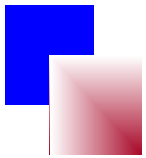
IAPR/IEEE Winter School on Biometrics 2022
9th January 2022

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

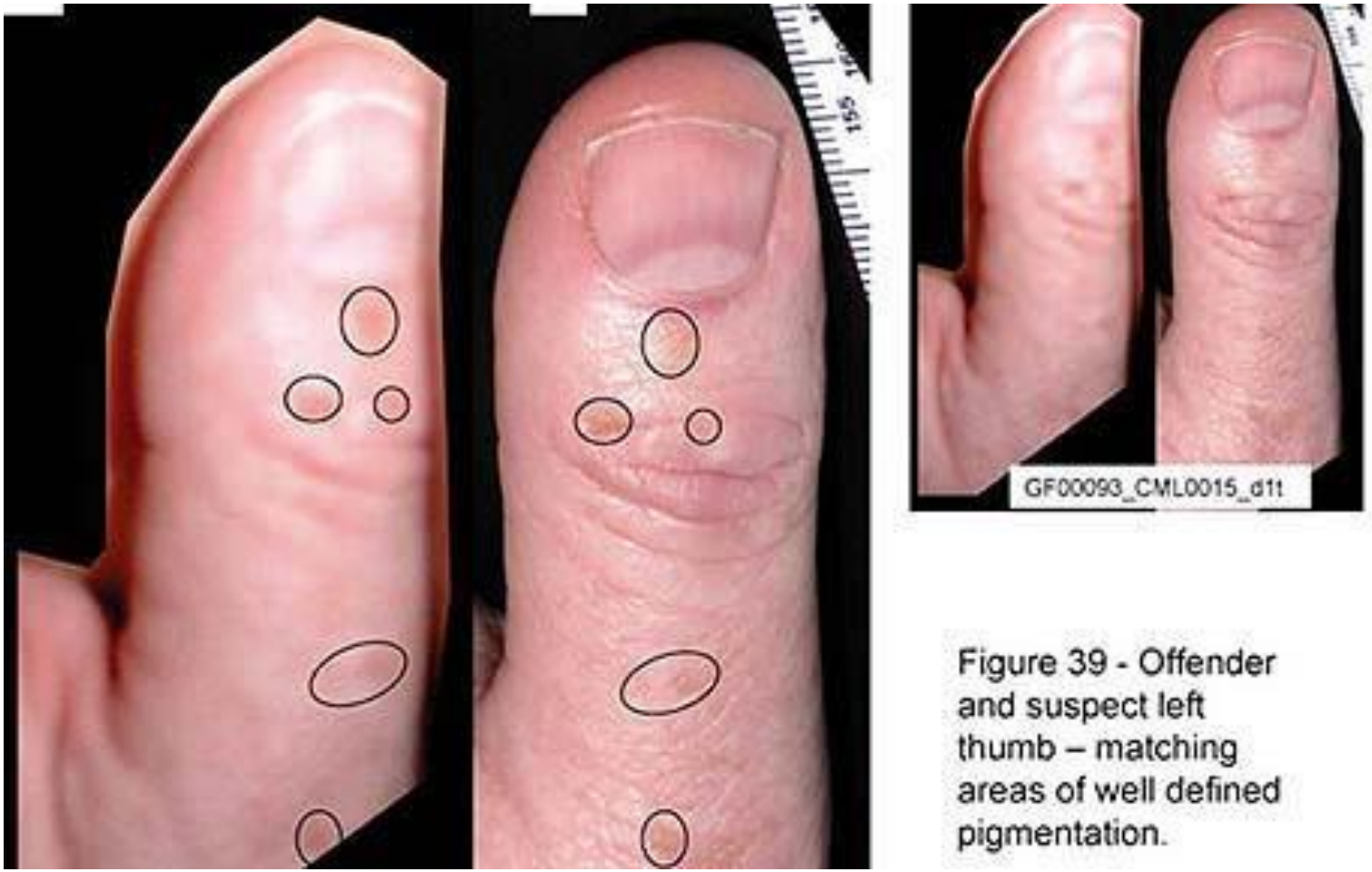


Figure 39 - Offender and suspect left thumb – matching areas of well defined pigmentation.

Bromley Paedophile Dean Hardy Jailed for 10 Years, Bromley Times, Jan. 2012
http://www.bromleytimes.co.uk/news/courtcrime/bromley_paedophile_dean_hardy_jailed_for_10_years_1_1176957

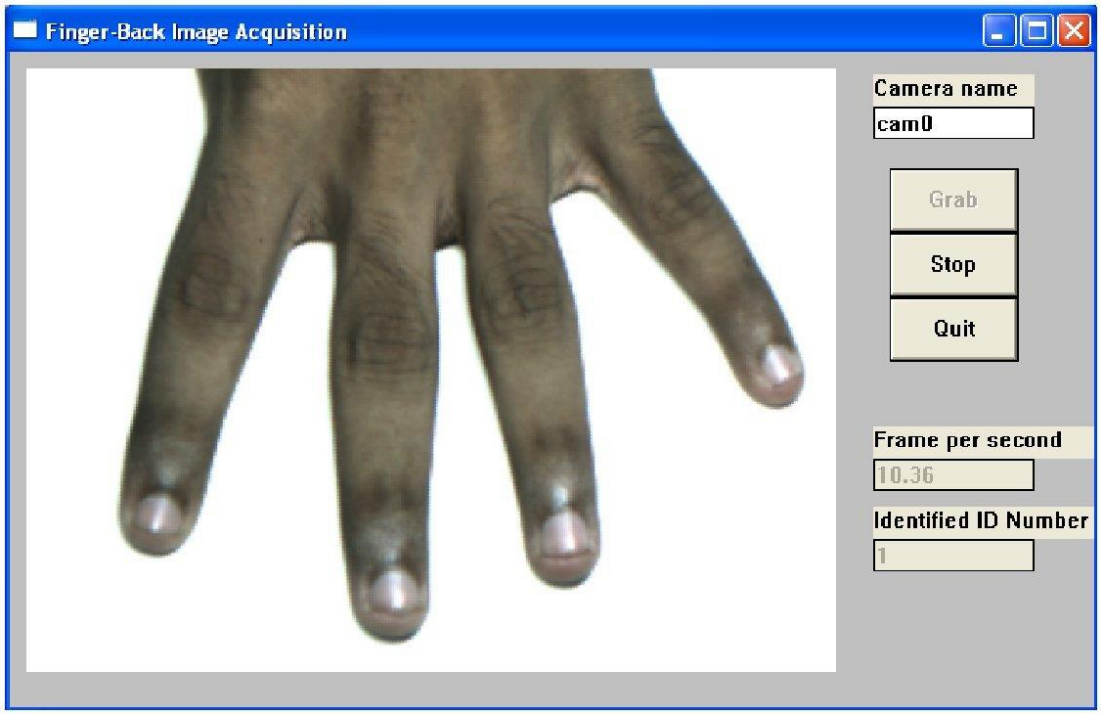
Early Work on Finger Knuckle Identification

- 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

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

Contactless Finger Knuckle Identification

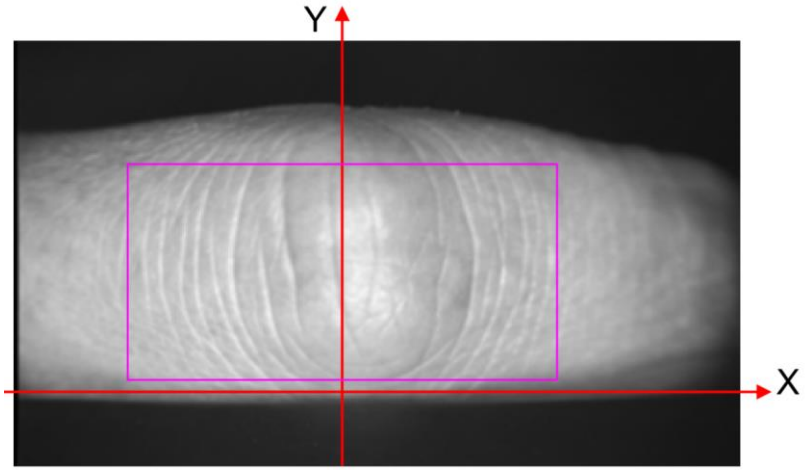
- First Paper on Pegfree and Contactless Identification
  - 2 Session Database, 105 Different Subjects. EER of 1.39%
  - Live System, Identification and Authentication
  - First Database in Public Domain (IITD Finger Knuckle)



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

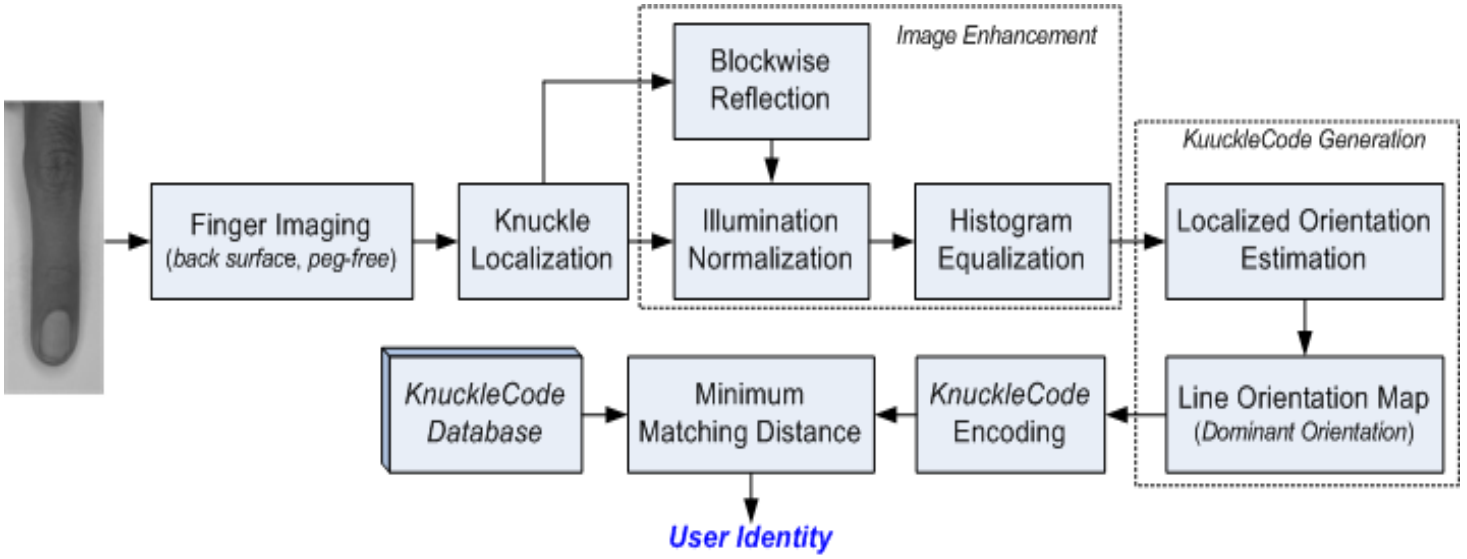
- Another Online Finger Knuckle Authentication
  - Constrained Imaging (similar to pegs)
  - Database from 165 different subjects
  - Alignment using BLOC, Fusion, Impressive Results



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

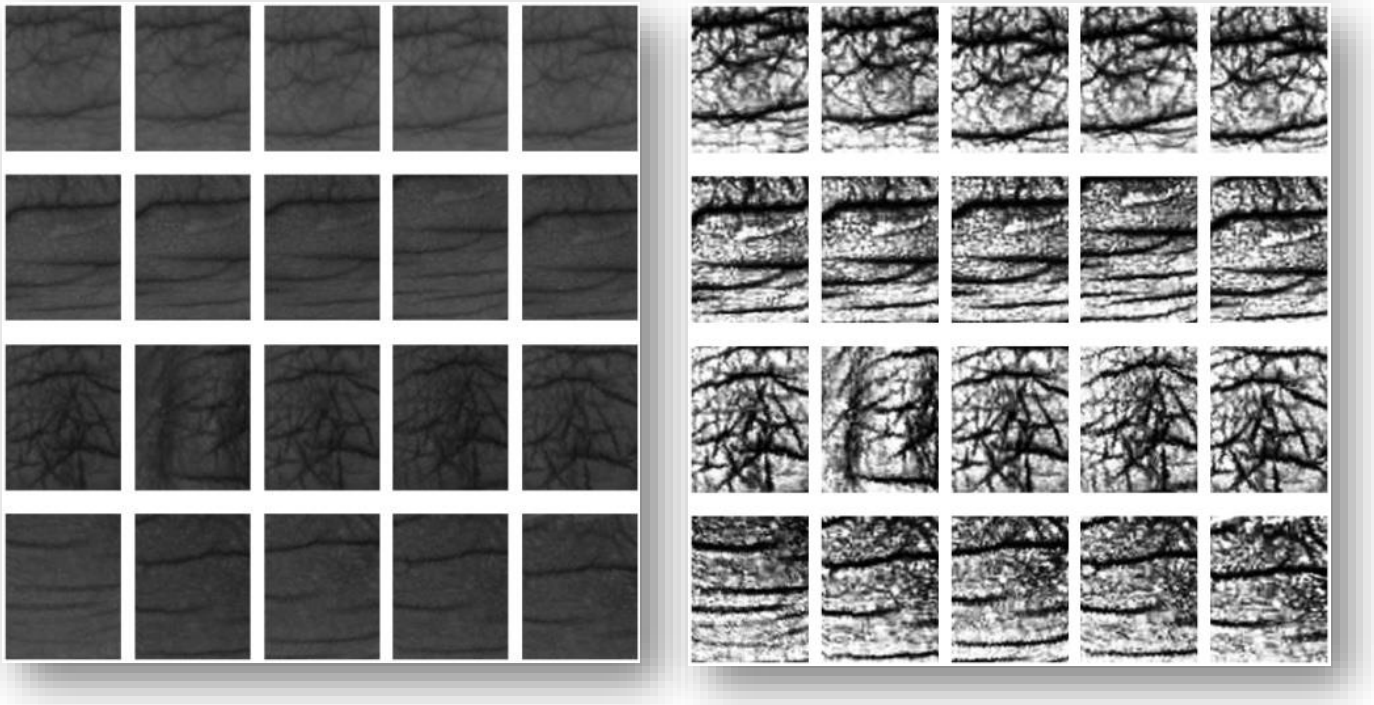
- KnuckleCodes (BTAS'09)*
  - Block Diagram



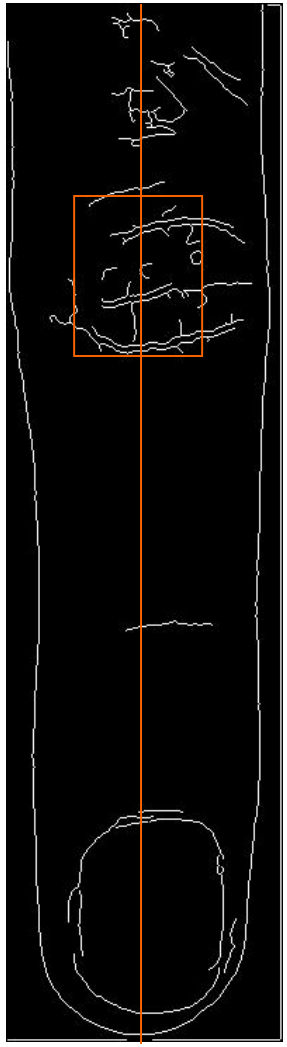
* A. Kumar and Y. Zhou, "Human Identification using KnuckleCodes," *Proc. BTAS'09*, Washington, D. C., Sep. 2009

Contactless Finger Knuckle Identification

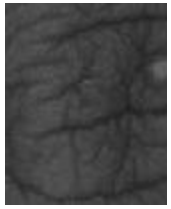
- KnuckleCodes
  - Highly Curved Surface → Uneven Reflections → Shadows
  - Nonlinear Image Enhancement
  - Estimate → Background Illumination



Knuckle Segmentation



- Using Edge Density
  - Extracted ROI →



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

Score Generation

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

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

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

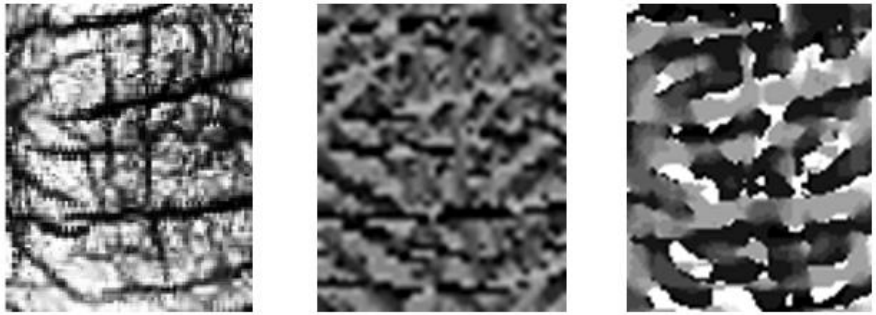
$$\widehat{\mathbf{R}}(\mathrm{x},\mathrm{y}) = \begin{cases}\mathbf{R}(x-w,y-h) & x\in[w+1,w+\mathrm{m}],\ y\in[h+1,\ h+\mathrm{n}]\\ -1 & \text{otherwise}\end{cases}$$

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

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

Experimental Results

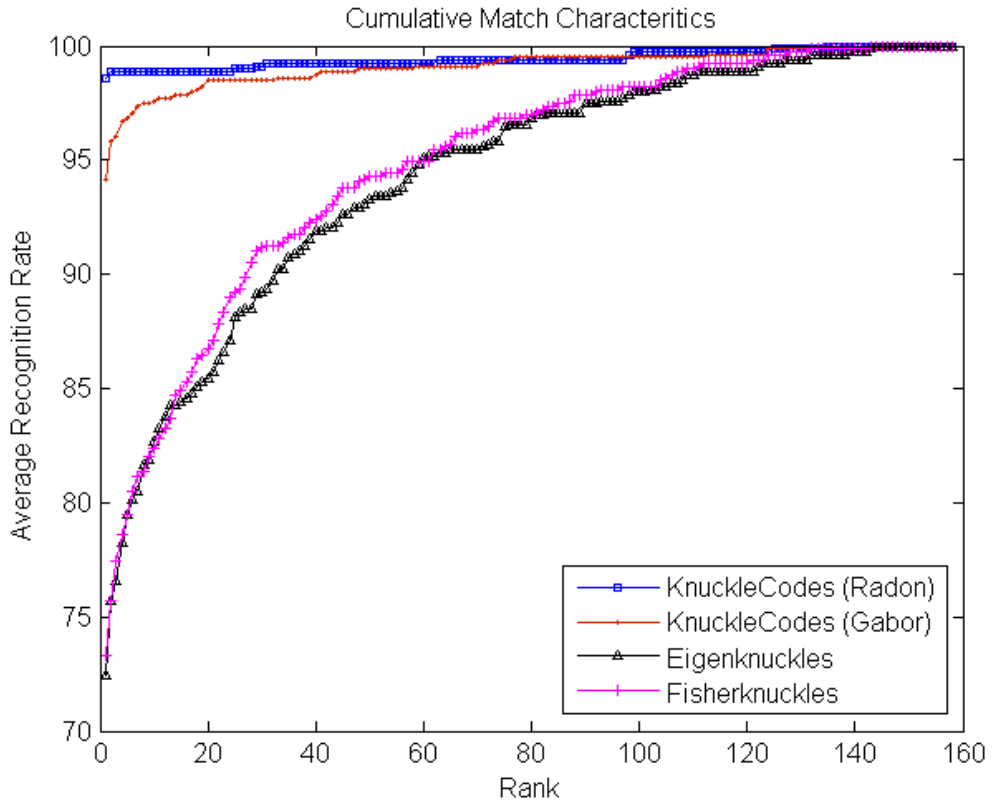
- Experiments
  - 158 Subjects, 5 Images per Subject, Age group $\rightarrow$ 16-55 year
  - Unconstrained (peg-free) imaging
  - Five-fold Cross-Validation, Average of Results
  - Genuine Scores $\rightarrow$ 790 (158×5)
  - Imposter Scores $\rightarrow$ 124030 ($158 \times 157 \times 5$)
  - Comparative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



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

Second Generation Biometrics

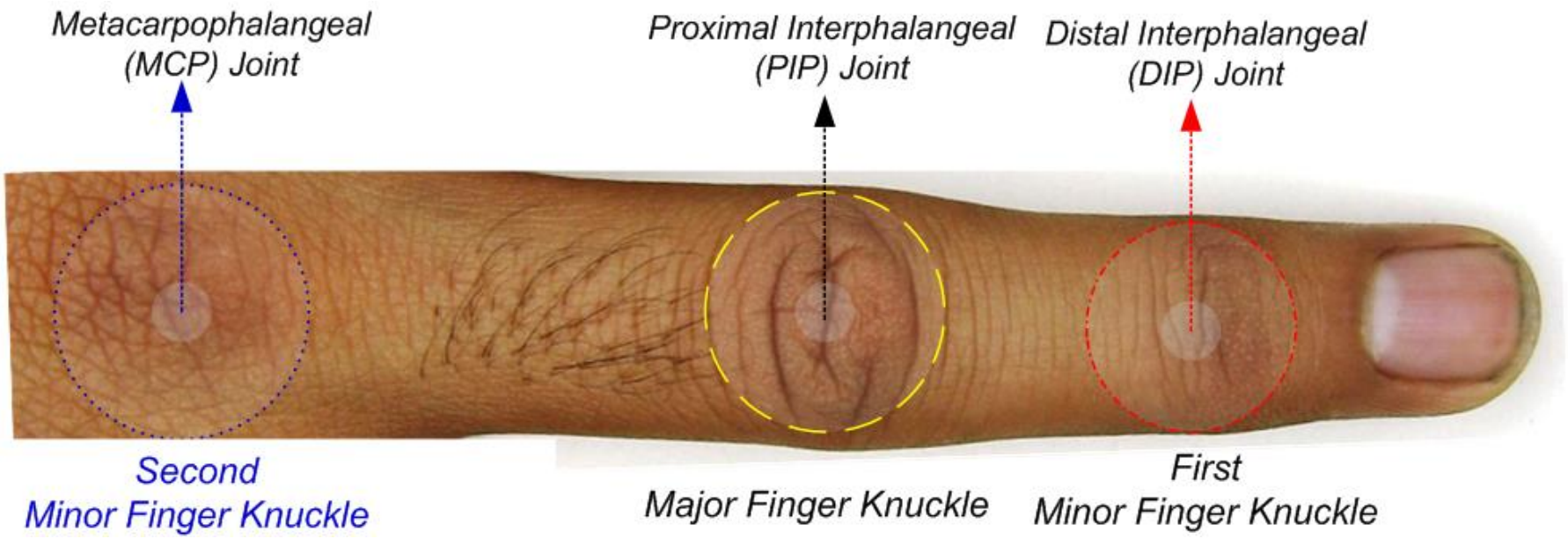
- Results
  - Cumulative Match Characteristics



- Promising Results
  - EER of 1.08% on database of 158 subjects
  - Recognition accuracy of 98.6%

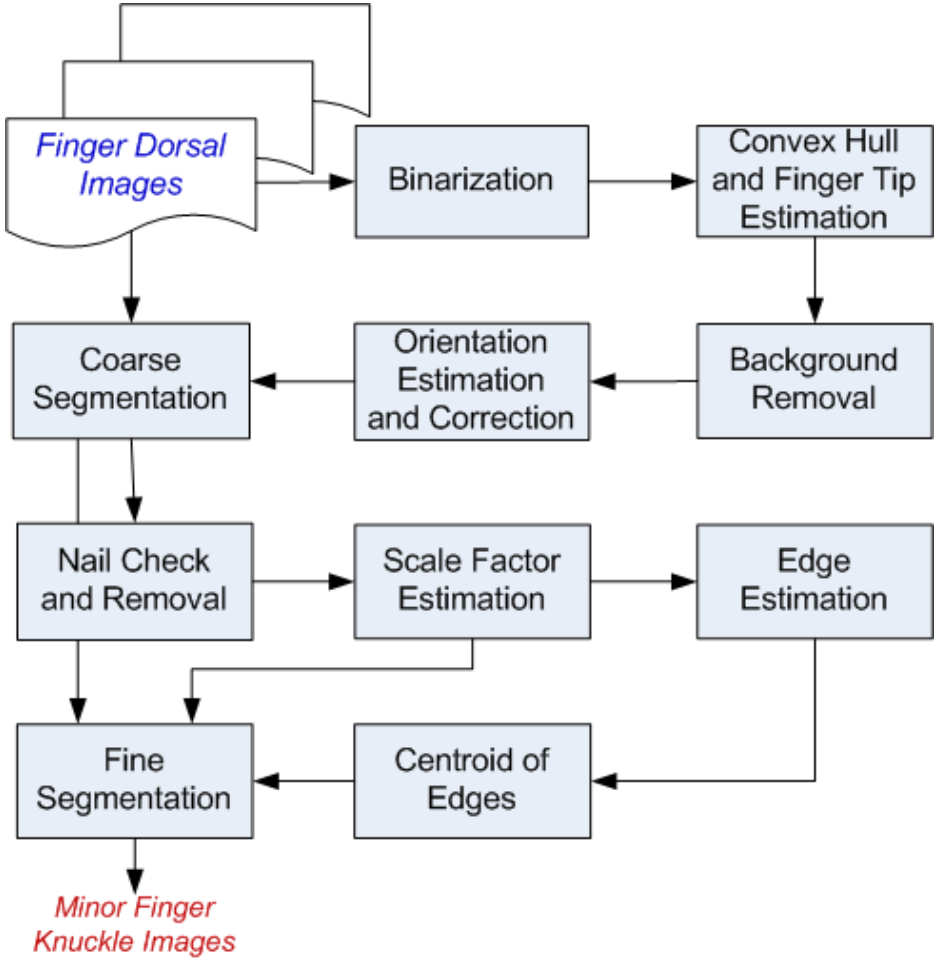
Taxonomy of Knuckle Patterns for Identification

- Major and Minor Knuckle Patterns



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 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

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

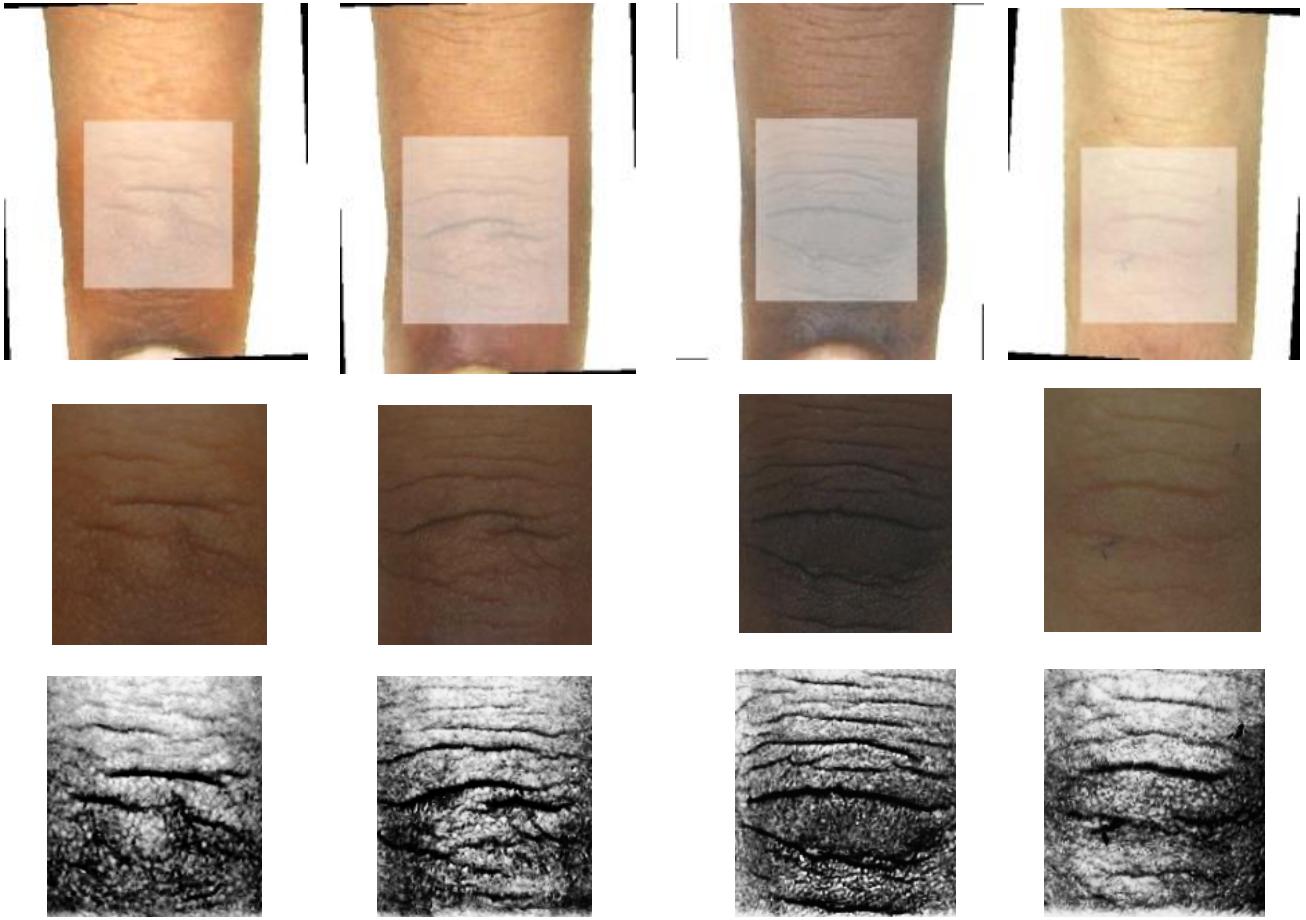
  - 10 Subjects $\rightarrow$ Parameter Estimation
  - 192 Subjects $\rightarrow$ Performance Evaluation

  - Five-fold Cross-Validation, Average of Results

  - Genuine Scores $\rightarrow$ 960 (192×5)
  - Imposter Scores $\rightarrow$ 183360 ($192 \times 191 \times 5$)

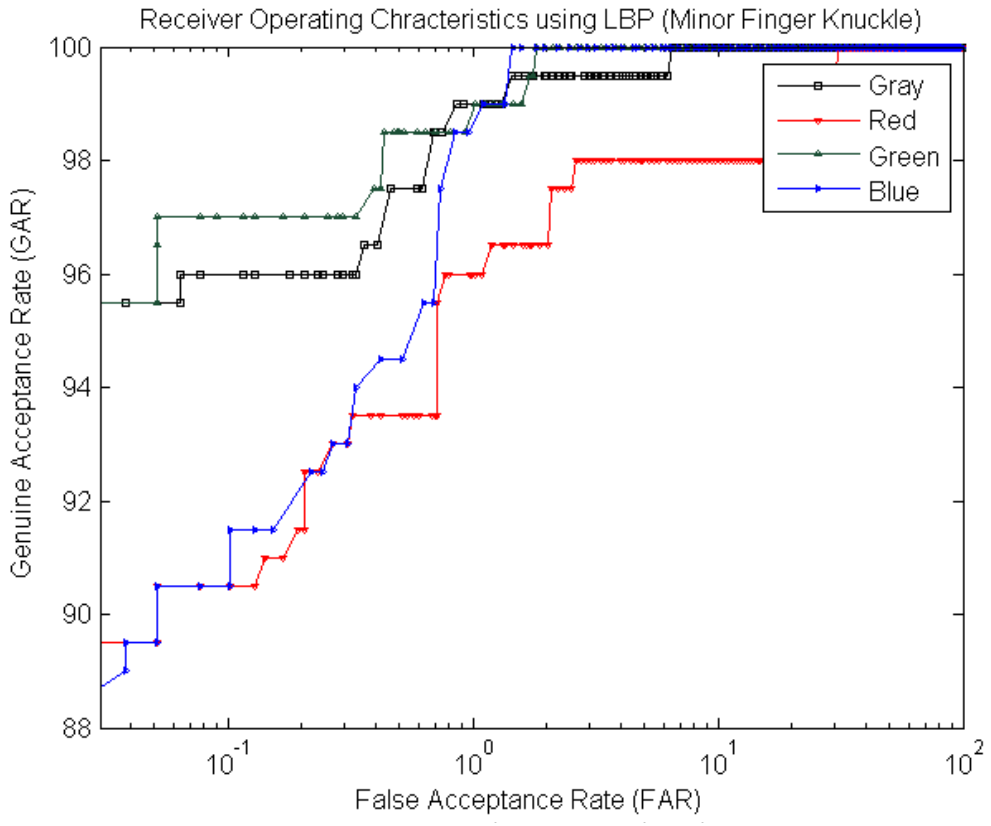
Experimental Results

- Minor Knuckle Segmentation and Enhancement
  - Sample Images



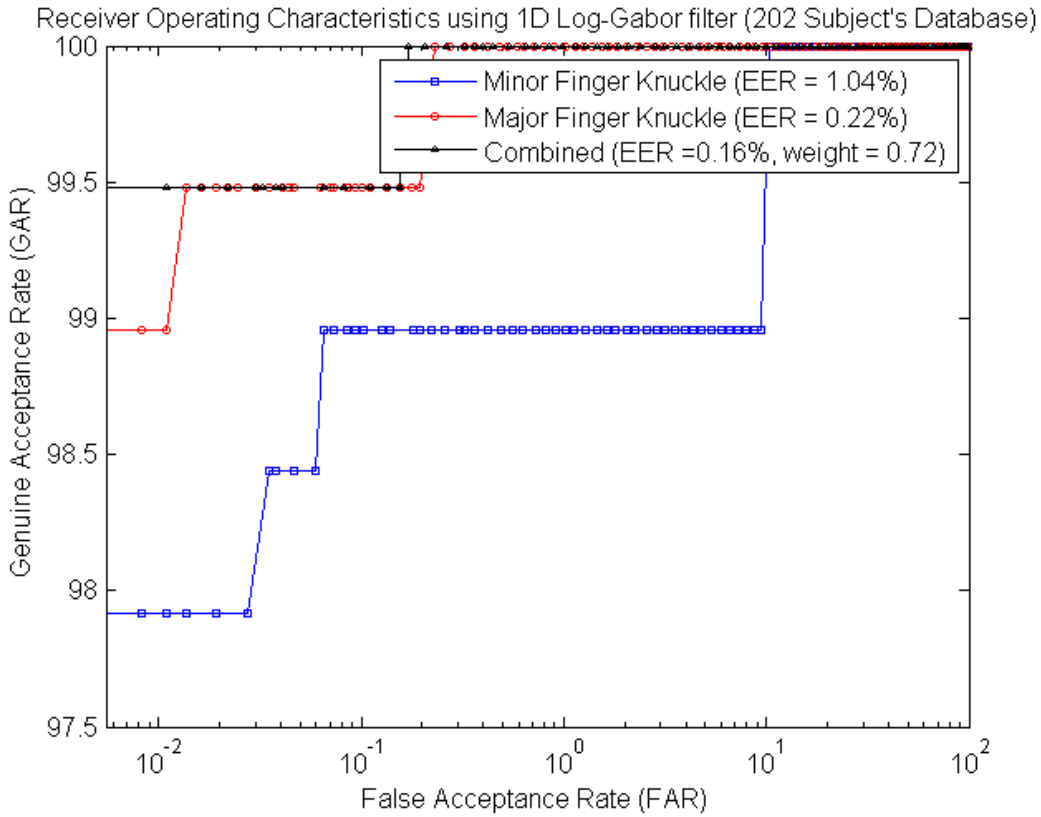
Experimental Results

- Exploring Color Channels
  - Comparative Receiver Operating Characteristics



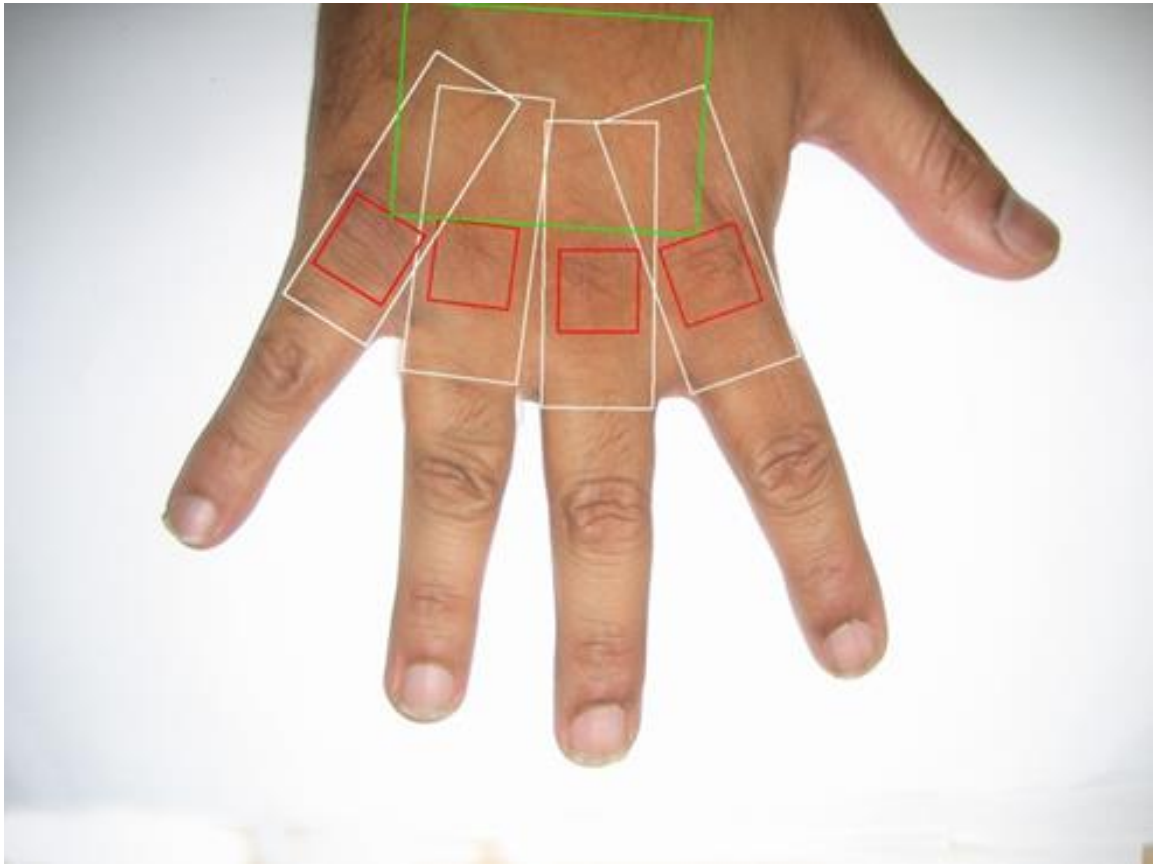
Experimental Results

- Results
  - Comparative Receiver Operating Characteristics



Second Minor Finger Knuckle Features

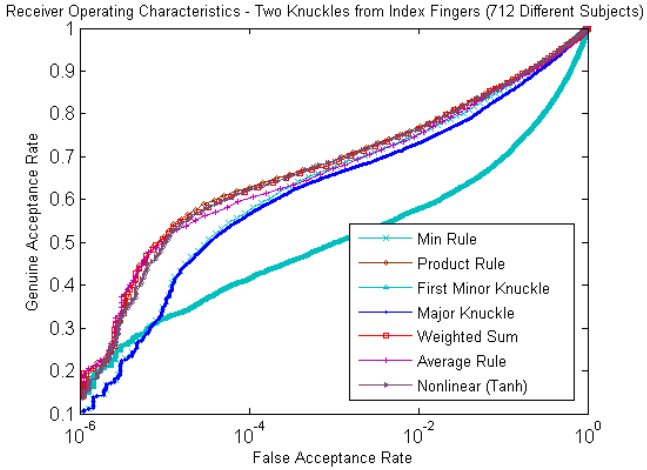
- Spatial Domain
  - Automated Detection and Segmentation

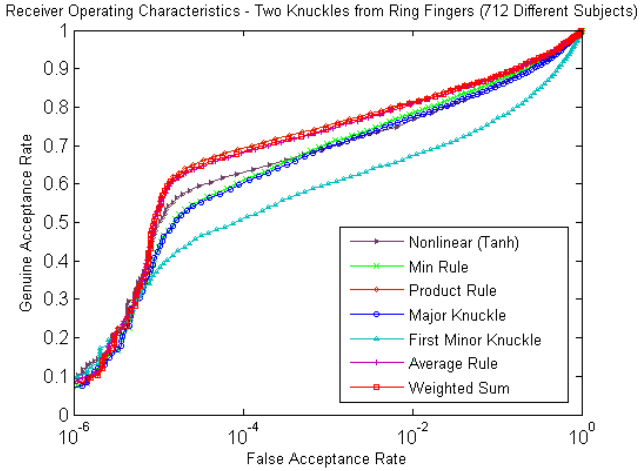


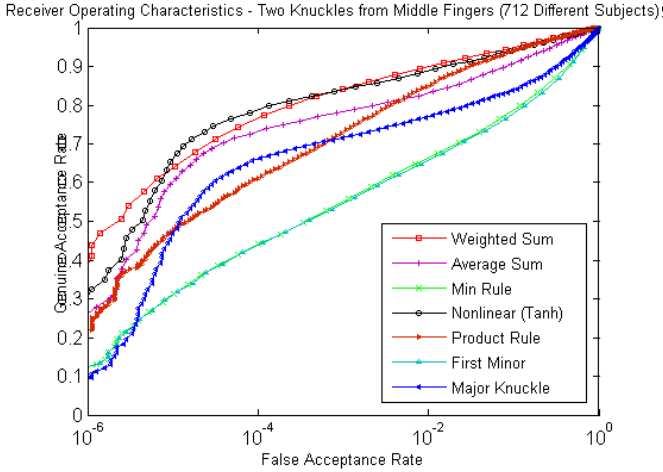
A. Kumar and Z. Xu 'Personal Identification using Minor Knuckle Patterns from Palm Dorsal Surface," *IEEE Transactions on Information Forensics and Security*, pp. 2338-2348, October 2016.

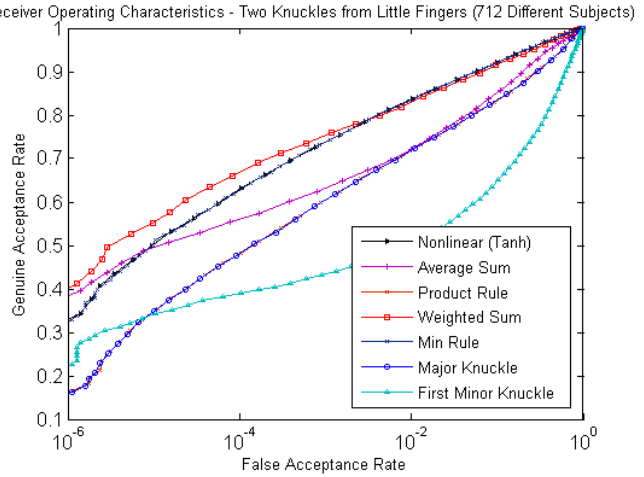
Results using Large Database

- Over 700 Subjects Database



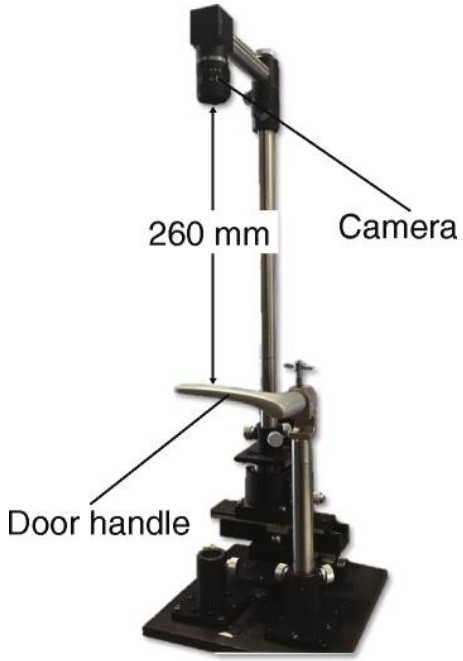


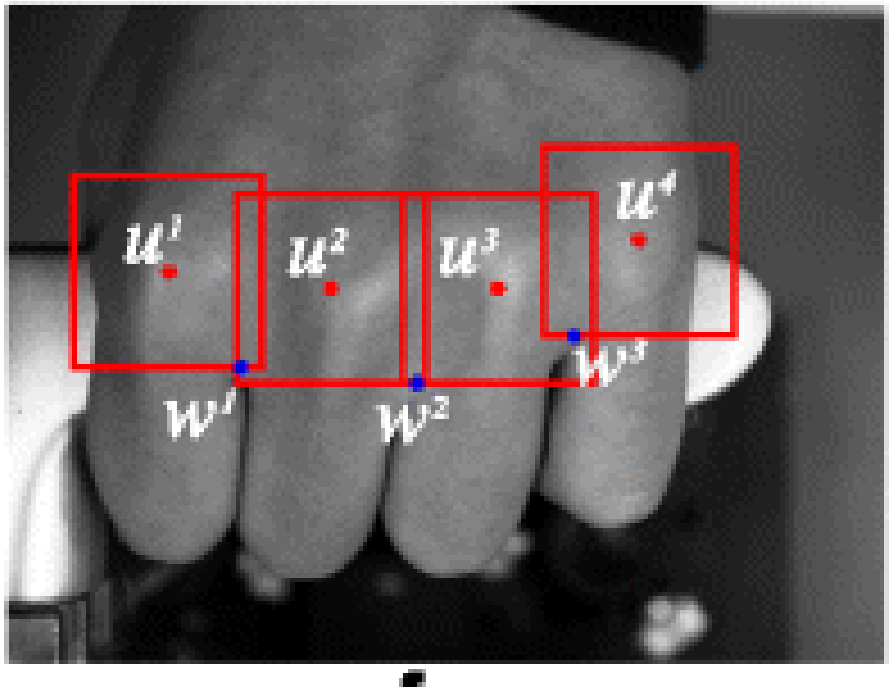




Door Security using Second Minor Knuckle

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

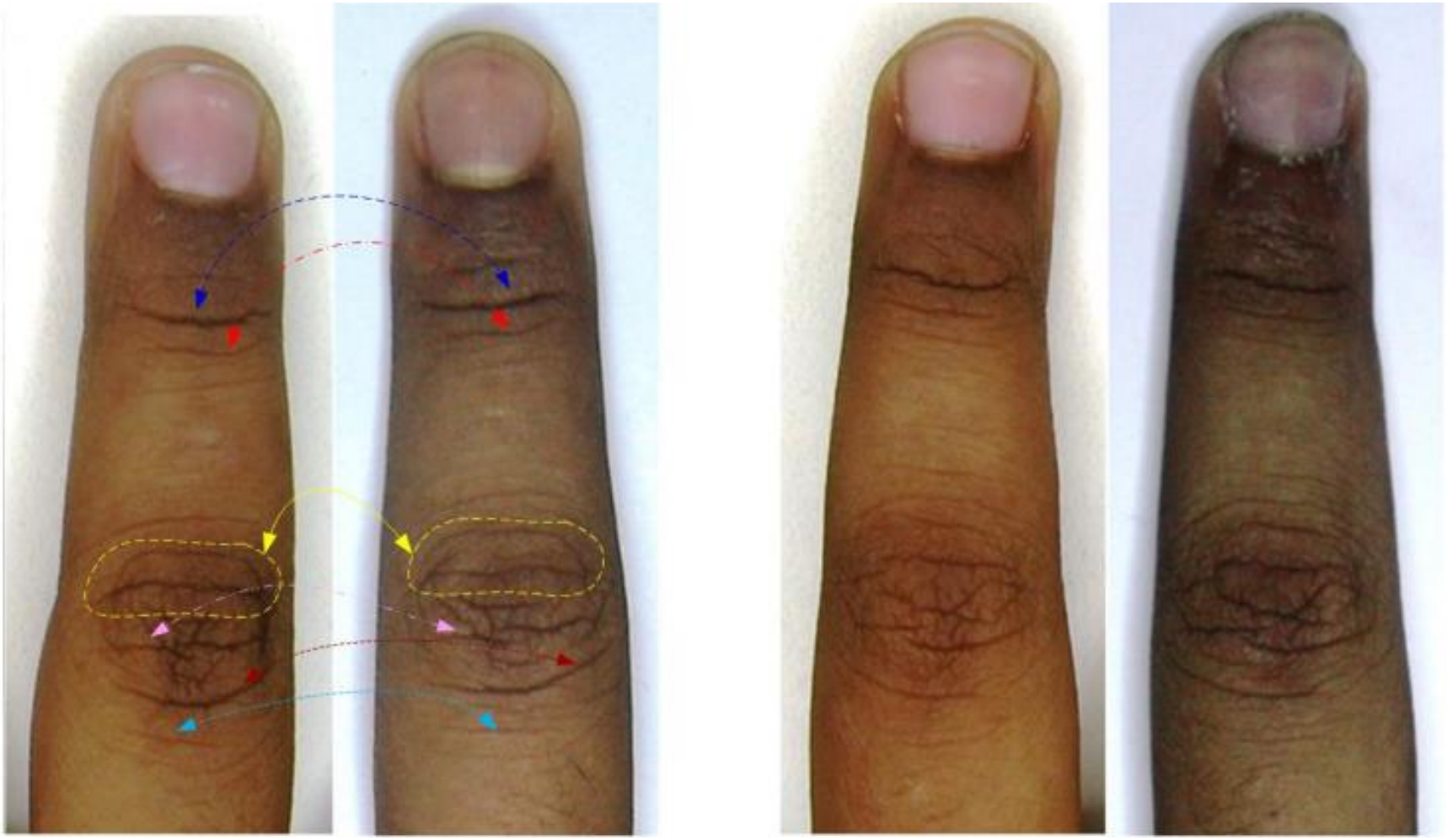




D. Kusanagi, S. Aoyama, K. Ito, T. Aoki, “A practical person authentication system using second minor finger knuckles for door security, *IPSJ Transactions on Computer Vision and Applications*, vol. 9, 2017.

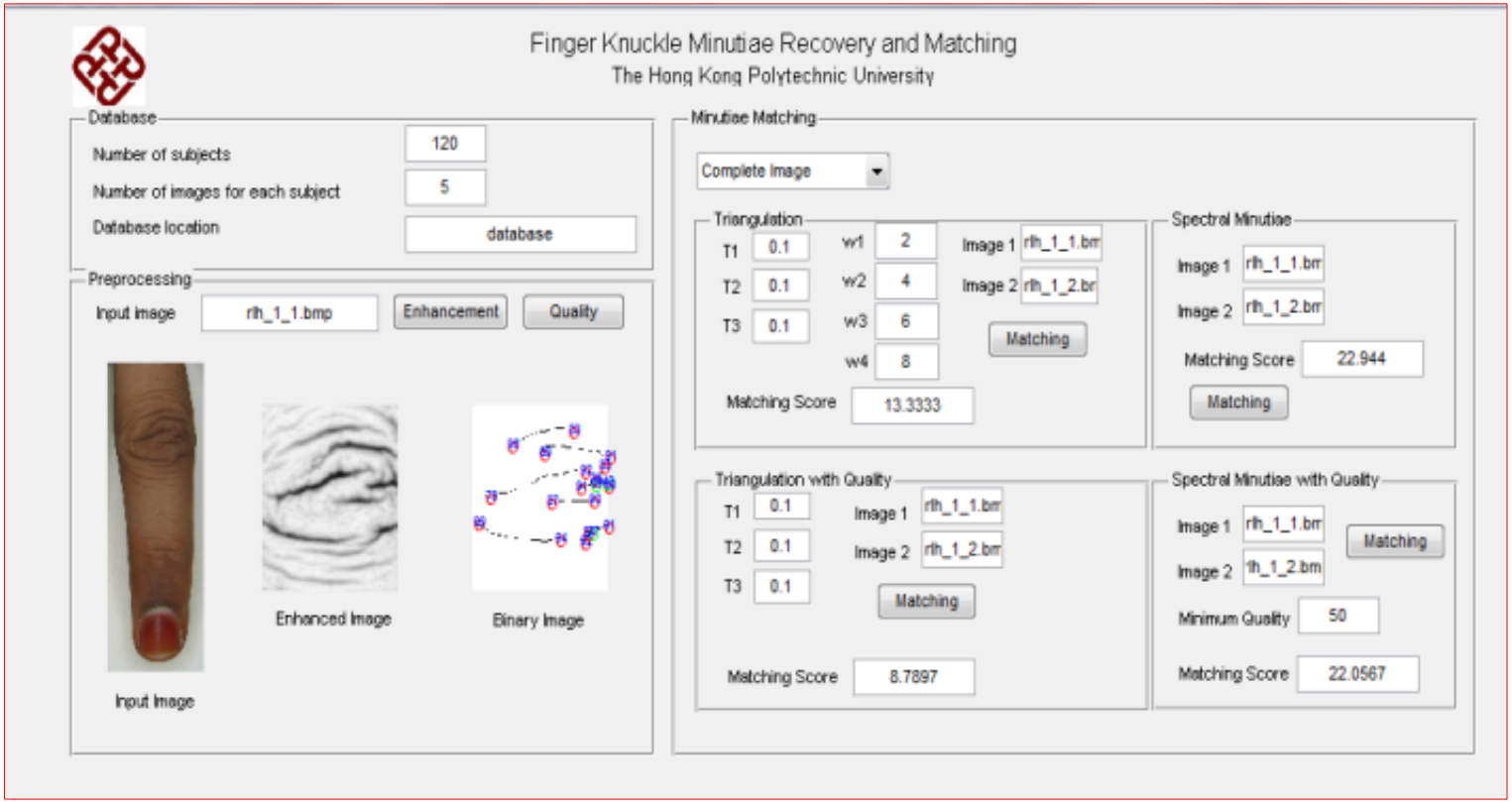
Knuckle Patterns Are Stable?

- Finger Knuckle Images after 6+ years



Recovering and Matching *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.

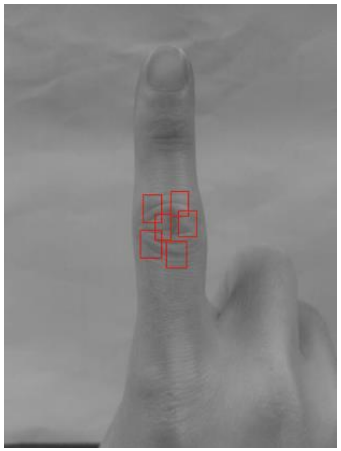
Smartphone-based Mobile Security

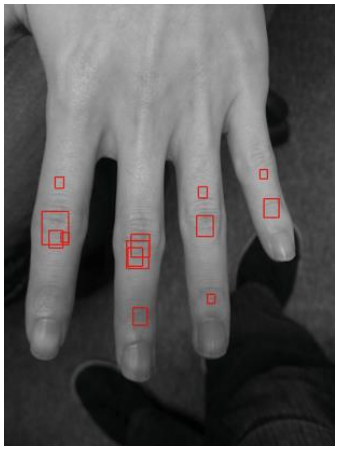
- Objectives
  - Contactless Finger Knuckle Identification using Mobile Phones
  - Built-in-Camera Imaging, *Android* OS and *OpenCV* Library
  - User Friendly Interface → Enrollment and Verification
  - Smartphone Unlocking using Finger Knuckle Patterns

Image Acquisition and Knuckle Detection

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

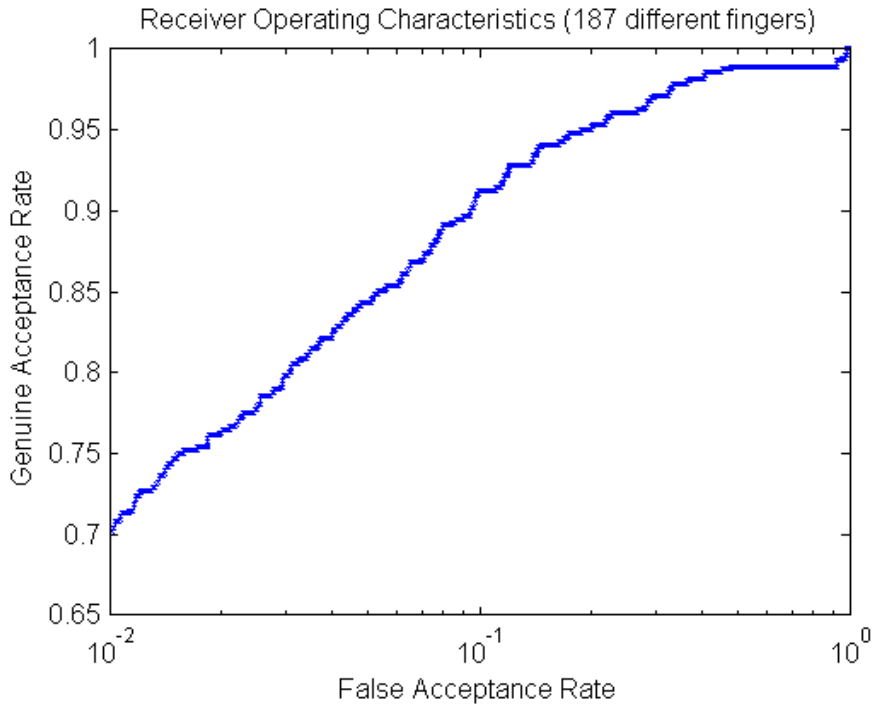
Cascade Classifier File	Hits	Missed	False	Accuracy*
File 1	72	28	20	72%
File 2	64	36	25	64%
File 3	65	35	29	65%
File 4	70	30	21	70%
File 5	23	77	26	23%
Accuracy = (Hits / number of testing samples) * 100%				





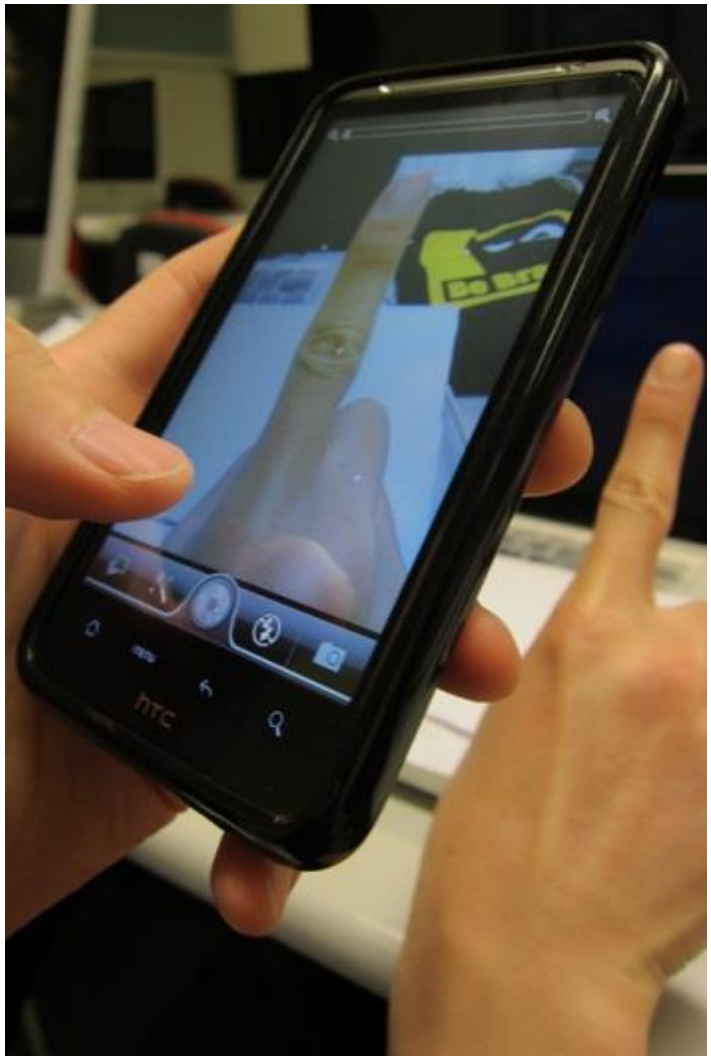
Results

- 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

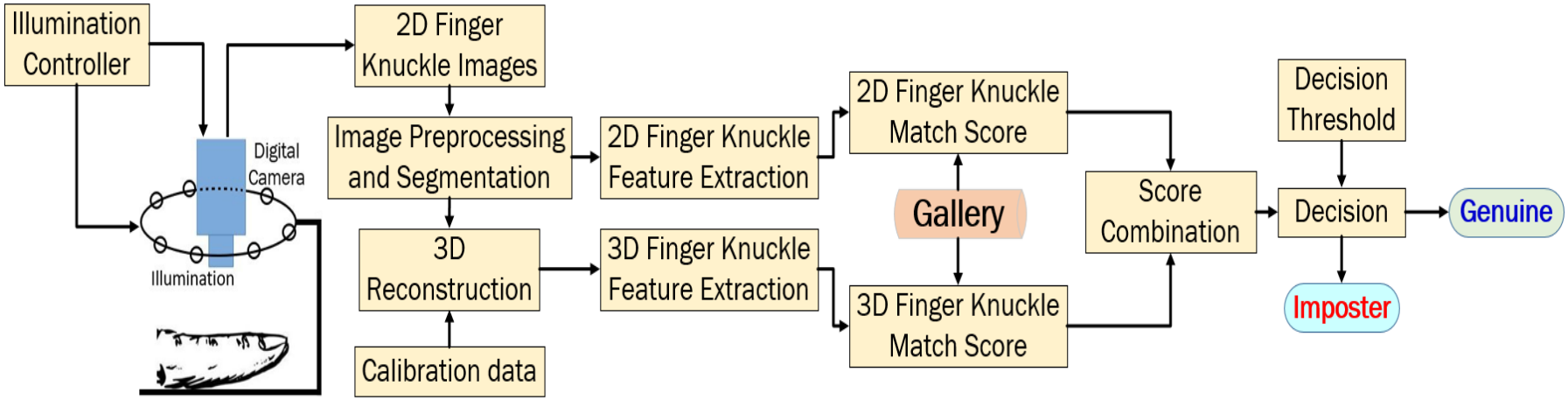
Convenience and User Friendly Interface



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

Contactless 3D Finger Knuckle Identification

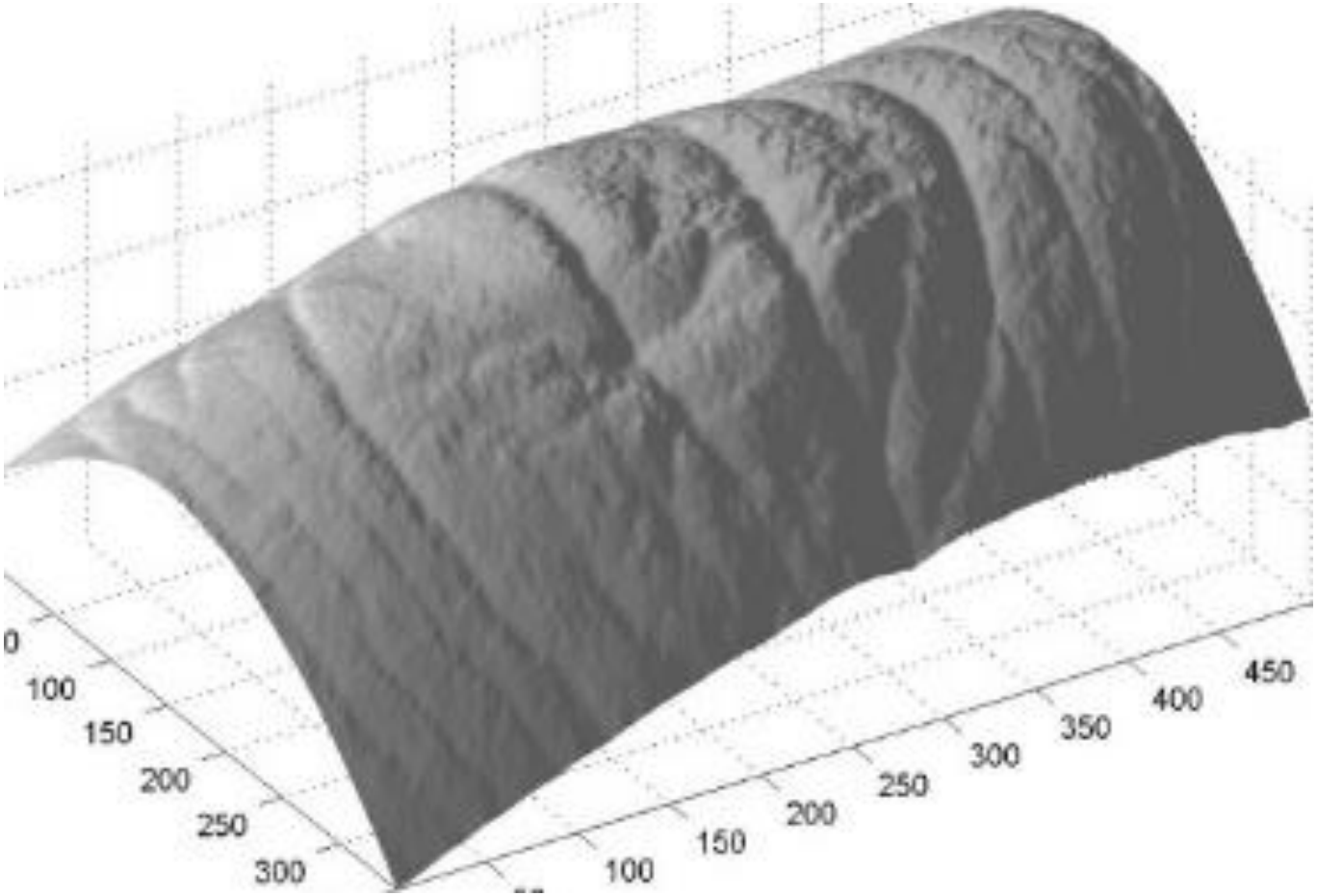
- 3D Finger Knuckle Recovery and Matching
  - First Work on 3D Finger Knuckle Identification (TPAMI 2020)
  - Low Cost 3D Finger Knuckle Recovery → Photometric Stereo



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

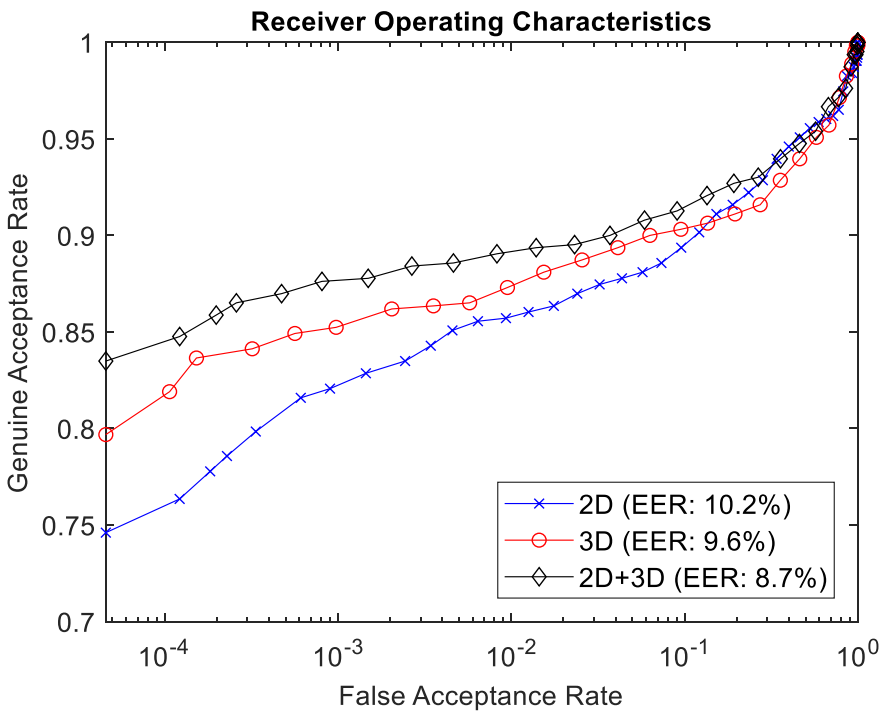
3D Finger Knuckle Acquisition

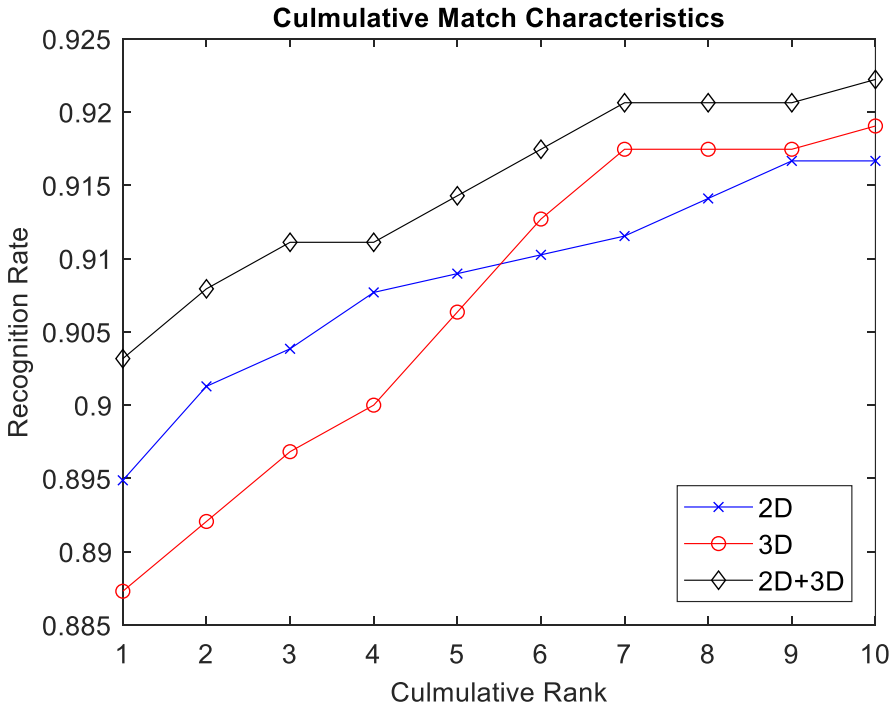
- Photometric Stereo
  - Single Camera, 7 LEDs, Illumination Controller



3D Finger Knuckle Matching

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





3D Finger Knuckle Matching

- Comparisons 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,* 2019.

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.

Live Demo

- Completely Contactless Finger Knuckle Identification
  - Online System for Real World Applications → Pls Try!

Acknowledgment

- Collaborators
  - Zhenyu Zhou
  - Zhihuan Xu
  - Bichai Wang
  - 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

- K. H. M. Cheng and A. Kumar, “Contactless biometric identification using 3D finger knuckle patterns,” *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 42, pp. 1868-1883, Aug. 2020.
- A. Kumar, “Contactless finger knuckle authentication under severe pose deformations,” *Proc. 8th Intl. Workshop Biometrics & Forensics*, Porto, Portugal April 2020.
- D. L. Woodard, P. J. Flynn, “Finger surface as a biometric identifier”, *Computer Vision and Image Understanding*, pp. 357-384, vol. 100, Aug. 2005.
- S. Malassiotis, N. Aifanti, and M. G. Strintzis, “Personal Authentication using 3-D finger geometry”, *IEEE Trans. Information Forensics and Security*, vol.1, no.1, pp.12-21, Mar. 2006.
- 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
- K. H. M. Cheng and A. Kumar, “Efficient and accurate 3D finger knuckle matching using surface key points,” *IEEE Transactions on Image Processing*, pp. 8903 - 8915 Sep. 2020.
- W. Jia, D.-S. Huang, and D. Zhang, “Palmprint verification based on robust line orientation code,” *Pattern Recognitio*n, vol. 41, pp. 1504-1513, 2008.
- Y. Hao, T. Tan, Z. Sun and Y. Han, “Identity verification using handprint,” *Proc. ICB 2007*, Lecture Notes Springer, vol. 4642, pp. 328-337, 2007.
- S. Aoyama, K. Ito, T. Aoki, “A finger-knuckle-print recognition algorithm using phase-based local block matching,” *Information Sciences*, vol. 268, pp. pp. 53-64, 2014.
- A. Kumar and Y. Zhou, “Human identification using knucklecodes,” *Proc. 3rd Intl. Conf. Biometrics, Theory and Applications*, Washington D. C., BTAS'09, pp. 147-152, Sep. 2009.
- *Contactless Finger Knuckle Identification using Smartphones* (Demo), http://www.youtube.com/watch?v=bjPJwbSiMgo
- *The Hong Kong Polytechnic University Mobile Phone Finger Knuckle Database*, http://www.comp.polyu.edu.hk/~csajaykr/knuckle.html, 2012
- K. R. Park, H.-A. Park, B. J. Kang, E. C. Lee, and D. S. Jeong, “A study on iris localization and recognition on mobile phones,” *Eurosip J. Advances Sig. Process*., vol. 2008, Article no. 281943, doi:10.1155/2008/281943, 2008.

References

- K. H. M. Cheng and A. Kumar, “Distinctive feature representation for contactless 3D hand biometrics using surface normal directions,” *Proc. IJCB 2020*, Houston, Sep. 2020.
- 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.
- K. Y. Cheng and A. Kumar, “Contactless finger knuckle identification using smartphones,” *Proc. IEEE Intl. Conf. BIOSIG 2012*, Darmstadt, Germany, Sep. 2012.
- http://www.inmagine.com/searchterms/hand_covering_face-2.html
- W. Chang-Yu, S. Shang-Ling, S. Feng-Rong, M. Liang-Mo, “A Novel Biometrics Technology- Finger-back Articular Skin Texture Recognition”, *ACTA Automatica Sinica*, vol.32, no.3, May 2006.
- *The Hong Kong Polytechnic University Contactless Finger Knuckle Image Database*, Version 1.0, October 2012; http://www.comp.polyu.edu.hk/~csajaykr/fn1.htm
- 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.
- A. Kumar, “Incorporating cohort information for reliable palmprint authentication,” *Proc. ICVGIP*, Bhubaneswar, India, pp. 583–590, Dec. 2008.
- D. G. Joshi, Y. V. Rao, S. Kar, V. Kumar, and R. Kumar, “Computer vision based approach to personal identification using finger crease patterns, *Pattern Recognition*, pp. 15-22, Jan. 1998.
- G. Gao, L. Zhang, Y. Yang, L. Zhang, D. Zhang, “Reconstruction based finger-knuckle-print verification with score level adaptive binary fusion,” *IEEE Trans Image Pr*ocess, pp. 5050–5062, 2013.
- D. Kusanagi, S. Aoyama, K. Ito, T. Aoki, “A person authentication system using second minor finger knuckles for door handle,” *Proc Asian Conf Pattern Recog*, pp. 1–5, 2015.
- K. H. M. Cheng and A. Kumar, “Deep feature collaboration for challenging 3D finger knuckle identification*,” IEEE Transactions on Information Forensics and Security*, Oct. 2020.
- K. Sricharan, A. Reddy and A. G. Ramakrishnan, “Knuckle based hand correlation for user verification,” *Proc. SPIE* vol. 6202, *Biometric Technology for Human Identification* III, 2006. doi: 10.1117/12.666438

Thank You !