Ultrahigh-speed compact optical correlation system using holographic disc

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ABSTRACT

We have developed prototype of a compact optical correlator for video copyright protection that integrates the optical correlation technology used in FARCO (Fast Recognition Optical Correlation) and a holographic storage system. Using the ability of parallel transformation as optical holographic memory, the recognition rate can be vastly improved. In addition, large capacity of optical storage allowed us to increase the amount of reference database. Using its rapid processing capability, a robust recognition system can be constructed by registering video image data. We expect that this optical correlation system is simple and energy-saving, and provides ultrahigh speed system compared with conventional server. This system enables use of an image search system in various fields where it has not previously been possible to use such systems.

Keywords: optical correlator, holographic memory, image search engine, video filtering

1. INTRODUCTION

The volume of information we handle is dramatically increasing as a result of the change from text data to still and moving image files. It is well known that images can currently only be retrieved using text browsing and index data searching. As such, the technology for this kind of image searching has not yet been established.

In contrast to digital recognition, optical analog operations process two-dimensional images instantaneously in parallel using a lens-based Fourier transform function. In the 1960s, two methods were proposed; the Vanderlugt Correlator(1) and the Joint Transform Correlator (JTC)(2). The Optical Correlator by INO gained the New Product Award at CLEO/QELS'99. In Japan, the conventional JTC was practically implemented by Hamamatsu Photonics CO. for fingerprint image processing(3). The process speed of optical correlators has been steadily improved, but operational speed, practicality and recognition rate were not fully tested against the fast-improving digitized system.

The authors previously proposed and fabricated the Fast Face Recognition Optical Correlator based on the Vanderlugt Correlator(4), which operates at the speed of 1000 faces/s(5,6). Combined with high-speed display devices, the four-channel processing could achieve such high operational speed as 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)(7). However, the recognition time of FARCO is limited to about 1,000 frames/s due to the data transfer speed and storage capacity of the DRAM used to be store digital reference images. The time of data transfer speed is converting from the digital data to optical image data in optical system. Using the ability of parallel transformation as optical holographic memory, the recognition rate can be vastly improved. In addition, large capacity of optical storage allows us to increase the amount of reference database.

To combine the large storage capacity of an optical disk and the parallel processing capability of an optical correlator, an optical-disk-based photorefractive correlator has been developed(8,9). It can achieve a high correlation rate without the need of a fast spatial light modulator (SLM). However, the system has practical problems mainly due to its complexity. The reference beam for the read out process is separated spatially with an off-axis optical configuration: therefore the spatial fluctuation of the storage media need to be strictly controlled and a large and heavy system is necessary, which, in turn, prevents the removability and interchangeability of the media as well as the miniaturization of the system.

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Recently, a novel holographic optical storage system that utilizes co-axial holography has been demonstrated.[10] This scheme can realize practical and small holographic optical storage systems more easily than conventional off-axis holographic systems. At present, the system seems to be most promising for ultrahigh density volumetric optical storage.

Figure 1 shows the concept of the high-speed optical correlator with a holographic optical disc[11]. We call this system Fast Recognition Optical Corelator, so called 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 disc at higher latency.

We have developed a prototype of a compact optical correlator based on a holographic optical disc for the purpose of video copyright protection[12]. This system needs to satisfy two major requirements: (1) high processing speed and (2) capacity to handle a large volume. Such a system uses images taken from a live video feed, and has to perform a one-to-one (1:1) or even one-to-many (1: N) search through a large database for a match, instantaneously. The data access rate of conventional search engines is limited to a maximum 1 Gbps, owing to the data transfer speed of the hard disk drive (HDD) used to store digital reference images. Therefore, a conventional search engine has a weakness in its image data transmission speed. A simple and compact recognition system that meets the required performance, we implemented a hybrid system based on the optical recognition principle, using a Fourier transform lens.

In this paper, we present an ultra high-speed compact optical correlation system that makes use of a holographic disc. Section 1 describes our optical correlation experiments that use video images and the fast data processing capability of FARCO. Section 2 explains the database for video images and the process of constructing a high speed and robust recognition system in more detail. Section 3 presents the ultra high-speed compact optical correlation system that benefits from a holographic disc with some results from our experiments. Section 4 introduces FReCs, our video filtering software, with Section 5 concluding the paper.

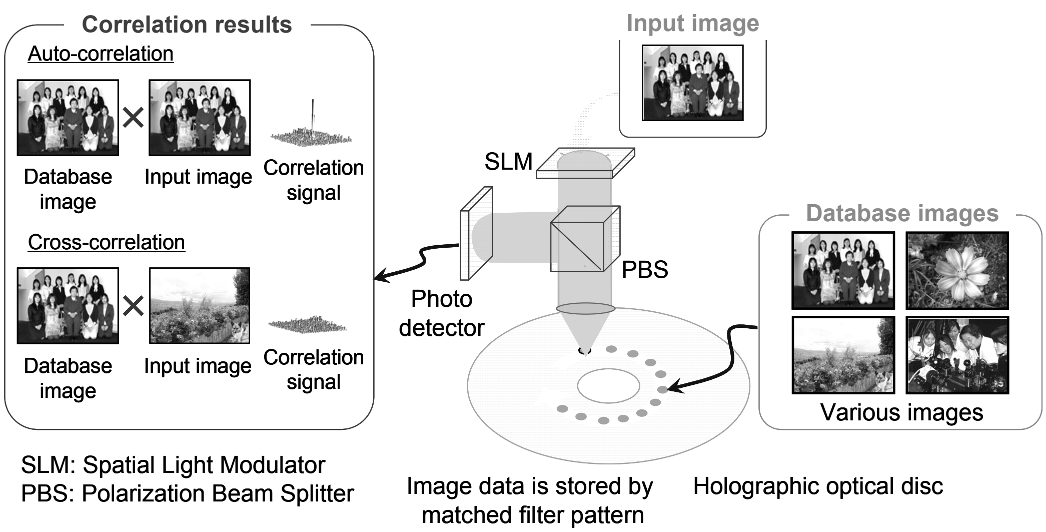
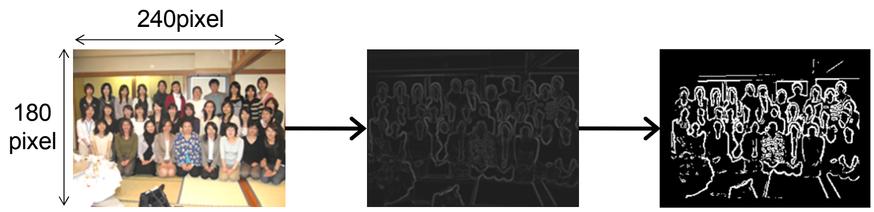


Fig.1 Concept of optical correlator based on a holographic optical disc

2. ULTRAHIGH-SPEED OPTICAL CORRELATION SYSTEM

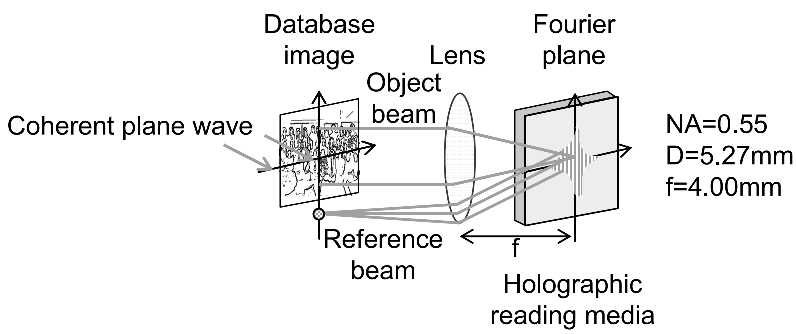
2.1 Optical correlation using holographic matched filter

Figure 1 shows the schematic of our optical configuration, which is identical to the one used in a co-axial holographic optical correlation system. Note that in the co-axial 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 Fig. 2(a). This image is Fourier transformed by the objective lens as shown in Fig. 2(b), and recorded as a hologram. This hologram works as the correlation filter. With the recorded image of one pixel as delta function and database image, we can easily obtain the correlation filter very in the co-axial holography system. Figure 2 shows the optical setup of the Fourier plane in close up. Writing a matched filter hologram, the recording image on the DMD is Fourier-transformed by the objective lens. Thus, correlation filters are implemented with ease in the co-axial holography. In the case of the correlation process, an input image on the same position is Fourier-transformed by the same objective lens. The correlation signal emerges on the CMOS plane.

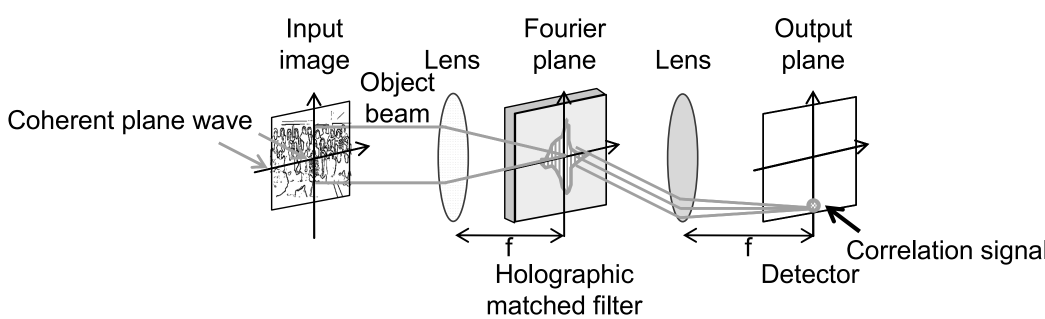


(a) Grayscale image from video (b) Edge enhancement (c) Binarization

Fig.2 Pre-processing for recording images



(a) Recording a matched filter

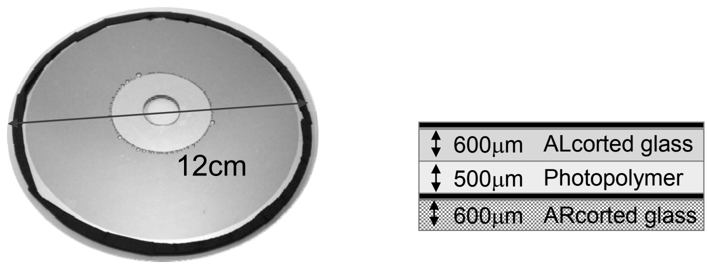


(b) Filtering (Optical correlation) Coherent plane wave lens detector (CMOS) Holographic matched filter

Fig.3 Concept for a matched filtering correlation in FARCO sysytem

2.2. Experimental results of multiplex recording and correlation using video image

Holographic optical disc features both high density and rapid playback. The above-mentioned co-axial holography method allows for image recoding with photopolymer(13) (thickness: 500μm) at multiplex recording pitch (Fig.5). For this experiment, using video images (Fig.4) recording in the same method, correlations were further examined. Images shown in Fig.2 are the database and input images. Shift-multiplexing was adopted as a recoding method. 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 laser is 200μm, correlation results for 100 multiplex memory holograms can be acquired all at once on the condition that multiplex recording pitch is 10μm. In this experiment, intensity values of correlation signals were obtained by CMOS censor.



(a) holographic optical disc (b) cross section

Fig.4 Holographic optical disc and cross section

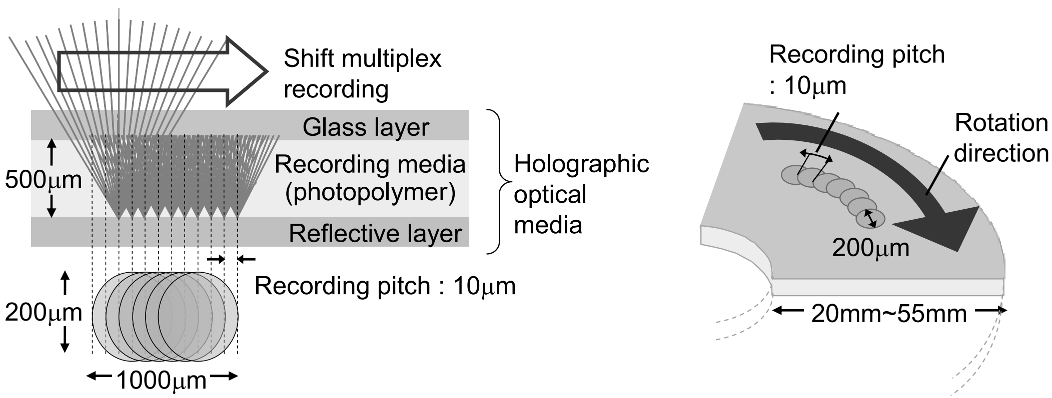


Fig.5 Multiplex recording method

3. COMPACT OPTICAL CORRELATION SYSTEM FARCO 3.0

With the holographic memory that can contain a large quantity of databases in the form of optical information, recorded information can correlate directly without decoding data. In recording, a CW laser is used for recording database holograms, and thus recording is slow and not very practical. And in correlating, when the shutter is open, the input image displayed on the DMD is correlated with the database images recorded on the holographic disc.

We performed a correlation experiment using our coded 30 images that is optional images (180 × 240 pixel) changed into the static image from 10 kinds of video with FARCO 3.0 optical set up (Fig.7). We aim FARCO 3.0 operation as system for evaluation of FARCO 2.0; it is on board CW LASER compact and cheep for searching.

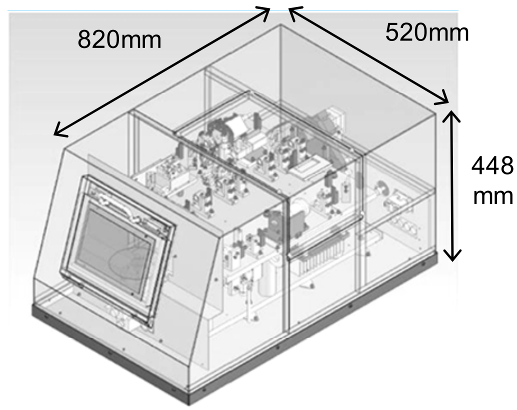


Fig.6 Concept of Compact optical correlation system (FARCO 3.0)

The image used this time is a designed optimum for optical correlation (Fig.2). We recorded images information of 30 coded images as object beam and white spot around it as reference beam to holographic disc as interference fringe. This hologram works as the correlation filter. If incidence of the same image is carried out to a reproduction picture, a high correlation value will be detected (auto-correlation). If it is different image, a correlation signal will become feeble and will serve as a low correlation value (cross-correlation). It attests by the height of this correlation value.

This time, we performed with shift multiplex recording pitch of 20 μm pitch and rotation speed of 300 rpm, and obtained high-precision result as EER (Equal Error Rate) 0.0% (Fig.8). Hereby, there is interchangeably between FARCO 3.0 and FARCO 2.0, and we obtained possibility to get same result if miniaturized system from FARCO 2.0.

The correlation speed of the outermost track in this system, if 240 × 320 pixel information is written onto a holographic disc at 10 micrometer pitch and at 2,400 rpm, this is equivalent to a data transfer rate of 100 Gbps to the CPU. An important point is that the correlation result is applied to an image of 240 × 320 bits, and the output signal of the correlation operation is only 1.3 Mbps against the data transfer of 100 Gbps. In these assumptions, optical correlation system can be innovative correlation engine.

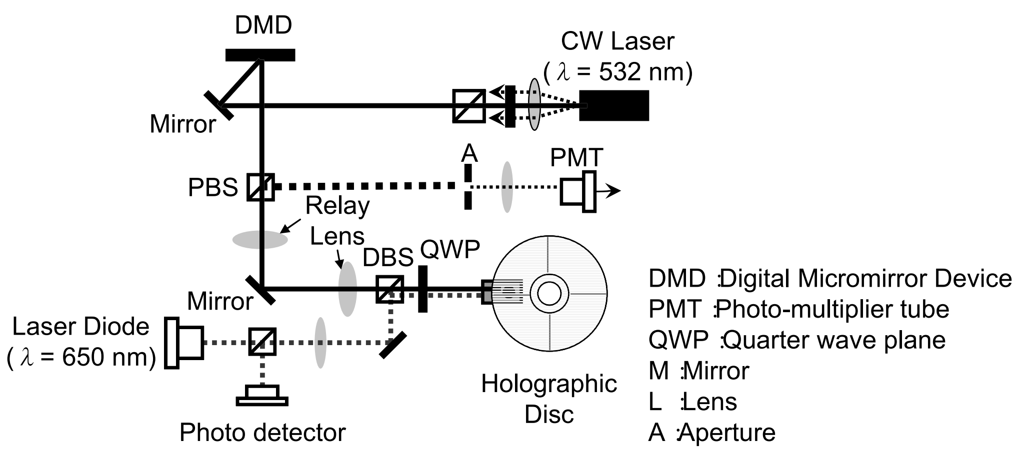


Fig.7 Optical retrieval configuration of FARCO 3.0

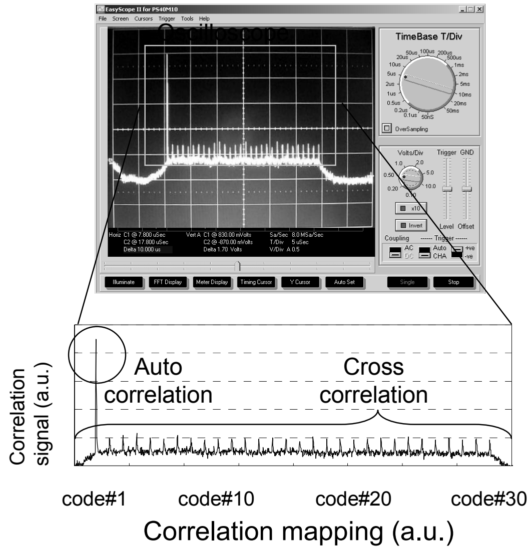


Fig.8 Experimental results of optical correlation mapping

Table1. Specifications of FARCO 3.0

Size	W 520 mm×D 820 mm ×H 448 mm
Laser (search)	CW (J200GS), λ = 532 nm, 5mW
Laser (Focus)	LD, λ = 650 nm
Indication device	DMD (Digital Micromirror Device) Pixel size:13.6 μm
Photo detector	Photo-multiplier tube
Object of search	Various binary page data

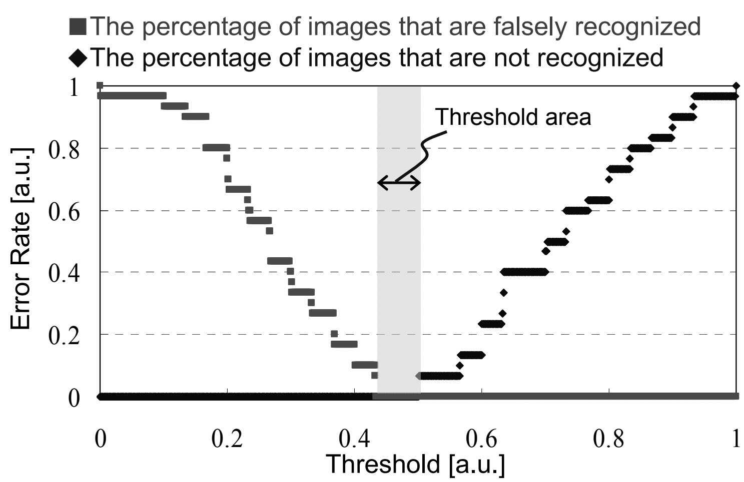


Fig.9 Error rate using 30 coded video images

4. "FReCs" VIDEO FILTERING SOFTWARE

We expect that there are various applications for the FARCO system, including the face recognition systems, data search engines, monitoring systems, and image search engines. Among other systems, we are developing the copyrighted video management system, called FReCs, as a future application of the FARCO system. FReCs currently does not use optical correlation but a software algorithm based on the recognition principle of FARCO. FReCs is now up and running for practical use. A brief summary of how the system works is given below.

FReCs has already been used by more than ten copyright holders and TV stations as part of the copyright management system. This system is currently operated by Photonic System Solutions Incorporated; a venture company spun off from Japan Women's University.

Figure 10 presents a flow chart of the copyright management procedure using FReCs. Firstly, the copyright holder delivers their proprietary data to the PSS office. Secondly, the PSS operator registers their data with FReCs. Thirdly, FReCs automatically patrols video-sharing sites on the net to detect the online contents that violate copyright. Fourthly, FReCs reports to the copyright holder any online content that violates copyright. Finally, when infringements are detected, the copyright holder can send e-mails to request removal of the content using FReCs's web interface. The recognition speed of FARCO is about 1000 times faster than that of the current FReCs. We plan to transfer the technologies of the FARCO optical correlator to FReCs to improve its performance.

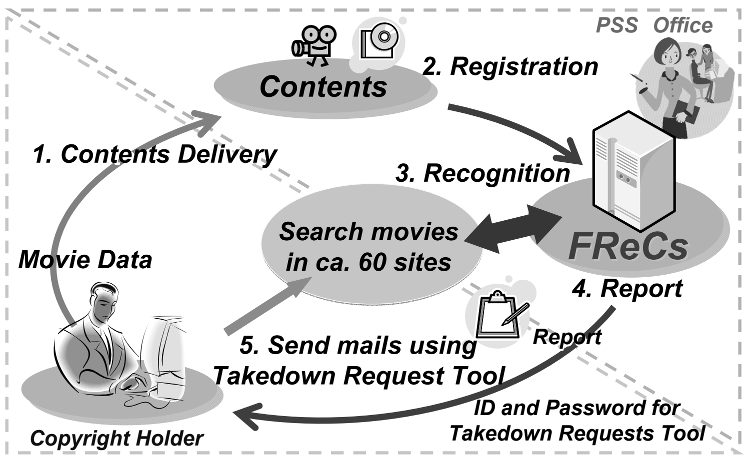


Fig.10 Flow chart of copyright management procedure using FReCs

5. CONCLUSIONS

In this paper, we have addressed three issues: (1) an ultra high speed optical correlation system using holographic memory has been constructed, (2) test and assessment results of video database using the algorithm of FARCO system, (3) description of FARCO 3.0, which is intended to be a portable, compact, high-speed image correlation engine by restricting its main function to read-only. We expect that an optical correlation of 20ms/frame is achievable, assuming that 12,000 pages of hologram are recorded in one track on the disc rotating at 1,000 rpm. This system can also be applied to various search engine systems.

Currently, research and development of video filtering is under way. Based on the original algorithm, we constructed a copyright-management system for videos named FReCs on software. This system is already being used by more than ten copyright holders and TV stations in Japan. We plan to introduce the technologies of Optical correlator FARCO to FReCs to improve its performance.

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