Fingerprints: Proving Ground for Pattern Recognition

Anil K. Jain

Michigan State University

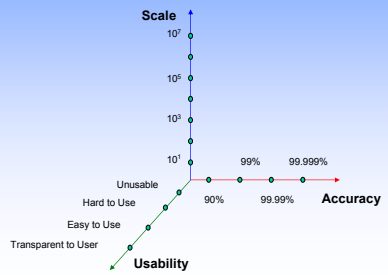
Fingerprints

"Perhaps the most beautiful and characteristic of all superficial marks (on human body) are the small furrows with the intervening ridges and their pores that are disposed in a singularly complex yet even order on the under surfaces of the hands and feet."

Francis Galton, Nature, June 28, 1888

Proving Ground

A number of societal problems now need a highly accurate, scalable, real-time, low cost, user-friendly fingerprint recognition system



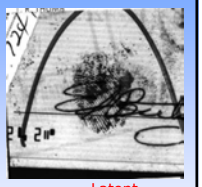
Fingerprints in Forensics

- Repeat Offenders: Compare rolled (ten print) inked impressions
- Crime Scenes: Compare latent prints with forensic database

FBI AFIS: ~50M 10 prints; 50,000 searches per day; 2 hour response time; only 15% matches are in "lights out mode"

Inked Prints & Latents

FBI card



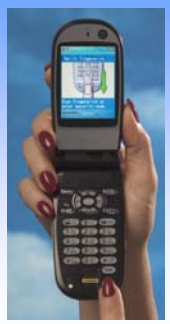
Latent

Fingerprints: New Era

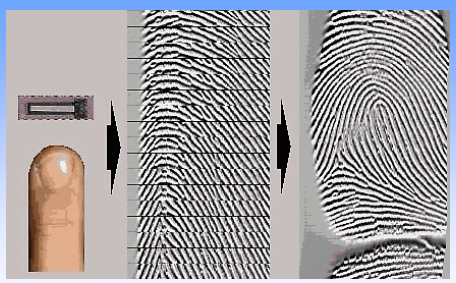
- Border security
- Financial fraud
- User convenience

New deployments need

- Cheap & compact sensors
- Fully automated matching



Live Scan Capture



Sensors based on optical, ultrasound, thermal, solid-state, multispectral technologies

Disney World, Orlando

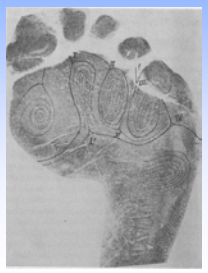
Throughput: 100K/day, 365 days/ year

Outline

- Dermatoglyphics
- Characteristics of fingerprints
- Applications
- Representation
- Matching
- Performance
- Research Directions

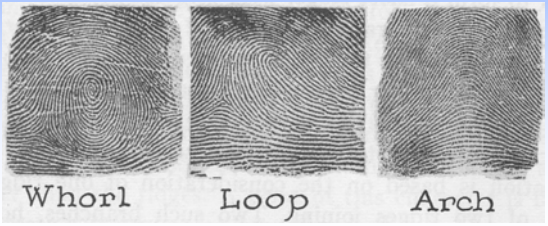
Dermatoglyphics

- Ridged (friction) skin on fingers, palms & soles
- Derma (skin) + glyphē (carve): study of ridged patterns



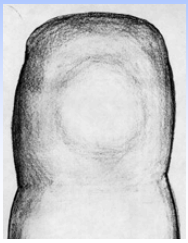
Fingerprints

- Patterns of epidermal ridges on fingers
- Ridges prevent slipping while grasping
- Main types of pattern: whorl, loop, arch



Fingerprint Formation

- Ridge formation starts at 1 or 2 focal points and spreads over the fingertip
- Localized ridge units merge to form ridges at ~10.5 weeks estimated gestational age



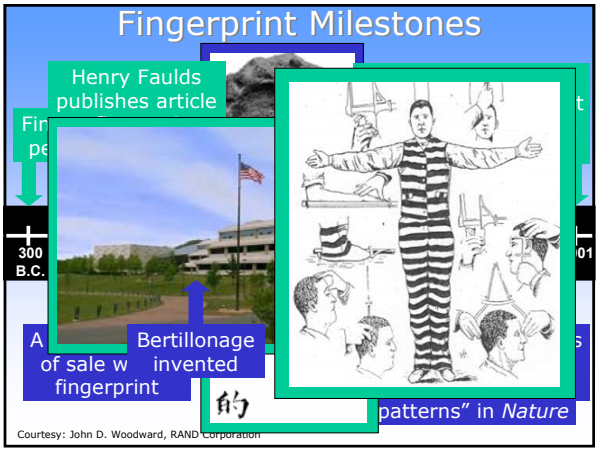
Biological Principles

- Uniqueness (individuality)
- Permanence (persistence)
- Classifiability (indexing)
- Genotype & phenotype characteristics

Identical twins have different prints

Fingerprint = "uniqueness"

Fingerprint Milestones

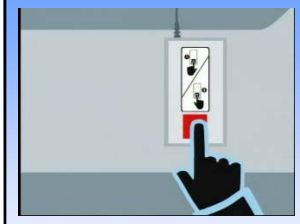


Courtesy: John D. Woodward, RAND Corporation

Fake Documents

The nineteen 9/11 terrorists had a total of 63 valid driver licenses

US-VISIT



~ 60 million visitors have been processed through US-VISIT; 1,100 criminals denied entry

Hong Kong Smart Identity Card

HK Smart ID Card

- Security: Prevent misuse of stolen cards
- Convenience: e-Certificate
- Service: electronic government services
- Travel: Passenger Clearance System

Identity Theft

Credit card fraud amounts to billions in losses for millions of customers

PAY BY TOUCH™

Customer pay by fingerprints; no need for cards/cash

Who is Moving the Mouse?

Personalization: Understand customer interests

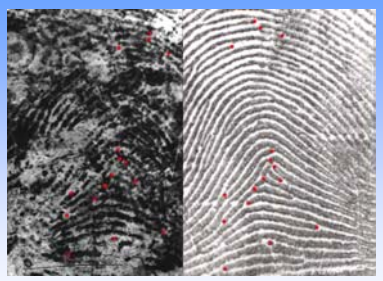
Comm. ACM, August 2006

Fingerprint Matching

Find the similarity between two fingerprints

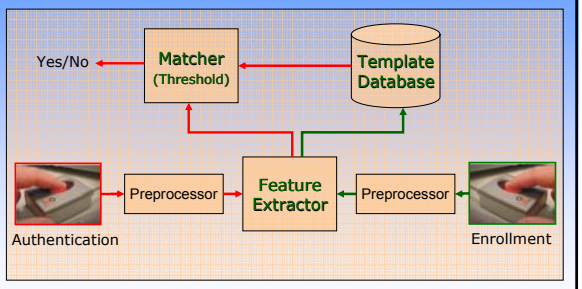
*

Latent Matching



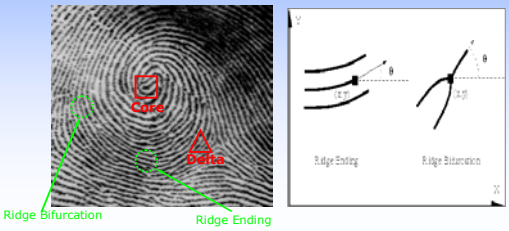
Latents at the Madrid bombing site were matched to those of Mayfield by FBI. He was arrested but later released after Spanish officials found the real culprit

Fingerprint Matching System



Features

- Local ridge characteristics (minutiae): ridge endings and bifurcations
- Singular points (core and delta): discontinuity in ridge orientations

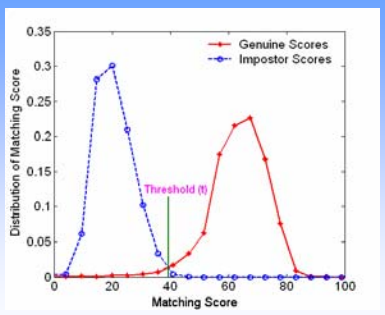


Matching

- Register query and template images
  - Estimate rotation, translation & distortion
- Compute the similarity
  - Find the number of corresponding minutiae

Minutiae-based Matchers

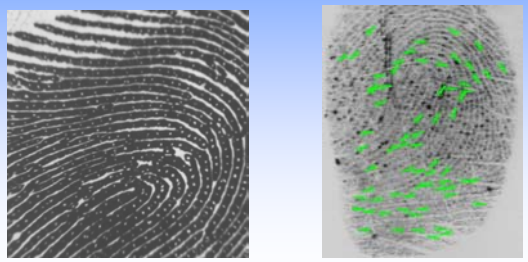
Match Score Distributions



False Accept Rate vs. False Reject Rate

Matching Errors

Large intra-class variation (distortion & noise)



"State-of-the-art" Error Rates

Test	Database Characteristics	False Reject Rate	False Accept Rate
FVC [2002]	100 fingers, 8 impressions/finger	0.2%	0.2%
FVC [2004]	Same as FVC 2002 with distortion	2%	2%
FpVTE [2003]	US govt. data (10,000 fingers)	0.1%	1%

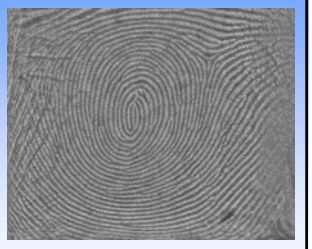
~100,000 passengers/day at HK airport; using the top FpVTE system, 100 "good" passengers will be stopped

Research Directions

- Sensing
- Spoof Detection
- Extended feature set (Level 3)
- Uniqueness of fingerprints
- Multibiometrics
- Template security
- Fingerprint fuzzy vault

Touchless Fingerprint Imaging

Touchless 3D image

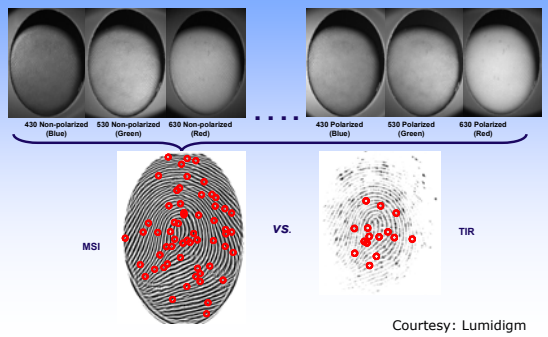


Touchless "rolled" image

Courtesy: TBS North America (NIJ Fast Capture Program)

Multispectral Imaging

Captures both surface and subsurface ridges



Courtesy: Lumidigm

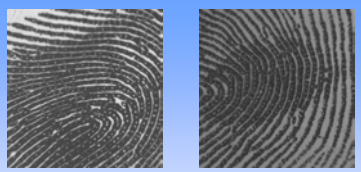
Spoof Detection

Finger made of glue

MSI sensor can see through the spoof

Deformation-Based Spoof Detection

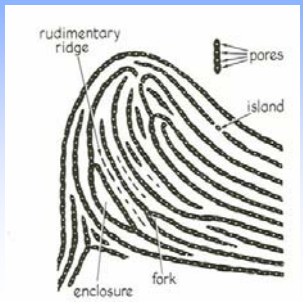
Live finger



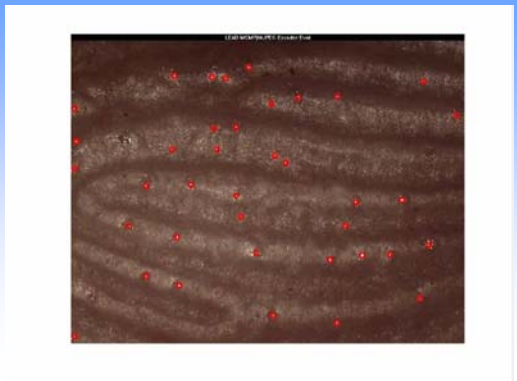
Gummy finger

Extended Feature Set

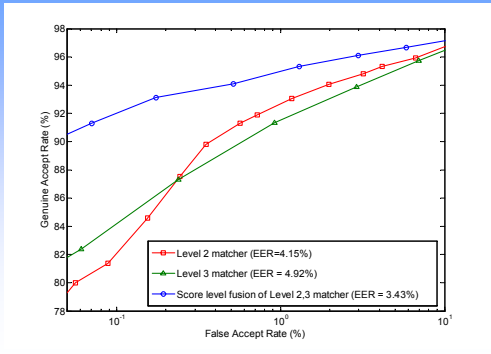
'It is NOT the points, but what's in between the points that matters' Edward German, *latent print examiner*



High Resolution Sensors



Levels 2 & 3 Feature Fusion



Are Fingerprints Unique?

"Only Once during the Existence of Our Solar System Will two Human Beings Be Born with Similar Finger Markings" *Harper's headline, 1910*

"Two Like Fingerprints Would be Found Only Once Every 10^{48} Years" *Scientific American, 1911*

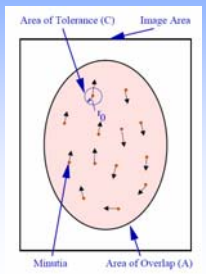
The uniqueness of fingerprints has been accepted over time because of relentless repetition and lack of contradiction

Challenges to Uniqueness

- *Daubert vs. Merrell Dow, 1993*
  - Test of hypothesis
  - Known or potential error rate
  - Peer reviewed and published
  - General acceptance
- Challenges *(USA v. Byron Mitchell, 1999)*
  - Error rate is not known
  - Uniqueness has not been tested

Probability of Random Correspondence

- Given two fingerprints with m & *n* minutiae, what is the probability they will share *q* minutiae?



1. m=n=52, q=12
   PRC = 4.4×10^{-3}
   (Observed value = 3.5×10^{-3})
2. m=n=52, q=26
   PRC = 3.4×10^{-14}

M = A/C=413 (NIST-4 database)

Template Security

Can fingerprint be reconstructed from minutiae?

Reconstructed images matched true fingerprints 23% of the time

Match on Card

Complete system (sensor, feature extractor, matcher, template) resides on card; template is never transmitted or released from card

IEEE Spectrum, July 2006

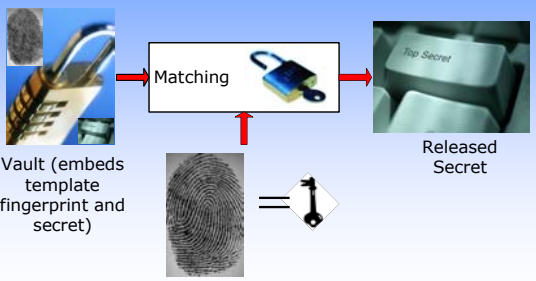
Match on Card

Biometric Smart Card (UPEK Inc.)

Biometric Key Chain (Privaris, Inc.)

Fingerprint Fuzzy Vault

Secure an encryption key with fingerprint so only the authorized user can access the secret



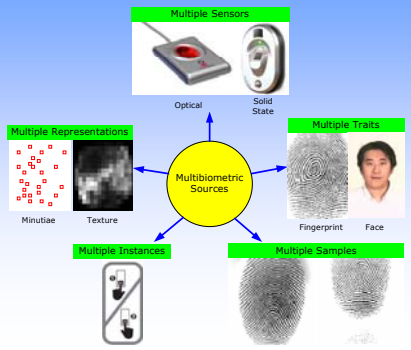
Vault (embeds template fingerprint and secret)

Released Secret

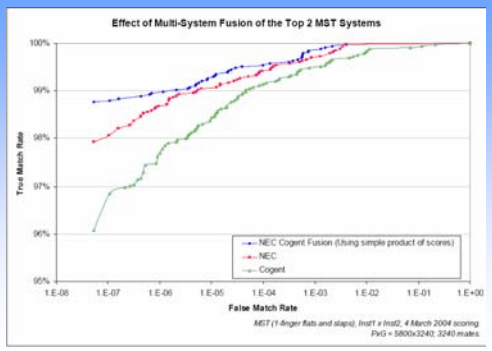
Query fingerprint

Multibiometrics

Failure to enroll, spoof attacks, error rate



Fusion of Matchers



Summary

- Fingerprint recognition is the earliest & largest deployment of pattern recognition
- Fingerprints are believed to be fail proof, but commercial systems have finite error rates
- Many societal needs (identity theft, financial fraud, security) require robust, accurate & cost-effective fingerprint matchers
- It is a proving ground for pattern recognition