

Exploring the Enabling Technologies of Contactless Fingerprint Reader

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Abstract-The most common way to identify a person is by using their fingerprint, which involves comparing two fingerprints: one that has been saved as having been previously captured and one that is now being scanned by a sensor. The human fingerprint is one of a kind; it can withstand the system for an individual's entire lifetime; and it is recognized in the field of forensic inquiry. In older systems, the finger is allowed to make as many contacts with the sensor as necessary throughout the scanning process, which might cause the sensor's quality to decline. The quality of fingerprint images may be improved using a variety of approaches, each of which has been presented by a different researcher. This study examines a variety of fingerprint identification methods, including Minutia-based mapping and the CNN algorithm, both of which make use of deep learning.

Keywords: Fingerprint, Fingerprint Sensor, Biometrics, Minutia, Neural Network, Deep Learning

I. INTRODUCTION

When it comes to identification in a variety of contexts, the singularity of a person's identity is a crucial factor to consider. This can be accomplished using several methods of identification, such as fingerprints, the face, or the iris. Biometric systems are essentially pattern recognition systems human physiological or behavioral characteristics If sufficient for universality, biometric features, Uniqueness, durability, and collectability. Three more factors should be considered in practical applications such as: performance, acceptance, bypass, i.e. It is robust enough against various cheating methods. A common biometric system contains four basic components:

- 1) A sensor module that captures biometric data.
- 2) Feature extraction module with captured data processed to extract feature vectors
- 3) a matching module that compares feature vectors against the template;
- 4) a decision module containing the user's sid and established or claimed identity is accepted or rejected.

The biometric system can operate in two modes:

Identification: A person is recognized by comparison with a whole database of templates to find matches. The system performs a one-to-many comparison to personal identity. The identified person does this no need to claim identity.

Verification (Authentication): Person to be identified his identity must be claimed and this template will be compared to individual biometric characteristics. System performs a one-to-one comparison to determine identity the only one. before the system can Specific biometrics of a person, the system needs something compare with So include a profile or template Biometric properties are stored in the system. Record of a person's characteristics are called registrations. Fingerprint Perception is the art of satisfying a person's identity. It is since everyone has their own fingerprint. This is his one of the most used and actively studied. Biometric technology.

The use of an individual's fingerprint as a form of identification in a variety of contexts is one of the earliest forms of skin impressions still in use today. Fingerprints have been used in history to characterize, act as a form of signature in commercial transactions, and be used in legal proceedings since the ninth century AD [1]. This practice began with clay in China during the Tang dynasty. Since the beginning of law enforcement, a thousand years ago, fingerprints have been used to identify suspects and criminals using clay. Since then, fingerprints have also been employed in forensic and investigative work. It has been going on up until this point. An impression of an individual made on a surface is known as a fingerprint [2]. The first automated fingerprint identification system (AFIS), launched in the 1980s and used for criminal identification, has been crucial to the operations of police and other law enforcement organizations throughout the globe [3]. The many ridges on the skin combine to form a pattern that is unique to each person's fingerprint [4]. This pattern may be found on each finger. The ridges and valleys that make up a fingerprint are captured in the image that is taken of the fingerprint (furrows). Because of the repeated contact of the finger with the sensor, dust and noise can be left on the sensor; therefore, the cleanliness of the sensor is an important issue. In addition to this, the contact-based fingerprint can lead to increased maintenance costs. Traditional fingerprint recognition systems allow the stored fingerprint to be matched by fingerprint verification and identification. The stored fingerprint can be matched by fingerprint verification and identification in physical

contact-based fingerprint recognition systems. Direct contact of the finger with the sensor can leave a latent fingerprint on the surface of the sensor, which can be easily lifted off the surface of the sensor. A contactless fingerprint recognition system [5] could be used to solve this problem. Because the technologies involve the acquisition of fingerprints, they may also pose some security concerns. According to the National Institute of Standards and Technology (NIST), one of the developing technologies for fingerprint recognition is the contactless fingerprint. The fingerprint that is acquired by a contactless sensor does not have the same issues as a latent or buried fingerprint [6]. The key challenges that can also be faced in a contactless fingerprint recognition system include the following: Captured images can be of poor quality, with different sizes, low resolution, background segmentation, or uncontrolled illumination; additionally, there may be difficulty extracting features such as minutiae, finger enhancement, and other similar characteristics. According to the NIST, a standard fingerprint image is generally requiring 500 dpi imaging sensors for a good-quality application and can be captured by smart-phones or a handheld electronic device. The scanned image from contactless fingerprint scanner contains ridge-valley contrast that is different from the ridge-valley of contacted scanned image [7]. Using biometric, authentication can be achieved dramatically faster, easier, and more secure than traditional password system [8].

II. RELATED WORK

For the purposes of research into contactless fingerprint identification, single-finger devices have been replaced by multi-finger capture systems as the point of departure. The weight of single-finger devices has steadily increased over the years. The first fully functional system, as well as the first hardware configurations for it, were published by Hiew et al. [9] and Wang et al. [10], respectively. The research concentrated almost entirely on a few different process modules. The variations in data gathering methodologies, processing methods, and quality issues between 2D and 3D were investigated in a study by Parziale and colleagues [11]. Labati et al. [12] provided a comprehensive review of touchless 2D and 3D fingerprint recognition systems. Within the scope of this study, there was a discussion on the application of unwrapping methods, which are used to transform touchless fingerprints into touch-based fingerprints that are similar. In addition to that, an excellent discussion of the various techniques for feature extraction and comparison was provided in this article. Malhotra et al. [13] have just released a survey study on mobile fingerprint identification systems that are based on smartphones. Hanzhuo et al. [14] achieved more exact minutiae extraction and pose-invariant matching using a technique that does not require physical contact with the fingerprint. In addition to that, a method for the direct extraction of minute details using a deep neural network was also developed. The use of contactless fingerprint technology was the

driving force behind both significant advances, which made them possible. Jannis et al. [15] developed a system for the automated recognition of fingerprints on mobile devices that does not require interaction. They also provided a detailed explanation of the identification procedure and the need for a fully automated capture system. In addition, they gave me the information.

A. Fingerprint Matching Techniques: It is necessary to carry out the fingerprint matching operation in order to compare the scanned fingerprint to the stored fingerprint. Rims that do not move at all during the lifting action can be used to individually identify a person, as can the different ridges that are found on each person's fingers [16]. There are two main categories that may be used to classify fingerprint matching techniques: those that focus on minute details and those that focus on broad features. By making use of the core techniques for fingerprinting, we can maximize the number of fingerprint pairings down to the most minute degree of detail that is conceivable. A feature-based method [17] can be used to extract fixed-length global features after applying a Gabor filter to the region surrounding the reference point. There are three other applications for fingerprint matching methods, which are as follows:

Minutiae-based: A vital stage in verification and identification issues is fingerprint matching. A fingerprint matching algorithm roughly compares two fingerprints and produces either a dichotomic output or a degree of similarity (a real integer bounded into an interval) matched or non-matched. The representation of the fingerprint obtained through enrollment is used as the blueprint (T) in the following, and the representation of the input fingerprint (I). If two fingerprints come from the same finger, they are said to be authentic; if not, they are said to be impostor fingerprints. The output of the minutia extraction stage is at least one set of minutiae. Each minutia is represented by its position coordinate and orientation angle, forming a 3-tuple $M = (x, y, \theta)$. The T and I fingerprints have m and n minutiae, respectively. a little thing in I is considered to match one subdivision M_i at T if within tolerance of M_i . Tolerance box is defined as the maximum allowable difference in clearance and direction to compensate for unavoidable errors. Change in position caused by feature point extractor and distortion.

Global and local minutiae matching: Fingerprint minutiae matching can initially be divided into two methods:

Global minutiae matching: Algorithms of this type approach the adjustment process considering everyone Specifics in a global manner. Since the number of components to align is at least three (2 orientations and angles), it can require high computational resources and often requires the use of a pre-alignment stage. Based on other extracted features such as single points and orientation maps.

The advantages of local feature point matching are simplicity, reduced computational complexity, and bias tolerance. Global feature point matching technology provides high discriminability. However, all these benefits can be achieved by using hybrid strategy that performs local minutia matching followed by an integration phase. The first step determines the pair of feature points to extract a subset of candidate alignments for I and T that match locally. The latter step that is less strict Required and intended to see how well local matches support global matches.

Local minutiae matching: They are constructed by comparing two fingerprints according to their local detail structure. this Structures are formed by considering various relationships based on the proximity between closer minutiae. They are characterized by properties that are invariant to global transformations such as translation and rotation. soshe does not consider global relations and allows matching with partial information. Identification spots may be found in the minutiae of a fingerprint, and their relative positions are also important. According to Galton, each ridge contains extremely few characteristics, and two fingerprints match only if their fingerprints match [18]. Minutiae are the spots on a fingerprint where ridges cease or diverge from one another.

Correlation-based: In general, matching by image correlation takes place when two fingerprint pictures are superimposed, and the similarity between them is determined by comparing the correlation between comparable pixels for various alignments. However, this ostensibly straightforward procedure rarely produces results that are acceptable, primarily because of unfavorable changes to the overall structure, brightness, and contrast of the image, both of which depend on distortions and skin condition. Additionally, this procedure might have expensive computational costs. This method makes use of two sets of fingers, each of which must be weighted, and then the ratio is computed for the associated elements. However, given that the displacement and rotation are not known, the relationship needs to be applied to all the available places. It is based on a significant amount of grayscale data; however, there is a possibility that the data quality is poor [18].

Pattern matching or Ridge feature based: Instead of relying on individual points to serve as the foundation for ridge characteristics, this method makes use of a succession of protrusions instead. It analyses the similarities and differences between the fundamental fingerprint patterns of the suitors and the burial fingerprint patterns. Calculating the difference between two fingerprint code vectors using the maximal characteristics of the fingerprint shape is required to complete the matching process [18].

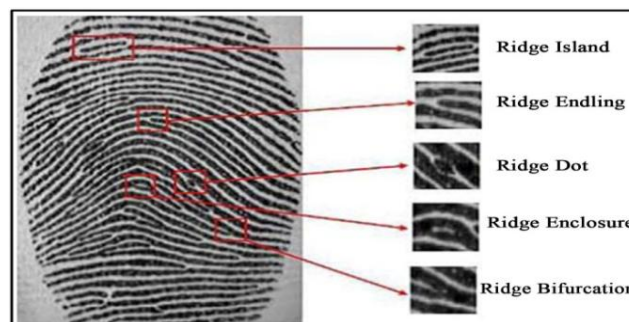


Fig.1. Ridgelinesminutiaetypesorpoints

B. Fingerprint Biometrics: The pattern of raised bumps and grooves on the palms and toes that are created by friction is what makes up a fingerprint. Because fingerprints are the most prevalent kind of identification, it is the one we will concentrate on in this tutorial [19]. Unique sole and foot prints are also a helpful identifier, but fingerprints are more generally utilized. In the finger picture, the grid is represented by black lines, while the ridges are represented by white lines. It is not uncommon to come across slopes and valleys that run parallel to one another and which may split off or even end. According to the findings of certain study, finger-shaped contact edges may be subdivided into three unique kinds. These categories include spiral rings, arcs, and other circular forms. Because the closure of the sharp end of the island ridge of the ridge, the bifurcation of the ridge, and other aspects of the ridge are required for the development of all minute types [20], ridges frequently give rise to minute types.

C. Fingerprint Recognition: The identification and verification of individuals using their fingerprints stretches all the way back to ancient times. An impression of a person's fingerprint is created when they drag a finger across a surface [21]. The collection of data, authentication of users, registration of users, and comparison of users are the four primary functions of the fingerprint authentication system. When accumulating information on a person's fingerprints, a sensor tool known as "data capture" is utilized. The use of fingerprinting as a digital template allows for the examination of individual characteristics and microscopic details. A procedure known as "authentication," which involves a comparison of identifying traits, gives users the ability to provide evidence that they are who they claim to be. A fingerprint is acquired and stored in case there is a discrepancy between the created concept and the missing data while doing a comparison of the two. It is a piece of software that searches through a database of scanned fingerprints to identify the one that most closely resembles a scanned fingerprint [19]. Since its inception in the 1980s as a tool to assist law enforcement agencies all over the world in the identification of offenders, the Automated Fingerprint Identification System (AFIS) has evolved into an invaluable resource [22].

D. Fingerprint Pattern: What are the types of fingerprint templates? There are many descriptions and descriptions of fingerprint patterns but Joannes Evanelista Purkinje discusses the function of the grooves and ridge holes in detail in that part of his article. He also described and explained 9 fingerprint patterns (1 arc 1 tent 2 rings 5 spirals) [23]. Purkinje made important observations about the four basic modes but the authors [19] of these observations focused on three basic modes by excluding only the tentacles in their study.



Fig. 2. Three basic fingers print ridge patterns

- **Loops:** The structure of the surface of the fingers. But other authors interpret it differently as the author [24] states that it enters from one end behind the finger and then curves out from the place where it entered.
- **Whorls:** The ridge pattern is described as a periodic pattern on the surface of the fingertip structures. There are four groups of spirals: simple (concentric) intermediate pocket rings (rings with spirals at the ends) double rings (two rings forming an S-shaped pattern) and random rings (irregular shape) [19].
- **Arch:** A crest pattern on the surface of a fingertip structure that grows between the start and end points of the pattern. A sort of crest that enters from one side and arches in the center and emerges from the other [24].

III. CATEGORIES OF FINGERPRINT MINUTIAE

The fingerprint minutiae can be of different categories. Table 1 is providing basics of these categories.

Table 1. Fingerprint Minutiae

Type of Minutiae	Description
Ridge ending	Steep edge of a ridge or point of sudden drop
Ridge Bifurcation	A point where a ridge splits into two ridges or a ridge split into two or more ridges
Ridge ponds, Lake, or enclosure	The ridge breaks and immediately rejoins and continues as a single ridge or as a gap between two separate ridges
Short ridge, islands, or	The ridge begins and ends after a short distance.

independent ridge	Ridge islands are slightly longer than peaks and occupy an area between two separate ridges
Ridge Dots	Neutral edges of equal length and width or very small edges
Spur	A short yoke with a disconnected link extends to the edge of the notch outside the yoke
Crossover or bridge	A connecting piece between two parallel edges. Bridges are small ridges that connect adjacent tall ridges. Intersections are formed when two edges cross each other

IV. CONTACTLESS FINGERPRINT CAPTURING TECHNIQUES

Contactless fingerprint authentication system is a technology allows you to capture fingerprints without physical contact on the sensor surface. Contactless system capture using contactless fingerprint capture ridge valley pattern. Contact-less fingerprint recognition systems uses digital camera to acquire the fingerprint image. There are advantages to using a digital camera. Fingerprint image acquired with a contactless device like these, they are undistorted and show no deformation. The image is touching pressure free. Contactless fingerprint authentication system can be shared preprocessing, feature extraction, and appropriate. Pretreatment is an important step before fingerprint feature extraction and matching. Further away Pretreatment is divided into four parts. normalized first, the second is fingerprint segmentation and the third is fingerprint improvement and finally finding a key point. Special function extraction can be done via Gabor filter or minutia extraction. Matching can be done with Support Vector machine or principal component analysis and three-distance method.

A. 2D Contactless Fingerprint Capturing Techniques: Two-dimensional fingerprint identification is mainly based on calorimetric optical elements such as cameras and lenses. Achievement can be divided into two categories.

Smartphone-Based Acquisition: Smartphones equipped with cameras of a high calibre are recommended for use in the process of capturing 2D fingerprint photos [25], and it is likely that you will have no trouble locating one of these devices. In order to determine whether the non-contact fingerprint identification technique was successful, 1320 photographs of fingerprints were taken outside with a Nokia N95 and an HTC Desire, utilizing natural light as the lighting source. If you use the built-in flash, the quality of your pictures could get worse, as indicated by the findings of this piece of research [26]. In the research that has been done on the subject, video-based contactless fingerprint recognition systems have been created to generate fingerprint photographs of high quality. The programme selects fingerprint images of the highest possible quality from among very short video frames. [27]. It is possible to recover up to five fingerprints from a multi-finger snapshot, which makes the use of a

contactless fingerprint system that is based on a smart phone a very helpful instrument [28].

Digital camera-based acquisition: When compared to using a smart phone for the same purpose, using a digital camera for the acquisition process allows for more creative freedom. It was determined to build a compact, optical, contactless fingerprint capture device with three cameras and various colored LEDs. The system's use of three cameras, each of which records a separate picture of the user's index finger, simplifies the placement of the user's finger while recording [27]. A contactless data collection system featuring a charge-coupled device (CCD) camera, mirror stepper motors, and a green LED The device's ability to capture five fingerprint images at once is a significant advantage. Nonetheless, only 25 seconds may be recorded at a time. Experiments on the technology have proven that it can obtain high-quality and contrasted fingerprint images [29].

B. 3D Contactless Fingerprint Capturing Techniques: 3D fingerprint reconstruction is a key component of 3D fingerprint recognition systems. In recent years several methods of 3D finger imaging have been proposed which can be divided into three categories according to the imaging method: 1) photometric stereo [30]; 2) structured light scanning [31]; 3) stereo vision [32].

Photometric stereo: The collection of several two-dimensional pictures of fingerprints captured with a high-speed camera and subjected to a variety of lighting conditions is necessary for stereo-based photometric approaches. The calculation of the reflectance of a three-dimensional surface may be done using photometric stereo based on the orientation of the surface with regard to the observer and the light source [33]. This is the underlying premise of the technique. The benefits of using this technology include its precision as well as its resistance to fraudulent activity [34]. It is a 3D fingerprint gathering system that is based on laser sensors. The method has the advantageous capability of immediately capturing 3D fingerprint patterns in the form of a point cloud [35].

Structured light scanning: System components for 3D fingerprint capture using structured light scanning generally include many high-speed cameras in addition to a DLP projector. Under the lighting conditions that were acquired throughout this procedure, a two-dimensional model of multiple fingerprint pictures was created. The triangulation method, in which three-dimensional depth data is computed based on point correspondences between pictures, is the idea that underpins this. The advantage is that they can recover ridge-to-valley detail and gain precise information regarding the 3D depth. Due to the need for special projectors and high-speed cameras, however, the hardware system needed for this method is too expensive and big to be practical [25].

Stereo Vision: In most cases, the generation of 3D fingerprints by stereo vision requires the use of two or more cameras. At various stages of the imaging process, many distinct, two-dimensional fingerprint pictures are obtained from the fingerprint subject. By measuring the distance between matching spots in three dimensions, the triangle rule is used in the process of reconstructing three-dimensional fingerprints. The low cost and simplicity of use of the system, in addition to its compact size, are all key advantages. However, current approaches sometimes require a significant amount of processing effort [25] because they require calculating the correlation between several different pixel values.

V. APPLICATIONS OF CONTACT-LESS FINGERPRINT TECHNOLOGY

Law Enforcement Agencies: Depending on how the fingerprints are use, every company has its own specific criteria for how they should be preserved. Since each business has its own unique set of demands, those organizations all have their own databases, which are frequently incompatible with one another. In more recent times, it has come to be acknowledged as a crucial stage in the process of creating law enforcement capabilities to establish databases that are uniform and accurate across all agencies.

Access Control: Access control is another area that can benefit from using the tool. In terms of usability, the fingerprint-based access control devices that are now available have a significant disadvantage. Users are frequently required to have their fingers scanned repeatedly before being allowed access. Due to the potential for anomalies between the fingerprint data captured by the capture device and the data saved in the database, it is possible that a fingerprint system will need to be utilized more than once. Because of this volatility, the margin for error in the system is increased, which in turn results in erroneous rejections and lowers trust in each game. Additional measures can be applied, if necessary, to boost levels of confidence associated with each game that is controlled by a high-security access system. The spoof detection method is a method that concentrates on identifying whether the finger is still alive and linked to the body at the present time.

Financial Transaction: E-commerce and private email communications are two examples of company activities that are ideal candidates for using biometric authentication. Token cards, badges, passwords, and PINs are just a few of the authentication techniques that are often used today. For the purpose of achieving high user trust and lowering the incidence of fraud in online transactions, these approaches may be supplemented with authentic fingerprint-based verification. Both automated teller machines (ATMs) and electronic commerce are examples of industries in the financial markets that have long benefited from

the use of contactless fingerprint readers that are available for purchase commercially.

VI. CONCLUSION

The fingerprints of a person are one of the most effective forms of biometric identification. Researchers have developed a wide array of approaches, including fingerprint identification systems that need touch and those that do not. In order to improve quality and match, a wide variety of technologies that are filter-based, minutiae-based, and feature extraction-based have been developed. The great majority of fingerprint recognition systems employ minutiae-based matching to verify both contacted and uncontacted individuals. This is because minutiae become more stable over time. It is possible to use the contactless system for Minutiae-based matching and high-boost filtering by employing a hybrid approach that is based on the concept of a deep learning algorithm. These are two issues that plague the contacting system because of sensor issues.

REFERENCES

- [1] Sonderegger, B., & Peter, M. U. (2013). The Fingerprint: 100 years in the Service of the Swiss Confederation. Confédération suisse: Federal Office of Police fedpol.
- [2] Perichappan, K. A. P., & Sasubilli, S. (2017). Accurate fingerprint enhancement and identification using minutiae extraction. *Journal of Computer and Communications*, 5(14), 28-38.
- [3] Drozdowski, P., Rathgeb, C., & Busch, C. (2019). Computational workload in biometric identification systems: An overview. *IET Biometrics*, 8(6), 351-368.
- [4] Chinnappan, C., & Porkodi, R. (2021). Fingerprint Recognition Technology Using Deep Learning: A Review. *SSRN Electron. J*, 9, 4647-4663.
- [5] Attrish, A., Bharat, N., Anand, V., & Kanhangad, V. (2021). A contactless fingerprint recognition system. *arXiv preprint arXiv:2108.09048*.
- [6] Stanton, B. C., Theofanos, M. F., Furman, S. M., Grother, P. J., Grother, P., & Pritzker, P. (2016). Usability testing of a contactless fingerprint device: Part 2. Gaithersburg, MD, USA: US Department of Commerce, National Institute of Standards and Technology.
- [7] Chowdhury, A. M., & Imtiaz, M. H. (2022). Contactless Fingerprint Recognition Using Deep Learning—A Systematic Review. *Journal of Cybersecurity and Privacy*, 2(3), 714-730.
- [8] Socheat, S., & Wang, T. (2020). Fingerprint Enhancement, Minutiae Extraction and Matching Techniques. *Journal of Computer and Communications*, 8(5), 55-74.
- [9] Hiew, B. Y., Teoh, A. B., & Pang, Y. H. (2007, May). Digital camera-based fingerprint recognition. In *2007 IEEE International Conference on Telecommunications and Malaysia International Conference on Communications* (pp. 676-681). IEEE.
- [10] Wang, L., Abd El-Maksoud, R. H., Sasian, J. M., Kuhn, W. P., Gee, K., & Valencia, V. S. (2009, August). A novel contactless aliveness-testing (CAT) fingerprint sensor. In *Novel Optical Systems Design and Optimization XII* (Vol. 7429, pp. 333-343). SPIE
- [11] Parziale, G., & Chen, Y. (2009). Advanced technologies for touchless fingerprint recognition. In *Handbook of Remote Biometrics* (pp. 83-109). Springer, London.
- [12] Labati, R. D., Genovese, A., Piuri, V., & Scotti, F. (2014). Touchless fingerprint biometrics: a survey on 2D and 3D technologies. *Journal of Internet Technology*, 15(3), 325-332.
- [13] Malhotra, A., Sankaran, A., Mittal, A., Vatsa, M., & Singh, R. (2017). Fingerphoto authentication using smartphone camera captured under varying environmental conditions. In *Human recognition in unconstrained environments* (pp. 119-144). Academic Press.
- [14] Tan, H., & Kumar, A. (2020). Towards more accurate contactless fingerprint minutiae extraction and pose-invariant matching. *IEEE Transactions on Information Forensics and Security*, 15, 3924-3937.
- [15] Priesnitz, J., Huesmann, R., Rathgeb, C., Buchmann, N., & Busch, C. (2022). Mobile contactless fingerprint recognition: implementation, performance, and usability aspects. *Sensors*, 22(3), 792.
- [16] Sabhanayagam, T., Venkatesan, V. P., & Senthamaraikannan, K. (2018). A comprehensive survey on various biometric systems. *International Journal of Applied Engineering Research*, 13(5), 2276-2297.
- [17] Zhang, F.D., Xin, S.Y. and Feng, J.F. (2019) Combining Global and Minutia Deep Features for Partial High Resolution Fingerprint Matching. *Pattern Recognition Letters*, 119, 139-147.
- [18] Pawar, S., Ghodke, A., Gaikwad, B.P. and Wakhure, G.P. (2016) A Survey of Minutiae Extraction from Various Fingerprint Images. *International Journal of Advanced Research in Computer Science and Software Engineering*, 6, 169.
- [19] Socheat, S., & Wang, T. (2020). Fingerprint Enhancement, Minutiae Extraction and Matching Techniques. *Journal of Computer and Communications*, 8(5), 55-74.
- [20] Mua'ad, M., Alqadi, Z. A., & Aldebei, K. (2021). Comparative Analysis of Fingerprint Features Extraction Methods. *Journal of Hunan University Natural Sciences*, 48(12).
- [21] Vidhya, R., & Gokila, S. (2022). Cloud-Based Biometric-Enhanced ATM Powered by Deep Learning. In *International Conference on Computing, Communication, Electrical and Biomedical Systems* (pp. 119-129). Springer, Cham.
- [22] De Hert, P., & Bouchagiar, G. (2021). Facial recognition, visual and biometric data in the US. Recent, promising developments to regulate intrusive technologies. Recent, promising developments to regulate intrusive technologies (October 18, 2021).
- [23] Datta, A. K., Lee, H. C., Ramotowski, R., & Gaensslen, R. E. (2001). *Advances in fingerprint technology*. CRC press.
- [24] Patel, U. (2015). A study on fingerprint (biometrics) recognition. *International Journal of Engineering Science*, 1, 1-6.
- [25] Yin, X., Zhu, Y., & Hu, J. (2021). A Survey on 2D and 3D Contactless Fingerprint Biometrics: A Taxonomy, Review, and Future Directions. *IEEE Open Journal of the Computer Society*, 2, 370-381.
- [26] Kukreja V. A retrospective study on handwritten mathematical symbols and expressions: Classification and recognition. *Engineering Applications of Artificial Intelligence*. 2021 Aug 1; 103:104292.
- [27] Kukreja V, Kumar D, Kaur A. Deep learning in Human Gait Recognition: An Overview. In *2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE) 2021 Mar 4* (pp. 9-13). IEEE.