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Ashwini K. Tamhankar
San Jose State University

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A HOLOGRAPHIC FINGERPRINT SENSOR USING SPECTRAL FILTER

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Master of Science

by

Ashwini K. Tamhankar

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ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

APPROVED FOR THE DEPARMENT OF PHYSICS

Ramen Bah

Dr. Ramen Bahuguna

Joseph F. Becker

Dr. Joseph F.Becker

Gareth T. Williams

Dr. Gareth Williams

APPROVED FOR THE UNIVERSITY

Thea I. Williamson 08/04/05

ABSTRACT

A HOLOGRAPHIC FINGERPRINT SENSOR USING SPECTRAL FILTER

by Ashwini K. Tamhankar

There are a lot of biometric systems on the market to identify human beings from their physical characteristics. Of all these systems the fingerprint identification system is considered more accurate and reliable. The purpose of the thesis was to develop a compact and simple fingerprint sensor to get a good quality fingerprint. A new fingerprint sensor has been successfully designed and built using a converging holographic optical element in the form of a diffraction grating along with a spectral filter. The fingerprint sensed by this sensor gives a smudge-free, high-resolution image with excellent contrast between ridges and valleys.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

The goal to positively identify an individual using biological criteria is a priority for many agencies, especially, personnel management, banking institutions, law enforcement security, and access control such as CIA, FBI, and Immigration. This created a need to develop different types of identification techniques.

Today, the term biometrics is most commonly used to describe any technology that can measure unique physiological and/or behavioral characteristics to accurately determine the identity of a human being [1]. Fingerprint verification, face recognition, retinal/iris scanning, voice, palm print, visual/thermal imaging, signature analysis, etc., are examples of how physical characteristics are used to instantly distinguish one person from another. However, the greatest hope seems to be lying in the possibility of the fingertip structure recognition.

It is well known that the finger ridge pattern is different for each individual and it does not change over the lifetime. That is why fingerprint identification is considered very accurate and is preferred over the other techniques.

With a criminal database expected to grow to more than 400 million records by the end of this century, many agencies face a significant challenge in upgrading their fingerprint processing operations to ensure responsive and accurate service. The civil fingerprint identification marketplace has been growing at an enormous rate for use in the areas of fraud protection, user verification, and driver's license applications. Scientists all over the world have been trying to develop a fast, accurate, reliable, and affordable fingerprint identification system. A fingerprint identification system generally includes a fingerprint classification system, an image database, and an image preprocessor to facilitate fingerprint recognition. Computer technology has helped a lot in the development of an image database and an image preprocessor. The remaining task is to design a scanner with a sensor extracting a very detailed, non-distorted, aberration free, and also clear of noise or “smudge-free” fingerprint.

There are varieties of sensors on the market, designed using different techniques. Scanners were previously built using a prism and a holographic grating sensor, but the constant need for improvement in fingerprint imaging brought up a new solution: the converging hologram with an interference filter.

This thesis is divided into the following sections:

Section II: introduces the principles of interference filters and describes the property of filters used in the newly developed sensor.

Section III: deals with the principles of holography including basic terms, recording, and reconstruction of holograms.

Section IV: introduces different types of fingerprint sensors and gives an analysis of existing designs, their respective problems and limitations.

SectionV: describes the set up and design of the newly designed fingerprint sensor as well as the quality of fingerprint images it produces.

SectionVI: deals with the quality of the new scanner and improvements that can be made in the future.

II. PRINCIPLES OF AN INTERFERENCE FILTER

A. Introduction

There are many fields in optics in which we need to distinguish and sense spectral distributions. Interference filters and filter sets can be used to accurately measure spectral distributions. They also have applications in diagnosis of disease (by tracing of fluorescent antibodies), spectral radiometry (which is the basis for all remote sensing schemes), colorimetry, and color separation in television cameras.

B. Interference filters

Interference filters [2] are multilayer thin-film devices. The filters can be edge filters or bandpass filters. Bandpass filters transmit a desired wavelength interval, while simultaneously blocking both longer and shorter wavelengths. In the recently developed fingerprint sensor, interference filter plays a crucial role in the imaging of a fingerprint.

1. Principle

These filters operate with the same principle as that of Fabry-Perot interferometer. The schematic of a Fabry-Perot interferometer is shown in Fig. 1.

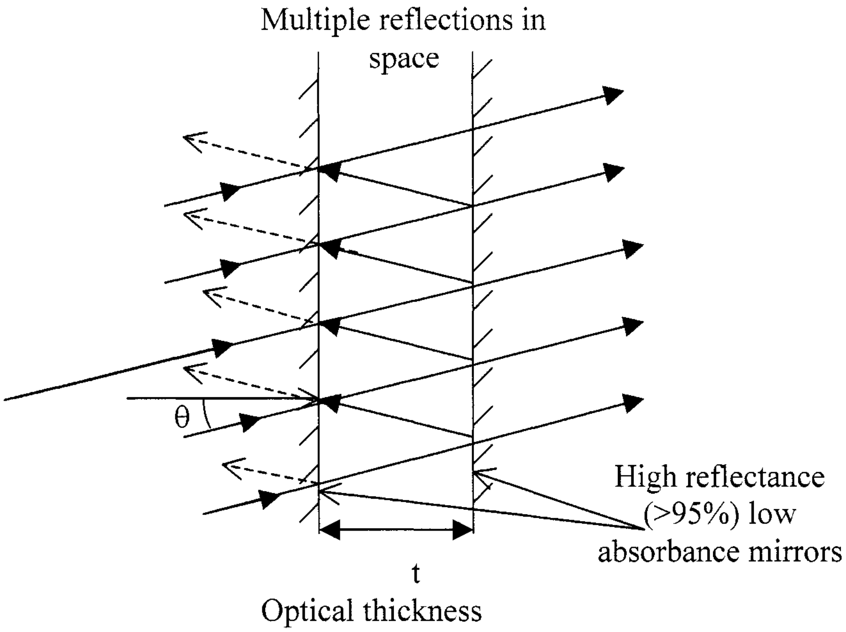


FIG. 1. Schematic of a Fabry-Perot interferometer.

Incident light undergoes multiple reflections between the cavities formed by two coated surfaces. Each of the transmitted wavefronts has undergone an even number of reflections (0, 2, 4…). A transmission maximum occurs when the optical path difference is an integral multiple of wavelengths:

$$2 * t * \cos\theta = m * \lambda,$$

where m denotes the order integer, t is the optical thickness, and θ is the angle of incidence.

At other wavelengths, destructive interference of transmitted wavefronts reduces the transmitted intensity to almost zero. The transmission peaks can be made very sharp by increasing the reflectivity of the mirror surfaces.

2. Bandpass filter design

A bandpass filter is basically a very thin Fabry-Perot interferometer. A thin layer of a dielectric material, having an optical thickness of half-wave of the desired transmission peak, replaces the air gap. The high reflectors are normal quarter wave stacks, with a broadband reflectance, peaking at the desired wavelength. The simplest bandpass interference filters are also called cavities. Two or more such filters can be deposited, one on top of the other, and separated by an absentee layer, to form a multiple cavity filter. The multiple cavity filter gives steeper band slopes, rejects nearband efficiently, and squares the passband peaks. A cross-section of a typical two-cavity pass interference filter is shown in Fig. 2.

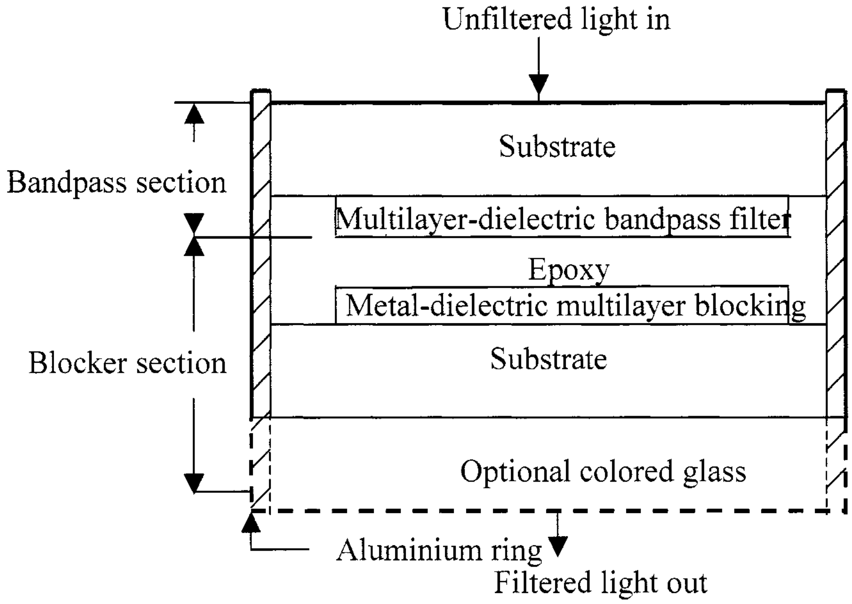


FIG. 2. Cross-section of a typical two-cavity pass interference filter.

3. Wavelength dependence on angle of incidence

It is a common characteristic of single/multilayer dielectric coatings and interference filters, that both their transmittance and reflectance spectra shift to shorter wavelengths as they are tilted from normal to oblique incidence. This applies to both edge and bandpass filters. This property of an interference filter is uniquely used in the recently developed fingerprint sensor.

In narrowband filters constructed with metallic layers in their stack, there is also a splitting of the transmittance peak into two separate and orthogonally polarized transmittance peaks, which shift to shorter wavelengths at different rates as tilt is increased. This splitting is absent in narrowband filters, whose stacks are of all-dielectric multilayer construction.

The wavelengths of the transmittance peaks or cavity resonance for bandpass interference filters are given by equation:

$$2 * n * t * \cos\theta = m * \lambda,$$

where n denotes the spacer refractive index, t is the spacer thickness, θ is the internal angle of incidence, m is the order number of the interference, and λ is the wavelength of a particular resonance transmittance peak.

III. PRINCIPLES OF HOLOGRAPHY

A. Introduction

Holograma is a Greek word, which can be broken into two parts with the following meanings, Holo → whole Grama → message

A hologram basically gives the “whole message.”

Dennis Gabor invented holography in 1948 while trying to improve the resolution of an electron microscope. The invention of holography by using the highly coherent laser light opened new doors for the number of applications of holography. Holography has numerous applications in aberration removal, interferometry, data storage, microscopy, and holographic optical element.

In this section we will discuss about properties, recording and developing of plane holograms.

B. Main characteristics involved in holography

In holography the information about the object is encoded on the film by interfering the wave from the object with a reference wave. Some amount of coherence is needed; laser is the best source. A lens is not necessary, although it could be used in special circumstances.

The image is three dimensional, possessing depth and parallax properties; it is as if one is viewing the object itself.

A hologram is a record of the interference pattern and so the image is not visible as such. To reconstruct the image the hologram is illuminated by an identical reference beam. The image is reconstructed at the same location as the object, not necessarily in the film plane as in the case of photography. The phase is preserved in the form of fringes.

C. Recording of a hologram

A hologram is recorded by interfering an object and a reference beam on a holographic plate as shown in Fig. 3. The object wave O is the beam scattered by the object. The reference wave R is usually a spherical or a plane wave. The two coherent beams, the reference beam and the object beam, which have been derived from the same laser, interfere to give extremely fine fringes on the holographic plate. Processing of the holographic plate in some chemicals records these fringes in the form of black lines; this constitutes the hologram.

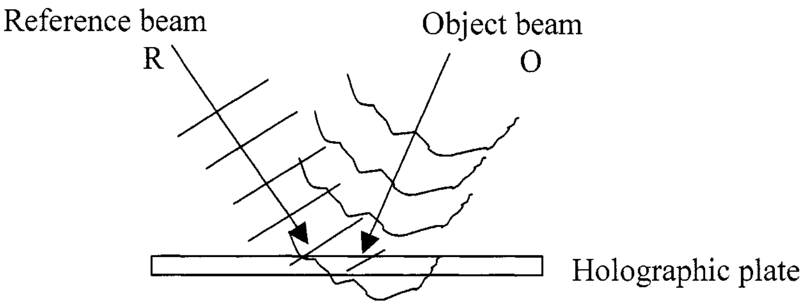


FIG. 3. Recording geometry of a hologram.

D. Reconstruction of the images

When a hologram is illuminated by a beam identical to the reference beam (used during recording), an image of the object is reconstructed in the same location as the object itself, as shown in Fig. 4.

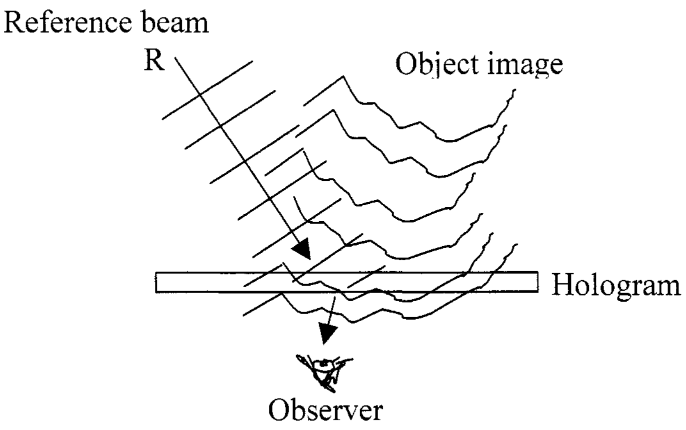


FIG. 4. Reconstruction of an image in a hologram.

E. The fringe spacing formula

The average fringe spacing in a hologram can be determined by considering the angle between the reference beam and the direction of the object wave, as illustrated in Fig. 5.

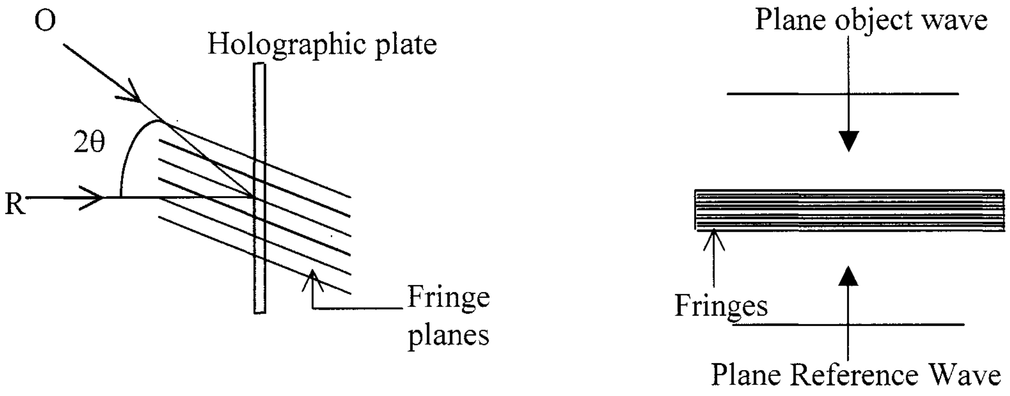


FIG. 5. Fringe pattern on a hologram.

By approximating the two waves as plane waves, the spacing is given by the following formula:

Fringe spacing = $\lambda o / 2 * \sin\theta$, where 2θ denotes the angle between the reference and the object waves, and λo is the incident wavelength.

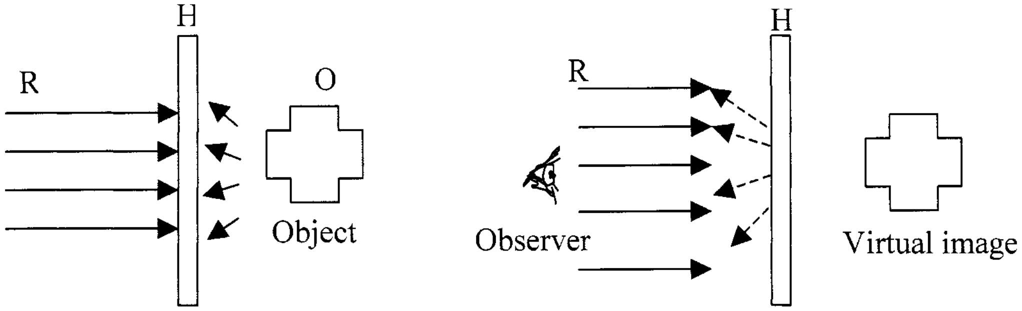
The fringe planes bisect the angle between the object and reference waves.

F. Reflection hologram

A reflection hologram is very simple to record. The recording and reconstruction of a reflection hologram is illustrated in Fig. 6.

In reflection holograms, the incident beam R acts as the reference beam and the transmitted part illuminates the object. The object scatters the wave back to the plate; this is the object wave O. The reference and the object waves, coming from the opposite sides of hologram, interfere to give very fine fringes (2θ is about 180 °), much finer than obtained in a transmission hologram. For this reason, a much higher resolution in the emulsion is required for recording a reflection hologram as compared to a transmission hologram.

As the name suggests, a reflection hologram is viewed in reflection. During reconstruction of the image, the hologram is illuminated with the beam identical to the reference beam, from the same side as the observer. The reconstructed image is virtual. The major feature of reflection holograms is that a single color wavefront may be reconstructed with white light illumination.



(a) Recording (b) Reconstruction

FIG. 6. Recording and reconstruction geometry for a reflection hologram.

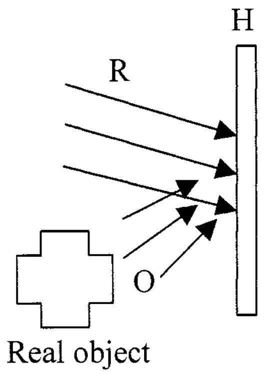
G. Transmission hologram

In a transmission hologram [3], the reference wave is plane or spherical. The recording and reconstruction for a transmission hologram is illustrated in Fig. 7.

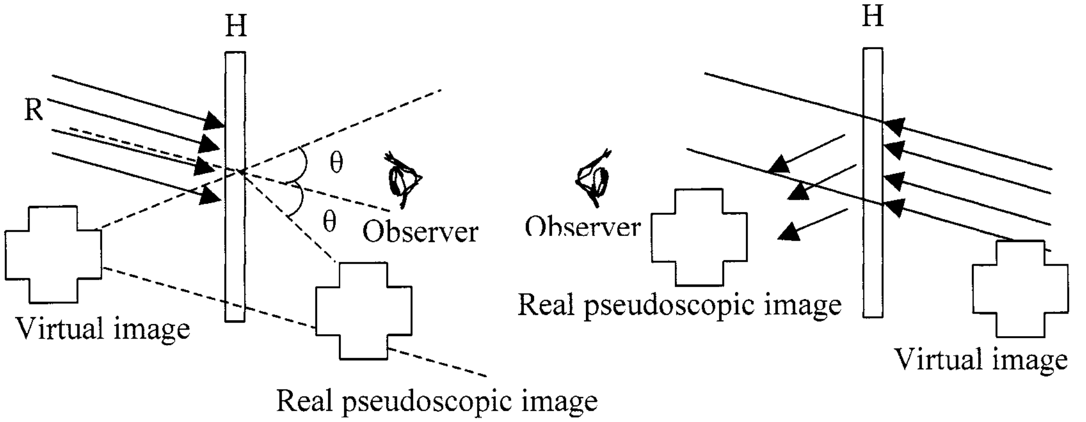
The reference and object waves are incident from the same side of the hologram plate, and interfere to give interference fringes. Image on the hologram can be reconstructed by a normal or conjugate reference beam illumination, as shown in Fig. 7. Two images, primary and secondary, are reconstructed.

In normal illumination, the hologram is illuminated with a beam identical to the reference beam. Two images, virtual and conjugate, are reconstructed. The virtual image of the object is orthoscopic and reconstructed at the same location of the object. The conjugate image might be real or virtual, depending on the particular geometry used to form the hologram, and can be located by the method shown in Fig. 8.

In conjugate illumination, the hologram is illuminated from the opposite side and in an antiparallel direction to the original reference beam. The two images, virtual and real, are formed at the same places as in the normal illumination. The only difference is that a virtual image becomes real, and vice versa.



(a) Recording

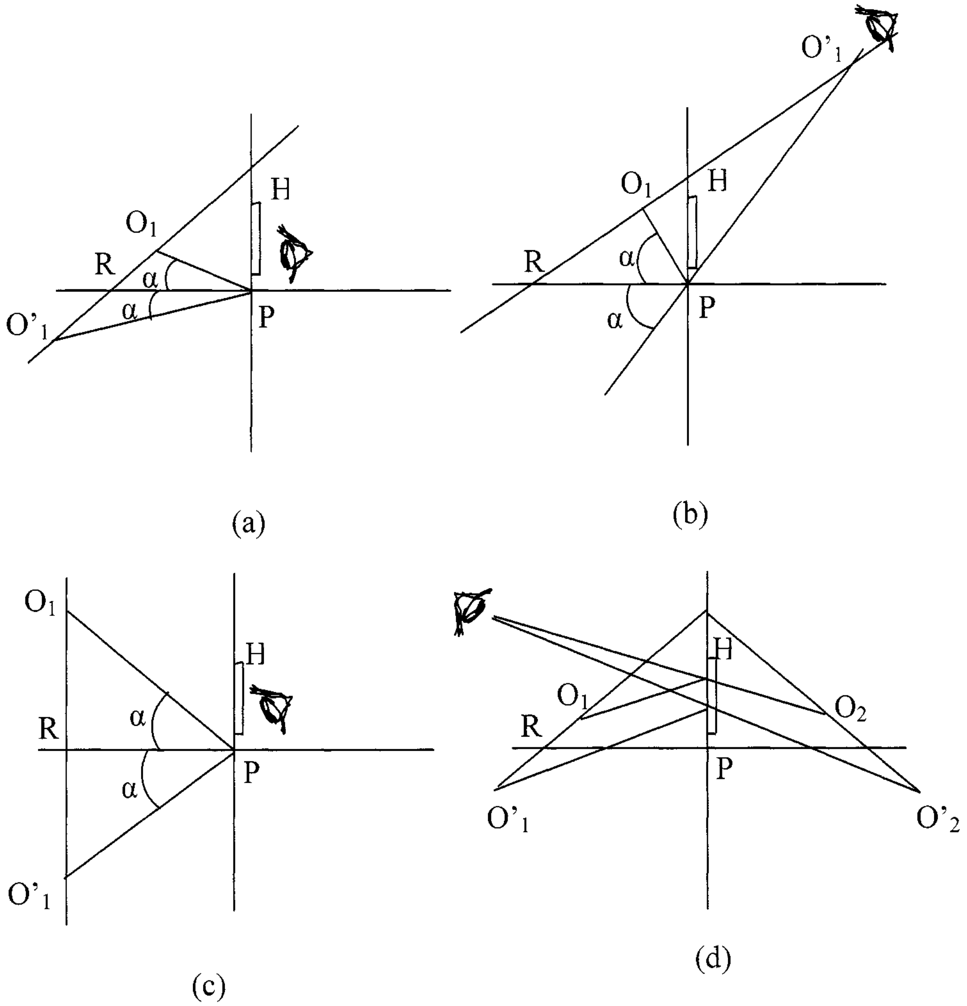


i) Normal illumination

ii) Conjugate illumination

(b) Reconstruction

FIG. 7. Recording and reconstruction of a transmission hologram.



(a) (b) (c) (d)

FIG. 8. Method to determine the conjugate image.

Method to determine the conjugate image is as follows: join the reference point source R, the object point O_1 by a straight line. Draw a perpendicular RP to the plate H through R. Measure the angle $RPO_1 = \alpha$ say. Draw a line passing through P at an angle $(-\alpha)$ and let it meet O_1R at O'_1. O'_1 is then the conjugate image. (a), (b) and (c) are different possible recording geometries; (d) is similar to (a) except that one is viewing the image in reflection. Reflection images of O_1 and O'_1 are seen as O_2 and O'_2 respectively.

H. Experimental procedures in holography

The basic requirement in holography is to obtain good contrast fringes on the holographic plate. There are some procedures and precautions [3] one must follow in order to achieve this goal. The important ones are explained below.

1. The source requirements

The most important requirement for obtaining a good interference is to have sufficient coherence between the interfering beams. Thus the optical path difference between the object and reference beams, as measured from the beam splitter, should be much less than the coherence length of the source, preferably near zero. The He-Ne lasers, that are available on the market, have a coherence length of few inches, which is usually sufficient for making holograms of objects whose depth is much less than an inch. Filtered mercury lamps which pass just the green light may also be used, but lasers are so far the best.

The required laser power to make a hologram depends on the expansion of the beams, which in turn depends on the size of the object, the size of the hologram plate that is being exposed, and the stability of the recording setup. In case of a low power laser, exposing the holographic plate for a longer time should do the same job as a higher power laser, exposing for a shorter time. The setup must be stable during the exposure. For bleached holograms it is advised to expose the plate long enough to obtain an optical density of 2 before bleaching. For making holograms of small objects, like coins, a 2-5mW laser is quite adequate.

A laser source can also be used for reconstruction. A white light source can be used for reflection holograms where the dispersion has either been reduced or the colors suppressed by the Bragg effect.

2. Mechanical stability

Mechanical stability is very essential to make a good hologram. All vibrations, like those coming from the floor, air blowing from fans or air conditioners, should be avoided or isolated. Vibration-isolated optical tables are preferable for mechanical stability. A wooden box filled with sand, and placed on a heavy slab kept over inflated motorcycle inner tubes, can isolate the floor vibrations to a reasonable extent. The components are mounted in the sand.

3. Beam expansion

The laser-output cross-section is typically 1 mm in diameter. While making a hologram, one needs a larger cross-section to illuminate the object, hence there is a need of expanding the beam. This can be achieved by one or more lenses or spherical mirrors.

4. The photographic emulsion

Selection of the proper holographic emulsion is very important before attempting to make a hologram. Transmission holograms with a small angle between the reference and the object waves do not require a resolution of more than 2000 lines/mm, and hence, Agfa 10E75 (red sensitive) is quite adequate. For transmission holograms with larger angles (>30°) and reflection holograms, which need a higher resolution, 8E75 (red sensitive) with a resolution of over 3000 lines/mm is used. For a green laser, for example, the Argon laser, the corresponding plates used are 10E56 and 8E56, respectively. Recently, we have been using PFG-01 instead of 8E75 plates.

5. Processing

The chemicals and the method used for processing the holograms vary depending on the types of the plates used. In the newly developed sensor, Agfa 8E75 (red sensitive) plates are used to record the hologram with the following method and chemicals.

The making of a hologram consisted of four steps: exposure, developing, bleaching, and drying. These are critical steps in preparation of a good hologram.

The following is the procedure used for processing the hologram:

1. Exposing: expose the photographic plate for 3 seconds.
2. Developing: develop in the developer for 1 minute until exposed portion becomes black.
3. Rinsing: rinse the plate in cold tap water for 1 minute.
4. Bleaching: put in bleach for 20 seconds until it clears.
5. Rinsing: rinse the plate in cold tap water for 1 minute.
6. Photoflo: put in Kodak Photoflo for 30 seconds.
7. Drying: let it dry vertically by itself for 15-20 minutes.

The following is the description for the chemicals used during processing.

6. Developer

There are various developer formulae in the holographic literature. KODAK-19 is used in the newly developed sensor, since it is less toxic than others.

7. Bleach

There are various bleaches that go with various developers, but again the dichromate bleach gives good results. The formula is given below:

Potassium dichromate: 4.0 g

Concentrated Sulphuric acid: 4.0 ml

Distilled water: 1.0 L

The above developer bleach combination yields reasonably bright holograms.

IV. TYPES OF FINGERPRINT SENSORS

The need to positively identify an individual created a need to develop different types of identification sensors. Fingerprint identification is considered very accurate and is preferred over other techniques.

A. Types of fingerprint sensors

There are many varieties of fingerprint identification sensors on the market designed using different techniques.

1. Solid-state, silicon-based capacitive fingerprint sensor

When a finger contacts the sensor [4] surface, it acts as one of the plates of a capacitor. The other plate, on the surface of the sensor, consists of a silicon chip containing an array of capacitive plates with sensing circuitry. Differences in the capacitance correspond to the ridges, valleys and pores that characterize a unique fingerprint. This information is converted to a video signal.

2. Ultrasonic fingerprint sensor

The ultrasound method of acquiring a fingerprint is based on sending acoustic signals towards the finger and detecting the echo. This is a non-optical fingerprint sensor. J. K. Schneider [5] describes a method of sensing a fingerprint using ultrasound. The images obtained using ultrasound are based upon the reflection and transmission coefficients of ultrasound, as it propagates through different media. Different media have varying acoustic impedance. The acoustic impedance Z is the product of material density ρ and the phase velocity c.

As an ultrasonic wave in medium 1, with acoustic impedance Z_1, passes into medium 2 with acoustic impedance Z_2 (provided that the path of propagation is orthogonal to the interface formed by medium 1 and medium 2), some amount of acoustic energy is reflected back in medium 1 and part of it is transmitted into medium 2.

The reflection coefficient is given by

$$R = (Z_2 - Z_1) / (Z_2 + Z_1).$$

The transmission coefficient is given by

$$T = 1 - R.$$

Therefore, by recording the reflection and transmission coefficients of ultrasonic wave corresponding to a particular interface, a gray scale image of that interface can be obtained. To get a good fingerprint, contrast between the ridges and valleys in the fingerprint must be maximum. This can be obtained by significantly varying the reflectivity coefficient from a ridge to a valley. In most ultrasonic fingerprint sensors, the finger to be imaged is generally placed upon a platen of some form during the scanning process. Therefore, the reflection coefficients are those that are formed between the platen of a reader and the ridges and valleys of the fingerprint, respectively. The intent is to allow most of the acoustical energy to pass into the finger. This is achieved by maximizing the ultrasonic return echo caused by the valley of the fingerprint (air) by creating a high coefficient of reflection, while simultaneously minimizing the return signal at a ridge by creating a low coefficient of reflection. The medium polystyrene, with reflection coefficient for ridges: $R_r = 23.2\%$, and for valleys: $R_v = 99.97\%$, was found out to give a good contrast.

The advantage of this system is that it works nicely whether a finger to be detected is oily or dry. The drawback is that this system takes a lot of time to capture a fingerprint, as the speed of sound is much less than the speed of light, and also this unit is a lot larger compared to regular optical systems.

3. Prism fingerprint sensor

Prism fingerprint sensors are based on the principle of total internal reflection to optically sense ridges and valleys of a finger surface. When a finger is pressed against a prism, because of the change in refractive index, the condition for total internal reflection for a glass air interface (as shown in Fig. 9) will no longer be met at the ridges. The light at the ridges will be absorbed, while the light at the valleys will be reflected.

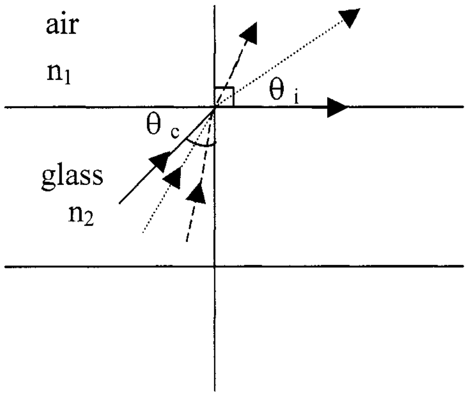


FIG. 9. Total internal reflection for glass air interface.

In Fig. 9, θ_i is the angle of incidence, and $\theta_c = \sin^{-1}(n_2 / n_1)$ is the critical angle.

Caulfield *et al.* [6] used a prism sensor based on total internal reflection in their holographic fingerprint recognition system. Based on the same principle, Igaki *et al.* [7] developed a plate sensor using a holographic grating. A typical prism sensor is shown in Fig. 10.

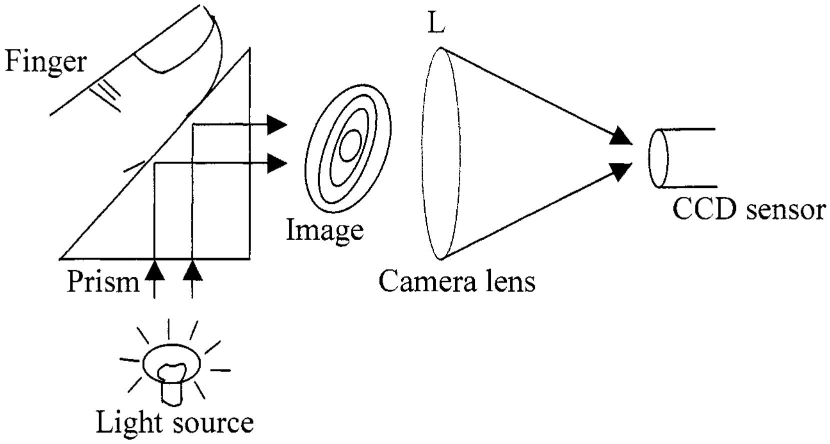


FIG. 10. A typical prism sensor.

The setup consists of a glass prism, a light source to illuminate a finger through the prism, and a camera lens to focus the image onto a CCD sensor.

The primary disadvantage of this type of prism fingerprint sensor is that the fingerprint is compressed in one orthogonal dimension with respect to the other, by a factor equal to the cosine of the angle, at which the image plane is inclined relative to the normal. In case of a right angled prism, the image-plane is viewed at an angle 45 ° to the normal is compressed in one dimension by cos 45°, *i.e.* by $1/\sqrt{2}$ factor. This problem can, however, be corrected by the camera software.

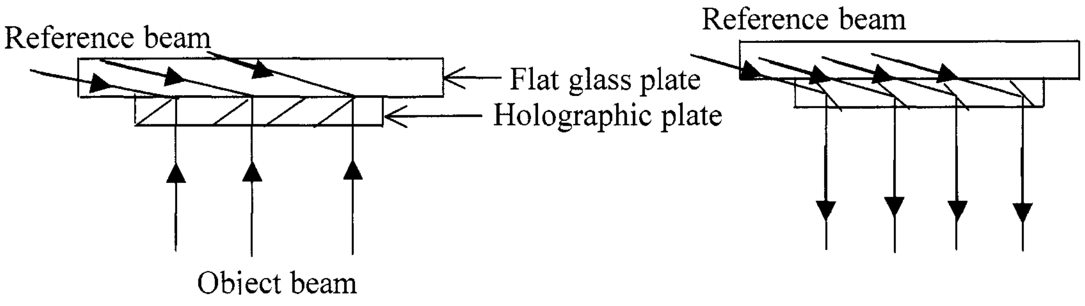
Another drawback, which is more serious in nature, is that different points in the image are at different distances from the CCD sensor causing trapezoidal distortion. Also, all points in the image cannot be focused by the camera at the same time. This causes the image to be blurred.

4. Fingerprint sensors using a holographic optical element

The drawbacks in the prism sensors, mentioned earlier, were eliminated by using holographic optical elements.

(a) In-line grating

A Japanese team [7] from Fujitsu Laboratories developed a holographic sensor using a flat glass plate and a plain grating hologram. The recording geometry and reconstruction of a hologram used in the system is shown in Fig. 11.



(a) Recording

(b) Reconstruction

FIG. 11. Recording geometry and reconstruction of an in-line hologram.

This sensor uses the principle of total internal reflection. The system is shown in Fig. 12.

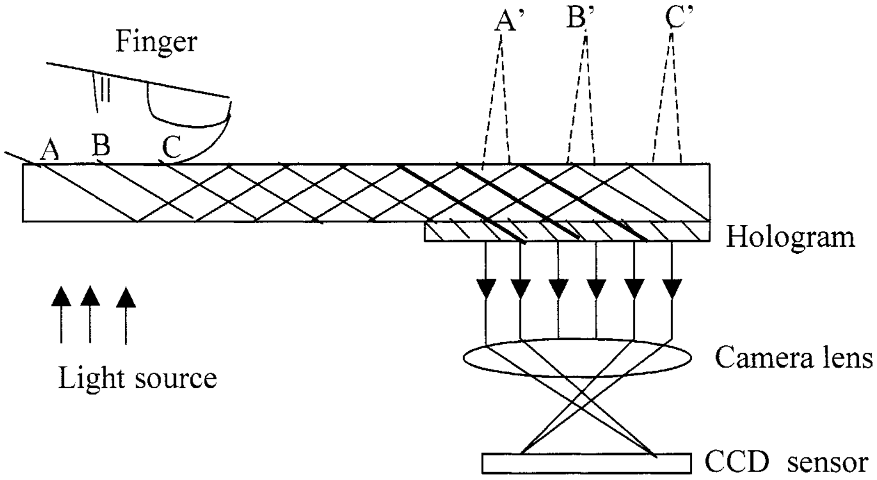


FIG. 12. In-line grating fingerprint sensor using a flat glass plate and a plain grating.

Light entering the flat glass plate hits ridges and valleys of the finger. At the ridges, light scatters in all directions. All rays, with an angle above the critical angle, are reflected repeatedly throughout the plate due to total internal reflection, then are diffracted by the hologram and focussed by a camera lens onto the CCD sensor. At valleys, light is also scattered, but no light reenters the glass at such steep angles; on the fingerprint image, valleys appear dark.

Use of a flat glass plate makes the optical path from any point of a fingerprint to a hologram equal. The trapezoidal distortion is eliminated.

One of the major disadvantages of this design is creation of an image with astigmatism. The light scattered from ridges of a finger, then goes through the holographic grating and does not focus to a sharp point as illustrated in Fig.13.

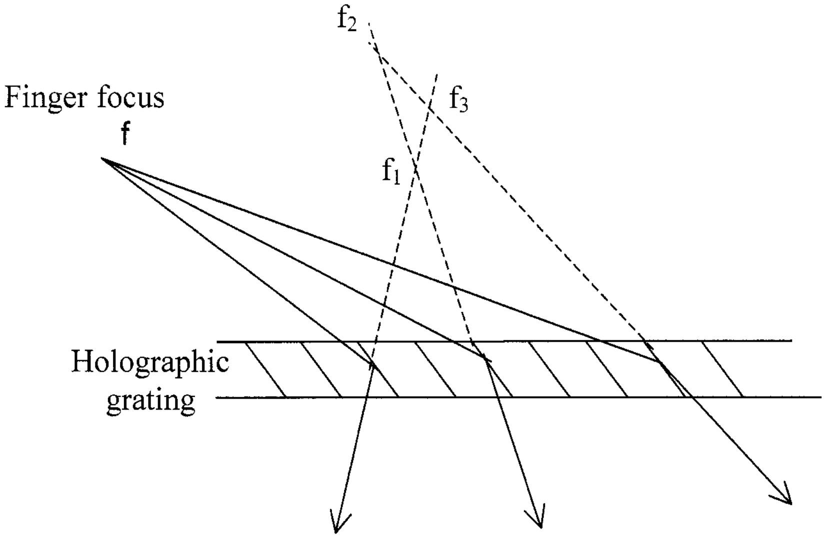


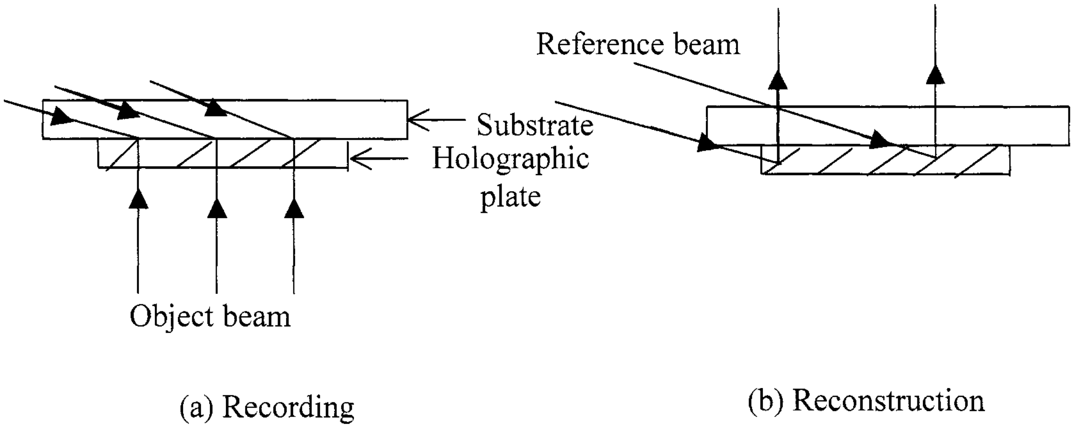
FIG. 13. Representation of astigmatism.

In this design, the scattered light from ridges has a diverging wavefront and produces a blurred focus f_1, f_2, f_3, as shown in Fig. 13, instead of having one single focus point reconstructed through the hologram. Although it is possible to correct this aberration using several optical elements, it creates a major drawback for industrial applications because of the large size of the system.

(b) Edge-lit hologram

M. Metz, C. Flatow, and a team [8, 9] from De Montfort University developed a technique using a holographic element, which allows a high resolution, compact, and inexpensive fingerprint capturing unit.

This system uses an edge-lit hologram whose recording geometry and reconstruction is shown in Fig. 14. Fringes formed in the hologram are nearly at 45 ° due to reference beam almost parallel and an object beam perpendicular to the plate during recording. The system is shown in Fig. 15.



(a) Recording

(b) Reconstruction

FIG. 14. Recording geometry and reconstruction of an edge-lit hologram.

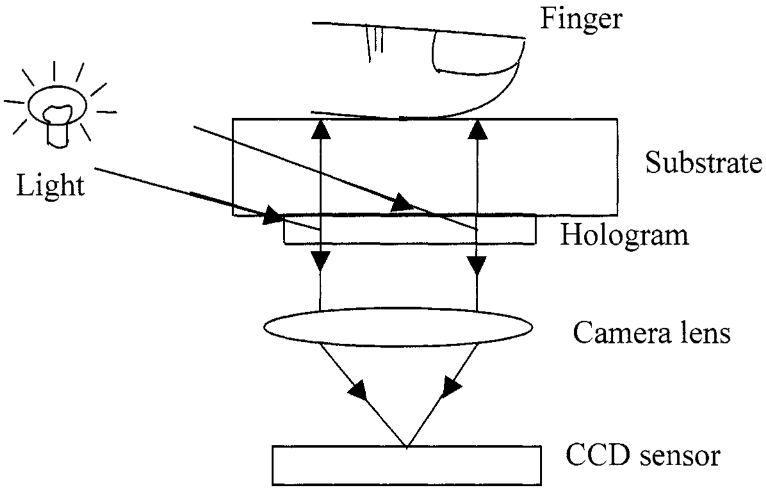


FIG. 15. Fingerprint imaging device using an edge-lit hologram.

The reference beam entering the substrate is reflected back towards the finger after hitting the hologram. The fingerprint with ridges bright and valleys dark is captured by the beam, is reflected back through the hologram towards the camera lens, and is focussed onto a CCD sensor. This setup creates a very detailed image with visible pores.

The drawbacks of Metz [8, 9] fingerprint scanning device are: an edge illumination is very hard to achieve, and imaging a finger directly onto the CCD, without use of an objective lens, creates a hot spot of light. Imaged fingerprint with nonuniform illumination creates "hotspot" that results in poor contrast. When a fingerprint is directly imaged on a CCD camera (without a lens) and is not focused, the quality of the image becomes poor due to diffraction effects.

5. Fingerprint sensors previously developed in the laboratory

Bahuguna and Carboline [10] developed a holographic fingerprint sensor that eliminated problems faced in the typical prism sensor. It consists of a right-angled prism, with a holographic grating glued to a base of the prism as shown in Fig. 16. The finger to be sensed is pressed against the base of the prism and the hypotenuse is illuminated with light. The image is captured on a holographic grating with a CCD camera.

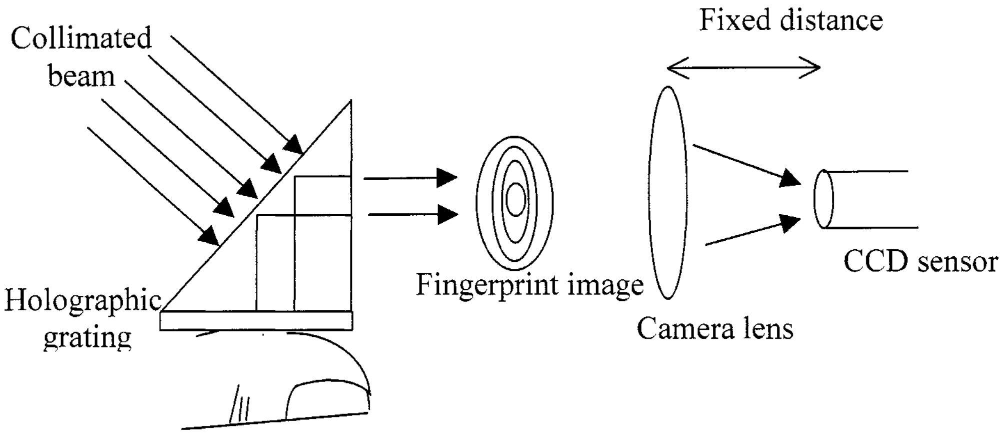


FIG. 16. Fingerprint sensor using a holographic grating.

The only limitation of this system is that the image has a center portion brighter than the perripheral region creating a "hotspot" at its center.

Bahuguna and Supper [11] developed a new sensor using a holographic optical element. This system is also based on the principle of total internal reflection. The advantage of this system over the previous one is that this sensor reduces “hotspot” and is compact in size. The setup of this system is shown in Fig. 17.

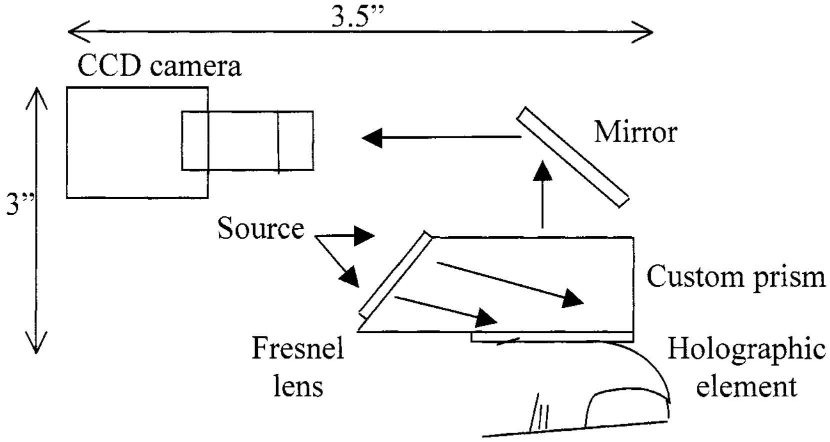


FIG. 17. Fingerprint sensor using a converging hologram.

The system consists of a converging holographic grating glued to the base surface of a trapezoidal prism. A collimated beam, formed by placing a diverging point source at the focal point of a Fresnel lens, is incident on the slanting face of the trapezoidal prism. The illuminating light is refracted and absorbed at ridges while totally internally reflected at valleys. The reflected light is diffracted by the holographic phase grating through the top parallel surface of the prism as a converging beam. A mirror folds the converging light beam and directs it to a camera system. This way, a detailed images of ridges, valleys, and pores of the finger is captured.

This system gives a high-resolution image, free of trapezoidal distortion. The only drawback of this system is that smudge due to the oil secretion on ridges is seen on the monitor along with the fingerprint when a finger is pressed against the prism. The problem is reduced significantly by the recently developed fingerprint sensor, which is discussed in the next section.

V. A HOLOGRAPHIC FINGERPRINT SENSOR USING A SPECTRAL FILTER

As discussed in the previous section, a holographic fingerprint sensor in the form of a diffraction grating, developed by Bahuguna and Corboline [10], eliminated the problems in a typical prism sensor. This sensor gives a highly detailed finger image with visible pores. The limiting aspect of this system is its size. Geometry of the sensor does not allow shorter distances between any of the optical elements. Later Bahuguna and Supper developed a converging holographic sensor, which is compact in size and gives a clear and a detailed fingerprint.

The common problem that remains in these sensors is that when a finger is pressed against the prism, a smudge is seen on the TV monitor along with a fingerprint, which adds some noise to the fingerprint. To reduce this problem, a new fingerprint sensor has been developed using a different technique. In the newly designed fingerprint sensor, the ridges appear bright and valleys dark resulting in a contrast that is reverse of that obtained in the above two sensors.

A. The new sensor

The newly designed fingerprint sensor is made of a converging hologram and a spectral filter. The sensor uses the principle of total internal reflection and a unique characteristic of a spectral filter. The idea behind this fingerprint sensor is to allow the information from the ridges to pass through the filter and spectrally block the information from the valleys.

1. The spectral filter

In the newly designed fingerprint sensor, 635 nm wavelength light is used to illuminate the finger. A spectral filter with the transmittance peak only greater than 635 nm, but not too close, is needed. The filter used in the sensor has two transmittance peaks at 728 nm and 610 nm wavelengths as shown in Fig. 18. It means that this filter transmits only 728 nm and 610 nm wavelengths at normal incidence and blocks all the other wavelengths. The requirement of the filter that it should have a transmittance peak only greater than 635nm, is not met by the currently used filter. However, there is a unique property of spectral filters as discussed in Section II, that the transmittance spectra shift to shorter wavelengths as the beam is tilted from normal to oblique incidence.

Experimentally, it was found that 632 nm (which is close to 635 nm) wavelength can get through the filter with maximum intensity at around oblique angle 42° as shown in Fig. 19. The above property of the spectral filter has a key role in the newly developed sensor. The filter was used without colored glass so that 635 nm wavelength can get through at an oblique incidence as shown in Fig. 19.

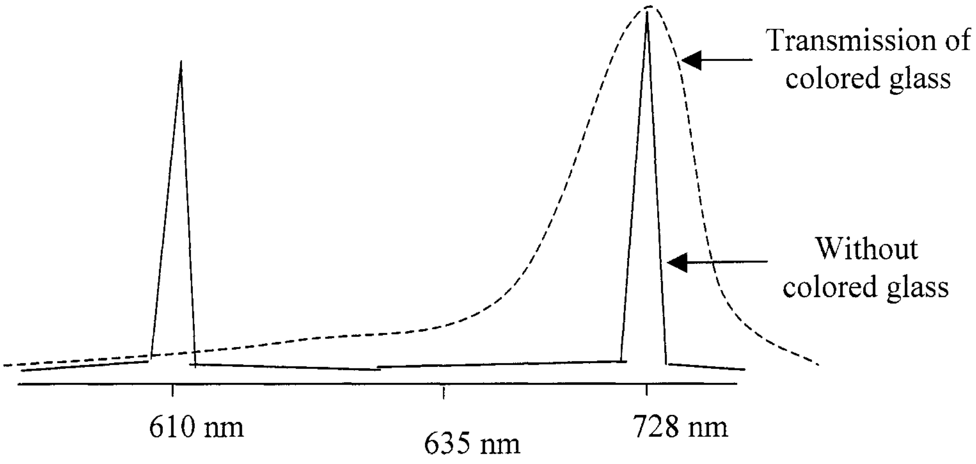


FIG. 18. Transmittance peaks in the spectral filter.

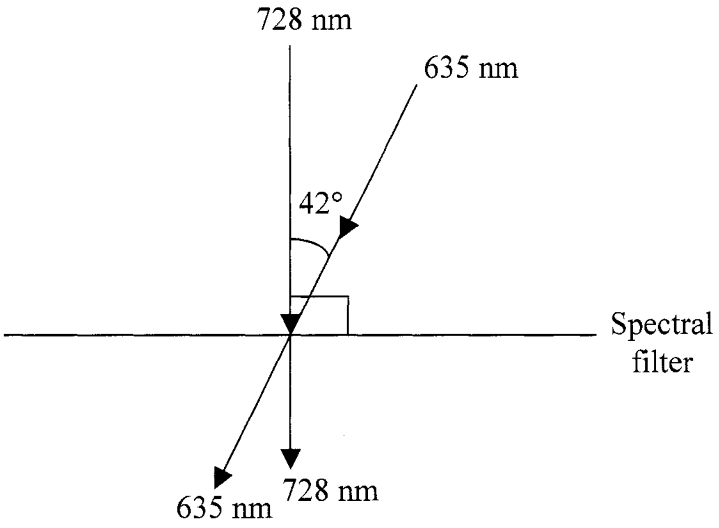


FIG. 19. Oblique angle of incidence for 635 nm wavelength.

2. Principle

The finger is pressed against the interference filter as shown in Fig. 20, which is exaggerated for clarification.

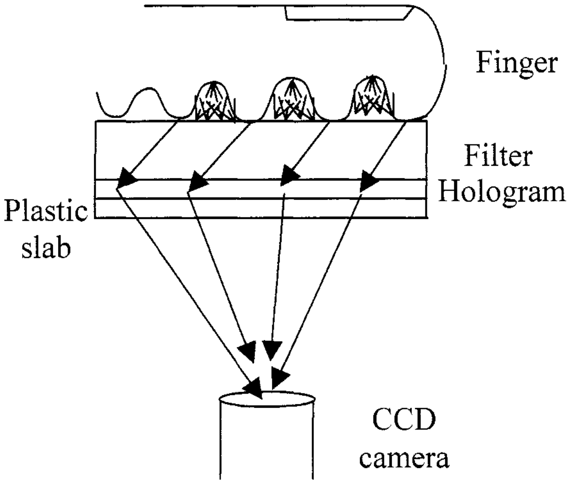


FIG. 20. Sensing a fingerprint.

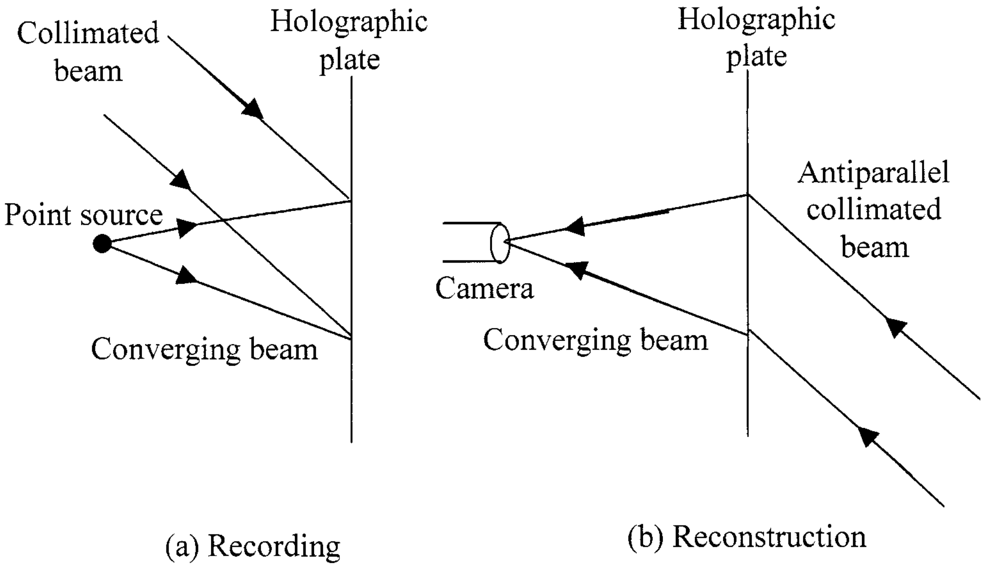
Light of 635 nm wavelength from the laser diodes uniformly illuminates the finger. The ridges scatter light in all directions, as the refractive indices of oil on the ridges and the filter glass match each other. The light rays from ridges, incident at an oblique angle greater than 42 °, are transmitted through the filter. The valleys also scatter light rays, but due to total internal reflection, rays can enter only within 42 ° angle inside glass. The rays within this angle are blocked by the filter, and hence are not transmitted by the filter. In this way, the information from valleys does not reach the camera. The converging hologram converges the rays from the ridges. These rays then pass through the plastic slab and are focussed onto the CCD camera lens. In this way, the information from the ridges is passed to the camera.

The converging rays thus carry information from the finger in the form of a high contrast pattern, the ridges appearing bright and the valleys dark. These rays are collected by the video camera and the image of the fingerprint is viewed on a TV monitor. The quality is extremely good, even the pores on the ridges can be seen.

The first task in the newly developed sensor was to build a converging hologram with a proper geometry. This would ensure that most of the rays, carrying information from ridges of the fingerprint, can be made to converge to the camera lens.

B. Recording geometry of a converging hologram

The basic recording geometry for a reflection and transmission hologram is discussed in Section III. The recording geometry of a converging hologram used in the newly developed sensor is shown in Fig. 21. The expanded collimated reference beam and the beam from the point source interfere at the holographic plate to give a converging transmission hologram. The important task in this case was to adjust the distance between the focussed point and the holographic plate to eventually make the rays from the fingerprint converge at the camera lens.

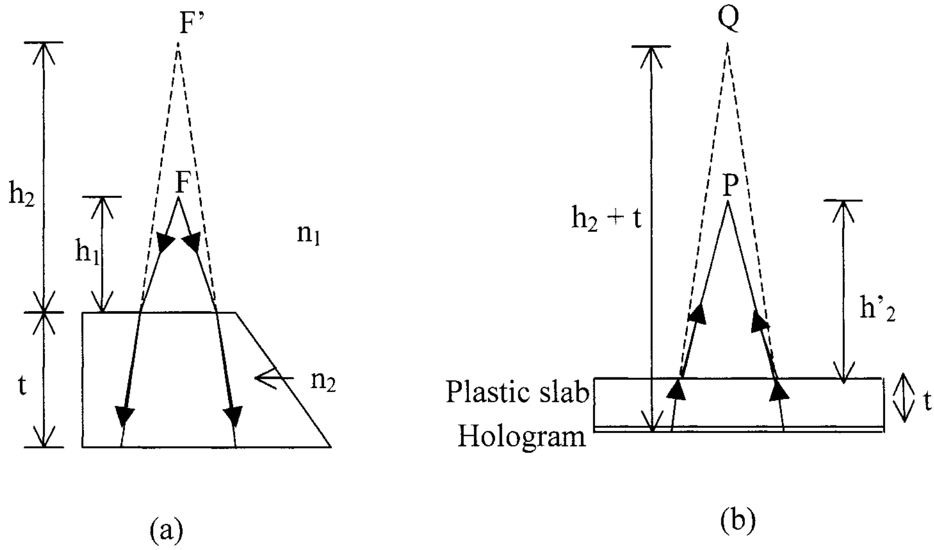


(a) Recording (b) Reconstruction

FIG. 21. Recording and reconstruction of a converging hologram.

First of all, by knowing the object distance of the camera lens, the distance between the point source and the holographic plate, required during the recording of a hologram, was calculated. The calculations are shown in the following section.

C. Recording geometry calculations



(a)

(b)

FIG. 22. Geometry for a hologram used in the fingerprint sensor.

F is the focussed point, F' is the focussed point of backward extended rays from the glass prism, h_1 is the distance between F and the pentaprism, h_2 is the distance between the F' and the prism, n_1 is the refractive index of air = 1, n_2 is the refractive index of prism (glass) = 1.5, t is the thickness of the prism = 3 cm, t' is the thickness of the plastic slab = 1 cm, and h'_2 is the object distance of CCD camera = 5.3 cm.

The thickness t of the prism was measured to be 3 cm. The object distance of the CCD camera was found to be 5.3 cm for full-size capture of the fingerprint. By using these known values with refractive indices in the formula:

$$n_1 / n_2 = h'_2 / (h_2 + t - t'),$$

we calculated h_2 distance as follows:

$$n_1 = 1, n_2 = 1.5,$$

$$n_1 / n_2 = h'_2 / (h_2 + t - t'),$$

$$1 / 1.5 = 5.3 / (h_2 + 3-1),$$

$$h_2 = 5.95 \text{ cm}.$$

To find the distance h_1:

$$n_1 / n_2 = h_1 / h_2,$$

$$1 / 1.5 = h_1 / 5.95,$$

$$h_1 = 4 \text{ cm}.$$

Therefore, the distance of the point source from the prism in the recording setup was found out to be 4 cm. The recording principle of a converging transmission hologram is shown in the Fig. 23.

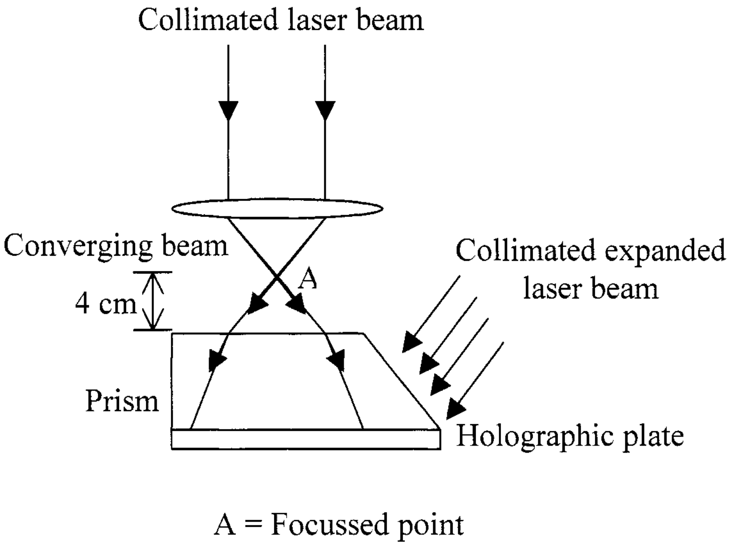


FIG. 23. Recording geometry of a converging hologram.

D. Recording setup for a converging transmission hologram

The recording setup for a converging hologram was achieved by using the following optical setup shown in Fig. 24.

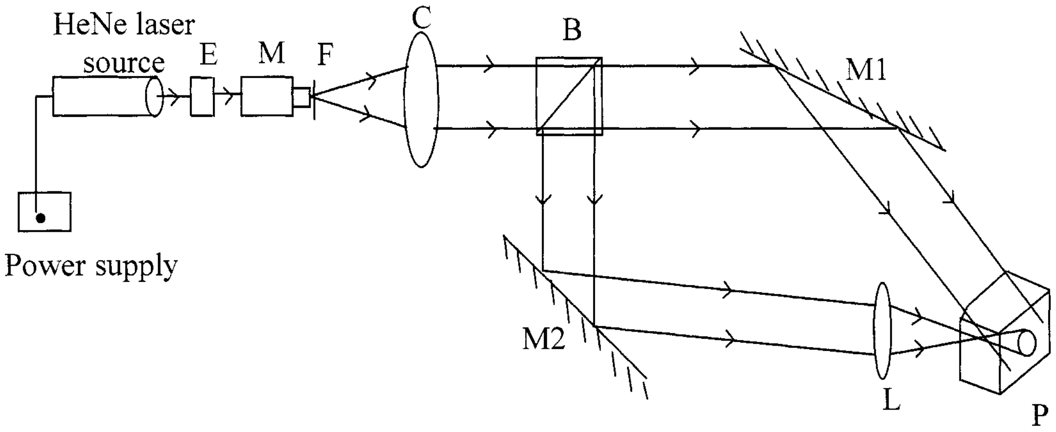


FIG. 24. Optical set-up used for recording of the converging hologram.

A 10 mW HeNe laser in the system is directed through an electronic shutter E and expanded by passing it through the microscopic objective M (40X), and then shined through a 10 micrometer pinhole F that acts as a spatial filter. The beam is then collimated with a positive lens C, with focal length 37cm, and passes through a beam splitter B. The collimated laser beam is split by the beam splitter, by amplitude division, into beam 1 and beam 2. Beam 1 hits the plane mirror M1, passes through one face of the trapezoidal prism P, and strikes on the holographic plate PFG-01 with silver halide emulsion away from the prism. Beam 2 hits the plane mirror M2. It then passes through the lens L with focal length 10 cm. The focal point of this lens acts as a point source. Beam 2, coming from this point source, passes through the adjacent face of the prism and strikes at the same portion of the holographic plate. These two beams interfere to give fine fringes, which bisect the angle subtended by these two beams as discussed in Section III.

It was found experimentally that the angle of incidence for maximum transmission at 632 nm (which is close to 635 nm) is 42°, as shown in Fig. 25. In the recording setup, the angle between beam 1 and beam 2 was adjusted to account for refraction at air-glass interface.

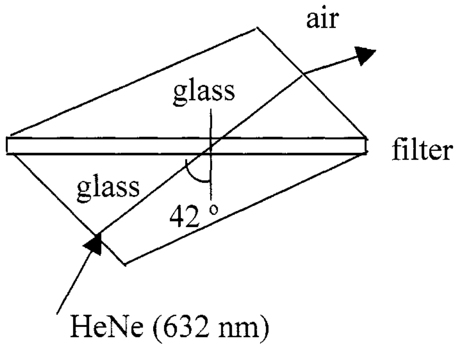


FIG. 25. Angle of incidence for 632 nm to get through the filter from glass to air.

In the recording step, the holographic emulsion was faced away from the prism; isopropyl alcohol was used as an index-matching fluid. After repeated recording and developing of holograms, the exposure time was optimized to 3 seconds. The final plate was exposed for 3 seconds, then developed to get amplitude grating, and bleached for 20 seconds to get a phase grating. Both developing and bleaching techniques are discussed in Section III.

E. Components used in the sensor

A good quality converging transmission hologram was successfully made satisfying all the required conditions. The remaining task was to find the correct interference filter. While recording a hologram, HeNe laser beam with 632 nm wavelength was used as shown in Fig 24. A filter, which transmits 632 nm wavelength incident at some oblique angle with the normal, was needed.

Also, the filter needed to be very thin to reduce the effect of refraction of the rays. This in turn, reduces the shift in the image of a fingerprint. The interference filter was selected without the colored glass, with two transmittance peaks, one at 728 nm and the other at 610 nm wavelength. This allowed 635 nm to get through at an oblique incidence. This filter was successfully used in the design of the newly developed sensor.

Another task was to find a compact source, emitting 632 nm wavelength light with maximum intensity to uniformly illuminate a finger. Small laser diodes of 635 nm wavelength were connected to a 3V supply, as shown in Fig. 26.

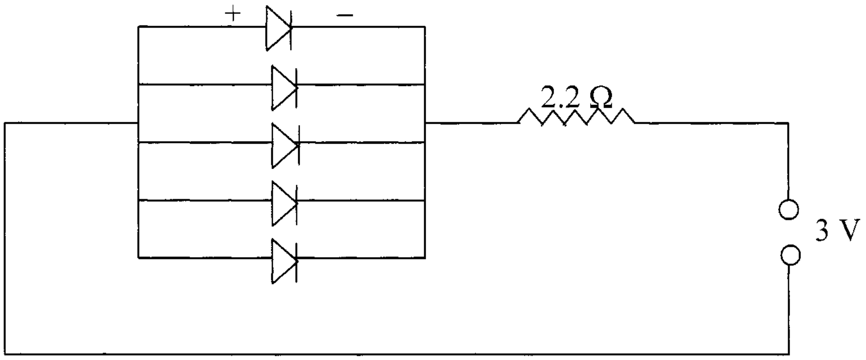


FIG. 26. Resistor circuit for the light source diodes.

F. Designing the sensor

The design of the sensor is shown in Fig. 27.

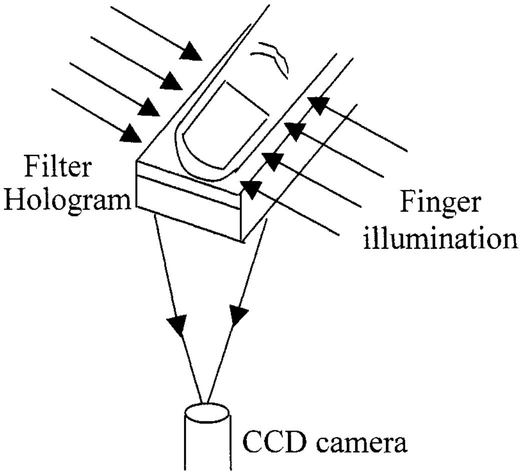


FIG. 27. Design of the final fingerprint sensor unit.

A good quality converging hologram is glued with Norland 68, an ultraviolet curing adhesive, to a plastic slab, which is used as a support to the hologram and the filter. The emulsion of hologram is now facing away from the slab and rotated at 180 °. The selected interference filter is then glued to the emulsion side of the hologram. The CCD camera is placed at a distance such as to get a clear fingerprint. The input voltage given to the CCD camera is 9 V. Using the CCD camera with a frame grabber allows direct connection to a computer.

G. Quality of a fingerprint

The quality of a fingerprint is extremely good; even the pores on the ridges can be seen. Ridges on the fingerprint are bright and valleys are dark. The fingerprint has a nice contrast and is uniformly bright and sharp. The final fingerprint is a high quality image.

VI. CONCLUSION

A fingerprint scanner using a converging transmission hologram and a spectral filter has been successfully developed, permitting the scanner of a very high quality fingerprint image with visible pores and very low smudge. Nowadays, taking someone's fingerprint is no longer restricted to criminal or government agency employees. Any new driver or an individual planning to travel abroad has to go through the excitement of being fingerprinted, which has greatly expanded the fingerprint business and opens new doors for the commercialization of this scanner.

On this scanner, the interface is glass, which permits easy cleaning. One of the possible improvements in this scanner would be the use of small size sources to illuminate a finger and folding the optical path, by using a mirror, to reduce the size of the sensor.

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