DETERMINATION OF BLOOD CAPILIARY OBSTRUCTION THROUGH LASER SPECKLE IMAGING VIA SIMULATING THE OBSTRUCTION CONDITION

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Abstract— Laser Speckle contrast imaging was first introduced in 1980s, since then it has emerged as a powerful tool for full-field imaging technique for blood flow measurement. In recent years laser speckle contrast imaging technology has gained large attention, due to its capability to rapidly adopt for blood flow studies in the brain. A speckle pattern is produced when a diffuse object is illuminated with a monochromatic highly coherent laser light, a random interference effect occurs which give rise to speckle patterns. Fluctuation in intensity occurs when object under consideration is in motion. Fluctuation in the intensity of speckle pattern can be used as a source of information to predict the movement of object under consideration. Velocity distribution are coded as speckle contrast variation, this is done as fluctuation in speckle pattern intensity causes a blurring of the speckle, and this leads to a decrease in the local speckle contrast. The research work thus focus upon the use of this powerful tool to measure the blood capillary obstruction by simulating obstruction condition using pressure cuffs. The study preforms study of speckle contrast under two different condition namely studying the speckle contrast without and then with pressure cuffs. Velocity of blood in capillary is a direct indication of fitness of skin, any abnormality in blood flow velocity in capillary can be an initial indication of skin disorder. The paper closes by presenting the result obtained by studying the two conditions. Thus evaluating the blood flow velocity in blood capillary of human arm.

I. INTRODUCTION

Laser Speckle Imaging is a non-invasive technique for monitoring blood flow. This technique of blood flow measurement not only provides good results but also relieves the subject off the pain of inserting pointed needles multiple times [1]. When a photon gets scattered from a travelling particle, its carrier frequency is shifted known as Doppler shifted. By analysis of the Doppler shift of the photon, or by studying the distribution of Doppler shifts from a perspective of distribution of photons, it is always possible to detect the dynamics of the particles scattering the light [4]. Analogy to this is that, when highly coherent light scatters from a random medium, the so scattered light tends to produce a random interference pattern called Speckle. Phase shift in the scattered light is produced when particle moves with in the random medium [6]. This changes the random interference pattern, producing time based fluctuations in the speckle pattern that is analogous to the intensity fluctuations that occurs due to Doppler shift. In last decade, there has been an accelerated adoption of the technology as the neuroscience community has used it to measure blood flow in the brain.

In this research work we have tried to determine the blood flow velocities in the capillary of the human arm [2]. The complete methodology and the experimental setup used to collect and analyze the data is presented in coming sections. The paper will not only provide the methodology to estimate the blood velocity but will also play a major role in laying the foundation of the methodology to detect abnormality in skin that is a direct indication to skin disease. As skin disease is often marked by increase of blood flow velocities in capillaries and redness on the skin, since redness alone is not an indication because it can be a local phenomenon resulting by momentarily effect of Allergic environment.

II. THEORITICAL BACKGROUND AND METHODOLOGY

A. The Speckle

Random interference of coherent light is accountable for rise of speckle. Whenever coherent light interacts with a random scattering medium, a photo-detector will receive light that has scattered from varying positions within the medium and will have thus traveled a distribution of distances, resulting in constructive and destructive interference that varies with the arrangement of the scattering particles with respect to the photo-detector [3]. Thus, if this scattered light is imaged on camera, one can see that the interference fluctuates randomly in space, making an arbitrarily fluctuating intensity pattern recognized as speckle. If scattering particles are moving, this will cause differences in the interference, which will appear as intensity deviations at the photo-detector. The temporal and spatial statistics of this speckle pattern provide information about the motion of the scattering particles. Motion can be quantized by studying the temporal or spatial variations. Using the latter approach, 2-D maps of blood flow can be obtained with very high spatial and temporal resolution by imaging the speckle pattern onto a CCD camera and quantifying the spatial blurring of the speckle pattern that results from blood flow [5].

Figure 1 shows the experimental set up for acquiring the laser speckle imagery.

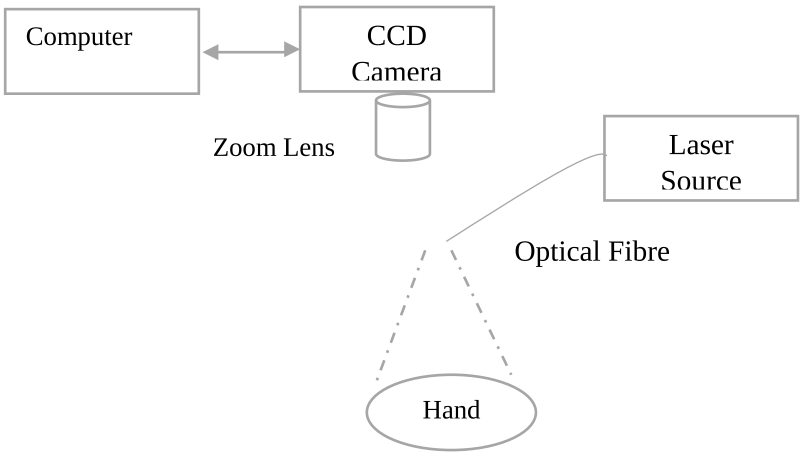


Figure 1: Experimental setup to acquire laser speckle imagery

Figure 2 shows the obtained LSI of a human hand the bright spots and dark spots are indication of construtive and destructive interference respectively.

Figure 2: The LSI of Hand, obtained by imaging hand of a volunteer

Speckle flow techniques are grounded on the variations over time of the dynamic speckle pattern generated by motion in the sample. In these methods, this changing speckle pattern is noted with a camera that has an integration time in the order of the speckle decorrelationtime (i.e., in the millisecond range). Due to the long integration time compared to the typical decorrelationtime of the speckle pattern, the speckle pattern will be blurred in the recorded image. The level of blurring is quantified by the speckle contrast. The speckle contrast Cis usually defined as the ratio of the standard:

$$C \equiv \frac{\sigma}{\langle I \rangle} = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle}$$
……eq(1)

The speckle contrast can be connected to blood velocity in object under consideration by the equation.

$$\frac{\sigma}{\langle I \rangle} = \sqrt{\frac{\tau_c}{2T}\left(1 - \exp\left(-\frac{2T}{\tau_c}\right)\right)}$$
……eq(2)

Where τ_c is correlation time and T is the exposure time. τ_c is assumed to be inversely proportional to a measure of the speed or flow of the scattering particles.

The simulation of obstruction in the blood flow was created by using a pressure cuff.

B. Methodology for calculation of contrast.

The speckle contrast is defined as the ratio of standard deviation of the intensities to the mean of the intensities (Richards and Briers, 1997) and can be represented by:

$$K = \sigma / I$$ …..eq (3)

The contrast is calculated locally that is local standard deviation and local mean are taken into account while evaluating the contrast, generally n x n window is taken. The optimal value is found out to be 5 x 5 as anything below that the speckle statistics becomes invalid and anything higher than five reduces the spatial resolution of the contrast image drastically.

Speckle contrast can be calculated in two ways spatially using a single image or temporally using a bank of image separated by finite time interval.

Spatial speckle contrast is calculated over a single speckle image using 5 x 5 window.

Steps involved in calculation of spatial contrast

1. A square window (usually 5 x 5) is selected as shown in figure 2.5, contrast is calculated for that window and this contrast value is kept in a new matrix at the center pixel of the window.
2. The window is moved first along the columns and then along the rows to cover the entire image and Step 1 is repeated for each position.

III. RESULTS

Speckle contrast changes with change in flow velocity, higher flow corresponds to lower speckle contrast and vice versa. In this section preliminary experiments are performed to prove this fundamental fact regarding speckle contrast. Experiments using flow phantoms are performed and flow velocity is calculated. Finally in this section a new multi-exposure model is proposed to estimate the velocity values obtained from speckle contrast.

The pressure cuff (of a sphygmomanometer) was placed on the upper arm (left hand) of the subject and speckle images were acquired from dorsal part of the hand. The first image was acquired in normal condition that is without application of pressure the second image was acquired after the pressure cuff was inflated applying a pressure of 180mm of mercury. The upper side of the hand was imaged as shown in the figure 1.

Table 1 shows the spatial contrast values determined by using the methodology described in section II. While figure 3 shows the contrast images obtained after processing of the LSI using described methodology.

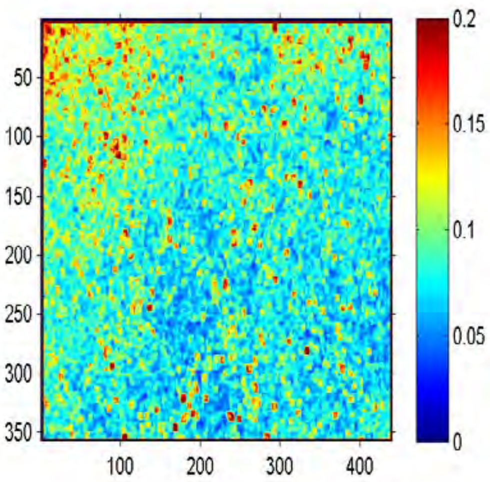
Table 1: Spatial Contrast values before and after inflation of the pressure cuff.

Subject No	Spatial contrast at normal condition	Spatial contrast when the pressure cuff in inflated
1	0.0995	0.1093
2	0.1102	0.1284
3	0.1265	0.1354

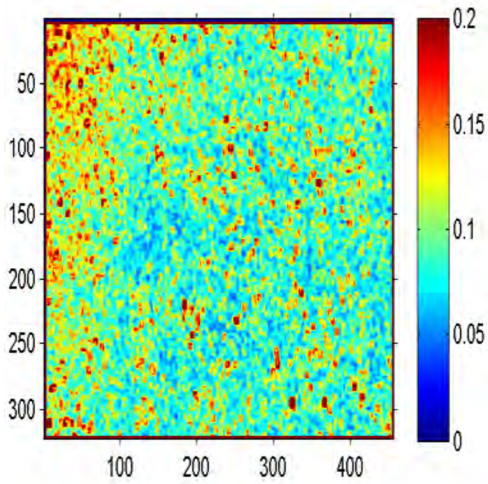
When the pressure cuff is inflated the brachial artery is blocked which causes reduction in blood flow as a result contrast which is inversely related to the flow velocity increases in case of inflation of the pressure

(a) Normal Condition

(b) Pressure cuff inflated



(a)



(b)

Figure 3: Spatial Speckle Contrast (a) normal condition (b) when pressure cuff is inflated.

It can be seen from the figure 3 that during normal condition (Fig 3a) the contrast values are lesser than when the pressure cuff is inflated (Fig 3b). Also by seeing the contrast image one can separate the different conditions of flow qualitatively.

IV. Conclusion

Laser Speckle imaging is an excellent and innovative way of measuring the blood flow velocity in Capillaries. The process not only being fast and effective but also is a non-invasive way of measuring the blood flow measurement. In this research work we have tried to calculate the speckle contrast value of the laser speckle image under two conditions to simulate the blockage in the capillary.

The speckle contrast value as expected is different for both the cases. The speckle contrast value for normal condition when the pressure cuff was deflated comes out to be 0.0995 case 1 while it in the similar case it was 0.1093. Since these values are correlating to the phenomenon that is expected to happen. The speckle contrast values are inversely proportional to the blood flow velocity hence the greater the speckle contrast the lesser the blood flow velocity and vice versa.

The research can also be extended to deal with the detection of skin abnormalities at an early stage as because the abnormalities are often marked by increased blood flow velocity in the capillaries.

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