MP2-D-2

A No Reference Geometrical Compensation Method Using Simple Correlation-Based Data Hiding

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***Abstract*—This paper proposes an image registration method in which a geometrical deformed image is geometrically compensated without using its corresponding reference image. The proposed method hides a simple two-dimensional matrix into an original image in the spatial domain to generate a stego image. Once a stego image is geometrically deformed, this method estimates the geometric parameters by correlation between the geometrical deformed stego image and two-dimensional matrix. Since the proposed method hides the identical matrix to the image regardless of image, this method does not require any reference image, whereas ordinary image registration method require the reference image that corresponds to the image to be compensated. Experimental results show the effectiveness of the proposed method.**

I. Introduction

Image registration that estimates translational displacements, rotation, and scaling between *two* images and geometrically compensates one of the images is desired for many fields. Not only image registration methods themselves, such as phase-only correlation (POC) or phase correlation [1]–[4] and discrete cosine transform-sign phase correlation (DCT-SPC) [5], but also those applications, such as security-related issues [6], motion analysis [7], and video retrieval [8], have been studied. As mentioned above, the ordinary image registration requires a reference image that corresponds to the image to be compensated.

On the other hand, data hiding technology has been diligently studied, for not only security-related problems [9], [10] but also non security-oriented issues [9], [11]. A data hiding scheme embeds data into a target signal referred to as the *original* signal. It, then, generates a slightly distorted signal that is referred to as a *stego* signal [12]. Since even slight geometrical deformation greatly prevents correct data extraction, geometric invariant schemes [13]–[17] and schemes with image compensation by template matching [18]–[20] have been proposed. This paper focuses the latter, but not for data extraction; dedicate to image registration.

This paper proposes an image registration method that does not require any reference image. A simple two-dimensional matrix is hidden to images in the spatial domain, and the approach based on simple correlation between a geometrically deformed stego image and the matrix estimates geometric parameters. The matrix is common for all images so that no image-dependent reference information is required in this method. This feature does not arise a security related problem [15], [18], because the proposed method is dedicated to non security application, i.e., image registration. Even the proposed method is quite simple, it well estimates rotated angle as well as translational displacements. This method also detects slight scaling.

II. Preliminary

This section briefly mentions POC [2]–[4] and conventional data hiding schemes against to geometric deformation [13]–[20].

A. POC and Its Application to Geometric Estimation

This section defines the POC function [2], [3] and geometric estimation using the POC [2]–[4] is mentioned.

Let $f(n_1,n_2)$ and $g(n_1,n_2)$ be two of $N_1 \times N_2$-sized images where $n_1 = 0,1,\ldots,N_1-1$ and $n_2 = 0,1,\ldots,N_2-1$, and $F(k_1,k_2)$ and $G(k_1,k_2)$ are the two-dimensional DFT (2D-DFT) of the two images, respectively. Normalized cross spectrum $R(k_1,k_2)$ between $F(k_1,k_2)$ and $G(k_1,k_2)$ is given by

$$R(k_1,k_2) = \frac{F(k_1,k_2)\overline{G(k_1,k_2)}}{\left|F(k_1,k_2)\overline{G(k_1,k_2)}\right|}, \quad (1)$$

where $k_1 = 0,1,\ldots,N_1-1$, $k_2 = 0,1,\ldots,N_2-1$, and $\overline{G(k_1,k_2)}$ denotes the complex conjugate of $G(k_1,k_2)$. POC function (n_1,n_2) is given as the 2D inverse DFT (2D-IDFT) of $R(k_1,k_2)$.

By applying this POC to $f(n_1,n_2)$ and $f(n_1-\delta_1,n_2-\delta_2)$, shift amount δ_1 and δ_2 are estimated in pixels as the peak position of $r(n_1,n_2)$ [2], [3]. Moreover, for two images $f(n_1,n_2)$ and $g(n_1,n_2)$ where $g(n_1,n_2)$ is rotated θ and resized λ times from $f(n_1,n_2)$, θ and λ are able to be estimated in samples [4], because θ and λ boil down to shift amounts by log-polar mapping (LPM).

As mentioned above, an ordinary image registration based on correlation including POC requires the reference image corresponding to the image to be geometrically compensated.

B. Data Hiding Schemes against Geometric Deformation

This section mentions conventional data hiding schemes that fight geometric deformation [13]–[20].

Exhaustive search tries to extract watermark by correlation between the deformed stego image and randomly (or all possibly) deformed watermark [13]. Another strategy is hiding data into geometric invariant domains [14], [15], [20] and using geometric invariant representation [16], [17]. Hiding a

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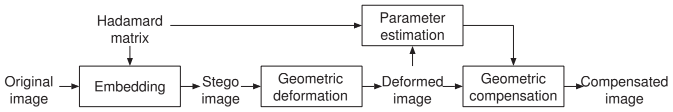


Fig. 1. Block diagram of the proposed method.

registration template, in addition to informative data, to compensate deformed stego image is another practical way [18], [19].

Among above mentioned approaches, former two extract hidden data without image registration [13]–[17] and the last does full [18] or partial [19], [20] image registration. From the perspective of data extraction, all three strategies are acceptable. If the concern is image registration, the last strategy with full registration is required, so this paper focuses the registration template.

In the next section, a novel geometric compensation method using a simple correlation-based data hiding scheme is proposed. The proposed method does not require the reference image corresponding to the image to be compensated.

III. Proposed Method

This section proposes a new image registration method that requires neither reference image nor image-dependent information.

Fig. 1 shows the block diagram of the proposed method in which Hadamard matrix is used as the registration template for its simplicity. In the proposed method, Hadamard matrix that is common for all images is hidden to an image by a simple data hiding manner in the spatial domain, and a correlation between a geometrically deformed image and the matrix estimates geometric parameters. With estimated parameters, the proposed method geometrically compensates the deformed image.

A. Hiding the Template

Though any data hiding manner can be used, this method uses scaled addition, so to say, in the spatial domain, for its simplicity. The following steps are applied to an original image. A $N_1 \times N_2$-sized original image in which each pixel has 2^K levels from zero to $2^K - 1$ is represented as $\mathbf{o} = \left\{o(n_1,n_2)\middle| n_1 = 0,1,\ldots,N_1-1, n_2 = 0,1,\ldots, N_2-1, 0 \le f(n_1,n_2) \le 2^K-1\right\}$.

1) Generate a Hadamard matrix of order 2^d, where 2^d satisfies
$$\max(N_1,N_2) \le 2^d, \qquad (2)$$
where d is a positive integer that is larger than one. Hadamard matrix of order 2^d, represented as $\mathbf{h}_{2^d}$, is given by
$$\mathbf{h}_{2^d} = \begin{bmatrix} \mathbf{h}_{2(d-1)} & \mathbf{h}_{2(d-1)} \\ \mathbf{h}_{2(d-1)} & -\mathbf{h}_{2(d-1)} \end{bmatrix}, \qquad (3)$$
where Hadamard matrix of order two, $\mathbf{h}_2$, is given as
$$\mathbf{h}_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}. \qquad (4)$$

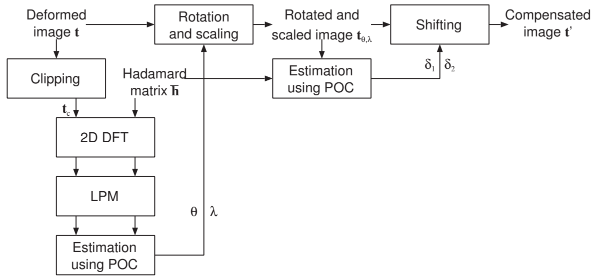


Fig. 2. Geometric parameters estimation and compensation.

2) Clip $N_1 \times N_2$-sized partial matrix $\bar{\mathbf{h}} = \left\{\bar{h}(n_1,n_2)\right\}$ from $\mathbf{h}_{2^d}$ as
$$\bar{h}(n_1,n_2) = h(n_1,n_2), \qquad (5)$$
where $h(n_1,n_2)$ is the top left element of $\mathbf{h}_{2^d}$, and $n_1 = 0,1,\ldots,N_1$ and $n_2 = 0,1,\ldots,N_2$.

3) Stego image $\mathbf{s} = \{s(n_1,n_2)\}$ is derived by
$$s(n_1,n_2) = o(n_1,n_2) + a\bar{h}(n_1,n_2), \qquad (6)$$
where a is the strength parameter.

It is noted that the proposed method hides Hadamard matrix to original image $\mathbf{o}$ regardless of image. That is, the matrix to be hidden is common for all images.

B. Geometric Compensation

Fig. 2 shows the block diagram of the geometric compensation in the proposed method in which POC is used as the correlation function. Image to be compensated $\mathbf{t} = \left\{t(n_1,n_2)\middle| n_1 = 0,1,\ldots,n_2 = 0,1,\ldots\right\}$ is a geometrically deformed version of stego image $\mathbf{s}$. The following algorithm is applied to $\mathbf{t}$ to compensate it. It is assumed that the size of original image $\mathbf{o}$ is known.

1) Clip $N_1 \times N_2$-sized left top partial image $\mathbf{t}_c = \{t_c(n_1,n_2)\}$ from $\mathbf{t}$, if $\mathbf{t}$ is larger than $\mathbf{o}$. Otherwise, set $\mathbf{t}_c = \mathbf{t}$.
2) Apply 2D-DFT to $\mathbf{t}_c$ and $\bar{\mathbf{h}}$ for obtaining $\mathbf{T}_c = \{T_c(k_1,k_2)\}$ and $\bar{\mathbf{H}} = \{\bar{H}(k_1,k_2)\}$, where $\mathbf{T}_c$ and $\bar{\mathbf{H}}$ are the 2D spectrum of $\mathbf{t}_c$ and $\bar{\mathbf{h}}$, respectively.
3) Apply LPM to $|\mathbf{T}_c|$ and $|\bar{\mathbf{H}}|$ for obtaining $\mathbf{T}_{c,\mathrm{LP}}$ and $\bar{\mathbf{H}}_{\mathrm{LP}}$, where $|\mathbf{T}_c|$ and $|\bar{\mathbf{H}}|$ are the amplitude of $\mathbf{T}_c$ and $\bar{\mathbf{H}}$, respectively, and $\mathbf{T}_{c,\mathrm{LP}}$ and $\bar{\mathbf{H}}_{\mathrm{LP}}$ are LPMed amplitude of $\mathbf{T}_c$ and $\bar{\mathbf{H}}$, respectively.
4) Calculate correlation function r_{LP} between $\mathbf{T}_{c,\mathrm{LP}}$ and $\bar{\mathbf{H}}_{\mathrm{LP}}$ by POC to estimate rotation angle θ and scaling parameter λ.
5) With estimated θ, compensate the angle of $\mathbf{t}$ and rotated image $\mathbf{t}_\theta$ is obtained. Then, $\mathbf{t}_\theta$ is scaled by using estimated λ and rotated and scaled image $\mathbf{t}_{\theta,\lambda}$ is generated.
6) Calculate correlation function r between $\mathbf{t}_{\theta,\lambda}$ and $\bar{\mathbf{h}}$ by POC to estimate shift parameters δ_1 and δ_2.
7) Shift $\mathbf{t}_{\theta,\lambda}$ by using estimated parameters δ_1 and δ_2 to obtain compensated image $\mathbf{t}'$.

C. Features

Two main features of the proposed method are summarized here, namely compensation without reference image and image

(a) Original. (b) Stego.

Fig. 3. A stego image example for image “lena” (strength parameter $a = 5$ and PSNR: 34.2 dB).

dependent information.

1) Compensation without Reference Image: As described in Sect. III-B, the proposed method estimates geometric parameters by correlation between the image to be compensated and Hadamard matrix. That is, no reference image corresponding to the image to be compensated is required in the proposed method by utilizing correlation-based data hiding with a matrix that is generally uncorrelated to any images, whereas ordinary image registration methods require the reference image [2]–[4].

2) Compensation without Image Dependent Information: As described in Sect. III-A, the proposed method hides Hadamard matrix to an original image regardless of image. That is, image independent information is hidden to the image as registration template. Thus, no image dependent information is required in the proposed method by hiding the matrix regardless of image.

IV. Experimental Results

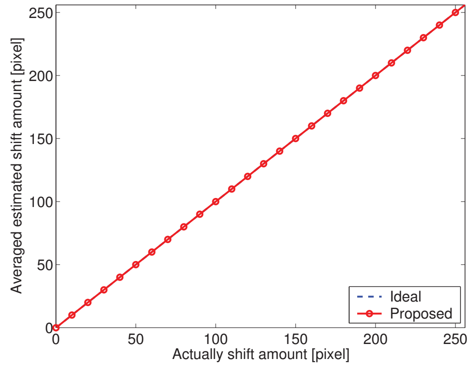
By using 512×512-sized 8-bits quantized grayscale images including “lena” shown in Fig. 3 (a), the estimation accuracy of geometric parameters by the proposed method was evaluated. Fig. 3 (b) shows a stego image of “lena” under the condition that strength parameter $a = 5$.

Hereafter, this paper uses 16 as the base of the logarithm in Step 3 in the compensation algorithm. To estimate parameters in subsamples, i.e., more accurate in Steps 4 and 6 in the compensation algorithm, this paper uses a simple correlation interpolation [3]. In each axis, the nine points that include the peak of POC function r as those center are DFTed, and are then zero padded in the frequency domain. Applying IDFT gives more accurate estimation. Under this condition, the proposed method estimates rotation angle in 0.01 degrees and shift amount in 0.1 pixels. Conditions are summarized in Table I.

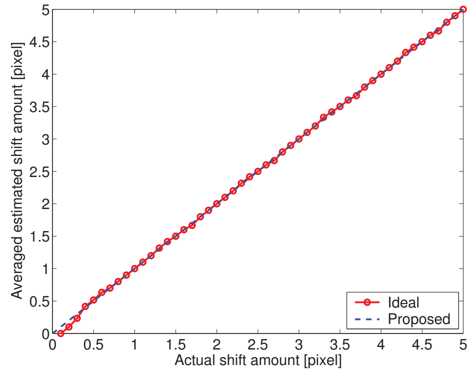
Fig. 4 (a) shows the estimated versus actual shift amounts in which a stego image is shifted in pixels. Thanks to that autocorrelation of Hadamard matrix is enough large under this condition, all shift amounts are accurately estimated. On the other hand, Fig. 4 (b) shows the results in which a stego image is shifted in 0.1 pixels. The proposed method also has enough accurate estimation ability for shifts in subpixels.

TABLE I
Conditions.

Base of the logarithm	16
Estimation unit	0.01 degrees for rotation
	0.1 samples in logarithm for scaling
	0.1 pixels for shift
Interpolation	Bilinear for deformation
	Bilinear for LPM
	Bilinear for compensation



(a) Shifted in pixels.



(b) Shifted in subpixels.

Fig. 4. Results for shift amount estimation. Estimated in 0.1 pixels.

Fig. 5 shows the actual and estimated rotation angles. The proposed method accurately estimates rotation angles between −60 and 60 degrees, though it could not correctly estimate other degrees. Fig. 6 shows the actual and estimated scaling ratios. The proposed method correctly detects 90% scaling down and scaling up up to 120%. It is observed that Hadamard matrix has two peaks in LPMed amplitude frequency domain, and it is considered that this property could be the reason of misestimation. Other deformed images are also geometrically compensated unless scaling parameter λ is misestimated.

Random rotation between 0 and 10 degrees, random scaling between 100% and 150%, and random pixel shift between 0 and 20 are applied to a stego image to generate several deformed images. Fig. 7 (a) shows an example of deformed image which rotation 10 degree, scaling up 110%, and shift 20 and 10 pixels horizontally and vertically, respectively from the stego image. The proposed method compensates geometric deformation of this image, and the difference between com-

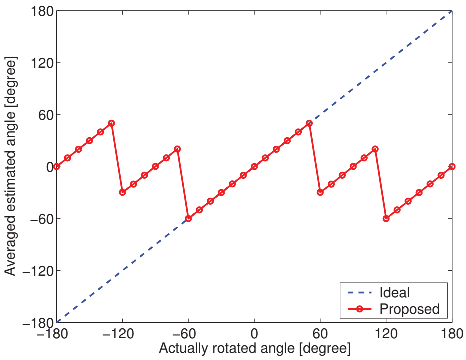


Fig. 5. Results for rotation angle estimation. Estimated in 0.01 degrees.

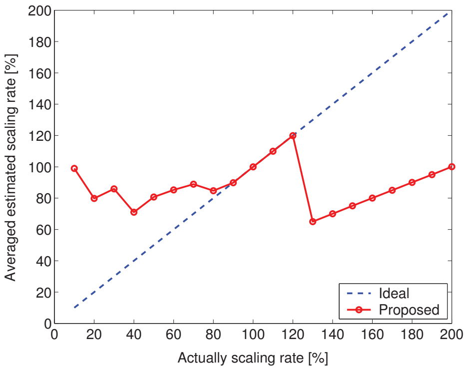


Fig. 6. Results for scaling parameter estimation. Estimated in 0.1 subsamples in LPMed domain.

pensated image and the stego image shown in Fig. 3 (b) is shown as Fig. 7 (b). From this figure, it is found that the proposed method estimates geometric parameters and compensates geometric deformation of the image well.

V. CONCLUSIONS

This paper has proposed a new geometrical compensation method that requires neither reference image nor image-dependent information. The proposed method hides a common simple matrix to images regardless of image, and it estimates geometric parameters based on a simple correlation between the deformed image and the matrix. Though the proposed method is quite simple, it estimates rotated angle as well as translational displacements. This method also estimates slight scaling.

Further works include employment of registration templates that were analyzed in the previous work [18] and investigation in properties of templates [18] and Hadamard matrix in transformed and mapped domains and in their effect to geometric parameters estimation.

(a) Deformed (rotate ten degree, scaling up 110%, and shift 20 and 10 pixels horizontally and vertically, respectively).

(b) Difference between compensated and stego.

Fig. 7. An example of compensation.

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