1998

A fingerprint identification system using an optical spatial light modulator (SLM)

Tom M. Corboline
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

---

Recommended Citation

Corboline, Tom M., "A fingerprint identification system using an optical spatial light modulator (SLM)" (1998). *Master's Theses*. 1625.
DOI: <https://doi.org/10.31979/etd.sme6-fdmr>
https://scholarworks.sjsu.edu/etd_theses/1625

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

A FINGERPRINT IDENTIFICATION SYSTEM USING AN OPTICAL SPATIAL LIGHT MODULATOR (SLM)

A Thesis

Presented to

The Faculty of the Department of Physics

San Jose' State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Tom M. Corboline

May 1998

UMI Number: 1389636

**Copyright 1998 by
Corboline, Tom M.**

All rights reserved.

**UMI Microform 1389636
Copyright 1998, by UMI Company. All rights reserved.**

**This microform edition is protected against unauthorized
copying under Title 17, United States Code.**

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

© 1998

TOM M. CORBOLINE

ALL RIGHTS RESERVED

APPROVED FOR THE DEPARTMENT OF PHYSICS

_____

Dr. Ramen Bahuguna

_____

Dr. Gareth Williams

_____

Dr. Joseph F. Becker

APPROVED FOR THE UNIVERSITY

_____

ABSTRACT

A FINGERPRINT IDENTIFICATION SYSTEM USING AN OPTICAL SPATIAL LIGHT MODULATOR (SLM)

by Tom M. Corboline

This thesis addresses the topic of matched filtering with the aid of a Spatial Light Modulator (SLM). A fingerprint identification system was built using an optical Spatial Light Modulator. The fingerprint is sensed by a holographic prism sensor which gives a high resolution image with an aspect ratio of unity. A US patent has been awarded for the fingerprint sensor. (Patent # 5,629,764 May 13, 1997).

Acknowledgments

This project was both exciting and interesting. I am glad that I was given the chance to work on this project. I learned a great deal working with Dr. Bahuguna and I would like to thank him for being my thesis advisor. He is a true experimentalist and it was a pleasure working with him in the lab.

A big thanks goes to Bruce Pastorius, President of Advanced Precision Technology, for funding this project. His vision is to lead the industry in biometric security devices. Because of this he funded this project which lead to the invention of a fingerprint sensor that is the best in the industry at the present time.

I will utilize the experience that I gained when I move into the industry.

CONTENTS

	Page
Acknowledgements	v
1 Fourier Transform Properties of Lenses	1
1.1 Introduction.....	1
1.2 Objects placed against the lens	1
1.3 Objects placed in front of the lens.....	3
1.4 Objects placed behind the lens.....	4
2 Matched Filtering.....	5
2.1 Introduction.....	5
2.2 Constructing a Vander Lugt Filter	5
2.3 Processing input data with matched filtering for correlation detection	6
3 The Mark II Prototype.....	8
3.1 Introduction.....	8
3.2 Smudge in image formation.....	9
3.3 $1/\sqrt{2}$ factor in the imaging technique.....	10
3.4 Sensitivity to phase variations.....	11
4 The Prism Fingerprint Sensor.....	13
4.1 Introduction.....	13
4.2 Recording of the holographic optical element.....	14
4.3 Sensing the fingerprint.....	15
4.4 Quality of the fingerprint.....	17

4.5	Conclusions	18
5	The Mark III System	20
5.1	Introduction.....	20
5.2	Spatial Light Modulator (SLM)	20
5.3	Recording of the matched filter.....	22
6	Miniaturization of the Mark III verification device.....	26
6.1	Introduction.....	26
6.2	Experimental set-up.....	26
6.3	Discussion of components used	28
6.4	The Mark III alignment problem.....	28
7	Conclusions	30
8	References	31

Chapter 1

Fourier Transform Properties of Lenses

1.1 Introduction

One of the most remarkable and useful properties of a converging lens is its inherent ability to perform two-dimensional Fourier transformations [1]. The use of a convex lens for Fourier transformations has the advantage of bringing the transform to the back focal plane of the lens instead of forming in the far field region. Another advantage is that the Fourier transform (FT) is performed at the speed of light and the relative size of a lens or lens system is usually much smaller than other means of obtaining Fourier transformations. We will see that in a special case the quadratic phase curvatures vanish from the Fourier transform at the back focal plane of the lens.

We treat three different cases of Fourier transformation by a lens. In the first case, the object is placed against the lens. In the second, the object is placed at some distance d_o in front of the lens. The last case being when an object is placed a distance d in front of the back focal plane of the lens. In the following treatment we assume a monochromatic plane wave with amplitude A incident on a transparency film used as an object. A more thorough introduction to Fourier transform properties of lenses can be reviewed elsewhere [1].

1.2 Object placed against the lens

Let an object be placed against the surface of a converging lens with focal length f , as seen in Fig 1.1. The field distribution at the back focal plane is given by

$$U_f(x_f, y_f) = \frac{A \exp[i \frac{k}{2f} (x_f^2 + y_f^2)]}{i \lambda f} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t_o(x, y) \exp[-\frac{i 2 \pi}{\lambda f} (x x_f + y y_f)] dx dy \quad (1-1)$$

where x_f and y_f are the positions in the back focal plane of the lens, λ is the wavelength of the incident light, f is the focal length of the lens, and k is $2\pi/\lambda$. A quadratic phase factor that precedes the integral shows that the Fourier transform relation between the object and the focal-plane amplitude distribution is not an exact one.

Figure 1.1- A transparency (object) placed against the lens.

One thing to note is that while the phase distribution across the focal plane is not the same as the phase distribution across the object spectrum, the difference between the two is a simple phase curvature [1]. When one measures the intensity this phase distribution is of no consequence because the intensity is not affected by the phase. The equation for the intensity is given below.

$$I_f(x_f, y_f) = \frac{A^2}{\lambda^2 f^2} \cdot \left| \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t_o(x, y) \exp\left[-\frac{i 2 \pi}{\lambda f} \cdot (x x_f + y y_f)\right] dx dy \right|^2 \quad (1-2)$$

This aspect of the Fourier transform becomes very important to the workings of the Mark III prototype which is discussed in detail in a subsequent chapter.

1.3 Object placed in front of the lens

Now we treat a more general case where the object is placed at some distance d_o in front of the lens (See Fig 1.2.). For this general case it can be seen that a phase factor still precedes the integral as evident in equation.(1-3) shown below.

$$U_f(x_f, y_f) = \frac{A \exp[i \frac{k}{2f} (1 - \frac{d_o}{f})(x_f^2 + y_f^2)]}{i\lambda f} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} t_o(x, y) \exp[-\frac{i2\pi}{\lambda f} (xx_f + yy_f)] dx dy \quad (1-3)$$

In the special case $d_o = f$ where the object is placed at the front focal plane of the lens the phase factor disappears and hence an exact Fourier transform is produced. Reducing the focal length of the Fourier transforming lens reduces the size of the FT. However, reducing the focal length of the lens usually increases the manufacturing cost of the lens. These two properties mentioned above play a major role in the design of the miniaturized version of the Mark III verification system.

Figure 1.2- A transparency (object) placed in front of the lens.

1.4 Objects placed behind the lens

In this last case a transparency is placed behind the lens a distance d from the back focal plane of the lens (see Fig. 1.3). If we make a geometrical-optics approximation then the amplitude of the spherical wave is Af/d [1]. The area that will be illuminated is dictated by the intersection of the converging cone of rays with the object plane. The overall amplitude at the back focal plane is:

$$U_f(x_f, y_f) = \frac{A \exp[i \frac{k}{2f} (1 - \frac{d_o}{f})(x_f^2 + y_f^2)]}{i\lambda f} \frac{f}{d} \iint_{-\infty}^{\infty} t_o P \exp[-\frac{i2\pi}{\lambda f} (xx_f + yy_f)] dx dy \quad (1.4)$$

Figure 1.3- A Transparency (object) placed behind the lens

where $P(x,y)$ is the pupil function. The pupil function is defined by

$$P(x, y) = \begin{cases} 1 & \text{inside the lens aperture} \\ 0 & \text{otherwise} \end{cases}$$

The result of this is essentially the same as the result that was observed in the case with the object placed against the lens except for the fact that the Fourier transform can be scaled by moving the transparency towards or away from the lens. One can see that the maximum size of the Fourier transform will occur when $d=f$, which is basically the case as described in section 1.2.

Chapter 2

Matched Filtering

2.1 Introduction

There are many different types of image processing used for character recognition. The concept of matched filtering is a technique that is quite extensively used in solving character recognition problems. This principle of matched filtering is an application of the Vander Lugt filter, which was introduced by A. B. Vander Lugt in 1963 [1]. This technique synthesizes a frequency-plane mask for coherent processors. These masks have the property of controlling the amplitude and phase of a transfer function in spite of the fact that they consist solely of patterns of absorption [2]. In this chapter we will illustrate how the matched filter is produced and how it is used in character recognition *via* a correlation peak.

2.2 Constructing a Vander Lugt filter

A Vander Lugt filter can be recorded by using a simple holographic recording system which is shown below in Fig. 2.1. The reference and object beams are coherent light waves derived from the same laser source, the path difference between these beams is matched within the coherence length of the laser. A raw laser beam is expanded, collimated, and then split using a beamsplitter into two different beams. One beam serves as the reference beam (beam A) and is directed onto the holographic plate. The other beam (object beam B) is directed through, as in our case, a transparency of a fingerprint and then focused by a converging lens onto the holographic plate. The resulting fringe pattern that is recorded on the plate is the frequency-plane mask for the Vander Lugt filter. The

holographic plate is placed at the back focal plane of the lens so the Fourier transformation of the fingerprint is focused on the recording medium.

Figure 2.1- The recording of the matched filter on a holographic plate. The reference and object beams are derived from the same laser source.

2.3 Processing input data with matched filtering for correlation detection

Matched filtering is a technique used to compare an object to a 'pre-recorded' filter. In our case the filter is the hologram of the Fourier transform of a fingerprint as recorded with the setup above. The setup for detecting the correlation is shown in Figure 2.2. The input signal is the original object as used in recording of the matched filter. It is well known from holographic theory that when a reference beam, identical to the one used in its recording, is directed onto the hologram, the image of the original object is reconstructed. On the other hand when the hologram is illuminated by the object beam, the reference beam is reconstructed. The latter holds true for the matched filtering technique. Because the reference beam was collimated when the filter was recorded, the reconstructed reference

Figure 2.2- The setup for matched filtering correlation detection.

beam is also collimated. The reference beam is then collected and focused by a lens onto a photo-diode array which sends a signal to an oscilloscope. This signal is called the “correlation peak.” The amplitude of the signal is an indication of how well the input object matches the filter. A large amplitude implies a high correlation between the object and the filter. A small amplitude implies low correlation. In the next chapter we discuss some previous work done at San Jose State University on matched filtering and explain some of the problems that were encountered.

Chapter 3

The Mark II Prototype

3.1 Introduction

The Mark II prototype for fingerprint comparison was developed by Dr. R. D. Bahuguna and Panfilo C. Deguzman at San Jose State University. Previous work done on this topic was published in P. C. Deguzman's thesis [2]. The setup for the Mark II system is illustrated below in Fig 3.1.

Fig. 3.1- The experimental set-up for the Mark II system

The above figure represents a “reader” device which is only capable of comparing Fourier transforms. Holograms cannot be recorded on this system. A laser diode is incorporated into the design for compactness and simplicity. The laser light travels from the diode to a plane mirror where it is reflected up through a 45°-45°-90° prism. The image of the fingerprint is transferred *via* total internal reflection (TIR) and is passed through a

focusing lens which focuses the Fourier transform (FT) of the image onto a microscope objective that expands the FT. This transform then passes through the matched filter of the finger being tested. This filter is pre-recorded and is done so on a similar system known as an 'enrollment' device. Since every fingerprint will produce a central diffraction order in the FT, the center is blocked to prevent that portion of the signal from reaching the detector. The central order will only add "noise" to the correlation signal.

The Mark II prototype had a few inherent problems, namely:

- 1) Image smudge
- 2) $1/\sqrt{2}$ factor in the imaging technique
- 3) Sensitivity to phase variations

These problems are discussed in detail below.

3.2 Smudge in image formation

The input device for the Mark II was a 45°-45°-90° prism. (see Figure 3.1). The image was transferred through the prism using the principle of frustrated total internal reflection. The light enters through the face A of the prism and then strikes the hypotenuse. The light falling on the hypotenuse is at 45° which is greater than the critical angle for the prism (for $n=1.5$, $\theta_c = 42^\circ$). All the light that strikes this surface is completely reflected with no losses. When a fingerprint is pressed on the hypotenuse of the prism the ridges of the fingerprint destroy the TIR by absorbing the light. This is due to the fact that fingers usually have a thin layer of oil on them and the change in the index of refraction is not very great (oil $n=1.33$ compared to glass $n=1.5$). As a result the light is not reflected at this interface and is transmitted and finally absorbed into the ridges. The one advantage of the oil is that it gives a good object contrast because the light is totally reflected where the valleys exist. There is also a drawback to this layer of oil. Not all fingers have a thick

enough oil layer on them to produce a good image. Some people have very dry hands (very little oil). It was discovered that if a small amount of oil was applied to the finger or to the surface of the prism then the image contrast would increase. But if the finger was pressed too hard or there was too much oil on the finger or the prism then an image smudge would appear. In the case where there is too much oil, the valleys and ridges start to blend together which scatters some light and decreases the contrast of the image. This results in a poor FT. The Mark II's correlation measurements can be greatly compromised with this "smudge" phenomenon.

3.3 $1/\sqrt{2}$ factor in the imaging technique

The problem encountered with this input system, like many other input systems that use a prism element, was a compression of the image in one direction by $1/\sqrt{2}$. This compression factor comes from the manner in which the prism is used. In this system a finger is pressed against the hypotenuse of the prism, see Figure 3.2. The light enters normally from one of the plane sides and hits the hypotenuse where the finger is pressed. In our case a 45° - 45° - 90° prism was use so the actual image transmitted is the projection of the image (see Figure 3.2), namely $L \cos(45^\circ)$, where L is the height of the fingerprint.

This compression of the image in one dimension can create some difficulties. Although this image compression does not affect the matched filtering, it does require that

Figure 3.2- The compression of the fingerprint in one dimension.

the recording and reconstruction be performed in the same manner. This compression factor can be corrected by the means of software but adds components and cost needed to accomplish the image processing. The correction of this compression factor is discussed in the next chapter.

3.4 Sensitivity to phase variations

The Mark II system had another problem associated in the inherent design and method by which the FT was produced. This problem surfaced not only in the system for transparencies but also in the real-time system. The Mark II system was sensitive to the phase information that the transparency created to the formation of the FT. This unwanted phase information is very unlikely to “match” during the reconstruction of the matched filter due to the variations in the thickness of the film. The manufacturing process creates thickness variations which lead to phase variations. Let us assume that in a real-time system, the matched filter recording was done using a transparency and the approval was done using the real finger. In that case the unwanted phase information from the transparency will reduce the correlation signal, which could lead to a false non match (FNM). A false non match occurs when the filter and the object are in fact the same but the

system fails to recognize the match between the two and falsely rejects the user.

Another phase effect that was observed was an unacceptably large correlation signal that resulted from merely cleaning the prism with a cleaning agent such as isopropyl alcohol. The streaks produced from wiping across the prism act like a coarse phase grating and the diffracted light may illuminate the recorded area of the matched filter and provide a partial correlation signal. This unwanted reconstruction signal from the matched filter may produce an undesirable correlation signal which could lead to a false match (FM). A false match is when the filter and the user are not the same but the system recognizes them as so and accepts the user.

Chapter 4

The Prism Fingerprint Sensor

4.1. Introduction

Total internal reflection has been used extensively to sense ridges and valleys of a finger. Caulfield, *et al.* [4] used a prism sensor based on this principle in their holographic fingerprint recognition system. Based on the same principle Igaki, *et al.* [5] developed a parallel plate sensor using a holographic grating. Recently, M. Metz, *et al.* [6,7] have developed an edge lit hologram to sense a fingerprint. Their system, however, is not based on total internal reflection. A typical prism sensor is shown in Figure 3.2. The finger is pressed on the hypotenuse of the prism. The points where the ridges touch the glass the total internal reflection is destroyed and the light is absorbed into the finger. The valleys of the finger (the points that do not touch the glass) are completely reflected. The resulting image from this typical sensor is viewed as a negative image of the fingerprint where the ridges are dark and the valleys are bright. The main disadvantage of the prism sensor is that the fingerprint is compressed in one dimension with respect to the other by a factor of $1/\sqrt{2}$. This is due to the fact that any figure on a plane viewed at an angle of 45° to the normal will compress in one dimension by $\cos 45^\circ$, *i.e.* by $1/\sqrt{2}$. Another drawback is that the plane containing the fingerprint is inclined with respect to the optical axis therefore the need for additional correction optics. The sensor discussed in this chapter eliminates both problems. It consists of a right angled prism and a holographic grating glued together with an index matching cement as shown in Figure 4.1. The finger to be sensed is pressed against one side of the prism and the hypotenuse illuminated with light. The grating is the

key component in correcting the compression of the image. The recording geometry of the grating corrects the image compression by reconstructing the zero order of the reference beam that reflects off face A of the prism and then is captured by the ccd video camera. The recording geometry is explained below.

Figure 4.1- The fingerprint sensor is cemented to a right-angle prism and the image is detected by a ccd video camera.

4.2. Recording of the holographic optical element

The holographic grating can be recorded in several ways. A simple method is illustrated in Figure 4.2. A collimated laser beam is split into two beams by amplitude division. One beam illuminates the hypotenuse side A of a right-angle prism and the other beam normally illuminates the side C at normal incidence. A holographic plate, *e.g.* Agfa 8E75 from the Agfa corporation, is placed in contact with side B using a layer of isopropyl alcohol. Other suitable liquids may also be used. A blackened glass plate is placed in contact with the holographic plate again using a suitable liquid such as isopropyl alcohol. This plate helps avoid any reflections off the back surface of the holographic plate. The

Figure 4.2- The recording of the fingerprint sensor with the aid of a prism.

holographic plate is exposed to the two laser beams with the aid of an electronic shutter. The exposure is dependent on the intensity of the light falling upon the plate at the prism. For our developing scheme we used the relation for the exposure time $t=200/P$ (experimentally determined) where P is the power in μW falling on the detector and t is the time in seconds. The plate is then developed until it has an optical density of 2.0 and then bleached to give a phase grating. Care must be taken to ensure that the emulsion thickness does not change due to chemical processing. The holographic grating is then glued to an identical prism with the emulsion now facing away from the face of the prism and rotated 180° . This constitutes the fingerprint sensor.

4.3. Sensing the fingerprint

The finger is pressed against the holographic plate as shown in Figure 4.3. Light from a white light source, preferably collimated, is incident normally to the face A of the prism. The rays then hit the face B at 45° and enters the holographic plate at almost 45° , provided the refractive index of the emulsion is close to the refractive index of the prism. These rays are totally internally reflected at the bottom surface of the holographic plate

Figure 4.3- The lateral shift of a valley in the holographic plate.

where the valleys of the finger are located. The ridges of the finger, however, absorb the light. The reflected rays thus carry information from the finger in the form of a high contrast pattern, the valleys appearing bright and the ridges dark. The totally internally reflected rays are bent along the normal to the face B by the fringe planes (see Figure 4.4) in the holographic grating. The rays are then reflected by the face A and exit through the face C. These rays are collected by a video camera and the image of the fingerprint viewed on a TV monitor.

Figure 4.4- The angle of the fringe plane in the holographic grating.

4.4. Quality of the fingerprint

The quality of the fingerprint image is extremely good, even the pores on the ridges can be seen. The quality is best when the prism is illuminated with collimated light. The image of the fingerprint is shifted by a distance x as illustrated in Fig. 4.4. With diffuse light the pores are still visible but they get slightly smeared because the image shift x is different for rays at different angles incident on the finger. The smearing can be reduced by using a very thin holographic plate preferably less than 0.3 mm thick. With diffuse illumination (shown in Figure 4.5) the fingerprint can also be seen with the naked eye over

Figure 4.5- The experimental set-up for diffuse illumination image capture.

a large field of view. The photographs in Figure 4.6 attest to the high quality of the fingerprint image. With diffuse illumination the latent fingerprints of previous users are hardly noticeable.

*Figure 4.6- (a) Photograph of a fingerprint with diffuse-beam illumination .
(b) Photograph of the same fingerprint with a collimated beam set-up*

4.5. Conclusions

A holographic fingerprint sensor has been developed which has the following advantages over the previous prism sensors:

1. The main advantage over other existing systems involving prisms is that the image is free of the $1/\sqrt{2}$ distortion. The existing prism-systems invariably show an elongated fingerprint with one dimension compressed by a factor of $1/\sqrt{2}$. The distortion can, however, be corrected by use of appropriate software.
2. It is easy to image the fingerprint because the plane containing the print is optically perpendicular to the axis of the video system. In the existing prism-systems, however, the plane is inclined to the optical axis thus involving additional optics to correct the aberrations.

3. White light (preferably with a filter) as well as laser light can be used to illuminate the prism. Collimated as well as diffuse illumination can be used. With diffuse laser-illumination, the diffuser should be rotated fast enough to average the speckles out.
4. With diffuse illumination the latent fingerprints from previous users are hardly noticeable.

Chapter 5

The Mark III System

5.1 Introduction

The objective of this project was to design a working prototype of a fingerprint matching system. A large scale model using transparencies was first constructed and then miniaturized. As discussed in Chapter 3, the Mark II system has various design flaws. The Mark III prototype was developed to improve and eliminate the problems associated with its predecessor. It completely eliminated the phase problem associated with the recording of the matched filter using transparencies of fingerprints. It also corrected the $1/\sqrt{2}$ factor that is typically present when using a prism as an input device. The Mark III system also greatly reduces the effects of cleaning the prism with isopropyl alcohol.

5.2 Spatial Light Modulator (SLM)

The main change to the Mark III version of the fingerprint matching system was the use of a device called a Spatial Light Modulator (SLM). A JVC-Hughes optical SLM was used in this experiment (see Figure 5.1) [8]. Electronic SLM's are also available but the goal was to develop a system that required no computer to transmit the input image, *i.e.* everything was to be done optically. An optical SLM is a device that accepts an incoherent or coherent image as input and converts this image to a coherent output image suitable for image processing. The modulation of the output beam is accomplished as a result of its interaction with the active medium which is controlled by the electric field imposed on it.

The addressing of the JVC-Hughes SLM was done optically. The SLM uses a liquid crystal which requires a “write” beam that contains the desired pattern encoded upon it. The “write” light is projected on the input side of the SLM and can be either coherent or white light. The polarization orientation of the output image can be dictated by the orientation of the SLM. Vertical polarization was required for this experiment and its importance is discussed later.

The requirements for the SLM to operate were:

- 1) The driver electronics frequency = 1Khz
- 2) The input image intensity $\geq 200 \mu\text{W}/\text{cm}^2$
- 3) 110 V AC for the driver electronics

Figure 5.1- Schematic of a Hughes-JVC liquid crystal light valve

5.3 Recording of the matched filter

The experiment was performed on a vibration-isolated Newport optical table. The set-up of the experiment is shown in Fig. 5.2. An explanation of the experiment follows:

The apparatus of this experiment has basically four parts.

- 1) Object input
- 2) The object beam
- 3) The reference beam
- 4) Correlation detection

Figure 5.2- The experimental set-up for the Mark III prototype. Shown here is the method for recording the hologram of the Fourier transform.

Part I- Object input

The object input was composed of a 100 W light bulb A, a transparency of a fingerprint B, a positive lens C, and the SLM D. Since this part of the experiment was not done in real-time, a transparency of a fingerprint was used instead of the real fingerprint. A $4f$ imaging system was used to keep unit magnification of the image. This means that the

object is a distance from the lens equal to twice the focal length. With the object at this distance the image will be reconstructed $2f$ from the lens on the other side. The object is imaged onto the input side of the SLM and the SLM then converts the incoherent image into a coherent image. This coherent image is then “picked-up” by the object beam on the output side of the SLM and continues on to the Fourier transforming lens L . The FT is now formed by the lens and then is focused and passes through a $\lambda/2$ waveplate which rotates the polarization by 90° . The FT is now expanded by a microscope objective which then images the FT onto the holographic plate.

Part 2- The object beam

The laser in the system is directed through an electronic shutter E and then to a beamsplitter F which then splits the beam into the reference beam and the object beam. The laser is oriented so that the beam is vertically polarized. The object beam is then directed by a plane mirror G through a 20X microscope objective H (used to expand the beam) and then shines through a $10\text{ }\mu\text{m}$ pinhole I that acts as a spatial filter. The beam then is collimated with a $f=37\text{ cm}$ positive lens J and passes through a polarizing beamsplitter (PBS) K (vertically oriented) in which sends the beam to the output side of the SLM where the image is then picked-up and then sent back through the PBS. The SLM D changes the orientation of the beam from vertical to horizontal so the beam is able to pass through in this direction. After the polarizing beamsplitter, the image beam passes through a $f=14\text{ cm}$ lens L to form the Fourier transform of the image. After passing through a $\lambda/2$ waveplate to change the polarization back to vertical, the microscope objective S that expands the Fourier Transform (FT) and refocuses it on the plate of the Newport thermoplastic holographic recorder where it interferes with the reference beam to make a hologram of the FT.

It was important to start out with the laser output vertically polarized. This results in a unit contrast. On the other hand, if the laser output is initially horizontally polarized, the $\mathbf{E}$ vectors will be inclined to each other by an angle θ at the holographic plate and would as a result decrease the contrast of the fringes.

Part 3- The reference beam

The reference beam originates at the first beamsplitter F (see Figure 5.2) and is then redirected by two mirrors M and N before going through a 20X microscope objective and a 25 μm spatial filter. The two mirrors are used to match the path lengths of the object beam and reference beam.

Figure 5.3- The experimental set-up for correlation detection

Part 4- Correlation detection

The correlation detection is accomplished with a linear array detector. After a hologram of the fingerprint is recorded the reference beam is blocked (see Figure 5.3). The object beam falling on the hologram reconstructs a signal in the direction of the reference

beam. The signal is then focused by a lens onto a linear array detector. If the signal is greater than a preset threshold level, the object beam is said to be matched to the hologram. This will happen when the fingerprint is identical to the one which was recorded on the filter. An example of what a Fourier transform of a fingerprint image is shown in Figure 5.4

Figure 5.4- The Fourier transform of a fingerprint image. Image capture acquired using Image Pro software

Chapter 6

Miniaturization of the Mark III verification device

6.1 Introduction

The goal of this phase of the project was to miniaturize the prototype instrument to a size that would be portable. The biggest advantage of the Mark III prototype is the input sensor that was developed for this system, described in chapter 4. It provides a high contrast virtually undistorted image the quality of which has never before been achieved. There are many design criteria that one must keep in mind when miniaturizing the size of an experiment from a large Newport optical table down to a breadboard measuring 30.5 x 46 cm. Space is obviously a concern for the layout of the components. Thermal loads and heat sinking are also important in designing a prototype instrument. This chapter will describe the design and problems in designing and constructing the Mark III breadboard prototype.

6.2 Experimental set-up

The layout for the Mark III verification prototype is shown below in Figure 6.1. A Toshiba laser diode *A* (Told9522) is mounted ≈ 10 cm away from a plane mirror *B*. The mirror is mounted at an inclined angle to direct the light up through the prism *C* and onto the holographic sensor element *D* (a US patent has been awarded). The input image is then transmitted *by* total internal reflection to a 50 mm Minolta camera objective *E*, approximately 12 mm away. The lens images the object onto the input plane of the spatial

lens L which then creates the FT of the image carried by the read beam. The FT is redirected by mirror M and is collected by a 20X microscope objective N . The microscope objective expands the FT which then passes through the previously recorded matched filter O . Lens P then focuses the reconstructed reference beam onto a photo-diode array P that sends a signal to an oscilloscope. A large signal means a good correlation, whereas a low signal indicates a poor correlation, as indicated in the previous chapter.

6.3 Discussion of components used

There are a few points worth mentioning here about the constraints that were encountered when building this prototype. The overall height of the prototype was dictated by the height of the SLM and the diameter of the camera lens. An attempt to keep the cost of the prototype to a minimum, inexpensive off-the-shelf items were used in the design. The Toshiba laser diodes used were relatively inexpensive $\approx \$100$ each. Laser diodes were used because of their small size and the minimal heat sinking required to operate them. Since we were concerned with the amount of space the prototype would occupy, all the power supplies were incorporated on the breadboard. The laser diode drivers were relatively small in size and performed well. They were mounted on a vertical to a plate to help dissipate the heat generated by the power supplies. The power for the diode drivers, model MPL 250 from Thor Labs, was supplied by a DC power supply mounted vertically to the side of the PBS platform. The controller for the SLM, mounted over the AC power supply also supplies power to the motherboard that controls the EG&G photo-diode array. The camera objective used was a convenient means for having a variable focus element in the system. A relatively short focal length lens was needed to keep the distances small between the components.

6.4 The Mark III alignment problem

Although the Mark III verification system was proven to work on a large scale, the miniature version still has an alignment problem that still needs some attention. The problem exists due to the fact that the matched filter would be recorded on a different device than the one it would be “read” or verified on. This creates a problem due to variability in the manufacturing process of these devices. The holograms’ alignment for verification is very crucial to the reliability of the correlation acceptance of the Mark III. A false reading could reject the true owner of the fingerprint or accept a completely false fingerprint. The solution to this problem has not yet been found but is the main focus of the research team continuing on this project.

Chapter 7

Conclusions

A working version of a fingerprint detection system was made with a spatial light modulator using the technique of matched filtering. A fingerprint sensor was invented in the development of this system and a patent has been awarded. The sensor features an undistorted image with an aspect ratio of 1 and high contrast with excellent resolution; the pores on the ridges of a fingerprint are resolvable. This system has a discrimination ratio of 8:1. This means that a fingerprint different from the one on the recorded matched filter will only give a correlation peak of 1/8 the level of the original fingerprint.

The Mark III system solved some problems that were inherent in the previous version. The sensitivity to phase variations was solved by using a spatial light modulator that only detects intensity variations. The fingerprint sensor solved the compression factor in one dimension, associated with prism methods and it reduced the smudge effect with diffuse illumination.

The principles used in the development of the fingerprint sensor have already culminated in a commercial product and further patents and commercial devices are anticipated. It is important in fingerprint matching to start with a high quality image so that the matching algorithm has good data to match against. There is a correlation between poor image quality and matching success. Although image quality is not the only factor that contributes to errors in matching, it is always best to minimize the number of process errors introduced to a system. The fingerprint sensor that was developed is a truly novel idea that will definitely find some use in the Biometrics industry.

References

1. J.W. Goodman, *Introduction to Fourier Optics* (McGraw-Hill Book Co., New York, 1968), Ch. 5.
2. Panfilo C. Deguzman, *Real-Time Fingerprint Identification by Matched Filtering* Masters Thesis, San Jose State University 1993.
3. Pollack, D.K., C.J. Koester, and J. T. Tippet (eds): *Optical Processing of Information*, Spartan Books, Inc., Baltimore, Md., 1963
4. H. J. Caulfield and D. R. Perkins, "Fingerprint Identification Apparatus", U.S. Patent #3,716301 assigned to Sperry Rand Corporation, New York, N.Y.
5. S. Igaki, S Eguchi, F. Yamagishi, H. Ikeda and T. Inagaki, "Real-time fingerprint sensor using a hologram, Appl. Opt. 31, 1794-1802 (1995).
6. M. Metz, "Edge-lit holography strives for market acceptance," Laser Focus World, May, 1994, pp 159-163.
7. M. Metz, C. Flatow, Z. Coleman and N. J. Phillips, "The use of edge-lit holograms for compact fingerprint capture," Conference Proceedings of "Card-Tech Secure-Tech 1995," held on April 10-13, 1995, Washington D.C., pp 221-228.
8. "Spatial Light Modulators: A user's guide." The Photonics Design and Applications Handbook 1991 pp. H-363

IMAGE EVALUATION TEST TARGET (QA-3)

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989

© 1993, Applied Image, Inc., All Rights Reserved