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3D Information Retrieving of Concealing Surface beneath Opaque Resin Layer by Fast-Fourier Low Coherence Interferometer

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Abstract. A normalized contrast method on a Superluminescent diode (SLD) low coherence interferometer could retrieve 2D image concealing under a light-scattering medium. In addition, a continuous wavelet transform on both white light and SLD vertical scanning interferometry could construct 3D profile of the interfaces in a dual-layer structure. In this research, 3D information on surface, concealing beneath opaque resin layer, will be produced by using SLD phase difference interferometry with a Fast Fourier Transform. The effect of opaqueness of coating resin layer to quality of 3D image from our method will be revealed.

1. Introduction
Hiding a 3D trademark on a surface beneath opaque coating layers might be one of the best ways to protect a counterfeit merchandise. However, process for getting information of the 3D trademark is more important than the making one. Since an optical technique has been a long well-known technique for a nondestructive measurement method, it is a suitable choice for this purpose. As coherent length of white light and light of Superluminescent diode (SLD) are short, roughness and 3D profile of uncoated and coated surface under transparent thin layer could be produced by using a continuous wavelet transform with vertical scanning interferometry.[1,2] 2D image concealing under a light-scattering medium could be retrieved by applying a normalized contrast method on the interferogram from a SLD Michelson interferometer.[3] Also a less time consuming method as SLD phase difference interferometer with a Fast Fourier Transform (FFT) is a great tool to construct 3D surface profile beneath transparent thin layer.[4] However, there still is no report to confirm that this method can be applied to retrieve 3D profile on the surface under opaque coating layers. Therefore, 3D profile on surface under a thin opaque resin layer is retrieved by using the SLD phase difference interferometer in this research. Moreover, the effect of opaqueness of coating resin layer to quality of 3D image in this method is presented by varying the opaqueness of the resin layer.

2. Principle of the methods
In general phase difference interferometry with FFT, 3D surface image is constructed from the height profile \( h(x, y) \), calculated from the phase difference \( \phi(x, y) \) in each position of the surface.[5,6] This method begins with a distribution function of interference fringe, which is

\[
i(x, y) = a(x, y) + c(x, y) \exp(2\pi f_0 x) + c^*(x, y) \exp(-2\pi f_0 x),
\]

(1)
where \( c(x,y) = \frac{i}{2} b(x,y) \exp [i \phi(x,y)] \), the asterisk indicates the complex conjugation and \( f_0 \) is central frequency of the signal. By applying FFT to equation (1), the signal spectrum at central frequency \( A(f_0, y) \) and two terms of the signal spectrum shifted \( C(f-f_0, y) \) and \( C^*(f+f_0, y) \) can be separated as:

\[
I(f,y) = \text{FFT}[i(x,y)] = A(f_0, y) + C(f-f_0, y) + C^*(f+f_0, y).
\]  

After the first and the third terms of equation (2) is eliminated, \( c(x,y) \) can be calculated by taking inverse FFT to \( C(f-f_0, y) \) term and phase distribution \( \phi(x,y) \) can be defined from:

\[
\phi(x,y) = \arctan \left( \frac{\text{Im}[c(x,y)]}{\text{Re}[c(x,y)]} \right),
\]

where \( \text{Re}[c(x,y)] \) and \( \text{Im}[c(x,y)] \) are real and image term of \( c(x,y) \), respectively. Since results of the arctangent function in equation (3) is in a range from \(-\pi/2\) to \(\pi/2\), a phase unwrapping algorithm is needed to applied for recalculating \( \phi(x,y) \) from equation (3). Finally, the height distribution \( h(x,y) \) of the surface beneath the thin layer, which its refractive index is \( n \) can be calculated from:

\[
h(x,y) = \frac{\lambda_0}{4\pi(n-1)} \phi(x,y),
\]

where \( \lambda_0 \) is the center-wavelength of the light source.

3. Experimental detail

3.1. Experimental setup

In this research, interferogram of the sample surface is taken by using SLD Michelson interferometer. Its diagram is shown in Figure 1. Low coherence light beam from SLD is passed from lens to a beam splitter. It is split into two beams. One propagates to a reference mirror. Another moves to a sample. These two beam reflect back to the beam splitter and interfere each other before moving to a CCD camera. A taken interference fringes is then analyzed by FFT method described in section 2. The SLD used in our experiment is SLD-350-HP3-TOW2-PD, which its center-wavelength is 848.8 nm, its spectral bandwidth is 59.5 nm and its coherence length is 5.34 \( \mu \)m. The reference mirror is a silver film coating mirror, which its roughness is \( \lambda/20 \).

![Figure 1. The diagram of SLD Michelson interferometer.](image)

3.2. Samples preparation

In this research, the ‘CU’-mark, engraved on a steel gauge box by laser etching as shown in Figure 2(a) is prepared. The size of ‘CU’-mark is 1.5x1.0 mm. Next, 3D profile of ‘CU’-mark on the uncoated surface (S-uncoated) is constructed by employing SLD phase difference interferometry with FFT. The same ‘CU’-mark surface is also coated by a transparent resin layer. To confirming that our method can expose the ‘CU’-mark on the interfaces in the dual layers, 3D image of the mark from this transparent layer coated surface (S00) is built by the same method for comparing with the one of S-uncoated. Next, the various semi-transparent resins, made by adding 0.5%, 1.0%, and 1.5% by volume of the opaque black resin to the transparent one, are coated to the same ‘CU’-mark surface for producing the sample
S05, S10, and S15, respectively. The transmittance of our resin layers in S00, S05, S10, and S15 at 850-nm wavelength light are 1.00, 0.49, 0.31, and 0.25, respectively. The refractive index of our resin layers in S00, S05, S10, and S15 at 850-nm wavelength light are 1.829, 1.536, 1.532, and 1.813, respectively. For revealing the effect of opaqueness of coating resin layer to quality of 3D image construction in our experiment, 3D profiles of ‘CU’ mark in every samples are retrieved by the same method as in S-uncoated and S00. Finally, the quality of 3D profile images in every cases is compared.

4. Results
By using the SLD phase difference interferometry with FFT, 3D profile of ‘CU’-mark for S-uncoated sample as in Figure 2(b) is constructed. A picture of S00 and 3D profile of the mark, built by the same method are shown in figure 3(a) and 3(b), respectively. By comparing 3D profile of the mark in figure 2(b) and figure 3(b), the quality of the image is almost the same. Of cause the transparent resin layer cannot hide the mark on the gauge box.

![Figure 2](image2.png)
![Figure 3](image3.png)

5. Discussion and conclusion
According to our results, SLD phase difference interferometry with FFT is a suitable, less-time consuming and nondestructive optical method for retrieving the concealing 3D mark on the surface beneath the semi-transparent layer. The transmittance of opaque layer for this method should not be less than 0.25. Even the simple photography can be retrieve the hided mark under the semi-transparent layer, but the 3D profiles of the mark still cannot be revealed. However, our research is just the beginning step to find the method for revealing a 3D trademark on a surface beneath opaque coating layers for protecting a counterfeit merchandise. By using the small light source as SLD, we hope that the handheld
3D retrieving tools is possibly made in the near future. The technology for protecting a counterfeit merchandise will be improve for one more step.

![Figure 4](image1)

**Figure 4.** (a) The picture of ‘CU’-mark beneath a 0.5% by volume of opaque black resin layer. (S05) (b) Its 3D profile constructed by SLD phase difference interferometry with FFT.

![Figure 5](image2)

**Figure 5.** (a) The picture of ‘CU’-mark beneath a 1.0% by volume of opaque black resin layer. (S10) (b) Its 3D profile constructed by SLD phase difference interferometry with FFT.

![Figure 6](image3)

**Figure 6.** (a) The picture of ‘CU’-mark beneath a 1.5% by volume of opaque black resin layer. (S15) (b) Its 3D profile constructed by SLD phase difference interferometry with FFT.

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