APPLICATION OF LASER FIBER OPTIC FOR BLOOD VELOCITY MEASURMENT

Dr. Munqith S. Dawood
Ass Prof
College of Engineering
Nahrain University- Baghdad

Dr. Anwaar A. Al-Dergazly
College of Engineering
Nahrain University- Baghdad

Sumia H. Jaafer (M.Sc.)
College of Engineering
Nahrain University- Baghdad

Abstract
The aim of this paper is to study the possibility of using laser technique for blood flow velocity measurement using the fiber optics to deliver the laser light and receive the scattered light from the blood flowing in different types of vessels. The measuring technique is based on utilizing the Doppler effect in light by using a He-Ne laser source. The correlation function has been used to consider the scattering light from different erythrocytes. Different angles of transmitted laser inside the vessel were used. It was found that the best angle for all vessels is 45 degrees between the light direction and the direction of blood flow.

Keywords : blood velocity, laser velocimeter, Michelson interferometer

Introduction

Recently, there has been much enthusiasm as well as big efforts by medical device companies and universities to investigate optical techniques for diagnostic and sensing instrument. One of them is the real time continuous monitoring for measuring blood flow velocity. This is necessary for emergency detection of an abrupt change of patient's health condition, and his biological activities.

Theory

The Doppler Effect is the change in frequency that occurs when there is a relative movement between the source and the target. It occurs because the waves emitted by the source are either compressed, if the source and target are moving towards each other, or spread out if they are moving away from each other [1].

The Doppler effect also occurs with light. However, the frequencies of light waves are very high and difficult to measure directly. This problem is solved by using the phenomenon of ‘beats’. This phenomenon appears when two waves of slightly different frequencies are superimposed. The received signal is a frequency that is equal to the difference in frequency between the two waves.

When mixing the Doppler-shifted wave with a reference wave of the original frequency, a beat frequency is produced that is much lower than either of the two constituent waves and is therefore much easier to measure. As this beat frequency is equal to the difference between the two frequencies, it is hence equal to the frequency shift produced by the Doppler effect, which is proportional to the target (erythrocyte) movement velocity,

$$V = (\lambda/2)\,\Delta f$$

where λ is the wavelength and Δf is the frequency difference [1].

Mathematical Simulation of Laser Doppler Blood Velocimetry.

Five major blood vessels have been considered for the simulation of laser Doppler velocimetry. These vessels have different diameters which characterize each one of them as shown in the table 1 [2].

Table 1 The systemic circulation of human

Vessel name	Diameter (cm)
Capillary	0.0005-0.001
Large arteries	0.2-0.6
Large vein	0.5-1
Descending aorta	1.6-2
Vena cava	1.9-2.1

Laser light is assumed to be guided into the vessel using the fiber optic. The light will illuminate the moving erythrocytes of the blood and scattered back from them. The scattered light collected by another fiber optic and guided it towards the optical detector. A phase shift in the reflected scattered light appears depending on the velocity of the moving erythrocytes. The electric field of the applied laser light in Laser Doppler velocimetry may be expressed as follows [3]:

$$E_i = E_0(r)\exp[ik_i.r - i\,t\,w_\circ] \quad (1)$$

where: $E_0(r)$ is the amplitude of the incident field at the point r.

w_0 Represent the angular frequency.

k_i Represent the wave vector of the laser light.

$$[k_i] = \frac{2\pi}{\lambda} \qquad (2)$$

where λ represents the light wavelength in the blood.

The electric field of the light scattered by the erythrocyte will be:

$$E_s = A \cdot f(r) E_0(r) \exp\left[i(k_f - k_i).r(t) - i\,t\,w_\circ \right] \qquad (3)$$

where A represents a constant which describes the amplitude of the scattered light;

f(r) represents the fractional reduction of the scattered light that enters the detector after passing through the scattering target (erythrocyte) .

The wave vector (k_i) in Equation (1) is represented by (k_f – k_i) in Equation (3). It represents Doppler frequency shift of the scattered light reflected from a moving erythrocyte, as shown in fig(1).

$$k = (k_f - k_i) \qquad (4)$$

So k is a function of the velocity (V), the angle (θ) between the laser beam and the direction of the moving erythrocyte.

The position of the target r in Equation (1), is represented by r(t) in Equation (3) which means the incidental position of the moving target.

Generally speaking, for a moving object with a constant velocity ,the incidental position of that object can be determined by the equation:

$$r(t) = \left[(r_0 + Vt) \right] \qquad (5)$$

Substituting equation (5) in equation (3) and assuming that the change in frequency due to erythrocyte velocity is Δw,it can be found that :

$$E_s = A \cdot f(r) E_0(r) \exp\left[ik(r_0 + Vt) - i w_\circ t \right] \qquad (6)$$

The angle velocity due to the erythrocyte motion in the blood is continuously changing as:

$$w = w_\circ \pm \Delta w$$

where $\Delta w = (4\pi V \cos\theta)/\lambda$

By assuming that $Vt << r_o$ then:

$$E_s = A \cdot f(r) E_0(r) \exp\left[i k r_0 - i\,t\,w \right] \qquad (7)$$

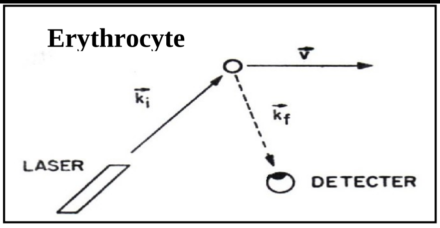

Figure 1. Schematic diagram of the scattering of laser light by a moving erythrocyte.

The transmitted initial laser beam and the scattered light to be collected are nearly in opposite directions.

In fact the fiber optic catheter collects light scattered in directions other than exact backward scattering, especially if the scattering occurs very near to the fiber optic aperture. The light scattered at a large angle from the exact backward direction go into the fiber optic aperture. However, the use of small aperture in the collection optics insures that only the light scattered into a small solid angle around the back direction is collected. To detect such a small change in the frequency, it is necessary to mix the scattered laser light having the frequency *W* with reference laser of frequency W_o, which originates at the aperture of the fiber optics. The mixing in this project carried on the surface of the photodiode detector **[4].**

Suppose that $E_{1.0.}$ is the reference laser field at the photodiode surface.

$$E_{1.0.} \equiv E_1 \exp(i w_\circ t) \qquad (8)$$

where E_1 is the amplitude of the reference laser field.

The mixing between the reference laser and the scattered light gives a fluctuation in the photocurrent output $I(t)$ of the photodiode or photomultiplier. The output of the photocurrent is proportional to the received fields as [5]:

$$I(t) = const\left| E_s + E_{1.0.} \right|^2 = const\left[\left| E_{1.0.} \right|^2 + 2\left| E_{1.0.} \cdot E_s \right| + \left| E_s \right|^2 \right] \qquad (9)$$

As $E_{1.0.} \rangle\rangle E_s$, then the last term in Equation (9), may be neglected to obtain

$$I(t) = const \left[\left| E_{1.0.} \right|^2 + 2 E_{1.0.} \cdot E_s \right] = I_0 + \delta I(t) \qquad (10)$$

where

$\delta I(t)$ Is the heterodyne beat part of the photocurrent and is expressed as:

$\delta I(t) = const\, 2E_{1.0.} \cdot E_s$	11

$\delta I(t) = 2const(A \cdot E_1)E_0(r)f(r)\cos[4\pi V(\cos\theta)t/\lambda]$	12

The fluctuation of the detector output is measured as the autocorrelation function of the time-dependent photocurrent.

$C_v(t) = \langle \delta I(t)\delta I(o) \rangle$ $= 4const^2(A \cdot E_1)^2 E_0^2(r) f^2(r)\cos[4\pi V(\cos\theta)t/\lambda]$	13

The factor $E_0^2(r)$ shows that the amplitude of the correlation function is proportional to the initial laser light intensity at the position of the moving erythrocyte.

The intensity of the scattered light is less by the factor $f^2(r)$ as this light comes back through the blood, and $(A \cdot E_1)^2$ shows that C_v is proportional to the power of the local oscillator.

If there are many erythrocytes that are moving at different points r in the same direction but with different speeds V(r), the total correlation function C(t) is the sum over all the erythrocytes.[5]

$C(t) = \sum C_v(t) = \int drp(r)C_v(t)$ $= 4const^2(A \cdot E_1)^2 \int drp(r)E_0^2(r)f^2(r)$ $\cos\{[4\pi \cos\theta V(r)/\lambda]t\}$	14

where p(r) is the density of the erythrocytes at a position r.

If the exit end of the fiber optics is chossed as the origin of the measuring coordinate, then the diameter of the vessel will be along the z axis, and the direction of the blood flow as x axis as shown in Fig.3 [3]. Since the laser beam does not spread so much, the illuminated volume is a cylinder of a cross section S. In our case the area S is about 0.2 mm^2 .

The radial distance along the laser beam from the origin in terms of z and the angle θ between the flow and the laser beam is expressed as

$r = z/\sin\theta$	15

Assuming uniform density of erythrocytes in blood, the factor *dr* becomes:

$$dr = (z / \sin\theta)dz$$

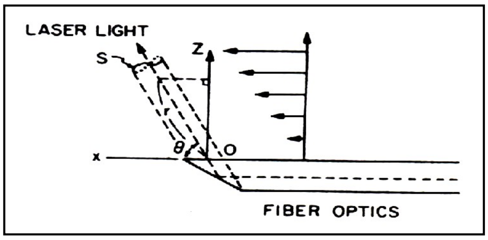

Figure 3 The flow pattern around the fiber optics.

The attenuation of the intensity $E_0^2(r)$ in the blood may be approximated by an exponential decay, thus [4,5];

$E_0^2(r) = E_0^2(0)\exp(-r/l_0)$ $= E_0^2(0)\exp(-z/l_0\sin\theta)$	16

where l_0 is the penetration depth and is 0.33mm.

Using the same reasoning and the definition of $f(r)$, and conclude that

$f^2(r) = \exp(-z/l_0\sin\theta)$	17

The velocity distribution in the vessel may be approximated by the parabolic profile:

$V(r) = 2V_{av}(1-(R-z)^2/R^2)$	18

where R is the radius of the vessel.

V_{av} Is the average velocity of the flow.

$\pi R^2 \cdot V_{av}$ is the volume of blood that passes through a cross section of the vessel per second[5].

$C(t) = a\int_0^{2R}\exp(-\alpha z)\cos[\beta V(z)t]dz$	19

$\alpha = \frac{2}{l_o}\sin\theta$	20

$\beta = 4\pi\cos\theta/\lambda$	21

$a = 4const^2(A \cdot E_1)^2 E_0^2(0)pS$	22

Since the factor $\exp(-\alpha z)$ decays very quickly as z becomes larger, the scattered light by the region of small z mainly contributes to this integration. In this region the velocity can be approximated as:

$V(z) = 4V_{av}z/R$	23

And the integration becomes

$$C(t) = a\int_0^{\infty} \exp(-\alpha z)\cos(\gamma z t)dz \qquad (24`)$$

where

$$\gamma = (4V_{av}\beta)/R \qquad (25)$$

$$\gamma = (16\pi \cos\theta V_{av})/(\lambda R). \qquad (26)$$

And by substitution of each variable the following equation can be found

$$C(t) = \frac{a\alpha}{\alpha^2 + \gamma^2 t^2} \qquad (27)$$

Calculations of the Average Velocity of Erythrocytes [5].

The value of average velocity can be estimated from the correlation data as follows, the correlation function C (t) given in Equation (27) has a maximum value Cmax at t=0.

$$C\max = C(0) = \frac{a}{\alpha}$$

The correlation function can be expressed in a normalized form as t=0 and C(0)=1.

Assume at certain time t_o =t, $C(t_o)$ =0.5 then:

$$to = \frac{\alpha}{\gamma}$$

The parameter t_o represent half-width maximum of the correlation function.

By using the values of each parameters, the average blood velocity can be calculated as follows[5]:

$$V_{av} = \frac{1}{8}\frac{\lambda R}{\pi l_o}\frac{\tan\theta}{to} \qquad (28)$$

Results and Discussion

The fluctuation of the detector output is measured as the correlation function of time as shown in Equation (27) for different radii. Four angles between laser beam and blood flow are considered they are 30,45,60 and 75 degrees.

Five groups will be considered for our calculations ;group one will be for large artery which is represented by Figures. 4-7. They represent relationship between the correlation function and the time for different angles. In each Figure we have three curves each one represent certain radius of the artery (R1=0.2 cm, R2=0.4 cm and R3=0.6 cm).

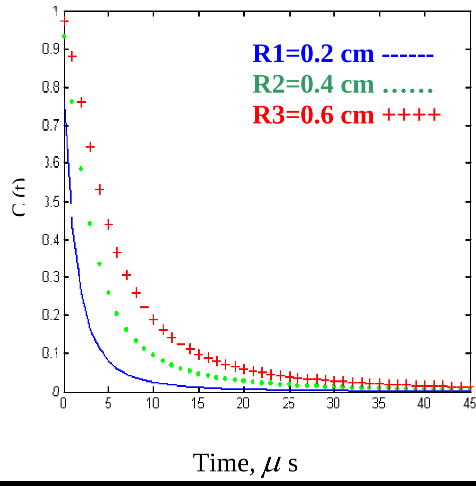

Figure 4 Correlation function versus time for large artery at θ =30° for different radii.

(31)

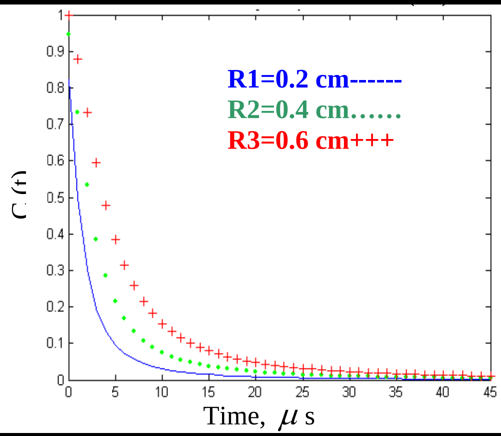

Figure 5 Correlation function versus time for large artery θ =45°for different radii..

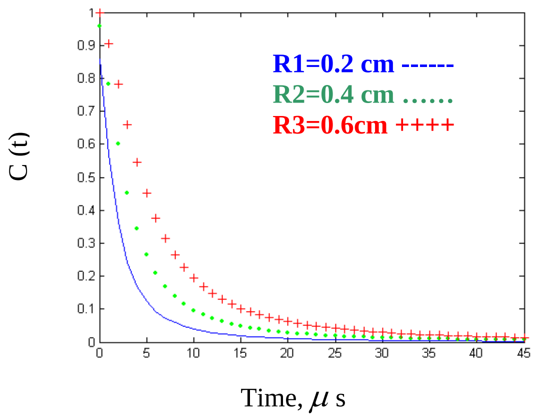

Figure 6 Correlation function versus time for large artery at θ =60°for different radii.

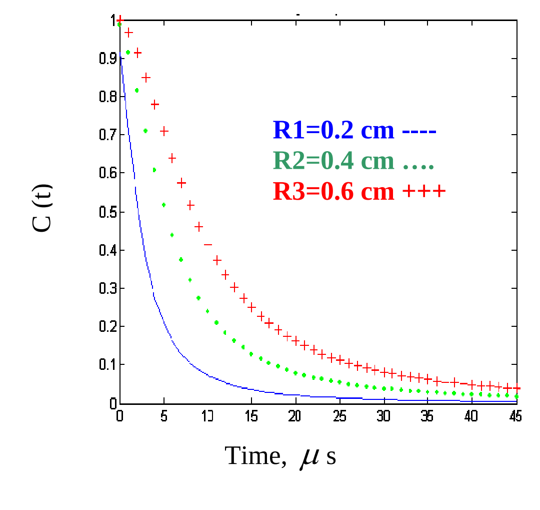

Figure 7 Correlation function versus time for large artery θ =75°for different radii.

From these curves it is possible to calculate the time which represent the midpoint of the correlation function for each curve. Then the time t_o was used to plot the relationship between the calculated velocity of erythrocytes and angle of the applied laser direction for different vessels as shown in figures 8-12. These figures show that the most practical angle is 45 degrees.

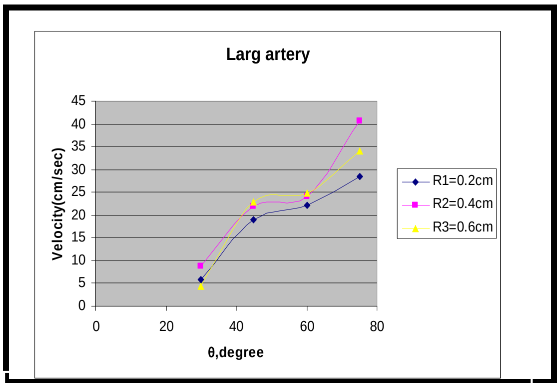

Figure 8 The velocity versus the angle between the flow direction and laser beam in large artery for different radii**.**

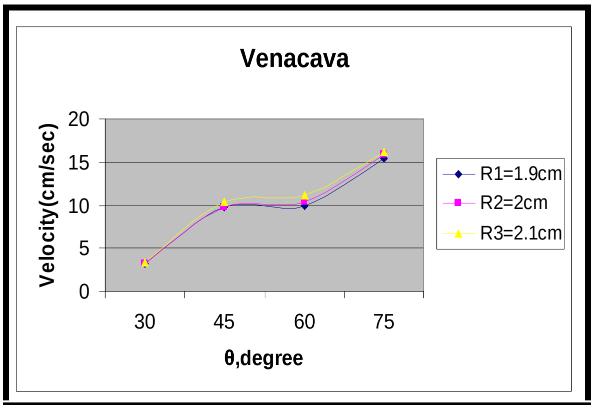

Figure 9 The velocity versus the angle between the flow and laser beam in vena cava for different radii**.**

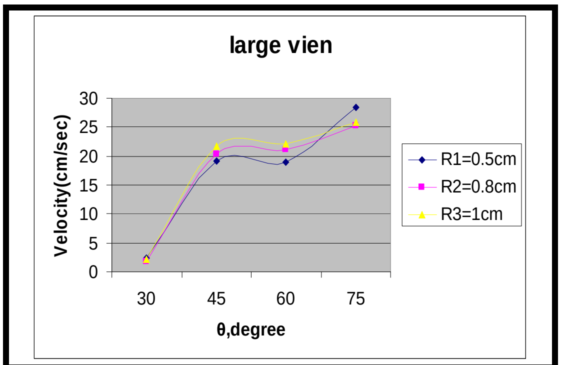

Figure 10 The velocity versus the angle between the flow and laser beam in large vein for different radii**.**

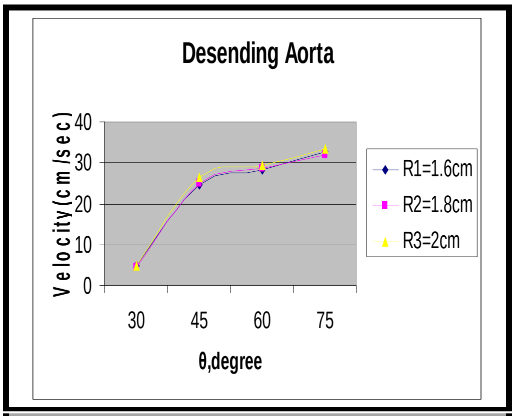

Figure 11 The velocity versus the angle between the flow and laser beam in descending aorta for different radii**.**

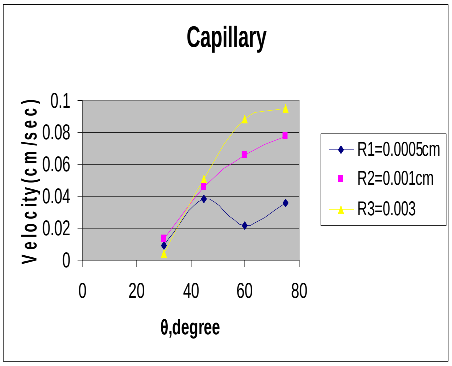

Figure 12 The velocity versus the angle between the flow and laser beam in capillary for different radii**.**

Table 2 list of symbols

A	amplitude of the scattered light;
C(t)	total correlation function
$C_v(t)$	fluctuation of the detector output
Δf	frequency difference.
Δw	change in frequency
$\delta I(t)$	heterodyne beat part of the photocurrent
$E_o(r)$	:amplitude of the incident field at the point r.
$E_o^2(r)$	attenuation of the intensity in the blood
E_1	amplitude of the local laser field.
$E_{1.0}$	local laser field at the photodiode surface.
E_i	incident field
E_s	electric field of the scattered light
f(r)	fractional reduction of the scattered light .
I(t)	photocurrent output of the photodiode
k_i	wave vector of the laser light.
l_0	penetration depth and is 0.33mm.
λ	wavelength
p(r)	density of the erythrocytes at a position r.
r	position of the target
θ	angle
V	movement velocity,
V_{av}	average velocity of the flow.
W	angle velocity
W_o	angular frequency.

Conclusions:

1. It is necessary to use the variations of the correlation function with time for the determination of the velocity of blood flow in the different blood vessels due to the large number of erythrocytes in the blood.
2. The angle between the laser beam and blood flow is one of important factors to determine the accurate measurement of the velocity. The more appropriate angle that gives values near to the normal value is about 45 degree.
3. The velocity of flow is a function of the vessel radius.

References

1-Svelto O.,"principle of laser ", 4th Edition, Plenum press ,Newyork.1998.

2- David O. Cooney " Biomedical Engineering principle", Marcel Dekker Inc. 1976.

3-Baskurt O.K." pathophsiologyical significance of blood rheology" Turkish Journal of medical scince vol.33 p.p. 347-353, 2003.

4- Bonner R. and Nossal R. "Model for laser Doppler measurements of blood flow in tissue "Appl. Opt. Vol. 20, 2097–107,1981.

5- Toyoichi Tanaka and George B.Benedek "measurement of the velocity of blood flow (in vivo) using a fiberoptic catheter and optical mixing spectroscopy", Applied optics, Vol.14, No.1, 1975.

تطبيق استخدام الليف البصري لقياس سرعة الدم بالليزر

د. منقذ سليم داود
قسم الهندسة الطبية
كلية الهندسة / جامعة النهرين

د. انوار عبد الستار الدركزلي
قسم هندسة الليزر
كلية الهندسة / جامعة النهرين

سمية حمد جعفر
كلية الهندسة / جامعة النهرين

الخلاصة:

تم في هذا البحث دراسة امكانية استخدام الالياف البصرية لايصال اشعة الليزر الى داخل الاوعية الدموية لقياس ومراقبة سرعة جريان الدم بواسطة ارسال اشعة هليوم نيون ليزر الحمراء واستلام الانعكاس الراجع من كريات الدم الحمراء وذلك بالستفادة من نظرية دوبلر ومنظومة مدخال مايكلسون.

اجريت الدراسة على اوعية دموية مختلفة الاقطار وتم التركيز على ان الاشعة المنعكسة تصل من عدة كريات دم حمراء في ان واحد لذلك استخدمت علاقة الارتباط المشترك في الحسابات ولقد ارسلت الاشعة بعدة زوايا ووجد ان فضل زاوية بين اتجاه الاشعة المرسلة واتجاه الدم هي ٤٥ درجة.