.0

is 1.3 μm). Measurements with MATHCAD are more complicated. Therefore, of the two methods, the first one is preferred.

2. Measurements using a microscope require more manual work; especially focus adjustment, which, with a large magnification of the lens (20x – 40x), is a time-consuming operation. This is a distinct disadvantage of such methods. The measurement error (1 μm) is comparable to the error of diffraction methods.

3. The diffraction method with the processing of the results using PAINT program, which is included with all versions of Microsoft Windows system, has the greatest advantages of the four considered methods.

Оптичні методи вимірювання діаметра волоса

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Анотація

При вирішенні різноманітних проблем медицини, при математичному моделюванні процесів в організмі людини необхідно знати фізичні параметри біологічних тканин. У косметології й дерматології це фізичні властивості волосся – його діаметр, щільність, теплоємність, теплопровідність, оптичні параметри. Існуючі методи дозволяють вирішити проблему їх вимірювання, але, зазвичай, з великими витратами часу й ресурсів. Тому метою цієї роботи є розробка та дослідження дешевих і швидких оптичних методів вимірювання діаметра волосся людини із використанням комп'ютерних методів обробки результатів експерименту.

Вивчено декілька методів вимірювання діаметра волосся людини. Проведено вимірювання діаметра волоса методом аналізу картини розсіювання лазерного випромінювання і за допомогою мікроскопа – із використанням цифрової приставки та окулярного мікрометра. Вимірювання дифракційними методами узгоджуються один з одним в межах похибки. Вимірювання за допомогою програми PAINT дещо точніше (середнє значення похибки – 0,7 мкм), ніж за допомогою програми MATHCAD (середнє значення похибки – 1,3 мкм). Вимірювання за допомогою програми MATHCAD складніші. Тому з цих двох методів перший є кращим. Вимірювання за допомогою мікроскопа вимагають більшої кількості ручної роботи – наведення на різкість, що при великій кратності об'єктива (20x – 40x) є трудомісткою операцією. Похибку вимірювань (1 мкм) можна порівняти з похибкою дифракційних методів. Таким чином, із чотирьох розглянутих методів найбільші переваги має дифракційний метод із обробкою результатів за допомогою програми PAINT, яка вбудована в WINDOWS, на відміну від MATHCAD, яку необхідно встановлювати у комп'ютер.

Ключові слова: волос; діаметр; вимірювання; оптичні методи; комп'ютерна обробка.

Оптические методы измерения диаметра волоса

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Аннотация

При математическом моделировании процессов в организме человека необходимо знать физические параметры биологических тканей. В косметологии и дерматологии это физические свойства волос – диаметр, плотность, теплоемкость, теплопроводность, оптические параметры. Существующие методы позволяют решить проблему их измерения, но, как правило, с большими затратами времени и ресурсов. Поэтому целью работы является разработка и исследование быстрых и дешевых оптических методов измерения диаметра волос человека с использованием компьютерных методов обработки результатов эксперимента.

Проведены измерения диаметра волоса методом анализа картины рассеяния лазерного излучения и с помощью микроскопа – с использованием цифровой приставки и окулярного микрометра. Измерения дифракционными методами согласуются друг с другом в пределах погрешностей. Измерения с помощью программы PAINT несколько точнее (среднее значение погрешности – 0,7 мкм), чем с помощью программы MATHCAD (среднее значение погрешности – 1,3 мкм). Измерения с помощью программы MATHCAD более сложные. Поэтому из этих двух методов первый предпочтительнее. Измерения с помощью микроскопа требуют большего количества ручной работы. Погрешность измерений (1 мкм) сравнима с погрешностью дифракционных методов. Таким образом, из четырех рассмотренных методов наибольшими преимуществами обладает дифракционный метод с обработкой результатов с помощью программы PAINT.

Ключевые слова: волос; диаметр; измерение; оптические методы; компьютерная обработка.

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