Advanced BME Laboratory (AM5019)
Biophotonics Lab
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EXPERIMENT: Assessment of blood flow using Laser Doppler flow meter

AIM:

To understand the working principle of LDF and its application in the assessment of flow.

OBJECTIVES:

To understand the LDF system and its components.
Analyze and compare the pulse rate and amplitude using doppler flowmetry experiments at the finger tip and dorsum (bone) region of the hand to distinguish static and dynamic flow.
Analyze and distinguish the signal at the finger-tip when pressure is applied with a cuff to the forearm.
Analyze and distinguish the signal at the finger-tip post exposure to IR radiation.

APPARATUS & SOFTWARE USED:

i. PPG sensor: OxyFlow probe (MSP310 XP; Probe ID 15) (835 nm)
ii. AD instruments Blood FlowMeter
iii. Data acquisition system: AD instruments
iv. LabChart software
v. MATLAB for further analysis.

Figure 1: LDF components

THEORY:

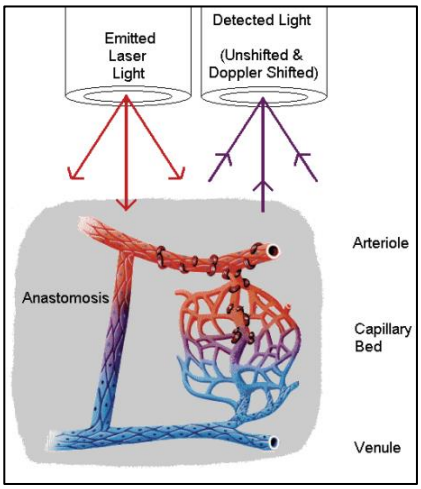

Figure 2: LDF principle

Laser Doppler blood flow monitor can be used to measure the total local microcirculatory blood perfusion in capillaries, arterioles, venules, and shunting vessels. It is a noninvasive technique of measuring microvascular blood flow in tissue and often provides a good indicator of peripheral vascular disease. It offers several clinical and research advantages, i.e. high sensitivity, no injectable traces, and ease of use. Similar to ultrasound, it depends on the Doppler effect, i.e., the change in frequency between an applied laser beam and the returning beam of light to determine the speed of blood cells in the sample volume. When a laser beam is directed towards the tissue under study, absorption and scattering of laser light take place. Laser light scattered by movable structures, such as red cells, is shifted in frequency due to the Doppler effect, while there is no shift in frequency of the light scattered in non-moving soft tissue. The mixing of these two different light frequencies produces a beat frequency. This beat frequency can be detected by the laser Doppler machine and then analyzed to provide a skin blood flow measurement. The blood cells move through the capillaries at about 1 mm/s. The effective radiation penetration depth is approximately 1 mm in soft tissue, and scattering and absorption take place mostly in the papilla region and the underlying corium – two dermal layers containing the capillary network of the skin.

$$Doppler\ frequency\ (f_D) = \frac{2.f_t.V.\cos\theta}{c}$$

f_d: Doppler shift;
c: speed of light in tissue;
f_t: transmitted beam frequency;
V: velocity of the blood;
Θ: angle of incidence between the beam and the direction of the flow;

The measuring depth depends on tissue properties such as the structure and density of the capillary beds, pigmentation, oxygenation, etc. It also depends on the wavelength of the laser light and on the distance between the sending and receiving fibers in the laser Doppler probe. In normal skin, a probe

with standard fiber separation (0.25mm) and a 780nm wavelength laser, the measuring depth will be of the order of 0.5–1mm.
Laser Doppler signals are recorded in blood PU (Perfusion Units) which is relative scale defined using a carefully controlled motility standard comprising of latex spheres undergoing Brownian motion. PU is a measurement of RBC flux.

$$PU = No.of\ RBC\ in\ volume \times Mean\ velocity\ of\ RBC;$$

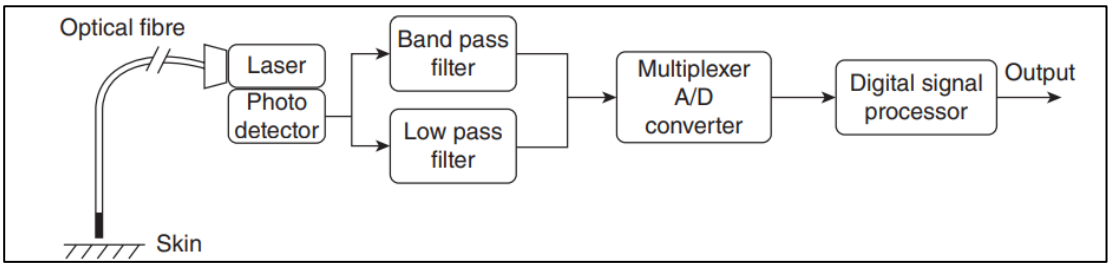

Figure 3: Instrumentation system

In principle, light from a low power laser is coupled into a quartz fiber and transmitted to the skin. The light is reflected from both the non-moving tissues (reference beam) and moving red blood cells (Doppler-shifted beam). The two beams are received by a plastic fiber and transmitted back to a photodiode where optical heterodyning takes place. The heterodyned output signal that is proportional to the Doppler shift frequency is amplified, and both RMS and DC values are calculated. The RMS value is weighted against the back-scattered light intensity using the measured DC value as an index of total received power. This gives a measure of the output flow velocity. The photodetector converts the optical signal into an electrical signal. The photodetector functions as a square law device and gives out current, which is proportional to the intensity of the incident light and, therefore, to the frequency of beating of the shifted and unshifted signals. The light falling on the photodetector is an optically mixed signal involving a Doppler-shifted signal back scattered from the moving red blood cells with the 'reference' signal reflected from the non-moving skin surface. The diode is connected in a configuration so that it gives wideband performance. A bandpass filter is used to remove noise outside the bandwidth and extract blood flow related AC components. A low-pass filter is also connected to the output of the photodetector and is used to extract DC components proportional to the intensity of the collected light. Outputs of the bandpass and low-pass filter are converted into digital form by a multiplexer and A/D.

PROCEDURE:

i. The subject was asked to sit in a relaxed position.
ii. The LDF probe was placed on dorsum (bone) region of the hand and the signal was recorded.
iii. Next, the LDF probe was placed on the finger tip of the hand and the signal was recorded.
iv. Following this, the LDF probe was placed on the finger tip and the signal was recorded when the blood flow was occluded using a cuff at the upper arm.
v. After this, the finger tip was exposed to an IR lamp for a few seconds. The LDF signal was then recorded from the fingertip.
vi. The LDF signals were then analyzed using MATLAB.

RESULTS & OBSERVATIONS:

Static and dynamic flow

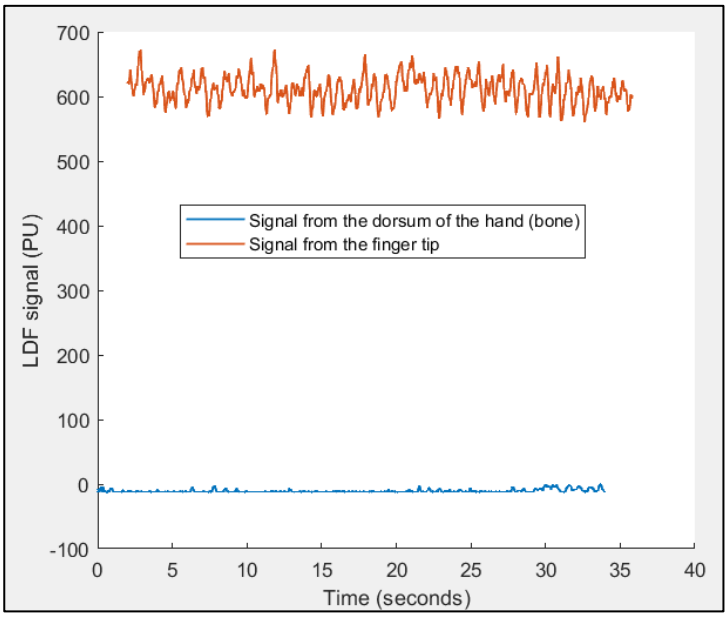

Figure 4: Static and dynamic flow

It can be observed that the perfusion is zero in the bone region of the dorsum of the hand for static flow. On the other hand, the signal at the finger tip has high PU in the range of 560 – 670 PU.

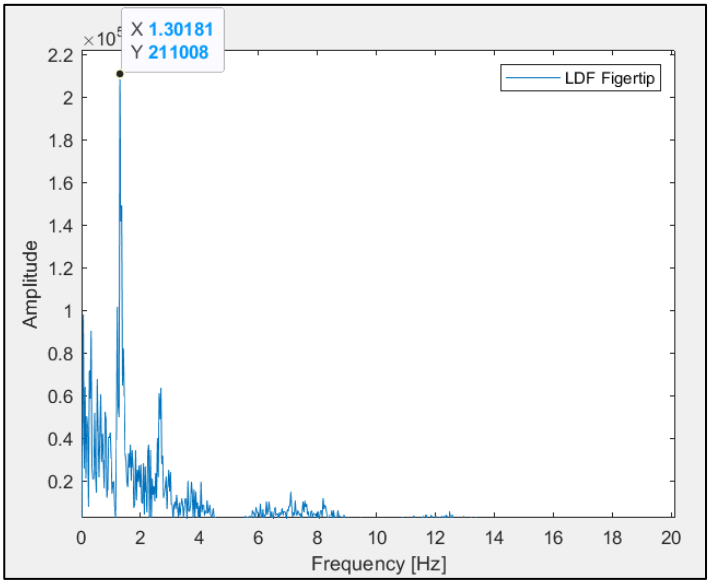

Figure 5: FT of LDF signal at the fingertip

Taking the FT of the LDF signal from the finger-tip it can be observed that the peak amplitude occurs at 1.3Hz.

LDF signal when blood flow is occluded using a sphygmomanometer cuff at the upper arm

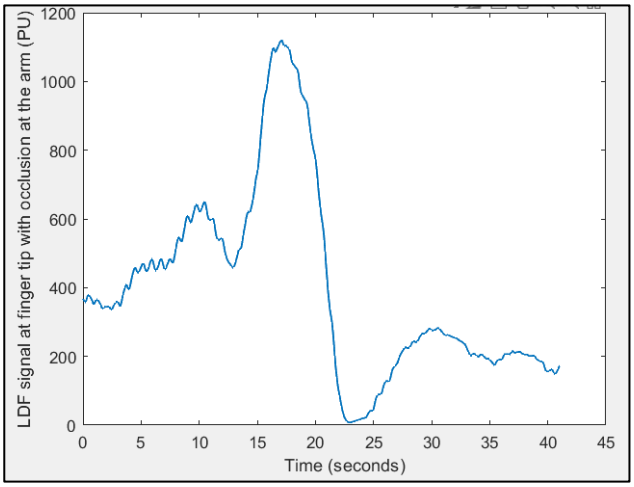

Figure 6: LDF signal at the fingertip during blood flow occlusion

The signal was recorded at the fingertip during the entire duration when blood flow was occluded by applying pressure to the upper arm. Around 23 seconds, it can be observed that the brachial artery is completely occluded due to which no blood flow is detected in the arteries and capillaries of the fingertip. After 23 seconds, the pressure was released and the perfusion starts. However, it takes time to reach back to its previous value of PU in the range of 560 – 670 PU.

LDF signal at fingertip post exposure to IR lamp

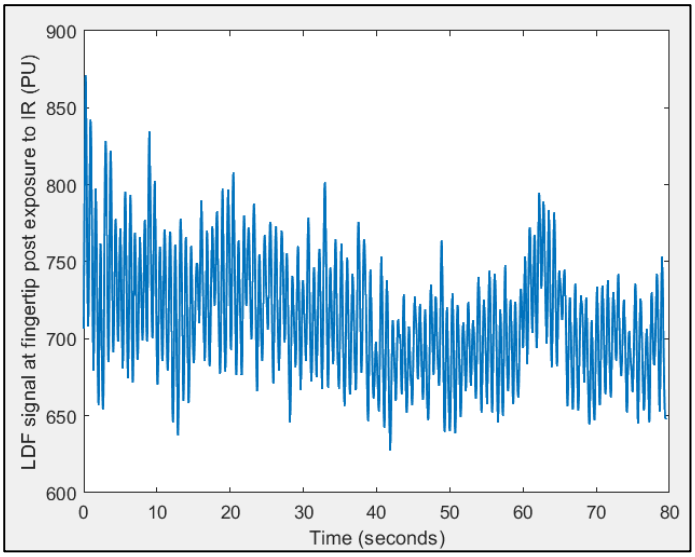

Figure 7: LDF signal at the fingertip post exposure to IR lamp

The LDF signal recorded at the fingertip post exposure to the IR lamp has increased perfusion 650- 850 PU than normal flow at the finger tip of 560-670 PU. The heating of the fingertip increased the local blood flow.

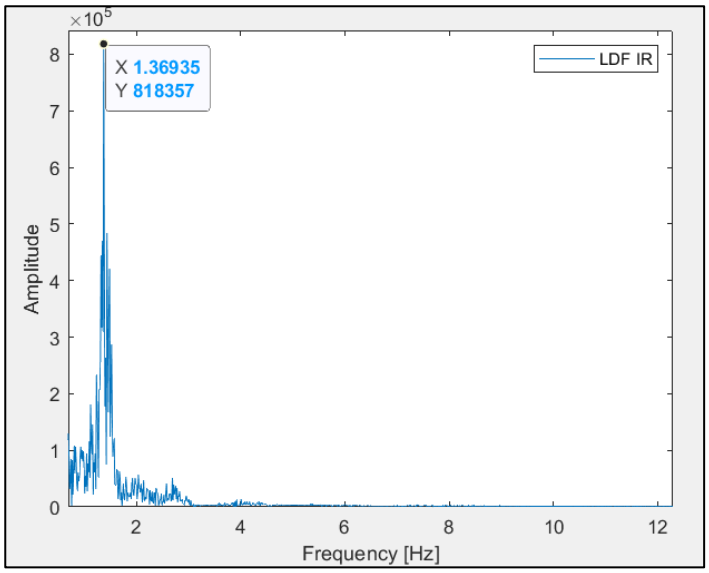

Figure 8: FT of LDF signal at the fingertip post exposure to IR lamp

Taking the FT of the LDF signal from the finger-tip post exposure to the IR lamp it can be observed that the peak amplitude occurs at 1.36 Hz. This is higher than the case of normal flow where the peak occurred at 1.3Hz.

CONCLUSIONS:

i. The LDF signal was collected and analyzed in three cases a. At the finger-tip and dorsum (bone) region of the hand to distinguish static and dynamic flow; b. At the finger tip during blood flow occlusion; c. At the fingertip post exposure to IR lamp;
ii. No perfusion was detected at the dorsum.
iii. During blood flow occlusion the perfusion dropped to zero on applying pressure using a cuff and slowly increased after release of the cuff.
iv. Post exposure to heat, at the finger tip the magnitude and frequency of the LDF signal increased.

CRITICAL REMARKS:

i. The subject should not move and the probe should be maintained in the same place to avoid motion artifacts.
ii. Since the technique samples from a very discrete volume, long-term assessments can be difficult unless experimental care is taken, or a laser Doppler imager used to sample spatial (as well as temporal) variation.