High Speed Holographic Optical Correlator for Face Recognition

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1. Introduction

Owing to the Japanese government plan, U-Japan, which promised to bring about the so-called 'ubiquitous society' by 2010, the use of Internet has dramatically increased and accordingly, development of the system through IT networks is thriving. The term 'ubiquitous society' became a buzzword, signifying easy access to content on the internet for anybody, anywhere and at any time. Face recognition has become the key technique, as a 'face' carries valuable information, captured for security purposes, without physical contact. They can function as identity information for purposes such as login for bank accounts, access to buildings, anti-theft or crime detection systems using CCTV cameras. Furthermore, within the domain of entertainment, face recognition techniques are applied to search for celebrities who look alike. Against this backdrop, a high performance face recognition system is sought after.

Face recognition has been used in a wide range of security systems, such as monitoring credit card users, identifying individuals with surveillance cameras and monitoring passengers at immigration control. Face recognition has been studied since the 1970s, with extensive research into and development of digital processing (Kaneko & Hasegawa, 1999; Kanade, 1971 ; Sirovich & Kirby, 1991 ; Savvides, M. et al. 2004). Yet there are still many technical challenges to overcome; for instance, the number of images that can be stored is limited in currently available systems, and the recognition rate needs to be improved to take account of photographic images taken at different angles and in varying conditions.

In contrast to digital recognition, optical analog operations process two-dimensional images instantaneously and in parallel, using a lens-based Fourier transform function. In the 1960s, two main types of correlator came into existence; the Vanderlugt Correlator and the Joint Transform Correlator (JTC) (Goodman & Moeller, 2004). Some correlators were a combination of the two (Thapliya & Kamiya, 2000; Kodate Inaba Watanabe & Kamiya, 2002 ; Kobayashi & Toyoda, 1999 ; Carrott Mallaley Dydyk & Mills, 1998). The authors previously proposed and produced the FARCO (Fast Face Recognition Optical Correlator), which was based on the Vanderlugt Correlator((a) Watanabe & Kodate 2005; (b)Watanabe & Kodate, 2005). Combined with high-speed display devices, four-channel processing was able to achieve operational speeds of up to 4000 faces/s. Running trial experiments on a 1-to-N identification basis using the optical parallel correlator, we succeeded in acquiring low error rates of 1 % False Acceptance Rate (FAR) and 2.3 % False Rejection Rate (FRR)(Savvides et

Source: State of the Art in Face Recognition, Book edited by: Dr. Mario I. Chacon M.,
ISBN -3-902613-42-4, pp. 250, January 2009, I-Tech, Vienna, Austria

al., 2004).We also developed an algorithm for a simple filter by optimizing the calculation algorithm, the quantization digits and the carrier spatial frequency for optical correlation. This correlation filter is more accurate, compared with classical correlation.
Recently, a novel holographic optical storage system that utilizes collinear holography has been demonstrated (Horimai & Tan, 2005). This scheme can realize practical and small holographic optical storage systems more easily than conventional off-axis holographic optical systems. At present, the system seems to be most promising for ultrahigh density volumetric optical storage.
Moreover, we proposed the super high-speed FARCO (S-FARCO) ((a) Watanabe & Kodate, 2006; (b) Watanabe & Kodate, 2006) that integrates optical correlation technology used in FARCO and a co-axial holographic optical storage system (Horimai Tan & Li, 2006). Preliminary correlation experiments using the co-axial optical set-up show an excellent performance of high correlation peaks and low error rates. This enables optical correlation without the need to decode information in the database, greatly reducing correlation time. We expect the optical correlation speed to be about 3 μs/frame, assuming 24000 pages of hologram in one track rotating at 600 rpm. A correlation speed faster than 370,000 frames/s was acquired when the system was used. Therefore, the S-FARCO system proved effective as a 1-to-N recognition system with a large database. It should be noted also that the advantage of our system lies in its wide applicability to various correlation schemes.
In recent years, the processing speed of computers has improved greatly. For example, the operation speed of a 128x128 pixels Fast Fourier Transform (FFT) is now about 30ms (CPU: 3GHz, 2GB). When processing the images of several tens of people, the recognition process time can be calculated by the software within a few seconds. Against this background, we propose three different configurations, which depend on the correlation speed and size of shown in Figure 1. FARCO is used for several thousand people at a correlation speed of 4000 faces per second. In response to demand for greater speed or more images, the S-FARCO system was applied. Optical correlation of 2.7μs/face is expected, assuming that 376800 faces can be processed in one second with 10 μm pitch of hologram in one track rotating at 600 rpm in S-FARCO 2.0 and 2.5. S-FARCO 2.5 is a smaller version of the

	FARCO Software	S-FARCO2.0	S-FARCO2.5
	2007 ver.1	2007	2008
Application	1:1 verification or 1:N identification for subjects numbering in the tens	1:N identification for several thousand to several hundred thousand or more subjects	1:N identification for several thousand to several hundred thousand or more subjects
Size [mm]		680 (W)×1120(B)×400(H)	450 (W)×750(B)×400(H)
Operation speed	10ms/faces	3μs/frames	3μs/frames
Format			

Fig. 1. Three different FARCO configurations

previous model (S-FARCO 2.0), with its size reduced by 40%, and is portable. Applied as a face recognition system, it is then possible to correlate more than 376800 faces per second. Software was also proposed for one-to-one ID recognition, which requires less calculation time.

In this chapter, we propose a much more rapid face recognition system using a holographic optical disc system named FARCO 2.0. Section 2 describes the concept of the optical parallel correlation system for facial recognition and the dedicated algorithm. Section 3 presents a correlation engine of a much higher speed for face, image and video data using optical correlation.

Section 4 presents an online face recognition system using the software which was constructed for FARCO algorithm based on phase information. Section 5 proposes a video identification system using a S-FARCO. Section 6 presents a discussion based on the results and summarizes the paper.

2. The concept of the optical correlation system for facial recognition and the dedicated algorithm

In this section we describe the concept of the optical parallel correlation system for facial recognition and the dedicated algorithm. A novel filtering correlation for face recognition which uses phase information with emphasis on the Fourier domain will be introduced. The filtering correlation method will be evaluated by comparing it with various other correlation methods.

2.1 Fast Face Recognition Optical Correlator (FARCO)

An algorithm for the FARCO is shown in Figure 2. In this system, pre- and post-processes with a PC are highly conducive to the enhancement of the S/N ratio and robustness. Firstly, facial images were captured automatically by a digital video camera. The two eyes are used

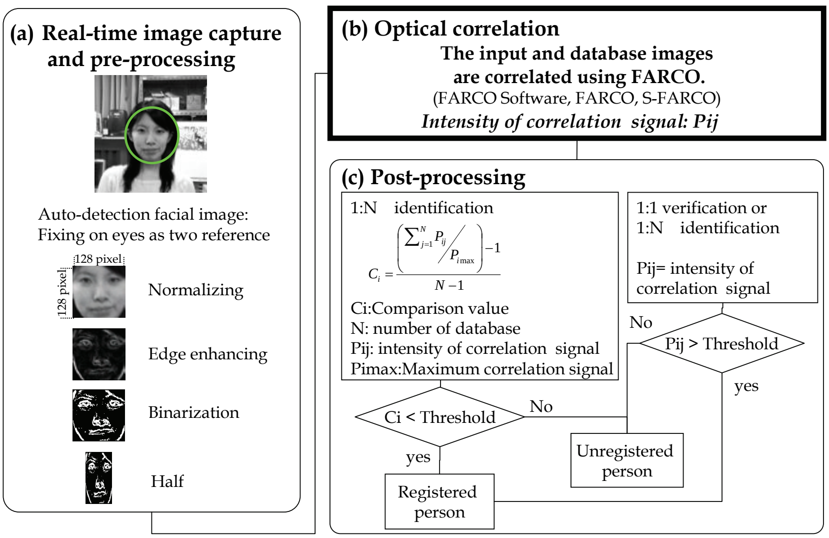


Fig. 2. Our hybrid facial recognition system: flow-chart representation

as focal points. The size of the extracted image was normalized to 128 x 128 pixels by the center. For input images taken at an angle, affined. transformation was used to adjust the image and the image was normalized, fixing on the position of the eyes. This was followed by edge enhancement with a Sobel filter, which binarized and defined the white area as 20%, and equalized the volume of transmitted light in the image. We have shown previously that binarization of the input (and database) images with appropriate adjustment of brightness is effective in improving the quality of the correlation signal.

The correlation signal is classified by a threshold level. In practical applications, the threshold value must be customized. The threshold value varies depending on its security level; on whether the system is designed to reject an unregistered person or permit at least one registered person. The optimum threshold value must be decided using the appropriate number of database images based on the biometrics guideline (Mansfield & Wayman, 2002) for each application. In this paper, the threshold value is fixed where the Equal Error Rate (EER) is at its lowest.

2.2 Design of correlation filter for practical face recognition software

2.2.1 Filtering correlation

In our previous work, the correlation filter of FARCO for the optical correlator was designed by focusing on the binary level and correlation signals, not overlapped by the 0th-order image, with an emphasis on the Fourier domain. The carrier-spatial frequency should be contained within the minimum frequency range of facial characteristics (details described in ((c) Watanabe & Kodate, 2005). In this section, we select parameters to optimize the correlation filter in accordance with the correlation speed for software. We call this method "filtering correlation" (Horner & Gianino, 1982), which will be evaluated in reference to the following two other methods (Watanabe & Kodate, 2005).

2.2.2 Phase-only correlation

The correlation function g(x, y) between two signals, f(x, y) and h(x, y) is expressed as the following Equation (1) using Fourier transform formulation

$$g(x, y) = F[F(u, v)H^*(u, v)] \tag{1}$$

in which * denotes its conjugate. F denotes the Fourier transform operator. While F(u , v) is the Fourier transform of one signal f(x, y), $H^*(u, v)$ is the correlation filter corresponding to the other signal h(x, y), and u and v stand for two vector components of the spatial frequency domain. The classical correlation filter for a signal h(x, y) was defined as $H^*(u, v)$. By setting every amplitude at the number equal to 1 or alternatively by multiplying it by 1/H (u, v), we obtained the phase-only filter (Horner & Gianinor, 1984).

$$H_p(u, v) = \exp\{-i\,\varphi(u, v)\} \tag{2}$$

where p stands for phase.

The performance of the two correlation methods was evaluated through one-to-N identification with a database of 30 frontal facial images. As shown in Figure 3, the database (Tarres (web)) is composed of facial images that vary in different ways (laughing, wearing glasses, different races and so on). Three correlation methods were examined for three image sizes: (a) 32 x 16, (b) 64 x 32 and (c) 128 x 64 respectively (Figure 4).

Fig. 3. Examples of database and input facial images

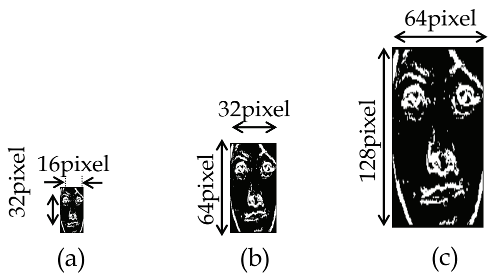


Fig. 4. Examples of database images of different sizes.(a) 32 x 16pixel, (b) 64 x 32pixel (c) 128 x 64pixel.

2.3 Experimental results

Experimental error rates of two different types of correlation methods are shown in Figure 5 and Table 1. If the intensity exceeded a threshold value, the input image would be regarded as a match with a registered person. Error rates divided by the total number of cases were given by the FRR and FAR. With the threshold value set at an optimum value (arbitrary units), the FAR and FRR are shown in Table 1. Error rates are plotted on the vertical axis and comparison values on the horizontal axis. EER has been improved by 0%.
As for the filtering correlation, EER attained the lowest value from among all the correlation methods, as shown in Figure 5 and Table 1. In a low resolution of 64x64 pixels, the EER reached 0% in the Filtering correlation only (both FRR and FAR are 0% as shown in Table 1. If the resolution is lowered to 32 pixels, the FRR becomes 100% at FAR 0%. These results indicate that the registered person cannot be recognized without accepting the others.
Because the FRR value can be improved by trying to log in as a user of the system several times, the value of the FRR at FAR 0% is important for the recognition system. Therefore, the Filtering correlation can be counted as an advantage. The Filtering correlation works effectively in the application targeted at low resolution images.

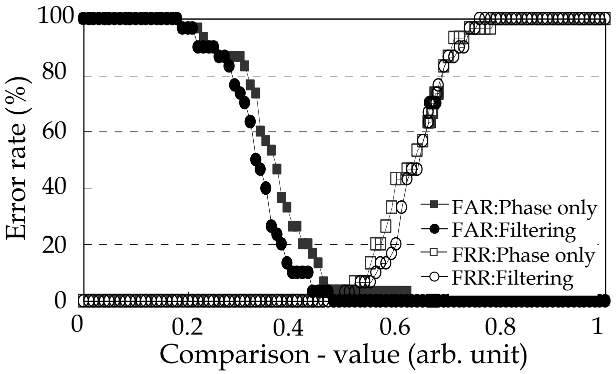


Fig. 5. Results for two kinds of correlation with 64 x 64 pixel

Image size Method	32x32(pixels)			64x64(pixels)			128x128(pixels)		
	FAR	FRR	**EER**	FAR	FRR	**EER**	FAR	FRR	**EER**
Phase-only correlation	0	100	**33**	0	46.7	**3.3**	0	3.3	**3.3**
Filtering correlation	0	100	**26**	**0**	**0**	**0**	0	0	**0**

Table 1. Experimental error rates of two different methods

3. A fast face recognition optical correlator of a much higher speed for face, image and video data using holographic optical correlator filter

This section presents a correlator of a much higher speed for face, image and video data using optical correlation. The data access rate of a conventional correlator is limited to a maximum of 1Gbps, due to the data transfer speed of the HDD used to store digital reference images. Therefore, a conventional correlator has a weakness in its image data transmission speed. Recently, a novel holographic optical storage system that utilizes co-axial holography has been demonstrated. This scheme can realize practical and small holographic optical storage systems more easily than conventional on-axis holographic optical systems. Using the ability of parallel transformation as holographic optical memory, the recognition rate can be vastly improved. In addition, the large capacity of optical storage allows us to increase the amount of data in the reference database. Preliminary correlation experiments using the holographic optical disc set-up show an excellent performance of high correlation peaks and low error rates at a multiplexing pitch of 10 μm and rotational speed of 300rpm. It is clear that the processing speed of our holographic optical calculation is remarkably high compared to the conventional digital signal processing architecture.

No storage device has yet been found, which meets both conditions, i.e. transfer speed and data capacity. DRAM has a high-speed data transfer rate, yet with a limited data capacity of up to several GB. The typical secondary storage devices include the hard disk drive, optical disc drive and magnetic tape streamer devices. HDD technology has been making significant progress in expanding data capacity. Recently, the capacity of HDD data storage has expanded to more than 1TB. However, even if a RAID system (Redundant Arrays of Inexpensive Disks) is used, the maximum transfer rate of a conventional HDD system is limited to the order of G bps. Typically, the input digital data is first transferred from HDD to the DRAM, followed by calculation of correlation. Therefore, a conventional image search correlation with large image database has a weakness in its image data transmission speed (Figure 6). It is demonstrated that the processing speed of our holographic optical calculation is remarkably higher than that of the conventional digital signal processing architecture (Figure 7).

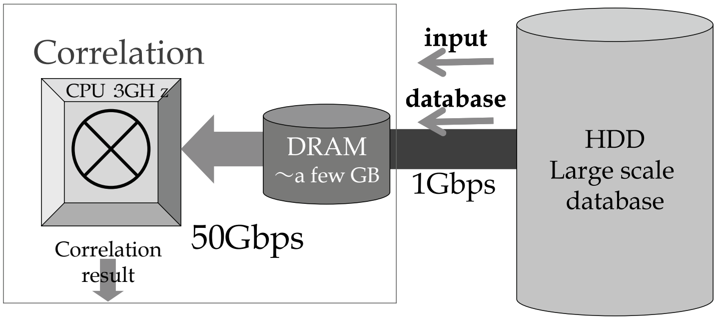


Fig. 6. Conventional search engine

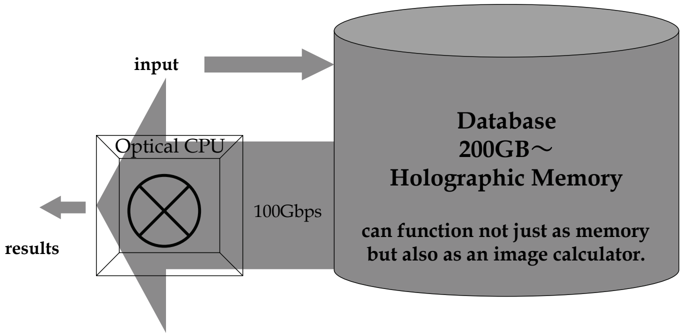


Fig. 7. Optical Correlation system

Figure 8 shows the concept of the high-speed optical correlator with a holographic optical disc. We call this system the Super Fast Recognition Optical Correlator, S-FARCO. A huge amount of data can be stored in the holographic optical disc in the form of matched filter patterns. In case the correlation process, an input image on the same position are illuminated the laser beam, the correlation signal appears through the matched filter on the output plane. The optical correlation process speeds up by simply rotating the optical disc at higher latency.

3.1 Holographic optical memory

Holographic optical memory, as the fourth-generation memory device with a large data storage capacity, has been developed with high expectations for replacing the current optical disc devices such as Blu-ray Disc and HD-DVD. Among other devices which belong to the same 'generation' (i.e. category), there are Near-field optical memory (Goto, K. 2004, Super-RENS (Tominaga et al., 2002), two-photon absorption memory (Kawata & Nakano, 2005). However, they are essentially all fit for recording two-dimensional data. Some enable

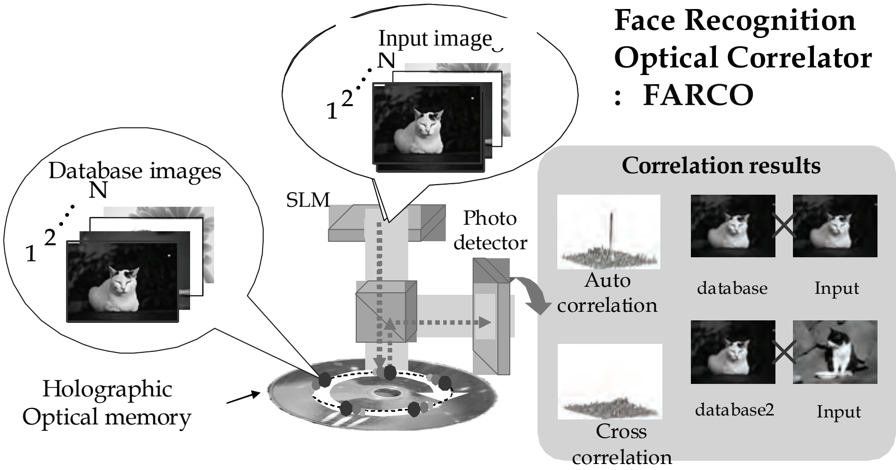


Fig. 8. Optical correlator using holographic optical disc : S-FARCO

high density by setting the recording bit below the level of the diffraction limit, while others make it possible to record data on multi-layers, holding the density constant. In contrast, holographic optical memory records data three-dimensionally across the whole recording material. The history of research into holographic optical memory dates back to 1948, one year after Dennis Gabor discovered holography (Coufal Psaltis & Sincerbox, 2000). In 1960, when holographic optical memory was first applied, combined with laser as a light source, some attention was focused on the technique of recording and reproducing wavelength. It was van Heerden who proposed holography as a memory device in 1963 (van Heerden 1963). Nevertheless, despite a rather long history in research, holographic optical memory was not applied for practical use. This could be ascribed to the fact that sufficient progress had not been made in two-dimensional image display, image pick-up devices and recording materials. In the 1990s, there were some breakthroughs in the development of PRISM (photorefractive information storage materials) and HDSS (holographic data storage system), due to the US government-funded projects (Hesselink, 2000; Orlov, 2000). In parallel with this development, holographic optical memory made progress. However, there were still a number of issues to overcome before it could be applied more widely. For instance, a large size (of space) is required for optical setup due to two interference or the difficulty in preventing deterioration of recording material quality. With this background, in 2004, a optical disc-shaped co-axial-type holographic optical memory was developed (Horimai & Tan 2005). This holographic optical memory enabled both a reference beam and object beam to be juxtaposed on the same axis, which is conducive to miniaturization. This could solve the issue of size, which was common under the two-interference system. Moreover, it is a reflecting-type optical disc memory of 12cm in diameter to which strengths in optical disc drive technique can be directly applicable. Therefore, this optical disc memory could be a promising device for the next generation.

The basic structure of the conventional optical device and co-axial holographic optical memory are shown in Figure 9(a) and (b) . Comparing these two types, it is predicted that the latter system, in which juxtaposition of reference and object beam on the same axis is possible, can be slimmed down.

The co-axial holographic optical system consists of a DMD (Digital Micro-mirror Device) as a two-dimensional spatial laser modulator, which displays two-dimensional digital data on the two-dimensional plane, and photopolymer as a recording material, a CMOS camera as a image device for reading out reproduced two-dimensional data and a lens (NA: 0.55) for image formation. Holding two beams (i.e. object and reference) on the same axis, the object light is placed at the centre of the image, while the reference light is on the outside. The beam from the DMD is passing through at the objective lens, and causes interference in the recording medium. DMD is illuminated by plane waves, its mirror focus light, which was modulated by the on/off switch into the recording material by objective lens. At the time of recording the data, both reference and signal beam are displayed. When images are reproduced, only reference image is displayed. The reproduced image becomes higher power, when it is closer to the reference image at the time of recording.

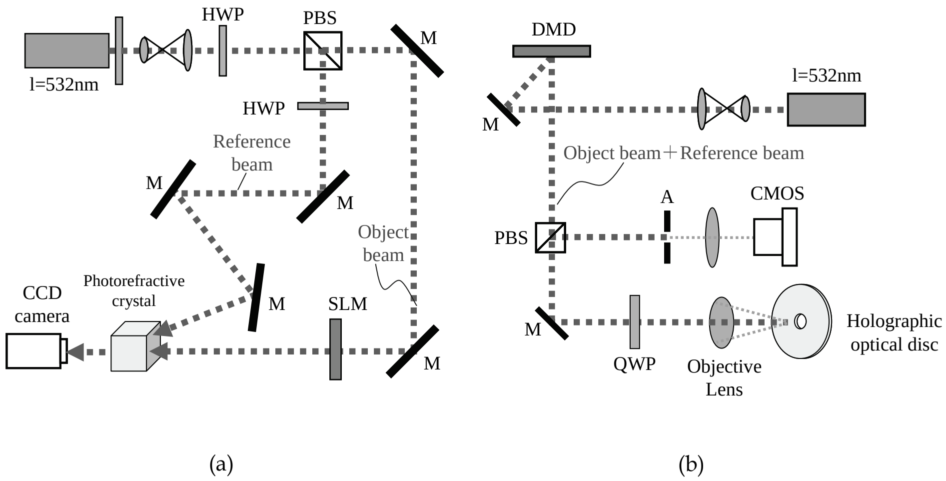


Fig. 9. (a) Two beam interference optical system, (b) Co-axial holographic optical memory system

An outline of the structure of the co-axial holographic optical memory is given in Figure 10. The recording material is sandwiched between two glasses, one coated by AL and the other by AR coated, and it is a reflection type memory. Write once photopolymer is used as a recording material. The spatial distribution is recorded through the distribution of refraction (Schilling L. M. et al. 1999 ; Sato, et al., 2006). Photopolymer is a photopolymerization monomer. At the initial stage, there are two types of monomers for maintaining the configurations: monomer 1 which photopolymerizate by corresponding to recording light and monomer 2 which does not correspond to the recording light. In proportion to the intensity of light, monomer 1 becomes polymerized, as monomer 2 gets pushed out into polymer-free space. At the stage of multiple recording, the monomer reduces in its density, and its sensitivity decreases accordingly. As all the data are recorded and the remaining monomer is completely polymerized, there will be no change even when it is illuminated by reproduced light.

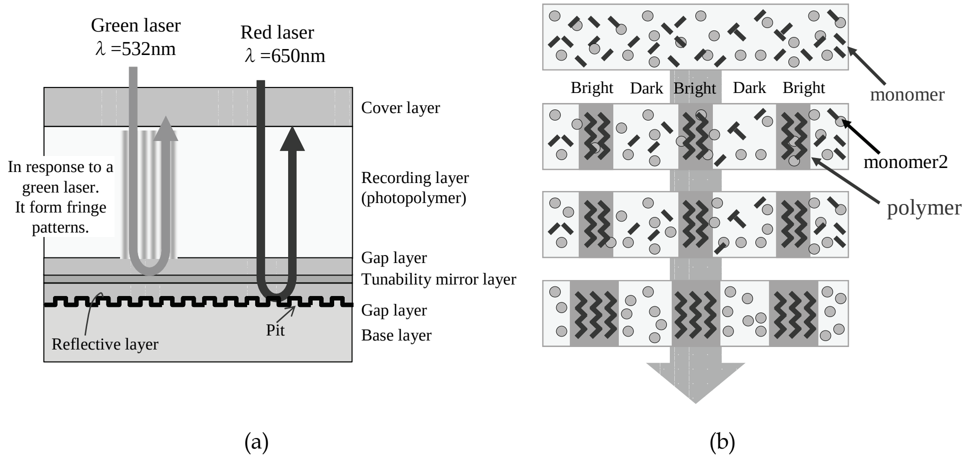


Fig. 10. The configuration of co-axial holographic optical memory and photopolymer. (a) Configuration of holographic optical memory, (b) Photopolymer curing

3.2 High speed optical correlation system

Figure 11 shows the schematic of our optical configuration, which is identical to the one used in a collinear holographic optical storage system. Note that in the collinear holographic system, the recording plane is the Fourier plane of the digital mirror device (DMD) image, as shown in the close-up part. The recorded image is composed of a reference point and the image to be recorded in the database, as shown in Figure 11 This image is Fourier transformed by the objective lens shown in Figure 11, and recorded as a hologram. This hologram works as the correlation filter. With the recorded image of one pixel as a delta function and database image, we can easily obtain the correlation filter in the co-axial holography system. Figure 11 shows the optical setup of the Fourier plane in close up.

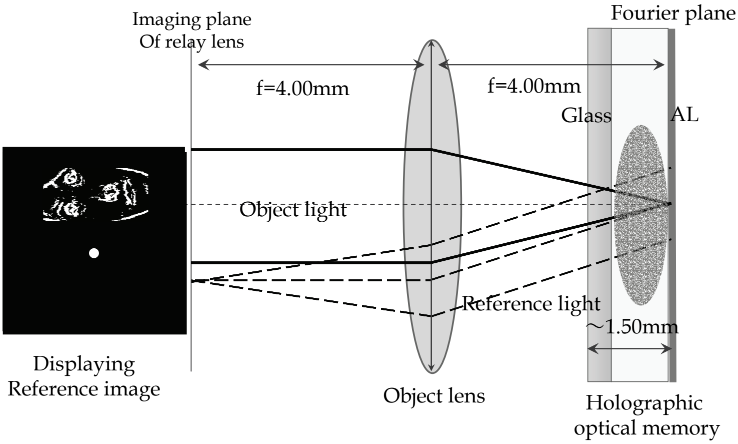


Fig. 11. The inset shows the enlarged part of the Fourier transformation part

Writing a matched filter hologram, the recording image on the DMD is Fourier-transformed by the object lens. Thus, correlation filters are implemented with ease in the co-axial holography. In the case of the correlation process, an input facial image on the same position is Fourier-transformed by the same objective lens. The correlation signal emerges on the CMOS plane.

3.3 Optical correlation using holographic optical matched filter

3.3.1 Experimental results of multiplex recording and correlation

Holographic optical memory features both high density and rapid playback. The above-mentioned co-axial holography method allows for image recoding with photopolymer (Schilling, et al. (1999) (thickness: 500μm) at multiplex recording pitch (10μm) (Figure 12) (Ichikawa Watanabe & Kodate (2006). For this experiment, correlations were further examined using facial images which were recorded in the same method (Figure 13).

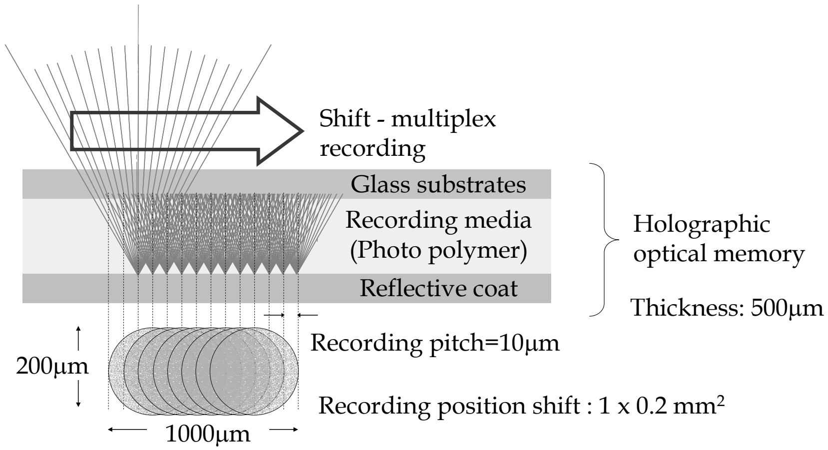


Fig. 12. Multiplex recording method

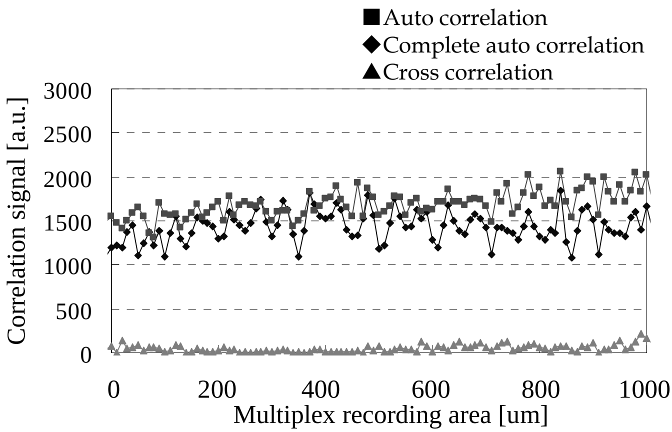


Fig. 13. Experimental results of 100 multiplex memory recording

Images shown in Figure 14 are the database and input images. Shift-multiplexing was adopted as a recoding method, while S-FARCO (wavelength: 532nm) was used as an optical set-up. The holographic optical media is composed of an AR-coated glass on the upper plane and an AL-coated glass with the photopolymer in between on the lower plane. Since the spot diameter of the laser is 200um, correlation results for 100 multiplex memory holograms can be acquired all at once on the condition that the multiplex recording pitch is 10μm. In this experiment, intensity values of correlation signals were obtained by CMOS sensor.

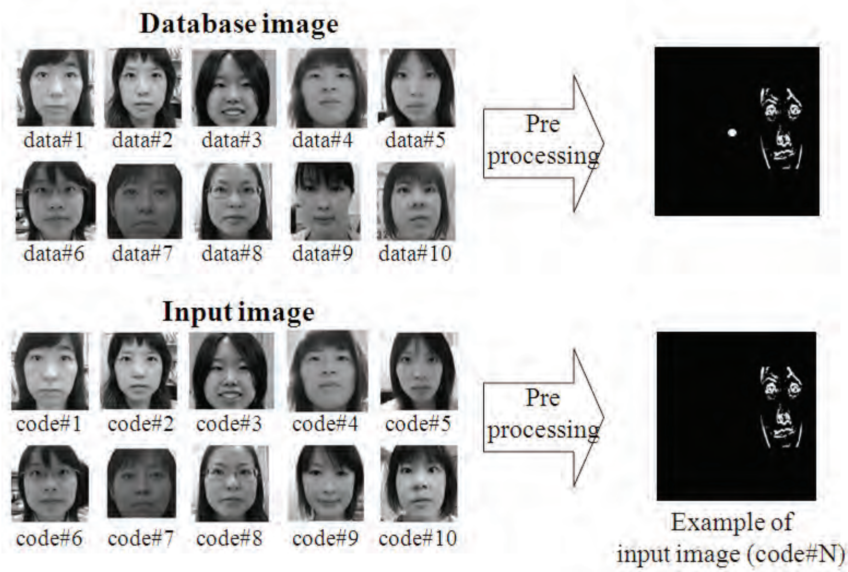


Fig. 14. Experimental samples of facial images

3.3.2 Experimental results of S-FARCO

We performed a correlation experiment under the conditions shown in Table 2. The intensities of the correlation peaks are compared with the threshold for verification. Figure 15 shows the dependences of the recognition error rates on the threshold: (a) the false-match rate, and false non- match rate and (b) the correlation between identical images. The intersection of lines (a) represents the equal error rate (EER) (when the threshold is chosen optimally), producing an EER of 0% in this experiment. An ultra high-speed system can achieve a processing speed of 5.3 μs/correlation at a multiplexing pitch of 10 micrometers and a rotational speed of 300rpm.

3.3.3 The correlation speed of a holographic optical matched filter

These preprocessed video images are recorded on a co-axial holographic optical system. The correlation speed of multiplexed recording is given by:

$$V_c = \frac{2\pi r}{d} \cdot \frac{R}{60}, \tag{3}$$

Write Mode	Laser	Q-SW
	Rotation speed	300
	Database image	30
	Input image	30
	Recorded pitch (μm)	10
	Input image size (pixels)	64 x 128
	Hologram media (μm/cm)	400 / 12
Correlation Mode	Laser	CW
	Rotation speed (rpm)	300
	Database image	30
	Detect device	PMT

Table 2. Experimental condition for holographic optical disc correlator

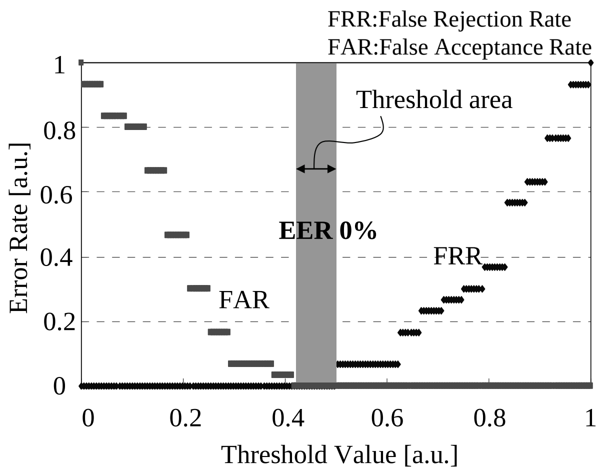


Fig. 15. Dependences of experimental recognition error rates with threshold

Multiplex recording pitch	Rotation (rpm)	Number of images for correlation per second (frames / s)	Image (320 x 240 pixels) Transfer speed (Gbps)
10μm	300	188,400	14
	600	376,800	29
	1000	628,000	48
	2000	1,256,000	96

Table 3. Correlation speed of the outermost track of an optical holographic optical disc

where r [mm], d [mm] and R [rpm] represent the diameter of the optical disc, the recording pitch and the rotating speed respectively. In a conventional correlation calculation which uses a digital computer, the data transfer and correlation calculation are achieved separately. In this system, if 240 x320 pixel information is written onto a holographic optical disc at 10 micrometer pitch and at 2,400 rpm, this is equivalent to data transfer of more than 100 G bps. An important point is that the correlation result is applied to an image of 320 x 240 bits, and the output signal of the correlation operation requires only 1.3 Mbps against the data transfer of 100 Gbps.

4. An online face recognition system

Section 4 presents an online face recognition system using the software which was constructed for the FARCO algorithm based on phase information. When FARCO software was optimized for the online environment, a low-resolution facial image size (64 x 64 pixels) was successfully implemented. An operation speed of less than 10ms was achieved using a personal computer with a CPU of 3 GHz and 2 GB memory. Furthermore, by applying eye coordinate detection in order to normalize facial images, online automatic face recognition became possible. The performance of our system was examined using 30 subjects. The experiment yielded excellent results, with low error rates, i.e. 0 % False Acceptance Rate and 0 % False Rejection Rate. Therefore, the online face recognition system proved efficient, and can be applied practically.

4.1 Application of online face recognition system

Applying the algorithm used for FARCO, a high-security online face recognition system was designed (Figure 16.). The registration process for facial images has four steps. First, an administrator informs users of the URL on which the online face recognition system is based. Then, the users access the URL. Several facial images were taken as reference images in their PCs or blogs on the internet. They were uploaded to the server together with their IDs, distributed at the time of registration in advance. Their facial images can be checked by the users themselves. A web page from an online face recognition is shown in Figure 16. (KEY images). The recognition process can be described as follows. When a facial image together with the subject's ID is inputted, the pre-processed image will be checked with the stored images in the database. The recognition result will be displayed on the webpage as in Figure 16 (Recognition result). As the system interface was designed for a web camera or surveillance camera, it can be applied widely and introduced at various places such as schools, offices and hospitals for multiple purposes.

The online face recognition system based on the algorithm for FARCO was constructed, with which a simulation was conducted (Ishikawa Watanabe & Kodate, (2007) ; Ishikawa Watanabe Ohta &Kodate, 2006). If the intensity exceeded a threshold value, the input image would be regarded as a match with a registered person. Error rates divided by the total number of cases were given by the false rejection rate (FRR) and false acceptance rate (FAR). Results demonstrated considerably low error rates: 0 % as FAR, 1.0 % as FRR and EER. However, in FARCO software, images are stored as digital data in the database such, as a hard disk drive. As a result, extra time is required for reading out data. In order to achieve high operation speeds by optical processing, it is necessary to eliminate this bottleneck.

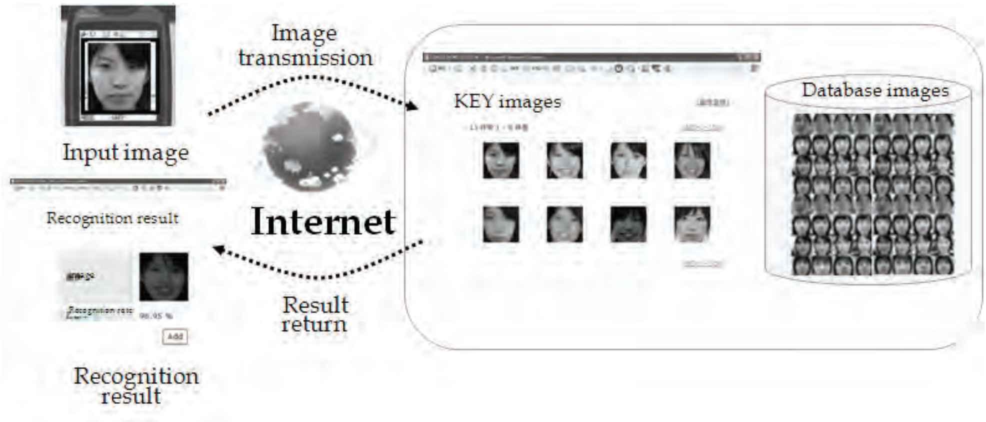


Fig. 16. Online face recognition system

4.2 Cellular phone face recognition system

Cellular phones are applied in a wide range of mobile systems, including e-mail, Internet, cameras and GPS. In this section, we propose a high-security facial recognition system with our Filtering correlation with 64x64 pixels that uses a cellular phone on a mobile network.

4.2.1 Structure of the system

A block diagram depicting the cellular phone face recognition system is shown in Figure 17. This system consists of the FARCO software for facial recognition, a control server for pre- and post-processing, and a cellular camera phone.

4.2.2 Operation of the system (Watanabe Ishikawa Ohta & Kodate, 2007)

(1) Registration

The registration process for students' facial images has four steps. Firstly, the administrator sends students the URL for i-application via e-mail. Secondly, students access the URL and download the Java application for taking input images on their own cellular phone. Thirdly, they start up the Java application and take their facial images as reference, then transmit them to the server along with their student IDs, which are issued to them beforehand. Finally, the administrator checks whether the student IDs and images in the server match, and then uploads their facial images onto the database.

(2) Recognition

The recognition process is as follows:

- Students start up the camera with the Java application and take their own facial images.
- Students transmit the image and ID (allocated at registration) back to the face image recognition server. Since the image and information are transferred on the https protocol, the privacy of the student is protected.
- In the face recognition server, the position coordinates of both eyes and nostrils are extracted from the input images. After normalization on the basis of coordinates to 128×128pixels, cutting, edge-enhancing and binarization take place.

- Subsequently, using the FARCO software, the correlation signal intensity is calculated in proportion to the resemblance of the two images.
- Using the intensity level, the system attempts to recognize the student's face based on the threshold value, which is set beforehand.
- If the student in question is recognized as a registered person, the server creates a one-time-password which will be sent with the result to the student.
- Students who acquire the password in this way can log in to the remote lecture contents server. Moreover, the face recognition server controls student registration and its database and recognition record. The Administrator can check this information through a web browser. A facial image and registration time are then recorded, which can help minimize fraud. Furthermore, images at registration can be renewed by freshly recorded images. A flow-chart of face recognition based on the Java application is shown in Figure 17.

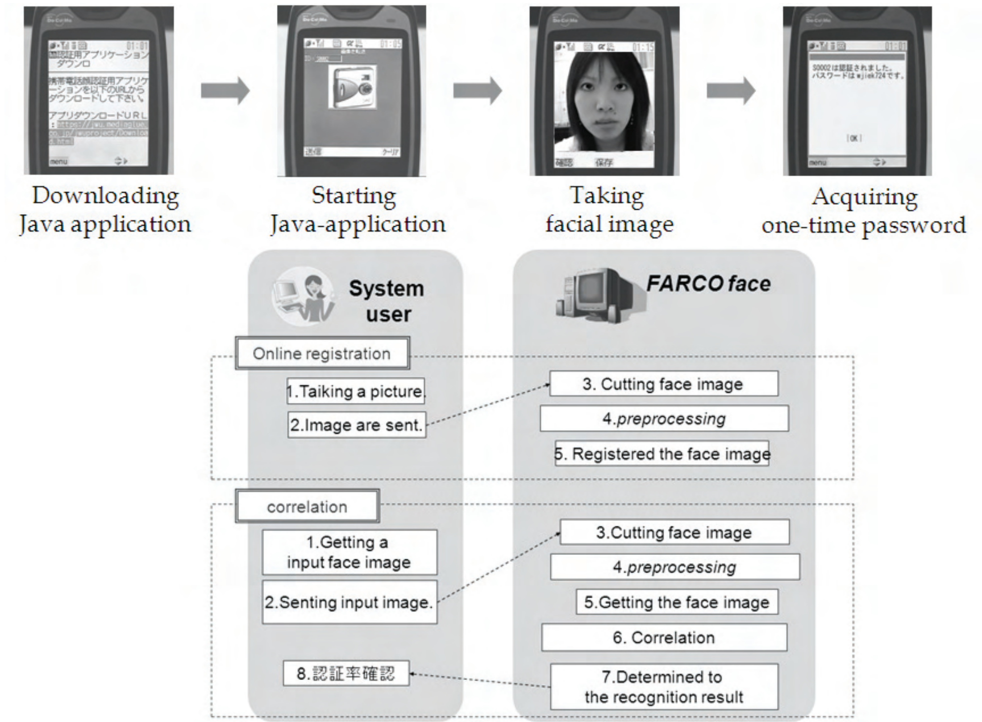


Fig. 17. A flow-chart of face recognition based on the Java application

4.2.3 Attendance management system experiment on students

Our cellular phone face recognition system was used as a lecture attendance management system, implemented 12 times on 30 students over a period of three months. The D505is and D506i (Mitsubishi Co.) were chosen from among various cellular phone types for the experiment. Students took their own facial images with the cellular phone and transmitted them to the server. Images were in the jpeg format (size 120x120pixels, 7kB).

The database images, composed of the registered 10 multiplexed images and the recognized images, were added as new database images. The experimental error rates over the duration of the three months are shown in Table 4. Results show considerably low error rates: 0 % as FAR and 2.0 % as FRR.

	First trial (%)	Second trial (%)	Third trial (%)
1st week	6.7	0	0
5th week	10.0	0	0
10th week	13.3	3.3	3.3
15th week	5.0	0	0
20th week	0	0	0
average	**9.9**	**2.9**	**2.0**

Table 4. Experimental error rates over duration of three months.

5. Various applications - video identification system -

It is widely acknowledged that current image retrieval technology is restricted to text browsing and index data searching. For unknown images and videos, the searching process can be highly complicated. As a result, the technology for this kind of image searching has not become established. In this section, we propose a video identification system using a holographic optical correlator. Taking advantage of the fast data processing capacity of FARCO, we constructed a high speed recognition system by registering the optimized video image file. Experiments on the system demonstrated that the processing speed of our holographic optical calculation is remarkably higher than that of the conventional digital signal processing architecture.

The users post the video contents to the FARCO server by the web interface as shown in Figure 18 (a). The video contents on the FARCO server are preprocessed (i.e. normalization, color information and other feature extraction) and transferred as binary data. These binary data are recorded in the form of matched filtering patterns.

With the explosion of use of video-sharing site, there is a high demand for a recognition system for moving images, working at high speed and with high accuracy. So far, the technology is restricted to text search through the tags attached to those motion images. This type of index search has weaknesses such as the difficulty in pinning down the actual content and specifying scenes, as well as the costs of creating tags for each item. In order to overcome the problems posed by these characteristics, several techniques are being actively researched and proposed. However, the ambiguity of labeling images and the sheer variety pose a number of challenges for this complex issue of differentiating the images. So far, we have developed a Fast Recognition Correlator system (FARCO) using the speed and parallelism of light. FARCO has been tested rigorously and proved its high performance. Combining this with the promising nature of the holographic optical disc, which was described above, we have proposed an all-optical ultra-fast image search engine system. The section below presents our newly developed FARCO video system with which motion images can be distinguished using our techniques applied to our face recognition.

5.1 Basic structure of the moving image recognition system and its algorithm

FARCO video system enables moving image search which is on the video-sharing site, identifying those images registered on the server.

5.1.1 Registration for moving images

- Users upload moving images that need to be singled out from the Web interface in the FARCO video.
- Those uploaded images are preprocessed, i.e. the images are frame-compressed, the color information is extracted and binarized.
- The data will be stored as basic information about the images.

5.1.2 Recognition for moving images

The recognition process is as follows:

- Users execute recognition of motion images on the web interface in FARCO video.
- By keyword search, input images have to be pinned down from the video-sharing site, and downloaded. Currently, twenty video-sharing sites are included in our data search system.
- By making the resolution level variable, quality adjustment becomes possible. Input data are preprocessed, prior to cross-comparison with registered moving images.

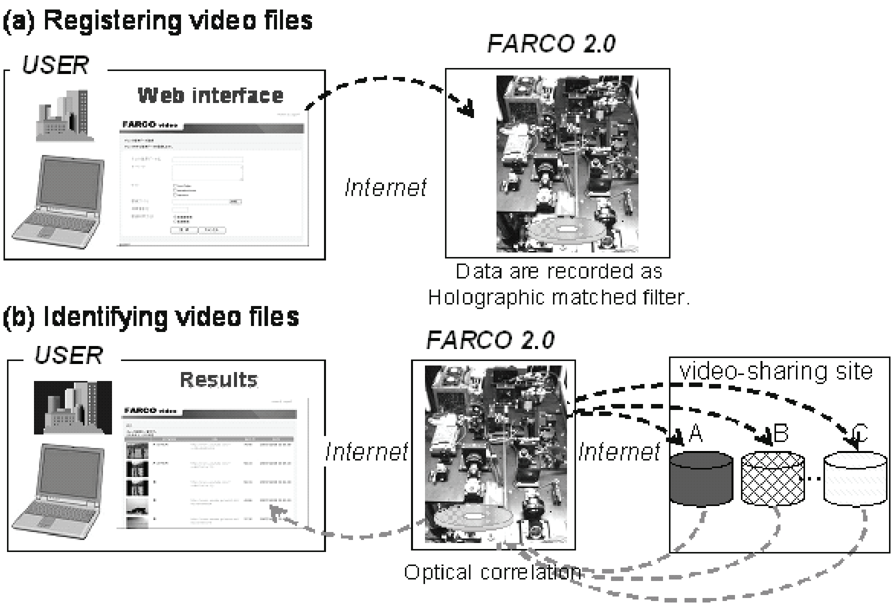
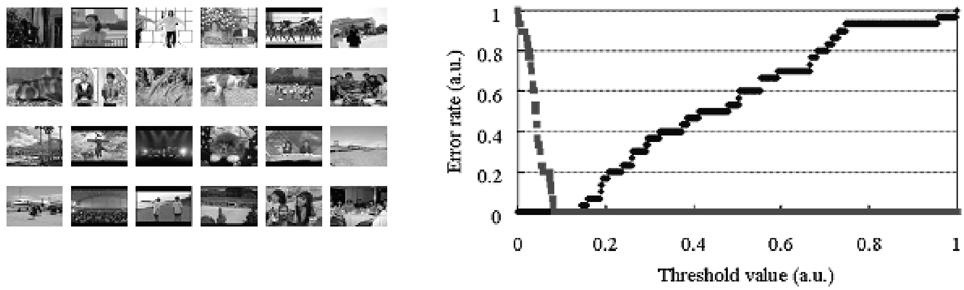


Fig. 18. The concept of video filtering system. (a) Registering video files, (b) Identifying video files

5.2 Experimental results

In our experimental system, each image file taken from DVD is registered as a video file, while the input video image file is downloaded from video sharing sites. We performed a correlation experiment using a co-axial holographic optical memory system. The example registered video image files are shown in Figure 19 (a). The intensities of the correlation peaks are compared with the threshold for verification. Figure 19. shows the dependence of the recognition error rates on the threshold: (a) false-match rate and false non-match rate and (b) the correlation between identical images. The intersection of lines (a) represents the equal error rate (EER) (when the threshold is chosen optimally), and in this experiment an EER of 0% was achieved. This ultra high-speed system can achieve a processing speed of 25 microseconds/correlation at a multiplexing pitch of 10 micron and rotational speed of 300rpm.



(a) (b)

Fig. 19. (a) Frame image examples (b) Experimental results using holographic optical matched filter

6. Conclusions

We presented an ultra high-speed optical correlation system for face recognition (S-FARCO) using holographic optical memory. By means of preliminary correlation experiments using the holographic optical disc set-up demonstration, we acquired low error rates, e.g. 0% Equal Error Rate. These are the world's first experimental results for an ultra high speed correlation system using a holographic optical disc. The S-FARCO is potentially 1000 times faster than FARCO software. We also constructed and evaluated the software correlation filter covering several hundred volunteers, demonstrating that the system is highly accurate, as facial images with low resolution (64x64 pixels) have been used successfully. Using a CPU with 3 GHz and 2 GB memory, an operation speed of less than 10ms was achieved. We obtained highly accurate experimental results and low error rates, i.e. 0 % FAR and 2.0 % FRR, using a high-security cellular phone face recognition system with our Filtering correlation. Even if the size of the image is small, an accurate result can be obtained using Filtering correlation. Therefore, Filtering correlation works effectively with web applications and face recognition using a monitoring camera. We have proposed a holographic optical video filtering system using a holographic optical correlator. Taking advantage of the fast data processing capacity of S-FARCO, we explored the possibility of realizing a high-speed recognition system by registering the optimized video image file. The results demonstrated that the processing speed of our holographic optical calculation was remarkably higher compared to the conventional digital signal processing architecture.

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