Detection of fake biotissue by polarimetric method using Mueller matrices

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Abstract. In this paper we consider a new method for improving the security of fingerprint identification systems. It is based on calculating polarimetric parameters using the Mueller matrix. This method was tested on gelatin samples that mimic real tissue with fingerprints. We showed that proposed method can increase the reliability of fingerprint sensors. In conclusion, recommendations on the modification of the laboratory setup and on the improving of the polarimetric technology are given.

1. Introduction
With growing popularity of digital devices such as smartphones, laptops and tablet computers, the amount of personal information stored in them has increased tremendously. Existing methods of protecting the access to gadgets do not always provide a high level of reliability. Traditional semiconductor or optical sensors use only information about the surface of the finger and do not consider the properties of internal biotissue. Thus, the fingerprint scanner on some smartphones can be fooled simply with the help of gelatin finger dummy or glue film imitating a fingerprint [1].

In this connection, the problem of developing an alternative way to identify a user becomes relevant. One of these ways is the ultrasonic fingerprint sensor [2]. An ultrasonic wave can penetrate to the depth of several millimeters deep into the tissue and the device is able to measure additional parameters such as blood flow velocity, which increases the recognition efficiency [3]. However, the high cost of such a sensor limits its scope.

A polarimetric modification of the optical sensor can act as an alternative method. In this case, fingerprint recognition will occur using light of different polarization, and information about the investigated object will be obtained by analyzing the polarization state of the light reflected and backscattered from it.

For this purpose, a method based on the calculation of the Mueller matrix for the object is used. This method is widely used to diagnose cancer tumors in medicine, establish posthumous damage of biological tissue, as well as an approximate determination of the time of death, from 1 to 140 hours with an accuracy of up to ± 1.5 hour [4, 5].

2. Theoretical basis
The propagation of light in biological tissue depends on the scattering and absorbing properties of its components: cells, cell organelles, and various fibrous structures [6]. In addition, the size, shape, density of such structures, their refractive index also influence the behavior of light in biological tissue [3, 7, 8].
In the wavelength range of 600–1600 nm, scattering in biological tissue predominates over the absorption. Moreover, the intensity of diffusely reflected light increases up to 35–75% of the total intensity of the incident light. Therefore, it is reasonable to use lasers of the visible, for example, He-Ne laser, or near IR range for research [9].

Many biotissues have optical anisotropy, and exhibit optical activity, often consisting of the linearly polarized light polarization plane turning around the direction of its propagation [10, 11]. As a result, one can use the polarimetric methods to determine environmental parameters [12].

By registering not only the intensity, but also the polarization of light scattered by the medium, it is possible to obtain much more information about the properties of the object (medium), distinguish complex organic compounds with similar absorption spectra, in particular to detect various pathologies of biological tissues [13, 14]. To describe the properties of the scattered light beam and its transformation, the Stokes vector method and the Mueller matrices are preferable in comparison with others, since it is applicable for partially polarized incoherent radiation [15].

In this work, the Mueller matrix is built based on 16 measurements of the light beam at different positions of polarizers and analyzers. The elements of the matrix depend on the scattering angle, the wavelength and the geometric and optical parameters of the scattering particles. The first letter indicates the state of polarization at the input, the second is the analyzed polarization. For example, HH means that the input light is horizontally polarized, and the analyzing arm is a polarizer with its axis in a horizontal position.

Table 1. Calculation of matrix elements for the method of 16 images: $M_{ij}$ are matrix elements, H is horizontal polarization, V is vertical polarization, P the polarization under +45°vangle, R stands for right-circular polarization.

| $M_{11}$=HH+HV+VH+VV | $M_{12}$=HH+HV-VH-VV | $M_{13}$=2PH+2PV-M_{11} | $M_{14}$=2RH+2RV-M_{11} |
| $M_{21}$=HH-HV+VH-VV | $M_{22}$=HH-HV-VH+VV | $M_{23}$=2PH-2PV-M_{21} | $M_{24}$=2RH-2RV-M_{21} |
| $M_{31}$=2HP+2VP-M_{11} | $M_{32}$=2HP-2VP-M_{12} | $M_{33}$=4PP-2PH-2PV-M_{31} | $M_{34}$=4RP-2RH-2RV-M_{31} |
| $M_{41}$=2HR+2VR-M_{11} | $M_{42}$=2HR-2VR-M_{12} | $M_{43}$=4PR-2PH-2PV-M_{41} | $M_{44}$=4RR-2RH-2RV-M_{41} |

3. Experiment
A block diagram of the laboratory setup for measurement of the Mueller matrix is shown in figure 1.

![Figure 1. Block diagram of the laboratory setup: 1 – He-Ne laser; 2 – quarter-wave plate; 3 – sample; 4 – quarter-wave plate; 5 – polarizer-analyzer; 6 – detector.](image-url)
The samples (3) are illuminated with a He-Ne laser (1) radiation beam. The backscattered at an angle of 30 degrees from the normal to the surface of the sample light passes through a polarizer-analyzer (5) and a quarter-wave plate (4) and is detected with a photodetector (6). By rotating the laser around its axis and by using a quarter-wave plate (2) we could change the polarization state of incident light.

For the experiments we used 3 different gelatin dummies imitating a human finger. For the manufacture of false prints, gelatin mixed with glycerin and water in proportions of 1:1:15 was used [1]. The thickness of the samples is 1 mm for the Fake finger 3, 7 mm for the Fake finger 2 and 5 millimeters for the Fake finger 1. Rhodamine 6G dye was also added to the samples in order to increase scattering inside the sample, since the samples without Rhodamine were obtained too transparent. The samples photo is presented by figure 2. This manufacturing technology is convenient for copying papillary finger patterns in "home conditions" and is often mentioned in various articles [1, 16, 17]. Manufactured dummies are very low in quality; however, such kind of dummies managed to overcome smartphones protection [17].

![Fake finger 1](image1.png) ![Fake finger 2](image2.png) ![Fake finger 3](image3.png)

**Figure 2.** Samples of gelatin finger pads used in the work. Fake finger 1 – thick dyed gelatin finger pad; Fake finger 2 – gelatin-made little finger pad; Fake finger 3 – thick gelatin film with paper on its backside.

4. **Results and discussion**

Mueller matrices for each sample were calculated using the experimental setup (figure 1). The elements of the matrix were normalized to the maximum element ($M_{11}$). Some of the elements of the matrices are presented in figure 3.
Since the internal structure of the models and the real finger is different, we can expect a change in the interaction of the particles with the light. Thus, depending on the presence of certain optical centers in the sample, the elements of the matrix will differ.

From the graph one can notice that the elements of the Mueller matrix of fake fingers have a greater scatter relative to each other and relative to zero. This may indicate a different internal structure of human skin and gelatin. The greatest variation was demonstrated by the elements $M_{14}$, $M_{22}$, $M_{23}$, $M_{33}$, $M_{41}$, $M_{43}$ and $M_{44}$. The large scatter in the values of the matrix elements of different fake fingers can be explained by the inhomogeneities of the sample structure. In the manufacture of samples inside the mixture could remain unmixed areas of different density. In gelatinous fingers there is no priority direction for the orientation of the polarizing light centers. Therefore, there is a greater variability of the values of the elements of the Mueller matrix than for the real finger.

For further data processing [18], more complex information base is needed. However, it is shown that the fundamental possibility of distinguishing fake fingers from real ones exists. It is necessary to experiment with different concentrations of gelatin mixture to study changes in the values of matrix elements. It is also necessary to take measurements on real fingers with different skin types and shades. In any case, much more experimental data are needed for further analysis.

In order to improve detection of fake fingers, the laboratory setup must be modified. In this work, a photodetector with an aperture of 10 millimeters was used. In this case, all the light falling on the detector is averaged in one value, which does not allow the detection of anomalous values, as well as the structural features of the sample. A CCD camera should be used instead of a point detector [19]. Thus, it will be possible to obtain 2D images and to get more information about the scattering object.

5. Conclusion
In this paper, a polarimetric method for fake fingerprints detection using Mueller matrices was demonstrated. We discussed the laboratory set-up for working with polarized light and described its elements. Mueller matrices for real biotissue and gelatinous fakes were obtained. Results have shown promise for application in fingerprint recognition systems.
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