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THREE-DIMENSIONAL IMAGE WATERMARKING USING FRACTIONAL FOURIER TRANSFORM

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Abstract: In this paper, we propose an optical image watermarking scheme using the fractional Fourier transform. A two-dimensional watermark is encrypted using a double random fractional order Fourier domain encoding technique. The encrypted image is watermarked into a three-dimensional intensity image reconstructed from a real in-line digital hologram. The watermark is recovered by applying the corresponding correct fractional orders and random phase masks. Results of computer simulation have been presented in support of the proposed watermarking scheme.

1. INTRODUCTION

A digital or optical cryptographic system permits only valid key holders access to the encrypted data. But once such data is decrypted, it becomes almost impossible to track its reproduction. With the availability of modern copiers and scanners, the digital media can be easily duplicated without any loss of quality; therefore, the digital products attract the attention of hackers. This allows unauthorized illegal use of information, called the data piracy. Piracy of information without appropriate permission from rightful owners not only deprives rights of original creators but also harms innovations. A digital watermark is intended to complement the cryptographic processes. A watermark is a visible or invisible identification code that is permanently embedded in the data and remains present within the data after any decryption process. A good watermarking scheme should meet a number of conditions [1-18]. For example, the host data quality should not be affected in a significant way by the hidden data. Another important issue with watermarking is the level of security. In other words how hard it is to decode the hidden information by an unauthorized user even if the watermarking technique is known.

A transformation domain is needed for embedding the watermark. The domain can be the spatial domain as well as the frequency domain. Several researchers have reported that it would be more robust to embed a watermark in the frequency domain [1,7,8]. Frequency domain techniques mostly depend on the spread spectrum approach. Therefore, the signal energy present in any signal frequency becomes undetectable.

The fractional Fourier transform (FRT) is a generalization of the ordinary Fourier transform with an order parameter α [19]. A Fourier transform is a first order FRT with $\alpha = 1$. Properties and applications of the ordinary Fourier transform are special cases of those of the FRT. The generalization of ordinary Fourier transform to the FRT comes at no additional cost in digital computation or optical implementation. Embedding watermark sequences into fractional Fourier domain has an important advantage over embedding in spatial domain or in frequency domain. Watermark in fractional order domain provides extra security against attackers since fractional orders of the transform provides extra degree of freedom [18,20].

Double random phase encoding technique has been widely used in image encryption, information hiding, and watermarking [2-5]. The technique offers high level of security and is robust to interference from noise and distortion. Optical information processing for encryption and watermarking have generated considerable interest in the optics community in the last one decade. Optical implementation of double random encoding technique has some very promising scalability advantages over their purely electronic counterparts as, in principle, the size of the key can be increased without increasing the processing time. The vast majority of digital watermarking has been reported for one-dimensional or two-dimensional images. Image watermarking using digital holography have been further investigated by several researchers [3,5,7,10,12-16]. Schemes based on optical correlation for watermark detection have also been demonstrated [6,15]. Watermarking of three-dimensional (3-D) images have also been reported [12,13]. In this paper, an image watermarking scheme using double random fractional order Fourier domain encoding is proposed. The two phase codes are respectively placed in the input and in the fractional Fourier domain. The encrypted image is then watermarked in a three-dimensional intensity image reconstructed from an in-line digital hologram. The 3-D intensity image serves as the host image. To successfully recover the watermark one has to use the corresponding correct fractional orders and the random phase codes. The proposed algorithm is supported by simulation results.

2. PRINCIPLE

Let function $f(x,y)$ represent the watermark to be encrypted by double random fractional Fourier domain encoding scheme. The watermark is multiplied with a random phase mask, RPM1, defined as $exp[2\pi jr(\xi,\eta)]$, and its FRT of order α is obtained. A two-dimensional FRT of function $\{f(x,y) \times exp[2\pi jr(\xi,\eta)]\}$ of order ($\alpha_1 = a_1\pi/2$) is given by $g(\xi,\eta)$ as [19]

$$g(\xi,\eta) = K\iint f(x,y)\times \exp[2\pi jr(x,y)]\times \exp\left(jx\frac{x^2+y^2+\xi^2+\eta^2}{\tan\alpha_1} - 2j\pi\frac{xy\xi\eta}{\sin\alpha_1}\right)dxdy \quad (1)$$

Here (x,y) and (ξ,η) represent the space and fractional domain coordinates, respectively. The parameter K is defined by

$$K = \frac{\exp\left[-j\left(\frac{1}{4}\pi \mathrm{sgn}(\sin\alpha_1)\right)-\frac{1}{2}\alpha_1\right]}{|\sin\alpha_1|^{1/2}} \quad (2)$$

The function $g(\xi,\eta)$ is multiplied by another random phase mask, RPM2, defined as $exp[2\pi jr(\rho,\sigma)]$, and an FRT of order ($\alpha_2 = a_2\pi/2$) is obtained, which is given as

$$e(\rho,\sigma) = K\iint \{g(\xi,\eta)\times \exp[2\pi jr(\xi,\eta)]\}\times \exp\left(j\pi\frac{\xi^2+\eta^2+\rho^2+\sigma^2}{\tan\alpha_2} - 2j\pi\frac{\xi\eta\rho\sigma}{\sin\alpha_2}\right)d\xi d\eta \quad (3)$$

The function $e(\rho,\sigma)$ is the encrypted image of watermark $f(x,y)$. The RPMs, $r(x,y)$ and $r(\xi,\eta)$ are two independent random functions uniformly distributed in the interval $[0,2\pi]$. The encrypted version of watermark, $e(\rho,\sigma)$, is combined with the host image, $h(\rho,\sigma)$. Thus the watermarked image, $w(\rho,\sigma)$, is given by

$$w(\rho,\sigma) = h(\rho,\sigma) + ae(\rho,\sigma) \quad (4)$$

where a is an arbitrary constant that ensures the invisibility of watermarked image and the robustness of the watermarked image against distortions. The value for a is selected by trial and error.

3. COMPUTER SIMULATION

A computer simulation on MATLAB platform was carried out to verify the proposed scheme. The 3-D intensity image used as host image has been obtained after reconstructing an in-line digital hologram of size 2048 × 2048 pixels. The digital hologram was a single capture Fresnel hologram but the reconstruction has been done applying the fractional Fourier transform algorithm. Fig. 1(a) shows the 3-D intensity image used as host image and (b) shows the intensity image of 2-D watermark. The watermark is encrypted using two independent random phase masks placed in spatial and fractional Fourier planes. The fractional orders used for encryption were $a_1 = 0.25$ and $a_2 = 0.55$. The orders were selected arbitrarily. The encrypted image of 2-D watermark has been shown in Fig. 1(c). The value used for arbitrary constant a was 0.15. The watermarked host image has been shown in Fig. 1(d) and the recovered watermark after using correct fractional orders and correct phase masks has been shown in Fig. 1(e).

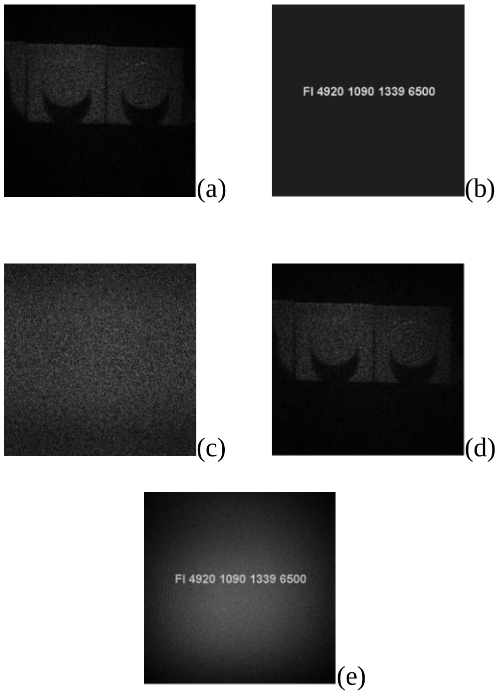

Fig. 1 Simulation results: (a) 3-D intensity image reconstructed from an in-line digital hologram, (b) intensity image of watermark, (c) encrypted intensity image of watermark, (d) watermarked 3-D intensity image, and (e) recovered watermark after applying correct random phase masks and fractional parameters.

In order to study the robustness of the proposed scheme, the watermarked image was occluded and its effect on recovery was carried out. Figs. 2(a,c,e) show the watermarked images with 25%, 50%, and 75% occlusions, respectively. Figs. 2(b,d,f) show the recovered watermarks respectively. It was observed that even with 75% occlusion the watermark is fully recovered but with deteriorated quality. However, it can be inferred that the proposed scheme is robust up to 75% of data loss. For a qualitative check we measured the correlation intensity between the watermark and the recovered watermark. With no occlusion it was 0.6184, with 25% occlusion it was 0.5992, with 50% occlusion it was 0.5506, and with 75% occlusion it was 0.4190.

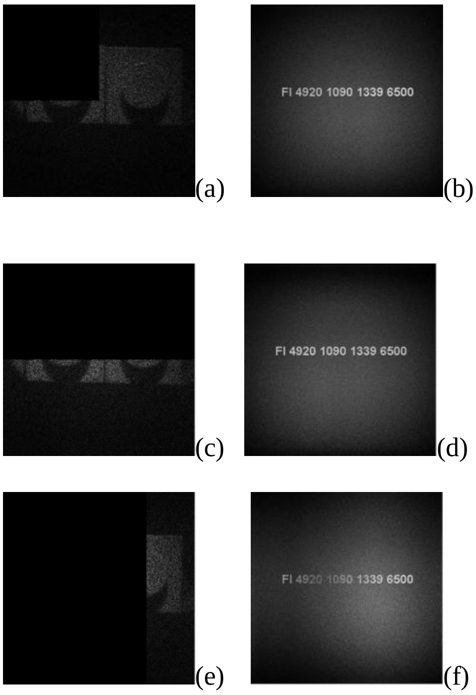

Fig. 2 Results of occlusion effect: (a) 25% occluded watermarked image, (b) corresponding recovered watermark, (c) 50% occluded watermarked image, (d) corresponding recovered watermark, (e) 75% occluded watermarked image, and (f) corresponding recovered watermark.

4. CONCLUSION

A fractional Fourier domain optical image watermark embedding scheme has been demonstrated. The scheme has the advantage that it can be optically implemented employing the conventional double random phase encoding technique. The encrypted image is watermarked into a 3-D host image reconstructed from a real in-line digital hologram. Embedding watermark in fraction Fourier domain enhances the level of security. The effect of occlusion of watermarked image on the recovered watermark has been studied. Simulation results have been presented in support of the proposed scheme.

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