PHASE SCRAMBLING FOR BLIND IMAGE MATCHING

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ABSTRACT

We propose a phase-scrambling method for blind image matching, which is a direct image matching between invisible images. The phase scrambling is motivated by visual protection of images and prevention of illegal image matching. Phase-only correlation (POC) can be directly applied to images protected by the proposed phase scrambling in order to estimate similarity and translation between images. POC with synchronized scrambling provides blind image matching, in which phase scrambling does not affect the accuracy of POC. The effect of visual protection and prevention of illegal image matching is evaluated through simulations to show the effectiveness of the proposed method.

***Index Terms*—** phase-only correlation, scrambling, registration, secure data management, image matching

1. INTRODUCTION

Phase-only correlation (POC), phase correlation, or PHAse Transform (PHAT), which is referred to herein as POC, is a correlation method that is used to estimate the similarity and translation between two signals [1]-[3]. POC with Fourier transform was developed as PHAT in the field of sound/sonar processing [1]. POC with discrete Fourier transform (DFT) was proposed by Kuglin and Hines [2]. The concept based on the Fourier shift property has been extended to the estimation of rotated and scaled values between two images by log-polar coordinate change [3].

Image matching is one application of POC. POC requires knowledge of the form of the image or phase information. If images require extreme security, encrypting and scrambling are generally used to protect information [4]. However, these protected images require decrypting or descrambling before image matching. In other words, POC cannot be directly applied to conventional encrypted or scrambled images. Blind image matching, which is direct image matching between invisible images, is desired for secure data management and low computational complexity. Based on this background, we previously proposed a sign scrambling method in DFT domain [5] as blind image matching for both POC and DCT sign phase correlation [6].

In the present paper, we propose a phase scrambling method that is the extended version of sign scrambling in DFT domain for enhancement of the effect of scrambling. POC can be directly applied to the proposed phase-scrambled images in order to estimate the similarity and translation, and provides the same accuracy as that under non-scrambling. In addition, the effects of visual protection and prevention of illegal image matching, which means the malicious and intentional act to guess the content of images, can be enhanced and controlled. Experimental results show that these effects of the proposed method are stronger than those of the sign scrambling method in DFT domain in [5].

2. PRELIMINARY

In this section, the phase-only correlation and sign scrambling in DFT domain are explained. Single dimensional notation is used for the sake of brevity.

2.1. Phase term and phase-only correlation

Let $G_i(k)$ be the N-point DFT coefficients of the N-point signal, $g_i(n)$. The phase term $\phi_{G_i}(k)$ is defined by

$$\phi_{G_i}(k) = G_i(k)/|G_i(k)| \quad (1)$$

where $|G_i(k)|$ denotes the absolute value of $G_i(k)$. If $|G_i(k)| = 0$, then $\phi_{G_i}(k)$ is defined by 0.

Let $\phi_{G_1}(k)$ and $\phi_{G_2}(k)$ be the phase terms of $g_1(n)$ and $g_2(n)$, respectively. The normalized cross spectrum, $R_\phi(k)$, is defined by the product of the complex conjugate of the phase term and the phase term as

$$R_\phi(k) = \phi^*_{G_1}(k) \cdot \phi_{G_2}(k) \quad (2)$$

where $\phi^*_{G_1}(k)$ denotes the complex conjugate of $\phi_{G_1}(k)$. Phase-only correlation, $r_\phi(n)$, is defined by the inverse DFT of $R_\phi(k)$ as

$$r_\phi(n) = \frac{1}{N}\sum_{k=0}^{N-1} R_\phi(k) W_N^{-nk} \quad (3)$$

where W_N denotes $\exp(j2\pi/N)$. The translation between two signals is estimated by the location of the maximum peak of $r_\phi(n)$ in Eq.(3) [2].

2.2. Sign scrambling in DFT domain

The sign scrambling in DFT domain that we proposed previously is called sign phase scrambling formally from the idea that positive and negative signs in DFT domain correspond to $\exp(j0)$ and $\exp(j\pi)$, respectively. To distinguish the proposed phase scrambling from sign phase scrambling, the sign phase scrambling is simply referred to in the present paper as sign scrambling.

Sign scrambling mainly motivated by blind image matching [5]. The concept of sign scrambling is based on the fact that the product of the same sign is 1. The scrambling is accomplished by multiplying DFT coefficients by random signs. The sign-scrambled DFT coefficient, $\widetilde{G_i}(k)$, is given as

$$\widetilde{G_i}(k) = G_i(k) \cdot s_{\alpha_i}(k) \tag{4}$$

where $s_{\alpha_i}(k)$ is a key sign sequence, and is generally generated by pseudo random generators with initial value α_i. The sign-scrambled signal is given by the inverse DFT of the sign-scrambled DFT coefficients. The two-dimensional expression of the sign-scrambled signal is referred to as the sign-scrambled image.

3. PHASE SCRAMBLING

We propose the phase scrambling for blind image matching.

3.1. Phase scrambling and visual protection

Phase scrambling is accomplished by multiplying DFT coefficients by arbitrary phase terms. The arbitrary phase term sequence is referred to as the key phase sequence.

Let $\theta_{\alpha_i}(k)$ be a key phase sequence. The phase-scrambled DFT coefficients, $\widetilde{G_i}(k)$, are defined as

$$\widetilde{G_i}(k) = G_i(k) \cdot e^{j\theta_{\alpha_i}(k)}. \tag{5}$$

Replacing $G_i(k)$ in Eq.(5) by its polar form yields

$$\begin{aligned}\widetilde{G_i}(k) &= |G_i(k)|\phi_{G_i}(k)e^{j\theta_{\alpha_i}(k)} \\ &= |G_i(k)|\widetilde{\phi}_{G_i}(k).\end{aligned} \tag{6}$$

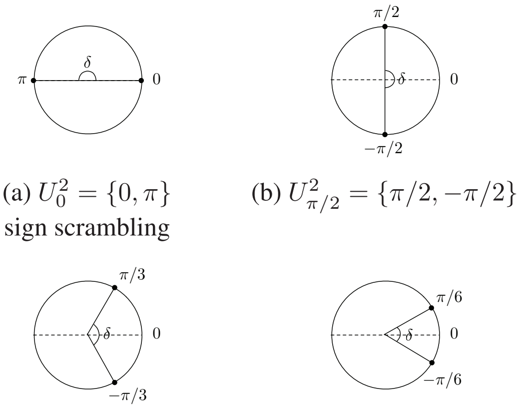
Therefore, phase scrambling affects only the phase term, and does not affect the magnitude of the DFT coefficients.

The phase-scrambled signal is given by the inverse DFT of phase-scrambled DFT coefficients. The phase-scrambled signal is extended to a two-dimensional expression, which is referred to as a phase-scrambled image.

3.2. Phase scrambling and signal matching

Let us consider the normalized cross spectrum under phase scrambling. From Eqs.(2) and (6), the normalized cross spectrum, $\widetilde{R}_\phi(k)$, under phase scrambling, is given by

$$\begin{aligned}\widetilde{R}_\phi(k) &= \widetilde{\phi}^*_{G_1}(k) \cdot \widetilde{\phi}_{G_2}(k) \\ &= \phi^*_{G_1}(k)e^{-j\theta_{\alpha_1}(k)} \cdot \phi_{G_2}(k)e^{j\theta_{\alpha_2}(k)}.\end{aligned} \tag{7}$$



(a) $U_0^2 = \{0, \pi\}$ sign scrambling

(b) $U_{\pi/2}^2 = \{\pi/2, -\pi/2\}$

(c) $U_{\pi/3}^2 = \{\pi/3, -\pi/3\}$

(d) $U_{\pi/6}^2 = \{\pi/6, -\pi/6\}$

Fig. 1. Examples of key phase sequence with $M = 2$

If the key phase sequences $\theta_{\alpha_1}(k)$ and $\theta_{\alpha_2}(k)$ are the same, then

$$e^{-j\theta_{\alpha_1}(k)} \cdot e^{j\theta_{\alpha_2}(k)} = 1. \tag{8}$$

From Eqs.(2), (7) and (8), we obtain

$$\widetilde{R}_\phi(k) = R_\phi(k). \tag{9}$$

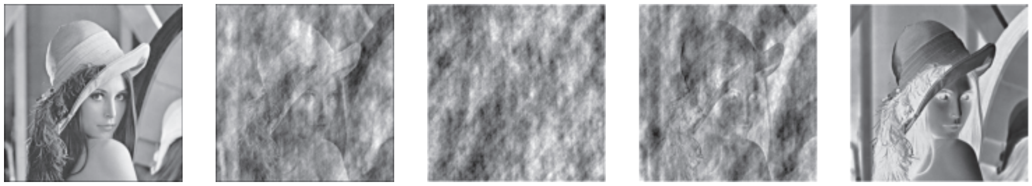
Therefore, under phase scrambling with the same key phase sequence, the same $r_\phi(n)$ as that between non-scrambled signals is obtained.

3.3. Key phase sequence

The $N \times N$-point key phase sequence, $\theta_{\alpha_i}(k_1, k_2)$, is determined from a set $U_{x_1}^M$ that consists of the M-member, $x_1, x_2, \cdots, x_M$, $(M \leq N \times N)$, i.e.,

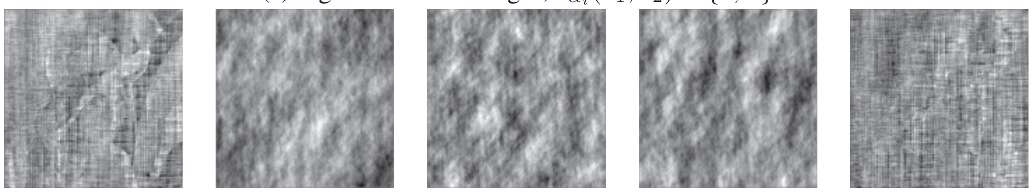
$$\theta_{\alpha_i}(k_1, k_2) \in U_{x_1}^M, \quad U_{x_1}^M = \{x_1, x_2, \cdots, x_M\}. \tag{10}$$

Let p_{x_1} be the ratio of the number of x_1 to $N \times N$ points, and let q_{x_1} be the occurrence probability of x_1 per point. The key sign sequence of sign scrambling in 2.2 corresponds to the key phase sequence $\theta_{\alpha_i}(k_1, k_2) \in U_0^2$, $U_0^2 = \{0, \pi\}$. Therefore, sign scrambling is a special case of the proposed phase scrambling. In sign scrambling, both the number and the value of members in Eq.(10) are fixed, while in the phase scrambling, they are flexible. Fig. 1 shows examples of the set with $M = 2$ in a key phase sequence. (a) corresponds to sign scrambling, and the differences of phase δ in (b), (c), and (d) are different, while δ in (a) and (b) are the same. The flexibility with p_{x_1} and δ in members controls the effect of visual protection and prevention of illegal image matching.



$p_0 = 1$ $p_0 = 0.75$ $p_0 = 0.5$ $p_0 = 0.25$ $p_0 = 0$

(a) Sign-scrambled images, $\theta_{\alpha_i}(k_1, k_2) \in \{0, \pi\}$



$p_{\pi/2} = 1$ $p_{\pi/2} = 0.75$ $p_{\pi/2} = 0.5$ $p_{\pi/2} = 0.25$ $p_{\pi/2} = 0$

(b) Phase-scrambled images with $\theta_{\alpha_i}(k_1, k_2) \in \{\pi/2, -\pi/2\}$

Fig. 2. Sign-scrambled images and phase-scrambled images. (a) p_0 affects the effect of visual protection in sign-scrambled images. (b) Phase scrambling protects the contents of original image, regardless of $p_{\pi/2}$, except for the case in which $p_{\pi/2} = 1$.

$\{\pi/2, -\pi/2\}$ $\{\pi/3, -\pi/3\}$ $\{\pi/4, -\pi/4\}$ $\{\pi/5, -\pi/5\}$ $\{\pi/6, -\pi/6\}$

Fig. 3. Phase-scrambled images with $\theta_{\alpha_i}(k_1, k_2) \in U_a^2$, $U_a^2 = \{a, -a\}$, $p_a = 0.5$, a = $\pi/2, \pi/3 \cdots, \pi/6$: The smaller the difference of phases in a set, the weaker the visual protection becomes.

4. SIMULATION

The effect of visual protection and prevention of illegal image matching of the proposed method is evaluated. A 512×512 8-bit monochrome image, 'lena', was used in the simulation.

4.1. Visual protection

In order to compare the effect of phase scrambling to that of sign scrambling, the key phase sequence with $M = 2$ is used. Fig. 2 (a) and (b) show the sign-scrambled images and phase-scrambled images with $\theta_{\alpha_i}(k_1, k_2) \in U_{\pi/2}^2$, $U_{\pi/2}^2 = \{\pi/2, -\pi/2\}$, respectively. The effect of visual protection in the sign scrambling depends on p_0, while the phase scrambling protects the information of the original image, regardless of $p_{\pi/2}$, except for the case in which $p_{\pi/2} = 1$.

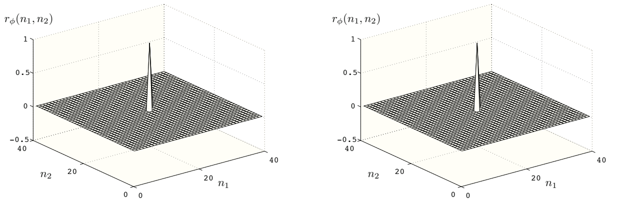
Fig. 3 shows the phase-scrambled image with $\theta_{\alpha_i}(k_1,k_2) \in U_a^2$, $U_a^2 = \{a, -a\}$, $p_a = 0.5$, $a = \pi/2, \pi/3, \cdots, \pi/6$. The smaller the difference of phases, the weaker the visual protection becomes. Therefore, in the phase scrambling, the value of the member of a set should be selected carefully.

4.2. Blind image matching

We evaluated shift estimation by POC under non-scrambling and phase scrambling with the same key phase sequence, $\theta_{\alpha_i}(k_1, k_2) \in U_{\pi/2}^2$. Fig. 4 (a) and (b) show the respective POC surfaces, in which a peak appears at the point that expresses the shift value between images. We confirmed that the two POC surfaces were identical. We can conclude that the phase scrambling provides blind image matching by POC.

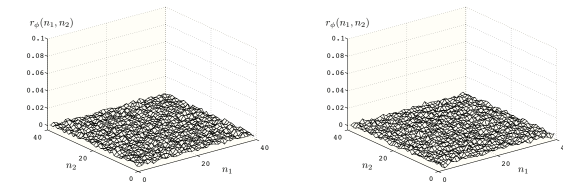
4.3. Prevention of illegal image matching

Let us consider an illegal image matching between a scrambled image and a non-scrambled image. The phase scrambling with $\theta_{\alpha_i}(k_1, k_2) \in U_{\pi/2}^2$ was compared with sign scrambling. Fig. 5 (a) and (b) show the POC surfaces in sign scrambling with $p_0 = 0.5$ and phase scrambling with $p_{\pi/2} = 0.5$, respectively. We can confirm that both sign scrambling and phase scrambling have the effect of preventing illegal image matching. Fig. 5 (c) and (d) show the POC surfaces in sign scrambling with $p_0 = 0.55$ and phase scrambling with $p_{\pi/2} = 0.55$, respectively. In the sign scrambling,

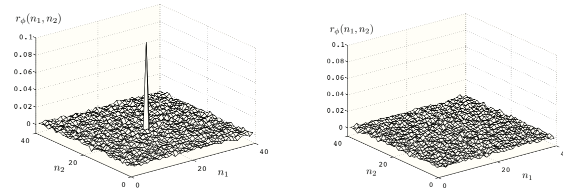


(a) nonscrambling (b) phase scrambling with the same key phase sequence

Fig. 4. Blind image matching. POC surfaces (a) and (b) are identical. The same accuracy is obtained from invisible images protected by phase scrambling.



(a) sign scrambling $p_0 = 0.5$ (b) phase scrambling $p_{\pi/2} = 0.5$



(c) sign scrambling $p_0 = 0.55$ (d) phase scrambling $p_{\pi/2} = 0.55$

Fig. 5. Illegal image matching between a scrambled image and a non-scrambled image. Sign scrambling with $p_0 = 0.55$ does not prevent the content of images from being guessed by one who has not authority to execute image matching.

a peak appears at the point that expresses the relative shift value. Therefore, sign scrambling is not sufficient to prevent the content of images from being guessed by POC.

4.4. Theoretical consideration

Let two key phase sequences be $\theta_{\alpha_1}(k_1, k_2)$ and $\theta_{\alpha_2}(k_1, k_2)$, where $\theta_{\alpha_i}(k_1, k_2) \in U_a^2$ and $U_a^2 = \{a, b\}$. The probability, $Q_2(q_a, q_b)$, that satisfies $\theta_{\alpha_1}(k_1, k_2) = \theta_{\alpha_2}(k_1, k_2)$ for any (k_1, k_2) is given as

$$Q_2(q_a, q_b)|_{q_b=1-q_a} = q_a^2 + (1-q_a)^2 = 2\left(q_a - \frac{1}{2}\right)^2 + \frac{1}{2}. \quad (11)$$

Therefore, Q_2 gives the minimum value of $1/2$ when $q_a = 0.5$.

Next, a set with M-member $U_{x_1}^M$ is considered. We assume that each occurrence probability $q_{x_i}, i = 1, 2, \cdots, M$ is the same. The probability, $Q_M(q_{x_1}, q_{x_2}, \cdots, q_{x_M})$, that satisfies $\theta_{\alpha_1}(k_1, k_2) = \theta_{\alpha_2}(k_1, k_2)$ for any (k_1, k_2) is given as

$$Q_M(q_{x_1}, q_{x_2}, \cdots, q_{x_M})\big|_{q_{x_1}=q_{x_2}=\cdots=q_{x_M}} = M\frac{1}{M^2} = \frac{1}{M}. \quad (12)$$

A large number of members in a set enhances the effect of preventing illegal image matching with respect to coincident probability. Therefore, the proposed phase scrambling has stronger effects of visual protection and prevention of illegal image matching than those of sign scrambling due to the flexibility of key phase sequence.

5. CONCLUSION

We have proposed phase scrambling for blind image matching using phase-only correlation. We have shown mathematically that POC can be directly applied to images under phase scrambling and that synchronized phase scrambling gives the same accuracy of POC as that under non-scrambling. In image matching system composed of a multitude of templates, only scrambling of a query without descrambling of a multitude of templates is effective in terms of computational complexity and memory complexity. The effect of visual protection and preventing illegal image matching was examined through simulations in order to demonstrate the effectiveness of the proposed method.

6. REFERENCES

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