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The Evolution of Forensic Facial Recognition: From Anthropometry to Multimodal Biometric Systems

Poorvi Ujjainia[1], Leoson Heisnam[2], Dr. Santosh Gaikwad[3], Sanjeev Saini[4], Arjun MS[5], Saumya Tripathi[6], Vaishalli[7]

[1]*Post Graduate, Department of Forensic Science, Chandigarh University, Mohali, Punjab, India*

[2]*Visiting Faculty, Department of cyber security and digital Forensic, National Forensic Science University, Manipur, India*

[3]*Associate professor, School of Basic and Applied Sciences, JSPM University, Pune, Maharashtra, India.*

[4]*Assistant Professor, Department of Mechanical Engineering, Maharishi Markandeshwar (Deemed to be University),Mullana, Ambala, Haryana, India*

[5]*Tutor, Department of Forensic Medicine and Toxicology, Kasturba Medical College, MAHE Manipal, Karnataka, India.*

[6]*Assistant Professor, Department of Biotechnology and Forensic Science, Bareilly, Uttar Pradesh, India.*

[7]*Assistant Professor, Department of Forensic Science, SGT University, Gurugram, Haryana, India.*

***Abstract* -** Forensic facial recognition is a crucial tool in contemporary investigations, benefiting from technological advancements that standardize and improve forensic processes for law enforcement agencies. Unlike other biometric applications, errors in facial recognition can have serious consequences, necessitating robust solutions tailored to the unique challenges of forensic contexts. This review provides a thorough examination of the evolution, challenges, and ethical considerations surrounding forensic facial recognition technology. It traces the development of technology from early anthropometric methods to modern deep learning approaches, and discusses the technical aspects and limitations of automated facial recognition systems. Furthermore, it discusses the legal landscape in India regarding automated facial recognition, highlighting important legislative provisions and their implications. The review also covers traditional and modern forensic methods, showcasing the shift from physical traits-based identification to multimodal biometric systems. Various applications of automated facial recognition, such as digital documentation, airport operations, and law enforcement initiatives, are explored to demonstrate the wide-ranging utility of this technology. In summary, this review offers a comprehensive analysis of forensic facial recognition, providing insights into its current status, challenges, and future directions.

Keywords: Automated facial recognition, Artificial Intelligence, Biometrics, Legislature, Forensic significance

1. Introduction

Forensic facial recognition plays a pivotal role in modern investigations, leveraging technological advancements to enhance the efficiency and standardization of forensic efforts conducted by law enforcement agencies[1], [2]. The integration of automated facial recognition systems within the judicial framework mandates a rigorous assessment and validation process anchored in empirically-grounded, scientifically sound methodologies. In contrast to various other biometric applications, the ramifications of an incorrect determination in forensic facial recognition carry substantially greater gravity, necessitating resilient solutions adept at surmounting the diverse array of challenges distinctive to the forensic domain[3], [4], [5]. Cutting-edge facial recognition systems, typically utilized for secure access and identification purposes, encounter impediments when employed in forensic scenarios. The fluctuations in facial morphology attributable to variables such as pose, lighting conditions, facial expressions, and image fidelity present formidable obstacles.[1], [2], [6], [7], [8].

Moreover, the forensic domain is typified by the presence of low-quality images often extracted from CCTV footage under suboptimal conditions, necessitating the employment of specialized recognition methodologies. Forensic facial recognition, conducted offline, diverges from real-time applications, affording a platform for meticulous scrutiny and alleviating time constraints. Acknowledging the gravity of potential errors, the judicial system demands a nuanced approach, integrating prior case knowledge to furnish a sophisticated level of support for one hypothesis over another [3], [7], [9]. Additionally, forensic facial reconstruction, aimed at recreating unknown faces, introduces an added layer of complexity for forensic examiners [8]. The evolution of automated facial recognition systems, as underscored by the National Institute of Standards and Technology (NIST), signifies remarkable progress. The precision of facial recognition techniques has escalated, achieving an accuracy rate of approximately 92% in identifying unknown subjects against a database of 1.6 million faces. Recent updates from 2018 disclose a diminished error rate of 0.2%, highlighting the rapid maturation of facial recognition technology[1]. Despite the triumphs of automated facial recognition systems in controlled environments, challenges associated with pose, illumination, expression, and aging impede their accuracy in forensic scenarios. Forensic facial recognition frequently necessitates a preprocessing phase, encompassing image enhancement or specialized matching algorithms to mitigate the repercussions of nonideal conditions [1], [7], [8], [9].

This thorough review explores the complex terrain of forensic facial recognition, examining the path of technological advancement, the hurdles faced by investigators, and the ethical dilemmas associated with the increasing use of facial recognition in democratic societies. From the incorporation of deep learning and convolutional neural networks to the growth of facial databases, this in-depth analysis aims to provide valuable insights into the status and future directions of forensic facial recognition technology.

2. Chronological Overview of Key Studies on Facial Recognition Technology: Anthropometry, Soft Biometrics, Forensic Applications, and AI

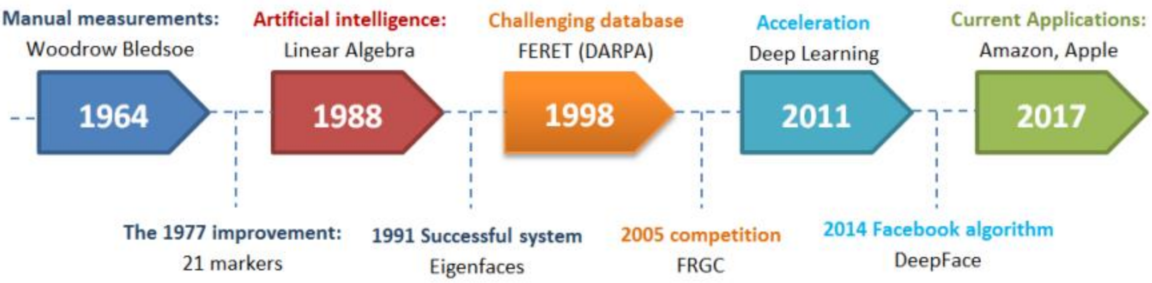
Table-1: The table provides a chronological overview of key studies spanning from 1932 to 2023, encompassing diverse aspects of facial recognition technology, including anthropometry, soft biometrics, forensic applications, and the role of artificial intelligence, elucidating their contributions and findings in this evolving field.[4], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]

Year	Author's Profile	Description of the Study	Findings
1932	Willoughby	Optimal Body Proportions	Proposes a systematic anthropometric method for determining optimal body proportions in adults, contributing to the early literature on anthropometry.
1986	Meaney et al.	Clinical Anthropometry and Medical Genetics	Presents a compilation of body measurements in the context of genetic and congenital disorders, offering insights into variations in body dimensions associated with specific genetic conditions.
1999	Burton et al.	Face Recognition in Low-Quality Video	Investigates challenges associated with recognizing faces in low-quality video conditions, particularly in security surveillance scenarios. Provides insights into the impact of video quality on facial identification accuracy.

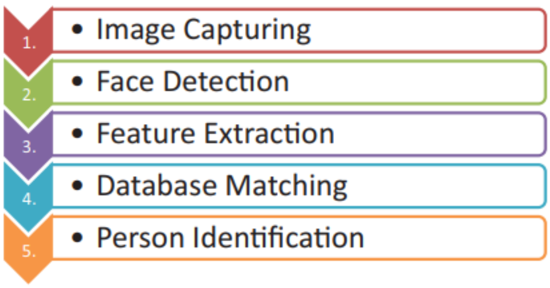
2003	Henneberg et al.	Research explores the human face from various perspectives, including craniometry, evolutionary aspects, and forensic identification.	Anthropometric examination of the relationships between soft and hard tissues contributes to anthropological studies.
2015	Arigbabu et al.	Feature extraction techniques and methods of application of facial soft biometrics.	Expounds upon recent advances in facial soft biometrics, providing an overview of evolving methodologies and technologies for enhanced precision in facial attribute recognition.
2019	Harakannanavar et al.	This article explores the foundational aspects of a face recognition system such as facial detection, tracking, alignment, and feature extraction.	Delves into technical challenges, performance metrics, and advancements in face recognition systems, offering a comprehensive evaluation of effectiveness and reliability.
2020	Adjabi et al.	Provides a comprehensive survey of face recognition technology, historical evolution, current methodologies, and future research directions.	Study underscores the ongoing potential for advancements in analyzing images for 2D facial recognition. Researchers are increasingly drawn to the prospects of 3D facial recognition, propelled by recent advancements in 3D sensor technology, that may address the principal limitations in 2D technologies.
2020	Jadhav et al.	Examines the pivotal role of artificial intelligence (AI) in driving automation in forensic science and criminal investigation	AI holds significant potential in Forensic Science and Criminal Investigation, enhancing efficiency, reducing time in tasks, and contributing to quicker case resolutions.
2020	Taskiran et al.	Offers a comprehensive review of the evolution of face recognition, covering past, present, and future trends	Present a classification of face recognition methods based on images and videos, delineating key historical advancements and outlining the primary processing steps involved.
2021	Aherwadi et al.	Criminal Identification System using Facial Recognition	Focuses on the application of facial recognition technology in criminal identification and its role in law enforcement. Elucidates the methodology, challenges, and potential advantages.
2023	Carragher DJ, Hancock PJ	Explore the joint performance of human operators and a meticulously accurate Automated Facial Recognition System (AFRS) utilizing a Deep Convolutional Neural Network (DCNN). Investigated the use of simulated automated facial recognition systems in forensic face matching tasks.	Found that simulated systems acted as effective decision-aids, improving accuracy in face matching tasks. Revealed positive implications for forensic applications. Suggested potential advancements in real-world systems.

3. Technical aspects of automated facial recognition

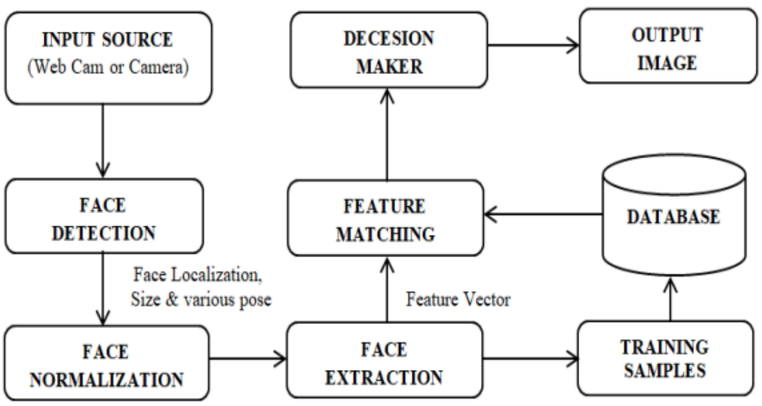
In these contexts, facial images of recognized individuals are initially enrolled in a system, forming a "gallery." Following this, facial images of these individuals or others, referred to as "probes," undergo matching against the gallery. Recognition entails a one-to-many matching process, while authentication involves one-to-one matching. Recognition poses greater challenges due to the larger gallery size and the necessity to conduct a comprehensive search of the entire gallery during each recognition attempt.[5]



Primary stages in the history of face recognition[16]



Workflow of a basic face-recognition system[1]



Various steps for Facial Recognition System[15]

Multi-modal approaches, which integrate both 3D and 2D data, generally outperform methods using 3D or 2D alone. However, comparisons often lack controls for the number of image samples, thereby mitigating the apparent performance difference between 3D + 2D and 2D [20] The process of 3D face recognition entails segmenting a range image based on principal curvature, identifying a bilateral symmetry plane, and normalizing for pose. Matching methods include profile matching and face surface matching [21], [22], [23], [24] In forensic face recognition, tools serve as aids to investigators but do not entirely perform identification. Ongoing studies focus on facial aging, facial marks, sketch-to-photo matching, video-based recognition, and NIR image-to-photo matching.[25], [26] This work aims to provide facial features understandable by non-experts, proposing soft biometric anthropometric features extracted based on forensic protocols. These features exhibit good accuracy in person recognition tasks. Commonly, 3D face data is acquired for enrolment, while 2D facial images are used for identification. Scale Invariant Feature Transform (SIFT) features extracted from 3D projected images are employed for matching, facilitating face re-projection with any orientation. Experiments involving 3D to 2D matching yield promising results. Appearance-based face recognition methods, such as Eigenfaces and Fisherfaces, utilize linear or non-linear techniques.[17], [22], [24] Kernel-based approaches and deep learning methods, such as Convolutional Neural Networks (CNNs), have significantly improved accuracy. Sparse representation-based classifiers and model-based approaches also contribute to facial recognition systems.[17] Explainable AI principles for face recognition emphasize providing evidence for decisions, ensuring interpretability, accuracy, and adherence to knowledge limits.[27], [28] Facial expression recognition involves holistic and feature-based processing. Holistic processing utilizes log-Normal filters for segmenting emotional segments, while feature-based processing analyzes permanent and transient facial features within each segment.[29], [30]

Diagram-1: Landmark on every face[18]

Various methodologies, such as geometric, local-texture, and deep learning techniques, contribute to facial recognition. In the geometric approach, attention and fixations are crucial factors in human face recognition, typically guided by landmark characteristics localized within the considered space via salience maps. Facial regions do not uniformly contribute to recognition; areas like the forehead and cheeks possess simpler structures compared to the more complex features like the nose or eyes. Landmarks on the face aid in registering facial features, normalizing expressions, and recognizing defined positions based on geometric distribution and grey level patterns. Elastic Graph Matching (EGM) is a common method for face recognition based on landmarks, implementing dynamic arc construction for object identification.[16]

Local-Texture Approach: Feature extraction strategies focusing on texture knowledge play a significant role in pattern recognition and computer vision. Texture extraction algorithms can be classified into statistical and structural methods, both contributing to effective feature extraction.[16]

Deep learning, a subset of machine learning, has gained prominence in pattern recognition and machine learning contests. Deep learning employs hierarchically organized information-processing levels within artificial neural networks for representation, pattern classification, and feature learning. The rise of deep learning can be attributed to advancements in processing capabilities, reduced computing hardware costs, and progress in machine learning research.[1], [17], [28]

Convolutional Neural Networks (CNNs): CNNs have demonstrated success in image recognition and classification tasks. CNNs comprise filters/kernels/neurons with learnable parameters, performing convolutions followed by non-linear operations. CNN architectures typically include convolutional, pooling, rectified linear unit, and fully connected layers. Popular CNN Architectures: LeNet, AlexNet, VGGNet, GoogleNet, and ResNet are notable examples of CNN architectures that have achieved significant success in various image recognition tasks.[1], [16], [30]

4. Limitation of automated facial recognition

Table-2: The table illustrates challenges encountered in facial recognition, along with corresponding descriptions and solutions aimed at addressing these limitations.[1], [15], [31], [32]

Challenge	Description	Solution
Variations in Illumination	Influenced by lighting conditions, resulting in dim or overly lit facial images.	Develop resilient face recognition systems capable of effective performance under various lighting conditions.
Variations in Camera Resolution	Discrepancies in resolutions lead to different image sizes and qualities.	Implement algorithms for consistent resolution and size across images in the database and those under scrutiny.
Variations in Pose	Limited coverage of facial angles in existing databases, causing imprecise recognition.	Advance database diversity and recognition methodologies to address pose variations.
Variations in Age	Challenges in compiling databases covering multiple age groups, leading to diminished accuracy.	Tackle age-related variations by exploring diverse image datasets and considering differences in image quality across decades.
Variations in Modalities	Differences in image capture methods introduce disparities affecting recognition accuracy.	Develop robust recognition systems accommodating diverse image representations, such as infrared illumination or sketches.
Variations in Facial Style & Expressions	Changes in style and expressions (e.g., hairstyles, makeup, smiling) challenge recognition.	Implement preprocessing techniques and include diverse images in the database to account for facial style and expression changes.
Effects of Occlusions	Obstructive objects (e.g., clothing, eyewear) and facial hair can hinder recognition accuracy.	Robust algorithms should consider occlusions during recognition, accounting for objects like clothing or facial hair.
Locating the Face Image	Challenges in precisely identifying the face due to poor image quality, backgrounds, and movement.	Develop robust algorithms capable of accurately locating faces in still images or video sequences despite challenges.
Identification of Similar Faces	Recognition inaccuracies may occur with identical siblings or similar-looking individuals in the database.	Implement additional steps beyond face recognition to address the challenges of identical siblings or similar faces.

5. Legal aspects of automated facial recognition in India

Table-3: The table outlines key provisions and amendments in various Indian legislations and acts related to data protection, criminal investigation, cyber security, and evidence admissibility.[33]

Legislation/Act/Rule	Key Provisions/Amendments
Personal Data Protection Bill 2019	-Addresses privacy concerns in India's digital landscape. Classifies biometric data as sensitive information. -Clause 36 provides exemptions for processing personal data in cases where it is necessary for the prevention, detection, investigation, or prosecution of offenses. -Clause 92 imposes strict conditions on the processing of biometric data, mandating explicit permission from the Central Government through legal enactment. - Article 21 deals with right to privacy.
Amendments to Identification of Prisoners Act 1920	- Legalizes collection of various biometric identifiers for criminal investigations
Sections 91 and 92 of the Code of Criminal Procedure	- Section 91: Empowers Courts or police station officers to summon documents or items for investigations. -Section 92: Regulates interception of documents held by postal or telegraph authorities
Section 144 of the CrPC	- Grants district magistrates' authority to issue directives prohibiting specific individuals or groups from certain actions
Information Technology (Amendment) Act, 2008	- Section 69: Establishes legal framework for lawful interception and monitoring of information. - Section 69 B: Regulates monitoring of traffic data
Rule 3(2) of the Information Technology (Procedure and Safeguard for Monitoring and Collecting Traffic Data or Information) Rules, 2009	- Enumerates objectives pertinent to cyber security like conducting forensic investigations, tracking breaches and threats, tracing viruses or contaminants etc.
Section 79(2)(c) and associated regulations	- Mandates cyber cafes to maintain records of user details for scrutiny by authorized officers
Indian Telegraph Act, 1985	- Establishes grounds and procedure for interception of communications by intelligence agencies
Section 45A of the Indian Evidence Act	- Defines relevance of opinion of Examiner of Electronic Evidence in legal proceedings
Section 65B of Indian Evidence Act	- Addresses admissibility of electronic records in legal proceedings

6. Application of automated facial recognition

- Digital Documentation: The Central Board of Secondary Education, a mandated educational authority in India overseeing both public and private schools, and under the governance of the Indian government, has commenced the use of Facial Recognition Technology (FRT) to grant students access to digital documents.
- Digi-Yatra: FRT has been integrated into airport operations in India as part of the Digi-Yatra initiative, a government program launched in 2018 by the Ministry of Civil Aviation. Its aim is to provide seamless, paperless travel experiences for air passengers nationwide. The policy introduces a facial biometric boarding system to automate airport processes from check-in to boarding, with facial data stored only for the duration

of the journey and mandatory deletion within an hour of flight departure. Regular audits are mandated to ensure adherence to data protection standards.

- Aadhaar and FRT: In 2018, the Unique Identification Authority of India (UIDAI) announced plans to integrate FRT into Aadhaar, India's national identity system. This integration aims to establish a multi-factor authentication process, offering users the option to combine approved authentication methods as endorsed by the central government.
- Child Identification: Media reports in April 2018 highlighted a successful trial of a facial recognition system commissioned by the Delhi High Court, resulting in the identification of around 3000 missing children. The court authorized the use of an Automated Facial Recognition System (AFRS) for tracking and reuniting missing children.
- Identification at Public Events: Delhi Police utilized AFRS software to screen attendees at a political rally led by the Prime Minister in December 2019. Reports indicated that Delhi Police maintained a database including individuals with criminal records, images of terror suspects, and a category labeled 'miscreants' for investigative purposes.
- Deployment by State Law Enforcement: Various state law enforcement agencies have implemented facial recognition systems, such as Punjab's Artificial Intelligence system, Pehchaan in Uttar Pradesh, Face Tagr and Neoface in Chennai, and the e-beat book app by Delhi Police.
- National Automated Facial Recognition System: In July 2019, the National Crime Records Bureau (NCRB) issued a Request for Proposal (RFP) for the National Automated Facial Recognition System (AFRS). The system is designed to match suspect photographs with databases containing images from various sources, though the initial RFP was recalled and replaced to clarify the system's scope, excluding CCTV integration and new camera installations. However, the revised RFP expands the AFRS database to include Scene of Crime images/videos, potentially conflicting with the previous stance on CCTV usage.[33]
- Disaster Victim Identification (DVI): In case of mass disasters which can either be Natural (tsunami, earthquakes, landslides) or Man made (terrorist attack, industrial explosion, etc.) automated facial recognition encompassing artificial intelligence can be used as a main tool for identifying the victims.[34], [35], [36]

7. Traditional forensic methods

In the field of forensic anthropology, meticulous examination of bone abnormalities and pathologies is essential for precise identification and differentiation of skeletal remains.[37] These advanced methodologies not only unravel mysteries of past civilizations but also shed light on modern populations' health and societal practices. Through such techniques, anthropologists and specialists gain profound insights into human biology, potentially revolutionizing the diagnosis and management of skeletal disorders in contemporary societies.[10], [11], [13]

Forensic identification techniques have evolved significantly over time. Methods like forensic anthropometry, forensic dactyloscopy, and le portrait parlé, dating back to the late 19th century, utilize physical and behavioural traits to identify individuals involved in criminal activities.[38] The introduction of automatic fingerprint identification systems (AFIS) in the 1960s marked the initial foray into forensic biometrics, followed by the adoption of forensic DNA profiling in the 1980s, enabling precise identity verification through DNA reference material stored in databases. In the 1990s, advancements in speaker, face, and gait recognition, driven by developments in mobile telecommunications and closed-circuit television (CCTV) surveillance, gained momentum in forensic biometrics. This period also saw the integration of biometric technologies with Bayesian likelihood ratio inference models for evidence evaluation.[19], [38], [39]

By the end of the 19th century, legal identification, especially in criminal law, emerged as a significant aspect of subject formation. Photography played a pivotal role in this evolution, with its integration into police archives initially constructed based on principles of anthropometry, physiognomy, and phrenology. Photography, particularly photographic portraiture, facilitated the inclusion of individualized images in the archive, aligning with the ideal of universal accessibility driven by industrial and technological advancements. Anthropometry persisted as a discipline, leaving its mark on the body through the production of permissible and admissible images for identification purposes.[40]

8. Modern forensic methods

Post-2001, there was a notable increase in interest towards soft biometric modalities, such as body measurements, gender, hair, skin colour, and clothing characteristics.[38] However, the limited distinctiveness and permanence of these features emphasized the need for a multimodal approach. Various types of multimodal systems exist, integrating 2D and 3D approaches or combining different biometrics such as fingerprints and voice. The field of facial recognition has evolved, incorporating advancements in technology, multimodal approaches, and explainable AI principles.[14], [25], [41]

Soft biometrics have been primarily divided into three distinct categories: facial, bodily, and accessory-related characteristics. The examination of facial features in both traditional and soft biometrics shares a common objective: to discern significant facial attributes possessing robust identifying and/or differentiating capabilities.[26], [38] Recently, the inclusion of facial wrinkles as a micro-feature for facial recognition has emerged. While the curvature of facial wrinkles around regions such as the head, eyes, and mouth may not be individually distinctive enough for recognition purposes, a study has demonstrated that a collective pattern of wrinkles could, in fact, be unique to each individual. [14]

Table-4: The table highlights the transition from traditional to modern forensic methods, emphasizing advancements such as the integration of soft biometrics and facial recognition technologies.

Traditional Forensic Methods	Modern Forensic Methods
Meticulous examination of bone abnormalities and pathologies [28].	Increased interest in soft biometric modalities post-2001 [32], integrating 2D and 3D approaches, and advancements in facial recognition [17], [36], [37].
Evolution of forensic techniques dating back to the 19th century [32].	Division of soft biometrics into facial, bodily, and accessory-related characteristics, with recent inclusion of facial wrinkles for recognition [18], [32], [36].
Emergence of legal identification in criminal law by the late 19th century [35].	Integration of biometrics with artificial intelligence is on development phase.

9. Various Biometrics used in modern days

DNA: Deoxyribonucleic acid (DNA) serves as the ultimate unique code for individuality, though identical twins share identical DNA patterns. Primarily used in forensic applications, DNA's utility for other purposes is hindered by contamination, real-time recognition issues, and privacy concerns.

Ear: Ear recognition relies on the distinct shape and structure of the ear, but its features are not highly distinctive for identity establishment.

Facial, hand, and hand vein infrared thermogram: Infrared thermography captures the unique heat patterns emitted by the human body, enabling covert recognition.

Fingerprint: Fingerprint matching accuracy is high, but computational resources required can be significant. Some fingerprints may not be suitable for automatic identification due to genetic, aging, or environmental factors.

Gait: Gait, although not highly distinctive, can verify identity in low-security applications. However, it requires intensive video-based acquisition and is computationally expensive.

Hand and finger geometry: Hand geometry recognition systems are simple, inexpensive, and unaffected by environmental factors. Some systems only measure a few fingers for compactness.

Iris: Iris texture provides highly distinctive information for personal recognition. Deployed systems are accurate, difficult to tamper with, and becoming more user-friendly and cost-effective.

Keystroke: While not entirely unique, keystroke analysis offers sufficient discriminatory information for identity verification.

Palmprint: Palmprints are expected to be highly distinctive and can be captured with high or low-resolution scanners, combining various features for accuracy.

Retinal scan: Retinal scan is considered the most secure biometric due to the difficulty of replication. However, it requires user cooperation and conscious effort.

Signature: Signatures, though changing over time, are accepted in various transactions as a form of verification.

Voice: Voice recognition, combining physiological and behavioural aspects, is not highly distinctive but offers protection against fraud. Text-independent systems are more secure but challenging to design.[7], [14], [24], [26], [38]

Conclusion

The exploration of forensic facial recognition technology offers a thorough grasp of its development, hurdles, applications, and legal implications. The shift from traditional forensic methods to modern automated facial recognition systems showcases substantial advancements propelled by technological progress and interdisciplinary collaboration. The analysis underscores the intricate challenges inherent in forensic facial recognition, stressing the need for resilient solutions capable of surmounting diverse obstacles like variations in lighting, camera quality, facial orientation, age, modalities, expressions, occlusions, and facial similarity. Despite these challenges, recent strides in deep learning and convolutional neural networks exhibit potential in enhancing the precision and dependability of facial recognition systems. Additionally, the extensive integration of facial recognition technology across sectors such as digital documentation, airport security, national identification systems, child protection, event management, and law enforcement underscore its increasing significance in contemporary society. However, alongside technological advancements, addressing the legal and ethical considerations surrounding automated facial recognition is imperative. Legislative measures such as the Personal Data Protection Bill and amendments to existing laws in India reflect endeavors to safeguard privacy rights and regulate the utilization of biometric data in forensic inquiries. While automated facial recognition holds considerable promise in revolutionizing forensic practices and augmenting security measures, a balanced approach considering technical, legal, and ethical dimensions is indispensable for its responsible and efficacious deployment in democratic societies. This comprehensive review furnishes valuable insights into the intricate terrain of forensic facial recognition, laying the groundwork for further advancement and informed decision-making in this swiftly progressing domain.

References

[1] P. Kaur, K. Krishan, S. K. Sharma, and T. Kanchan, “Facial-recognition algorithms: A literature review,” *Med Sci Law*, vol. 60, no. 2, pp. 131–139, 2020.

[2] T. Ali, R. Veldhuis, and L. Spreeuwers, “Forensic face recognition: A survey,” *Centre for Telematics and Information Technology, University of Twente, Tech. Rep. TR-CTIT-10-40*, vol. 1, 2010.

[3] Z. A. Khan and A. Rizvi, “AI based facial recognition technology and criminal justice: Issues and challenges,” *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. 12, no. 14, pp. 3384–3392, 2021.

[4] E. B. Jadhav, M. S. Sankhla, and R. Kumar, “Artificial intelligence: Advancing automation in forensic science & criminal investigation,” *Journal of Seybold Report ISSN NO*, vol. 1533, p. 9211, 2020.

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[5] K. W. Bowyer, K. Chang, and P. Flynn, "A survey of approaches and challenges in 3D and multi-modal 3D+ 2D face recognition," *Computer vision and image understanding*, vol. 101, no. 1, pp. 1–15, 2006.

[6] A. K. Jain, B. Klare, and U. Park, "Face matching and retrieval in forensics applications," *IEEE multimedia*, vol. 19, no. 1, p. 20, 2012.

[7] A. K. Jain, A. Ross, and S. Prabhakar, "An introduction to biometric recognition," *IEEE Transactions on circuits and systems for video technology*, vol. 14, no. 1, pp. 4–20, 2004.

[8] P. J. Phillips *et al.*, "Face recognition accuracy of forensic examiners, superrecognizers, and face recognition algorithms," *Proceedings of the National Academy of Sciences*, vol. 115, no. 24, pp. 6171–6176, 2018.

[9] K. L. Ritchie *et al.*, "Public attitudes towards the use of automatic facial recognition technology in criminal justice systems around the world," *PLoS One*, vol. 16, no. 10, p. e0258241, 2021.

[10] D. P. Willoughby, "An anthropometric method for arriving at the optimal proportions of the body in any adult individual," *Research Quarterly. American Physical Education Association*, vol. 3, no. 1, pp. 48–77, 1932.

[11] F. J. Meaney, L. A. Farrer, J. M. Opitz, and J. F. Reynolds, "Clinical anthropometry and medical genetics: a compilation of body measurements in genetic and congenital disorders," *Am J Med Genet*, vol. 25, no. 2, pp. 343–359, 1986.

[12] A. M. Burton, S. Wilson, M. Cowan, and V. Bruce, "Face recognition in poor-quality video: Evidence from security surveillance," *PsycholSci*, vol. 10, no. 3, pp. 243–248, 1999.

[13] M. Henneberg, E. Simpson, and C. Stephan, "Human Face in Biological Anthropology: Craniometry, Evolution and Forensic Identification," in *The Human Face: Measurement and Meaning*, M. Katsikitis, Ed., Boston, MA: Springer US, 2003, pp. 29–48. doi: 10.1007/978-1-4615-1063-5_2.

[14] O. A. Arigbabu, S. M. S. Ahmad, W. A. W. Adnan, and S. Yussof, "Recent advances in facial soft biometrics," *Vis Comput*, vol. 31, pp. 513–525, 2015.

[15] S. S. Harakannanavar, V. I. P. Vidyashree, C. R. Prashanth, and K. B. Raja, "Technical Challenges, Performance metrics and Advancements in Face Recognition System," *International Journal of Computer Sciences and Technology*, vol. 7, no. 3, pp. 836–847, 2019.

[16] I. Adjabi, A. Ouahabi, A. Benzaoui, and A. Taleb-Ahmed, "Past, present, and future of face recognition: A review," *Electronics (Basel)*, vol. 9, no. 8, p. 1188, 2020.

[17] M. Taskiran, N. Kahraman, and C. E. Erdem, "Face recognition: Past, present and future (a review)," *Digit Signal Process*, vol. 106, p. 102809, 2020.

[18] N. B. Aherwadi, D. Chokshi, D. S. Pande, and A. Khamparia, "Criminal Identification System using Facial Recognition," in *Proceedings of the International Conference on Innovative Computing & Communication (ICICC)*, 2021.

[19] D. J. Carragher and P. J. B. Hancock, "Simulated automated facial recognition systems as decision-aids in forensic face matching tasks.," *J ExpPsychol Gen*, vol. 152, no. 5, p. 1286, 2023.

[20] P. J. Phillips *et al.*, "Overview of the face recognition grand challenge," in *2005 IEEE computer society conference on computer vision and pattern recognition (CVPR'05)*, IEEE, 2005, pp. 947–954.

[21] R. Shyam and Y. N. Singh, "A taxonomy of 2D and 3D face recognition methods," in *2014 International Conference on Signal Processing and Integrated Networks (SPIN)*, IEEE, 2014, pp. 749–754.

[22] A. F. Abate, M. Nappi, D. Riccio, and G. Sabatino, "2D and 3D face recognition: A survey," *Pattern Recognit Lett*, vol. 28, no. 14, pp. 1885–1906, 2007.

[23] D. Smeets, P. Claes, D. Vandermeulen, and J. G. Clement, "Objective 3D face recognition: Evolution, approaches and challenges," *Forensic Sci Int*, vol. 201, no. 1, pp. 125–132, 2010, doi: https://doi.org/10.1016/j.forsciint.2010.03.023.

[24] M. Tistarelli, E. Grosso, and D. Meuwly, "Biometrics in forensic science: challenges, lessons and new technologies," in *Biometric Authentication: First International Workshop, BIOMET 2014, Sofia, Bulgaria, June 23-24, 2014. Revised Selected Papers 1*, Springer, 2014, pp. 153–164.

[25] A. I. Awad and A. E. Hassanien, "Impact of some biometric modalities on forensic science," *Computational intelligence in digital forensics: Forensic investigation and applications*, pp. 47–62, 2014.

[26] P. Tome, R. Vera-Rodriguez, J. Fierrez, and J. Ortega-Garcia, “Facial soft biometric features for forensic face recognition,” *Forensic Sci Int*, vol. 257, pp. 271–284, 2015.

[27] P. J. Phillips and M. Przybocki, “Four principles of explainable ai as applied to biometrics and facial forensic algorithms,” *arXiv preprint arXiv:2002.01014*, 2020.

[28] C. G. Zeinstra, D. Meuwly, A. C. Ruifrok, R. N. J. Veldhuis, and L. J. Spreeuwers, “Forensic face recognition as a means to determine strength of evidence: a survey,” *Forensic Sci Rev*, vol. 30, no. 1, pp. 21–32, 2018.

[29] S. K. Singh, M. Vatsa, R. Singh, and K. K. Shukla, “A comparative study of various face recognition algorithms (feature based, eigen based, line based, neural network approaches),” in *2003 IEEE International Workshop on Computer Architectures for Machine Perception*, IEEE, 2003, pp. 12-pp.

[30] Z. Hammal and C. Massot, “Holistic and feature-based information towards dynamic multi-expressions recognition,” in *International Conference on Computer Vision Theory and Applications*, SCITEPRESS, 2010, pp. 300–309.

[31] J. I. Olszewska, “Automated face recognition: Challenges and solutions,” *Pattern Recognition-Analysis and Applications*, vol. 4, 2016.

[32] M. Jacquet and C. Champod, “Automated face recognition in forensic science: Review and perspectives,” *Forensic Sci Int*, vol. 307, p. 110124, 2020, doi: https://doi.org/10.1016/j.forsciint.2019.110124.

[33] E. Hickok *et al.*, “Facial Recognition Technology in India,” *Centre for Internet and Society, https://cis-india. org/internet-governance/facialrecognition-technology-in-india. pdf*, 2021.

[34] P. Jain, “Mass Fatality Incidence and Disaster Victim Identification-A Comprehensive Review,” 2024.

[35] A. G. Ortiz, G. H. Soares, G. C. da Rosa, M. G. H. Biazevic, and E. Michel-Crosato, “A pilot study of an automated personal identification process: applying machine learning to panoramic radiographs,” *Imaging Sci Dent*, vol. 51, no. 2, p. 187, 2021.

[36] B. L. Pate, “Identifying and tracking disaster victims: state-of-the-art technology review,” *Fam Community Health*, pp. 23–34, 2008.

[37] B. Moza *et al.*, “Advancements in the Imaging Techniques for Detection of Skeletal Pathologies: A Comprehensive Review,” *TuijinJishu/Journal of Propulsion Technology*, vol. 45, no. 1, p. 2024.

[38] D. Meuwly and R. Veldhuis, “Forensic biometrics: From two communities to one discipline,” in *2012 BIOSIG-Proceedings of the International Conference of Biometrics Special Interest Group (BIOSIG)*, IEEE, 2012, pp. 1–12.

[39] G. Pavlich, “The subjects of criminal identification,” *PunishmSoc*, vol. 11, no. 2, pp. 171–190, 2009.

[40] P. J. Hutchings, “Modern forensics: Photography and other suspects,” *Law & Literature*, vol. 9, no. 2, pp. 229–243, 1997.

[41] K. N. Kotsoglou and M. Oswald, “The long arm of the algorithm? Automated Facial Recognition as evidence and trigger for police intervention,” *Forensic Sci Int*, vol. 2, pp. 86–89, 2020, doi: https://doi.org/10.1016/j.fsisyn.2020.01.002.