Completely Contactless Finger Knuckle Print Identification for Real-World Applications

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Motivation and Objectives

➢ Motivation

▪ Traditional Biometrics → Limitations and Privacy Concerns

▪ About 2-4% of Fingerprints are Not Usable (NIST & UIDAI Study)

▪ Multimodal Biometrics → Finger Knuckle + … Face or Fingerprint or

▪ Identification At-A-Distance

We cannot see fingerprints from 20+ centimeter while you can still see finger knuckle
Contactless Finger Knuckle Identification

- Applications
Contactless Finger Knuckle Identification

➢ Applications
Contactless Finger Knuckle Identification

➢ Applications

Bromley Paedophile Dean Hardy Jailed for 10 Years, Bromley Times, Jan. 2012
http://www.bromleytimes.co.uk/news/courtcime/bromley_paedophile_dean_hardy_jailed_for_10_years_1_1176957
Early Work on Finger Knuckle Identification

➢ Prior Work on Finger Knuckle based Identification
  ▪ Using Pegs, Ring Finger, 192 dpi, Cross-Correlation (21×21 matrix)
  ▪ 125 Different Subject (IISc Bangalore, India), 1.2% EER

Contactless Finger Knuckle Identification

- First Paper on Pegfree and Contactless Identification
  - 2 Session Database, 105 Different Subjects. EER of 1.39%
  - Live System, Identification and Authentication
  - First Database in Public Domain (IITD Finger Knuckle)

Constrained Knuckle Imaging

- Another Online Finger Knuckle Authentication
  - Constrained Imaging (similar to pegs)
  - Database from 165 different subjects
  - Alignment using BLOC, Fusion, Impressive Results

Contactless Finger Knuckle Identification

➢ KnuckleCodes (BTAS’09)*
  ▪ Block Diagram

Contactless Finger Knuckle Identification

KnuckleCodes
- Highly Curved Surface → Uneven Reflections → Shadows
- Nonlinear Image Enhancement
- Estimate → Background Illumination
Knuckle Segmentation

➢ Using Edge Density

- Extracted ROI →
Feature Extraction

- Localized Radon Transform (LRT)
  - LRT of a discrete image \( g \) on a limited local region \( R^2_q \) is:

  \[
  s[L_\theta] = M_g(\theta) = \sum_{(x,y) \in L_\theta} g[x,y]
  \]

  \( R^2_q = \{0,1,\ldots,q-1\} \), \( q \rightarrow \) Region size  
  \( L_\theta \rightarrow \) Set of points on the line within the region forming angle \( \theta \) with the positive \( x \)-axis
Score Generation

➢ Matching KnuckleCodes
  ▪ Partially Matching Knuckles → Translation and Rotation of Fingers
  ▪ Matching Score for two Z-bit KnuckleCodes

\[
S(R, T) = \min_{\forall i \in [0, 2w], \forall j \in [0, 2h]} \left( \sum_{x=1}^{m} \sum_{y=1}^{n} \phi(\hat{R}(x+i, y+j), T(x, y)) \right)
\]

\[
w = \text{floor}\left(\frac{m}{3}\right), \quad h = \text{floor}\left(\frac{n}{3}\right)
\]

\[
\hat{R}(x, y) = \begin{cases} 
R(x-w, y-h) & x \in [w+1, w+m], \ y \in [h+1, h+n] \\
-1 & \text{otherwise}
\end{cases}
\]

\[
\phi(J_b, K_b) = \begin{cases} 
0 & \text{if } J_b = K_b \ \forall \ b \\
1 & \text{otherwise}
\end{cases}
\quad b = 1, 2, ..Z
\]

▪ Size of KnuckleCodes → One fourth of knuckle image size ($X_p = 2$)
Experimental Results

Experiments

- 158 Subjects, 5 Images per Subject, Age group → 16-55 year
- Unconstrained (peg-free) imaging
- Five-fold Cross-Validation, Average of Results
- Genuine Scores → 790 (158 × 5)
- Imposter Scores → 124030 (158 × 157 × 5)
- Comparative Performance using (even) Gabor filters
  - \( f = 1/(2\sqrt{2}) \), 12 filters, 15 × 15 mask size

KnuckleCodes generated for knuckle image in (a) using LRT in (b), and using even Gabor filters in (c)
Second Generation Biometrics

➢ Results
  ▪ Cumulative Match Characteristics

Promising Results
- EER of 1.08% on database of 158 subjects
- Recognition accuracy of 98.6%
Taxonomy of Knuckle Patterns for Identification

➢ Major and Minor Knuckle Patterns

Minor Knuckle Segmentation

Experimental Results

Experiments

- 202 Subjects, 5 Images per Subject, Age group → 4-60 year
- Less Constrained (peg-free) imaging

- 10 Subjects → Parameter Estimation
- 192 Subjects → Performance Evaluation

- Five-fold Cross-Validation, Average of Results

- Genuine Scores → 960 (192 × 5)
- Imposter Scores → 183360 (192 × 191 × 5)
Experimental Results

➢ Minor Knuckle Segmentation and Enhancement
  ▪ Sample Images
Experimental Results

- Exploring Color Channels
  - Comparative Receiver Operating Characteristics
Experimental Results

➢ Results

▪ Comparative Receiver Operating Characteristics
Second Minor Finger Knuckle Features

➢ Spatial Domain
  ▪ Automated Detection and Segmentation

Results using Large Database

➢ Over 700 Subjects Database
Door Security using Second Minor Knuckle

- Contactless Authentication during Door Access
  - Multiple Simultaneous Second Minor Finger Knuckle Acquisition
  - Online System, RoI alignment in frequency domain

Knuckle Patterns Are Stable?

➢ Finger Knuckle Images after 6+ years
Recovering and Matching Knuckle Minutiae

Minutiae Patterns From Finger Knuckle Images

Smartphone-based Mobile Security

➢ Objectives

- Contactless Finger Knuckle Identification using Mobile Phones
- Built-in-Camera Imaging, Android OS and OpenCV Library
- User Friendly Interface → Enrollment and Verification
- Smartphone Unlocking using Finger Knuckle Patterns
Image Acquisition and Knuckle Detection

Knuckle Detection using *Cascade Classifiers*
- Performance using automated knuckle detection (790 Images)

<table>
<thead>
<tr>
<th>Cascade Classifier File</th>
<th>Hits</th>
<th>Missed</th>
<th>False</th>
<th>Accuracy*</th>
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<tr>
<td>File 1</td>
<td>72</td>
<td>28</td>
<td>20</td>
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<tr>
<td>File 2</td>
<td>64</td>
<td>36</td>
<td>25</td>
<td>64%</td>
</tr>
<tr>
<td>File 3</td>
<td>65</td>
<td>35</td>
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<td>65%</td>
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<td>File 4</td>
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<tr>
<td>File 5</td>
<td>23</td>
<td>77</td>
<td>26</td>
<td>23%</td>
</tr>
</tbody>
</table>

Accuracy = (Hits / number of testing samples) * 100%
Results

➢ Receiver Operating Characteristics
  ▪ 187 Different Fingers, 109 Subjects, 561 Images

  - Equal Error Rate of about 9% for matching 187 different fingers
  - Mobile phone is expected to have 5-6 users/fingers
Convenience and User Friendly Interface

Contactless 3D Finger Knuckle Identification

- 3D Finger Knuckle Recovery and Matching
  - First Work on 3D Finger Knuckle Identification (TPAMI 2020)
  - Low Cost 3D Finger Knuckle Recovery → Photometric Stereo

3D Finger Knuckle Acquisition

- Photometric Stereo
  - Single Camera, 7 LEDs, Illumination Controller
3D Finger Knuckle Matching

➢ Feature Extraction and Matching
   ▪ Surface Normals → Feature Extraction
   ▪ Performance Improvement → Simultaneous usage of 2D and 3D

![Receiver Operating Characteristics](image1)

![Cumulative Match Characteristics](image2)
### 3D Finger Knuckle Matching

#### Comparisons and Complexity

Comparative computational time (in milliseconds)

<table>
<thead>
<tr>
<th></th>
<th>Surface Normal Estimation</th>
<th>Depth Integration</th>
<th>Feature Extraction</th>
<th>Total</th>
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<td>0.57</td>
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<td>0.57</td>
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<tr>
<td>Ours</td>
<td>0.72</td>
<td>-</td>
<td>0.58</td>
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</tr>
</tbody>
</table>

Live Demo

➢ Completely Contactless Finger Knuckle Identification

- Online System for Real World Applications → Pls Try!
Acknowledgment

➢ Collaborators

▪ Zhenyu Zhou
▪ Zhihuan Xu
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▪ K. Y. Cheng
▪ Kevin H. M. Cheng

... and hundreds of volunteers in India and China who freely provided us their finger dorsal images for our research during last 15+ years ...
References

- Contactless Finger Knuckle Identification using Smartphones (Demo), http://www.youtube.com/watch?v=bjPJwbSiMgo
References

Thank You!