Digital Holographic Technique Based Fingerprint Authentication for Criminal Investigation

S. Thansy and M. K. Sheeja

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Thansy . S[1] and Dr. Sheeja M.K[2]

***Abstract*— In this age of highly advanced digital image processing, it is very difficult to store biometric details like fingerprint of a highly wanted criminal in a secure manner. Any digitally stored data can be forged, or the stored data can be easily destroyed or manipulated. Hence, a secure storage and easily recovered method need to be applied in such fields. Digital holographic data storage is one of the most secure storage methods available that can be used to resolve this problem. It provides a credible way in the fingerprint acquisition in the criminal investigation field. The accurate phase reconstruction is the unique advantage of digital holography compared with traditional fingerprint acquisition methods. In addition, digital holography has many significant advantages, such as simple, high accuracy and high resolution, moreover, it is a non-destructive method, does not undermine the on-site fingerprints. Also, some digital image processing can be applied to the original hologram and the reconstructed image, such as the image contrast brightening, filtering and so on. Therefore, it is possible to obtain a digital hologram with higher quality. Hence, digital holography can be used for secure storage and analysis of fingerprints in the criminal investigation field.**

I. INTRODUCTION

Fingerprints are the most accurate and commonly used biometric technique for personal identification. Since 1880s fingerprints were used as biometric techniques for human identification in the criminal investigation field[1]. It is the invariant property and uniqueness of fingerprint which makes it a person identifier. The main problem arises when it comes to the secure storage of the fingerprints.By conventional methods latent fingerprints cannot be collected without staining the surface with the fingerprint. Also with the very advanced techniques in digital image processing, any image stored digitally can be manipulated or destroyed. It is a matter of concern when it comes to the fingerprints of highly wanted criminals. Such fingerprints stored digitally can be easily manipulated by simply influencing an officer in the forensic department. Also if a malicious attacker gains access to the device, the attacker also gains access to the biometric.

Many techniques were used for increasing the security of stored fingerprints. Stark C Draper proposed a method using Selpian Wolf codes which described a method to encode fingerprint biometrics securely for storage.They presented a model for a secure biometric system. But there was a trade off between the security of the system and the robustness of authentication[2]. Davida,Frankel,and Matt considered the use of error correction coding as a solution to this problem[3]. Juels and Sudan introduced the idea of a fuzzy vault to formalize the use of error correction codes for such applications[4].Several researchers have explored crypotographic aspects of the problem in more depth. In all these methods the fingerprints have to be encoded first. But even after encoding, they are stored in a digital manner, which again can be forged.

Here comes the need of digital holography in the criminal investigation field.Digital holography is a perfect combination of optical holography and computers.Compared with other imaging tools, digital holography has got many significant advantages like it has got high resolution and accuracy, it is contact less and fast, quasi-real time reconstruction is possible and a lot of powerful digital image processing techniques can be applied.In this paper the application of digital holography in the field of criminal investigation is proposed. The fingerprint samples collected if stored in the form of digital holograms cannot be manipulated or forged. When required these digital holograms can be reconstructed and used. The advantage of the holographic data storage make this a unique and novel method for the secure storage and analysis of fingerprints in the criminal investigation field.

II. THEORETICAL ANALYSIS

A. Recording Of Digital Hologram

The hologram generation is an interference process, and holograms are usually recorded with a laser light source.The wave containing the information of the object is called the object wave, and the other interfering wave is the reference wave. For simplicity, the reference wave is sometimes taken to be a uniform plane wave. In general, the object wave at the recording plane can be described as

$$E_0(x,y) = a_0(x,y)exp(i\phi_0(x,y)) \quad (1)$$

where a_0 is the amplitude and ϕ_0 is the phase of the object wave.The reference wave at the recording plane can similarly be described as

$$E_R(x,y) = a_R(x,y)exp(i\phi_R(x,y)) \quad (2)$$

where a_R is the amplitude and ϕ_R is the phase of the reference wave.Then, the recording intensity I(x,y) is proportional to the hologram function h(x,y)in digital holography, can be expressed as

$$h(x,y) \propto I(x,y) = \left|E_0(x,y) + E_R(x,y)\right|^2 (3)$$

$$= (E_0(x,y) + E_R(x,y))(E_0(x,y) + E_R(x,y))^* \quad (4)$$

[1]Thansy . S, PG Scholar, Department of Electronics and Communication Engineering,SCT College Of Engineering, Thiruvananthapuram,Kerala

[2]Dr.Sheeja M.K,Professor,Department of Electronics and Communication Engineering,SCT College Of Engineering,Thiruvananthapuram,Kerala

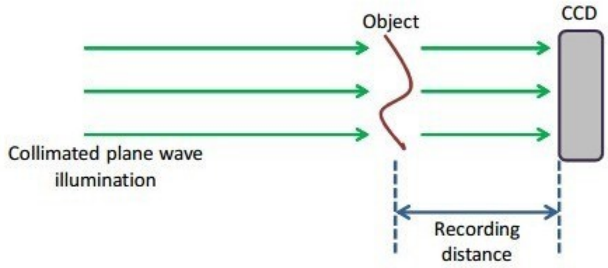

Fig. 1: Diagram of a Gabor set up

$$= |E_0(x,y)|^2 + |E_R(x,y)|^2 + E_0(x,y)E_R^*(x,y) + E_R(x,y)E_0^*(x,y) \quad (5)$$

which contains the dc term (the first two terms), as well as information of the virtual image (the third term) and the real image (the fourth term), respectively.

There are various experimental arrangements for generating a digital hologram. Two of these arrangements are - the Gabor setup and the Mach-Zehnder setup.

The Gabor set up is an inline set up and is shown in Fig. 1.When a collimated beam is incident on the object, the optical field behind the object depends on the nature of the object. The interacting fields forming a hologram on the recording plane comprises of the diffracted field from the object and the part of the reference beam bypassing the object. For opaque objects, the Gabor setup registers the hologram of the edge of the object.

The Mach-Zehnder setup can be either in-line or off-axis, and is shown in Fig.2. The original collimated beam passes through a beam-splitter, so that the object beam and the reference beam can be separated. The object is usually a reflective object, and the object beam contains the information of the surface of the object. The depth or height information of that surface, which modulates the phase of the reflected light, is encoded in the interference pattern or hologram. Reconstruction of the hologram, along with proper phase unwrapping, can yield the exact surface profile of the object.

B. Reconstruction Of The Fresnel Digital Hologram

In this Section, the most commonly used reconstruction approach in digital holography, viz., the Fresnel reconstruction approach, is summarized. Fig.3 shows the commonly used coordinate system for the object plane, the hologram plane and the image plane during reconstruction. Generally, the reconstruction of a hologram can be achieved by the Fresnel-Kirchhoff integral[5]:

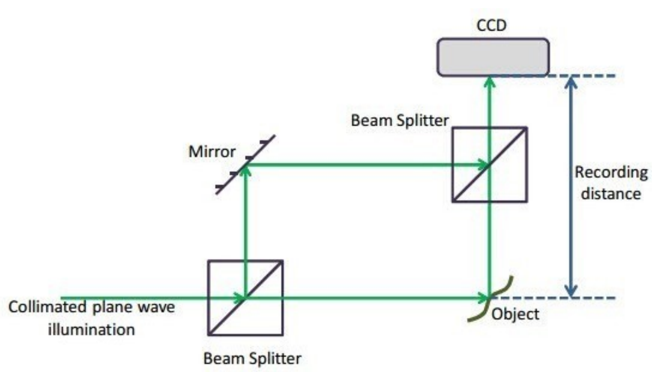

Fig. 2: Diagram of a Mach-Zehnder setup

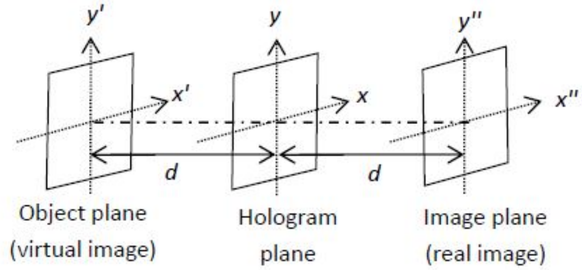

Fig. 3: Diagram showing the relation between the object plane, the hologram plane and the image plane

$$E'(x',y') = \frac{i}{\lambda}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} h(x,y)E_R^*\frac{e^{-i\frac{2\pi\rho}{\lambda}}}{\rho}dx\,dy, \quad (6)$$

where

$$\rho = \sqrt{(x-x')^2 + (y-y')^2 + d^2} \quad (7)$$

represents the distance between a point in the hologram plane and a point in the reconstruction plane (here, for instance, the object or virtual image plane), λ is the wavelength and d represents the recording distance, which is equal to the reconstruction distance. $E_R^*(x,y)$ denotes the reconstruction wave, which, for a plane wave, can be modeled simply as a real constant. Equation (5) can be expanded to a Taylor series:

$$\rho = d + \frac{(x-x')^2}{2d} + \frac{(y-y')^2}{2d} - \frac{1}{8}*\frac{[(x-x')^2 + (y-y')^2]^2}{d^3} + ..., \quad (8)$$

where the fourth term can be neglected if it is small compared to the wavelength. Therefore, if the recording distance d can satisfy the following condition:

$$\frac{1}{8}*\frac{[(x-x')^2 + (y-y')^2]^2}{d^3} << \lambda\,, \quad (9)$$

the distance ρ can be expressed as:

$$\rho = d + \frac{(x-x')^2}{2d} + \frac{(y-y')^2}{2d} \quad (10)$$

The condition expressed in (9) is called the Fresnel approximation. In this way, the optical field at the object plane can be reconstructed. The intensity of the reconstructed object field is

$$I(x',y') = \left|E'(x',y')\right|^2 \quad (11)$$

and the phase is,

$$\phi(x',y') = arc\,tan\frac{Im[E'(x',y')]}{Re[E'(x',y')]} \quad (12)$$

In digital holography, the recording is done on a CCD camera which has a certain pixel size [6].In digital reconstruction,if

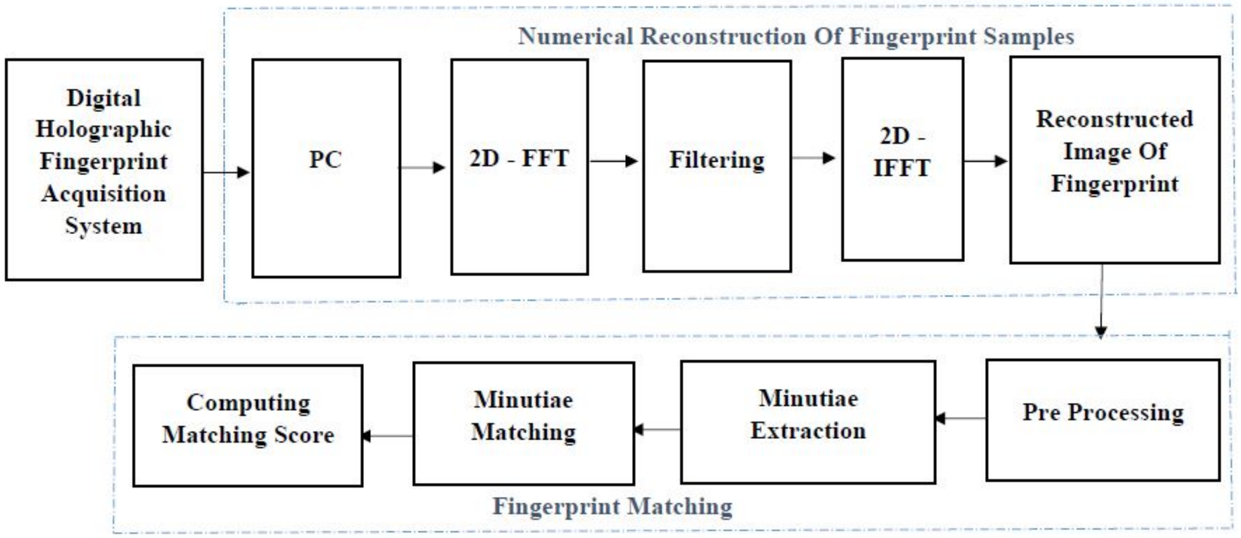

Fig. 4: Block Diagram of the System

Δx and Δy represent the pixel size in the hologram plane, the pixel size in the reconstruction plane $\Delta x^{'}$ and $\Delta y^{'}$ are calculated as:

$$\Delta x^{'} = \frac{\lambda d}{N_x \Delta x} \, and \, \Delta y^{'} = \frac{\lambda d}{N_y \Delta y} \tag{13}$$

where N_x is the number of the pixels in the x-direction and N_y is the number of the pixels in the y-direction. This introduces a pixel magnification factor in the Fresnel reconstruction. If only the intensity map is desired, this effect can be eliminated by resizing the result. However, if the phase is also required, this effect has to be carefully taken into account.

III. EXPERIMENTAL SET UP

Making a hologram involves recording a two beam interference pattern. To make a hologram we need two coherent light waves. One beam is reflected from the fingerprint sample and carries information about the sample. This wave is called the object beam. The other is a plane wave without information, which is called reference beam. The object beam and the reference beam, generate an interference pattern which is recorded as a digital hologram on the Charge Coupled Device (CCD) camera. The system can be divided into three stages namely,

1) Digital holographic fingerprint acquisition
2) Reconstruction of digital hologram of fingerprint
3) Fingerprint Recognition Using Minutiae Score Matching

Block Diagram of the system is shown Fig.4 .

A. Digital Holographic Fingerprint Acquisition The core part of this set up is a Helium - Neon laser of wavelength 632nm.The light from the laser first falls on the beam splitter which splits the beam into two separate beams - object beam and reference beam as shown in Fig.5.Beam splitters are identified by their beam ratio. While recording a transmissive digital hologram the reference beam should be stronger than the object beam. By making the reference beam stronger than the object beam, the cross interference of the object wave front with itself is reduced, thus it will reduce overall noise seen in the image.Fingerprint sample along with it's acquired digital hologram is shown in Fig.6. A shutter can be placed between the laser and the beam splitter. This is used to control the exposure time. Holograms made without spatial filters produce poor quality images. It cleans the laser beam from cosmetic defects which may be due to dust particles, multiple reflections and scattering. Thus spatial filter removes random fluctuations from the intensity profile of a laser

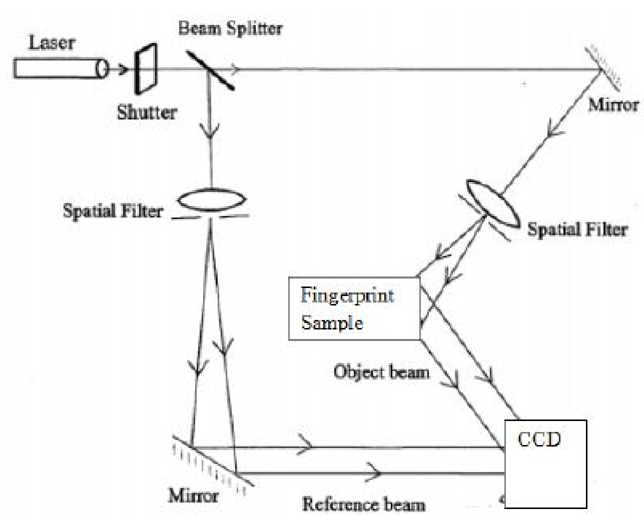

Fig. 5: Optical setup for Recording the Digital Hologram of Fingerprint

beam. This greatly improves the resolution of the holographic images. The main function of the spatial filter is to filter the inter interference of wave fronts from the laser. The main components of a spatial filter are a lens and a pinhole. The light from the laser source is directed into the lens. Only light that is perfectly focused on the pinhole can pass through. All other light, which contains the imperfections, is blocked. The digital hologram is recorded on a CCD camera which is connected to a computer from which it can be numerically reconstructed to obtain the amplitude and phase images separately.

B. Reconstruction Of Digital Hologram Fig.7 schematically illustrates the image-reconstruction procedure of digital holography using the Fourier-transform method. A 2D Fourier transform (FT) localizes the object-wave information, and the large angle difference separates the object wave from unwanted image components of the hologram in the spatial frequency domain xy. Due to the filtering in the spatial frequency domain, only the object-wave information is obtained. After the calculation of a 2D inverse FT (IFT), removal of the spatial carrier generated by tilting the reference wave, and calculation of diffraction integrals, focused intensity and quantitative phase images are obtained from a single hologram. A 2D fast Fourier transform (FFT) is used to accelerate the calculation. Although spatial characteristics, such as field of view and resolution, are partially sacrificed to obtain intensity and phase images of an object from a hologram, single-shot holographic imaging can be achieved. Modern high-speed cameras have got a frame rate of 1 Mfps, and such cameras can be used to perform digital holographic recording with a frame rate of 106 fps. In contrast, the high calculation cost is a problem that should be solved. It takes much more time to compute the diffraction integrals with a commercially available computer because of the demanding calculation requirements for the 2D FFTs. Use of graphics processing unit (GPU) and field programmable gate array (FPGA) are possible solutions to achieve holographic image reconstruction with extremely high throughput.

C. Fingerprint Recognition Using Minutiae Score Matching Fingerprints are widely used in daily life for more than 100 years due to its feasibility, distinctiveness, permanence, accuracy, reliability, and acceptability. Fingerprint is a pattern of ridges, furrows and minutiae, which are extracted using inked impression on a paper or sensors. A good quality fingerprint contains 25 to 80 minutiae depending on sensor resolution and finger placement on the sensor. The false minutiae are the false ridge breaks due to insufficient amount of ink and cross-connections due to over inking. It is difficult to extract reliably minutia from poor quality fingerprint impressions arising from very dry fingers and fingers mutilated by scars, scratches due to accidents, injuries. Minutia based fingerprint recognition consists of Thinning, Minutiae extraction, Minutiae matching and Computing matching score. Fingerprint Recognition using Minutiae Score Matching can be done with the help of MATLAB codes.

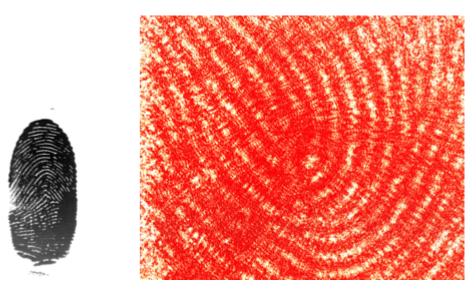

Fig. 6: Fingerprint and Digital Hologram of Fingerprint

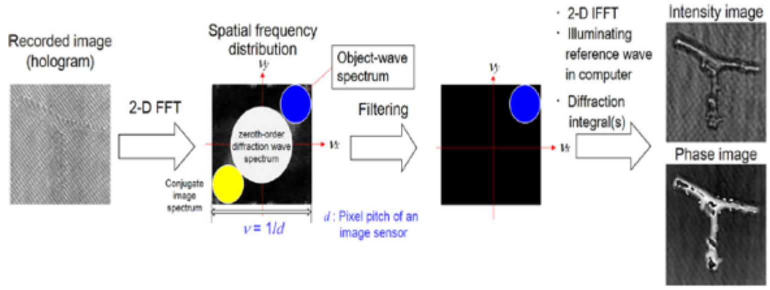

Fig. 7: Numerical Reconstruction of Digital Hologram

Fig. 8 shows the block diagram of Fingerprint Recognition Using Minutiae Score Matching (FRMSM) which is used to match the test fingerprint with the template database which contains fingerprints reconstructed from digital holograms using Minutia Matching Score.

Fingerprint Image: The input fingerprint image is the gray scale image of a person, which has intensity values ranging from 0 to 255. In a fingerprint image, the ridges appear as dark lines while the valleys are the light areas between the ridges. Minutiae points are the locations where a ridge becomes discontinuous. A ridge can either come to an end, which is called as termination or it can split into two ridges, which is called as bifurcation. The two minutiae types of terminations and bifurcations are of more interest for further processes compared to other features of a fingerprint image.

Binarization: Binarization is used to convert gray scale image into binary image by fixing the threshold value. The pixel values above and below the threshold are set to '1' and '0' respectively. A fingerprint sample after Binarization is shown in the Fig.9.

Block Filter: The binarized fingerprint sample is thinned using Block Filter to reduce the thickness of all ridge lines to a single pixel width to extract minutiae points effectively. Thinning does not change the location and orientation of minutiae points compared to original fingerprint which ensures accurate estimation of minutiae points. Thinning preserves outermost pixels by placing white pixels at the boundary of the sample, as a result first five and last five rows, first five and last five columns are assigned value of one. Dilation and erosion are used to thin the ridges. A

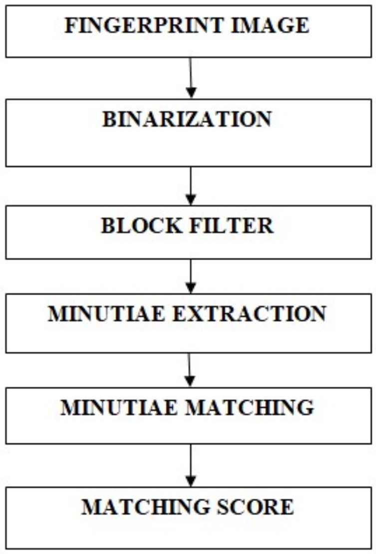

Fig. 8: Block Diagram for Fingerprint Recogniton using Minutiae Score Matching

fingerprint sample after thinning is shown in Fig.10.

Minutiae Extraction: The minutiae location and the minutiae angles are derived after minutiae extraction. The terminations which lie at the outer boundaries are not considered as minutiae points, and Crossing Number is used to locate the minutiae points in fingerprint image. Crossing Number is defined as half of the sum of differences between intensity values of two adjacent pixels. If crossing Number is 1, 2 and 3 or greater than 3 then minutiae points are classified as Termination, Normal ridge and Bifurcation respectively. To calculate the bifurcation angle, we use the advantage of the fact that termination and bifurcation are dual in nature. The termination in an image corresponds to the bifurcation in its negative image hence by applying the same set of rules to the negative image, we get the bifurcation angles. Fig.11 shows the extracted minutiae points from a fingerprint sample.

Minutiae Matching: To compare the input fingerprint data with the template data minutiae matching is used. For

Fig. 9: Binarized Fingerprint Sample

Fig. 10: Thinned Fingerprint Sample

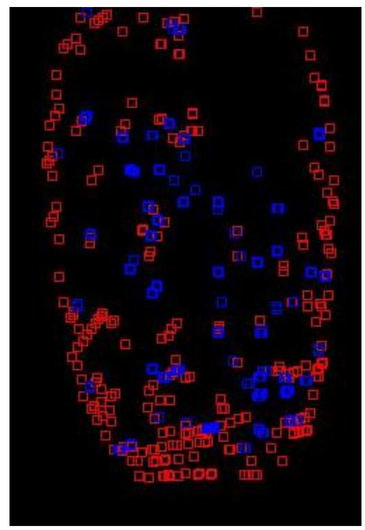

Fig. 11: Minutiae Points Extracted from Fingerprint Sample

efficient matching process, the extracted data is stored in the matrix format. During the matching process, each input minutiae point is compared with template minutiae point. In each case, template and input minutiae are selected as reference points for their respective data sets. The reference points are used to convert the remaining data points to polar coordinates. Finally matching score of two fingerprint samples are computed, if matching score is greater than or equal to 0.50 samples are matched and if it is less than 0.50 then they are mismatched.

IV. RESULT AND DISCUSSION

A set of digital holograms of fingerprints were recorded.Fig.12 shows the photograph of the experimental set up used for recording the digital hologram of fingerprint. After recording, the recorded digital holograms were numerically reconstructed and the output fingerprint was analysed. It was observed that the output obtained was having the same size as that of the input fingerprint.Fig.13 shows one of the reconstructed image of fingerprint sample.After reconstruction the reconstructed fingerprint samples were matched with input fingerprint samples using Fingerprint Recognition Using Minutiae Score Matching(FRMSM).The reconstructed fingerprint samples were matched with input

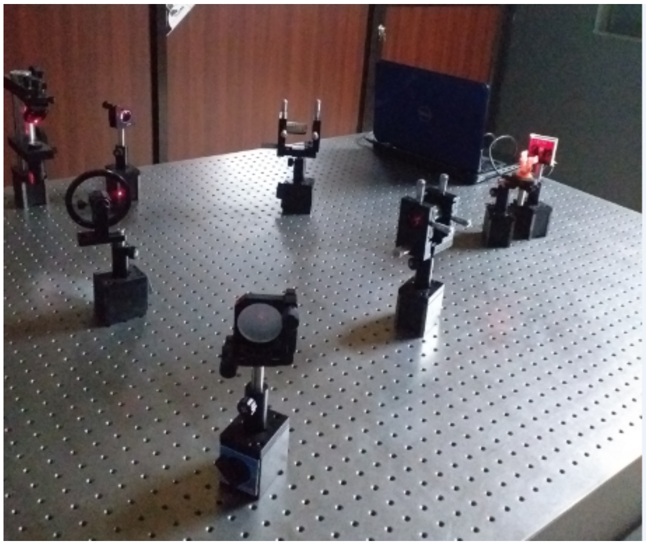

Fig. 12: Experimental setup used for Recording the Digital Hologram

Fig. 13: Reconstructed Fingerprint Sample

fingerprint samples which were aligned in different positions and it was found that they were correctly matched. Also performance metrics like False Matching Ratio and False Non Matching Ratio were evaluated.

V. CONCLUSION

Digital holography can be applied to the fingerprint acquisition field for criminal investigation. With the plane mirror to carry the fingerprint, one can theoretically analyze the principle of digital holographic recording and reconstruction, and investigate the reconstruction methods of the fingerprint amplitude and phase contrast image, and then can obtain the clear fingerprint amplitude and phase contrast image. The phase contrast image is clearer than the amplitude image, so the police can obtain fingerprint veins information not only from the amplitude image, but also from the phase contrast image. It provides a credible way in the fingerprint acquisition in the criminal investigation field. The accurate phase reconstruction is the unique advantage of digital holography compared with the traditional fingerprint acquisition methods. In addition, digital holography has many significant advantages, such as contact-less, fast, simple, high accuracy and high resolution, moreover, it is a non-destructive method, does not undermine the on-site fingerprints. Also, some digital image processing can be applied to the original hologram and the reconstructed image, such as the image contrast brightening, filtering and so on. Therefore, it is possible to obtain the digital hologram with higher quality. Correspondingly, the better fingerprint image can be expected in the near future. Hence, digital holography can be applied for acquiring fingerprint, and has a strong practical application in the criminal investigation field.

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