3D Partial Bloody Fingermark Imaging based on Digital Holography and Transport of Intensity

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Abstract: We propose a single-shot 3D optical imaging technique that combines digital holography and transport of intensity equation to retrieve the 3D topography of partial bloody fingermarks deposited on substrates and coated with columnar thin films.

Keywords: Digital holography, transport of intensity, phase retrieval, partial bloody fingermark

1. Introduction

Fingerprint scanning is widely used in security applications to identify criminals and victims during criminal investigations because it provides a very convenient technique for human identification due to its uniqueness and durability. However, most of the work in mapping fingerprints rely on 2D pictures; furthermore, level-3 details from latent and partial bloody fingerprints are hard to obtain. As is well-known, holography, and particularly, digital holography (DH), is extensively used for phase retrieval during 3D imaging and can reveal details in the order of wavelength. However, the reconstructed phase is wrapped, and large phase excursions and phase gradients can cause errors during unwrapping using conventional methods like phase unwrapping via max flow (PUMA). We had proposed multi-wavelength DH (MWDH) as a method of 3D imaging of latent fingermarks deposited on a substrate and encapsulated by columnar thin films (CTFs) which can reveal level-3 details such as pores [1]. In MWDH, the reconstructed phases from two illuminating wavelengths are subtracted to yield a resulting phase corresponding to the synthetic wavelength, thereby eliminating or reducing errors during phase unwrapping. In this paper, we present an alternate method that uses the transport-of-intensity equation (TIE) combined with DH to directly retrieve the unwrapped fingerprint phase from a single capture of the hologram. In this case, the multiple records of the intensities around the reconstruction or image plane, which is required for use in the TIE, are accomplished numerically [2]. DH+TIE also eliminates alignment errors encountered in experimental measurements using only the TIE, where physical shifting of the object or the CCD is required to record several intensities around the image plane.

2. Transport of Intensity Equation and Digital Holography

TIE is a partial differential equation (PDE) that represents energy conservation, and is derived from the imaginary part of the Helmholtz equation or the paraxial wave equation [2]:

$$\nabla_{\perp}^{2}\varphi + k_0 \frac{1}{I}\frac{\partial I}{\partial z} \approx 0, \tag{1}$$

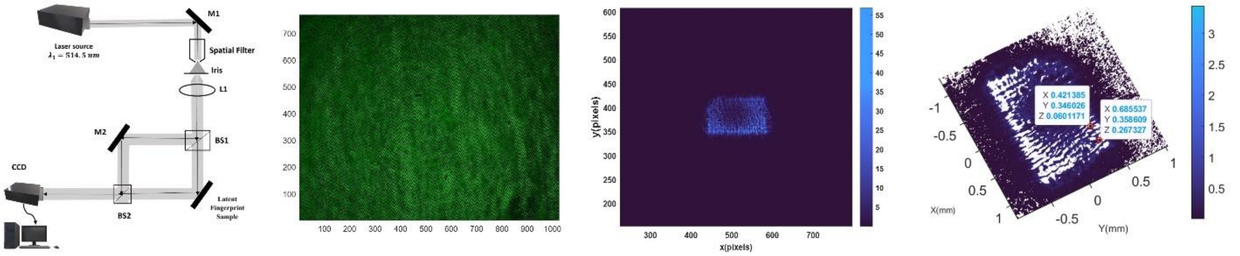
where φ is the phase, I is the optical field intensity, $k_0 = 2\pi/\lambda$ is the wavenumber where λ denotes the free-space wavelength, and $\nabla_{\perp}^{2} = \vec{\nabla}_{\perp} \cdot \vec{\nabla}_{\perp}$, where $\vec{\nabla}_{\perp}$ is the transverse gradient operator. Under the assumption of near-uniform intensity, which typically is true for a phase object near the image plane, Eq. (1) can be solved for the phase φ as

$$\varphi = \mathcal{F}^{-1}\left\{\frac{1}{k_x^2+k_y^2}\mathcal{F}\left\{\frac{k_0}{I}\frac{\partial I}{\partial z}\right\}\right\} \approx \mathcal{F}^{-1}\left\{\frac{1}{k_x^2+k_y^2}\mathcal{F}\left\{\frac{k_0}{\Delta z}\frac{I(z+\Delta z)-I(z-\Delta z)}{I(z+\Delta z)+I(z-\Delta z)}\right\}\right\}. \tag{2}$$

In Eq. (2), $\mathcal{F}$ and $\mathcal{F}^{-1}$ are the forward and inverse Fourier transform operators, respectively, and k_x and k_y are spatial frequency variables. The various intensities on the rightmost side of Eq. (2), needed to calculate $\partial I/\partial z$ around the reconstruction plane, can be obtained during reconstruction from a digital hologram simply by numerical propagation through defocusing distances $\pm\Delta z$ around the image plane. As is clear from Eqs. (1,2), during phase retrieval using TIE, no phase unwrapping is needed. The concept of DH+TIE consists of three steps: (i) recording the digital hologram from the object, (ii) reconstructing intensity profiles at two slightly defocused planes around the image plane, and (iii) employing TIE using these intensity images to retrieve the unwrapped phase and, hence, the topography of the object.

3. Phase Retrieval and Fingermark Topography using DH+TIE

A schematic of the setup is shown in Figure 1. A typical off-axis setup for holographic recording in reflection geometry is utilized to record holograms of partial bloody fingermarks digitally. The object comprises a partial bloody fingermark on a glass slide and encapsulated by a 1000-nm-thick CTF of chalcogenide glass [3]. An Ar-ion laser provides illumination at λ = 514.5 nm. The laser beam is collimated and expanded by a spatial filter assembly and a collimation lens with 250-mm focal length. Then a Mach-Zehnder interferometer setup is used to obtain the interference pattern between the object beam and the reference beam. The CCD camera (Thorlabs, DCU223C) has a resolution of 1024×768 pixels and a pixel pitch of 4.65 µm along both x- and y-axes. A small angle is introduced to the reference beam which is usually 2.5°. Figure 1(b) is a representative hologram recorded by the CCD camera. The distance from the object to the CCD camera is set to 310 mm. Then the obtained hologram is processed in the spatial-frequency domain to isolate the desired spatial sideband and back-propagated to two planes around the reconstruction plane, where two intensity profiles are determined numerically at $z = \pm\Delta z$, where $\Delta z = 0.001$ mm. These intensity images are used in TIE [Eq. (2)] to retrieve the phase map for the partial bloody fingermark, as illustrated in Figure 1(c). Then the phase (φ) is converted to the height (h) profile using $h = \frac{\lambda\varphi}{2\pi}\cos\theta,$ where $\theta \approx 35^\circ$ is the object illumination angle. The recovered 3D profile is shown in Figure 1(d). Level-3 details can also be seen, with two pores being highlighted in red. The calculated typical local height of a ridge is approximately 3.68 µm, and the typical distance between two pores is about 264 µm. Note that 3D information is still partially recoverable in the central dark patch, which is a blotch of blood in the fingermark, visible to the naked eye when held up to the light.



(a) (b) (c) (d)

Figure 1. (a) Schematic of holographic acquisition on a Mach-Zehnder interferometer; (b) typical recorded off-axis hologram; (c) retrieved phase map; and (d) 3D topography, for the latent fingermark sample using DH+TIE, with pore locations in red.

4. Conclusion

A simple one-shot technique using DH+TIE is proposed for 3D topography of partial bloody fingermarks deposited on various substrates and encapsulated by CTFs. The method eliminates the need for multi-wavelength illumination, thereby reducing hologram-acquisition time. 3D images obtained by DH+TIE and MDWH, which appear qualitatively similar, will be quantitatively compared using mean-square-error calculations in future work. Incorporation of transport-of-phase equation [4] with TIE for enhanced phase accuracy is currently in progress.

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6. References

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