Infrared versus white light sources for polarimetric imaging setup

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Abstract. The results of the experimental investigation of polarized backscattered light from a biological tissue using cross-polarization imaging technique are presented. A new approach for detecting different morphological abnormalities of the cutaneous structure caused by various diseases and aberrations (pathologies) irradiating the exact sector of the object under study with incoherent infrared light is proposed. The obtained results are compared with results of our previous experiments of illuminating the skin sector with incoherent white light source. Such proposed technique provides the possibility to get the comprehensive information on the structure of the object containing scar structures and other abnormalities and skin illnesses. This method can be used to develop medical devices that are applicable for diagnosing diseases, which are hardly distinguishable at early stages and for monitoring the patient’s condition.

1. Introduction

Recently the study of the texture of biological tissues and their morphological changes in various pathological processes occurring directly with them is currently one of the most challenging areas of research. Techniques for in-vivo cutaneous structure measurements have to be non-invasive, fast and easy to carry out, hence optical methods are preferred [1]. It is proved that the spatial and structural organization of the collagen fibres (CF) of the conjunctive tissue is inevitably damaged during various abnormal processes that are extrinsic for healthy tissues [2]. The information on the nature and damage rate of the CF can be used to diagnose diseases, identify early neoplastic processes and determine the response to medical treatment. Also, recent studies have displayed that biological tissue, particularly skin, changes the polarization degree of the incident light [3]. It is the simultaneous registration of orthogonal polarization states, which allows obtaining the corresponding images of the internal structure of the scattering objects, which is the basis for the proposed method of spatial visualization of skin defects using polarimetric image processing in infrared light [4-7].

2. Theory of the method

Linearly polarized light that illuminates skin is backscattered by superficial layers. It is depolarized by birefringent structure of the biological tissue. It is possible to distinguish such superficially backscattered light from the total diffusely reflected light that is dominated by light penetrating deeply into the dermis [8]. The main objects that could affect alteration of polarization state are scattering particles such as CF, cell nuclei and mitochondria that demonstrate birefringent effect. Thus, the evolution of diseases could be diagnosed and monitored by measuring changes of the polarization rate.
In general, the spatial state of CF influences the polarization state, which ensures that radiation does not scatter, but also changes its polarization as it passes through the tissue (i.e., depolarization is only the reverse).

The light is linearly polarized by a linearly polarizing filter. It has orientation parallel to the plane established by the source-skin-camera, \( I_0 \), incident onto a section of scattering medium. Just light which enters the skin and backscatters toward the surface is collected by the camera. While polarized light incidents the skin, back reflectance of light from the original layers of skin is observed by the camera. This initial backscattered reflectance retains the linear polarization of the incident light, and compose approximately 3% of the incident light. The rest 93% penetrates deeper into the cutaneous layer, and the orientation of polarization becomes randomized by multiple scattering objects. Finally, about half of this deeply penetrating light is lost to absorption, but half of the light is backscattered to the surface, escapes the skin, and is viewed by the camera. Hence, about 45% of the incident light escapes as randomly polarized light [9, 10].

3. Experiment
The experimental setup for studying the backscattered polarized light is presented in figure 1.

![Figure 1. Scheme of the experimental setup with infrared light source.](image)

In current research model experiments were carried out on biological tissues in particular on human skin in a darkened room. In this system, an incoherent infrared (IR) diode with the wave length \( \lambda = 925 \text{ nm} \) was used as the light source. Firstly, the illuminating light passes through the analyzing linear polarizer placed in front of the IR camera, which optical axis is oriented parallel to the orientation of polarization of the incident beam, reaches the sample under study and then penetrates in it. Secondly, the backscattered light from the studying biological tissue passes through the second linear polarizer and recorded with a camera that displays the resulting image on a computer screen [11-14].

The position of the second analyzing polarizer during one measurement changes, so at first we obtain the image of the object in co-polarized light \( (I_{par}) \), and then in cross-polarized light \( (I_{per}) \). By setting the setup to cross-polarized mode, reflections from the surface specular are suppressed and depth sensitivity is enhancing, while setting the system to co-polarized mode enhances surface structures [15, 16]. As a result, a preliminary database of images in cross- and co-polarization was obtained.

Degree of polarization imaging is calculation of degree of polarization for each pixel of the polarization image and gives new features of this method. Two images obtained for the co-polarized and cross-polarized components are algebraically combined to yield a residual degree of polarization [17]. Detected pictures were processed in the Wolfram Mathematica. The Pol image is based on the ratio of a numerator that emphasized superficial subsurface reflectance and a denominator that
represented the total subsurface reflectance [18]. The Pol image was insensitive to changes in illumination light intensity and variations in surface pigmentation but was sensitive to the superficially scattered polarized illumination light. Pol image was calculated by the Eq. 1

\[ Pol = \frac{I_{\text{par}} - I_{\text{per}}}{I_{\text{par}} + I_{\text{per}}} \] (1)

Figure 2 shows normal couple of light images of skin sites with the mole represented by \( I_{\text{par}} \) and \( I_{\text{per}} \) (Left and Central) and polarized light image (Right) represented by Pol picture. The Pol image is a residual polarization coefficient and reflects the subcutaneous tissue structure.

![Figure 2. Images of skin sites representing mole.](image)

Concurrently the other experimentation setup was realized. This time as the illuminating source was chosen the incoherent white light source because it has a smaller wave length compared to the IR. Moreover, the collecting lens was added and the IR filter was removed.

Further, the same measurements were carried out on the experimental setup with white light. As a result, the images in two co-and cross-polarizations and the final Pol image for the second setup were obtained (figure 3).

![Figure 3. Images of skin sites representing mole in white light.](image)

When analysing images in the white light, it is obvious that we managed to achieve a rather good result examining a skin area containing a mole that is heterogeneous in structure (figure 3). It has a different morphological texture that is the reason why in the image with perpendicular polarization it is noticeable that its edges have become lighter and less distinct and the centre of the mole, which has a greater depth, remains the same.
4. Results of the research and their discussion
As a result, two series of images using IR and white light sources of skin sites representing the same mole were obtained. Analysing the final results for two setups it is obvious that the penetration depth of two light sources is differ from each other. This fact is proved by the results of our research, for example when illuminating the sector with white light the Pol image did not cancel the melanin pigmentation of the mole but showed an enhanced Pol signal, so we can say that internal structure cutaneous layers is more visible in white light in a perpendicular plane of polarization.

The possible explanation is that the nevus depth exceeds the depth of white light penetration unlike the infrared light. Thus, it is reasonable to choose the light source depending on the type of the abnormality and the depth of its location. The Pol images in IR light successfully removed the superficial epidermal pigmentation of the mole to reveal normal skin underneath. Final images can visualize the damages of the normal texture of the dermis by skin pathologies.

Further, we are planning to explore the relationship between Mueller matrix images and the ultrastructure of a tissue because polarized light imaging can be implemented with the help of the Mueller matrix formalism to characterize each pixel of an image. The main aim is to find the way how to characterize the size and density of mitochondria, collagen fibres and other structures.

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