Fingerprint matching, spoof and liveness detection: classification and literature review

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Major Highlights

- It provides a comprehensive review on the fingerprint algorithms and techniques which have been published in the last few decades (1975-2019).

- It divides the research on fingerprint into nine different approaches and four historical eras.

- According to the fingerprint research papers, the study concluded that the minutiae were the major breakthrough and continuously researched technique.

- Similarly, deep learning approach has outperformed other approaches and gained significant attention during last years and seems to dominate in the future research as well.

Performance Evaluation of Datasets

Datasets	Approaches	Ref.	Maximum Accuracy
FVC 2000	Feature based	[24]	95%
	Image enhancement	[12]	86.8%
FVC 2002	Feature based	[92], [94], [96], [11]	95.2% [11]
	Image enhancement	[12]	83%
	Latent	[13]	95.2%
	Machine Learning unsupervised	[14]	83.5%
	Template based	[78], [77]	95.37% [78]
FVC 2004	Feature based	[94], [11], [28], [29]	91.56% [29]
	Fuzzy logic	[44]	91.7%
	Survey	[93]	92%-96%
	Template based	[79], [80]	95% [79]
NIST SD4	Feature based	[22]	85%
	Machine Learning	[68]	90%
	Latent	[100], [60]	74% [100]
NIST SD9	Holistic	[45]	82%
NIST SD14	Latent	[100], [60]	74% [100]
NIST SD27	Latent	[100], [60]	74% [100]
	Survey	[93]	75%
NIST SD29	Latent	[100], [60]	52.9% [60]
NIST SD30	Latent	[100],[60]	52.9% [60]
Other Datasets	Feature based	[3], [26], [23], [97]	99.46% [97]
	Machine Learning (Conventional)	[67], [74]	94% [67]
	Machine Learning (Deep Learning)	[75]	92.09%
	Genetic algorithm	[25]	99%
	Holistic	[49], [51]	82% [49]
	Image enhancement	[52], [53], [12]	97% [12]
	Latent	[58], [59]	96.2% [58]
	Template based	[77]	92.4%

Summary of the Approaches used in Era 1

Ref.	Year	Method	Accuracy	Datasets	Advantages	Disadvantages
[3]	1975	Minutiae Matching, Fourier filtering.	90.7%	Other Datasets	Laid the foundation of future systems.	Time consuming. Multiple scanners used.
[90]	1990	Neural Networks, minutiae by using Gabor filter and back-propagation neural network.	-	-	Trained network with good detection ratio and low false alarm rate.	Dimensions limited and reduced representations
[21]	1991	Topology based matching algorithm, structural model of minutiae.	-	-	Does not rely on core points, faster matching speed.	If tree matching fails, then probability of failure might be more.
[41]	1992	Hybrid fuzzy-neural system, cluster sets of minutiae.	-	-	Learns and adapts online, no a-prior knowledge of clusters are required.	Appropriate choice of parameters is critical for efficient operation.
[67]	1994	Image-based ridge-valley features, K-L transforms, neural networks.	94%	Other Datasets	High classification accuracy.	Parallel SIMD hardware is required.
[51]	1994	Directional Fourier filtering.	85%	Other Datasets	Entire fingerprint image was used in directional filtering.	Local ridge spacing and local ridge orientation parameters need to be accurately estimated.
[52]	1998	Normalization, orientation image estimation, frequency image estimation, region mask generation and filtering.	90%	Other Datasets	Removes unrecoverable corrupted regions from the fingerprint image.	High computational complexity.
[68]	1999	FingerCode summarizing local ridges of fingerprint.	90%	NIST SD4	More robust to noise.	Long matching time.
[45]	2000	Bank of Gabor filters, local and global details in the fingerprint.	92%	NIST SD9	Computationally efficient indexing capability.	Less accuracy.

Summary of the Approaches used in Era 2

Ref.	Year	Method	Accuracy	Datasets	Advantages	Disadvantages
[22]	2003	Features based on triangles formed by minutiae triplets	86.5%	NIST SD4	Scale, shear, and occlusion invariant	Require manual intervention for final match
[24]	2004	Implementation of minutiae based approach	92%	FVC 2000	Rotation invariant	Slow matching speed
[13]	2005	Localized secondary features derived from relative minutiae information	94.02%	FVC 2002	Partial fingerprint matching	Complexity
[57]	2005	Phase based fingerprint matching	96.20%	Other Datasets	Low quality fingerprint matching	Small dataset used
[25]	2006	Minutiae matching based on genetic algorithms	98%	Other Datasets	Fast fingerprint matching	Small dataset used
[76]	2006	Minutiae update through successive Bayesian estimation	94.80%	Other Datasets	Works with small sensor size	Complexity
[84]	2006	Adaptive score fusion based on automatic quality estimation in the spatial frequency domain	93.20%	Other Datasets	Low quality fingerprint matching	—
[92]	2006	Fingerprint matching based on global orientation field and local minutiae matching	90.4%—94.2%	FVC 2002	More discriminative in fingerprint matching and small template size requirement	Slow for partial fingerprint matching

Summary of the Approaches used in Era 3

Ref.	Year	Method	Accuracy	Datasets	Advantages	Disadvantages
[44]	2008	Multi-resolution/multi-orientation properties of curvelets	83.3%—90%	FVC 2004	High recognition accuracy with compressed images	High complexity
[58]	2008	Spaced frequency transformation algorithm/Line scan algorithm	95%	Other Datasets	Partial fingerprint matching	Lack of pre-classification of fingerprint images
[49]	2008	Huffman Coding	96.66%	Other Datasets	Simplicity, reliability and cost	Different captured environments for images
[26]	2009	Random Sample Consensus algorithm for pore based matching	87.6%	Other Datasets	Direct pore based matching	Complexity in describing pores
[53]	2009	Type-2 Fuzzy logic to enhance fingerprint image	—	—	Better quality than type-1 fuzzy logic	Small sample size used
[23]	2009	Dempster Shafer theory match score fusion of minutiae and pore features	81.4%	Other Datasets	Fast matching speed	High resolution image database required
[14]	2009	Coordinate geometry of detected singular points	83.5%	FVC 2004	Classify fingerprints in absence of some singular points	Classification relies on core and delta points detection
[94]	2009	Orientation field, coherence, and Pointcare index for core point detection	84%	FVC 2002,2004	Simplicity	Low accuracy on unconstrained dataset
[27]	2010	Pore-valley descriptor to characterize pores based on their location and orientation	70.5%	Other Datasets	Partial fingerprint matching	High resolution image dataset
[59]	2011	Singularity, ridge quality map, ridge flow map, ridge wavelength map, and skeleton	74%	Other Datasets	High accuracy on latent fingerprint matching	Not robust in the presence of large amount of noise and distortion
[60]	2011	Semi-automated identification system for simultaneous latent fingerprint matching	52.9%	NIST SD14,27,29,30	Large total number of minutiae in simultaneous latent fingerprint	Small dataset used
[96]	2011	Fingerprint matching based on number of minutiae pairings	65%—70%	FVC 2002	Simplicity	Low identification accuracy

Summary of the Approaches used in Era 4

Ref.	Year	Method	Accuracy	Datasets	Advantages	Disadvantages
[11]	2012	Minutiae Triplets	93.7%—97%	FVC 2002	Invariance to translation, rotation, and order of minutiae in the feature	Unable to match latent fingerprints
[73]	2012	Multi-Layer Perceptron neural network classifier	88.8%	Other Datasets	Fast matching speed	Small number of training samples used
[80]	2012	Random selection of minutiae points to construct sub-templates	—	—	Number of available bio-metrics, privacy of user	Require 3-D touchless fingerprint scanner
[28]	2012	Crossing number method based on pixel representation value 0	85.95%	FVC 2004	No trignometry calculation and floating-point calculation	High error rates
[29]	2012	Singular point position and their relative distance	91.56%	FVC 2004	Invariant to rotation	Does not work for arch fingerprints
[97]	2012	Speed-up robust local features	99.46%	Other Datasets	Invariant to rotation and recognize partial fingerprints	Tested on small datasets
[12]	2014	Convolutional deep belief neural network	91.5%—93.4%	FVC 2000	Unsupervised feature learning	High error rates
[86]	2014	Multiple regression technique	83%	Other Datasets	Prediction of expert performance and subjective assessment of difficulty in fingerprint comparison	Limited image-processing tools
[74]	2015	Scattering convolutional network	91.9%	Other Datasets	Translation invariant	High number of features created
[35]	2018	Deep CNN using local patches utilizing minutaie information	98.3%—99.8%	Other Datasets	Uses local patches rather than whole fingerprint image for spoof detection	Separate training required for different patch sizes
[101]	2019	Score level based latent fingerprint enhancement using SIFT features	—	—	Pre-processing step used that reduces the noise	No accuracy results were reported