BME 381J – Functional Imaging Laboratory

Homework 5: Laser Speckle Imaging and Dynamic Light Scattering

due November 25. Turn in via canvas.

1 Introduction

Laser speckle is a random interference pattern that results from the coherent addition of light at a detector. A speckle pattern can be observed by shining a laser pointer onto a rough surface such as a piece of paper or a wall. The twinkling pattern is a speckle pattern. While speckle is often a source of noise in imaging systems, it can also be used to obtain detailed information about the motion of scattering particles. Laser speckle contrast imaging has been used for imaging blood flow in the brain, retina and skin.

When an object is diffusely illuminated with coherent light and the scattered light is imaged onto a CCD camera, a speckle pattern is produced. If the scattering particles are stationary, a static speckle pattern is produced. If the scattering particles are in motion then a time varying speckle pattern is produced. The temporal variations in intensity at any pixel in the image are related to the speed and motion of the scattering particles. Since any motion of the scattering particles is encoded in the temporal dynamics of a speckle pattern, speckle imaging is a very sensitive method for measuring motion. Direct measurement of the temporal intensity fluctuations is the basis for laser Doppler perfusion measurements. While laser Doppler is a standard technique for assessment of blood flow, its primary disadvantage is that it is limited to measurements at a single spatial location. Laser speckle contrast imaging on the other hand produces two-dimensional images of blood flow.

Laser speckle contrast imaging uses the spatial statistics of a time-integrated speckle pattern to image blood flow. When a time varying speckle pattern is imaged onto a CCD camera, the temporal intensity fluctuations of the speckle pattern are integrated over the duration of the CCD's exposure time. Therefore in areas of higher blood flow where the speckle intensity fluctuations are more rapid, the time integrated intensity will be more uniform. In areas of lower blood flow the time integrated intensity will have more variation. To quantify the spatial statistics of the speckle pattern, the speckle contrast, K, is defined as the ratio of the standard deviation to the mean intensity in a localized region of the image,

$$K = \frac{\sigma_s}{\langle I \rangle} \tag{1}$$

In practice a sliding window of 5×5 or 7×7 pixels is used to compute the speckle contrast. The speckle contrast varies between 0 and 1 and a lower value of K indicates a larger blood flow. To produce a blood flow image, the speckle contrast is computed at each pixel of the raw speckle image using a sliding $N \times N$ window.

The value of K depends on the time over which the speckle fluctuations are integrated, which is the exposure time of the CCD camera, T. The exact relationship between the exposure time and speckle contrast is a complicated function of the velocity distribution of scattering particles, as well as the scattering properties of both stationary and moving tissue. For a the case of linear motion, the relationship is given as

$$K = \left(\frac{e^{-2x} - 1 + 2x}{2x^2} \right)^{1/2} \tag{2}$$

where $x = T/\tau_c$ and τ_c is the correlation time of the speckle intensity fluctuations and T is the camera exposure time.

2 Data Analysis

The description of the data collection is included in the Towle et al paper. The data consists of a series of raw speckle image files collected over a period of 5 minutes. Each file contains 10 raw laser speckle images. The script `read_raw_basler.m` allows you to read the contents of each image file into a $m \times n \times N$ array, where each image is $m \times n$ pixels and there are N images in a file.

1. Read one of the raw image files into matlab and display the raw images with the `imagesc` command. Your images should be displayed as 8-bit grayscale images. Please submit the code you wrote for reading in the images and displaying the images, and an image of one raw frame.

2. Plot a histogram of the raw pixel values for one raw speckle image. What is the range of intensities? Provide a brief explanation about what the numbers on both axes of the histogram plot represent.

3. Write a matlab function to compute the speckle contrast image of a raw speckle image for a specified window size. Try to avoid using nested for loops or the processing will be very slow. The matlab command `colfilt` may be useful for simplifying your function. Make sure you use the 'sliding' option if you use `colfilt`. Use your function to compute the speckle contrast for the raw images you read in step 1. Display the speckle contrast images using the command `imagesc`. Typical syntax for this command is `imagesc(sc, [min max]); axis image; colormap(jet)`. Look through the help for more details. Submit your code and one of the images you create.

4. Display the speckle contrast image for a single raw image (ie, one of the 10 images in one of the files) with the average of 10 speckle contrast images (ie, all of the

images in one file). How does the image quality change with averaging? Is it equivalent to average the speckle contrast images after processing each raw image vs averaging the raw speckle contrast images together first and processing a single averaged raw image? Explain your answer.

5. Look at your speckle contrast image and select 3-4 regions of interest. For each region, determine the mean speckle contrast in the region for all of the files in the data. You should average the 10 speckle contrast images in each file. Plot the timecourse of the speckle contrast for all regions of interest. Each line on the plot should have 102 data points. The time between data points is 24 seconds. Submit your code and the plot of speckle contrast vs time for your regions of interest.

6. Convert the speckle contrast values to correlation times, τ_c using Eq 2. The exposure time of the camera was $T = 5$ ms. You will need to use interpolation to invert this equation. Plot $1/\tau_c$ vs time.

7. Optional: create a movie of the blood flow dynamics from this data similar to the one shown in class.

3 References

1. J. Briers, Laser Doppler, speckle and related techniques for blood perfusion mapping and imaging., Physiol Meas, vol. 22, no. 4, pp. R35 66, 2001.

2. J. Briers, G Richards, and X. He, Capillary blood flow monitoring using laser speckle contrast analysis, J Biomed Opt, vol. 4, pp. 164-175, 1999.

3. A. Dunn, H. Bolay, M. Moskowitz, and D. Boas, Dynamic imaging of cerebral blood flow using laser speckle, Journal of Cerebral Blood Flow an Metabolism, vol. 21, pp. 195-201, 2001.