FLUCTUATIONS OF LIGHT SCATTERED ON HUMAN ERYTHROCYTES – A STATISTICAL ANALYSIS*

C. V. L. POP [1], C. VAMOS [2], I. TURCU [1]

[1] National R&D Institute for Isotopic & Molecular Technologies, 71–103 Donath Str., P.O. Box 700, 400293, Cluj-Napoca, Romania, E-mail: popcl@L40.itim-cj.ro
[2] "T. Popoviciu" Institute of Numerical Analysis, Romanian Academy, P.O. Box 68, Cluj-Napoca, Romania

Received December 21, 2005

Coherent light scattered on erythrocytes suspensions shows complex fluctuations related to the unpredictable movement of cells. A numerical algorithm is developed able to determine the conditional probabilities for increasing and decreasing parts of the process. This separation gives information about the dominant time scale of the investigated dynamics.

Key words: light scattering, human erythrocyte, fluctuations, time series, probability.

1. INTRODUCTION

The biological systems are very complex and the main feature of their dynamics is the large amount of information revealed by the measurements. This fact is an advantage in biodiagnosis applications, but on the other hand it raises a major difficulty: the characteristic information is relatively hard to be extracted, sophisticated mathematical models and numerical algorithms being needed in order to differentiate between systems with seemingly similar behavior.

The aim of this paper is to develop a numerical algorithm able to characterize the information obtained by means of the laser radiation scattering on human erythrocytes suspensions. The information supplied by this technique is a stationary time series of the intensity of the laser radiation coherently scattered by the human erythrocytes in the suspension.

These fluctuations are unpredictable and are related to the unpredictable movement of the scattering cells. The dynamics of the scattering process consists of a deterministic part due to sedimentation and a stochastic part typical to Gaussian distribution of scatterers velocity. The deterministic part can be obtained as the average shift of the local light intensity and the stochastic part as the dispersion around the average intensity.

* Paper presented at the 5th International Balkan Workshop on Applied Physics, 5–7 July 2004, Constanța, Romania.

2. EXPERIMENTAL METHOD

For all experiments, blood was obtained from healthy male donors, was collected on natrium citrate 3.8% and was used after one or two hours. The erythrocytes were separated from the blood plasma by centrifugation at 4000 rpm for 10 min and were washed three times in an isotonic saline buffer (145 mM NaCl, 5 mM KCl, 5mM Hepes, pH 7.4). The red blood cells were diluted in isotonic saline with haematocrit (volume fraction) values in the range 10^{-6} –0.4.

The used light source was a 633 nm linearly polarized continuous-wave He-Ne laser (Uniphase model 1125P) with a power of 5 mW. The beam diameter at $1/e^2$ was 0.81 mm and the beam divergence 1 mrad. The laser beam was directed onto a 1 mm thick quartz cuvette containing the blood sample [1, 2].

The intensity of the light scattered at small angles was captured and also was converted in an electric signal by a photodiode. The measurements were performed at typical distance between photodetector and the cuvette, in order to capture single speckles. The sensitive area of the photodiode is $A \approx 0.2\ \text{cm}^2$ corresponding to a solid angle $\Delta\Omega \approx 2\times10^{-5}$ sr. The detector measuring the scattered light is positioned in the forward direction at 2° off-axis. Measured value was corrected for the refractive index mismatch on the water/air interface.

The detected current is amplified and transferred to a PC by an A/D 12-bits converter having $\nu = 20$ Hz sampling rate. The measurements at each haematocrit took until order of 10^4 data were accumulated, Fig. 1.

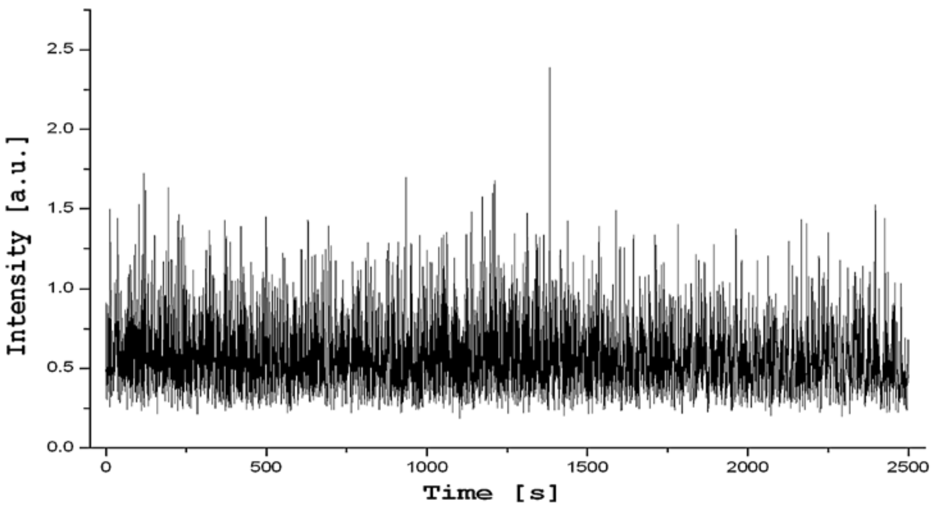

Fig. 1. – The time series of the intensity of the laser radiation scattered by the human erythrocytes suspension.

3. NUMERICAL ALGORITHM

Our numerical method is a generalization of the method presented in [3–5]. In these articles the authors find a different version of the Langevin equation associated to a long time series using the conditional probabilities of the delayed time evolution. We analyze the time series without any assumption regarding the mathematical model that has generated the signal. A statistical analysis of the conditional probabilities corresponding to the increasing and decreasing parts of the time series allows a global characterization.

For the time series $\{x_t\}$ obtained from the measurement ($\{x_t\}$ being the measured values for the intensity of scattered light – Fig. 1), the limits x_{min} and x_{max}, of the range of the measured values are determined. This interval is then divided in $2S$ equal subintervals or boxes with the length given by

$$\mathrm{d}x = \frac{x_{\max} - x_{\min}}{2S} \tag{1}$$

In this article the value $S = 50$ is used. The global probability density $p(i)$ with $i \leq 2S$ is calculated. Because many of the values $p(i)$ are very small, we have eliminated the intervals i for which $p(i) < r \cdot p_{\max}$, where p_{max} is the maximum of $p(i)$ and $r = 0.05$ is a real parameter. Then new values for x_{min}, x_{max}, and dx are calculated and the box i is given by

$$\left[x(i) - \frac{\mathrm{d}x}{2}, x(i) + \frac{\mathrm{d}x}{2}\right], \quad \text{where} \quad x(i) = x_{\min} + \left(i + \frac{1}{2}\right) \cdot \mathrm{d}x \tag{2}$$

We denote by $p_\tau(j;\, i)$ the conditional probability density that the value x_t is in the j box if the value $x_{t-\tau}$ is in the i box, where τ is the delay parameter. The probability that x_t is greater than the median of this density $m_\tau(i)$ is equal with the probability that x_t is smaller. Therefore the difference x_t - $m_\tau(i)$ characterizes the average dynamics of the points of the time series contained within the box i.

If one of the fluctuations of the signal has a time scale of the magnitude order comparable with the delay parameter τ, then $p_\tau(j;\, i)$ can be decomposed in two parts: one for increasing values of the fluctuation and the other for the decreasing values. For a moment t we calculate the average of λ values before and after the given moment:

$$\overline{x}_t^+ = \frac{1}{\lambda} \sum_{s=t+1}^{t+\lambda} x_s, \qquad \overline{x}_t^- = \frac{1}{\lambda} \sum_{s=t-\lambda}^{t-1} x_s. \tag{3}$$

With the values x_t for which $\overline{x}_t^+ > \overline{x}_t^-$ we determine the conditional probability density $p_\tau^+(j;i)$ for the up-going part of the fluctuations, and for $\overline{x}_t^+ < \overline{x}_t^-$ we obtain $p_\tau^-(j;i)$ for the down-going part of the fluctuations. These two conditional probabilities are quite different as one can see in Fig. 2 where the values $\lambda = 5$ and $i = 50$ are used.

In Fig. 3 we present the dependence of the medians of the conditional probability densities $m_\tau^+(i)$ and $m_\tau^-(i)$ on the initial value i. The same is presented

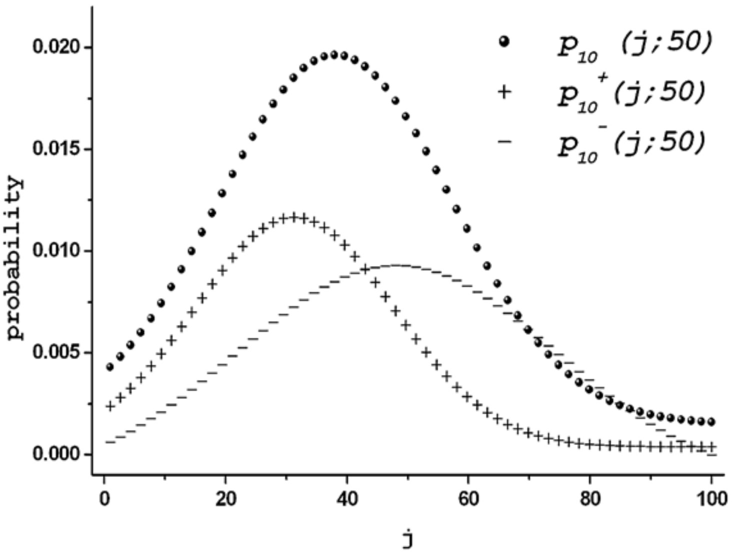

Fig. 2. – The global, up-going and down-going conditional probability densities.

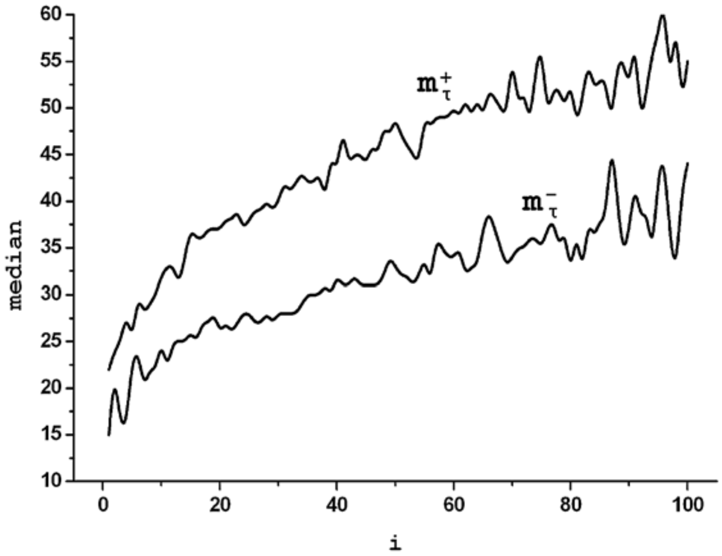

Fig. 3. – The medians of the conditional probability densities.

in Fig. 4, but for the dispersions $\sigma_\tau^+(i)$ and $\sigma_\tau^-(i)$ of the two conditional probabilities. One can note that for both quantities there is a significant difference over the entire range of the time series values.

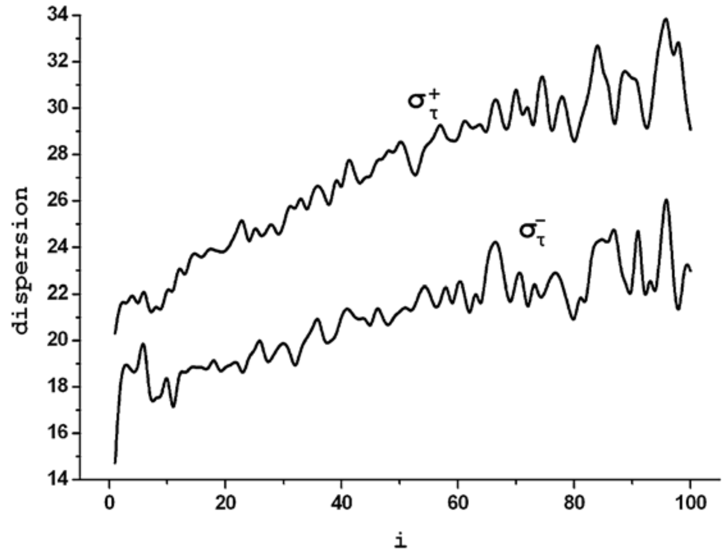

Fig. 4. – The dispersions of the conditional probability densities.

4. RESULTS AND DISCUSSIONS

For a given delay τ, we can introduce two *τ*-dependent parameters as a quantitative measure of the contribution of the corresponding fluctuation to the time series:

$$\Delta_\tau = \sum_i m_\tau^+(i) - m_\tau^-(i) \tag{4}$$

$$\Sigma_\tau = \sum_i \sigma_\tau^+(i) - \sigma_\tau^-(i) \tag{5}$$

Fig. 5 shows the typical dependence of the parameters Δ_τ and Σ_τ with a large maximum corresponding to the dominant fluctuations.

In our case the time scale for the dominant fluctuations are centered on 300 ms. After 1.2 seconds the medians (and also the dispersions) of the up-going and down-going fluctuations become close enough so that for larger delays they cannot be discriminated.

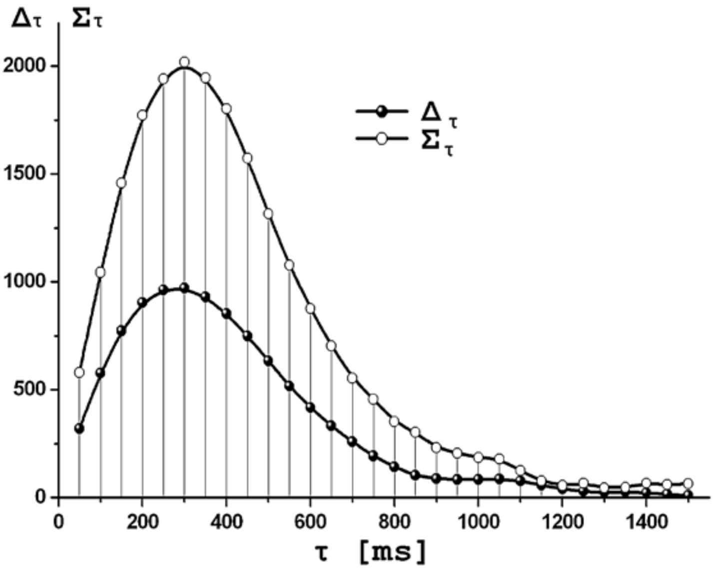

Fig. 5. – The dominant fluctuation time scale obtained from the median difference and dispersion difference.

REFERENCES

1. I. Turcu, C. V. L. Pop, S. Neamtu, Intensity fluctuating pattern of light coherently scattered on microparticles, Studia Universitatis Babeș-Bolyai, Physica, Special Issue 1, Vol. XLVIII, 240–245 (2003).
2. C. V. L. Pop, I. Turcu, L. I. Ciortea, Local characterization of time series by detrended fluctuation analysis (DFA), Studia Universitatis Babes-Bolyai, Physica, Special Issue, 480–485 (2001).
3. S. Siegert, R. Friedrich, J. Peinke, Analysis of data sets of stochastic systems, Phys. Lett. A 243, 275–280 (1998).
4. J. Gradisek, S. Siegert, R. Friedrich, I. Grabec, Analysis of time series from stochastic processes, Phys. Rev. E 62, 3146–55 (2000).
5. R. Friedrich, S. Siegert, J. Peinke, St. Luck, M. Siefert, M. Lindemann, J. Raethjen, G. Deuschl, G. Pfister, Extracting model equations from experimental data, Phys. Lett. A 271, 217–222 (2000).