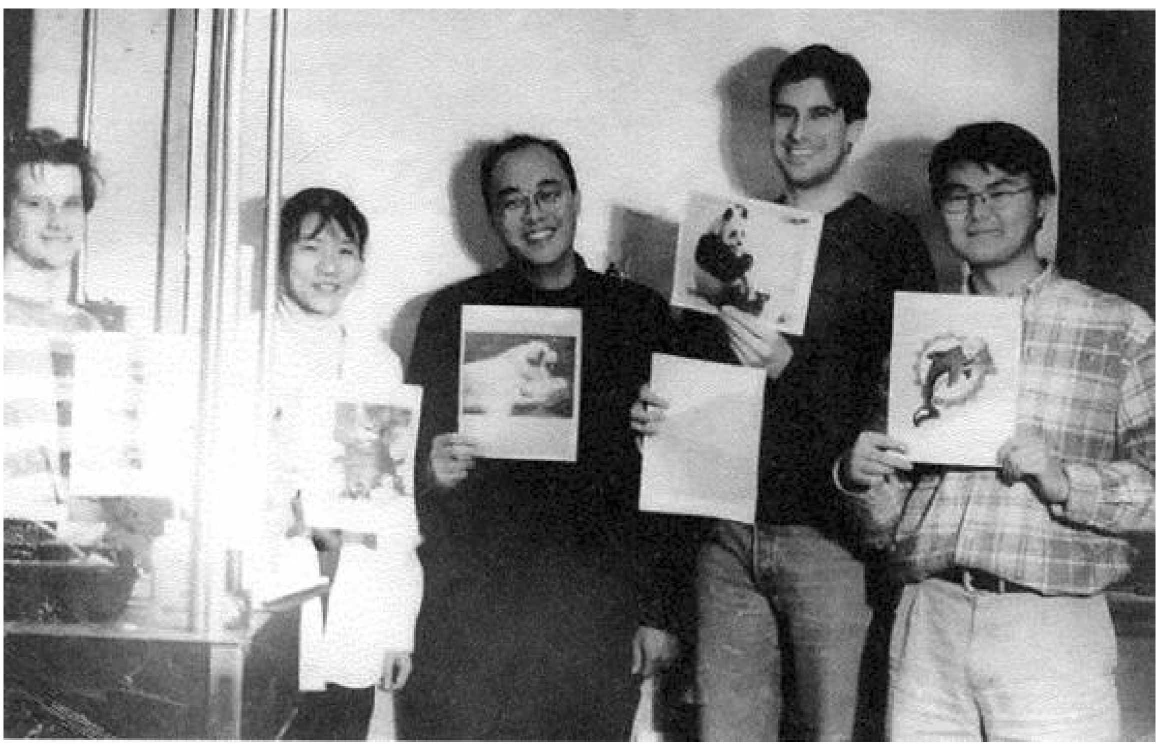
ECE1640H

Advanced Labs for Special Topics in Photonics

LABORATORY
INSTRUCTION NOTES

OPTICAL IMAGE PROCCESSING



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Revised April 2003

Fingerprint Identification by the Joint Transform Correlator (JTC)

Purpose

The purpose of this experiment is to become familiar with the method of the Joint Transform Correlator (JTC), which is considered one of the most popular types of optical correlators. Optical correlators have been used for identifying facial appearance, fingerprints, handwriting, and characters. JTC was first proposed by Weaver and Goodman in 1966. In this experiment, you will learn to interrogate fingerprints using the JTC.

Preparation

Read the following references to familiarize yourself with how images are interrogated using the JTC. Note the advantages and disadvantages, especially when compared with the Vander Lugt Correlator.

1. Keigo Iizuka, *Elements of Photonics*, Vol. 1, Chapter 1, “Fourier optics: concepts and applications,” pp. 64-81, 2002.
2. Bahram Javidi, “Optical information processing for encryption and security systems,” *Optics and Photonics News*, pp. 29-33, March 1997.
3. Bahram Javidi, “Optical pattern recognition for validation and security verification,” *Optical Engineering*, **33**(6) pp. 1752-1756, 1994.
4. Kenneth H. Fielding, Joseph L. Horner, and Charles K. Makekau, “Optical fingerprint identification by binary joint transform correlation,” *Optical Engineering*, **30**(12) pp. 1958-1961, 1991.

Experimental Procedure

1. Preparation of the input film

Using 35mm black and white film, photograph pictures of two fingerprints arranged side by side. The input film $t_s(x_1, y_1)$ is made by photographing a pair of the same fingerprints, such as those shown in Fig. 1(a). The input film $t_d(x_1, y_1)$ is made by photographing a pair of different fingerprints, such as those shown in Fig. 1(b).

(a) Same fingerprints side by side for film $t_s(x_1, y_1)$.

(b) Different fingerprints side by side for film $t_d(x_1, y_1)$.

Fig. 1. Objects for film $t_s(x_1, y_1)$ and $t_d(x_1, y_1)$.

The purpose of this experiment is to demonstrate that the correlation peaks appear when the film $t_s(x_1, y_1)$ is used as the input image, whereas the correlation peaks disappear when the film $t_s(x_1, y_1)$ is replaced by the film $t_d(x_1, y_1)$.

Question 1: What are the necessary considerations about the choice of a reduction ratio when the input film is photographed? If the image on the input film is too large, the period of the sinusoidal pattern expected to appear when it is Fourier transformed in Operation I becomes too fine to be recorded. On the other hand, if the image on the input film is too small, the size of the film emulsion grains become comparable to the size of the recorded image and the system becomes too noisy.

2. Operation I: Fourier transform of the input image

If the transmission pattern of only one fingerprint is represented by g(x), that of two identical fingerprints is represented by

$$t(x) = g(x-a) + g(x+a) \tag{1}$$

where $2a$ is the spacing between the two identical fingerprints. Operation I generates the *intensity* pattern $|T(f_x)|^2$ of the Fourier transform of Eq. (1):

$$|T(f_x)|^2 = 2|G(f_x)|^2 (1 + \cos 4\pi a f_x) \tag{2}$$

Thus, the Fourier transform of the identical fingerprints generates a sinusoidal pattern on the output of Operation I. The spatial frequency of the sinusoidal pattern is determined $2a$. It is important to realize that the sinusoidal modulation appears only when the two fingerprints on the input film are identical. This is precisely the principle of operation of the JTC method for verifying the identity of the two input images.

Operation II is nothing but a means to easily detect the presence of the sinusoidal modulation.

There is more than one configuration for constructing an arrangement for Operation I. At least three possible configurations using a convex lens are found in Chapter 1 of *Elements of Photonics* (see Figs. 1.23, 1.24, and 1.25 in *Elements of Photonics).* We are going to choose the configuration shown in Fig. 1.25 of *Elements of Photonics* for Operation I. For convenience, this arrangement is also shown in Fig. 2(a) of these laboratory instruction notes.

Question 2: Why is the configuration in Fig. 1.25 more appropriate than Fig 1.23 or 1.24?

Question 3: The configuration in Fig. 1.25 generates an unwanted quadratic factor. Will this factor interfere with the results we are looking for? If not, why not?

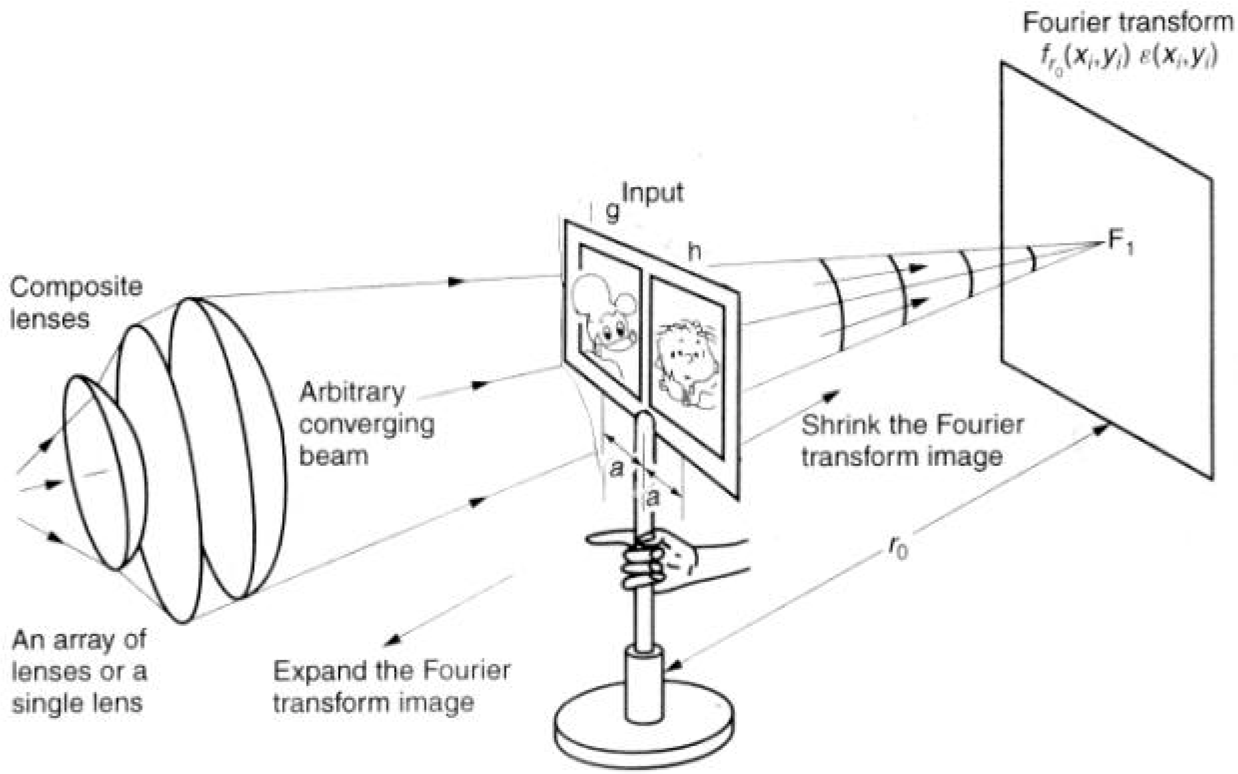

Fig. 2(a). Joint transform correlator (JTC). Operation I: Fabrication of film $t(x_2, y_2)$

Now let us insert the film $t_s(x_1, y_1)$ into the system shown in Fig. 2(a) of these laboratory instruction notes for Operation I. Project the output image onto the white wall of the laboratory. Keep adjusting the positions of the lenses until a sinusoidal pattern becomes visually observable. By photographing this projected image with 35 mm black and white film, the Fourier transform $t(x_2, y_2)$ is made. Film $t(x_2, y_2)$ will be used as the input for the next operation of the second Fourier transform.

Question 4: What is the appropriate photographic reduction ratio when making $t(x_2, y_2)$ out of the sinusoidal pattern projected on the laboratory wall? Think now about the consequence in the second Fourier transform in the next operation. Good experimentalists always think ahead.

3. Operation II: Display of the correlation

Figure 2(b) shows the setup for the second Fourier transform to generate the correlation peaks. Fig. 2(b) is similar to the configuration shown in Fig. 1.24 of *Elements of Photonics*.

Question 5: As a matter of fact, we could have used a configuration similar to Fig. 2(a) again. In what cases should the arrangement shown in Fig. 2(b) be used instead of that in Fig. 2(a) for the Fourier transforming operation?

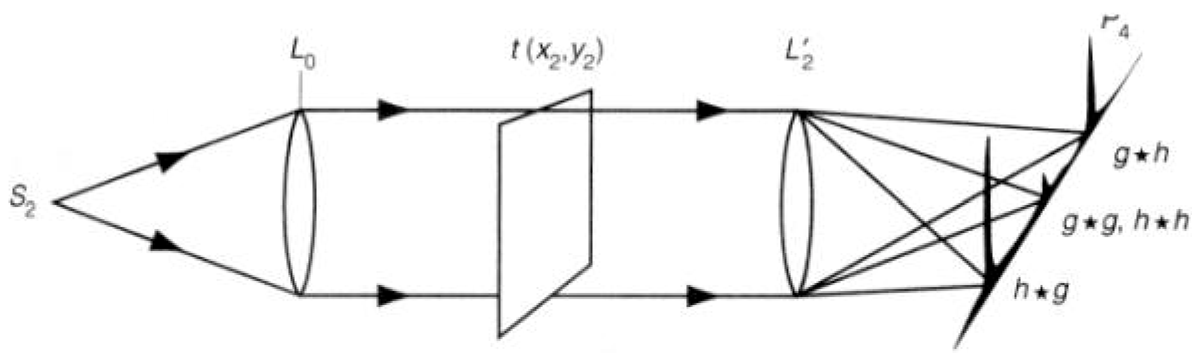

Fig. 2(b). Joint transform correlator (JTC). Operation II: Display of the correlation.

Repeat Operations I and II, this time using the input film $t_d(x_1, y_1)$ with the different fingerprints. Verify that the correlation peaks are no longer observable.

4. Determination of the signal to noise ratio (S/N)

By moving a photodetector along a line connecting the two correlation peaks, determine the S/N of such a system.

Question 6: Make suggestions on how to improve the S/N of the system.

Question 7: Discuss the practical aspects of the JTC compared to the Vander Lugt correlator.

An intuitive explanation of the principle of the JTC

What is peculiar about identical pictures side by side? The peculiarity is that every point on one picture has its corresponding point on the other picture. Every point makes a pair of two points. Moreover, the spacing of each pair are all the same and are *2a* as illustrated by Fig. 3.

The pictures in Fig. 3 can be considered to have been made out of an ensemble of two-point pairs whose center is almost randomly translated in the *x* direction.

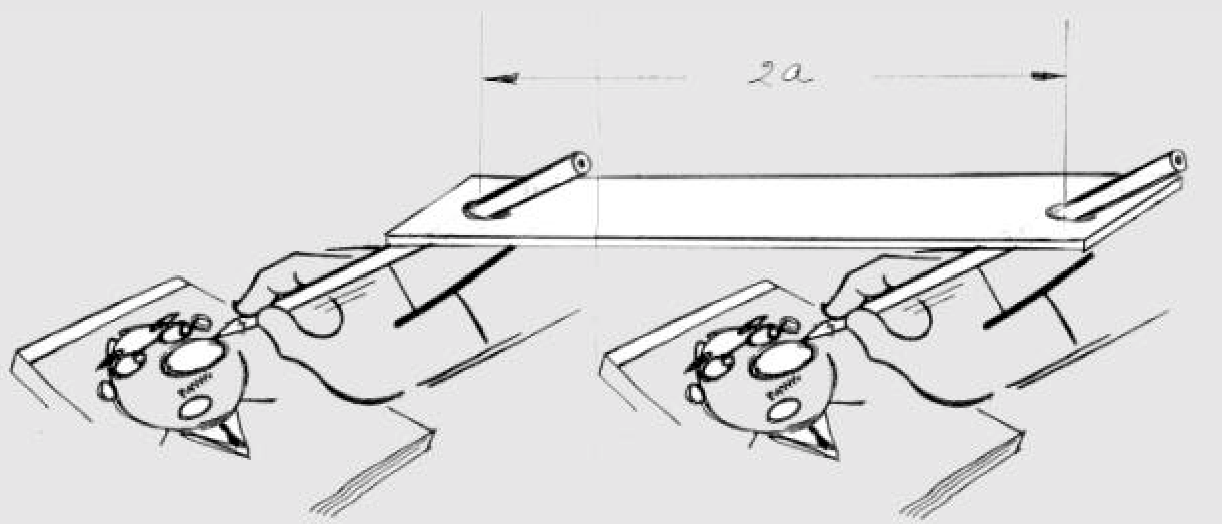

Fig. 3. Locking the pencils together makes two identical figures.

Recall that as far as the intensity pattern is concerned, the Fourier transform pattern of a random array of similar apertures is identical with that of the *single aperture* (see p. 36 in *Elements of Photonics*). The intensity pattern $|T(f_x)|^2$ of the Fourier transform of a single aperture (in this case the two-point pair) is

$$|T(f_x)|^2 = |\mathcal{F}(\delta\,(x - a) + |\delta\,(x + a))|^2 = 2(1 + \cos 4\pi\, f_x\, a)$$

Thus, the output pattern of Operation I of the JTC in Fig. 2(a) is sinusoidal in amplitude in the x direction and the spatial frequency of the sinusoidal modulation is determined by the spacing *2a*.

If this sinusoidal pattern is Fourier transformed in Operation II of the JTC in Fig. 2(b), the output will be two peaks, one on each side of the 0^{th} order peak.

Now let us consider the case when the two pictures are not identical. The number of perfect two-point pairs would become scarce, and the output pattern from Operation I of the JTC in Fig. 2(a) is no longer sinusoidal. Consequently, no correlation peaks would appear in Operation II of the JTC in Fig. 2(b).

It should be noted that the function of Operation II is merely to identify the presence of the sinusoidal pattern in the output of Operation I.

Question 8: Would it be possible by using the JTC to interrogate multiple input pictures arranged in such a manner as shown in Fig. 4?

Fig. 4. The wanted man is shown on the top left. Is it possible to find the wanted man hiding himself among the right four figures by using the JTC?