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Image hiding scheme based on time-averaged elliptic oscillations

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ABSTRACT

Image hiding technique based on time-averaged elliptic oscillations is proposed in this paper. The scheme is based on a single cover image representing a cross-moiré grating. The secret image is embedded into the background moiré grating by using a specially developed random scrambling algorithm. The secret is leaked in a form of a pattern of time-averaged moiré fringes when the cover image is elliptically oscillated. Also, the secret is leaked only if the parameters of elliptic oscillations are set to predefined values. Computational experiments are used to validate the proposed technique and to demonstrate the efficiency of its implementation.

1. Introduction

A dichotomous secret image hiding scheme based on time-averaged techniques used for the registration of the oscillating encoded cover image is a well-known approach in geometric moiré optics [1,2]. Conditionally, such an image hiding scheme can be entitled as dynamic visual cryptography (DVC) [2,3]. Classical visual cryptography (VC) is a cryptographic technique which allows visual information (pictures or text) to be encrypted in such a way that the decryption can be performed solely by the human visual system [4]. The decryption of the secret in a VC scheme does not require a computer. However, any VC scheme is a visual secret sharing scheme – the secret image is broken up into a number of shares so that only someone with all shares could decrypt the image [5,6]. Each share is usually printed on a separate transparency, and decryption is performed by simply overlaying the shares.

The DVC scheme is similar to the VC scheme in the sense that a computer is not required for performing the decryption of the secret. The secret image is embedded into one cover image, which must be oscillated in order to leak the secret [1,2]. Time-averaging optical techniques are used to register the oscillating cover image (the exposure time must be much longer than a single period of periodic oscillations) [1]. Thus, the DVC scheme does not employ image sharing – a single cover image is used instead.

Any image hiding scheme – VC or DVC has its own drawbacks. Complex means are used to eliminate the probability of cheating in VC schemes [7–9]. Special chaotic scrambling algorithms are required to embed the secret into the single cover image in DVC schemes [1].

The security of DVC schemes can be improved by generating such stochastic moiré gratings that the secret image is leaked from only when the cover image is oscillated according to a periodic (but non-harmonic) time function – but the secret is not leaked at any amplitude or any direction of uni-directional harmonic oscillations [2]. Chaotic time functions [3], special moiré grating optimization techniques [10], deformable moiré gratings [11] can be used to further increase the security of DVC schemes.

All up-mentioned DVC schemes are based on uni-directional oscillations of the cover image. However, it is well known that generation of uni-directional oscillations can be a challenging problem even for harmonic oscillations – especially when the considered engineering structures comprise many degrees of freedom or are nonlinear [12]. A simple uni-directional forcing of such structures can result into complex (even chaotic) trajectories of motion [13]. In this paper we consider the one of the simplest cases of such effects – elliptical oscillations.

On the other hand, the employment of elliptical oscillations opens a completely new approach for the generation of the cover image. Uni-directional oscillations enable to exploit a simple and straightforward strategy for the construction of the cover image – every column (row) of such an image can be interpreted as an isolated one-dimensional array of pixels. In principal, DVC schemes based on uni-directional oscillations can be considered as one-dimensional problems (except the chaotic scrambling algorithm which is used to hide the secret image – but does not affect the structure of any of the one-dimensional gratings) [1]. Such DVC schemes based on uni-directional oscillations are highly sensitive to changes of the direction of oscillation – the secret image becomes non-interpretable if the angle between the orientation

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of one-dimensional moiré gratings and the direction of one-directional oscillations becomes higher than 5 degrees [1].

It is clear that the construction of the cover image for a DVC scheme based on elliptic oscillations must be based on a completely different approach – this becomes a full two-dimensional problem. The main objective of this paper is to develop such a DVC scheme based on elliptical oscillations.

2. Preliminaries

One-dimensional moiré grating can be interpreted as a harmonic variation of grayscale color [12]:

$$F(x) = \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right), \quad (1)$$

where x is the longitudinal coordinate, λ is a pitch of moiré grating in the state of equilibrium. Numerical value 0 of function $F(x)$ corresponds to black color, 1 – to white color, values from the interval (0, 1) correspond to an appropriate grayscale level.

Let us consider that moiré grating in Eq. (1) is harmonically oscillated around the state of equilibrium according to the deflection function:

$$u(t) = a\sin(\omega t + \varphi), \quad (2)$$

where a is the amplitude of harmonic oscillations; ω is the cyclic frequency and φ is the phase. One-dimensional time averaged image reads [1,12]:

$$\lim_{T\to\infty}\frac{1}{T}\int_0^T\left(\frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}(x - a\sin(\omega t + \varphi))\right)\right)dt$$
$$= \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right)J_0\left(\frac{2\pi}{\lambda}a\right) \quad (3)$$

where T is the exposure time; J_0 is the zero order Bessel function of the first kind.

Note that the resulting time averaged image does not depend on ω. However, since the exposure time cannot be infinite in any physical experiment, the cyclic frequency becomes an important factor. A large number of periods of oscillation must fit into a finite exposure time in order to minimize optical effects introduced by the fractional part of the last period (unless the exposure time is exactly fitted to the period of oscillation) [1]. The situation is even more complex from the biomedical point of view [11]. A naked eye follows the slow oscillation of the cover image, and human visual system is not able to interpret the time averaged image then. The holistic human visual system (including eyes, nerves, visual cortex) can interpret the time averaged image only when the cyclic frequency is high enough (usually over 30 Hz) and eye balls cannot longer track the cover image [11].

Time averaged image becomes grey when the amplitude of harmonic oscillations is equal to:

$$a = \frac{\lambda}{2\pi}r_i, \quad (4)$$

where r_i is the ith root of J_0. This optical effect is illustrated in Fig. 1. Stationary one-dimensional moiré grating is shown at the left side of Fig. 1(a) (where the amplitude $a = 0$). Note that the moiré grating is constructed only in a finite interval $6 \le x \le 26$ and the white background is assumed elsewhere. Time averaged image of an oscillating one-dimensional moiré grating (note that the time averaged image does not depend on the frequency of oscillations) is visualized as a column of pixels at every discrete value of the amplitude a (Fig. 1(a)). The graph of $J_0\left(\frac{2\pi}{\lambda}a\right)$ is shown in Fig. 1(b); dashed vertical lines mark roots of J_0. It can be clearly seen that the centerlines of time-averaged moiré fringes coincide with the roots of J_0 (Fig. 1(a) and (b)).

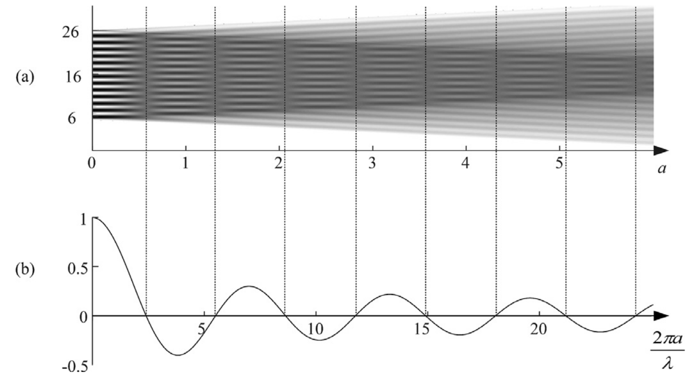

Fig. 1. Pattern of time averaged fringes at $\lambda = 1.5$: (a) an array of grayscale one-dimensional time averaged images at monotonously increasing amplitude of transverse harmonic oscillations; (b) zero order Bessel function of the first kind $J_0(2\pi a/\lambda)$; dashed lines interconnect the centers of time averaged fringes and roots of the Bessel function.

3. Two-dimensional moiré gratings

3.1. Simple moiré gratings in two dimensions

An array of parallel black and white lines on a flat surface can be described by the following formula [12]:

$$F(x, y) = \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right), \quad (5)$$

where x is the longitudinal coordinate; λ is a pitch along the moiré grating; y-axis coincides with the direction of the constitutive grating lines. In analogy to the one-dimensional grating, we assume that the surface performs harmonic oscillations as a non-deformable body. Unidirectional oscillations of the two-dimensional non-deformable surface along the x-axis yield:

$$\lim_{T\to\infty}\frac{1}{T}\int_0^T F(x - a\sin t, y)dt$$
$$= \lim_{T\to\infty}\frac{1}{T}\int_0^T\left(\frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}(x - a\sin t)\right)\right)dt$$
$$= \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right)J_0\left(\frac{2\pi}{\lambda}a\right). \quad (6)$$

Time averaged image becomes a uniformly gray surface at $a = \frac{\lambda}{2\pi}r_i$. On the other hand, oscillations along the y-axis do not alter the static image:

$$\lim_{T\to\infty}\frac{1}{T}\int_0^T F(x, y - a\sin t)dt$$
$$= \lim_{T\to\infty}\frac{1}{T}\int_0^T\left(\frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right)\right)dt = \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right). \quad (7)$$

This is a well-known effect in experimental mechanics that deformations along constitutive lines of a grating do not change the optical image of the surface [12,14].

3.2. Two-dimensional cross-gratings; unidirectional oscillations

A static two-dimensional cross-grating is described by:

$$F_2(x, y) = \frac{1}{2} + \frac{1}{2}\cos\left(\frac{2\pi}{\lambda}x\right)\cos\left(\frac{2\pi}{\mu}y\right), \quad (8)$$

where λ – is the pitch of the grating in the horizontal direction; μ is the pitch in the vertical direction. An example of a two-dimensional moiré cross-grating with $\lambda = 0.75$ and $\mu = 0.5$ is illustrated in Fig. 2(a).

If a cross-grating in Eq. (8) is oscillated along the x- and y-axis, the resulting time-averaged image reads: