COMPUTER SIMULATION RESULTS OF LIGHT SCATTERED ON RED BLOOD CELLS*

D. CHICEA

Physics Department, University Lucian Blaga, Str. Dr. Ion Ratiu nr. 7-9, Sibiu, 550012, Romania, dan.chicea@ulbsibiu.ro

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A program was developed to simulate coherent light scattering on a biological fluid. The target is a suspension having RBC like scattering centres. The variation of pattern with the scattering centres concentration was analyzed and found in good agreement with experimental results.

Key words: light scattering, biological fluid, randomly distributed centres.

1. INTRODUCTION

Laser light scattering on random surfaces was extensively studied. The diffraction pattern contains a large number of small bright spots, called laser speckles, described in [1], [2], [3], [4]. A typical image is presented in [3]. A similar pattern should result when laser light is scattered on biological fluid, like blood, where the scattering centres are randomly distributed.

A program was developed and used to simulate coherent light scattering on diluted blood. Scattering centre concentration over a wide range was used as input data. The upper margin of the range was selected to be the minimum concentration when multiple scattering becomes probable. The configuration and the way the program works are described in the next section (section 2). The light intensity on a square area of 2×2 cm^2 was calculated for different number of scattering centres over a wide range, up to the limit where multiple scattering becomes probable. 3D images of the light intensity variation on the square area and the results of the statistical calculations are presented in section 3. Conclusions of the simulation performed so far are presented in section 4.

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2. MATERIALS AND METHODS

A beam of coherent light, like the one produced by a LASER device, is assumed to be incident on a sample containing scattering centres, randomly distributed. Figure 1 presents the schematic of the computer experiment. The laser beam is supposed to be along the Z axis towards $+\infty$.

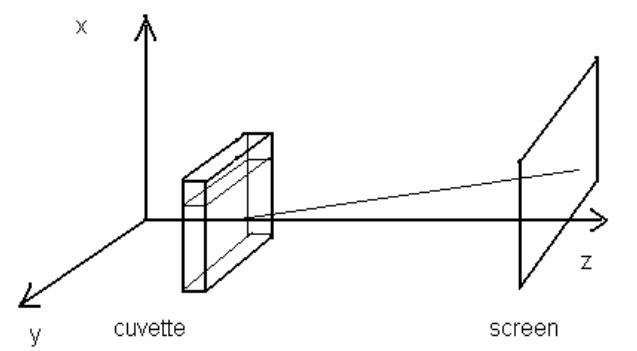

Fig. 1. The schematic of the computer experiment.

The model of the sample is erythrocytes (Red Blood Cells, hereafter RBC) randomly distributed in diluted blood, having a complex movement, which is the overlapping of sedimentation in gravitational field and the Brownian motion. The dimensions of the scattering centres are those of RBC, that is a diameter of 7.5 μm [5]. The scattering centre concentration range was selected in such a way to make multiple scattering improbable. A simple way to assess the concentration is to calculate the volume ratio of one layer of RBC deposited on one of the glass walls of the cuvette to the volume of the cuvette. It yields a maximum value of $7.5*10^{-3}$ volume concentration, which is equivalent to hematocrit. Dividing the total volume of the scattering centres in the volume unit of the cuvette to the volume of one RBC we find the number of the scattering centres in volume unit. The RBC volume is about $90\mu m^3$ [5] and that yields a maximum of $8*10^4/mm^3$ corresponding to a hematocrit of $5*10^{-3}$. The maximum number of scattering centres that was considered is 10000 to make sure that multiple scattering is improbable.

The beam transverse surface was assumed to be 1 mm^2, the distance between cuvette and screen was 2 m. The screen area where the scattered light intensity was calculated was a square of 2x2 cm^2 apart from the beam direction with 14 cm, therefore beginning with an angular deviation of 4 degrees. Over the 2 cm that are the screen area dimension, the angular variation of the scattered beam is less than 0.6 degrees. For this reason the phase factor [6] variation was neglected.

The program reads the input data file and generates the 3 coordinates of each of the scattering centres inside the 1x1x1 mm^3 that is the cuvette area exposed the the laser beam. Next, each pixel having the size of 0.1x0.1 mm^2 is selected and the

contribution of the scattered light from each centre is added to the pixel intensity, recording the intensity and the wave phase. Output files are produced in different format proper for being analyzed and plotted.

Another program was written to analyze the distribution of the light intensity on the screen. The average of the values, the mean square deviation per point and the distribution of the values on 50 intervals were calculated.

The number of scattering centres was selected in the range from 50 to 10000. The computation time increases significantly with the scattering centres number, getting as big as 20 minutes for 10000 on a 2.6 MHz processor. Results are presented in section 3.

3. SIMULATION RESULTS

The calculated light intensity on the screen was plotted for each of the calculated images. Figure 2 presents the 3D intensity distribution on the 2x2 cm^2 screen area, in units of 0.1 mm on X and Y axes, for 50 scattering centres and Figure 3 the contour lines of the same image.

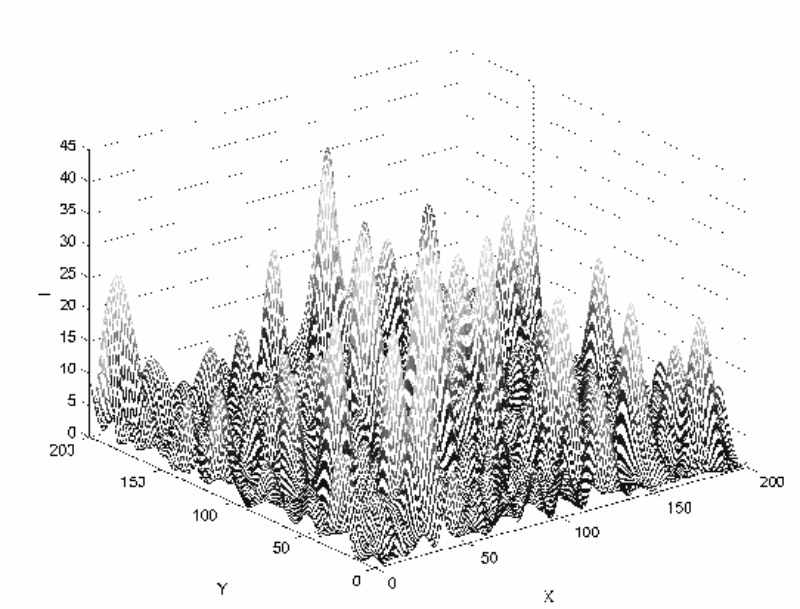

Fig. 2. Light intensity distribution on the screen, for a sample with 50 scattering centres.

A speckled image was found, in good agreement with the experimental work reported in [4] and [7] and with the computer simulation reported in [8].

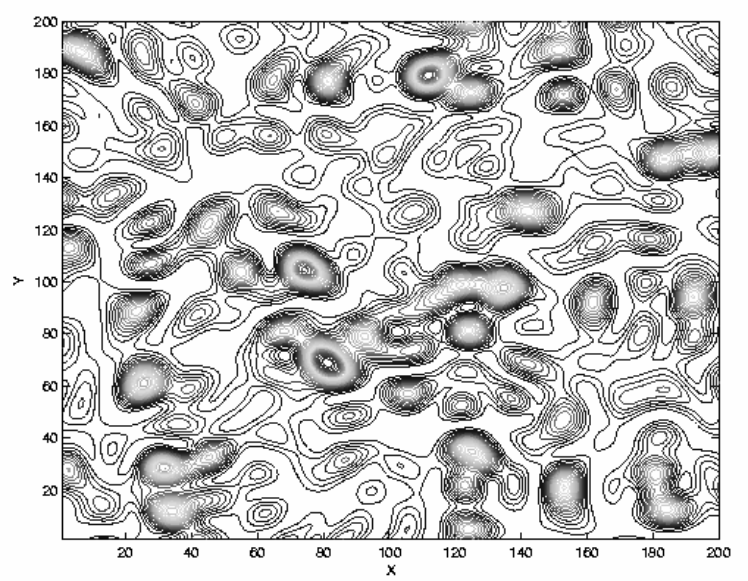

Fig. 3. Contours for light intensity distribution on the screen, for a sample with 50 scattering centres.

The work reported in [8] presents the intensity variation on a smaller area on the screen, covering a small number of maxima and minima, for one RBC concentration, focusing on the time variation of the fluctuating intensity. The work presented in this paper is essentially different, as it simulates the scattered light intensity image at one time (photo-like image) on a big area on the screen, for a wide range or RBC concentration, as previously mentioned.

Examining the plots with the intensity variation on the screen for the whole set of 26 different scattering centre configurations and numbers we found that the pattern is pretty much the same.

The number of maxima was carefully counted for each configuration and the numbers of scattering centres and maxima is presented in Table 1. Examining Table 1 and the images we notice that the number of maxima does not depend of the number of scattering centres in the sample.

Another interesting thing was found after calculating the average value and the standard deviation per point for each one of the 26 configurations that were computed. Figures 4 and 5 reveal the variation of the average intensity on the screen and of the standard deviation per data point. Examining them we notice that the variation of both the average intensity and of the standard deviation per point with the number of scattering centres is linear, which is confirmed by the values of the R^2 parameter very close to unity (R^2=1 means perfect fit).

Table 1

The number of scattering centres and the number of maxima for the configurations that were randomly generated.

Number of scattering centres	Number of maxima
50	44
100	50
150	48
200	47
300	49
400	48
500	46
1000	45
2000	50
3000	46
4000	48
5000	46
6000	47
7000	48
8000	48
9000	50
10000	47

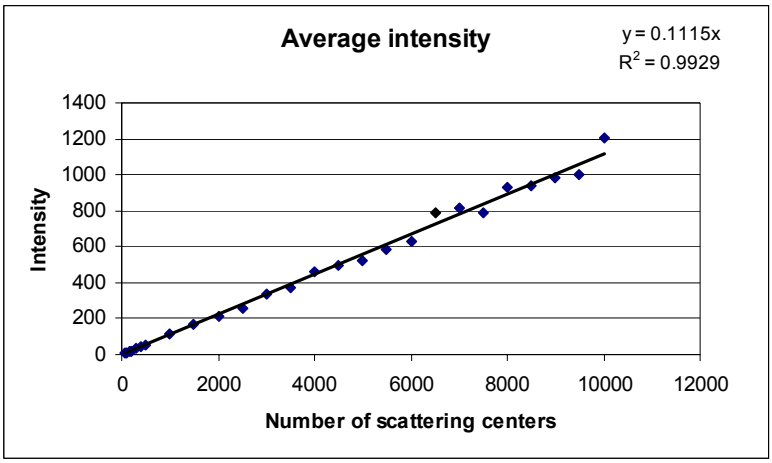

Fig. 4. The variation of the average intensity on screen with the number of the scattering centres and the linear fit.

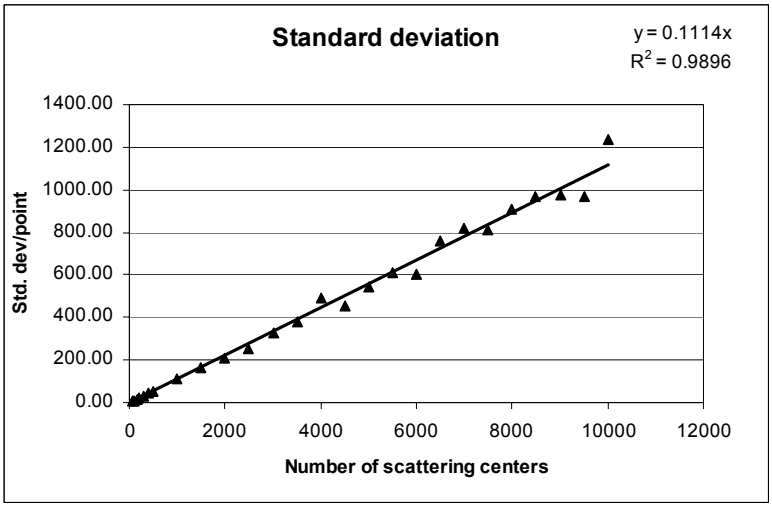

Fig. 5. The variation of the average intensity on screen with the number of the scattering centres and the linear fit.

4. CONCLUSION

The computer simulation described in this work produced realistic results, similar with the experimental work reported in [4] and [7]. The work reported in [8] focused on the time variation of the intensity in one small location on the screen while this computer simulation analyzed the light intensity at one specific time over an extended screen, for a wide range of scattering centres concentrations.

The new results we found using this computer simulation are that the average amplitude of the maxima of the light intensity increases with the number of the scattering centres.

Another new thing we found is that the number of maxima on the screen does not depend of the number of scattering centres in the sample.

Moreover, the average of the light intensity on the square location and the standard deviation were found to have a linear increase with the increase of the scattering centres concentration.

The good agreement of the computer simulation results with the pattern of the light scattering on disordered systems reported in literature suggests a simple and fast procedure of assessing the scattering centres concentration in a sample. First of all a set of calibration experiments must be performed using samples with known concentrations of the scattering centres. Digital images of the scattered light must be taken and normalized. Statistical calculations are to be performed on the digitized images and calibration curves, average intensity versus scattering centres concentrations are to be produced during calibration.

The sample with the unknown concentration can be placed later on in the cuvette and the procedure shall be repeated. Using the calibration curve, the scattering centres concentration can be assessed. A direct application might be a fast way of assessing RBC Count (red blood cell count). Work is in progress on this subject.

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