Fingerprint Recognition Using Deep Learning - A Review

David Winters*[1]

[1] Computer Science and Engineering, Shivalik Group of Collegers,
Dehradun, 248001, India
Email: jcsiseditor@gmail.com

Abstract

There have been efforts to address the problems with fingerprint identification systems that require physical contact by creating contactless fingerprint identification systems. Numerous studies on various aspects of contactless fingerprint processing, including the use of deep learning in various algorithmic frameworks, classical image processing, and the machine-learning pipeline, have been published. It was demonstrated that the deep learning-based solutions were more accurate than the alternatives. This effort was driven by a desire to provide a thorough assessment of these successes and their identified limitations. This study examined three approaches to contactless fingerprint recognition: (i) methods for capturing images of the fingerprint, (ii) traditional preprocessing techniques for enhancing fingerprint images for recognition tasks, and (iii) deep learning. (i) taking a picture of your finger, and (ii) using conventional image processing to get the picture ready for recognition. In total, eight research papers were found to meet both the inclusion and exclusion criteria. Based on this review's findings, we discussed the potential benefits of deep learning methods for biometrics and the challenges that still need to be overcome before these methods can be used in practical biometric settings.

Keywords: Biometrics; contactless fingerprint; deep learning; fingerprint recognition.

1. Introduction

The technology that allows for contactless fingerprint identification has the potential to become one of the most trustworthy methods for performing biometric identification [1,2]. As an alternative to the more conventional method of fingerprinting that relies on physical contact, the first contactless fingerprint identification system was presented in 2004 [3, 4]. Since then, there has been an increase in interest, which is demonstrated by the consistently expanding number of articles produced by a variety of research organizations. This work provides additional evidence to support the hypothesis that the demand for non-contact fingerprint identification technologies is fast growing [5]. It has also been claimed by the National Institute of Standards and Technology (NIST) that a contactless fingerprint identification system is a key component of next-generation fingerprint technologies [6]. In most cases, a high-resolution camera is required for a contactless fingerprint system to function [7,8]. The collected images reveal the finer characteristics of fingerprints, such as ridges, valleys, and wrinkles, among other things [9]. Traditional contact-based fingerprint identification systems provide a number of issues, one of which is the process of acquiring fingerprints [10]. During the process of acquiring a contact-based fingerprint, problems such as a latent fingerprint left on the sensor surface by a prior user can result in a poor quality fingerprint [10–12]. Additionally, fingerprints are subject to deformation and distortion as a result of the pressure that is placed on the sensor surface [12]. It is possible for there to be distortions as a result of non-uniform finger pressure being applied to the device, finger ridge alterations as a result of severe labor or injuries, variable illumination being applied to the finger skin, or motion artifacts occurring during the process of image capture [13]. When fingerprints come into touch with the scanner, the flow of the ridges may become interrupted.

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During the capturing process, there is also a possibility of a substantial amount of background noise being injected [14]. In many cases, only a portion of a fingerprint is collected due to the possibility that the remaining portion will be lost or smudged during the process of capture [8], as shown in Figure 1.

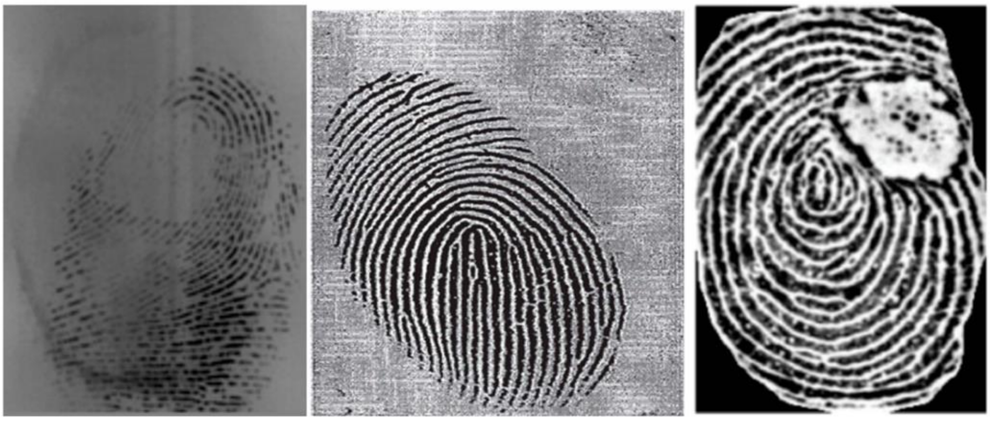

Figure 1: Several difficulties are associated with the creation of fingerprint impressions based on contact: images that are a) hazy, warped b) deformed c) distorted, deformed images

This procedure is susceptible to variables such as background and illumination, as well as incomplete information, low quality, distortions, and other types of errors [15]. There may be a large range of intra- and inter-class variability in the fingerprint that is acquired as a result of the variances in sensors and the acquisition environment. This variability can be measured in terms of resolution, orientation, sensor noise, and skin conditions. The image of a fingerprint that is captured by a contactless sensor does not have any issues with deformation or latent fingerprints that are hidden [7,10]. On the other hand, new difficulties will inevitably arise here. For instance, the collected images may be of poor quality, with variable sizes, low resolutions, background segmentation, or uncontrolled illumination, and thus may present challenges when attempting to extract characteristics such as minutiae, finger augmentation, and so on [16]. According to the National Institute of Standards and Technology (NIST), a standard fingerprint image, which is typically the frontal part of the finger, requires imaging sensors with a resolution of 500 dots per inch for a high-quality application [17]. Smartphones and other hand-held electronic devices are able to take pictures of these [7, 18-20].

The ridge–valley contrast that is obtained by the contactless finger picture is distinct from that which is obtained by a print created by making physical contact with a live-scan capturing device [24]. [13,16,25,26] Various technologies for the acquisition of fingerprint pictures, such as 2D and 3D fingerprints, have been developed in order to address this issue. Image processing can help alleviate some problems, however the majority of the problems still lie in the domains of contactless 2D and 3D fingerprinting [27]. Deep learning technology has shown promising results in recent years in the areas of image identification, classification, and feature representation. These deep learning models have also been implemented in fingerprint-based biometric devices that do not require physical contact. It is required to perform a comprehensive survey on the most recent research findings on 2D and 3D contactless fingerprint recognition systems based on deep-learning technology. This is necessary in order to grasp those models and figure out the future path of future development. It is important to keep in mind that there is a specific method of acquiring contactless finger photo images, and this method has the potential to have an effect on the performance of the deep learning models. In addition, it would be helpful to have an understanding of how the limits of traditional machine learning pave the way for the application of deep learning in the field of contactless fingerprints. Deep neural network (DNN) techniques for fingerprint recognition without physical contact were investigated in this study. In order to accomplish this, it was necessary for us to investigate the machine learning (ML)-based techniques in order to contrast them with the DNN methods. The first steps in contactless fingerprint identification involve taking a photo of the fingerprint and processing the image. The processes of feature extraction and recognition based on ML and DNN approaches have both been investigated by our team. In order to determine whether or not the proposed DNN approaches are practically viable, a number of test outputs and how well they performed were

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evaluated. The methods of fingerprint capturing, fingerprint preprocessing, and feature extraction in traditional image processing and machine learning were explored in this work, as well as the replacement of traditional methods by deep learning. There were a total of 32 papers (excluding duplicates) found that were connected to these subjects. After applying the criteria for inclusion and exclusion, we decided to conduct a full-text review of eight different studies. The ridge–valley contrast that is obtained by the contactless finger picture is distinct from that which is obtained by a print created by making physical contact with a live-scan capturing device [24]. [13,16,25,26] Various technologies for the acquisition of fingerprint pictures, such as 2D and 3D fingerprints, have been developed in order to address this issue. Image processing can help alleviate some problems, however the majority of the problems still lie in the domains of contactless 2D and 3D fingerprinting [27]. Deep learning technology has shown promising results in recent years in the areas of image identification, classification, and feature representation. These deep learning models have also been implemented in fingerprint-based biometric devices that do not require physical contact. It is required to perform a comprehensive survey on the most recent research findings on 2D and 3D contactless fingerprint recognition systems based on deep-learning technology. This is necessary in order to grasp those models and figure out the future path of future development. It is important to keep in mind that there is a specific method of capturing contactless finger picture images, and that this method has the potential to influence how well deep learning models function. In addition, it will be helpful to have an understanding of the ways in which the limits of traditional machine learning pave the way for deep learning in the area of contactless fingerprints. Deep neural network (DNN) techniques for fingerprint recognition without physical contact were investigated in this study. In order to accomplish this, it was necessary for us to investigate the machine learning (ML)-based techniques in order to contrast them with the DNN methods. The first steps in contactless fingerprint identification involve taking a photo of the fingerprint and processing the image. The processes of feature extraction and recognition based on ML and DNN approaches have both been investigated by our team. In order to determine whether or not the proposed DNN approaches are practically viable, a number of test outputs and how well they performed were evaluated. The methods of fingerprint capturing, fingerprint preprocessing, and feature extraction in traditional image processing and machine learning were explored in this work, as well as the replacement of traditional methods by deep learning. There were a total of 32 papers (excluding duplicates) found that were connected to these subjects. After applying the criteria for inclusion and exclusion, we decided to conduct a full-text review of eight different studies.

2. Fingerprint Capturing Methods

A contactless fingerprint capture involves presenting one or more fingers to an optical device such as a camera or lens. This can be done with one or more fingers. These devices can either be general-purpose devices that have been modified to fit the specific requirements of contactless fingerprint recognition or they can be prototypes of new hardware designs developed by researchers. One of the generally available methods for capturing 2D contactless fingerprint photographs is to use an image acquisition method that is based on a smartphone [4]. The National Institute of Standards and Technology (NIST) [17] produced a document to evaluate techniques of contactless fingerprint capturing; the publication gives necessary directions for equipment that capture contactless fingerprints. It covers the smartphone's homogeneous lighting, its ability to segment the backdrop, and its motion reduction capabilities during photography. Smartphones also allow for the deployment of techniques that capture many fingers at once. The feature extraction of all five fingers can occur from a single image, which is one of the benefits of multi-finger capture, which also has the advantage of being more efficient. 1320 fingerprints were taken in order to conduct an analysis of how well the Nokia N95 and HTC Desire mobile phones performed in this regard. In order to get the desired level of lighting and to cover all of the finger region, a phone equipped with a flashlight was utilized. On the other hand, users rated the image quality to be subpar, which makes sense given that a flashlight is most effective in a dimly illuminated environment [22]. If you want to increase image quality and cut down on camera noise, shooting in low-light conditions could be a very crucial factor. Auto-focus and keeping a consistent distance between the hand and the phone are both possible tactics that could be effective. The distance between the hand and the phone in Figure 4 is the same, as is the amount of illumination.

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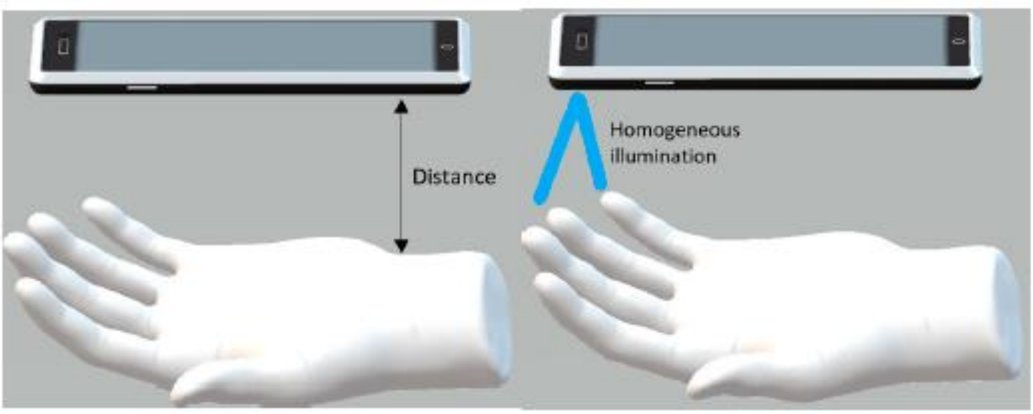

Figure 2: Homogeneous distance illumination with auto focus capturing by smartphone.

Figure 5a shows the impressions of a fingerprint captured with a contact-based fingerprint device, and Figure 5b shows the equivalent finger image acquired with a non-contact device (the Galaxy S8). Both of these images can be found in the same figure. (Shown in Figure 5b). The equivalent contactless fingerprint image would require extra processing in order to discover features such as ridges, valleys, delta cores, and minutiae, whereas the contact-based fingerprint can be directly used for finding features such as these.

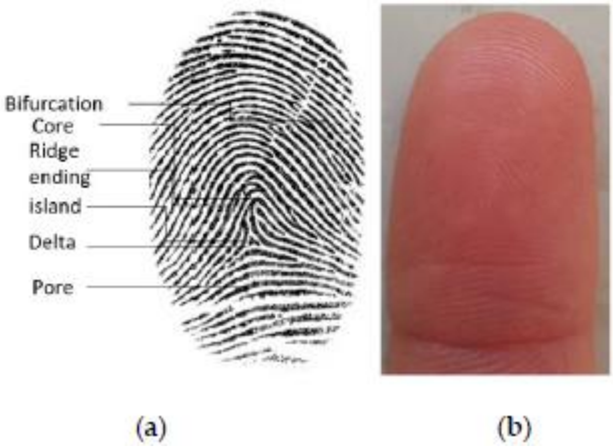

Figure 3 : Contact-based fingerprint, (**b**) contactless fingerprint (Samsung Galaxy S8) [15].

Another instrument that can be used to take contactless 2D fingerprint photographs is a digital camera. White-color-based image sensors and LED-color-based image sensors are the system's defining characteristics [10]. The collection of fingerprints from three users. The charge-coupled camera device has a green LED that it emits, and it has a stepper motor with a mirror that allows it to take pictures of five fingers at the same time, which makes it very practical. This involves photometric stereo methods, structured light scanning, and stereo vision in addition to each other. The photometric stereo-based 3D fingerprint approach uses a high-speed camera to record several 2D photos of the fingerprint under a variety of different lighting conditions. The primary premise behind this method is known as time of flight (ToF), and it involves measuring the surface reflectance of a fingerprint in relation to a light source. Because there is only one high-speed camera and a number of LEDs used in this system, the price is quite reasonable. The method of capturing is depicted using the camera and the finger location in figure 6.

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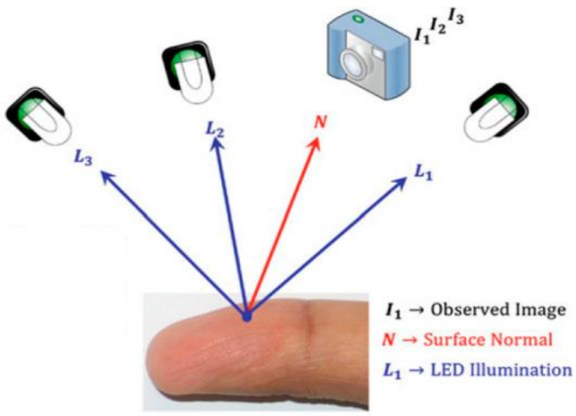

Figure 4: Acquisition of 3D fingerprint using photometric stereo techniques [39].

A number of high-speed cameras and a digital light-processing projector are required for the structured light-scanning technology. During the process of capture, several 2D fingerprint photos are taken under pattern illuminations, and 3D depth information is then derived using triangulation based on the point correspondences between the images. The ridge-valley details may be recovered using this method, and the resulting 3D depth information is relatively precise. Nevertheless, the hardware system is cumbersome and prohibitively expensive. The stereo-vision-based contactless 3D fingerprint method typically consists of two or more cameras to capture the user's fingerprint data. During the process of capture, two-dimensional fingerprint images are obtained from a variety of perspectives. The triangulation principle is used to reassemble the three-dimensional fingerprints by computing the three-dimensional depth information that exists between corresponding spots. The fact that the systems are easy to use, inexpensive, and very compact is a significant advantage. However, present solutions typically require a great deal of time because to the substantial computation that is required to determine the correspondences between pixel locations.

3. Classical Method to Extract Features from Contactless Fingerprints

The basic steps for contactless fingerprint recognition pipeline are shown in Figure 7 as a flowchart:

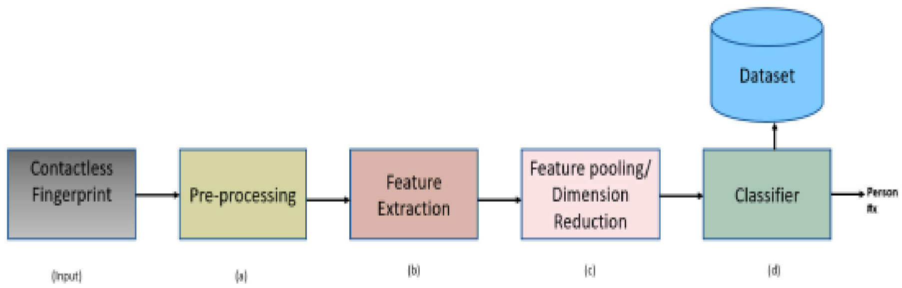

Figure 5: The steps of fingerprint recognition process

The vast majority of the device's contact-based fingerprint photos are taken in grayscale and are ready to have their features extracted. On the other hand, the majority of contactless systems for imaging the finger generate color RGB images, which need to be pre-processed before feature extraction can take place. When processed with traditional methods, both contactless 2D and 3D photos have issues with low focus of ridge/valley and fuzzy ROI (background). This is especially true for contactless 3D images. Processing problems can also be caused by fingers that are rotated or misplaced, as well as by a lack of skin deformation. During the process of acquiring images, a processing pipeline for those images needs to be built, and it must take into account both the chosen hardware and the necessary

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ambient conditions. The image processing procedure starts with the standard preprocessing steps, which are as follows:
Segmentation and Detection of Fingerprints: The first thing that has to be done is to identify the finger based on its color and its shape. There are four distinct areas for enhancing contactless 2D and 3D finger identification and image segmentation [13]. These categories include sharpness, shape, color contrast, and image depth information. Strategies that are based on sharpness take advantage of the disparity in sharpness that exists between the focused, blurry background and the sharp finger area. This effect is most effective when applied to photographs that were taken with a very close proximity of the subject's finger to the sensor and a large aperture. According to the results of an experiment [10], the variance-modified Laplacian of Gaussian (VMLOG) algorithm is the one that works best for contactless 2D fingerprint-capturing devices. The forms of all of the fingers, from the thumb to the little finger, are extremely similar for decoding any finger position. An approach that is based on machine learning was utilized, and then applied to a binarized image that used the LUV color model [10]. The examination of the YCbCr color space is a very important step to take in order to make the color of the skin contrast with the backdrop color and differentiate the color of the skin from the background color. An alternative method of picture segmentation and a strategy to obtaining image depth information combining an RGB image obtained from a mobile device. These were able to isolate the finger slap from the busy backdrops in order to continue processing it. The finger slap consisted of the four fingers except the thumb.

Extraction of Features Based on the Minute: Converting photos from RGB to greyscale is one of the primary requirements for pre-processed contactless fingerprints. This is also one of the essential prerequisites. As a result, aspects of return on investment (ROI) including minutiae, ridge valley extraction, and finger orientation estimate need to be managed using a machine-learning approach. After the finger has been located, the region of interest (ROI) must be extracted, a process that requires the width, height, and resolution to be normalized. This stage of the 3D contactless fingerprint preprocessing requires an extracted image of the fingerprint to be used as the input. It is important to keep in mind that the output is where finger detection and ROI extraction take place. The color-based segmentation of limited ROI extraction setups is dependent on the geometry of the contactless three-dimensional finger [10]. The location of the core point was determined by many processes based on the direction and contour of the ridge line. When using a support vector machine, or SVM, it is simple to categorize minutiae-based fingerprints and to detect the minutiae points as the detection points to refer to as a category. Additionally, it is simple to detect the minutiae points as the detection points. SVM is able to determine the image quality by using five feature vector lengths, such as the gray mean, the gray variance, the contrast, and the coherence ratios. Implementing these functionalities requires a significant amount of training time.

Improved quality of the fingerprint image: picture enhancement techniques such as spatial domain techniques and frequency domain techniques can be used to increase the quality of a picture. These approaches can be used to boost contrast and sharpness in an image. A fingerprint image that has been enhanced should have a lighting pattern that is consistent throughout the image. In the research that was done on this topic, three distinct approaches were found: a normalization that made use of mean and variance filters, histogram enhancements such as contrast-limited adaptive histogram equalization (CLAHE), and local binary patterns (LBP) for improving the ridge–valley contrast of the 2D contactless fingerprint system. Another problem that contactless 3D fingerprint enhancement must overcome is the reduction of the blurred image relative to the original image [14]. Genovese et al. came up with the idea of using a combination of image processing methods and machine learning in order to extract sweat pores from level-3 fingerprint patterns.

6. Conclusion

The contactless fingerprint snapshot capture method, the traditional approach to fingerprint recognition, and the application of deep learning were the primary focuses of this review. In particular, we have elaborated deep-learning algorithms since these methods have demonstrated progress in contactless fingerprint recognition, despite the fact that very little research has been conducted on the topic. The accuracy of contactless fingerprints is always improving, and as a result, a wide variety of new fingerprinting applications have been made possible thanks to them. They have made the security system more vulnerable to dangers relating to the growth of terrorist activity and cybercrime. The use of contactless fingerprint biometrics has also spread to commercial facilities, portions of the border

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crossing process, airports, and government access points. In addition, fraudulent activity on credit card accounts, unauthorized access to websites, and, most importantly, the critical corruption of government agencies such as the Department of Defense and the Department of Homeland Security call for the development of systems that can be solved with contactless fingerprint biometrics. These deep learning approaches have shown promising generalization capacity across a variety of datasets. We have provided a summary of their architecture as well as its implementation at several sub-stages, such as pre-processing, feature extraction, classification, and matching. The potential downsides of using deep learning models were also investigated in this study. In conclusion, deep learning-based contactless 3D fingerprint identification systems have demonstrated improved usability, and they are quickly becoming a commonly utilized alternative to traditional biometric performance modalities. As a result, the focus of our future research will be on developing new deep-learning approaches or improving upon those that already exist in order to meet specific foreseeable issues associated with contactless fingerprints. These challenges include accelerating the process of feature extraction, decreasing the amount of time necessary to analyzes photos, and boosting identification accuracy. In addition, additional palmprint patterns and other biometric traits will be taken into consideration as potential applications of deep learning techniques.

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