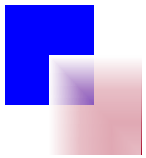
IAPR/IEEE Winter School on Biometrics 2023
8th January 2023

Finger Knuckle Identification in the Wild



Ajay Kumar
Department of Computing
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

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

Privacy Concerns in Typical Biometric Modalities

Biometric Modality	Possible Health/Medical Indicators
Retina	Eye related disease (e.g. diabetic retinopathy)
DNA	Genetic diseases or susceptibility to diseases, gender
Palmprint	Prediction of congenital heart disease and laryngoscopy in diabetics
Face	Facial thermograms for fever and related medical conditions/diseases
Gait	Physical disability
EEG	Heart diseases

Contactless Finger Knuckle Identification

- Applications

Contactless Finger Knuckle Identification

- Applications

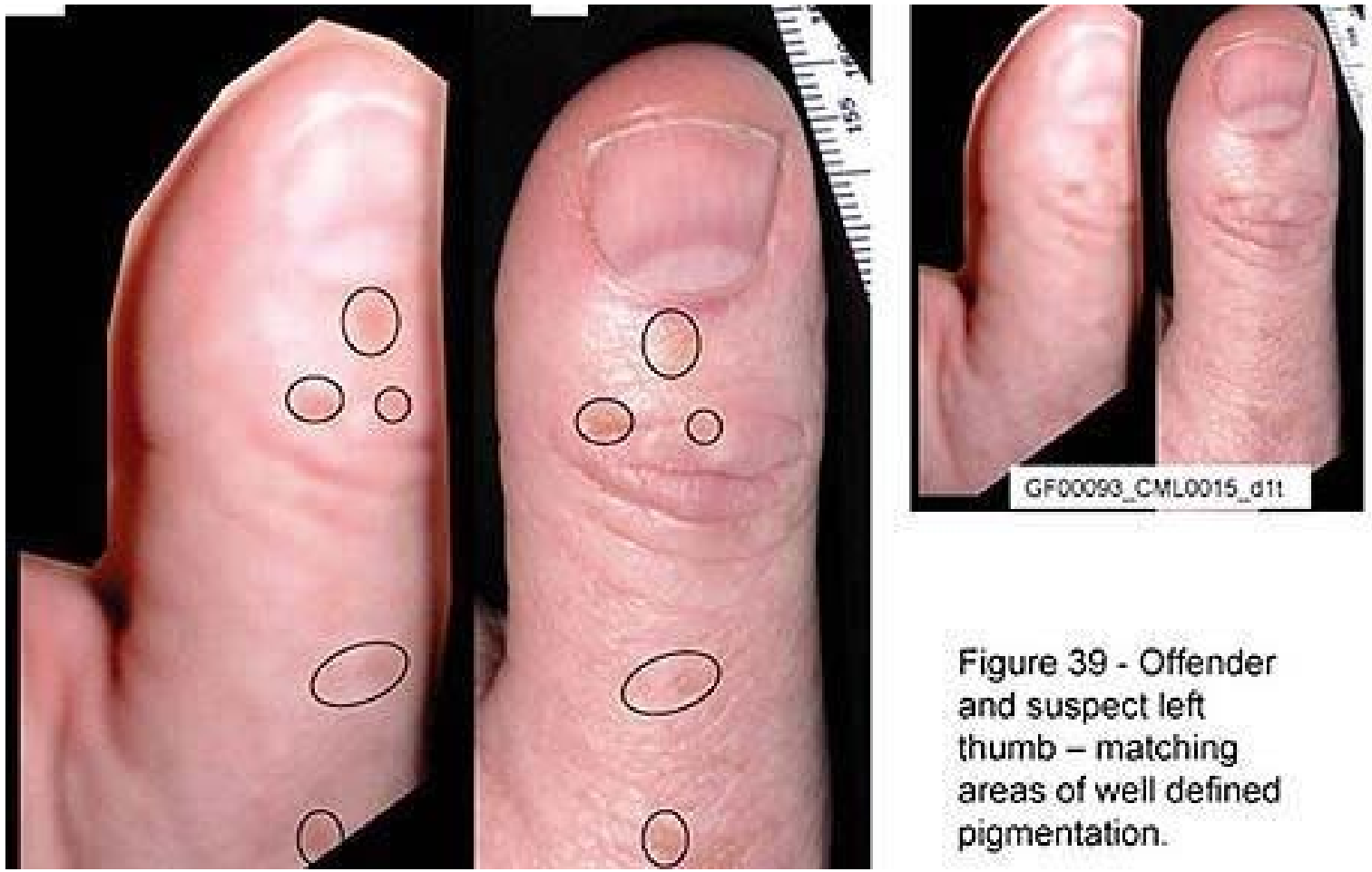


Figure 39 - Offender and suspect left thumb – matching areas of well defined pigmentation.

Bromley Paedophile Dean Hardy Jailed for 10 Years,
http://www.bromleytimes.co.uk/news/courtcrime/bromley_paedophile_dean_hardy_jailed_for_10_years_1_1176957

Contactless Finger Knuckle Identification

- Surveillance

Contactless Finger Knuckle Identification

- Surveillance

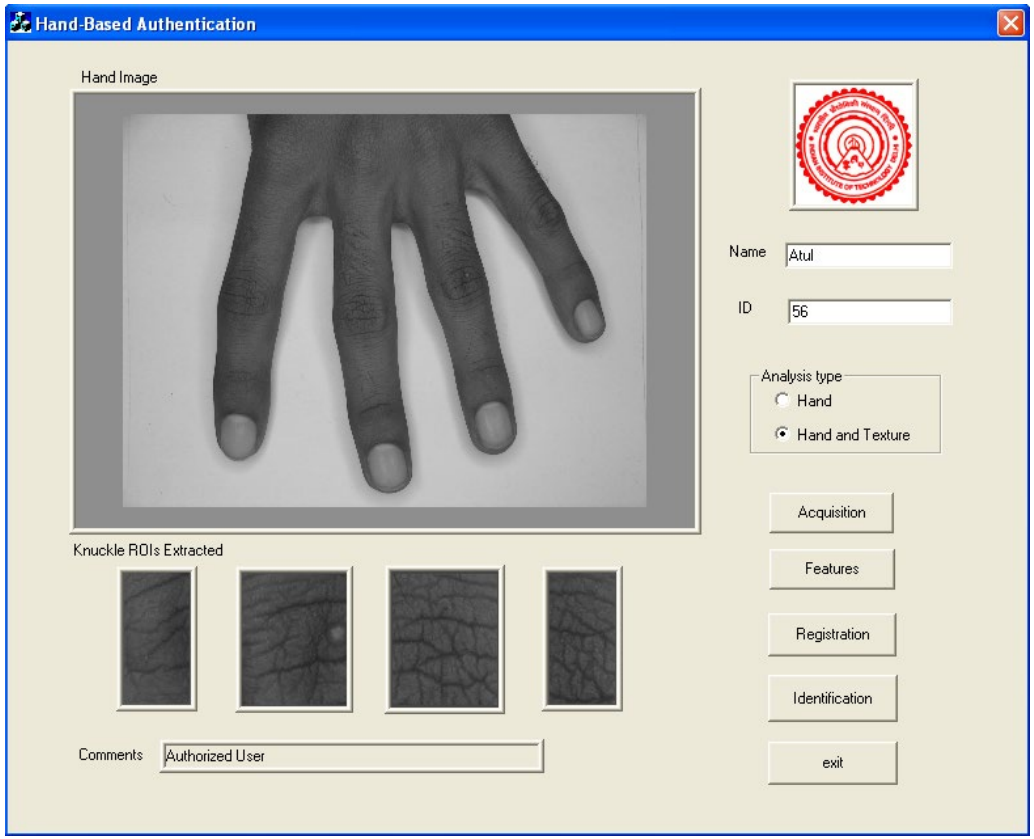
Early Work on Finger Knuckle Identification

- 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

K. K. Sricharan, A. A. Reddy, A.G. Ramakrishanan, "Knuckle based Hand Correlation for User Authentication ," *Proc. SPIE 6202,* 2006

Early Work on Finger Knuckle Identification

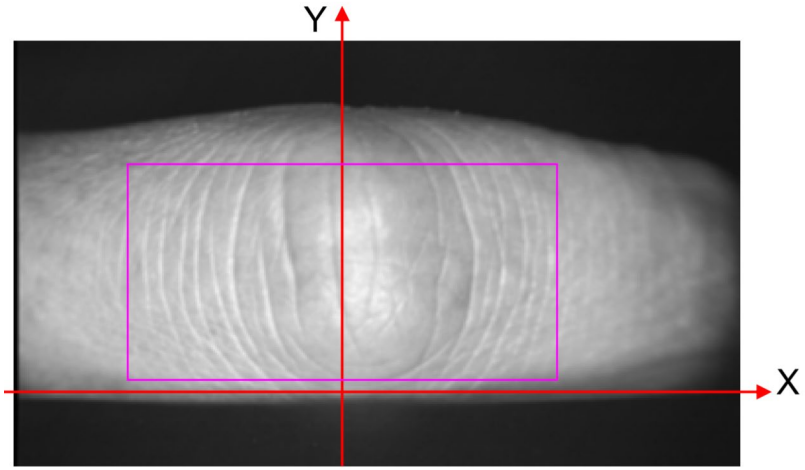
- First Work on Pegfree and Contactless Identification
  - 2 Session Database, 105 Different Subjects. EER of 1.39%
  - Live System, First Database in Public Domain (IITD Finger Knuckle)



A. Kumar and Ch. Ravikanth, “Personal authentication using finger knuckle surface”, *IEEE Trans. Info. Forensics & Security*, vol. 4, no. 1, pp. 98-110, Mar. 2009

Constrained Knuckle Imaging

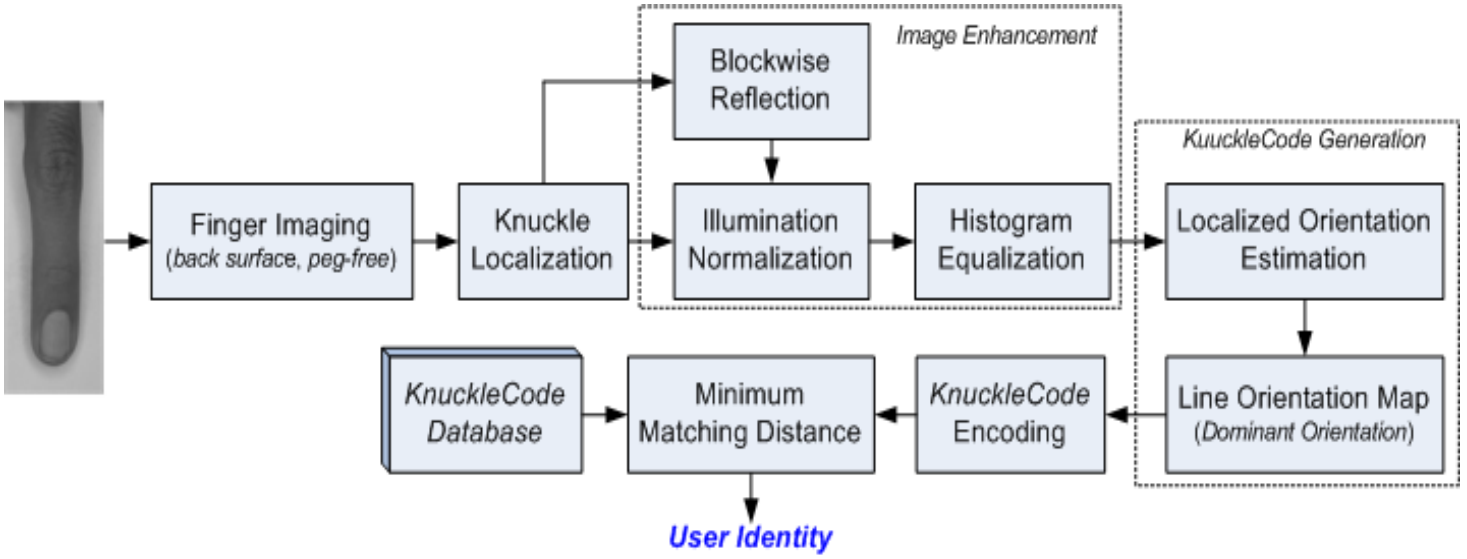
- Another Online Finger Knuckle Authentication
  - Constrained Imaging (similar to pegs)
  - Database from 165 different subjects
  - Alignment using BLOC, Fusion, Impressive Results



L. Zhang, L. Zhang, D. Zhang, H. Zhu, “Ensemble of local and global information for finger–knuckle-print recognition”, *Pattern Recognition*, vol. 44, pp. 990-1998, Sep. 2011

Contactless Finger Knuckle Identification

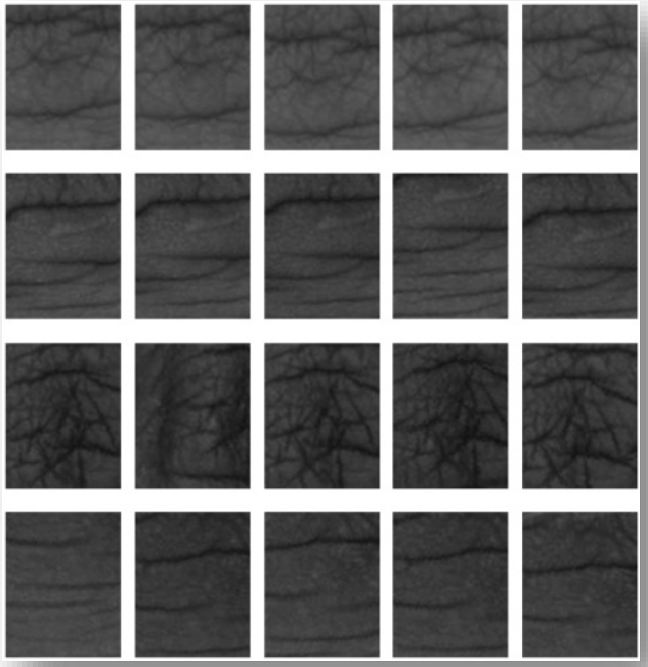
- KnuckleCodes (BTAS'09)*
  - Block Diagram

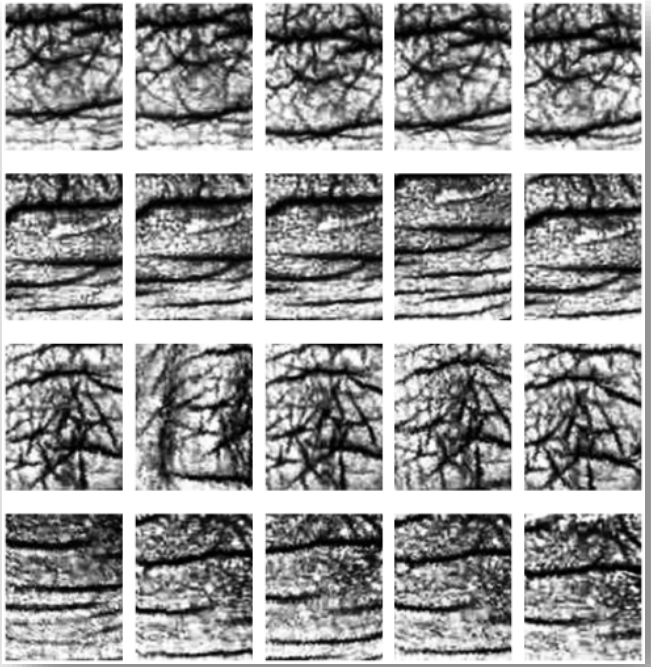


* A. Kumar and Y. Zhou, "Human Identification using KnuckleCodes," *Proc. BTAS'09*, Washington, D. C., Sep. 2009

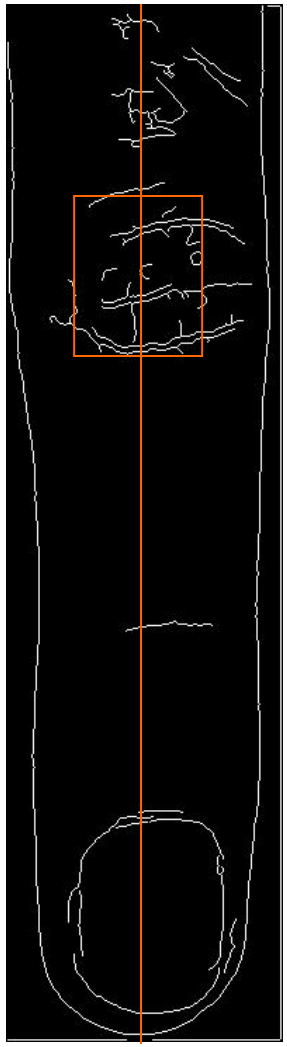
Contactless Finger Knuckle Identification

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

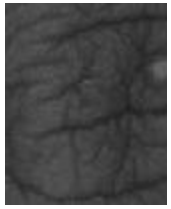




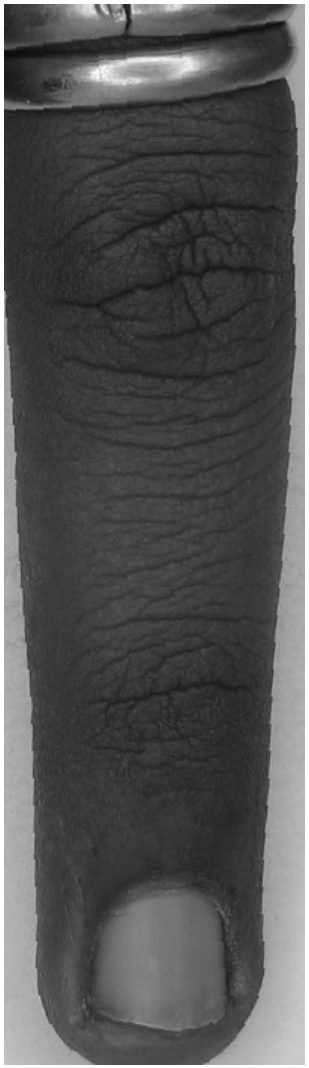
Knuckle Segmentation



- Using Edge Density
  - Extracted ROI →



Ring Detection



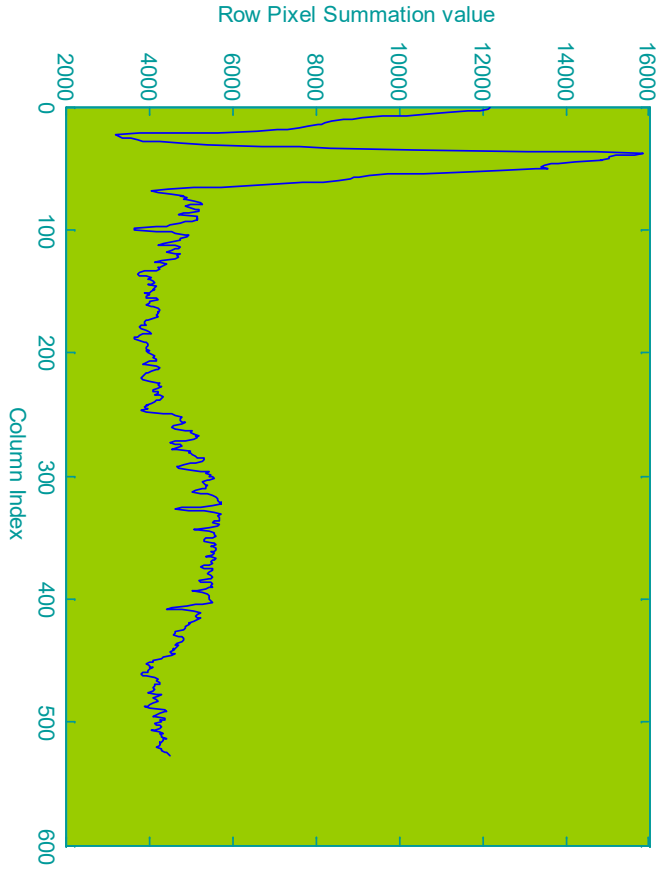
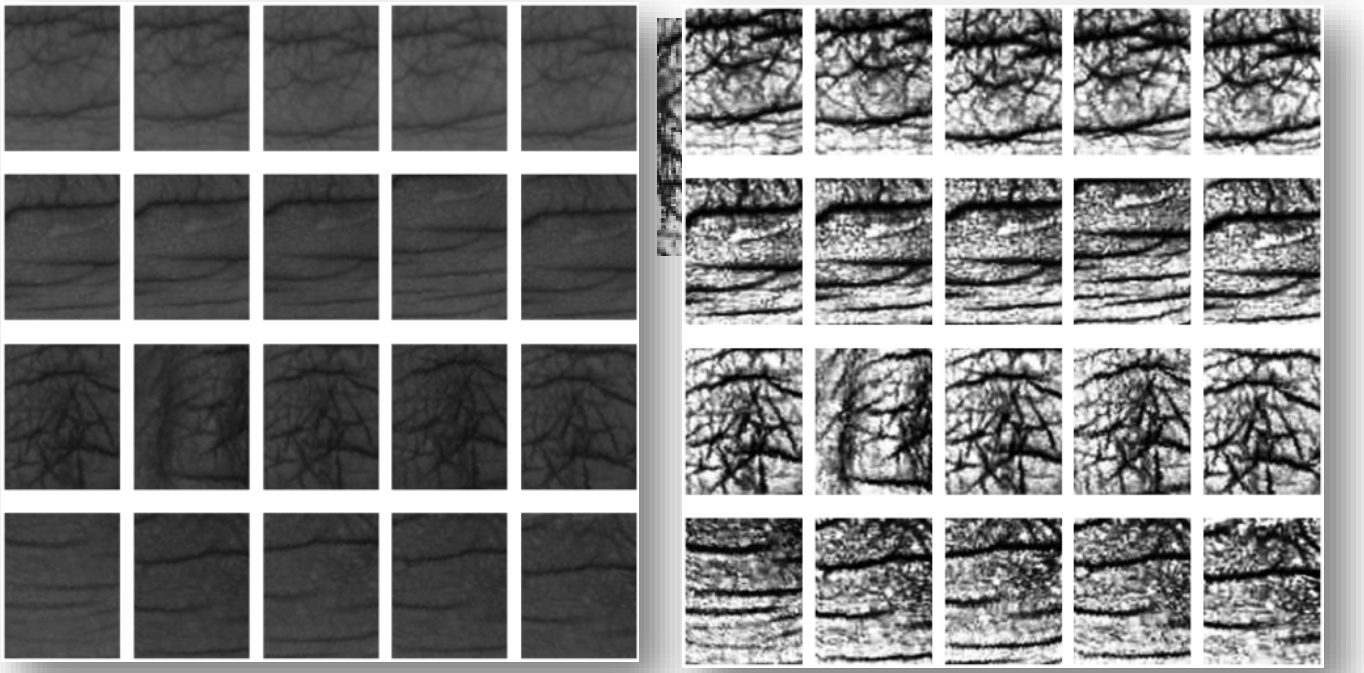


Image Enhancement

- Finger Knuckles
  - Highly Curved Surface → Uneven Reflections → Shadows
  - Nonlinear Image Enhancement
  - Estimate → Background Illumination



Feature Extraction

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

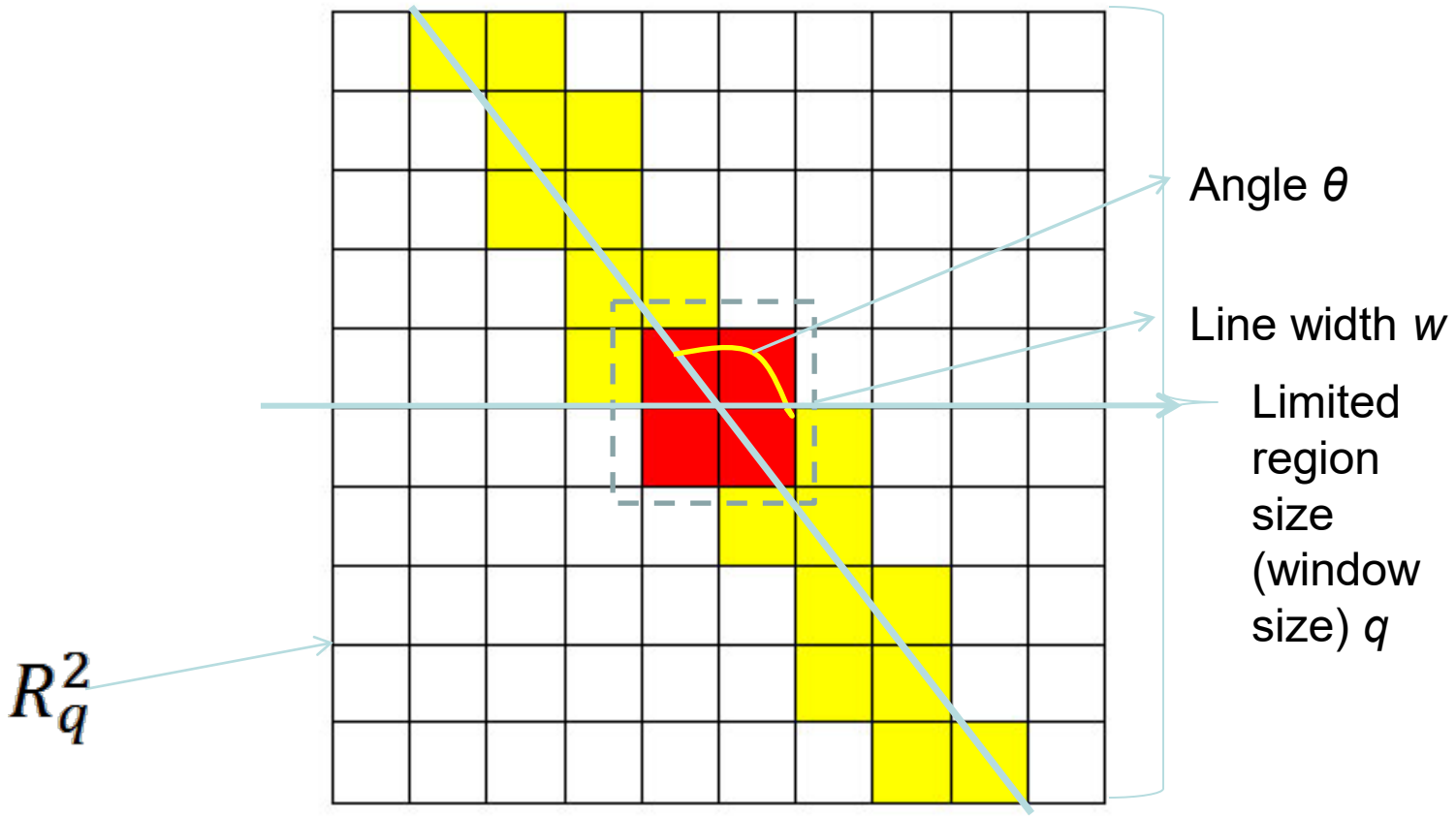
$$s[L_\theta] = \mathrm{M}_g(\theta) = \sum_{(x,y)\in L_\theta} g[x,y]$$

R_q^2 = {0,1,…,*q*-1}, *q* → Region size

L_θ → Set of points on the line within the region forming angle θ with the positive *x*-axis

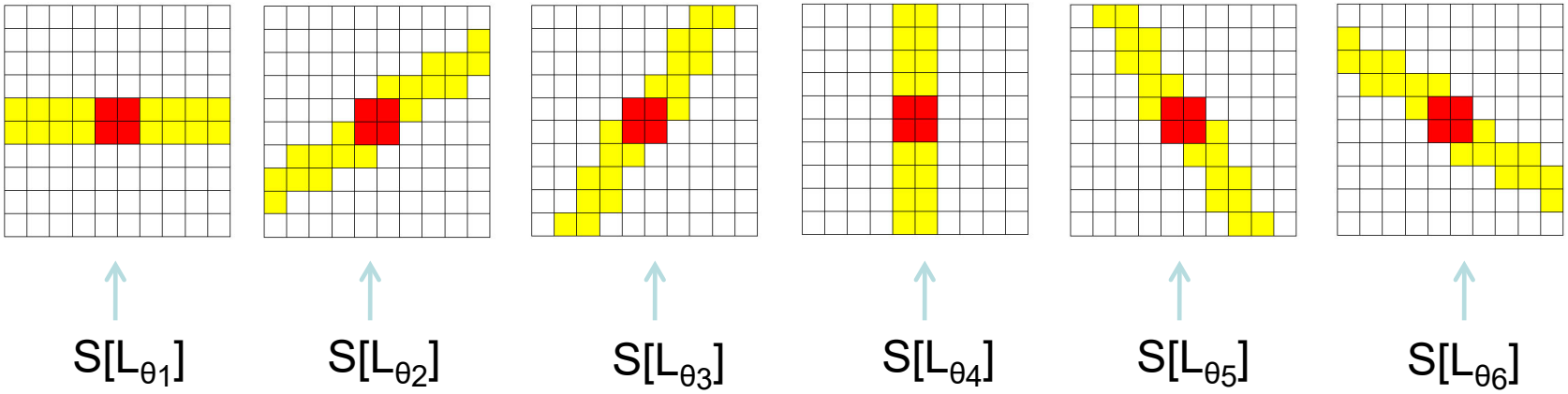
Feature Extraction

- Localized Radon Transform



Feature Extraction

- Localized Radon Transform



Select the direction which results in minimum (maximum) magnitude

Score Generation

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

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

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

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

$$\phi(J_b,K_b) = \begin{cases}0 & if\ \ J_b = K_b\ \forall\, b\\ 1 & otherwise\end{cases} \qquad b = 1, 2, ..Z$$

  - Size of KnuckleCodes → One fourth of knuckle image size ($X_p = 2$)

Experimental Results

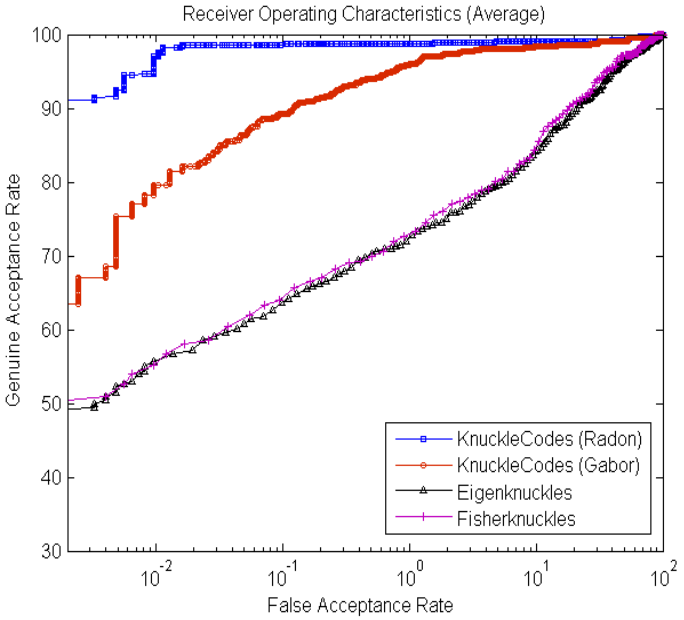
- Experiments
  - 158 Subjects, 5 Images per Subject, Age group $\rightarrow$ 16-55 year
  - Unconstrained (peg-free) imaging
  - Five-fold Cross-Validation, Average of Results
  - Genuine Scores $\rightarrow$ 790 (158×5)
  - Imposter Scores $\rightarrow$ 124030 ($158 \times 157 \times 5$)
  - Comparative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

(a) (b) (c)

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

Experimental Results

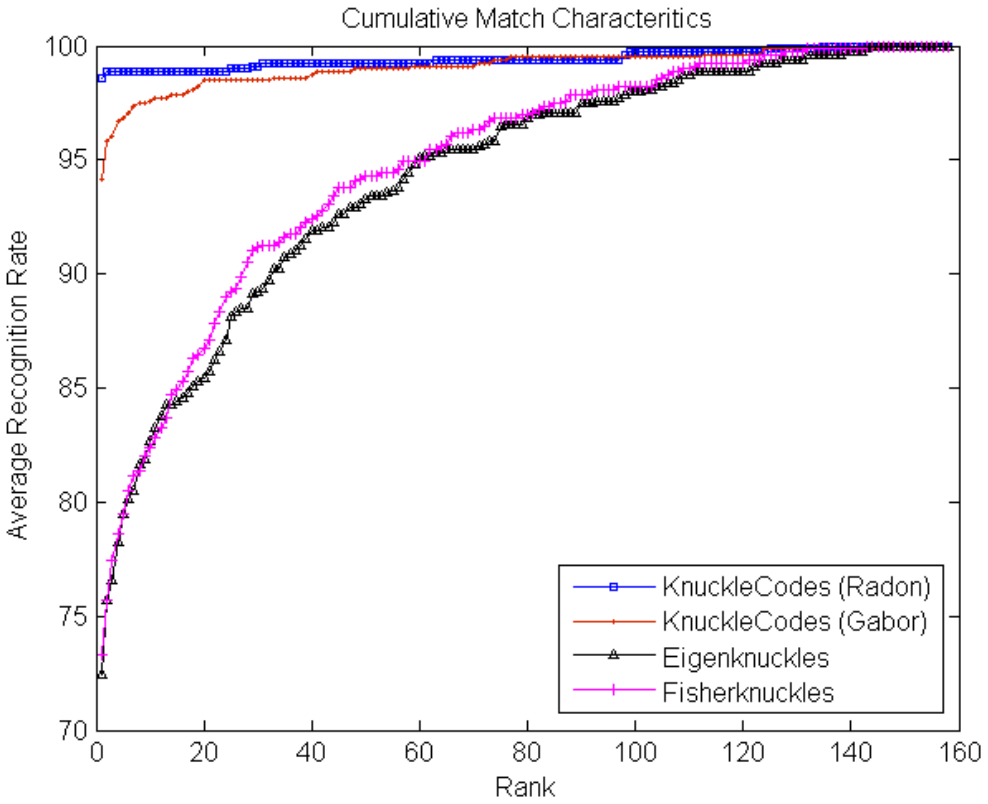
- Results
  - Comparative Receiver Operating Characteristics



	Equal Error Rate			
EER (%)	KnuckleCodes (Radon)	KnuckleCodes (Gabor)	EigenKnuckles	Fisherknuckles
Mean	1.08	2.66	13.92%	12.66%
Std deviation	1.08	1.81	1.24	1.27%

Second Generation Biometrics

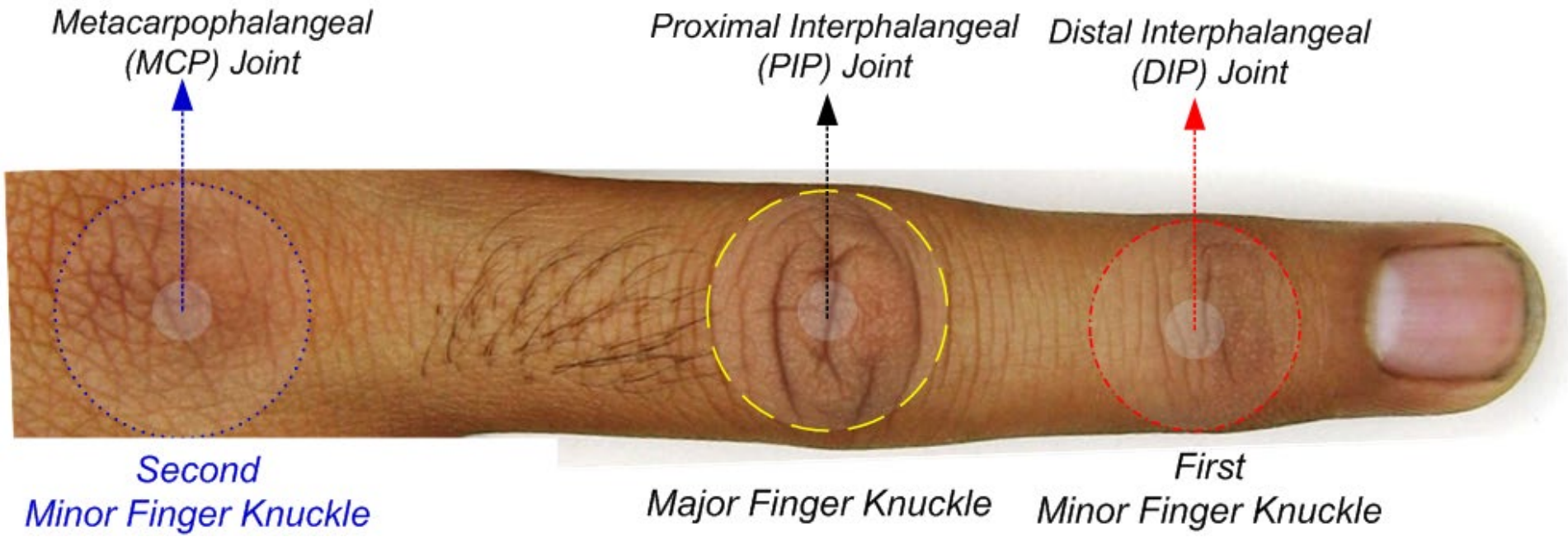
- Results
  - Cumulative Match Characteristics



- 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

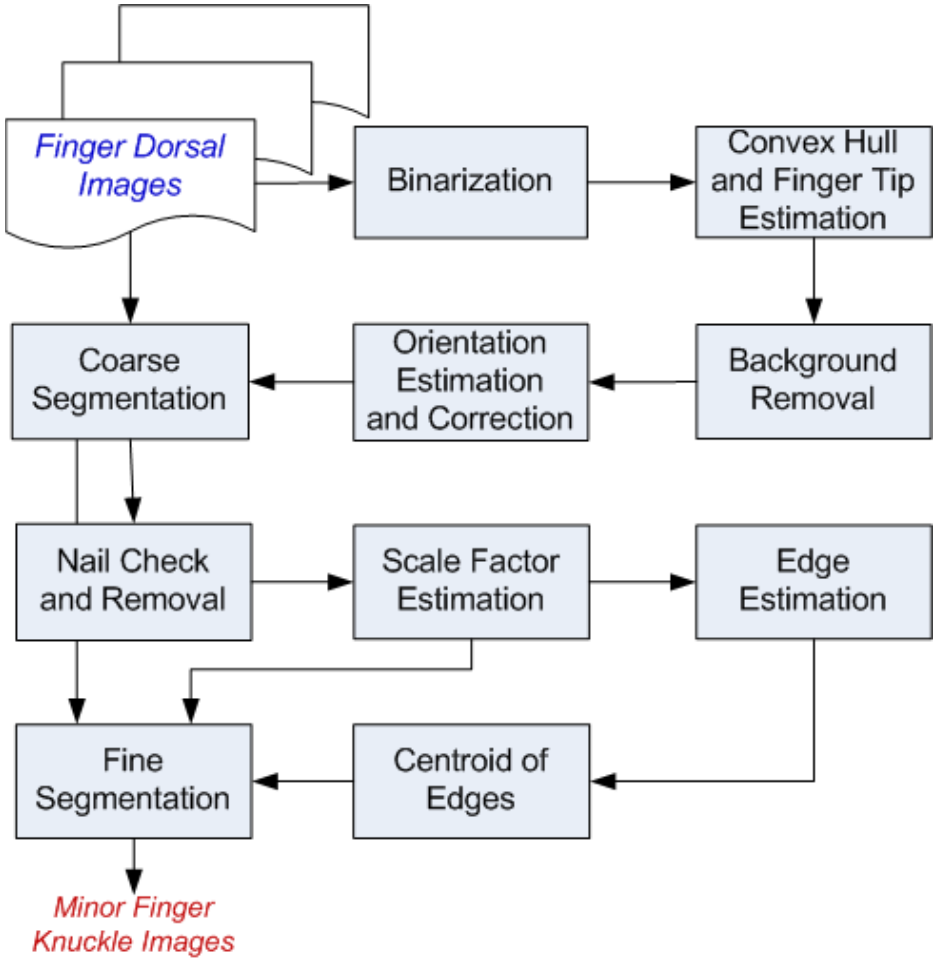


A. Kumar, "Importance of being unique from finger dorsal patterns: Exploring minor finger knuckle patterns in verifying human identities," *IEEE Trans. Information Forensics & Security*, vol. 9, pp. 1288-1298, August 2014.

Minor Finger Knuckle?

- Why Minor Knuckle?
  - Forensic Analysis Images/Video
  - Higher Accuracy → Combine Major and Minor Finger Knuckle
  - Occlusion → Hair or Objects

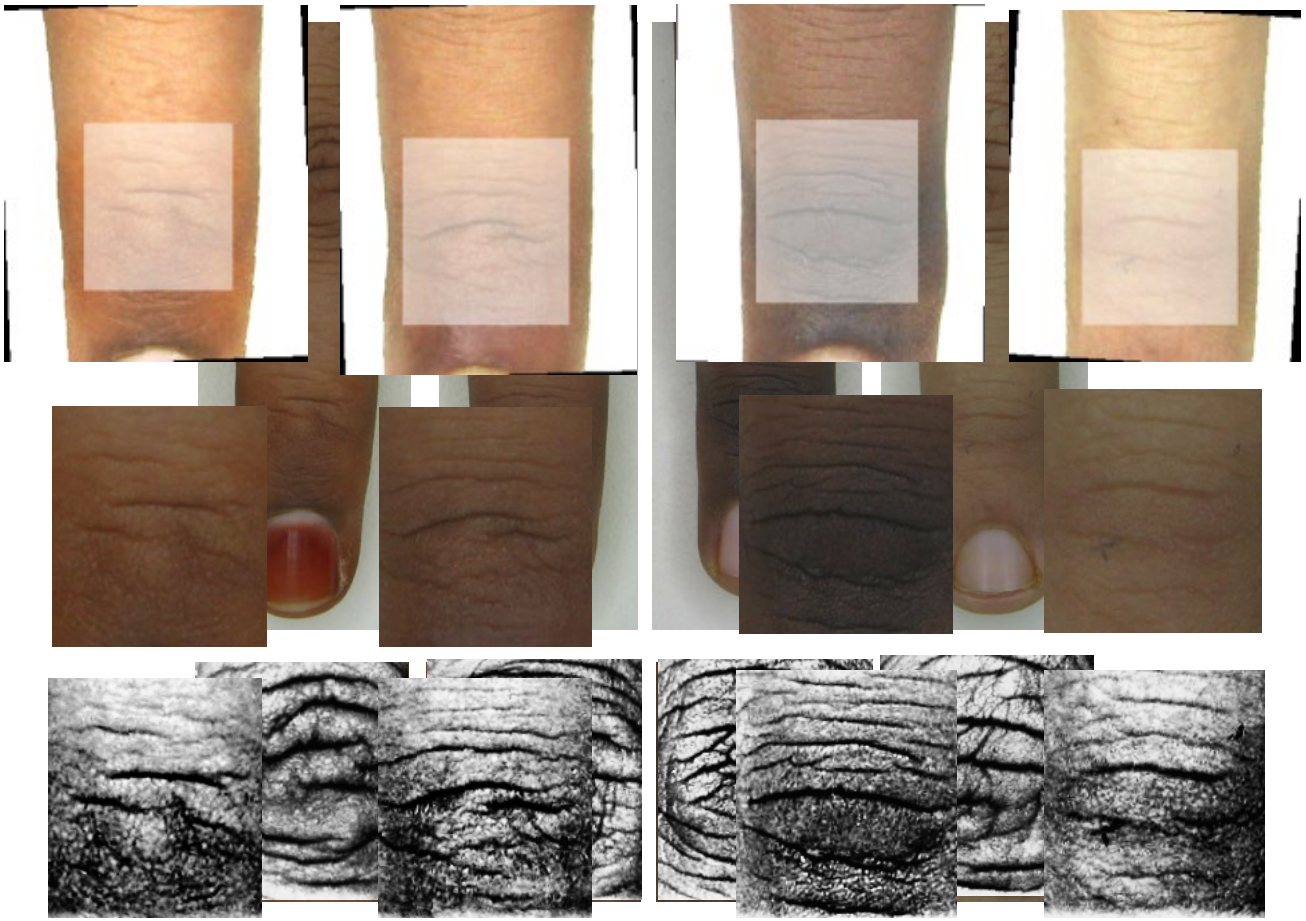
Knuckle Segmentation



A. Kumar, “Importance of being unique from finger dorsal patterns: exploring minor finger knuckle patterns in verifying human identities,” *IEEE Transactions on Information Forensics and Security*, pp. 12881298, Aug. 2014.

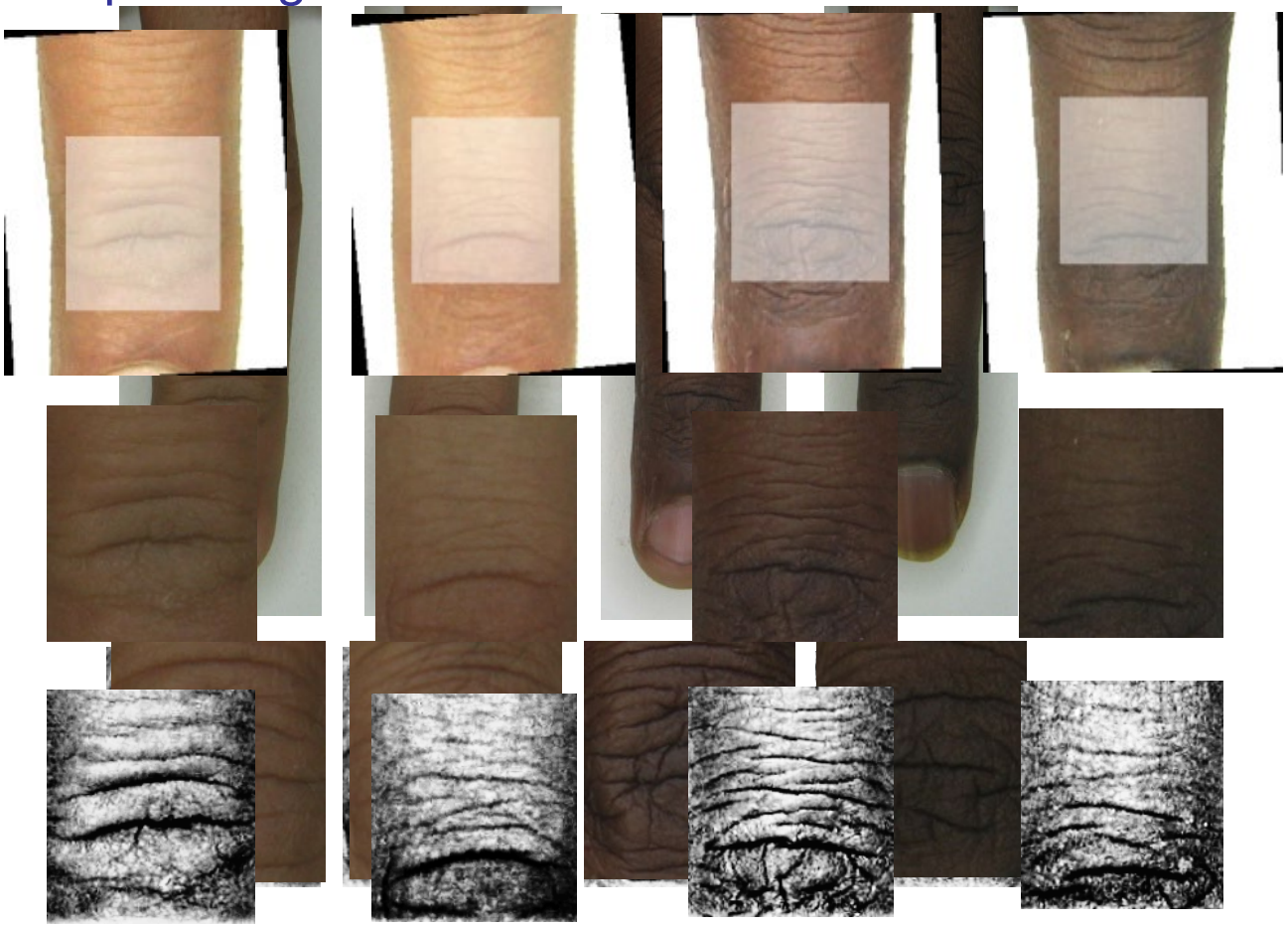
Experimental Results

- Knuckle Segmentation
  - Sample Images



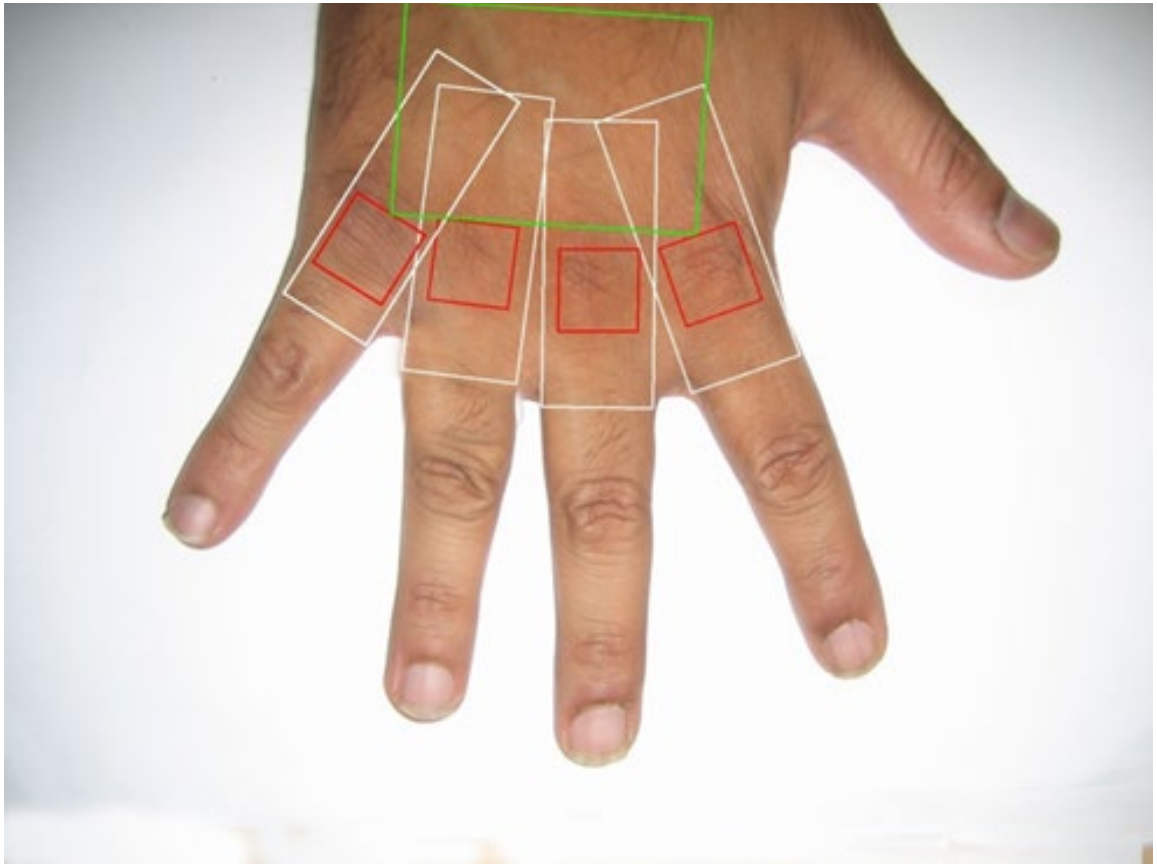
Experimental Results

- Knuckle Segmentation
  - Sample Images



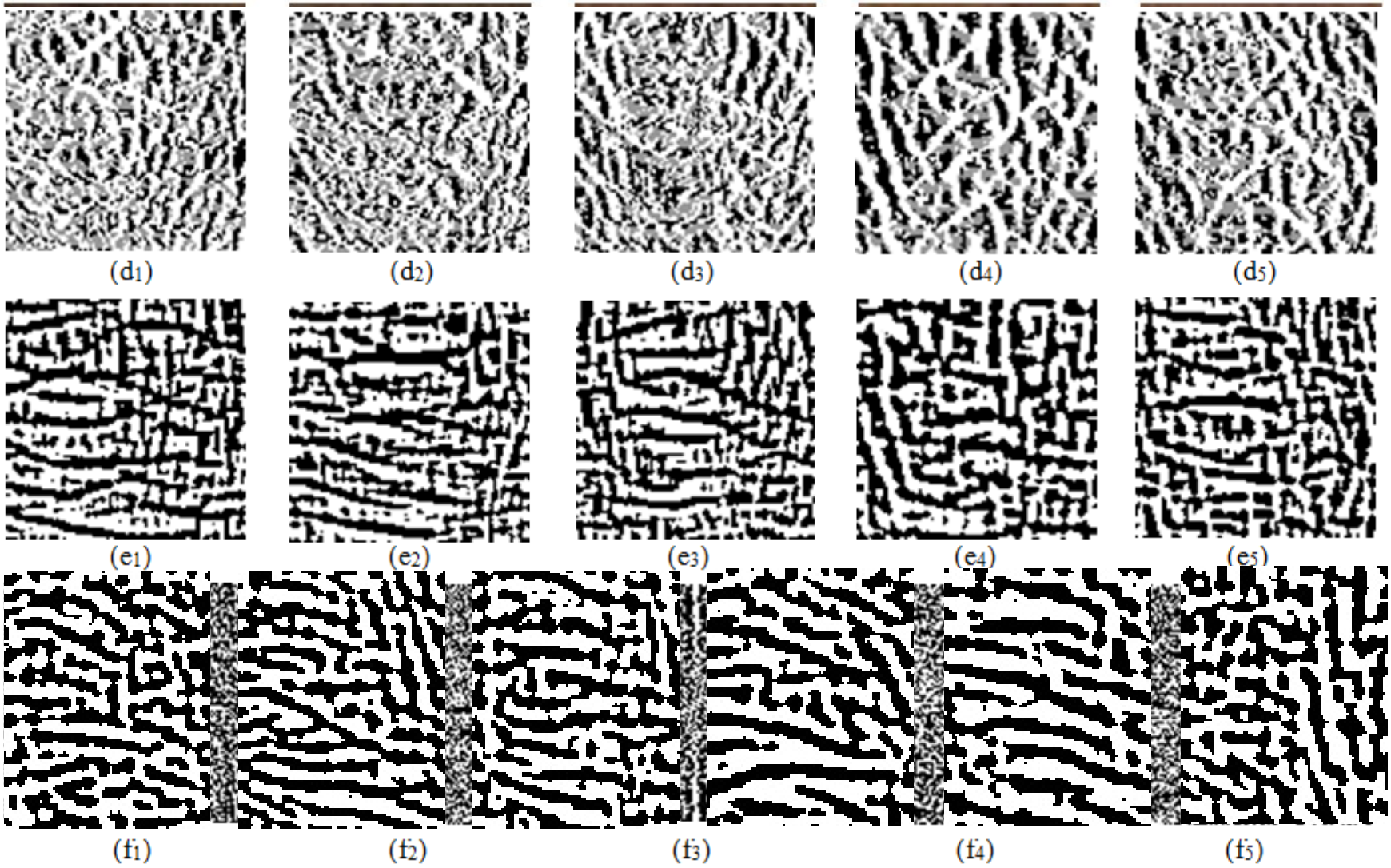
Second Minor Finger Knuckle Features

- Spatial Domain
  - Automated Detection and Segmentation



A. Kumar and Z. Xu 'Personal Identification using Minor Knuckle Patterns from Palm Dorsal Surface," *IEEE Transactions on Information Forensics and Security*, pp. 2338-2348, October 2016.

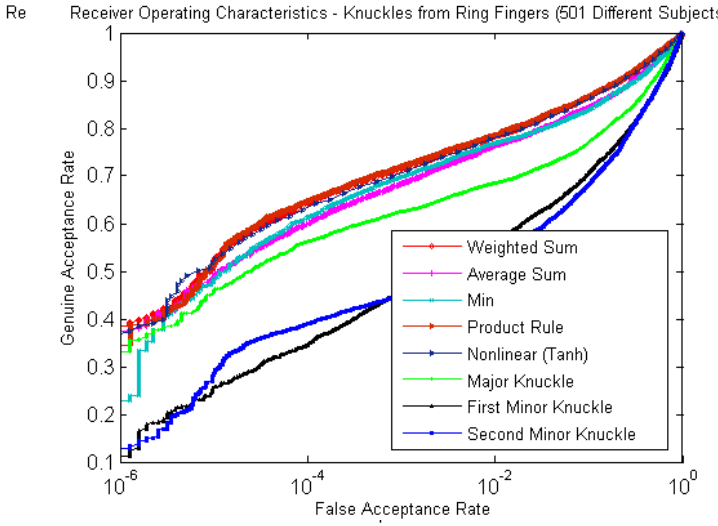
Feature Extraction and Matching

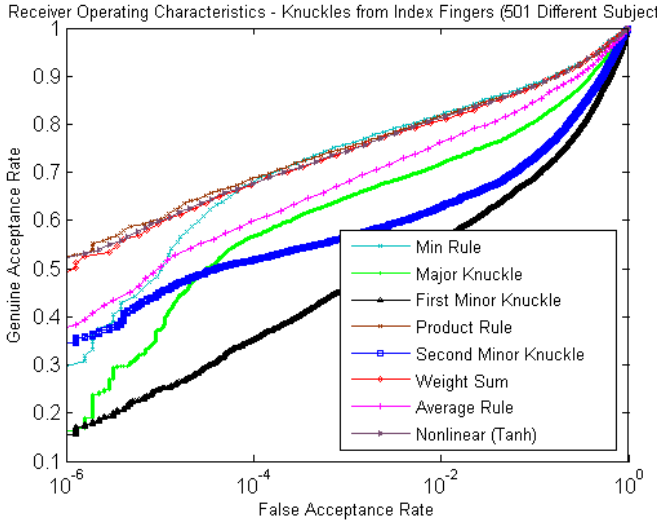


A. Kumar and Z. Xu 'Personal Identification using Minor Knuckle Patterns from Palm Dorsal Surface," *IEEE Transactions on Information Forensics and Security*, pp. 2338-2348, October 2016.

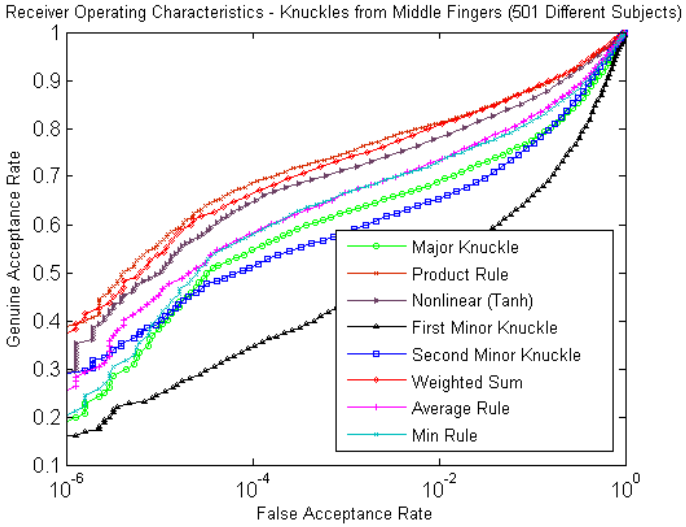
Results using Large Database

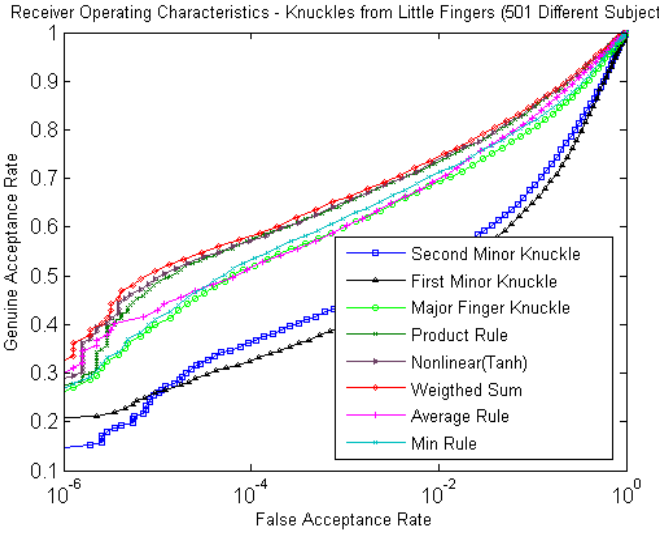
- Over 500 Subjects Database





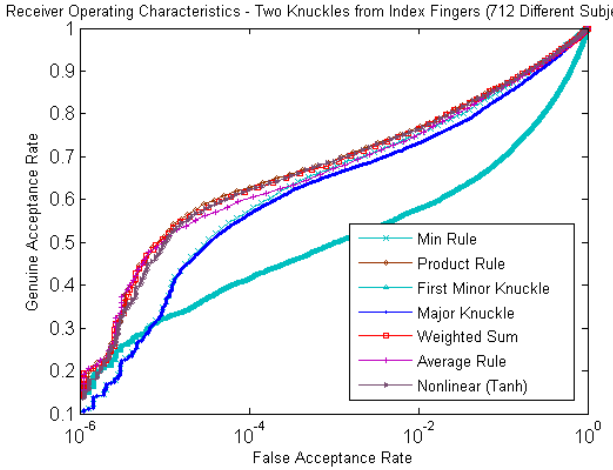
(b)

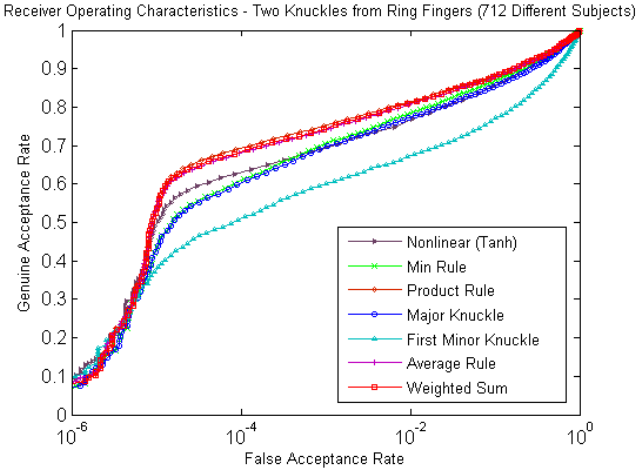


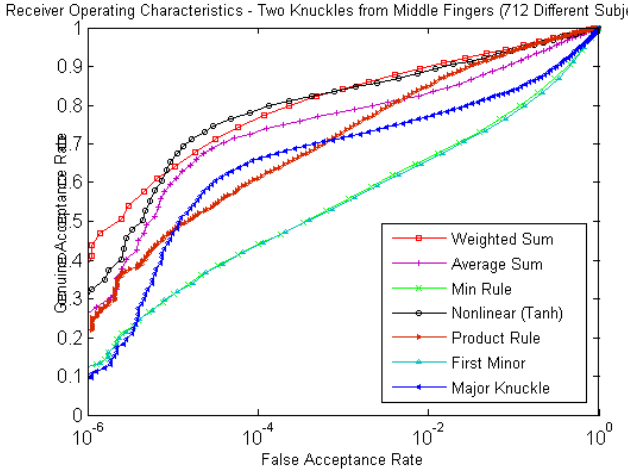


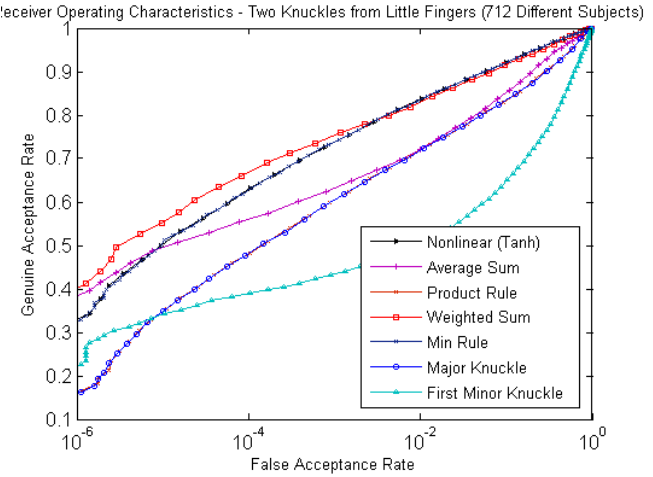
Results using Large Database

- Over 700 Subjects Database



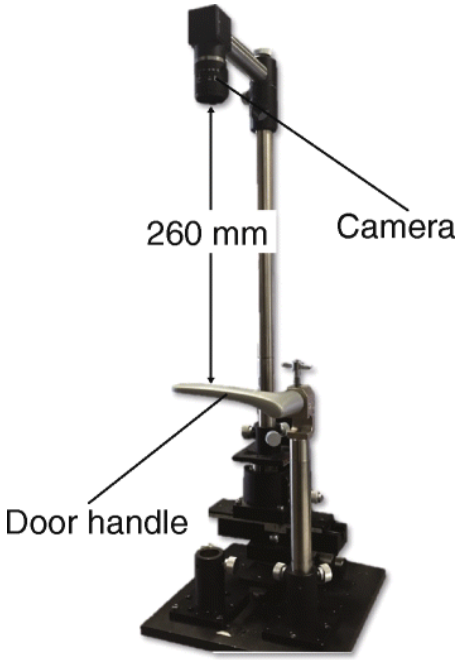


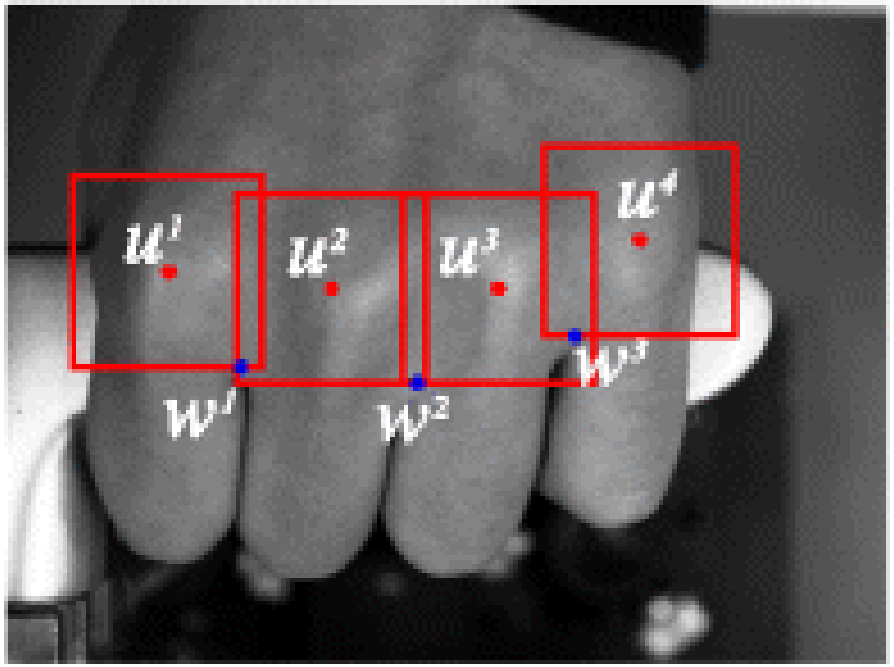




Door Security using Second Minor Knuckle

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

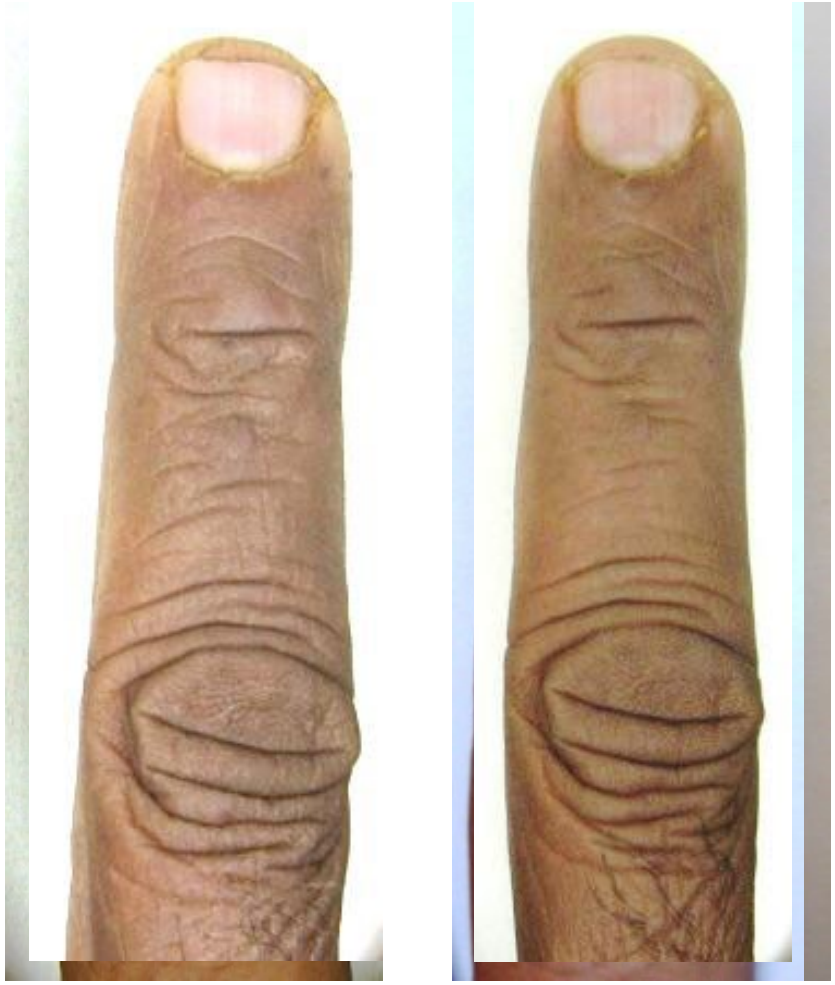




D. Kusanagi, S. Aoyama, K. Ito, T. Aoki, "A practical person authentication system using second minor finger knuckles for door security, *IPSJ Transactions on Computer Vision and Applications*, vol. 9, 2017.

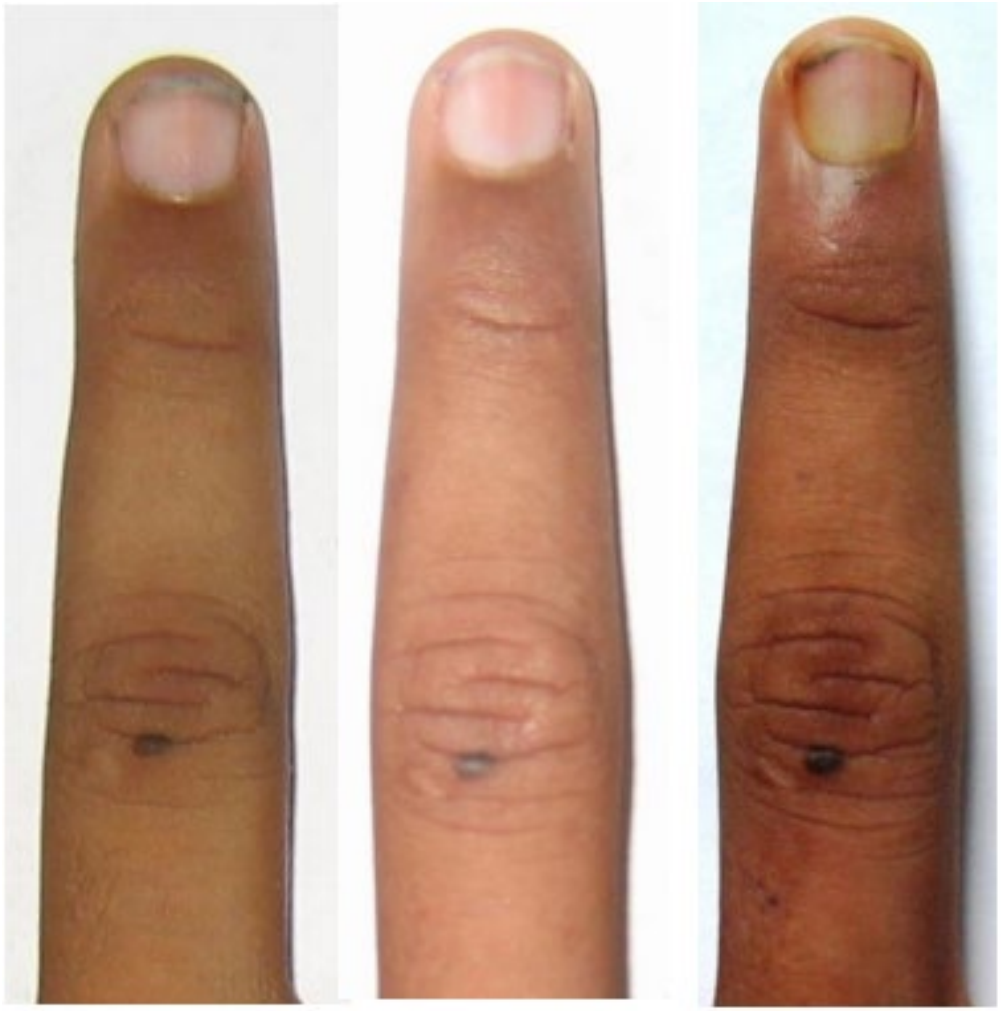
Knuckle Patterns Are Stable?

- Knuckle Images before (*in left*) and after 6+ years (*in Right*)



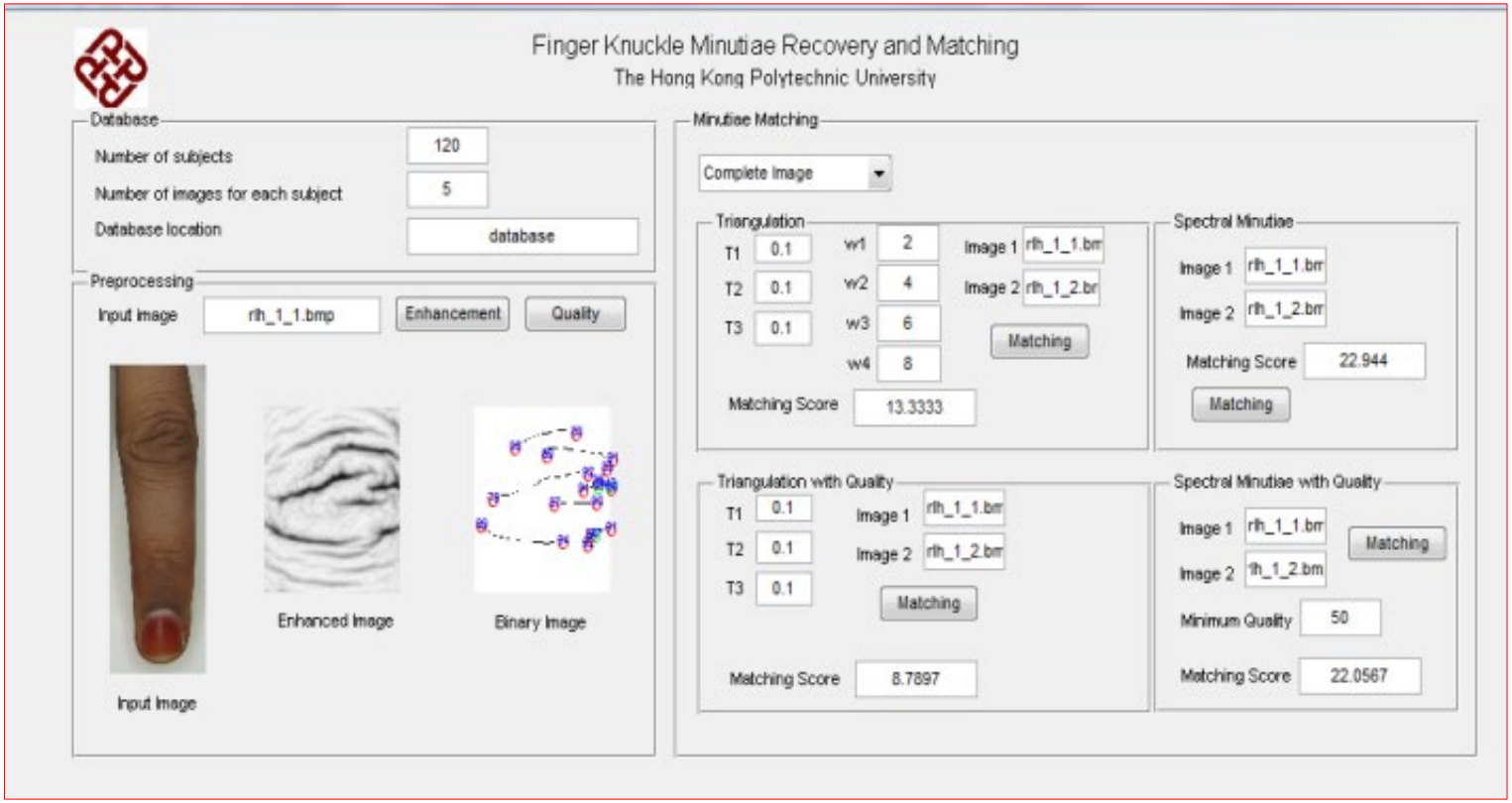
Knuckle Patterns Are Stable?

- Knuckle Images from ~13, ~15 and ~17 years of age (girl)



Can We Recover and Match *Knuckle* Minutiae?

- Minutiae Patterns From Finger Knuckle Images



A. Kumar and B. Wang, "Recovering and Matching Minutiae Patterns from Finger Knuckle Images," *Pattern Recognition Letters,* October 2015.

Smartphone-based Mobile Security

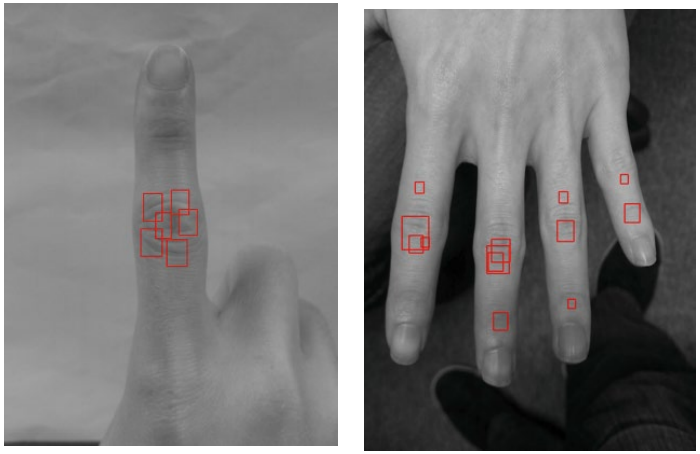
- Objectives
  - Contactless Finger Knuckle Identification using Mobile Phones
  - Exploit Built-in-Camera Imaging, *Android* OS and *OpenCV* Library
  - User Friendly Interface → Enrollment and Verification

Image Acquisition and Knuckle Detection

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

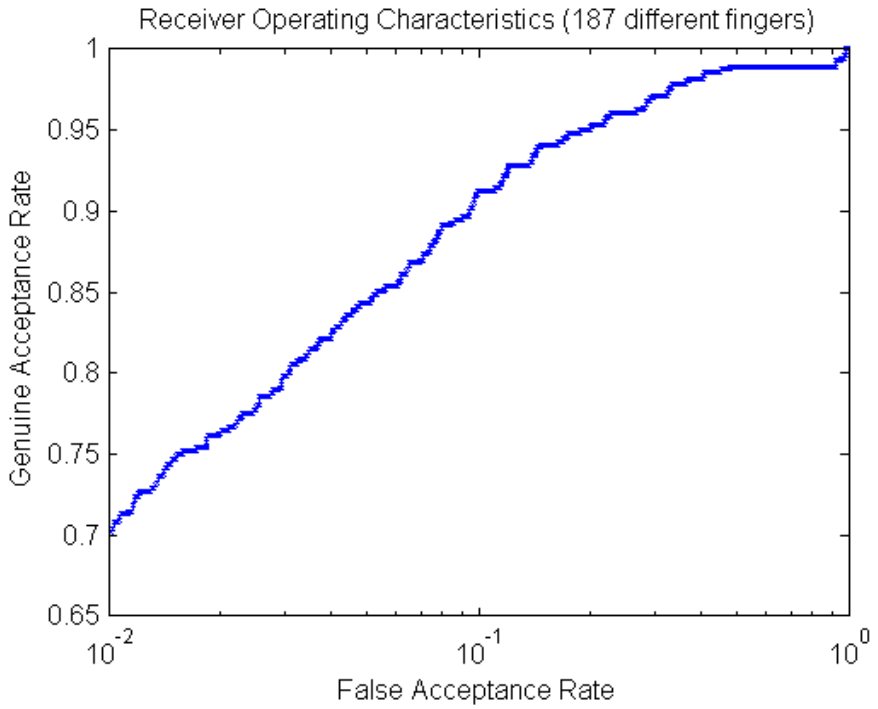
Cascade Classifier File	Hits	Missed	False	Accuracy*
File 1	72	28	20	72%
File 2	64	36	25	64%
File 3	65	35	29	65%
File 4	70	30	21	70%
File 5	23	77	26	23%

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



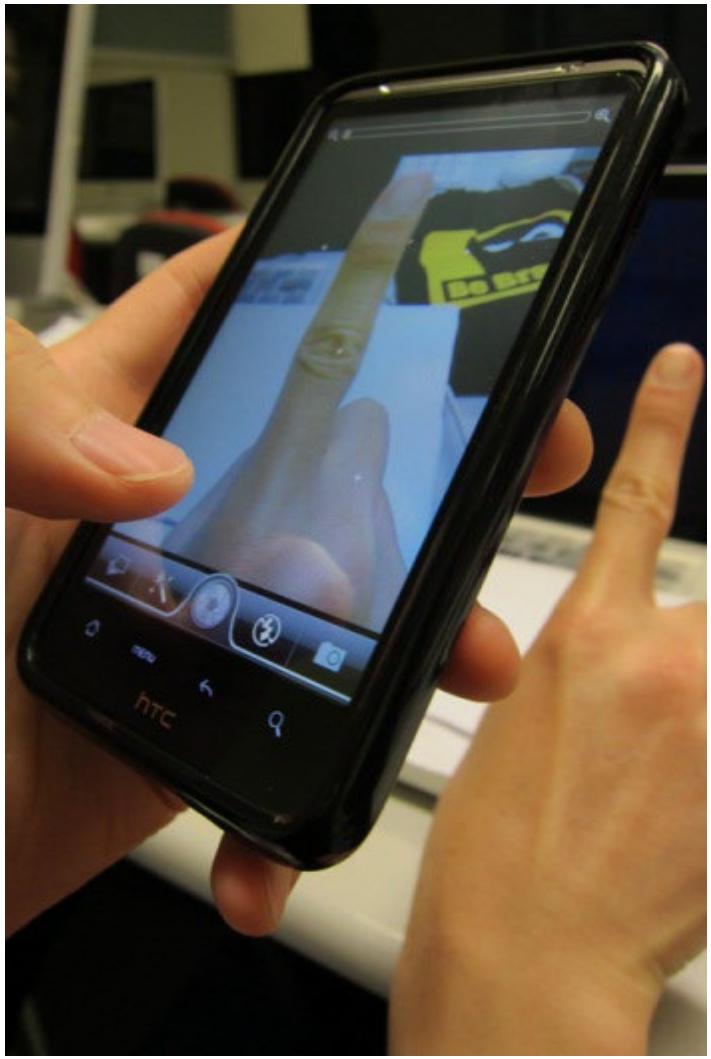
Results

- 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

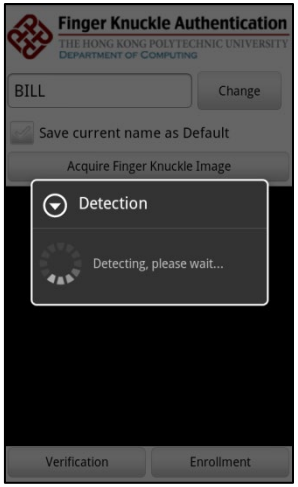


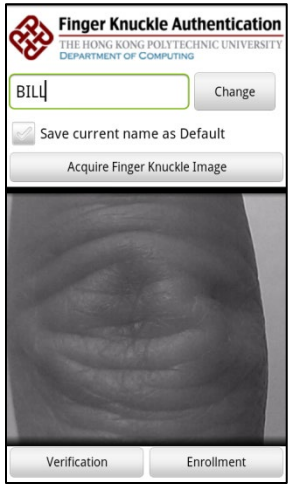
K. Y. Cheng and A. Kumar, “Contactless finger knuckle identification using smartphones,” *Proc. BIOSIG 2012*, Sep. 2012.

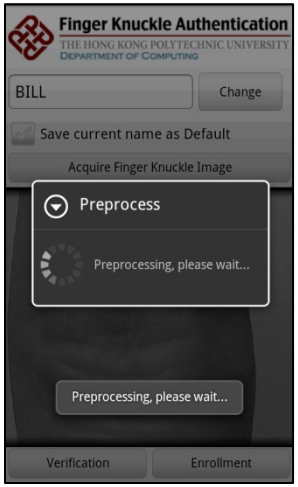
User Friendly Interface

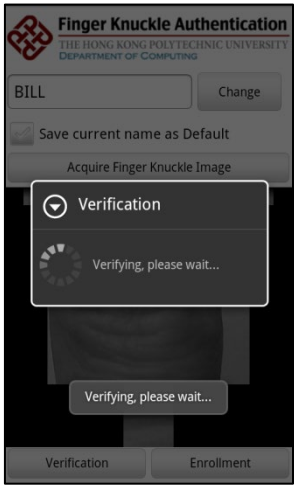
Live Demo at YouTube → Enter '*Finger Knuckle Mobile Phone*' in Google

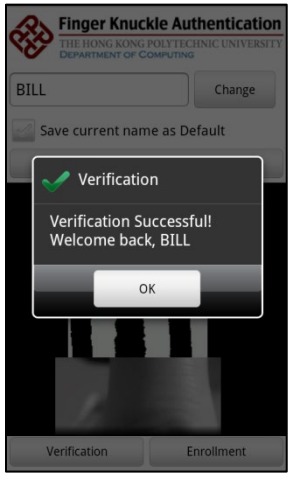
- Verification

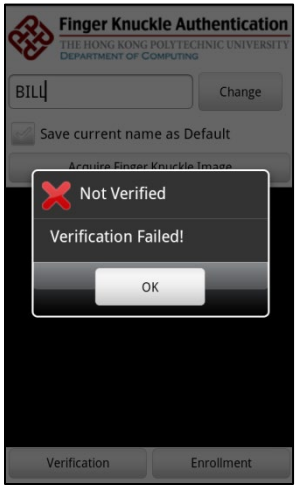






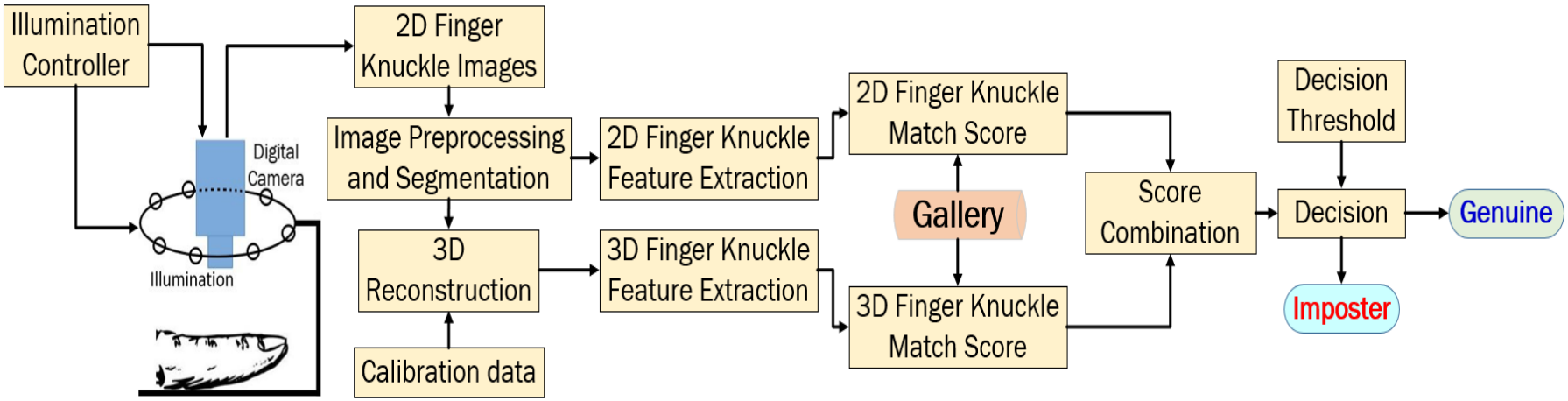






Contactless 3D Finger Knuckle Identification

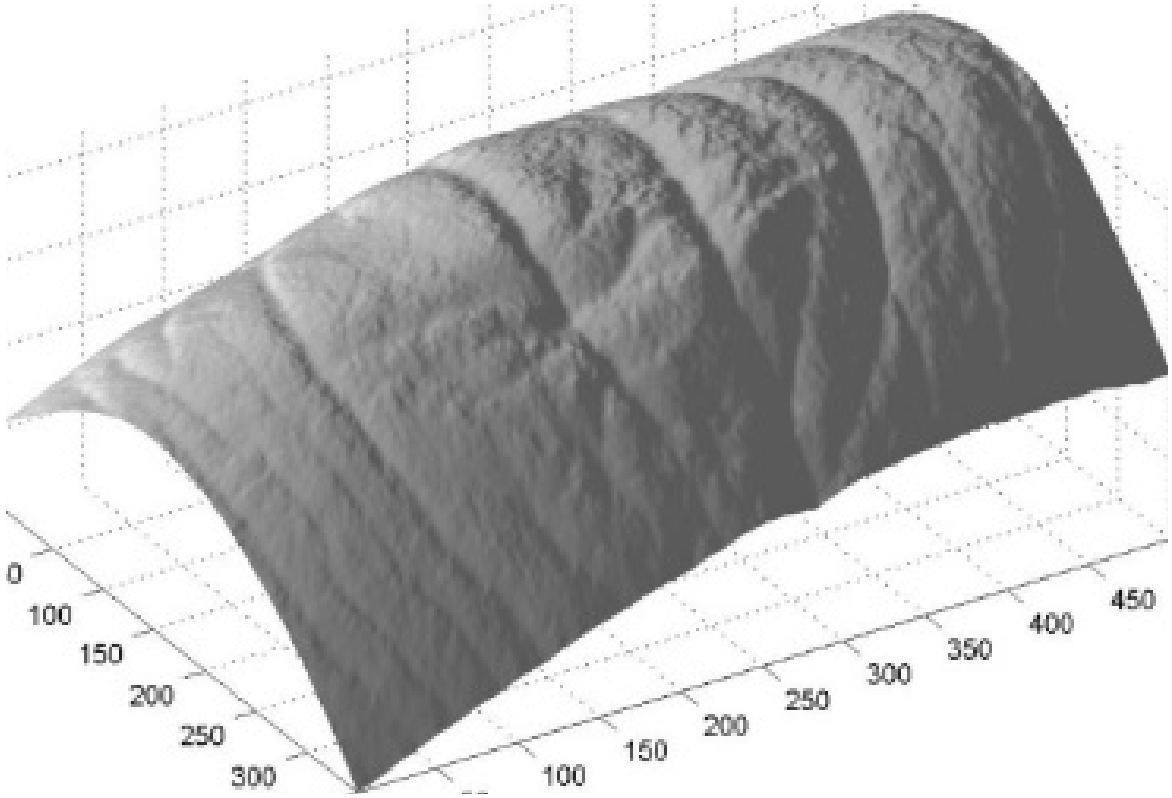
- 3D Finger Knuckle Recovery and Matching
  - First Work on 3D Finger Knuckle Identification (TPAMI 2020)
  - Low Cost 3D Finger Knuckle Recovery → Photometric Stereo



Kevin H. M. Cheng, A. Kumar, "'Contactless Biometric Identification using 3D Finger Knuckle Patterns," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 42, pp. 1868-1883, Aug. 2020

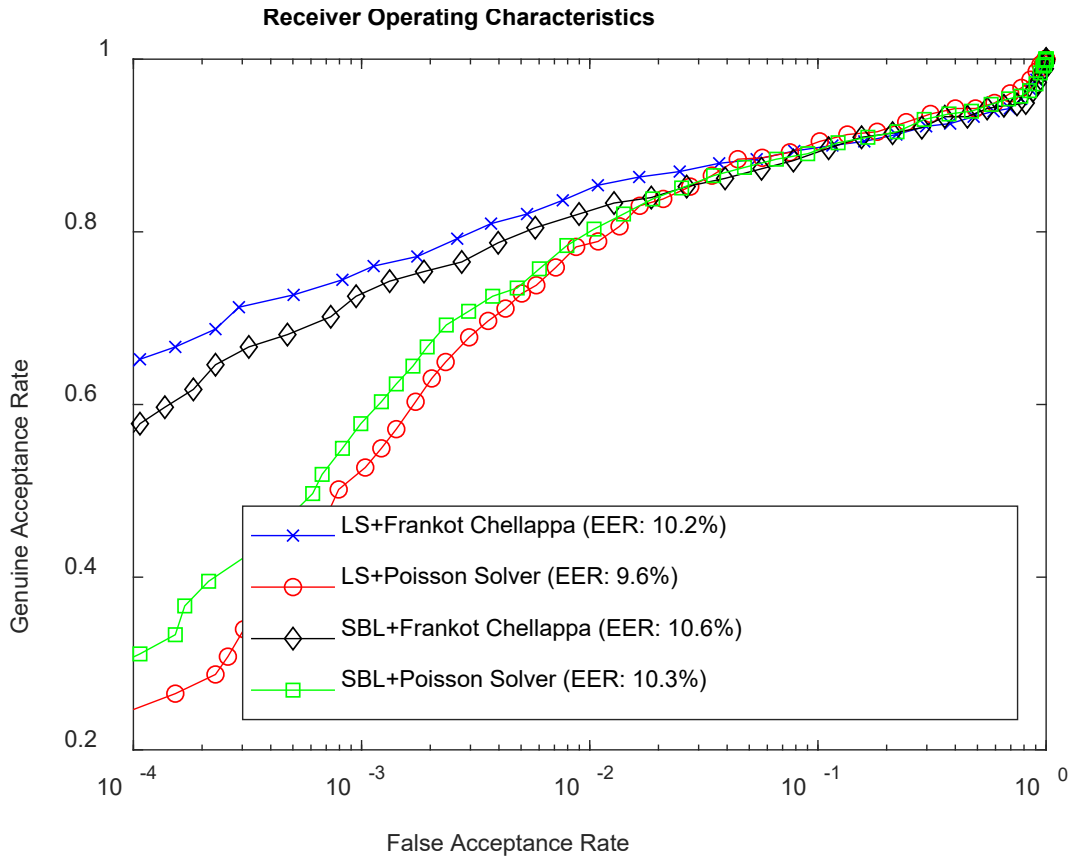
3D Finger Knuckle Acquisition

- Photometric Stereo
  - Single Camera, 7 LEDs, Illumination Controller



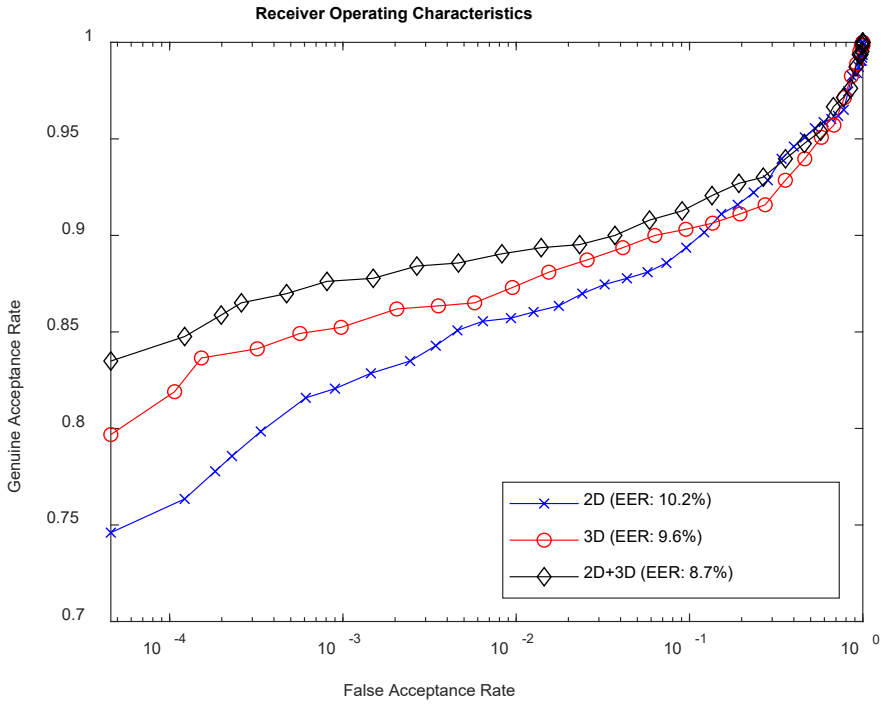
3D Finger Knuckle Acquisition

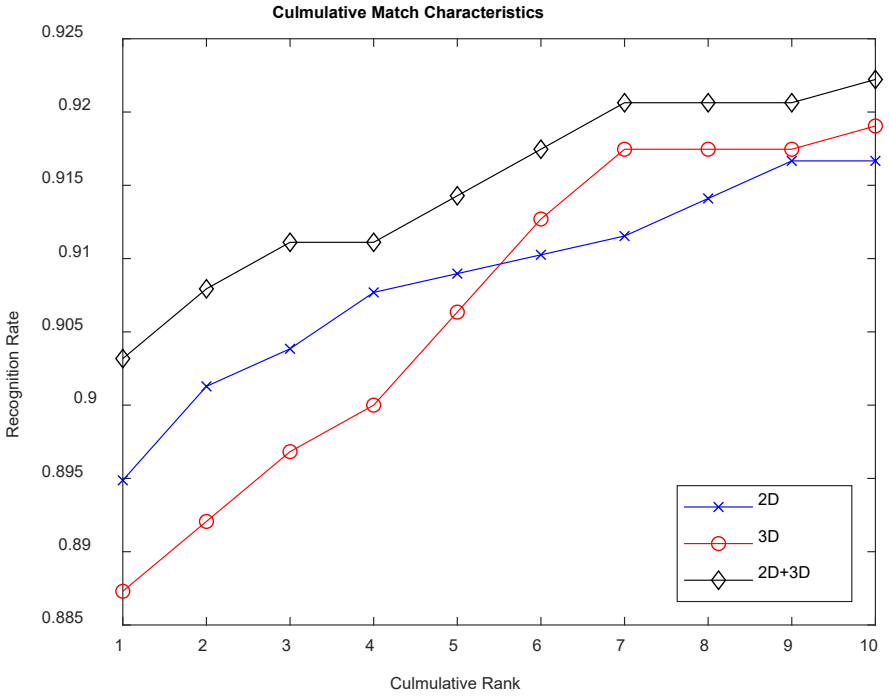
- Photometric Stereo
  - Single Camera, 7 LEDs, Illumination Controller



3D Finger Knuckle Matching

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





3D Finger Knuckle Matching

- Comparison and Complexity

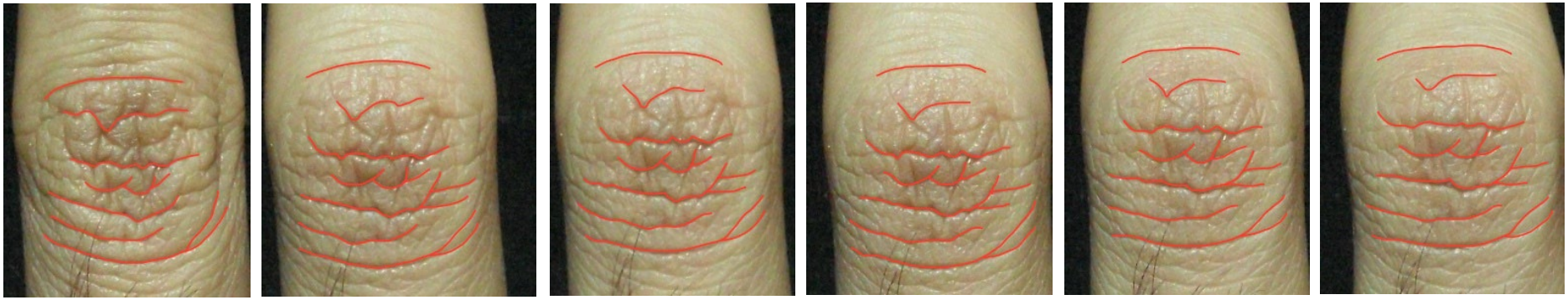
Comparative computational time (in milliseconds)

	Surface Normal Estimation	Depth Integration	Feature Extraction	Total
Surface Code [30]	0.72	0.57	2.77	4.1
Binary Shape [31]	0.72	0.57	0.86	2.2
Ours	**0.72**	-	**0.58**	**1.3**

Kevin H. M. Cheng, A. Kumar, "'Contactless Biometric Identification using 3D Finger Knuckle Patterns," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* 2020.

Pose Invariant Finger Knuckle Identification

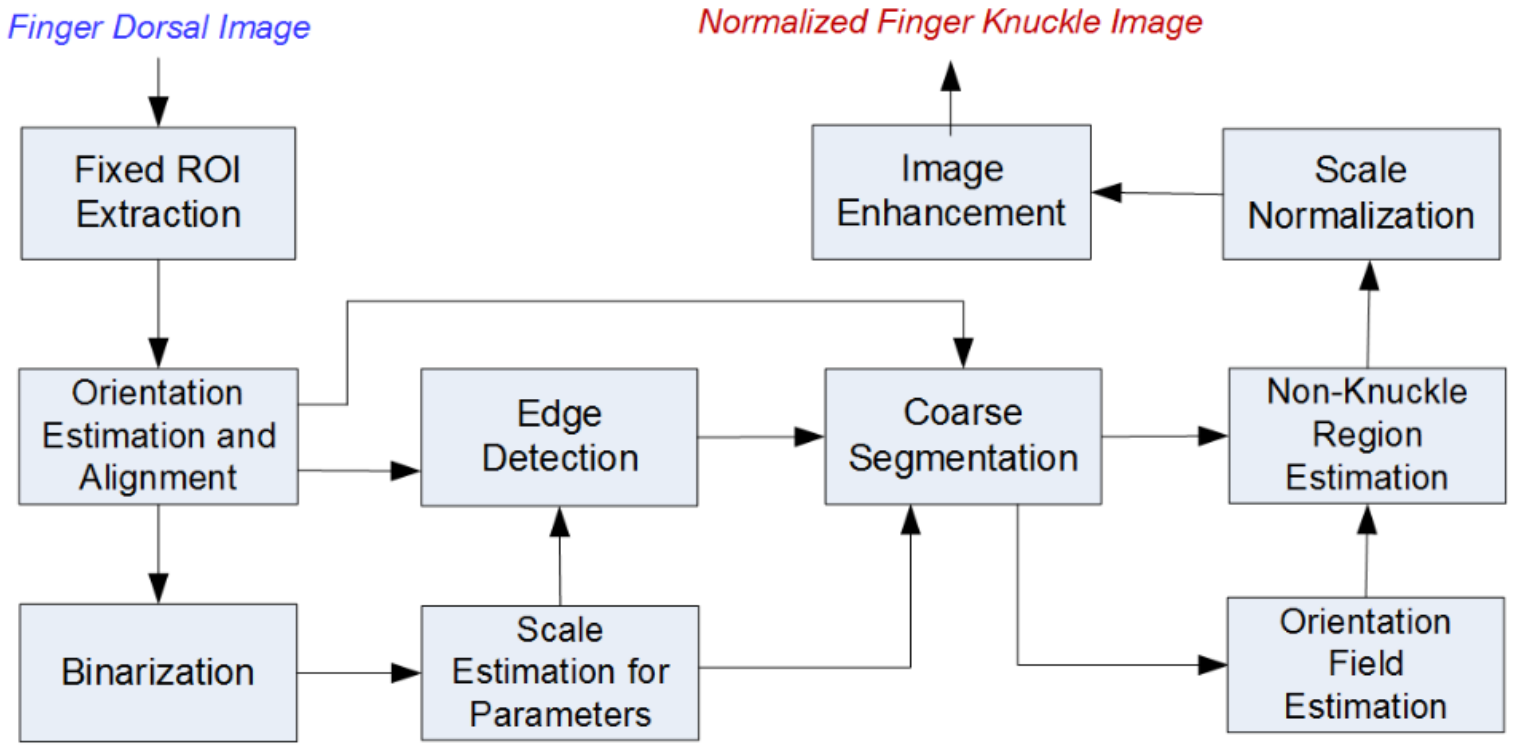
- Matching Knuckle Images with Varying Poses
  - First Work (2019), Varying Poses → Deformations



A. Kumar, "'Towards Pose Invariant and Completely Contactless Finger Knuckle Recognition," *IEEE Transactions on Biometrics, Behavior and Identity Science, A*ugust 2019.

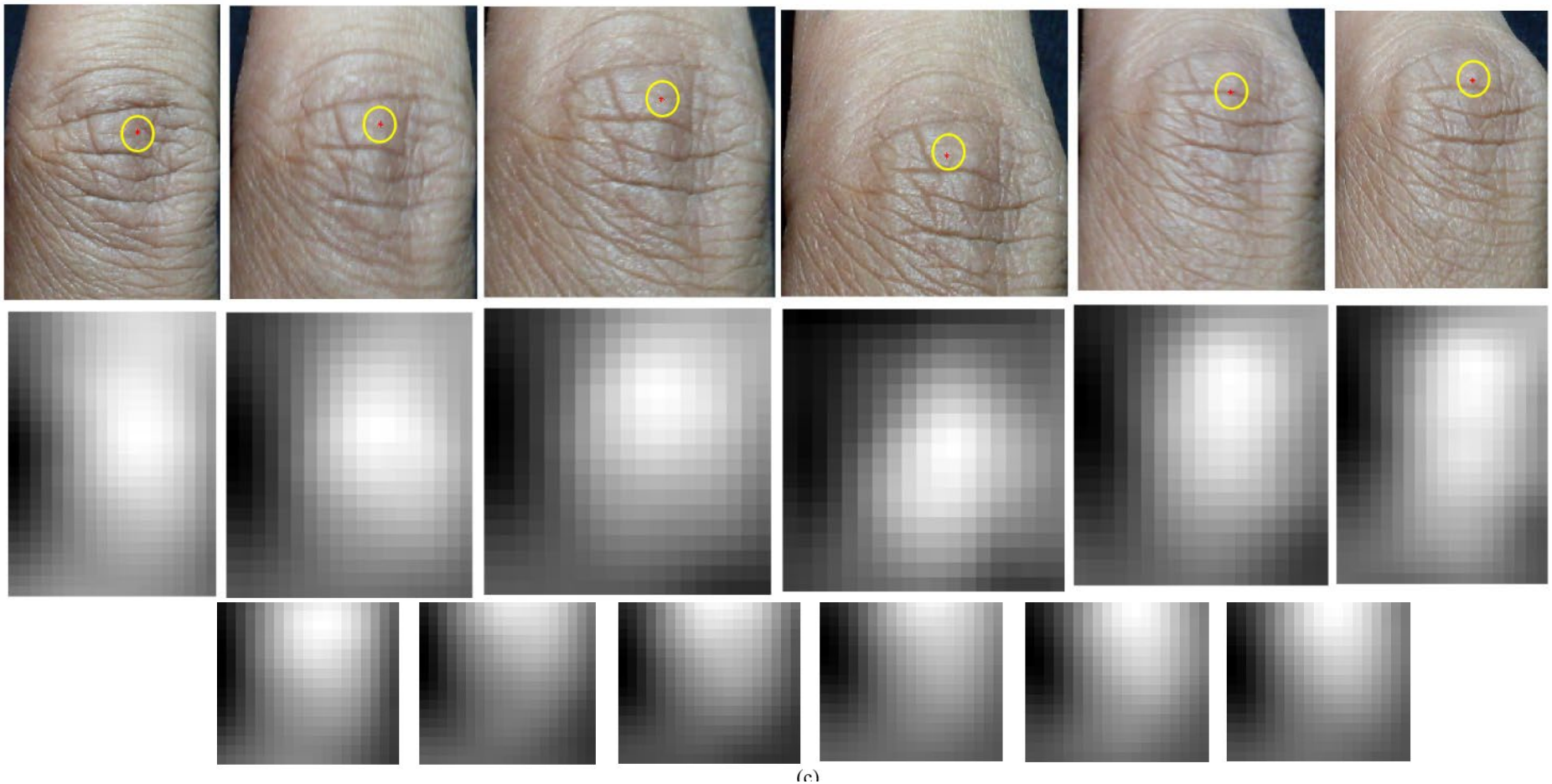
Pose Invariant Finger Knuckle Identification

- Block Diagram
  - Key Challenge → ROI Extraction and Alignment



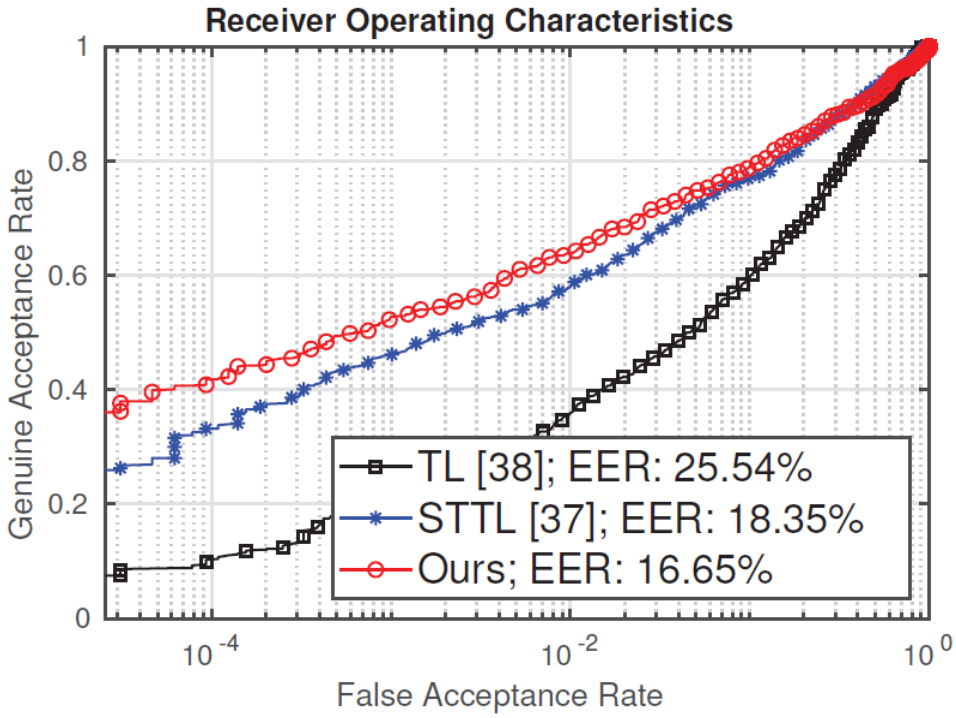
Pose Invariant Finger Knuckle Identification

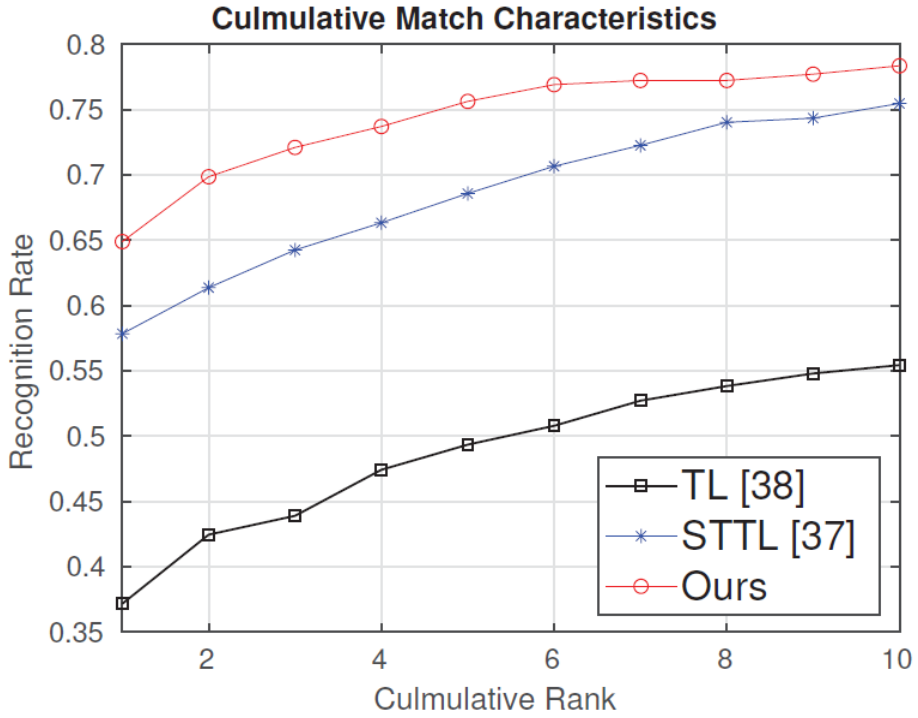
- Detecting Knuckle Crease Flow Center
  - Automated Extraction of Knuckle Center



Pose Invariant Finger Knuckle Identification

- Database and Results
  - Database from 221 Different Subjects, 104 Subjects in 2 Sessions
  - Promising Results, Need for Further Work

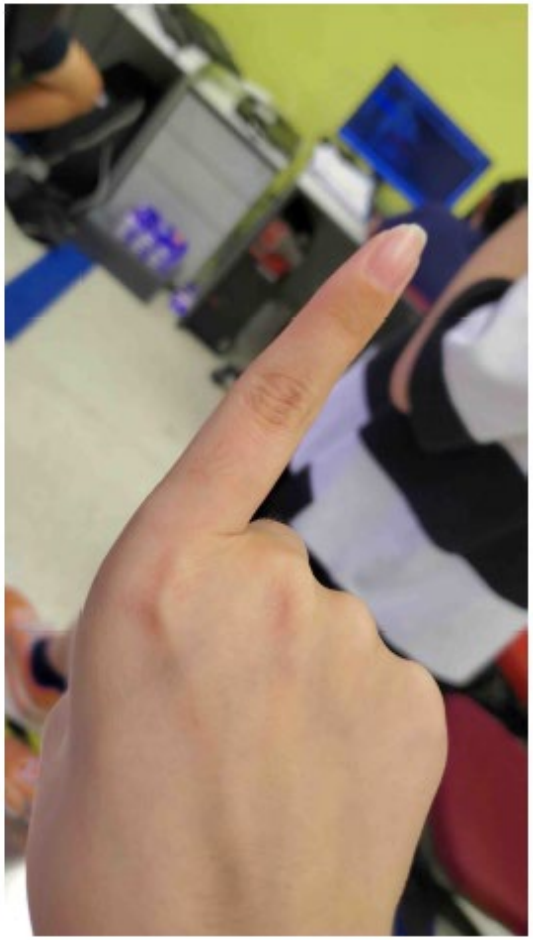




A. Kumar, "'Towards Pose Invariant and Completely Contactless Finger Knuckle Recognition," *IEEE Transactions on Biometrics, Behavior and Identity Science,* August 2019.

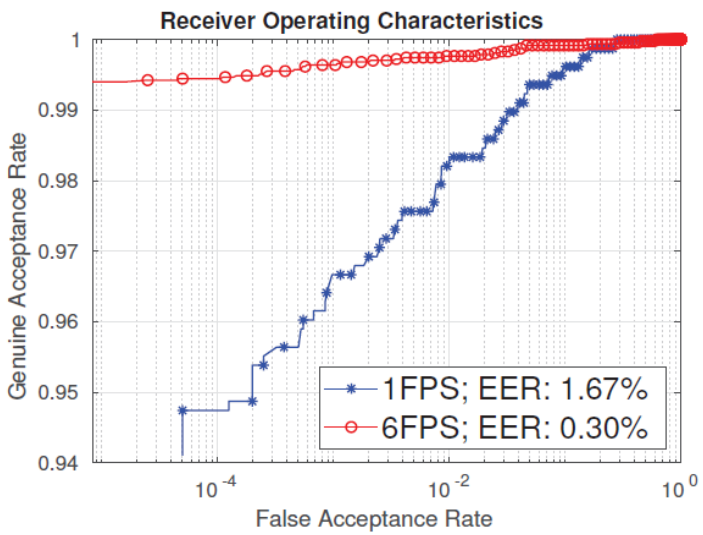
Finger Knuckle Identification in Wild

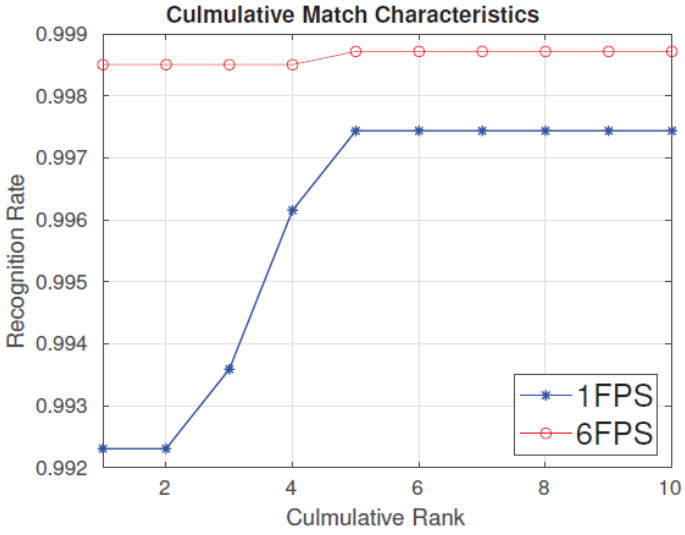
- Smartphone-Based Knuckle Identification in a Wild



Finger Knuckle Identification in Wild

- Smartphone-Based Knuckle Identification in a Wild





- Database from 52 Different Subjects, 15-20s video
- 1789 (52 x15) genuine and 39780 (52 x 51 x15) for 1fps

Acknowledgment

- Collaborators
  - Zhenyu Zhou
  - Zhihuan Xu
  - Bichai Wang
  - K. Y. Cheng
  - Ch. Ravikanth
  - Kevin H. M. Cheng

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

Live Demo

- Finger Knuckle Identification in a Wild
  - Online System for Real World Applications

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