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Imaging Flows Using CMOS Sensors

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Laser Doppler flowmetry is a well-established tool for imaging flows. It has been used as a clinical tool for measuring microcirculation in superficial tissue for applications including studies of allergic reactions, burn depth assessment, skin cancer diagnosis, assessment of skin diseases and investigating the effects of transdermal drug delivery. Imaging is often performed by scanning a single laser beam over an area of interest to build up an image point by point, however, the acquisition time is relatively long due to the necessary mechanical scanning. For example a typical commercially available system can take up to 5 min to obtain a 256 × 256 image. Line scanners utilizing a 64 × 1 photodetector array can provide 64 × 64 pixel images in 4 s. An alternative technique is Laser Speckle Contrast Analysis (LASCA), in which a full name CCD camera is employed to acquire speckle images and a block of pixels is used to calculate the speckle contrast. The measured speckle contrast is proportional to the velocity of the moving blood cells. Although LASCA provides a cost effective method for real-time blood flow imaging the measurement results are exposure time dependent and the spatial averaging performed across a sub-array (often 5 × 5 or 7 × 7 pixels) results in a reduction in spatial resolution.

In recent years with the development of high frame rate CMOS technology and fast signal processors such as field programmable gate arrays (FPGAs), an implementation of full field laser Doppler flowmetry based on a commercial CMOS image sensor coupled with a digital signal processor has been demonstrated. The Doppler signal detected by the sensor at each pixel is multiplexed, digitized and then transferred off chip for signal processing. The advantage of this system over the scanning laser Doppler imaging system is that the frame rate of the system is increased due to the absence of moving scanning components. We have developed such a system which has allowed a direct comparison of laser speckle and laser Doppler imaging to be carried out in which the detected light is processed in real time on an FPGA using both processing algorithms.

Custom made cameras with on-chip processing can also be fabricated using CMOS technology [1]. A custom made camera design offers several advantages over commercial cameras as the specifications can be tailored to the signals of interest. For laser Doppler blood flowmetry, the pixel size, current to voltage conversion gain and number of digitization bits can be designed to best match those of typical signals. Appropriate anti-aliasing filters can also be added at the pixel level. Integration of the pixel front-end with on-chip processing enables each pixel to be sampled at a minimum rate of 40 kHz with a low data readout rate required, as the output is a processed flow image rather than a series of raw data images. In CMOS custom made designs there are considerable design constraints in terms of the silicon area of the processing electronics and the ratio between the areas of the pixel level electronics to that of the photo-detectors (fill factor). The circuits used in the discrete electronics systems cannot simply be replicated on-chip as the relatively low frequencies used in LDBF means that on-chip component sizes are commensurately often large. Therefore moving from discrete electronics at a single point to a fully integrated sensor array is a challenging task and design optimizations and compromises need to be made. The system design and results from flow phantoms and blood flow will be presented.

Reference

[1] He et al, Laser Doppler Blood Flow Imaging Using a CMOS Imaging Sensor with On-Chip Signal Processing, Sensors 13(9):12632-12647, 2013