Japanese Journal of Applied Physics

The Japan Society of Applied Physics

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To cite this article: Satoshi Honma *et al* 2011 *Jpn. J. Appl. Phys.* **50** 09ME13

DOI: 10.1143/JJAP.50.09ME13

Face Recognition System with Holographic Memory and Stereovision Technology

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Received February 15, 2011; accepted June 20, 2011; published online September 20, 2011

We have proposed a face recognition system with holographic memory and stereovision technology (FARSHAS). In this system, facial three-dimensional data is captured by stereovision technology and then the facial images at a position in front of the virtual camera is reconstructed automatically. Using the corrected facial images, we estimated theoretically the error rate of the facial recognition system.

Many researchers have proposed the high-speed optical correlator with holographic memories and applied it to character recognition and data retrieval, for example.[1–5] The fast recognition optical correlator (FARCO) is one of the successful applications, and it achieves high-speed processing of over 100,000 faces/s.[6] However, face recognition systems based on the correlator of two dimensional (2D) images often has the problem that a small difference in the face-to-camera angle of the input data from that of reference data causes serious reduction of the cross-correlation even if the persons in the facial images are the same. It is important to adjust the facial angle in front of the camera strictly to achieve angular alignment of the input and reference images for high recognition efficiency.

We have proposed a face recognition system with holographic memory and stereovision technology (FARSHAS).[7,8] The reconstructed various-angle views of a face with computer graphic (CG) technology using three-dimensional (3D) data provided by the stereovision technology are recoded to the database as reference data. The system offers a high authentication rate even if the face-to-camera angle varies. However we must record a great number of facial images at angles varying in steps of one degree from right to left and up and down to the database to achieve a high authentication rate.

In this paper, we propose a new face recognition system capable of estimating and correcting facial angle. By reconstructing the facial image rotated to a position in front of the virtual camera, we match the image to one of many facial images in the database. We show that this system offers dramatic reduction of the reference data volume and improvement of the authentication rate.

The stereovision technology is a satisfactory method of measuring 3D objects by calculating the disparity between the photographs captured from the two cameras. It is possible to reconstruct the facial images captured at arbitrary angles by the virtual camera. We estimate facial angles automatically as follows. Figure 1 shows the preparation process of input and reference images. (1) We captured the two pictures with a stereocamera. (2) We searched the facial region and the position of the eyes in the picture captured by the right camera, using the Haar Cascade classifier of OpenCV. We implemented rotation and scaling to transfer the eyes to predetermined locations in an image of predefined size, by affine transformation. This process is necessary in order to use the following pattern-matching method. We detected the corner positions of the eyes and mouth in the picture with more precision by the pattern-matching method using template images. (3) We calculated the disparity between the two pictures captured from the stereocamera in only the facial region, and obtained the 3D geometry of the face. (4) The facial angle of the 3D object was adjusted to position the corners of the eyes and mouth on the same x–y plane, where x-, y-, and z-axes indicate the horizontal, perpendicular, and depth directions, respectively. (5) The 3D face is transformed to a 2D image. Some points of unknown location in stereovision are interpolated using the information of the adjacent pixels. We implement normalization, edge extraction and binarization for the input and reference images. Figure 2 shows the results just after normalization. We found that the facial images reorientated to the virtual camera are reconstructed even if the subject's original face was rotated in the range of -10 to 10° right to left or up and down. Figure 3 shows another person's facial images. These input and reference images are resized to 60×60 pixels, where the right and left corners of the eyes are located at $(5, 15)$ and $(55, 15)$, respectively.

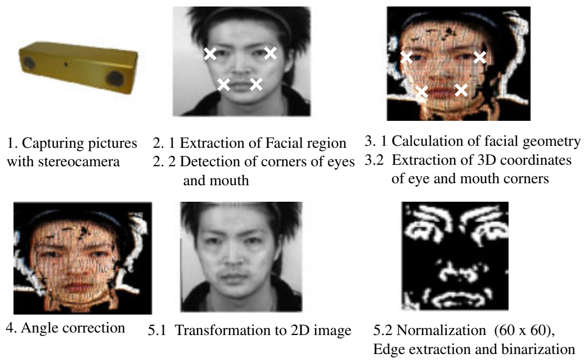

Fig. 1. (Color online) Preparation process of input and reference images.

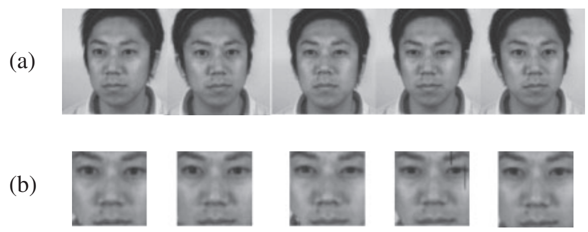

Fig. 2. Reconstructed facial image at front of virtual camera: (a) original facial images, and (b) reconstructed facial images.

Figure 4 shows the optical setup of the correlator based on phase-only correlation. The encryption and decryption technique of reference images with a phase code key is used. In a recording process, we previously calculate the

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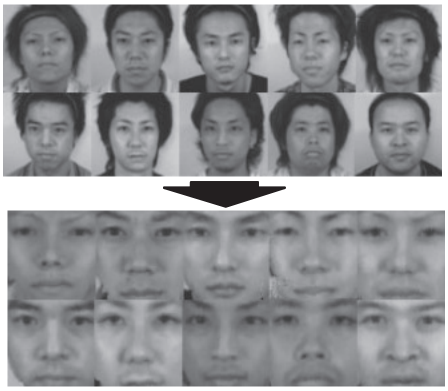

Fig. 3. Images implemented by angular correction and normalization.

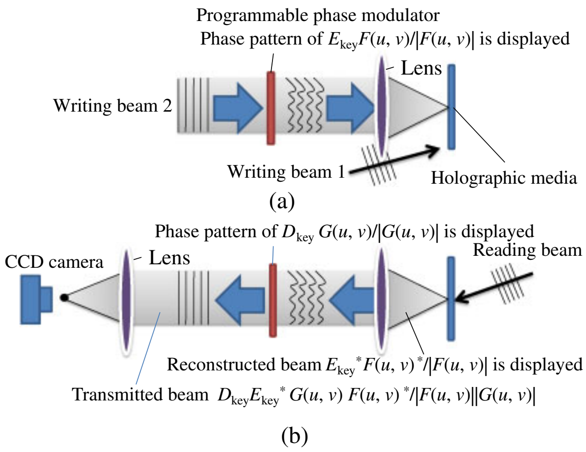

Fig. 4. (Color online) Optical setup of the optical correlator based on phase-only correlation using holographic memory and phase modulator. (a) Recording process of reference data. (b) Image-matching process.

Fourier transformation $F(u, v)$ of the reference image $f(x, y)$, and multiply the phase distribution $F(u, v)/|F(u, v)|$ with the phase encryption code key E_{key}. The encrypted phase data E_{key} $F(u, v)/|F(u, v)|$ is displayed at the programmable phase modulator (PPM), as shown in Fig. 4(a). Writing beam 2 with the encrypted data is transmitted through a lens and transformed to a speckle pattern. It is recorded as a hologram by writing beams 1 and 2.

In the matching process shown in Fig. 4(b), a reading beam counterpropagating to writing beam 1 irradiates the hologram. The beam diffracted from the hologram has the phase-conjugated distribution $E_{key}{}^{*}F(u, v)^{*}/|F(u, v)|$ with writing beam 2. On the other hand, the phase distribution $G(u, v)/|G(u, v)|$ is multiplied with the phase decryption key D_{key}, where $G(u, v)$ is the Fourier transform of the input image $g(x, y)$. The phase data is displayed at PPM. When D_{key} is equal to E_{key}, the decryption key cancels out the encryption key, and then the beam transmitted through PPM has the phase distribution corresponding to $G(u, v)F(u, v)^{*}/|G(u, v)||F(u, v)|$. The beam is implemented by Fourier transformation via a lens. We identify whether the person of the input image and that of the reference image are the same or not by comparing the intensity of the peak with the threshold value.

The output beam does not have an obvious peak, even if the input image is equal to the reference image, when the decryption key is different from the encryption key. This

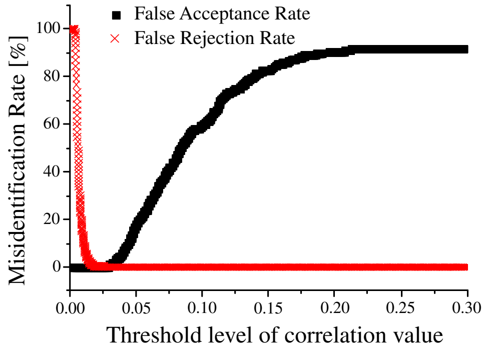

Fig. 5. (Color online) Analytical results of FRR and FAR.

implies that the recognition system can be used only by people who know the correct decryption key and, hence personal information in the database is protected from other persons.

We evaluated theoretically the accuracy of the authentication rate using facial images for 40 persons. We took five pictures per person with the facial angle varied in the range of 0 to 10° around the upright axis. We selected the optimum picture for the highest correlation rate in the dataset. We also took five other pictures with the facial angle varied in the range of 0 to −10° around the upright axis and selected the optimum picture by the same process. We registered two pictures per person into the database of the recognition system. After completing the database, we took other 10 pictures per person as input data, where the facial angle was varied from right and left, and up and down from −10 to 10°.

We calculated the false rejection rate (FRR) and the false acceptance rate (FRR). Figure 5 shows the analysis result. The equal error rate (EER) was 0.15% when we determined the threshold value to be 0.029. We found that the misidentification rate could be suppressed at a low level even though only two sets of reference data per person were recorded in the database. Therefore, this system offers a high authentication rate and dramatic reduction of the reference data volume.

We showed that it is able to achieve a high authentication rate even when the subject's facial angle was rotated in the range of −10 to 10° right to left and up and down and to reduce the reference data volume. We suppressed the amount of calculation for facial three-dimensional geometry by limiting the calculation region by the face detection technique in an image using the Haar-like filter. It took about 0.1 s to create an angular corrected facial image using a personal computer with an Intel Corei3-540 (3.06 GHz) core processor.

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