No Reference Affine Compensation Using Three 2-D Barcodes

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***Abstract*—This paper proposes an image registration scheme using multiple two-dimensional (2-D) barcodes. The proposed scheme never requires any reference image which correspond to the image to be compensated, whereas correlation-based schemes require a reference image such as the original image. The proposed scheme superimposes three 2-D barcodes on an original image, whereas one barcode is used in ordinary applications. 2-D barcodes carry information to be used in an image registration; positions of barcodes, relations among barcodes, and so on. The image with 2-D barcodes is printed for distribution and is registered after redigitized by a scanner. By using the 2-D barcode that is robust to the geometric deformation, 2-D barcodes can be decoded before registration, i.e., information for image registration is obtained before compensation. The proposed scheme compensates an affine distortion of the image by using decoded geometric relations.**

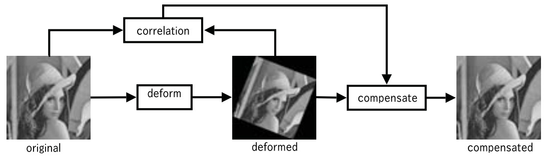
I. INTRODUCTION

Though papers still widely transmit and distribute information, such analog information are redigitized due to filing cost reduction and/or combination with digital data [1]. Digitizing information on papers by a digital scanner is a popular way, whereas it gives geometrical deformation to the redigitized image. So, applying image registration to redigitized images is desired [2].

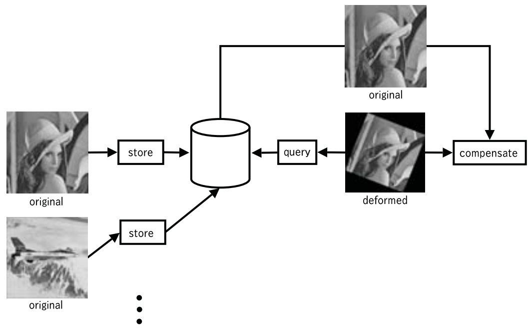
The most well-known class in image registration is based on correlation or phase correlation [3] which compares the image to be compensated with the corresponding original image. Identifying the distorted image to determine its corresponding image and storing all the original images in this class cost highly. On the other hand, a digital watermark-based image registration that does not require the original image for registration has been proposed [4], it, however, distorts whole the image by embedding data for registration.

This paper proposes a novel no reference image registration scheme using multiple two-dimensional (2-D) barcodes [5]. The proposed scheme superimposes 2-D barcodes, which each barcode conveys data for image registration, on an original image. By using data decoded from 2-D barcodes in a redigitized image, the proposed scheme compensates affine deformation. A user can puts 2-D barcodes outside region-of-interest such as text or image in a document to prevent distortion. It is noted that employing 2-D barcodes for image registration and using multiple 2-D barcodes simultaneously are new.

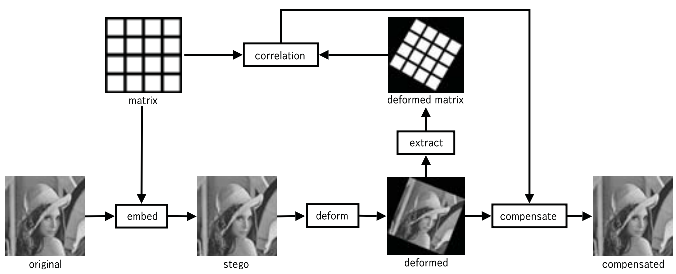
The organization of this paper is as follows. Section II mentions the conventional image registration schemes and those problems. Section III presents a new image registration scheme using multiple 2-D barcodes. The computer simulations and experimental results are shown in Section IV. Finally, conclusions are drawn in Section V.



(a) Correlation-based [3].



(b) The original image should be identified and retrieved to compensate a deformed image.



(c) Digital watermarking-based [4].

Fig. 1. Conventional image registration schemes.

II. CONVENTIONAL SCHEMES

This section briefly describes two correlation-based image registration schemes; one requires the reference image corresponding to the image to be compensated (e.g., [3]) and the other does not require the reference image by using digital watermarking [4].

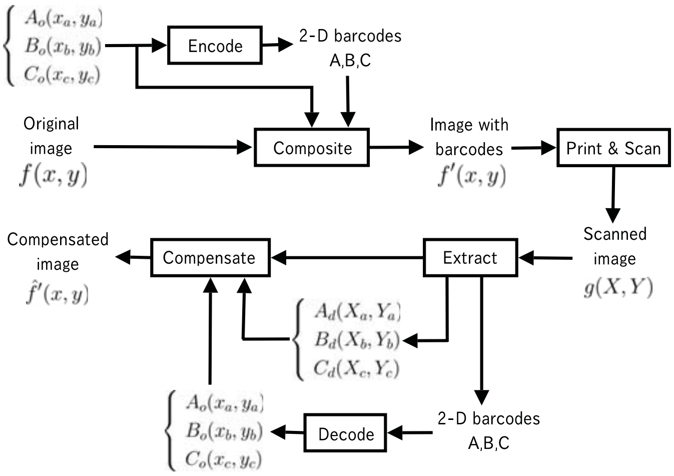


Fig. 2. Proposed system.

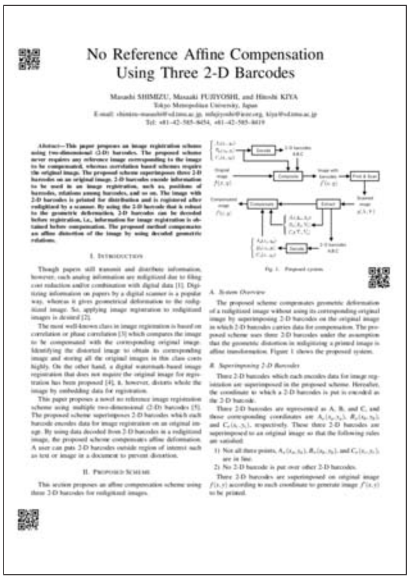

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Fig. 3. An example of superimposing 2-D barcodes on a document image.

An ordinary correlation-based registration scheme directly calculates the correlation between the original and deformed images to compensate the deformed image as shown in Fig. 1 (a). This class of the schemes should store original images for future registration as shown in Fig. 1 (b). Furthermore, this class should identify the original image corresponding to the deformed image among possible original images in the storage. These operations cost highly.

The other class based on digital watermarking does not require such operations [4]. A scheme hides the common 2-D pattern to the original image regardless of the image. To compensate a deformed image, it calculates the correlation between the original and deformed 2-D patterns rather than images as shown in Fig. 1 (c). This scheme is free from the restoration, identification, and retrieval of the original image, it, however, distorts the whole image to hide the pattern. That is, regions-of-interest in an image are distorted in this scheme.

In the next section, a novel no reference image registration scheme is proposed. The proposed scheme utilizes multiple 2-D barcodes for image registration, whereas one 2-D barcode is often used for providing information such as uniform resource locator.

III. Proposed Scheme

This section proposes an affine compensation scheme using three 2-D barcodes for redigitized images.

A. System Overview

The proposed scheme superimposes 2-D barcodes on the original image in which 2-D barcodes carries data for compensation so that the scheme compensates geometric deformation of a redigitized image without using its corresponding original image. The proposed scheme uses three 2-D barcodes under the assumption that the geometric distortion in redigitizing a printed image is an affine transformation. Figure 2 shows the block diagram of the proposed system.

B. Superimposing 2-D Barcodes

Three 2-D barcodes which each barcode conveys data for image registration are superimposed in the proposed scheme. Hereafter, the coordinate to which a 2-D barcodes is put is encoded as the 2-D barcode.

Three 2-D barcodes are represented as A, B, and C, and those corresponding coordinates are $A_o(x_a, y_a)$, $B_o(x_b, y_b)$, and $C_o(x_c, y_c)$, respectively. These three 2-D barcodes are superimposed to an original image with following rules:

1) Not all three points, $A_o(x_a, y_a)$, $B_o(x_b, y_b)$, and $C_o(x_c, y_c)$, are in line.
2) No 2-D barcode is put over other 2-D barcodes.

Three 2-D barcodes are superimposed on original image $f(x, y)$ according to each coordinate to generate image $f'(x, y)$ that is to be printed. Figure 3 shows an example of superimposing 2-D barcodes on a document image.

C. Affine Compensation

The compensation algorithm in the proposed scheme is as follows.

1) Three 2-D barcodes are extracted from image $g(X, Y)$ that is the image affine-deformed by redigitizing. The coordinates of the barcodes in $g(X, Y)$ are represented by $A_d(X_a, Y_a)$, $B_d(X_b, Y_b)$, and $C_d(X_c, Y_c)$, hereafter.
2) Decode 2-D barcodes to obtain the coordinates of barcodes in the original image, i.e., $A_o(x_a, y_a)$, $B_o(x_b, y_b)$, and $C_o(x_c, y_c)$.
3) Solve the system of equations represented by Eqs. (1), (2), and (3) to determine affine transformation matrix $\mathbf{P}$

that is given as Eq. (4).

$$\begin{pmatrix} X_a \\ Y_a \\ 1 \end{pmatrix} = \mathbf{P} \begin{pmatrix} x_a \\ y_a \\ 1 \end{pmatrix}, \quad (1)$$

$$\begin{pmatrix} X_b \\ Y_b \\ 1 \end{pmatrix} = \mathbf{P} \begin{pmatrix} x_b \\ y_b \\ 1 \end{pmatrix}, \quad (2)$$

$$\begin{pmatrix} X_c \\ Y_c \\ 1 \end{pmatrix} = \mathbf{P} \begin{pmatrix} x_c \\ y_c \\ 1 \end{pmatrix}, \quad (3)$$

$$\mathbf{P} = \begin{pmatrix} a & b & \Delta x \\ c & d & \Delta y \\ 0 & 0 & 1 \end{pmatrix}. \quad (4)$$

4) Calculate $\mathbf{P}^{-1}$, the inverse matrix of $\mathbf{P}$, for applying Eq. (5) to all pixels in deformed image $g(X,Y)$ to obtain compensated image $\hat{f}'(x,y)$.

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \mathbf{P}^{-1} \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix}. \quad (5)$$

D. Features

The proposed scheme has two major features mentioned below.

1) Affine Compensation Ability: As described in Sect. III-C, the proposed scheme knows three coordinates $A_o(x_a,y_a)$, $B_o(x_b,y_b)$ and $C_o(x_c,y_c)$, and it also obtain the corresponding coordinates $A_d(X_a,Y_a)$, $B_d(X_b,Y_b)$, and $C_d(X_c,Y_c)$ from an affine-deformed image. The proposed scheme, thus, estimates affine transformation matrix $\mathbf{P}$ by solving the simultaneous equations given by Eqs. (1), (2), and (3), and this makes the proposed scheme possible to compensate the deformed image with $\mathbf{P}^{-1}$.

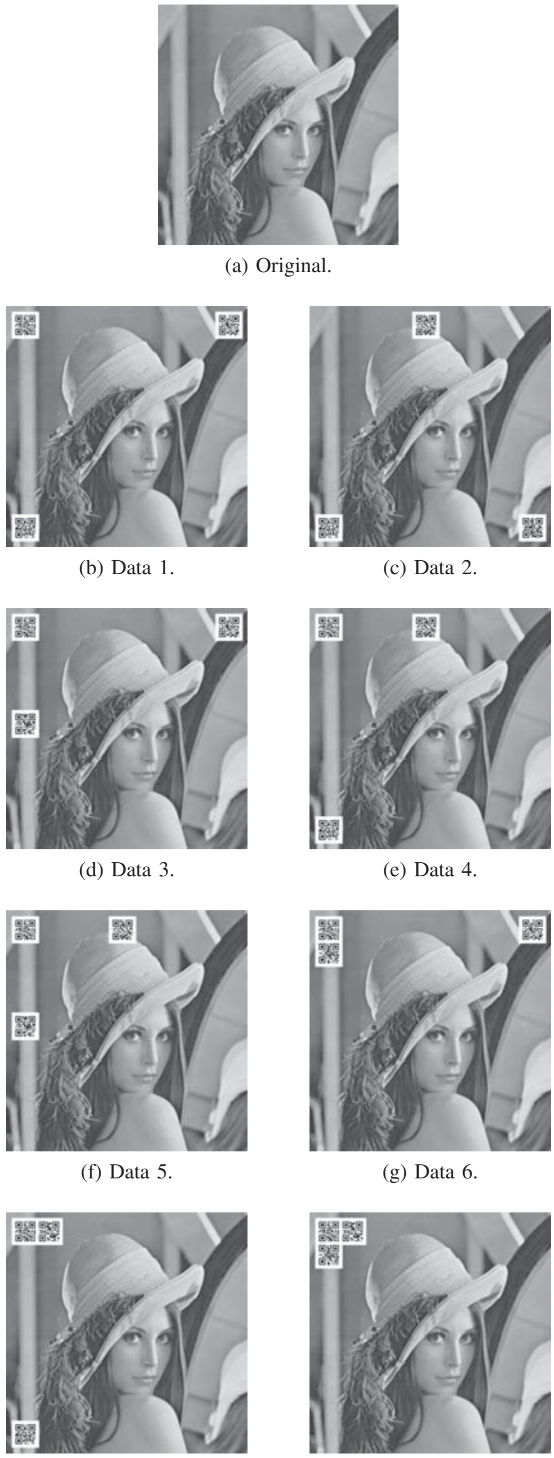
It is noteworthy that all six affine parameters in $\mathbf{P}$, i.e., a, b, c, d, Δx, and Δy, have S in those denominator, where

$$S = \frac{1}{2}\{(x_b - x_a)(y_c - y_a) - (y_b - y_a)(x_c - x_a)\}. \quad (6)$$

Since this S represents the area of a triangle $A_oB_oC_o$ whose vertices are $A_o(x_a,y_a)$, $B_o(x_b,y_b)$, and $C_o(x_c,y_c)$, affine parameters estimation in the proposed scheme is hampered by placing $A_o(x_a,y_a)$, $B_o(x_b,y_b)$, and $C_o(x_c,y_c)$ in line, i.e., $S = 0$. The proposed scheme, thus, introduces Rule 1 as described in Sect. III-B.

In addition, three 2-D barcodes must not overlap each other so that the coordinates $A_o(x_a,y_a)$, $B_o(x_b,y_b)$, and $C_o(x_c,y_c)$ are correctly decoded from the barcodes. The proposed scheme, thus, introduces Rule 2 as described in Sect. III-B.

2) No Reference Compensation: The scheme proposed above encodes three coordinates $A_o(x_a,y_a)$, $B_o(x_b,y_b)$, and $C_o(x_c,y_c)$ as three 2-D barcodes A, B, and C, respectively. So, the proposed scheme is able to not only obtain the coordinate of three barcodes, $A_d(X_a,Y_a)$, $B_d(X_b,Y_b)$, and $C_d(X_c,Y_c)$, directly from an affine deformed image, but also obtain the original coordinates of three barcodes, $A_o(x_a,y_a)$, $B_o(x_b,y_b)$, and $C_o(x_c,y_c)$, by decoding barcodes on the deformed image. By using these six coordinates, it is possible to compensate an affine deformed image without using any reference image as described in Sect. III-D1. That is, the proposed scheme is a no reference compensation scheme, whereas conventional



(a) Original.

(b) Data 1. (c) Data 2.

(d) Data 3. (e) Data 4.

(f) Data 5. (g) Data 6.

(h) Data 7. (i) Data 8.

Fig. 4. Original image $f(x,y)$ and images superimposed three 2-D barcodes $f'(x,y)$'s.

TABLE I
COORDINATE OF 2-D BARCODES $A_o\,(x_a, y_a)$, $B_o\,(x_b, y_b)$, AND $C_o\,(x_c, y_c)$, AND THE RATIO OF THE AREA, D.

	$A_o\,(x_a, y_a)$	$B_o\,(x_b, y_b)$	$C_o\,(x_c, y_c)$	D [%]
data 1	(20, 20)	(450, 20)	(20, 450)	35.27
data 2	(225, 20)	(450, 450)	(20, 450)	35.27
data 3	(20, 20)	(450, 20)	(20, 225)	16.81
data 4	(20, 20)	(225, 20)	(20, 450)	16.81
data 5	(20, 20)	(225, 20)	(20, 225)	8.01
data 6	(20, 20)	(450, 20)	(20, 70)	4.10
data 7	(20, 20)	(70, 20)	(20, 450)	4.10
data 8	(20, 20)	(70, 20)	(20, 70)	0.48

schemes based on correlation need the corresponding reference image for registration [3].

In this paper, the proposed scheme assumes that the employed 2-D barcode is robust to affine transformation so that the proposed scheme decodes 2-D barcodes before image compensation. Moreover, some 2-D barcodes are well designed so that the encoded information is decodable from a part of a 2-D barcode. Such barcodes may relax the constraint of Rule 2 in the proposed scheme that is no 2-D barcode is put over other 2-D barcodes.

IV. EXPERIMENTAL RESULTS

This section evaluate the proposed scheme with image "Lena" (512×512 pixels, eight bits-quantized) shown in Fig. 4 (a). QR code [5] which consists of 21×21 cells (version 1) and 5×5 pixels are in a cell is used as a 2-D barcode.

Eight superimposed images shown as Figs. 4 (b)–(i) are generated according to the eight sets of coordinates $A_o\,(x_a, y_a)$, $B_o\,(x_b, y_b)$, and $C_o\,(x_c, y_c)$ listed in Table I. Here, let D in Table I denote the ratio of area as

$$D = \frac{\text{the area of triangle } A_oB_oC_o}{\text{the area of an original image}} \times 10^2 = \frac{10^2 S}{N_1 N_2}[\%], \quad (7)$$

where S is given by Eq. (6), and N_1 and N_2 are the width and height of the original image, respectively.

The coordinate of the 2-D barcodes in deformed image, i.e., $A_d\,(X_a, Y_a)$, $B_d\,(X_b, Y_b)$, and $C_d\,(X_c, Y_c)$, are given in pixels and manually. Pixels are bilinearly interpolated in all experiments in this section, when the interpolation is needed.

A. Computer Simulation

This section investigates the accuracy of affine parameter estimation of the proposed scheme. Images with 2-D barcodes are affine deformed in a computer using given parameter a_o, b_o, c_o, d_o, Δx_o, and Δy_o, and then the proposed scheme estimates these affine parameters. Estimation error, that are the differences between estimated parameters (a, b, c, d, Δx, and Δy) and given parameters (a_o, b_o, c_o, d_o, Δx_o, and Δy_o), are evaluated. Since the proposed scheme always estimates Δx and Δy correctly in this simulation, the results for these parameters are omitted.

Rotation the image shown in Fig. 4 (b) by 5° generates the image shown in Fig. 5 (a), i.e., $a_o = \cos 5°$, $b_o = -\sin 5°$, $c_o = \sin 5°$, $\Delta x_o = 0$, and Δy_o, and the estimation accuracy for this image is shown in Fig. 6. From Fig. 6, it is found the less

(a) Rotated ($\theta = 5°$).

(b) Scaled ($a_o = d_o = 0.75$).

(c) Skewed ($b_0 = \tan 5°$).

(d) Complex.

Fig. 5. Affine deformed images for Fig. 4 (b) (data 1).

D becomes, the worse the estimation accuracy is. Moreover, the proposed scheme serves the same estimation accuracies for the conditions in which the same D but different coordinates, c.f., results for data 1–4.

Figure 7 shows the estimation accuracies for the image scaled by 75 %, i.e., $a_o = d_o = 0.75$, $b_o = c_o = \Delta x_o = \Delta y_o = 0$, where the scaled image is shown in Fig. 5 (b). It is also found that decreasing D makes the accuracy worse and that the barcode layout makes no different in the accuracy as far as D is fixed.

For the skewed image shown in Fig. 5 (c) ($b_o = \tan 5°$, $a_o = d_o = 1$, $c_o = \Delta x_o = \Delta y_o = 0$), the proposed scheme estimates the affine parameters with accuracy shown in Fig. 8. As the same as rotation and scaling, the accuracy is degraded using small D and the barcode layout does not affect the accuracy for the same D conditions. It is noted from the

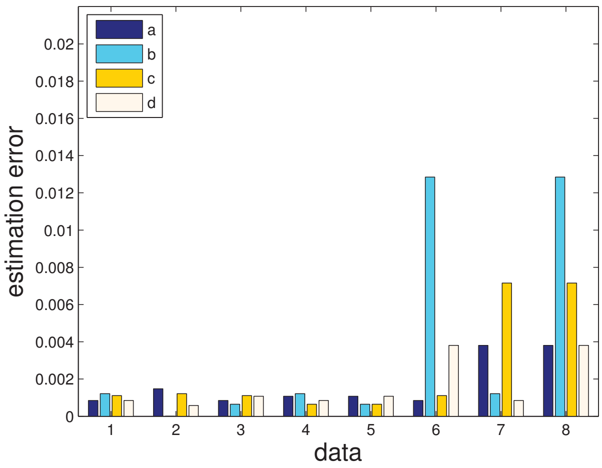


Fig. 6. Estimation accuracy for rotation ($\theta = 5°$).

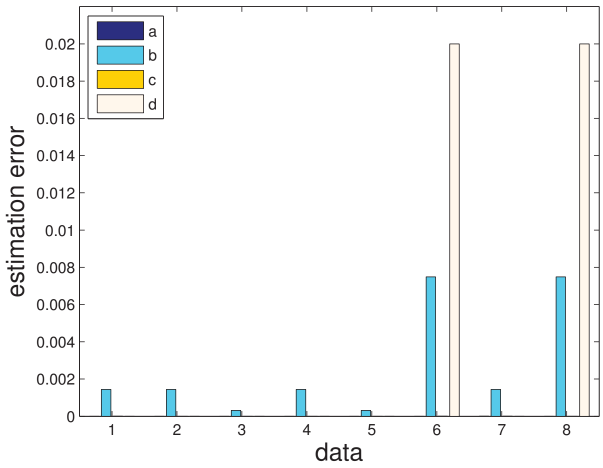


Fig. 8. Estimation accuracy for skew ($b_o = \tan 5°$).

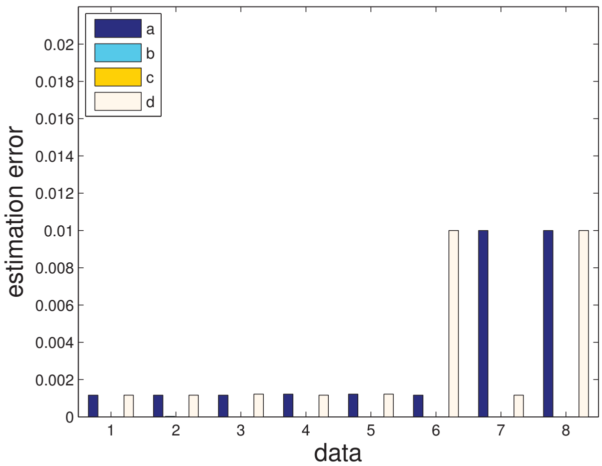


Fig. 7. Estimation accuracy for scaling ($a_o = d_o = 0.75$).

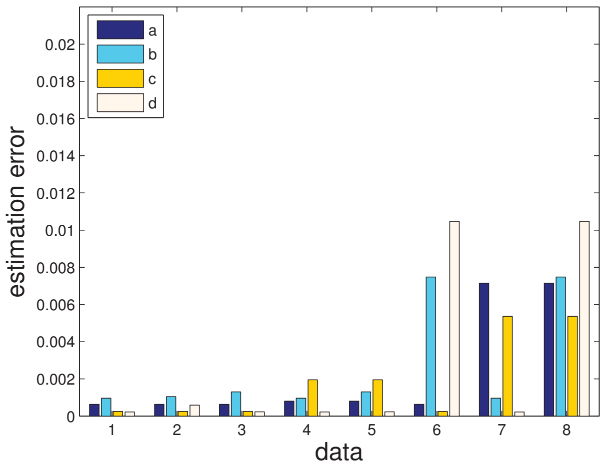


Fig. 9. Estimation accuracy for composite affine transformation.

results for data 3, 5, and 7 that placing two 2-D barcodes vertically with a particular distance improves the estimation accuracy. This implies the proposed scheme estimates affine parameters accurately by taking account into barcode layout when a user knows the affine deformation introduces distortion to a particular direction.

At the last of this section, the results for the image with composite affine transformation are drawn. The image deformed with affine parameters $a_o = 0.7471$, $b_o = -0.0654$, $c_o = 0.1525$, $d_o = 0.9905$, and $\Delta x_o = \Delta y_o = 0$ is shown in Fig. 5 (d), and the estimation accuracy is shown in Fig. 9. It is confirmed that the three results described above hold here again; area ratio D affects the estimation accuracy, the same accuracy is given for the same D regardless of the barcode layout, and the good barcode layout exists for the distortion for a particular direction.

Addition to the above simulations in which all three barcodes are available on a redigitized image, the estimation accuracy is evaluated under another condition; not all is available. It could be happened by a blot or a tear as shown in Fig. 10, though a robust barcode is used. The estimation error by using two barcodes among three barcodes is similar to that by three barcodes which are layouted as shown in Figs. 4 (g)

Fig. 10. An example of a damaged image.

(a) Redigitized image.

(b) Difference between the superimposed and redigitized image.

(c) Image compensated by the proposed scheme.

(d) Difference between the superimposed and compensated images (proposed scheme).

(e) Image compensated by the phase correlation-based scheme [3].

(f) Difference between the superimposed and compensated images (phase correlation-based [3]).

Fig. 11. Redigitized and compensated images for Fig. 4 (b) (data 1).

and (h). That is, even a barcode is unavailable, the proposed scheme estimates affine parameters for deformations with a particular direction.

B. Performance Evaluation in the Real Environment

To evaluate the compensation performance of the proposed scheme, eight images with 2-D barcodes shown in Fig. 4 are printed out by a printer and are redigitized by an image scanner. The used printer and scanner are EPSON LP-9100PS3 with 75 ppi and Canon CanoScan LiDE 40 with 75 ppi. The proposed scheme compensates the affine deformation of redigitized images.

For the redigitized image shown in Fig. 11 (a) and the image compensated by the proposed scheme shown in Fig. 11 (c), the differences to the superimposed image shown in Fig. 4 (b) are depicted in Figs. 11 (b) and (d), respectively. For comparison, the image compensated by the phase correlation-based scheme [3] is shown in Fig. 11 (e) and the difference between Figs. 11 (e) and 4 (b) is shown as Fig. 11 (f). From Fig. 11, it is found that the proposed scheme compensates affine deformation as well as the phase correlation-based scheme using the reference image, though the proposed scheme does not require any reference image.

V. Conclusions

This paper has proposed a no reference affine compensation scheme for redigitized images. The proposed scheme uses three 2-D barcodes which each barcode carries the coordinate of the barcode in an image. Computer simulation shows the estimation accuracy of the proposed scheme depends on the barcode layout, and experiments in the real environment show that the proposed scheme compensates affine deformation of redigitized images as well as the correlation-based image registration scheme using reference images.

Further works include the proposal of an extended scheme for projection compensation [6] by using four feature points.

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