Image Biometric Verification in Spatial Frequency Domain

Vijayakumar Bhagavatula
Acknowledgments

- Dr. Marios Savvides
- Dr. Chunyan Xie
- Jason Thornton
- Krithika Venkataramani
- Pablo Hennings

- Technology Support Working Group (TSWG)
- CyLab
Outline

- Motivation for Biometrics
- Use of spatial frequency domain --- Correlation filters
- Face recognition including face recognition grand challenge (FRGC)
- Iris recognition including iris challenge evaluation (ICE)
- Fingerprint verification
- Palmprint verification
- Cancelable biometric templates
- Conclusions
Motivation

- Recognizing the identity of a person can improve security of access to physical and virtual spaces.
- Most current methods rely on passwords ("what you know"), ID cards ("what you have") that can be easily forgotten or stolen.
- Identity recognition based on biometrics (e.g., Fingerprints, face, iris, etc.) focuses on "what you are".
- Biometrics: measurable, physical characteristics or behavioral traits used to identify or verify a person.
Biometric Types

Courtesy: Prof. Arun Ross
Biometric Applications

- Hajj pilgrims in Saudi Arabia
- Fingerprint at checkout counter
- Ben Gurion Airport
- Cell Phone with Fingerprint Sensor
- Disney World
- Smart gun
Terminology

- **Verification** *(1:1 matching)*
  - Am I who I say I am?
  - Example application: Trusted Traveler Card, ATM smart card

- **Identification** *(1:N matching)*
  - Does this face match to one of those in a database?
  - Example application: Looking for suspects in crowds

- **Recognition** = **Verification** + **Identification**
Challenge: Pattern Variability

- **Challenge**: To tolerate pattern variability (some times called distortions) while maintaining discrimination
- Facial appearance change due to illumination
- Fingerprint image change due to plastic deformation
Eigenfaces

- Each $d \times d$ image represented as a point in a $d^2$-dimensional space.
- Performs principal component analysis (PCA) on training faces to build a subspace. PCA finds principal directions of variance in training data by diagonalizing the covariance matrix.

**Eigenfaces**

- Eigenfaces is an image-domain technique; other image-domain techniques exist.
- The 2-D Fourier transform is an information-preserving operation.
- Spatial frequency-domain approaches (also called correlation filters) work very well for automatic target recognition (ATR); can biometrics benefit by operating in spatial frequency domain?

$$F(u, v) = \int \int f(x, y)e^{-j2\pi(ux+vy)} \, dx \, dy$$
Correlation Filters

Test Image → FFT → Correlation Filter → IFFT → Analyze → Decision

Training

Recognition

Filter Design

Correlation output

Match

No Match

FFT

Analyze

Decision

Training Images
Peak to Sidelobe Ratio (PSR)

- PSR invariant to constant illumination changes

\[
PSR = \frac{\text{Peak} - \text{mean}}{\sigma}
\]

1. Locate peak
2. Mask a small pixel region
3. Compute the mean and in a bigger region centered at the peak

- Match declared when PSR is large, i.e., peak must not only be large, but sidelobes must be small.
CMU PIE Database

PIE Database, one face under 21 illuminations
65 subjects
Train on 3, 7, 16, -> Test on 10.

Match Quality = 40.95
Occlusion of Eyes

Using the same filter as before,
Match Quality = 30.60
Uncentered Images

Match Quality = 22.38

PSR = 22.38
Impostor

Using someone else’s filter
PSR = 4.77
Features of Correlation Filters

- Shift-invariant; no need for centering the test image
- Graceful degradation
- Can handle multiple appearances of the reference image in the test image
- Closed-form solutions based on well-defined metrics

49 Faces from PIE Database with illumination variations
Training Images

- Three face images (dark left half face, normal face illumination, dark right half face) used to synthesize a correlation filter and an individual eigenspace to perform verification

n = 3
n = 7
n = 16
Equal Error Rate using Individual Eigenfaces

Equal Error Rate using Individual Eigenface Subspace Method on PIE Database with Background Illumination

Average Equal Error Rate = 19.8 %
Peak-to-Sidelobe Ratio using Correlation Filter

PSR Performance for Class 1, Min Avg PSR Distance=23.1

Peak-to-Sidelobe Ratio (PSR)

Threshold

Authentic

Impostor

Authenticate

Reject

Image No.
Face Recognition Grand Challenge (FRGC)

- To facilitate the advancement of face recognition research, FRGC has been organized by NIST

- Ver 2.0

- 625 Subjects; 50,000 Recordings; 70 Gbytes

FRGC Dataset: Experiment 4

Generic Training Set consisting of 222 people with a total of 12,776 images

Feature extraction → Feature space generation

Reduced Dimensional Feature Space

Reduced Dimensionality Feature Representation of Gallery Set 16,028

Reduced Dimensionality Feature Representation of Probe Set 8,014

Similarity Matching

Gallery Set of 466 people (16,028) images total

Probe Set of 466 people (8,014) images total
FRGC “Gallery” Images

Controlled (Indoor)

16,028 gallery images of 466 people
FRGC “Probe” Images

Uncontrolled (Indoor)
FRGC “Probe” Images

Outdoor illumination images are very challenging due to harsh cast shadows.
The verification rate of PCA is about 12% at False Accept Rate 0.1%.

ROC curve from P. Jonathan Phillips et al (CVPR 2005)
FRGC Expt. 4 Performance

- Eigenfaces (Baseline) results provided by FRGC team
- Performance measured at 0.1 % FAR (False Acceptance Rate)

72% @ 0.1FAR
Iris Biometric

**Pattern source:** muscle ligaments (sphincter, dilator), and connective tissue

**Biometric Advantages**
- Extremely unique pattern.
- Remains stable over an individual’s lifetime.
Iris Verification

Source: National Geographic Magazine
Iris Recognition System in UAE

- "Largest national deployment so far of iris recognition ... now in its third year of operation."
- 17 air, land, sea ports; 6500 people/day
- Database of 420,000 iris codes of expellees
- Report zero false matches; 0.2% false rejections
- Daugman, International Airport Review (2) 2004
Iris Segmentation

**Standard iris segmentation**: commonly used, proposed by Daugman


---

Eye image

<table>
<thead>
<tr>
<th><img src="image1" alt="Eye image" /></th>
<th><img src="image2" alt="Bounded iris region" /></th>
</tr>
</thead>
</table>

“Unwrapped” iris pattern

| ![Unwrapped iris pattern](image3) |
Daugman’s Iris Code Method

- 2D Gabor Wavelet Transform
  \[ \int \int \ G(r, \theta) I(r, \theta) r dr d\theta \]
  \[ G(r, \theta) = e^{-i \omega (\theta - \theta_0)} e^{-\frac{(r-r_0)^2}{\alpha^2}} e^{-\frac{(\theta-\theta_0)^2}{\beta^2}} \]

- 5 parameters in Gabor function \( \alpha, \beta, \omega, \theta_0 \) and \( r_0 \)

- Hamming distance between iris codes used to decide authentic/impostor

Iris Recognition: Correlation Filters

We use correlation filters for iris recognition. We design a filter for each iris class using a set of training images.

Determining an iris match with a correlation filter
Define Experiments

Exp 1
- Right Eye
  - 1425 Iris Images
  - 124 Individuals

Exp 2
- Left Eye
  - 1528 Iris Images
  - 120 Individuals

112 Overlapping Individuals
132 Total Individuals

Source: Jonathon P. Phillips, NIST
Bar Plot Performance Results
Fully Automatic, FAR=0.001

Results from Open Book Challenge Problem
NOT Independent Evaluation

Source: Jonathon P. Phillips, NIST
Iris On the Move (IOM)
Fingerprint Recognition

■ 1880 – Fingerprint identification in India by Herschel

■ Fingerprint identification used in law enforcement
  ▼ Automated Fingerprint Identification Systems (AFIS) FBI Standards
    ▼ Minimum resolution of 500 dpi (inked as well as live scan)
    ▼ Some companies: Bioscrypt, Sagem, etc.

■ Current interest – digital live-scan devices
  ▼ Sensors - optical, capacitive, electric-field, thermal, ultrasound

■ Access control applications
  ▼ cell phone, PDA, computer, bank ATM, buildings,..
Minutiae Extraction

- Minutiae – ridge endings/bifurcations
- Minutiae extraction
  - Orientation field estimation
  - Ridge extraction
  - Thinning
  - Minutiae extraction


Vijayakumar Bhagavatula
Minutiae matching

- Minutiae Matching
  - Find a reference minutiae pair
  - Alignment of template and test sets
  - Minutiae matching by searching around an elastic bounding box

NIST 24 Database

- Digital Video of Live-scan Fingerprint Data
- Optical sensor DFR-90 from Indenticator technology of 500 dpi resolution
- Chosen data set - plastic distortion set
  - The finger is rolled and twisted
- 10 fingers of 10 people (5 female and 5 male)
- 10 secs of MPEG2 movie per finger
  - 300 images of size 448x478 pixels (padded to 512x512 pixels)
- Chosen subset - 10 thumb prints

Class 3

Class 10
Evaluation Protocol

- **Training**: uniformly sampled images from the 300 images of a class
- **Test**: correlate filters of each class against 300 images of all classes
  - Images of the same class as the filter – 300 authentics per filter
  - Images of a different class from the filter – 2700 impostors per filter
Resolution Effect

Palmprints

- Palmprints have a conglomerate of features.
- These include principal lines, smaller creases or wrinkles, fingerprint-like ridges and textures.
- Palmprints can be easily aligned about fiducial points of the hand’s geometry or shape.
Palmprint Verification

Training Images

Design Process

Correlation Filter

FFT

IFFT

Verification

Authentic

Imposter

Vijayakumar Bhagavatula
Experiment Specifications

- *PolyU* Palmprint Database
- 100 palms (classes)
- Left hands flipped to look as right hands
- 3 images per class for training
- 3 images per class for testing
- 5 different experiments using region sizes with sides of 64, 80, 96, 112, and 128 pixels

Dataset used
Palmprint Verification Results

Results of OTSDF filter classifier using 100 classes.

<table>
<thead>
<tr>
<th>n</th>
<th>Avg FRRz ($M_1$)</th>
<th>Avg FARz ($M_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>2.6% (8)</td>
<td>0.07% (23)</td>
</tr>
<tr>
<td>80</td>
<td>1.0% (3)</td>
<td>0.02% (6)</td>
</tr>
<tr>
<td>96</td>
<td>0.3% (1)</td>
<td>0.01% (3)</td>
</tr>
<tr>
<td>112</td>
<td>1.0% (3)</td>
<td>0.01% (3)</td>
</tr>
<tr>
<td>128</td>
<td>0.3% (1)</td>
<td>0.03% (10)</td>
</tr>
</tbody>
</table>

Avg FRRz: Average FRR at zero FAR. $M_1$ misses out of 300.
Avg FARz: Average FAR at zero FRR. $M_2$ misses out of 29, 700.
Cancellable Biometric Filters

- A biometric filter (stored on a card) can be lost or stolen
  - Can we reissue a different one (just as we reissue a different credit card)?
  - There are only a limited set of biometric images per person (e.g., only one face)
  - We have to figure out a way to encrypt them and ‘work’ or authenticate in the encrypted domain and NOT directly in the original biometric domain.
Enrollment Stage

Training Images $\ast$ Random PSF $\rightarrow$ Encrypted Training Images $\rightarrow$ Encrypted Template

Random Number Generator

seed

PIN
Authentication Stage

Test Image * Random Convolution Kernel

Encrypted Test Image * Encrypted Template

Random Number Generator

seed

PIN

PSR
Example of Encrypted Images

Authentic Person

Impostor Person
Correlation from an Authentic using Kernel 1
Correlation without Encryption
Correlation from an Impostor
Output from an Authentic using a Cancelled Kernel
Summary

- Correlation filters
  - Achieved excellent performance in face recognition grand challenge (FRGC)
  - Performed very well in iris challenge evaluation (ICE)
  - Also successful in fingerprint recognition and palmprint recognition

- All biometric modalities have their own strengths & weaknesses, suggesting that we may have to use multiple modalities in fielded systems

- Correlation filters provide a single matching engine for a variety of image biometrics --- making multi-biometric approaches feasible.