Blood flow imaging is enhanced using new detector technology

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The performance of laser Doppler imaging (LDI), used for measuring in-vivo blood flow in biological tissues such as skin or brain tissue, has been dramatically improved by exploiting high-speed CMOS image sensor technology. By measuring the signal at a plurality of points simultaneously, the time required to detect changes in the blood flow has been reduced by two orders of magnitude. This new medical imaging system produces more detailed images of the blood flow than ever before. This advance has not only resulted in faster imaging speed, but the improved image clarity also allows more accurate diagnoses in medical applications.

Changes in peripheral blood flow are known to be a precise indicator of health disorders. If the blood flow could be measured quickly, reliably, and non-invasively, physicians would be provided with new options for patient screening, earlier disease diagnostic, and monitoring the effect of treatment. Laser imaging is a natural candidate for this as it allows measuring blood flow changes non-invasively and without any physical contact. However, present blood flow imaging systems are not yet suitable for clinical applications, because they are either too slow or insufficiently accurate and require special skills to operate.

There have been several approaches to the development of laser blood flow imagers. Scanning imagers—for instance two different LDI systems have been developed by Wärdell et al.\(^1\) and by Essex and Byrne\(^2\)—suffer from low imaging speed. Full-field imagers—the laser speckle imagers (LSI) by Fercher and Briers\(^3\) and Dunn,\(^4\) for example—do not distinguish between changes in blood concentration or velocity and cover only a small velocity range. To overcome these problems, we have developed a new imaging system that attempts to incorporate the advantages of both LDI and LSI without featuring the disadvantages.

Our new digital imaging modality uses the latest CMOS image sensor technology. The new imager is based on an integrating CMOS image sensor with random region-of-interest (ROI) addressing capability.\(^5\) This feature allows the acquisition of the Doppler signal at many spots simultaneously at a sub-frame rate of several kHz. Such a parallel detection approach substantially reduces the measurement time. Integrating detectors also have a better signal-to-noise ratio than non-integrating detectors, especially when measuring simultaneously in a plurality of points. The random addressing integrating detector also allows the use of the same detector for both LDI and LSI, extending the ability of the instrument.

The new laser Doppler imaging system allows imaging and real-time monitoring of blood flow in biological tissues, e.g. skin microcirculation, in an area of up to \(15 \times 15\) cm\(^2\). The system generates two-dimensional blood flow related maps (perfusion, concentration, and speed) with a frame rate of 0.1Hz to 10Hz, depending on the map size and sam-

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pling resolution for fast Fourier transform (FFT). For instance, the system can handle ten $64 \times 64$ pixel images per second or one $256 \times 256$ pixel image. In comparison, current commercial systems need more than five minutes for comparable flow-map image quality. The schematic drawing of the full-field laser Doppler imager is illustrated in Figure 1.

An extended laser beam illuminates the sample. The sample is imaged with an objective lens onto the CMOS image sensor (2D photodetector array). The intensity variations at each pixel are recorded into the computer memory and processed in real-time, applying FFT and image speckle contrast analysis algorithms. Here, FFT calculates the Doppler spectrum related to the power spectrum of the intensity fluctuations at the measured point. Perfusion, concentration and speed signals are calculated from the obtained data. Finally, two-dimensional false-color maps of the blood flow are displayed on the computer monitor, as shown in Figure 2. The changes of the blood flow over extended areas of tissue can now be monitored in real time providing the physician with functional information about the microcirculation, (see Figure 3). In contrast with conventional laser Doppler flowmetry—which measures a single point—functional mapping images not only correlate in magnitude with the degree of perfusion, but also localize changes of blood flow with high spatial specificity.

Our main objective was to develop a reliable, objective, user- and patient-friendly high-speed imaging system for measuring the blood flow in various biological tissues. Although the experience is still needed to interpret the images, the measurements themselves could be administered very easily due the instrument design. Our system is a fully user-independent, therefore highly reliable, instrument that greatly reduces costs and improves patient benefit.

![Intensity image](image1)

![Perfusion map](image2)

![Concentration map](image3)

![Speed map](image4)

**Figure 2.** Blood flow related images of human fingers. Images size is $512 \times 512$ pixels. The imaging time is 5 seconds in total.

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![Series of perfusion images](image5)

**Figure 3.** A series of perfusion images ($256 \times 256$ pixels) obtained during the arm artery occlusion experiment. The imaging time is 3 seconds per image. Numbers show the relative time when the image was obtained.
References
2. T. J. H. Essex and P. O. Byrne, A laser Doppler scanner for imaging blood flow in skin,
3. A. F. Fercher and J. D. Briers, Flow visualization by means of single-exposure speckle
4. A. K. Dunn, H. Bolay, M. A. Moskovitz, and D. A. Boss, Dynamic imaging of cere-
bral blood flow using laser speckle, Journal of Cerebral Blood Flow and Metabolism
5. A. Serov and T. Lasser, High-speed laser Doppler perfusion imaging using an integra-
ting CMOS image sensor, Optics Express 13(17), pp. 6416–6428, 2005.