Improving of Medical Imaging by the Use of Noninvasive Optical Technologies

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Abstract— **Among the applied methods of tissue parameters measurement, a tendency to develop imaging methods based on detection and analysis of natural and forced biooptical phenomena is significant. Transmission variant of light-tissue interaction is considered in the paper. The work on the performed optoelectronic systems for human tissue transillumination is in progress. The transillumination image enables to disclose information on the functional condition, unavailable in the traditional X-ray technique. Preliminary results which were obtained by the authors during the finger and hand transillumination tests are promising. Some of them are presented in the paper. They show that effective imaging is possible even in a simple system and indicate that the further development of the designed noninvasive systems seems to be advisable.**

Keywords-medical imaging; light-tissue interaction; optical technologies; noninvasive transillumination

I. INTRODUCTION

In 1895, Wilhelm Conrad Roentgen [20] made the first radiogram of a hand, starting the development of image diagnostics methods. Other imaging methods appeared after a few dozen of years only. Modern imaging technology includes among others X-ray imaging, videoendoscopy, ultrasonography (USG), computer tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and thermography [1][2]. All these methods allow the detection of different properties of tissues through a variety of utilized phenomena. Particular techniques differ from the point of view of the advantages and disadvantages, a range of applications, degree of invasive or noninvasive interaction, patient ballast, and complication of procedures. For example, MRI has always been especially suited for vascular imaging.

The associated application of various methods is presently developed, allowing obtaining a more complete set of information on the object, compared to the tests made in one diagnostic technique only. Thanks to the selective optical properties of tissue cells, optoelectronic noninvasive imaging methods can be used for determination of essential features of tissue sets, particularly useful in developing combined diagnostics [3].

As far back as 1876, Karl van Vierordt [19] already observed changes in the solar spectrum transmitted by the finger tissues of his own hand. He discovered that after pressure causing inadequate blood supply, a change occurred in the spectrum composition obtained, which he related to the changing participation of oxygenated and reduced hemoglobins in the tissues. Information on the first attempts of transillumination with optical radiation appeared in 1929 [4]. In 1977, a hundred years after van Vierodt's observations, Minolta built the first oximeter based on the transillumination of the ear lobe. Fast development of such techniques, however, occurred in 1980's [5].

Due to strong scattering of the light, the practical implementation of optical transillumination for medical imaging is a difficult task [6–12]. This technology allows for supporting detection of pathological formations in some tissue sets, particularly those located on body perimeter. The subject of the presented work-in-progress is based on our own previous experience in an expanded use of the transmission photoplethysmography and pulse oximetry principles.

In Section 2, optical properties of human tissues are briefly mentioned. In Section 3, specific attributes of optical imaging and the proposed transmitting-receiving systems are described. Preliminary results related to transillumination images which were collected by us for human fingers and whole hands seem to be very promising. In Section 4, we present some selected results of imaging.

II. OPTICAL PROPERTIES OF HUMAN TISSUES

There is a window in which optical radiation can penetrate into human tissue set and propagate through it. This window includes red light and the NIR (Near Infrared) wavelengths [13][14]. A particular tissue composition depends very much on blood and water content what results in differences between values of optical parameters if to determine them at several compositions of various kinds and size. The effects of radiation influence on the object may concern its area and volume and the type of interaction largely depends on the properties of the beam of radiation. One of the most useful properties of using red and NIR wavelengths is that oxygenated hemoglobin and deoxygenated hemoglobin both absorb light differently in this region.

A given set of living tissues consists of many components which create the complex spatial configuration. When a biological object is exposed to selective illumination, we can receive the selective optical response to particular wavelengths. Depending on the locality and diameter of the light beam passing through the object the effects of light-tissue interaction can differ very much. The interactions occurring between the light and the tissues result

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in scattering, absorption and fluorescence, providing information on the structure, physiology, biochemistry and molecular functions. Optical imaging may be used for description of surface and volume structures.

III. Attributes of Optical Imaging

A. Powers and Limitations of Tissue Transillumination

Combined application of various methods simultaneously is presently developed, allowing for obtaining a more complete set of information on the object, compared to the tests made with one diagnostic technique only. In such an approach, tendency to develop noninvasive methods based on detection and analysis of biooptical signals phenomena is perceptible.

Transillumination is understood as the phenomenon of transmitting optical radiation with defined parameters by a given object, which becomes the carrier of information about the characteristics of this object. In case of biological objects, the optical properties of body fluids and other tissues are utilized. Photons in turbid media, such as most human tissues, are absorbed as well as scattered many times before being transmitted. Scattering and absorption can complicate the transillumination image. Due to the easiness of setting the location in relation to the measuring system and due to the variability of the optical properties, convenient objects in the transillumination tests are those located on body perimeter.

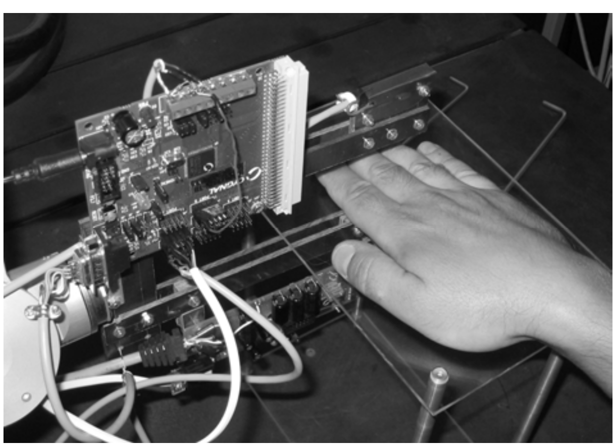
Under the noninvasive “transillumination” and “illumination from underneath”, it is possible to diagnose and monitor the parameters of tissues and organs examined. It is related to achievements in optoelectronic devices and new capabilities of numerical processing.

Optical radiation that is to play the role of an effective information carrier should be sufficiently coherent and, due to the high optical density of the object, should also have possibly high intensity. However, for higher power density quantities, some destructive photothermal effects may occur. Wavelength and power of radiation selected improperly may not only act ineffectively, but may cause damage or destruction of the object.

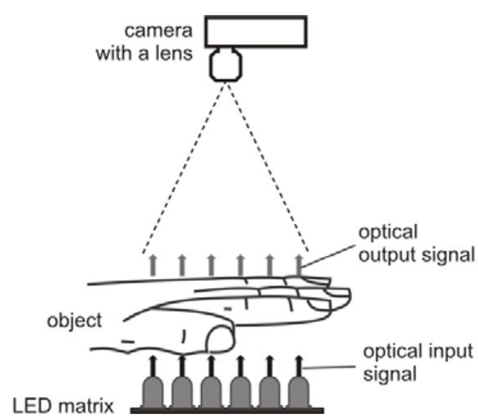
B. Transmitting-Receiving Systems

This paper includes a brief discussion of selected issues related to the biophysical and optical phenomena used and preliminary examples obtained by the authors with transillumination scanning applied to human hand and fingers. Our previous experience with measurements based on transmission pulse oximetry [15][16] has been utilized in an extended modified way. The basic application difficulty in an effective transillumination of thick tissue layers is the low power of radiation to be detected. Therefore, it is necessary to force the optical power of the source and to apply sensitive photodetectors. Various variants of systems were considered, however, always the high-efficient light emitting diodes LEDs were used as light sources. Two variants of these systems which we currently use are shown in Fig. 1a and Fig. 1b.

The experimental transillumination of hand and foot fingers is possible in a quite simple as well as efficient transmitting-receiving system presented in Fig. 1a. The mechanical structure of this system was constructed in the form of letter C [16][17]. The assembly is flexible and contains the motorization, brakes, motion transmission mechanisms, cable bundle, and pneumatic and electrical circuits. The optical part of the transmitting-receiving system consists of an illuminating LED diode placed opposite the sensitive receiving PIN photodiode (without the additional systems focusing the optical beam) which are fit at the structure ends in optical channels of 3 mm diameter and about 20 mm length. The object’s scanning is made in a rectangular x-y coordinates system. A hand examined is laid on a transparent plate stabilizing its position. The hand should remain immobilized in relation to the scanning system. The immobilization may not disturb the object’s function maintaining simultaneously the examined person’s comfort.



(a)



(b)

Figure 1. Two variants of the performed measuring systems: (a) view of the scanning system where the input is the transverse motion of the system in relation to the hand fingers; (b) scheme of a system designed to study the transillumination effects with a monochromatic camera.

Scheme of another system variant is shown in Fig. 1b. The object transillumination is realized with a system consisting of hardware and program parts. The system makes it possible to study the transillumination effects in the optical range, including the visible and near infrared radiation (up to 1000 nm). The single and multi-element illuminating electroluminescent sources of light were tested. A monochromatic camera CMOS has been used as a light detector.

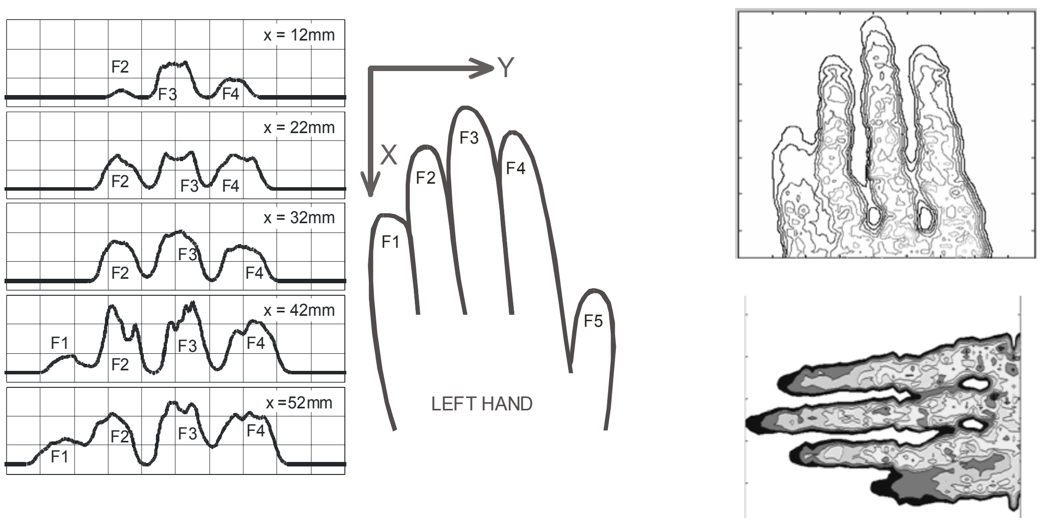
IV. EXAMPLES OF RESULTS

The selected results obtained with the system shown in Fig. 1a are presented in Fig. 2. The transverse motion of the scanning system in relation to the fingers was input. Several wavelengths were used for the tests. The results presented herein have been obtained for an ELJ-880-228B emitting light at the wavelength $\lambda = 880$ nm [18]. This LED was driven with current impulses. The PIN BPW24R photodiode was used as the sensitive photodetector.

Fig. 2a presents the standardized values of the converted output signal from the photodiode for several *x* values. Particular levels of output signals show differences in light attenuation for a given position. The results obtained as transillumination images are shown in Fig. 2b. The grayness intensity is represented by the output signal values of the fingers examined (F1, F2, F3, F4). The specific isolines illustrate transmission properties of fingers at the used wavelength. Despite the system simplicity, the imaging obtained was as anticipated before. For example, differences between the amplitude variability for fingers without and with joint degeneration were observed.

Some examples of images observed with the system shown in Fig. 1b are presented in Fig. 3. It is possible to distinguish the structures of the object that occur sufficiently near the camera input surface. Thus, the observation of the internal structures is possible of such objects as hands, feet, etc.

Results of measurements shown in Fig. 2 do not still allow to distinguish the difference between the diseased and healthy joint because imaging of higher resolution has to be performed. However, results obtained with the system presented in Fig. 1b indicate that there is a possibility of optical detecting the pathological changes of joints.



(a) (b)

Figure 2. Examples of imaging results obtained by the use the system shown in Fig. 1a: (a) Specification of the output signals dependency on the *y* location for selected cross-sections with *x* coordinate; (b) Examples of transillumination images obtainef for hand fingers.

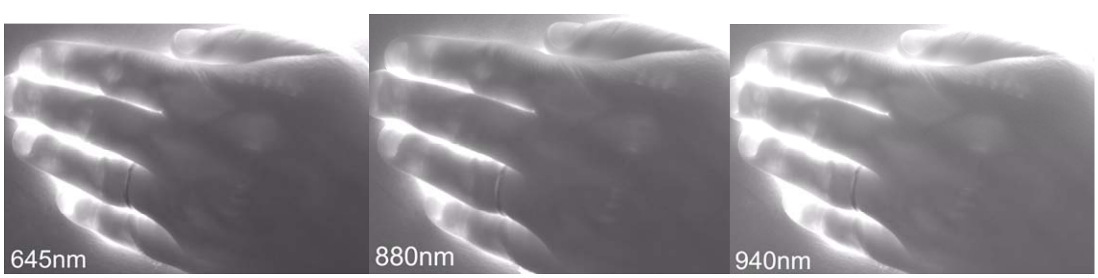


Figure 3. Comparison of results obtained by the use of the system shown in Fig. 1b for the left hand transilluminated from the palm side at three wavelenghts, respectively: 645 nm, 880 nm, and 940 nm.

Results presented in Fig. 3 show that transillumination of peripheral body sites is possible with red and near-infrared incident wavelengths. We may acquire not only the outlines of the object structure but also observe the blood vessels near the surface. Furthermore, there are visible bright components related to the finger joints. During studies, symptoms of rheumatic degeneration were observed. Strong light scattering by human tissues makes it hard to evaluate the structures occurring more deeply. The obtained images especially allowed the observation of the near-surface blood vessels and bone structures. The possibility of efficient transillumination greatly depends on the transmission properties of the object as well as the spectral characteristics of the LEDs and camera. The best effects were obtained for three wavelengths: 645 nm, 880 nm and 940 nm. All these wavelengths are included in the transillumination window where the hemoglobin species are the main light absorbers in arterial and venous blood [5]. Independently from the LED spectrum, the monochromatic camera allows obtaining of imaging in the gray scale.

From the diagnostic point of view, the improving advantages of the proposed method, compared qualitatively with, e.g., traditional X-ray imaging include:

- The lack of harmful influence of optical radiation of properly selected parameters on the human organism.
- The possibility of noninvasive continuous monitoring of the chosen parts of the body.
- The possibility of detecting the local concentration of the blood, e.g., hematoma.

V. CONCLUSION AND FUTURE WORK

The particular methods of medical imaging are not the alternative methods, but they can complement each other, according to the present tendencies to applying so-called combined imaging. The proposed optical imaging of such objects as the hand or foot has no the direct equivalent described in the accessible literature neither in the trade offer. It seems to be reasonable to test transillumination techniques not yet described in other reference data. The presented preliminary results of tests show that effective transillumination scanning is possible even in a simple system and indicate that the further development of the developed measuring system is appropriate and justified. The applied technique can be the useful tool in the process of diagnosing of, e.g., surface blood vessels and the rheumatoid inflammation of joints. From the combined imaging point of view, the optical imaging may provide information on the functional condition unavailable in other techniques. Transillumination imaging has the lower resolution in the comparison with, e.g., the RTG techniques, but they allow to detect changes invisible on the X-ray pictures. We have concentrated our current works on developing efficient transillumination of thick layers of tissues and building algorithms representing the anatomic and functional properties.

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