საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 17, №1, 2023
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 17, no. 1, 2023

Biophysics

Description of Time-Dependent Light Transmission through Human Palm Using Optical Spectroscopy and Formalism of Path Integrals: a Pylot Study

Zaza Melikishvili[*,], Tamaz Medoidze[*], Zaza Jaliashvili[*],
Vera Kinkladze[*], Alexander Gamkrelidze[§]**

[*] *Vladimir Chavchanidze Institute of Cybernetics, Georgian Technical University, Tbilisi, Georgia*
[**] *Green Energy Conversion Institute, Tbilisi, Georgia*
[§] *Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*

(Presented by Academy Member George Japaridze)

We present an analytical approach to the problem of light interaction with biological tissues based on path integral formalism. The special device – optical tomograph is built. Our understanding of the operating principle of an optical tomograph is based on the Feynman interpretation of quantum mechanics. According to it, a photon with a certain wavelength (color) has a classical trajectory determined by optical parameters when passing through a biological tissue. Observing it and determining its parameters are informative from the point of view of diagnosing the physiological and structural states of biological tissue. *© 2023 Bull. Georg. Natl. Acad. Sci.*

biomedical optics and spectroscopy, multi-wavelength transmission PPG, IP formalism

By analyzing the light passed through the human palm, we can obtain 11(eleven) parameters that allow us to monitor the state of human health simultaneously by these parameterssuch as concentration and spatial distribution of major chromophores, i.e. oxy- and deoxyhemoglobin, melanin, bilirubin, carotene, water in 400 – 1000 nm and five characteristic oscillations spectral shapes arising from both local and central regulatory mechanisms (HRV and blood pressure signals) in 0.0095-1.6 Hz range.

To obtain such data, we built device: dynamic optical-laser tomograph, which allows to register scattered optical signal modulated by the absorption of biological tissues, both in stationary and non-stationary modes.

The device consists of light sources (halogen lamp and laser), two spectrometers and a PC connected to them. Spectrometers measure reflected and transmitted light respectively. Exciting and measurable light is transported using fiber optic cables.

The device works with both transmissive and reflective geometries. The non-stationary spectrum is represented on (Fig. 1).

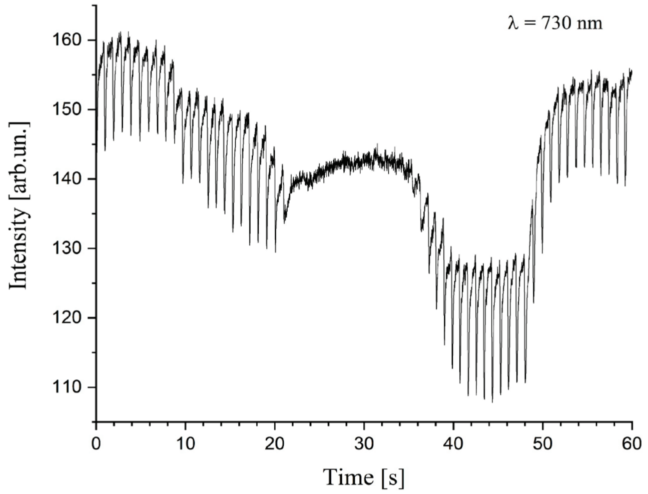

Fig. 1. The time-dependent transmission signal of human palm at $\lambda = 730$ nm.

In general, we can write the resulting signal as [1-3]:

$$I_{\mathrm{detected}}\left(\Gamma_A,\Gamma_B,\Theta,d,\lambda,t\right) = I_{PPG}\left(t\right)\cdot I_{PI}\left(\Gamma_A,\Gamma_B,\Theta,d\right)\cdot I_{tra}\left(\ell\left(\lambda\right)\right), \quad (1)$$

where l_{PPG} is the PPG part of the signal and l_{PI} is the part obtained via Feynman's path integral formalism [1] and l_{tra} is the transmitted intensity across the path, ℓ, where absorption is described by the Beer-Lambert law. After the integral Fourier transform of the l_{PPG} and the presentation of the remaining members of the formula in the form of absorbing and scattering chromophores, we obtain the above mentioned eleven parameters that allow us to monitor the human health state simultaneously.

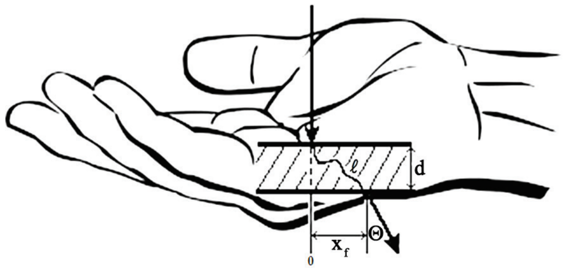

Fig. 2. The trajectory of the "classical" motion of photons in the palm, ℓ, according to Feynman (photons fall in the normal direction onto a layer of thickness d) [1].

Fig. 2 shows the process of photons passing through biological tissues, namely through the palm, which in the stationary case can be represented as follows [1-3]:

$$P\left(x_f,\theta\right) = const\cdot\exp\left[-\frac{6}{\mu_s\left(1-g\right)d^3}\left(x_f-\frac{\theta d}{2}\right)^2-\frac{\theta^2}{2\mu_s\left(1-g\right)d}\right] \quad (2)$$

$$l_{PI}\left(\Gamma_A,\Gamma_B,\Theta,d\right)\to l_{PI}\left(x_f,\theta,d\right)\sim P\left(x_f,\theta\right).$$

Here, μ_s is the coefficient of single scattering of photons,

g- scattering anisotropy factor,

d - biotissue layer thickness,

x_f - deviation from optical axis,

θ - photon exit (or escape) angle.

Fig. 1 also shows a special case of the non-stationary term of (1), $I_{PPG}(t)$ – the time dependence of the intensity of light passing through the palm when measuring blood pressure, where the pulsations caused by the heartbeat with the corresponding measurable frequency are clearly visible. The occlusion effect caused by the cuff is also clearly visible. In particular, in the interval of 22-36 seconds, the pulsation is no longer observed, which corresponds to the systolic pressure.

Thus, simultaneous observation of pulsation and pressure is possible with this method.

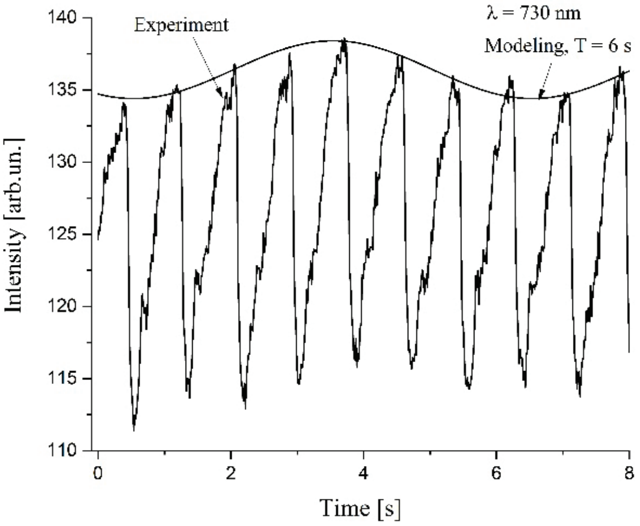

Fig. 3. Respiration modeling with PPG signal captured in transmission mode.

Recently, PPG has begun to acquire its new boost, after not only the heart rate in the 0.5–5 Hz pulsation frequency range, but also the average values of the signal, as well as its low-frequency fluctuations, began to be isolated and analyzed by PPG (Traube – Goering waves; Sympathetic nerve activity in skin).

Fig. 3 shows a PPG signal captured in transmission mode. The modulation corresponding to the beat maxima is well described by a sinusoid with a period of 6s and a corresponding frequency of 0.16 Hz. This PPG modulation is caused by breathing [4, 5].

This experiment shows that with this type of device and method, we can also observe the breathing process. The frequency and depth of modulation can be used to judge the proper functioning of the respiratory system.

To evaluate the theoretical model of photon migration in biological tissue (Fig. 2, formula (2)) we measured the intensity of light passing through the palm in the visible - near infrared spectrum at certain values of x_f for the value $\theta \approx 0$.

Fig. 4 shows the transmitted light spectral shapes for x_f values of 0 mm, 2 mm, 4 mm and 5 mm. Since the length ℓ of the photon trajectory changes along with x_f, the shape of the spectrum changes, which is consistent with the model.

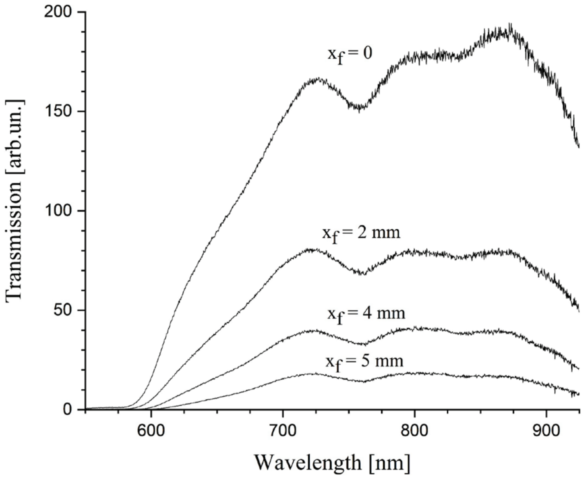

Fig. 4. Dependence of the transmitted intensity on the deviation from the incidence axis.

The obtained experimental points for the following wavelengths $\lambda = 725$ nm, 805 nm and 865 nm correspond to the theoretical curve obtained by formula (2) for the value $\theta = 0$. The fitting procedure gave the following optical parameters of the biological tissue: $\mu_s = 50\text{cm}^{-1}$ and g=0.9. The trend line added to these points showed very good agreement with the R^2 values of 0.9573, 0.9733 and 0.9779, which means that the IP method is a suitable analytical method for assessing the state of human health. The result obtained is shown in Fig. 5.

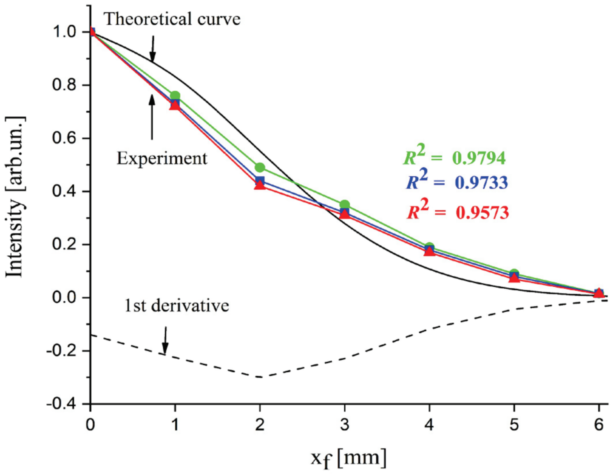

Fig. 5. Theoretical curve and its derivative vs experiment (line + symbol).

Fig. 5 shows the first derivative of the theoretical curve as an inset. A derivative minimum of about 2 mm indicates that the theoretical curve has an inflection point. The experimental curves also contain a breakpoint in the region of 2 mm. Due to the low number of experimental points, a fracture is observed instead of an inflection.

Conclusion

1. The analytical model is confirmed by experiment.
2. Using this method, we can control in real time: heart function,blood circulation and respiration, which is important in intensive care, as well as for monitoring and treating various diseases.

ბიოფიზიკა

ადამიანის ხელის მტევანში გამავალი სინათლის დროზე დამოკიდებულების აღწერა ოპტიკური სპექტროსკოპიის და ტრაექტორიების მიხედვით ინტეგრალების ფორმალიზმის გამოყენებით: საპილოტე კვლევა

ზ. მელიქიშვილი*,, თ. მედოიძე*, ზ. ჯალიაშვილი*, ვ. ქინქლაძე*,**
ა. გამყრელიძე§

**საქართველოს ტექნიკური უნივერსიტეტი, ვლადიმერ ჭავჭანიძის სახ. კიბერნეტიკის ინსტიტუტი, თბილისი, საქართველო*
***გრინ ენერჯი ქონვერშნ ინსთითუთ (მწვანე ენერგიის გარდაქმნის ინსტიტუტი), თბილისი, საქართველო*
§ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, ზუსტ და საბუნებისმეტყველო მეცნიერებათა ფაკულტეტი, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის გ. ჯაფარიძის მიერ)

ნაშრომში წარმოდგენილია ბიოლოგიურ ქსოვილებთან სინათლის ურთიერთქმედების პრობლემის ანალიტიკური მიდგომა, რომელიც ეფუძნება ტრაექტორიების მიხედვით ინტეგრალების ფორმალიზმს. აგებულია სპეციალური მოწყობილობა – ოპტიკური ტომოგრაფი, რომლის მუშაობის პრინციპის ჩვენი გაგება ეფუძნება კვანტური მექანიკის ფეინმანისეულ ინტერპრეტაციას. ამის მიხედვით, ბიოლოგიურ ქსოვილში გავლისას, გარკვეული ტალღის სიგრძის (ფერის) მქონე ფოტონს აქვს კლასიკური ტრაექტორია, რომელიც განისაზღვრება ბიოლოგიური ქსოვილის ოპტიკური პარამეტრებით. ამ პარამეტრების დადგენა ინფორმაციულია ქსოვილების როგორც ფიზიოლოგიური, ასევე სტრუქტურული მდგომარეობის აღწერის (დიაგნოსტიკის) თვალსაზრისით.

REFERENCES

1. Feynman R. P. & Hibbs A. R. (1965) Quantum mechanics and path integrals' 1st ed. McGraw-Hill College, New York.
2. Perelman L. T., Wu J., Itzkan I., & Feld M. S. (1994) Photon migration in turbid media using path integrals. *Physical Review Letters*, **72**(9): 1341–1344. https://doi.org/10.1103/physrevlett.72.1341
3. Perelman L. T., Wu J., Wang Y., Itzkan I., Dasari R.R., & Feld M. S. (1995) Time-dependent photon migration using path integrals. *Physical Review E*, **51**(6): 6134 – 6141. https://doi.org/10.1103/physreve.51.6134
4. StefanovskaA., Bracic M. & Kvernmo H. (1999) Wavelet analysis of oscillations in the peripheral blood circulation measured by laser Doppler technique. *IEEE Transactions on Biomedical Engineering*, **46**(10): 1230–1239. https://doi.org/10.1109/10.790500
5. Söderström T., Stefanovska A., Veber M., & Svensson H. (2003) Involvement of sympathetic nerve activity in skin blood flow oscillations in humans. *American Journal of Physiology-Heart and Circulatory Physiology*, **284**(5): H1638–H1646. https://doi.org/10.1152/ajpheart.00826.2000

Received December, 2022