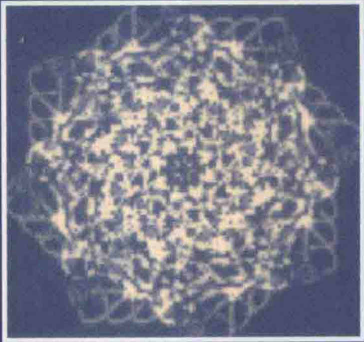
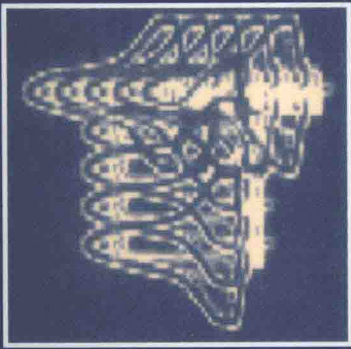
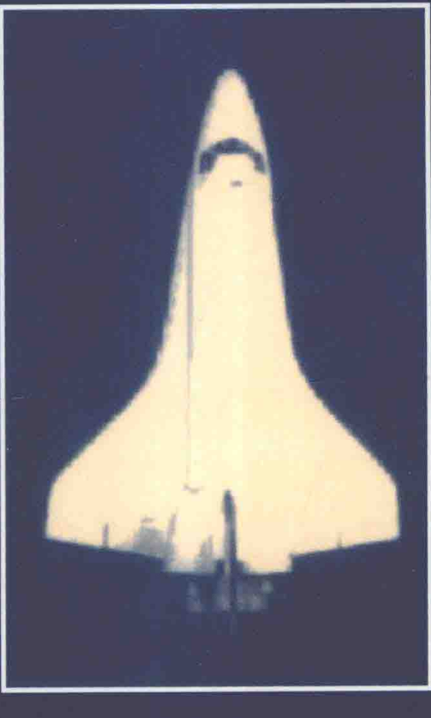
OPTICAL PATTERN RECOGNITION







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Preface

Smart automatic machines that may reduce our working load and minimize risk in work have been sought for a long time. This suggests supplementing rather than supplanting, and extending rather than denying, our human capabilities to work. To be smart, the machine must understand a scene as a human does. In other words, the machine must be able to recognize the scene by comparing the present scene and the past scenes. The machine operates based more on the scene it views, and it is less controlled by a set of thousands of instructions. For these smart machines, a picture is, indeed, worth a thousand words. Pattern recognition is the primary task of any smart automatic machine. Because the pattern to be recognized is often received optically, it is perhaps most natural and straightforward to recognize an optical pattern by using optics. This book reviews in depth the recent progress in optical pattern recognition, although no attempt has been made to give an encyclopedic presentation.

The book was designed to incorporate multiple facets and approaches essential for today's optical pattern recognition research enterprise to proceed. To this end, we have brought together leading researchers worldwide, all focusing their efforts on selected aspects of optical pattern recognition issues in 15 chapters. The first chapter overviews pattern recognition that is performed mainly with an optical correlator. The following four chapters describe new approaches to optical pattern recognition: neural networks, wavelet transform, fractional Fourier transform, and mathematical morphology. Nonlinear methods are discussed in the following three chapters. One method employs a nonlinear device in a Fourier plane. The other two methods apply nonlinear-quadratic and composite filters, respectively. These nonlinear filters are implemented in a conventional linear optical system. The next two chapters describe optoelectronic hybrid systems that use an optical system and a digital computer in recognizing an input pattern. The remaining five chapters present devices and materials used in an optical pattern recognition system: photorefractive crystals, microlasers, bacteriorhodopsin, liquid-crystal spatial light modulators, and complex-function spatial light modulators.

We thank all the authors for their excellent contributions, and we are honored to have had an opportunity to work with them. It is early yet to estimate the magnitude of the contribution optical pattern recognition will make to the extension of human capabilities and the corresponding convenience in human life, and it would be more than a little reckless to rank it now along with optical disk and fiber communication. But the contribution will be in that class and will indeed be profound.

Francis T. S. Yu
Suganda Jutamulia

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Pattern recognition with optics

Francis T. S. Yu and Don A. Gregory

1.1 Introduction

The roots of optical pattern recognition can be traced back to Abbé's work in 1873 [1], when he developed a method that led to the discovery of spatial filtering to improve the resolution of microscopes. However, optical pattern recognition was not actually appreciated until the complex spatial filtering work of VanderLugt in 1964 [2]. Since then, techniques, architectures, and algorithms have been developed to construct efficient optical correlators for pattern recognition application.

Our objective in this chapter is to discuss the optical architectures and techniques as applied to recent advances in pattern recognition. Basically there are two approaches in the optical implementation of pattern recognition, namely, the correlation approach and the neural net approach. In the correlation approach, there are two frequently used architectures: the VanderLugt correlator (VLC) and the joint transform correlator (JTC). The first JTC architecture was demonstrated by Weaver and Goodman in 1966 [3] and independently by Rau [4]. Because of a lack of interface devices, the JTC was virtually stagnant until 1984, when a real-time programmable JTC was reported by Yu and Lu [5]. Since then the JTC has assumed a major role in various processing applications.

Aside from correlation applications to pattern recognition, artificial neural networks (NN's) are also well suited. The first optical NN is attributed to Psaltis and Farhat in 1985 [6], who showed that pattern retrieval can be achieved with a lenslet array interconnection network.

In this chapter, advances in this rapidly growing field are reviewed and the basic optical architectures and techniques addressed. The pros and cons of each approach are discussed. Because of recent technical advances in interface devices [such as electronically addressable spatial light modulators (SLM's), nonlinear optical devices, etc.], new philosophies and new algorithms have been developed for the design of better pattern recognition systems.

1.2 Optical correlators

The optical implementation of pattern recognition can be accomplished with either Fourier-domain complex matched filtering or spatial-domain filtering. Correlators that use Fourier-domain matched filtering are commonly known as VLC's [2], and an example of spatial-domain filtering is the JTC [3–5]. The basic distinctions between them are that the VLC depends on Fourier-domain spatial filter synthesis (e.g., Fourier hologram), whereas the JTC depends on spatial-domain (impulse-response) filter synthesis. In other words,

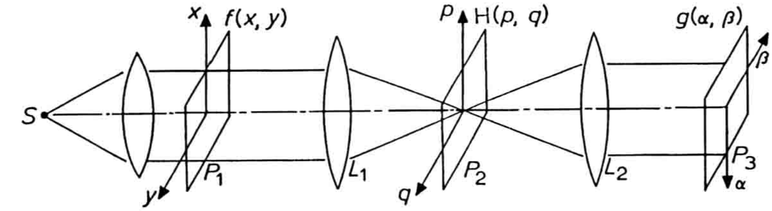

Fig. 1.1. VLC.

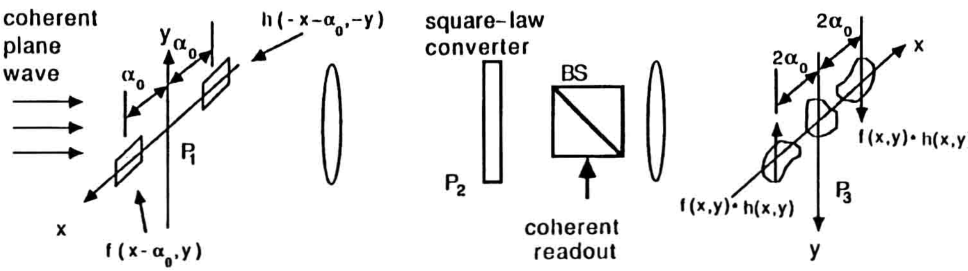

Fig. 1.2. JTC.

the complex spatial detection of the VanderLugt arrangement is input scene *independent*, whereas the joint transform method is input scene *dependent* [7]. The basic optical setups of these two types of correlator are depicted in Figs. 1.1 and 1.2. A prefabricated Fourier-domain matched filter $H(p, q)$ is needed in the VLC, whereas a matched filter is not required in the JTC but a spatial-domain impulse response $h(x, y)$ is needed. Although the JTC avoids spatial filter synthesis problems, it generally suffers lower detection efficiency, particularly when applied to multitarget recognition or targets embedded in intense background noise [8]. Nonetheless, the JTC has many merits, particularly when interfaced with electronically addressable SLM's.

The JTC has other advantages, such as higher space–bandwidth products, lower carrier frequency, higher index modulation, and suitability for real-time implementation. Disadvantages include inefficient use of illuminating light, a large transform lens, stringent spatial coherence requirements, and the overall small size of the joint transform spectrum. A quasi-Fourier-transform JTC (QFJTC) that can alleviate some of these limitations is shown in Fig. 1.3 [9, 10]. The depth of focus is given by [10]

$$\delta \leq 2\lambda(f/b)^2. \tag{1.1}$$

To illustrate the shift-invariant property of the QFJTC, an input object such as that shown in Fig. 1.4(a) is used. The joint transform power spectrum (JTPS) is recorded as a photographic transparency, which could be thought of as a joint transform hologram (JTH). When the recorded JTH is simply illuminated with coherent light, the cross-correlation distribution can be viewed in the ouput plane [shown in Fig. 1.4(b)], where autocorrelation peaks indicating the location of the input character, G, are detected.

Representative experimental results were obtained with the QFJTC with the input object and the reference functions of Fig. 1.5(a). Three JTHs – for $\delta = 0$, $\delta = f/10 = 50$ mm, and $\delta = f/5 = 100$ mm – are shown in Fig. 1.5(b), which shows that the size of the JTPS enlarges as δ increases. Figure 1.6 illustrates that the correlation peak intensity increases as δ

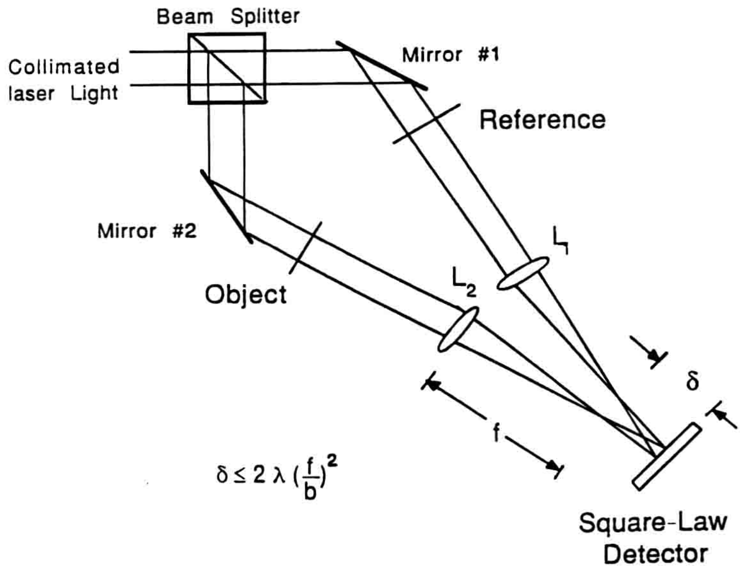

Fig. 1.3. QFJTC.

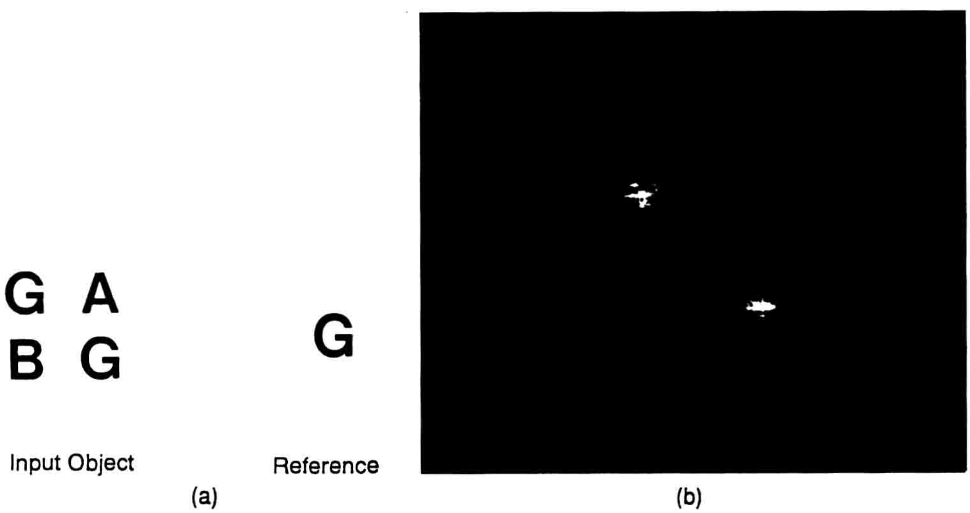

Fig. 1.4. (a) Input object and reference function, (b) output correlator distribution.

increases, whereas the size of the correlation spot decreases as δ increases. Thus the QFJTC architecture can improve the signal-to-noise ratio (SNR) and the accuracy of detection.

1.3 Hybrid optical correlators

It is apparent that a purely optical correlator has drawbacks that make certain tasks difficult or impossible to perform. The first problem is that optical systems are difficult to program, in the sense of programming general-purpose digital–electronic computers. A purely optical system can be designed to perform specific tasks (analogous to a hard-wired electronic computer), but it cannot be used when more flexibility is required. A second problem is that