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Linear conoscopic holography as aid for forensic handwriting expert

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ABSTRACT

Conoscopic holography is a fringe generation method widely used to reconstruct surface profiles with high precision. By means of linear fringe method, it is possible obtaining a depth analysis with resolution better than 1 μm. This depth allows utilizing conoscopic holography also to aid the forensic handwriting expert.

In fact manuscripts have 3D characteristics, which can be acquired only with systems having a high level of details in the *z* dimension. In particular, this peculiarity has been used for analyzing line crossing cases, some of the more controversy during signature association in trials. Sometimes the analysis of the only 3D profile is not sufficient to clearly associate a signature to a specific person. In this article, a method to generate a pressure profile by means of a linear conoscopic holography System, which can identify a person from a template generated by this profile, in a way similar to biometric voice recognition systems is proposed.

1. Introduction

Human handwritings are among the most complicated objects to recognize [1,2]. Signatures remain one of today's most acceptable means of verifying document validity such as bank checks. If the signature is found to be false, the check is considered to be false as well.

Since questioned document examinations play an important investigative and forensic role in many types of crime [3,4], it is necessary to build a system that objectively identifies forged handwriting.

When people attempt to forge handwriting, they focus on the general appearance, letter formation, size, style and slant of the writing. Handwriting consists, however, of individualized strokes and pressures that are not obvious to the naked eye.

A forensic expert applies various techniques for the examination of graphical signature characteristics. However, the visual inspection of the signature pattern only renders subjective and descriptive results and is therefore subject to frequent criticism in courts of justice.

For these reasons having a precise system able to objectively reproduce some signature parts, such as line crossing, which can be clearly considered characteristic of an individual signature, would allow to surely assign (or not assign) that signature to a precise author. Previous works [4–10] have proposed a method based on conoscopic holography to create a 3D profile of such signatures characteristic areas and a related procedure to determine line-crossing order. This method allows deciding if a particular signature was affixed by a specific person and analyzing the same areas of "secure signatures", such as signatures which clearly belong to the questioned person.

However, some cases exist where the mere 3D profile examination cannot be conclusive, while the information is still present in the acquired data. If we made a parallel with voice recognition systems, the approach, for voice, is based on the determination of an intensity profile associated to each letter pronounced by an individual in a different way from another one. The result is an intensity profile that depends on the frequency for some characteristics words (in particular, some vocals) [11–13]. The same approach can be envisaged with signatures, starting from conoscopic holography acquired data. It is possible to implement a pressure-to-space diagram related to some specific and characteristics words, which can be used to identify a person or to say if a signature belongs (or not) to a specific person. These diagrams can be constructed starting from 3D information retrieved by linear fringe methods, such as conoscopic holography.

This paper is organized as follows: in Section 2, the conoscopic holography and used conoscopic range finder are briefly described. In Section 3, the proposed method is described and the experimental results are presented. Section 4 provides the conclusions and hints to further research.

2. Conoscopic holography

Conoscopic holography was invented in 1985 by Gabriel Sirat and Demetri Psaltis at the California Institute of Technology [14].

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Conoscopic holography is an incoherent holographic technique based on the properties of crystal optics. In the basic interference set-up a point of light is projected on a diffuse object. This point creates a light point, which diffuses light in every direction. In a conoscopic system a complete solid angle of the diffused light is analyzed by the system. The measurement process corresponds to the retrieval of the distance of the light point from a fixed reference plane.

Conoscopic holography has already been described in depth many times, here we present only what is necessary to understand the following discussion [15–18].

In conoscopic holography, the object and reference beams of coherent holography are replaced by the ordinary and the extraordinary components of a single beam propagating in uniaxial birefringent media. Therefore, the signal and reference beams have the same geometrical paths but different optical path-lengths; the two beams are naturally coherent one with the other and therefore the technique allows producing holograms, even with non-coherent light.

Conoscopic holography has some advantages over classical holography if spatially limited illuminated area is concerned (one singular point):

- much greater stability than classical holography because the geometrical paths of both wave fronts are almost the same;
- an interfringe distance adjustable to common CCD camera resolution; thus interfacing with a computer system is facilitated;
- the possibility of using not spatially coherent quasi-monochromatic light because of the small phase difference, which is introduced.

The basic principle resides in considering a uniaxial crystal sandwiched between two circular polarizers in order to provide an interference fringe pattern (see Fig. 1). In particular, using two uniaxial birefringent crystals and a liquid crystal valve it is possible obtaining linear conoscopic holography.

Each object point $p(x, y, z)$ either emits, diffuses or reflects quasi-monochromatic, non-polarized and spatial incoherent light intensity $I(p)$. A ray, with wavelength λ, making an angle α with the system optical axis (see Fig. 1) passes through the first circular polarizer, which generates two orthogonal polarized, 90° phase shifted, rays. Within the uniaxial birefringent crystal, the two rays propagate according to two modes, namely the ordinary and the extraordinary modes, with different velocities.

In a uniaxial birefringent crystal the light propagates with different velocities, i.e. with different indices of refraction along practically equal geometrical paths. The birefringence is defined as: $\Delta n = [n_O - n_E]$, where n_O is the principal ordinary index and n_E is the principal extraordinary index.

The ordinary refraction index is constant. At the contrary the extraordinary refraction index is a function of the angle between the optical axis of the crystal and the direction of propagation. According to Ref. [15], the extraordinary refraction, function of the angle α, can be written as:

$$n(\alpha) \approx n_O + \Delta n \sin^2 \alpha \quad (1)$$

The phase delay, in other words the difference of optical path between extraordinary and ordinary waves, is given by:

$$\Delta\varphi = \frac{2\pi}{\lambda} \cdot \frac{L}{\cos\alpha} \cdot \Delta n \cdot \sin^2 \alpha \overset{\text{if}\,\alpha\,\text{is small}}{\Rightarrow} \Delta\varphi \approx \frac{2\pi}{\lambda} \cdot L \cdot \Delta n \cdot \alpha^2. \quad (2)$$

In Eq. (2), L is the length of the crystal and λ is the optical wavelength.

For simplicity, we use the convention that the light outside the crystal propagates in a medium of refractive index $n = 1$. The intensity at $r(x', y', 0)$ on the recording plane ($z = 0$) due to point source $p(x, y, z)$ will be given by:

$$I(r, p) = I(p)\left(1 + \gamma_0 \cos\left\{\frac{2\pi L\,\Delta n}{z^2\lambda}[(x - x')^2 + (y - y')^2]\right\}\right) \quad (3)$$

The Eq. (3) can be rewritten as:

$$I(r, p) = I(p)\left[1 + \gamma_0 \cos\left(K\frac{r^2}{Z_C^2}\right)\right] \quad (4)$$

Eq. (4) represents a Gabor Zone Lens (GZP) plus a constant bias, where K depends on the opto-geometrical parameters of the system and the wavelength, γ_0 is known as fringe visibility, r is the radial distance from the center of the Gabor zone lens, and Z_C is the so-called conoscopic corrected distance, the geometrical mean distance of the ordinary and extraordinary rays to the recording plane.

To remove the $I(p)$ and increase the signal-to-noise ratio, an electro-optic valve is utilized to rotate the polarization by 90° such that when the valve voltage change. In this way, it is possible to obtain two different Gabor Zone Lens that follow the equations

$$I_+(r, p) = I(p)\left[1 + \gamma_0 \cos\left(K\frac{r^2}{Z_C^2}\right)\right]$$
$$I_-(r, p) = I(p)\left[1 - \gamma_0 \cos\left(K\frac{r^2}{Z_C^2}\right)\right] \quad (5)$$

called positive and negative interferograms, which could be combined to calculate the conoscopic hologram contrast as suggested in Ref. [16].

$$C = \frac{I_+(r, p) - I_-(r, p)}{I_+(r, p) + I_-(r, p)} = \gamma_0 \cos\left(K\frac{r^2}{Z_C^2}\right) \quad (6)$$

The resulting pattern (complementary hologram) has a radial symmetry; therefore all the information is contained in one radius.

The resulting fringe pattern [17] have a quadratic dependence from the distance between the object point $p(x, y, z)$ and the center of the Gabor Zone Lens (GZL). As a consequence, the interference term, i.e. the term of the detector response which is sensitive to the relative phase of the interfering polarization components, is proportional to $\cos(\Delta\varphi)$, where $\Delta\varphi$ is the difference in the phase of the light between the polarization components emanating from a single point in the object volume and can expressed, according to Eq. (6) as:

$$\Delta\varphi = K\frac{r^2}{Z_C^2} \quad (7)$$

In either the on-axis or more general case, it can be seen that the phase difference $\Delta\varphi$ depends quadratically on the displacement of detector point $r(x', y', 0)$ from the geometric axis, and, more particularly, depends quadratically on the displacement of detector point $r(x', y', 0)$ from the geometric axis along a particular direction in the detector plane. This behavior is referred to as a “quadratic fringe” and it is also shown in Fig. 2, where circular fringes are not uniform along a projection horizontal plane.

In signature pressure profile extraction, in particular referred toword having low-pressure intensity, speed and precision requirements suggest the advantages of replacing quadratic dependence of the interference pattern with a linear dependence. In the prior art quadratic case, determination of the distance to the object point requires simultaneous determination of two parameters: the centroid and coefficient of quadratic equation. The measurement is correspondingly less accurate, for a given exposure, than in the linear case, where the same measurement requires algorithmic determination of the slope alone. Additionally, deconvolution of the interferograms in the known quadratic case requires