Bezugla N.V.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Yakovenko I.O.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Filippova M.V.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Poluektov S.O.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

AUTOMATED SYSTEM FOR PHOTOMETRIC IMAGES PROCESSING OF SCATTERING SPOT

The article discusses the methods and technical tools for scattering spot photometric imaging, obtaining and analyzing methods for assessing its qualitative and quantitative characteristics. The using photometric images of the scattering spot spatial analysis methods advantages are substantiated and given. The morphological features of normal and pathological tissues were analyzed, and their influence on the nature of scattered light for collagen fibers with chaotic and ordered orientation was substantiated.

The authors proposed an automated system scheme for measuring and processing photometric images, including a measuring unit for implementing the photometry by ellipsoidal reflectors and a unit for processing photometric images of the scattering spot. Based on the proposed scheme, the installation of the measuring unit, which allows for obtaining photometric images in reflected and transmitted light, was implemented, and the experiment's methodology was described. The basis of the image processing unit is the developed algorithm, which includes procedures for spatial analysis of the scattering spot by intersections. The software was developed in Python using the libraries and modules for file processing, creating a graphical interface, working with arrays, data analysis, and graphing. Examples of the functioning of the software for processing one and several images are given. The processing results were compared using similar apps to confirm the functional adequacy of the developed software.

The developed system allows for photometric images of the scattering spot comprehensive analysis depending on the task. The paper results are a graphic representation of the scattering spot in the form of the pixel brightness dependence on the spatial coordinate and the relative intensity value. These results can be obtained for the entire photometric image and its central section. Also, the developed software allows arithmetic operations (addition, subtraction, multiplication, division) on two images to highlight a proper signal on the background image, evaluate the influence of one image on the other, etc.

Key words: *photometric image, scattering spot, spatial distribution, photometry by ellipsoidal reflectors, Python, biological media.*

Formulation of the problem. A monochrome CCD camera is the most straightforward tool for obtaining photometric images of the scattering spot during laser irradiation of the biological media [1–2]. More complex systems based on the methods of photon correlation spectroscopy [3] and small-angle approximation [4–5] are used to obtain information about biological tissues at the microscopic level. In these works, the evaluation of the photometric image parameters consists in determining the scattering spot shape and size or additional analysis of the count and brightness of pixels in the obtained color images [4–5]. As shown in works [6–7], the spatial analysis

of the light distribution is also essential, allowing it to determine both the image shape and dimensions and to distinguish the distinct zones of bright pixels in the field of the photometric image. However, to determine the quantitative (pixel brightness) and qualitative (spatial distribution) characteristics of photometric images, various software tools are used to convert an image (.jpg, .bmp, .png) into a text file (.txt), determine the required intersection, build a spatial distribution of the entire image or characteristic cross-section, pixel brightness calculation.

Analysis of recent research and publications. From an optical point of view, the morphological

features of biological tissues (BT) are described by optical properties: scattering coefficient μ_s, absorption coefficient μ_a, scattering anisotropy factor g, and refractive index n. Pathological conditions in the tissues lead to changes in the structure and size of the cellular composition and partial or complete destruction of the surrounding tissues [1, 8], which in turn affects the optical properties [9–11] and manifests itself in light scattering during interaction with tissue [12, 13]. So, for example, the authors' works [1–2] show the influence of the collagen fiber orientation on the backscattered light nature presented by the monochrome photometric images. Thus, the scattering spot has an elongated shape for scar tissue with parallel fiber orientation. The scattering spot form is close to round for normal tissue with chaotic fiber orientation. In works [4, 5], the pixel brightness gradient determined differences in the fiber architecture of deformed fabrics. Also, the spatial distribution is cut off when examining samples of biological tissues with longitudinal and transverse fiber placement [14].

Analysis of the scattering spot parameters in the photometric images is a prerequisite for assessing biological tissues condition. In turn, the used analytical methods can be applied in the design of hardware and software for diffuse optical tomography [15, 16], Raman spectroscopy [17–19], dosimetry during laser therapy [20], etc.

Task statement. The article aims to develop an algorithm and software for the photometric images of the scattering spot automated processing for operations on a series of images and obtain results in numerical (intensity) and graphical (spatial distribution) forms.

Outline of the main material of the study. Based on the methods of obtaining and processing the scattering spot parameters analysis, spatial photometry of biological media was chosen as the fundamental [7]. With the help of the technique, it is possible to obtain a graphical representation of the entire scattering spot in brightness dependence form on the spatial coordinate to estimate its shape and size and the pixel brightness value. It can be used, for example, to establish the density of structural elements of biological tissue samples or relative thickness when analyzing the entire scattering spot or to compare optical properties in distinct sections. To obtain photometric images of the scattering spot, photometry by ellipsoidal reflectors was used [15].

To improve the considered methods, a scheme of an automated system for obtaining and processing photometric images was proposed, shown in Fig. 1.

The automated system consists of measuring and processing blocks, the principle of which is as follows. The light flux from the light source (helium-neon laser LGN-208a) is directed to the ellipsoidal reflector (ER) and, with the help of a flat mirror, falls on the area of the studied sample of biological tissue located in the first focal plane of the ER. Due to the peculiarities of the shape of the mirror ellipsoidal reflector, the backscattered radiation is transferred to the second focal plane of the ER, which projects the scattering spot onto the CCD matrix (video camera DMK 21AU04.AS) 6 with the help of an optical system (optical head of the MBS-10 microscope) and a connector (TV adapter). Processing of the obtained photometric images is carried out using specialized software.

The experimental setup developed according to the proposed scheme is shown in Fig. 2.

The installation elements are placed on the optical bench. To obtain a photometric image of the scattering spot in the transmitted light, two ER 3 are used in the experimental setup. At the same time, a sample of biological tissue 2 is placed between them.

The software is implemented in Python with imported libraries (Fig. 3) and according to the developed algorithm (Fig. 4).

The developed algorithm is based on the spatial photometry principles by the intersection's method [15] and arithmetic operations with matrices. Since the algorithm implementation is carried out with the image, which is presented as a pixel brightness matrix, it must be converted into a text file with the extension .txt. The algorithm divided into three branches depending on the uploaded images count, and at the same time, the available operation is selected.

The main window of the software developed based on the algorithm is presented in Fig. 5. The interface is conditionally divided into four fields. Field 1 means further work on the software with text files. Field 2 displays the path to the downloaded files. Select the required one from the drop-down list in field 3 to perform operations on one of the downloaded graphs. Field 4 selects arithmetic processes that function only when two graphs are loaded. The "analyze" operation is used to construct 3D and 2D graphs. When the "analysis" button is pressed, the relative intensity value is displayed, defined as the total pixel brightness value by their total count. All results are automatically saved in the program's location folder.

When analyzing one file, the user can obtain the overall spatial distribution of the scattering spot in the form of a three-dimensional graph, relative intensity values, and a two-dimensional graph of the central cross-section. The result of the execution of the
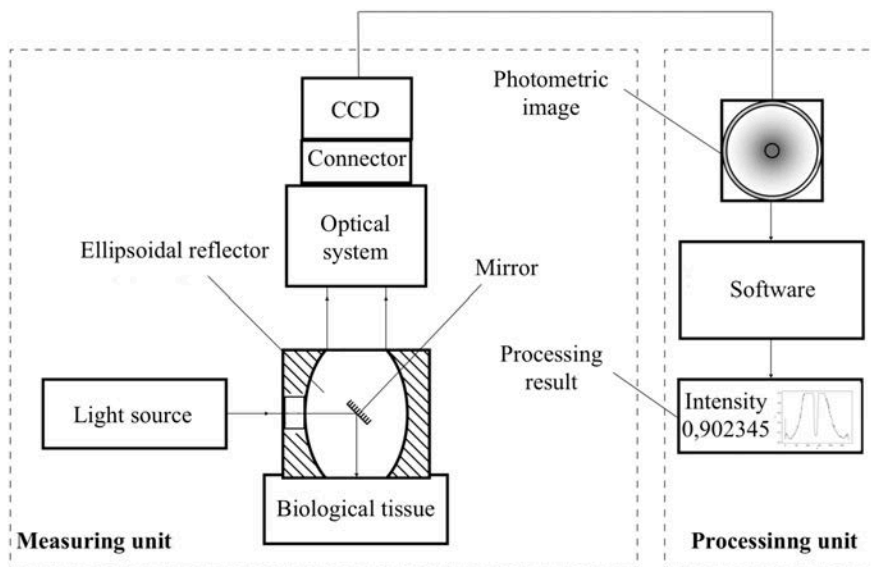
**Fig. 1. Photometric images measurement
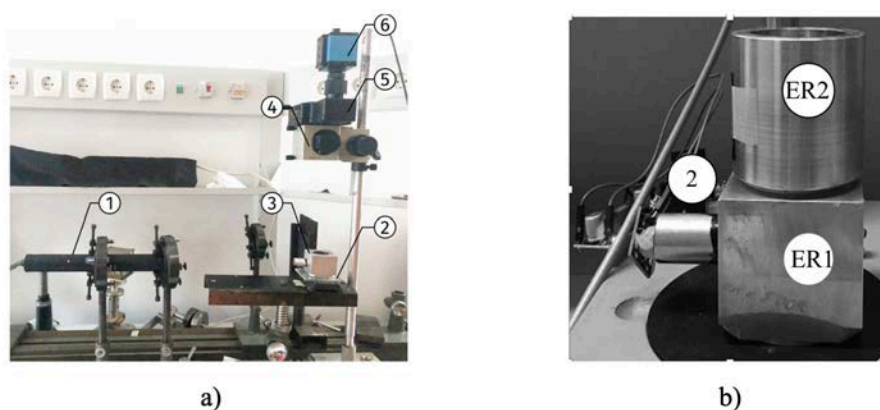and processing automated system scheme**

**Fig. 2. Automated measurement system experimental setup: a) general view
for registration in reflected light, b) placement of ellipsoidal reflectors for
registration in transmitted light: 1 – laser, 2 – BT sample; 3 – ellipsoidal
reflector; 4 – MBS10 microscope; 5 – TV adapter; 6 – video camera**

```
import sys
import os
import random

from PyQt5 import QtWidgets
from mainWindow5 import Ui_MainWindow

import numpy as
import pandas as pd
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
```

Fig. 3. Imported libraries

described branch of the algorithm is the output of the relative intensity value and the production and saving of the obtained graphs. An example of the photometric image analysis is shown in Fig. 6. The corresponding manipulator buttons control the position of the three-dimensional graph. When you move the mouse to a certain point on the graph, its spatial coordinate and pixel brightness value are displayed.

In analyzing two scattering spots, one can choose one of four arithmetic operations: addition, subtraction, multiplication, and division. Then, according to the algorithm, the dimensions of the matrices are checked. If the matrix's dimensions do not match, a window with the corresponding error is displayed, after which you can end work with the software or select other files. If the dimensions match, the program performs the specified operation, outputs a matrix of pixel brightness values and a three-dimensional graph of the obtained photometric
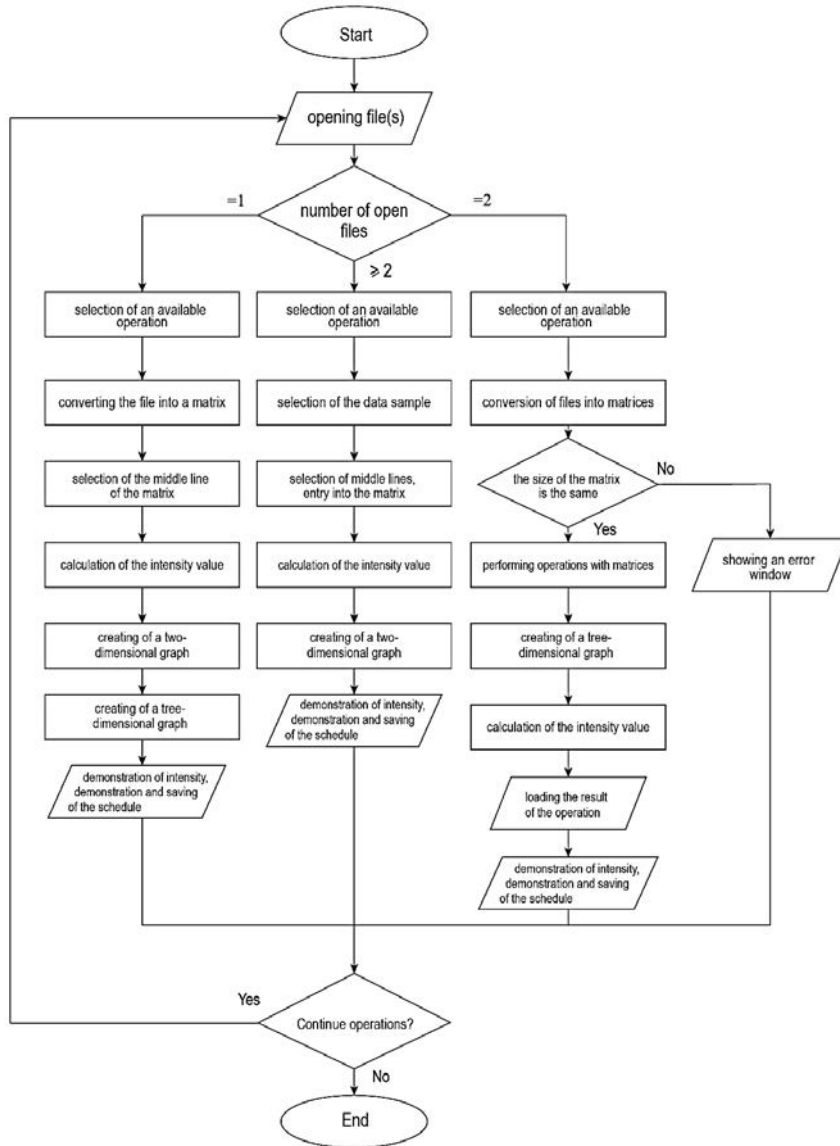
Fig. 4. The software algorithm

image, and saves them. In addition, in the "Graph selection" field (Fig. 5), you can choose one of the downloaded files and plot its central intersection. This type of processing is proper, for example, when comparing two images, subtracting background noise from an image, calibrating pixel brightness, etc.

An example of the difference in the scattering spot brightness for two photometric images is shown in Fig. 7.

When analyzing two or more files, the result is calculating the photometric image relative intensity value and constructing two-dimensional graphs of the central cross-section, which are stored in the folder where the program is located. The program allows you to build and save graphs separately (for this, you need to close the plotting window) or get graphs of central intersections of several images on one (as shown in Fig. 8).
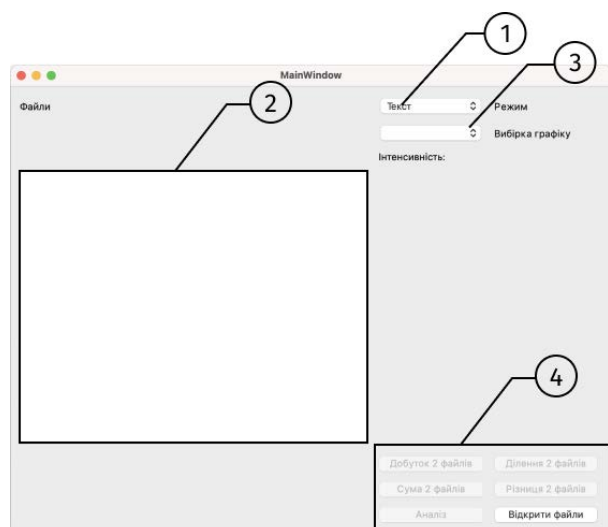
Fig. 5. The software interface
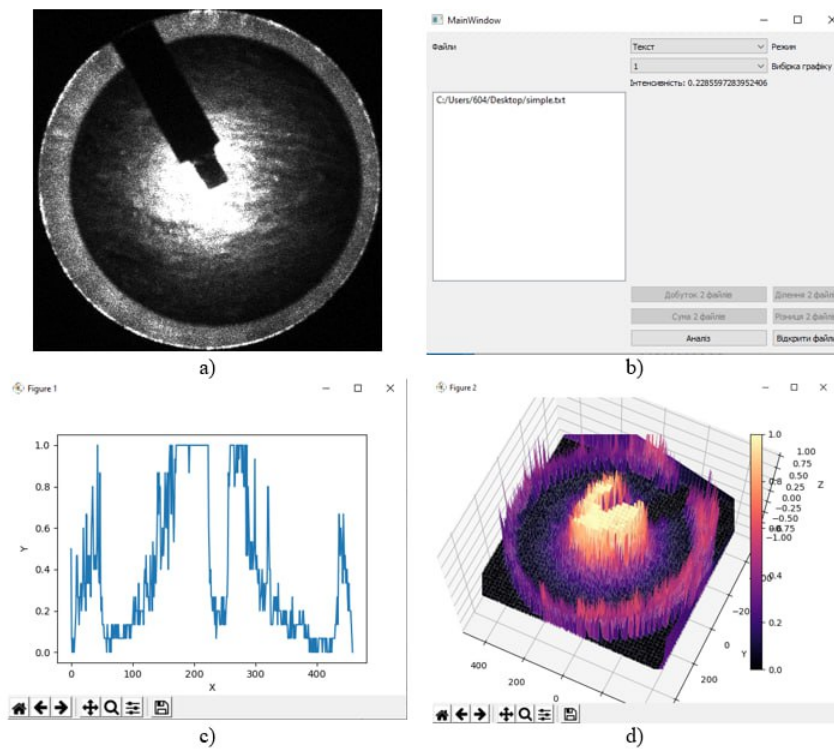
Fig. 6. One file processing example: a) photometric image, b) software
interface with loaded image, c) two-dimensional graph of the central
section, d) three-dimensional graph of the spatial distribution of the
scattering spot

Fig. 7. The program operation example with two files:
a) photometric image of scattering spot 1, b) photometric image of scattering
spot 2, c) resulting graph after the subtraction operation, d) brightness values
matrix of the resulting graph

Fig. 8. Program example with four files:
a) program interface with loaded image, b) graphs of central intersections

The operation of the developed software has been tested using separate available programs of similar purposes. The relative intensity values of the photometric images scattering spot showed commensurability with the intensity values obtained using the software "Iris v. 5.59". The spatial distribution of the scattering spot and a plot of the central cross-section was obtained using the "Gnuplot" software. At the same time, to build each graph in this software, it is necessary first to download each file separately, and secondly, to highlight the central intersection, you must use additional operations and programs (Excel, Notepad). It significantly increases image processing time, especially when multiple images need to be analyzed (from 6 times to one central section of one image to 12 times to obtain central sections of four images). The process of performing arithmetic operations on images with the help of separate programs is even more complicated and time-consuming because first, you need to download the file to Excel to perform the arithmetic operation itself, then save it in Notepad to a text file, and only then plot the graph.

Conclusions. In this paper, the automated system scheme for measuring and processing photometric images of the scattering spot is proposed, based on which the installation was assembled, and the software was developed. A comparison of the results of photometric image processing performed on the developed software and with the help of separate freely available software showed the advantages of the first one. They consist in a significant reduction in processing time, especially when examining a series of images.

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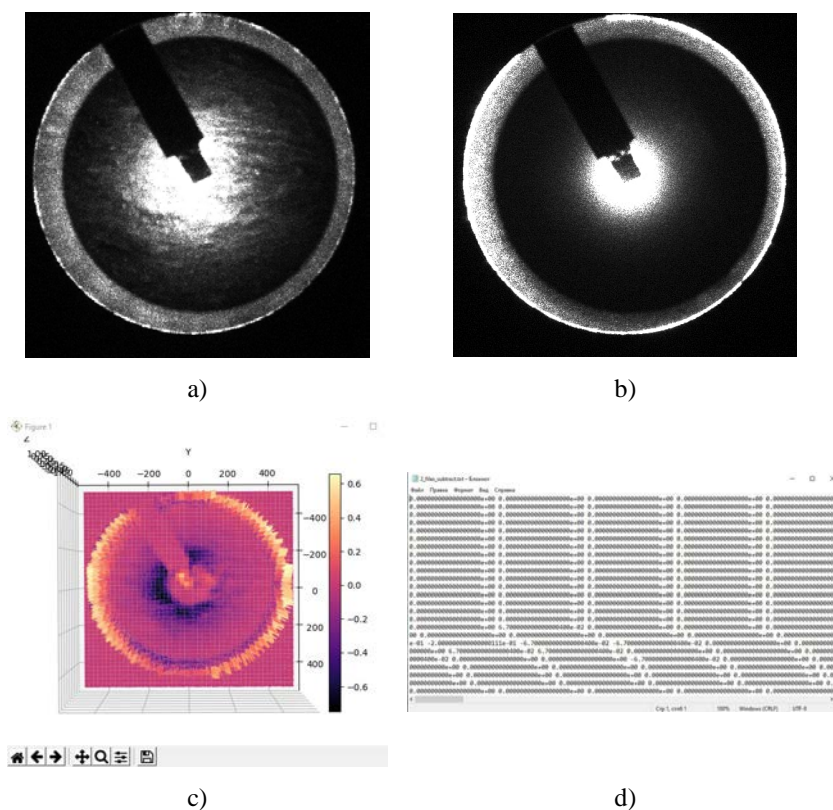1. De Vries H.j.C., Zeegelaar I.E., Middelkoop E., Gijsbers G., Van Marle J., Wildeveuur C.H.R., Westerhof W. Reduced wound contraction and scar formation in punch biopsy wounds. Native collagen dermal substitutes. A clinical study. *British Journal of Dermatology*. 1995. No.132(5). Pp. 690-697. DOI: 10.1111/j.1365-2133.1995.tb00712.x
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Безугла Н.В., Яковенко І.О., Філіппова М.В., Полуектов С.О. АВТОМАТИЗОВАНА СИСТЕМА ОБРОБКИ ФОТОМЕТРИЧНИХ ЗОБРАЖЕНЬ ПЛЯМИ РОЗСІЯННЯ

У статті розглянуто методи та технічні засоби отримання фотометричних зображень плями розсіяння, а також проведено аналіз методів оцінки її якісних та кількісних характеристик. Обґрунтовано та наведено переваги використання методів просторового аналізу фотометричних зображень плями розсіяння. Проаналізовані морфологічні особливості здорових та патологічних тканин та обґрунтовано їх вплив на характер розсіяного світла для колагенових волокон з хаотичною та впорядкованою орієнтацією.

Авторами запропоновано схему автоматизованої системи вимірювання та обробки фотометричних зображень, яка складається з вимірювального блоку, що реалізує метод фотометрії еліпсоїдальними рефлекторами, та блоку обробки фотометричних зображень плями розсіяння. На основі запропонованої схеми реалізовано установку вимірювального блоку, що дозволяє отримувати фотометричні зображення у відбитому світлі та світлі, що пройшло, та описано методику проведення

експерименту. В основу роботи блоку обробки зображень покладено розроблений алгоритм, що включає процедури просторового аналізу плями розсіяння методом перетинів. Розроблено програмне забезпечення у програмному середовищі Python з використанням бібліотек та модулів для обробки файлів, створення графічного інтерфейсу, роботи з масивами, аналізу даних та побудови графіків. Наведено приклади функціонування програмного забезпечення для обробки одного та декількох зображень. Для підтвердження адекватності роботи розробленого програмного забезпечення порівняно результати обробки з використанням доступних аналогічних програмних засобів.

Розроблена система дозволяє проводити комплексний аналіз фотометричних зображень плями розсіяння в залежності від поставленого завдання. Результатами роботи є графічне представлення плями розсіяння у вигляді залежності яскравості пікселів від просторової координати та числове значення відносної інтенсивності. Дані результати можна отримати як для всього фотометричного зображення, так і для його центрального перетину. Також розроблене програмне забезпечення дозволяє виконувати арифметичні операції (додавання, віднімання, множення, ділення) над двома зображеннями з метою виділення корисного сигналу на фоновому зображені, оцінити вплив одного зображення на друге тощо.

Ключові слова: *фотометричне зображення, пляма розсіяння, просторовий розподіл, фотометрія еліпсоїдальними рефлекторами, Python, біологічне середовище.*