Processing of the Retinal Artery Image using Higher Orders of Two Beam Interference

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Abstract- The coherent illumination is assumed in the fabrication of the interferometer fringes modulated by the considered image. The modulated fringes resulted from the multiplication of the ordinary fringe system and the retinal arterial image. Digital cascaded two-beam interference using feedback rays is considered giving a cosine function of higher order \( n \) greater than one \((n > 1)\). The processing of the retinal artery image for normal and occlusion artery is investigated using digital two beam interference of higher orders. Five segments from the retinal arteries are considered. The higher order power of two beam interference is compared with the ordinary two and multiple beam interference. The refractive index distribution of the retinal artery is extracted from the fringe shift occurred in the artery.

Key words: Retinal artery occlusion, Cosine function of higher orders in two beam interference, Image processing using interferometry.

1. INTRODUCTION

Retinal image analysis, concepts, and application are presented in a review article [1]. Image enhancement, segmentation, and restoration are the main topics in this article. In addition, dimensionless measure of retinal photography is presented. Morphological image processing exploits features of the vasculature shape that are known a priori, such as it being piecewise linear and connected. In this work, and others [2-5] they measure retinal vessel widths. The diameter of the central artery is computed from the noninvasive measurements in humans [3]. While an accurate assessment of changes in retinal vessel diameter using multiple frame electrophotography synchronized fundus photography is outlined in [4]. In addition, measurement of retinal blood vessel width using computerized image analysis is investigated in [5]. Another work on quantification and characterization of arteries in retinal image is presented in [6]. Reproducible estimation of retinal vessel width by computerized micro-densitometry is organized in [7].

A Retinal Artery Occlusion can occur in either the Central Retinal Artery or in a Branch Retinal Artery that splits off the Central Retinal Artery. Either artery can become blocked by a clot or “embolus” in the bloodstream. A Retinal Artery Occlusion is considered a medical emergency and requires immediate attention. When an artery occlusion occurs, it decreases the oxygen supply to the area of the Retina nourished by the affected artery, causing permanent vision loss. Most patients who suffer Retinal Artery Occlusions are between the ages of 50 and 80. They notice a sudden, painless loss of vision that can be a complete loss of vision if it is a Central Retinal Artery Occlusion, or can be a partial loss of their visual field if it is a Branch Retinal Artery Occlusion [8]. In general, retinal arteries may become blocked when a blood clot or fat deposits get stuck in the arteries. These blockages are more likely if there is hardening of the arteries (atherosclerosis) in the eye. Clots may travel from other parts of the body and block an artery in the retina. The most common sources of clots are the heart and carotid artery in the neck [9, 10].

The principle of OCT applied on retinal images is based on interferometry [11-14]. In a typical early generation OCT system, visible light (i.e., to visualize the beam) and broadband, short-coherence length, near-IR light are coupled into one branch of a Michelson interferometer. The light is then split into two paths, one leading to a reference mirror and the second is focused onto the retina. Light is reflected and backscattered from refractive index interfaces within the retina according to the optical properties of each interface. The reflected light from the retina (i.e., the sample arm) and from the reference mirror is recoupled into the interferometer, to ultimately be detected after interference in the spectrometer. Using “time domain” OCT, reflection sites at various depths in the tissue can be sampled by changing the path length of the reference arm.

In this work, image processing of retinal arteries is realized by interferometry. The method is based on using microscopic images of retina and placing it in the interference cosine term. Higher order two beam interference is suggested by the author in order to get sharper fringes than the ordinary two and multiple beam interference. We compute the refractive index of different segments from the arteries considering the fringe shift occurred with respect to interference spacing [15] occurred in the modulated trigonometric function.

2. THEORETICAL ANALYSIS

Before we start the interferometer processing using normal and occlusion retinal images, we give cross section from the retinal image as shown in the Fig. 1. The retina has arteries and veins. In addition, the optic disc is shown. Higher order two beam interference is described using feedback rays as shown in the Fig. 2. The interference pattern is governed by this equation:

\[
I_{\text{feedback}}(x, y; N) = I_0 \cos^{2(N+1)}(\delta)
\]  

Where \( N \) is the number of feedback rays. In the particular case where \( N = 0 \) we get the ordinary two beam interference governed by the known equation governed by \( \cos^2 \) function, \( \delta \): phase difference between the interfering beams.

Equation (1) is rewritten in discrete form as follows:
\[
I_{\text{feedback}}(x,y,N) = I_0 \sum_{n=1}^{N} \sum_{m=1}^{M} \left\{ \cos^{2(N+1)}(\Phi(n\Delta x , m \Delta y ; z) - \Psi(n\Delta x , m \Delta y)) \right\}
\]

Where \(\delta = \Phi(n\Delta x , m \Delta y ; z) - \Psi(n\Delta x , m \Delta y)\), phase difference between the object and the reference beams respectively and O.P.D. is the corresponding optical path difference.

**The Retina**

![Image of retina]

Fig. 1: Image of retina.

\[I_{x, y, z} = I_1 \frac{1}{1 + F \sin^2(\frac{\phi}{\lambda})} \]

\[\delta = \frac{2\pi}{\lambda} \text{ O.P.D} \]

The equation (2) is rewritten in discrete form as follows:

\[
I(x,y,z) = I_0 \sum_{n=1}^{N} \sum_{m=1}^{M} \left\{ \frac{1}{1 + F \sin^2(\Phi(n\Delta x , m \Delta y ; z) - \Psi(n\Delta x , m \Delta y))} \right\}
\]

The intensity distribution of multiple beam interference is well known as the Airy pattern and represented as follows:

\[\begin{align*}
I(x,y,z) &= I_0 \frac{1}{1 + F \sin^2(\phi/\lambda)}; \\
\delta &= \frac{2\pi}{\lambda} \text{ O.P.D}
\end{align*}\]

The equation (2) is rewritten in discrete form as follows:

\[
I(x,y,z) = I_0 \sum_{n=1}^{N} \sum_{m=1}^{M} \left\{ \frac{1}{1 + F \sin^2(\Phi(n\Delta x , m \Delta y ; z) - \Psi(n\Delta x , m \Delta y))} \right\}
\]

The refractive index of the microscopic image is computed from the interference fringe shift [15] as follows:

\[
\mu(x,y) = 1 + a(x,y) \frac{\delta z}{\Delta z}
\]

\(\delta Z\) is the fringe shift, \(\Delta z\) is the fringe spacing, and \(a(x, y)\) represents the amplitude of the image lies between 0 and 1.

The mean refractive index and the S.D. or the root mean square value computed using these known formulae:

\[
< \mu > = \frac{1}{N} \sum_{i=1}^{N} \mu_i
\]

\[
\sigma = \sqrt{\sum_{i=1}^{N} (\mu_i - < \mu >)^2}
\]

3. RESULTS AND DISCUSSION

Retinal image with numbers placed beside the investigated arteries in the retina are shown in the Fig. 3. Five segments from the retinal arteries are shown in the Fig. 4. All images have resized to be of dimensions 512×512 pixels.

![Image of retina with numbers]

Fig. 3: Retinal image with numbers placed beside the investigated arteries of dimensions 512×512 pixels corresponding to 2×2 cm.

Modulated ordinary two beam interference of retinal artery 1 is computed using equation (2) where \(N = 0\) i.e. No feedback rays. The fringes are plotted as shown in the Fig. 5 (a). The trajectory of the artery is recognized from the shift occurred in the image and the refractive index of the retinal artery is computed from the fringe shift using equation (5). The modulated multiple beam interference of retinal artery (1) is computed using equation (4) in matrix form and plotted as
shown in the Fig. 5 (b). It is shown that the fringes are sharper than two beam fringes as expected. Now, the two beam interference of feedback rays considering N= 25 is computed from equation (2) giving sharper fringes than multiple beam fringes governed by the Airy distribution equation (4).

Fig. 4: From above, five segments from the retinal arteries 1, 2, 3, 4, and 5 of resized dimensions 512x 512 pixels are shown.

Fig. 5 (a): Modulated ordinary two beam interference of retinal artery 1.

Fig. 5 (b): Modulated multiple beam interference of retinal artery 1.

Fig. 5 (c): Two beam interference of higher order cos^{2N}, where N = 25. The discontinuous red line is placed on the center of the fringe shift of segment from artery 1.

Fig. 6 (a): Modulated ordinary two beam interference of retinal artery2.

Fig. 6 (b): Modulated multiple beam interference of retinal artery2.

Fig. 6 (c): Two beam interference of higher power cos^{m}, where N = 25. The discontinuous red line is placed on the center of the fringe shift of segment from artery.
Fig. 7 (a): Modulated ordinary two beam interference of retinal artery 3.

Fig. 7 (b): Modulated multiple beam interference of retinal artery 3.

Fig. 7 (c): Two beam interference of higher power \( \cos^{25} \), where \( N = 25 \). The discontinuous red line is placed on the center of the fringe shift of segment from artery 3.

Fig. 8 (a): Modulated ordinary two beam interference of retinal artery 4.

Fig. 8 (b): Modulated multiple beam interference of retinal artery 4.

Fig. 8 (c): Two beam interference of higher power \( \cos^{25} \), where \( N = 25 \). The discontinuous red line is placed on the center of the fringe shift of segment from artery 4.

Fig. 9 (a): Modulated ordinary two beam interference of retinal artery 5.

Fig. 9 (b): Modulated multiple beam interference of retinal artery 5.

The refractive index corresponding to the segment of artery 1 is computed from equation (4) considering the mean value of \( a(x, y) = 118/256 = 0.461 \) and the inter fringe spacing is computed as \( \Delta Z = 36 \) pixels. Consequently, we get the results shown in the table (1). The error in the values obtained in the table is much greater than the expected values obtained for retinal refractive index. The method gives the deviation path of fringe shift giving information about the refractive index trajectory.
Fig. 9 (c): Two beam interference of higher power \( \cos^{2N} \), where \( N = 25 \). The fringe shift of artery 5 is shown.

Table (1): Refractive index variation for the retinal segment of artery where \( \Delta Z = 36 \) pixels and the mean value \( <a(x, y)> = 180/256 = 0.461 \)

<table>
<thead>
<tr>
<th>( Z ) (pixels)</th>
<th>( Z ) image (pixels)</th>
<th>( \delta Z = Z - Z ) image (pixels)</th>
<th>( \mu(Z)=1+&lt;a&gt;/\delta Z/\Delta Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>10</td>
<td>44</td>
<td>1.5634</td>
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<td>87</td>
<td>46</td>
<td>31</td>
<td>1.3970</td>
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<td>121</td>
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<td>50</td>
<td>1.6403</td>
</tr>
<tr>
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<td>48</td>
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</tr>
<tr>
<td>497</td>
<td>449</td>
<td>48</td>
<td>1.6147</td>
</tr>
</tbody>
</table>

A plaque blocking retinal arteriole outlined by the horizontal arrow is shown as in the Fig. 10 (a). A segment from the image with the retinal artery plaque shown as transparent compared with the lower normal artery indicated in the same image is plotted as in the Fig. 10 (b). The images shown in a, and b are resized to be of dimensions 512×512 pixels. The modulated fringes in all cases, are computed and plotted as shown in the Fig. 11 (a) for ordinary two beams, Fig. 11 (b) for the multiple beam interference, while the Fig. 11 (c) is for two beam interference of higher orders \( N \). The interference patterns corresponding to the segmented image shown in the Fig. 10 (b) are plotted as shown in the Figs. 12 (a-c).

Fig. (11): The different interference patterns showing the plaque shift shown in the image Fig. 10 (a).

Fig. 12 (a): Modulated ordinary two beam interference of retinal artery plaque shown in the Fig. 10 (b).

Image of retinal artery occlusion of dimensions 512×512 pixels is plotted as shown in the Fig. 13. The different modulated interference images are computed and plotted as
shown in the Fig. 14 (a) for ordinary two beam interference, and in the Fig. 14 (b) for multiple beam interference, and the improved sharper interference image shown in the Fig. 14 (c).

The mean refractive index computed from equation (6) is 
\[ \langle \mu \rangle = 1.6019 \] and the root square mean value computed using the equation (6) is 
\[ \sigma = r. \ m. \ s. (\mu) = 2.6447 \times 10^{-2}. \]

4. CONCLUSION

The fringe shift occurred in the interference straight line fringes is dependent on the optical path difference occurred from the object. Consequently, the refractive index originated from the optical path difference is deduced from the fringe shift. The application is on the diagnosis of retinal artery occlusion using the interferometer mapping technique. This can be demonstrated by looking through the refractive index distribution. The non-uniformity of the fringe shift may be considered as an early investigation of the retinal arterial occlusion.

REFERENCES


[8] Robert H. Kelly, MD, 929 College Avenue Fort Worth, TX 76104.


