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

Accuracy

Usability

Unusable

Hard to Use

Easy to Use

Transparent to User

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"
**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) + glyph (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

- 300 B.C.
- 1839
- 1880
- 1883
- 1900
- 1905
- 1924
- 1967
- 1999
- 2001

First use of fingerprints in British criminal case
Galton / Henry system of classification adopted by Scotland Yard
Mitchell Trauring publishes "Automatic comparison of fingerprint patterns" in Nature
US Congress authorizes DOJ to collect fingerprints and arrest information
Henry Faulds publishes article on fingerprints in Nature
A Chinese deed of sale with a fingerprint
Development of an Automated Fingerprint Identification System for the FBI
FBI inaugurates full operation of "IAFIS"
Bertillonage invented

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

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

Who is Moving the Mouse?
Personalization: Understand customer interests

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

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

~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**
- Optical Sensor
- MSI Sensor
- True Finger
- Finger made of glue
- Finger with glue spoof

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

False Accept Rate (%)
Genuine Accept Rate (%)

Level 2 matcher (EER=4.15%)
Level 3 matcher (EER = 4.92%)
Score level fusion of Level 2,3 matcher (EER = 3.43%)

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^{40} 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 x 10^{-3}
   (Observed value = 3.5 x 10^{-3})

2. m=n=52, q=26
   PRC = 3.4 x 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

IEEE Spectrum, July 2006

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

Multibiometrics
Failure to enroll, spoof attacks, error rate

Fusion of Matchers
Effect of Multi-System Fusion of the Top 2 MIST Systems
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