Extracting overlapping 2D-images by central-derivatives-based algorithm

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Abstract. Usual algorithms, such as, 5-steps and a backward-derivatives-based (BDB) method, could extract an image of a top layer from a one of a base layer in a 2D full-field optical coherent tomography (FFOCT). Those both algorithms still give the robust images. For improving the quality of the image in 2D-FFOCT, in this research a central-derivatives-based (CDB) algorithm is introduced to apply for investigating two overlapping 2D images. According to our simulation, it shows that the performance of CDB-algorithm is as good as the one of 5-step algorithm in case a phase difference between each fringe images is not more than 40 degree. It is also less robust by comparing with the one of BDB-algorithm. By our experimental results, it can also be concluded that the CDB-algorithm can separate two overlapping 2D images with more brightness than the ones applied by BDB-algorithm.

1. Introduction

The optical coherence tomography (OCT) [1,2] is a famous technique to study the cross section images of a sample at different depths by taking the advantage of a low coherent light source, such as; a superluminescent diode (SLD). However, this technique takes a lot of time to obtain a full-field image. To eliminate this problem, the full-field optical coherence tomography (FFOCT) is proposed and developed [3-5]. Due to the light source of FFOCT is not the point source, the interference of light source causes unwanted interference fringe on an image. For removing the unwanted fringes from the FFOCT-image, the 5-step phase shift and the backward-derivative based (BDB) algorithm was applied [3]. But those both algorithms still give the robust images. Thus, the central-derivative-based (CDB) algorithm is introduced for cleaning the simulated fringes in this research. Moreover, this CDB-algorithm is also applied to separate the FFOCT-images of overlapping alphabets, coated on different thin layers, in order to prove the efficiency of CDB-algorithm.

2. Theory and algorithms

The FFOCT-image from the interferometer normally observed by CCD camera. In this research, the Michelson Interferometer, which its schematic is shown in figure 1, is applied. The interference fringes on the FFOCT-image is given by [6]

\[ I(x, y, z) = I_0(x, y) + C(x, y, z)\sin(\omega z + \phi(x, y)), \] (1)
where

\[ C(x, y, z) = \gamma I_0 \exp\left(-\frac{(z - z_0)}{\ell_c}\right) \]  \hspace{1cm} (2)

represents the envelope of intensity, \( I_0 \) is a constant background intensity, \( \omega \) is a constant spatial angular frequency, \( \phi \) is phase constant, \( \ell_c \) is the coherence length, and \( z_0 \) is the scanning position representing the equal optical path of the reflected light from the mirror and the one from the sample. Our goal is to solve for \( C(x, y, z) \) and to remove \( \phi(x, y) \) from the FFOCT-image.

Since the relation between the first- (\( I' \)), the second- (\( I'' \)), and the third- (\( I''' \)) order derivative of equation (1) relate by [3]

\[ I'''' - I''' = \omega^4 C^2(x, y, z), \]  \hspace{1cm} (3)

\( C(x, y, z) \) can be solved by the relation:

\[ C(x, y, z) = \left|I'''' - I''' \right|^{\frac{1}{2}}. \]  \hspace{1cm} (4)

The \( \omega^4 \) in equation (4) is disappeared because of the derivative of equation (1) with respect to \( \omega z \).

Instead of using BDB, CDB-algorithm making use of derivative properties of the interference pattern by utilizing seven respective FFOCT-images, is applied to define \( I' \), \( I'' \), and \( I''' \) for equation (4) by:

\[ I' = \frac{-I_6 + 8I_5 - 8I_4 + I_2}{12dz} \]  \hspace{1cm} (5)

\[ I'' = \frac{-I_6 + 16I_5 - 30I_4 + 16I_3 - I_2}{12dz^2} \]  \hspace{1cm} (6)

\[ I''' = \frac{-I_6 + 8I_5 - 13I_4 + 13I_3 - 8I_2 + I_1}{8dz^3} \]  \hspace{1cm} (7)

where \( I_n \) denotes the intensity at \( n^{th} \) image and \( n = 1,2,3,4,5,6,7 \). \( I' \), \( I'' \) and \( I''' \) belong to the fourth image of the sequence.
3. Simulation

For simulation, the sequence of fringe images on the plain white background, \( I_0 = 1 \), with the XY-plane size of 300x300 pixels at phase step 10, 20, 30, 40, 50, 60, 70, 80 and 90 degree are simulated. We let the fringe contrast of images, \( \gamma \), is 1. For comparing, the fringe of simulated image’s sequence is deleted by applying CDB-, BDB-, and 5-step algorithms, respectively. These three methods are compared by \( \langle \Delta I \rangle \), which is the mean of difference intensity between the one of fringe-removed images and the original ones. Also, the correlation of its variance, \( \sigma^2 \langle \Delta I \rangle \), between these three algorithms is presented. \( \langle \Delta I \rangle \) and \( \sigma^2 \langle \Delta I \rangle \) of each method are plotted as a function of phase step as in figure 2(a) and 2(b), respectively.

![Figure 2](image)

Figure 2. The relationship between phase step and (a) the mean difference, \( \langle \Delta I \rangle \), (b) the variance, \( \sigma^2 \langle \Delta I \rangle \), of image intensity.

Since \( \langle \Delta I \rangle \) relates to the average of intensity drop in the fringe-removed images, more minus \( \langle \Delta I \rangle \) show more decreasing intensity of the images. According to figure 2(a), \( \langle \Delta I \rangle \) of CDB-algorithm is just around one to tenth in case 90-degree phase step and less than the one of BDB-algorithm. That means the fringe-removed image from CDB-algorithm is brighter than the one from BDB-algorithm in that phase step value. Moreover, \( \langle \Delta I \rangle \) of CDB- and 5-step algorithms is insignificant different, which is nearly zero for less than 40-degree of phase step. Also, \( \sigma^2 \langle \Delta I \rangle \) represents the parasitic fringe of fringe-removed images from each methods. Our results show that \( \sigma^2 \langle \Delta I \rangle \) of CDB-algorithm is nearly zero as other methods for less than 40-degree of phase step. Low \( \sigma^2 \langle \Delta I \rangle \) means more fringe removed from the image. However, \( \sigma^2 \langle \Delta I \rangle \) is the highest one for 90-degree phase step. Since its value is in order \( 10^{-3} \), it can be considered that its variation is insignificantly low.

For calculation time comparison, the phase step of the simulated images is given as 84.83-degree, equaling to the experimental value. After applied these three methods, the BDB-method is the fastest one. It uses only 0.3826 second for calculation. The calculation time for 5-step and CDB-algorithm are 0.5375 and 0.6550 second, respectively. Even the calculation time of CDB-algorithm is slowest, the time difference from BDB-algorithm is just only less than a half second.
4. Experiment

For investigating the efficiency of CDB-algorithm to separate the FFOCT-images of overlapping layers, a sample of overlapping images of “C” and “U” alphabets is prepared by writing “C” on a reflected surface under cover slide and “U” on a top surface of cover slide. Both alphabets are written by a silver marker and the thickness of the cover slide is 0.13-0.16 nm. The photos of “C”, “U”, and overlapping “C” and “U” are shown in figure 3. The sequence of FFOCT-images for each layer is taken by using the MI with SLD light source (\(\lambda_0 = 848.8\) nm and \(\Delta\lambda = 59.5\) nm) with step size \(dz = 100\) nm, equaling to 84.38 degree phase shift. Finally, the “C” and “U” images are separated by applied the CDB-, BDB-, and 5-step algorithms to taken sequential FFOCT-images.

![Figure 3. (a) “C” alphabets on reflected surface (b) “U” alphabets on a cover slide (c) Overlapping alphabets of sample](image)

The fringe FFOCT-images of “C” and “U” alphabets are shown in figure 4(a) and 4(b), respectively. Also, the fringe-removing images of these two alphabets, applied by CDB-, BDB-, and 5-step algorithm are shown in figure 4(c) to 4(h). According to the experiment, image of "C" on the bottom and "U" on the top layer can be separately seen. However, since "U" is on the top surface of the cover slide and "C" is on the reflected surface, the image of "U" is darker than the one of "C" in every method. The images from CDB-algorithm have also higher intensity than the ones from BDB-algorithm. It agrees with the simulation result. But the intensity of the images from CDB-algorithm is also higher than the one from 5-step algorithms. This disagrees with the simulation result that is because of the experimental factors, such as, flatness of sample’s surface, etc. However, the fringe-removed images from CDB-algorithm have most parasitic fringe. It agrees with the simulation results of \(\sigma^2(\Delta f)\) comparison. According to our results, this CDB-algorithm suits for separating the FFOCT-images of any overlapping layers.

5. Conclusion

In conclusion, the CDB-algorithm produces fringe-removed images with higher intensity than the ones from BDB-algorithm and almost as same as the ones from 5-step algorithm. However, fringe-removed images from CDB-algorithm have the most parasitic fringe. BDB-algorithm leaves some parasitic fringe, contrasting with the simulation result. That is because of experimental factors, such as, flatness of sample’s surface, etc. However, 5-step algorithm leave almost no fringe. By comparing the calculation times, CDB-algorithm is slowest but it is just less than a half second of BDB-algorithm, which is the fastest method.
Figure 4. Interference pattern at (a) top surface and (b) bottom surface. Images obtained from each algorithm. (c) top surface of 5-step algorithm, (d) bottom surface of 5-step algorithm, (e) top surface of BDB-algorithm, (f) bottom surface of BDB-algorithm, (g) top surface of CDB-algorithm, and (h) bottom surface of CDB-algorithm.

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