Blood flow analyses with laser speckle flowgraphy

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In the last two decades we have studied and developed two types of laser speckle flowgraphy (LSFG) systems to visualize blood flow distribution in skin tissue, human retina, etc.. The system based on analyses of the laser scattering phenomena consists of a diode laser, illuminating and imaging optical systems, an image sensor, a frame capture board, and a personal computer. By evaluating the time variation of the image speckles at each pixel point in the image sensor, and displaying the results in a two-dimensional (2D) color coded map, the blood flow distribution in the target tissue appears on the personal computer monitor. Currently LSFG systems are divided into two types. One type uses a charge coupled device (CCD) camera and is capable of visualizing the fast blood flow change with a rate of 30 maps/s and useful for ophthalmologic research. The other one consists of a line sensor and a stepping motor which is suitable for measuring the blood flow in a wide area of skin tissue. Various types of LSFG instruments used in clinical studies are demonstrated.

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The blood flow in the human skin tissue has been studied using a laser Doppler flowmeter (LDV)[1]. The technique is based on the laser scattering phenomena, especially on the interference effect of many wavelets with different shift of Doppler frequency, scattered from the blood cells moving in various directions. The light intensity of the observing point in the backscattered field varies in time due to the change of frequency shift. With the increase of the blood velocity, the intensity varies faster, and therefore the average frequency of the signal becomes higher. The LDV is thus used to monitor the blood flow in one point of the target tissue. Recently several new instruments have been developed to visualize the blood flow distribution in the skin tissue by scanning the two-dimensional (2D) laser spot. However the time-consuming scanning procedure with the single laser spot may not be suitable for the observation of rapidly varying blood flow. From different viewpoints, we have studied and developed various systems such as laser speckle flowgraphy (LSFG), to visualize a blood flow map of skin tissue, the human retina, the brain of rat, etc. using the laser speckle technique[2−4]. What follows is a brief review of our work on the LSFG systems.

Let us explain the LSFG system for ophthalmology using Fig. 1 as an illustration. The light from the diode laser is expanded by the relay lens and illuminates the retinal surface with a fairly large spot (4 mm^2). The laser reaches to the moving blood cells in the vessels as well as the capillary network, and scatters back through the lenses to the image plane where a random interference pattern or so called speckle pattern appears. According to the motion of the blood cells, the structure of the image speckles varies in time, and the rate of variation at one point is proportional to the average flow velocity at the corresponding objective point. The intensity fluctuation is captured by a charge coupled device (CCD) camera or a line sensor and the rate of time variation is calculated at each pixel point. By displaying the results in 2D form, the blood flow map of the retina is visualized. Figure 2 shows the example of LSFG attached to the retinal camera. The laser unit is set under the objective lens and the image sensor unit is mounted in place of 35 mm camera. Figure 3(a) is an example of the blood flow map taken from an early version of LSFG, and Fig. 3(b) is from the current version showing the field of view becoming much greater than the previous version. It is possible to display the time variation of blood flow at one point or at the area specified by a rubber band in the animated display of blood flow maps as seen in Fig. 3(c).

Recently we have developed a retinal camera equipped with LSFG for animal experiments. Figure 4(a) shows the instrument with the tilting stages, and taken from

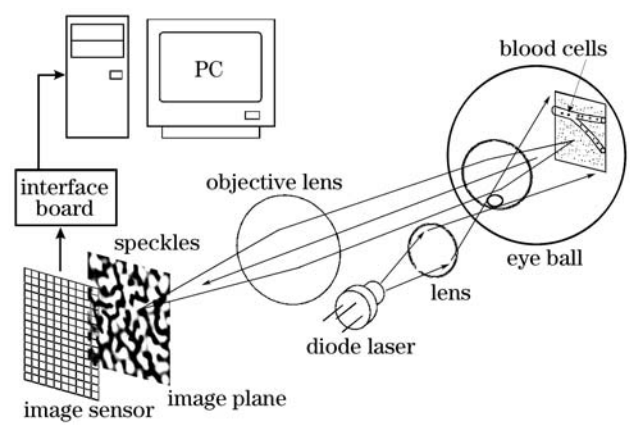

Fig. 1. Block diagram of laser speckle flowgraphy for ophthalmologic application.

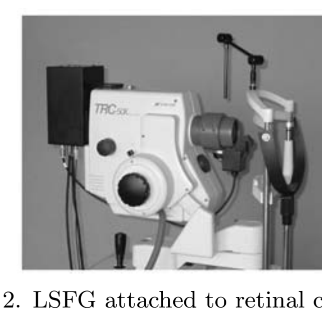

Fig. 2. LSFG attached to retinal camera.

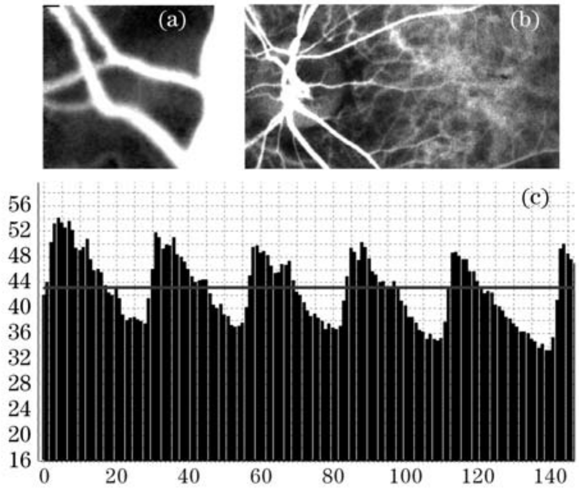

Fig. 3. Blood flow maps of retina measured by LSFG of (a) old and (b) current versions. (c) The periodic flow variation due to the heart beat.

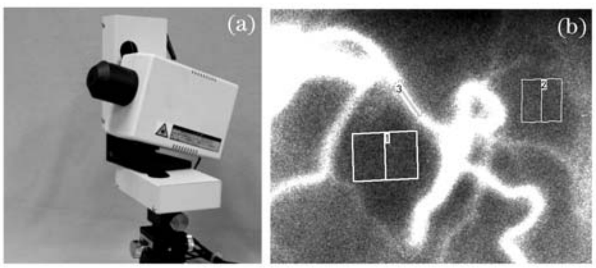

Fig. 4. (a) Retinal camera equipped with LSFG for animal experiment. (b) Blood flow taken for optic nerve head of white rabbit.

this instrument the optic nerve head of a white rabbit is shown in Fig. 4(b). The performance of this LSFG system is now much improved and applicable to the analyses of the human optic nerve head.

Figure 5(a) is another type of LSFG for animal experiments. The field of view is about 15-mm square which is suitable for studying the blood flow of leg or brain of small animals. Figure 5(b) shows an example of the flow map for the brain of a newborn rat demonstrating that the left half is in ischemia. This instrument is useful to measure the quick response of blood flow changes in the finger tip.

Besides these LSFG systems using the CCD camera, we have developed another type of LSFG instrument using a line sensor with a stepping motor. The laser in this instrument is expanded to a long line (up to 15 cm) and the line is scanned mechanically by the stepping motor perpendicular to the line in the 2D flow map. Although the time resolution becomes lower, a wide field of view

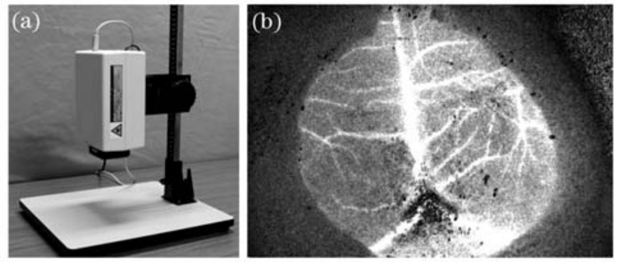

Fig. 5. (a) LSFG for studying blood flow in small tissue area. (b) Blood flow in the brain of newborn rat.

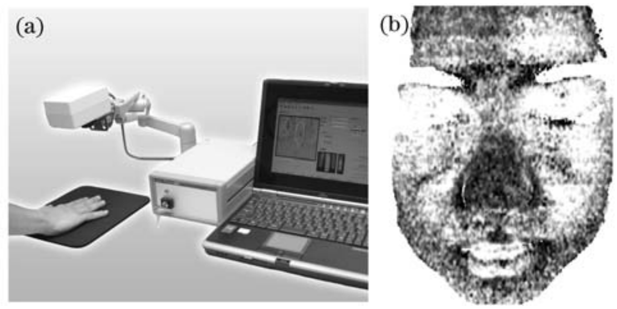

Fig. 6. (a) LSFG for skin blood flow analyses. (b) Increase of blood flow after drinking.

is achieved. Figure 6(a) shows the LSFG system to measure the skin blood flow of a hand, leg, face, etc.. Figure 6(b) shows the increase of blood flow after drinking. The measuring time is about 5−10 s, depending on the size of the object tissue.

In conclusion, we have shown various types of LSFG system used in basic research and clinical diagnosis. The performances of the LSFG is progressing rapidly for ophthalmologic applications. In particular, LSFG applications are proving useful with respect to the study of the relationship between blood flow and various diseases such as glaucoma, macular degeneration, and diabetic retinopathy.

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