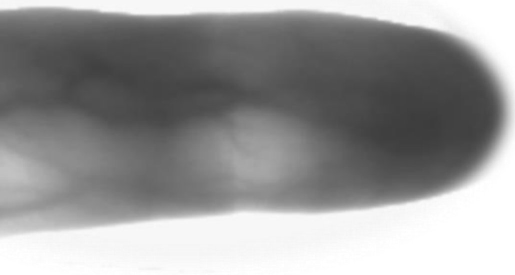
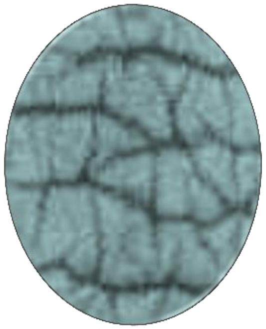


Accurate Personal Identification using Finger Vein and Finger Knuckle Biometric Images



Ajay Kumar

Department of Computing

The Hong Kong Polytechnic University, Hong Kong

IEEE/IAPR Winter School on Biometrics, 13th January 2017, Hong Kong

Multimodal Systems

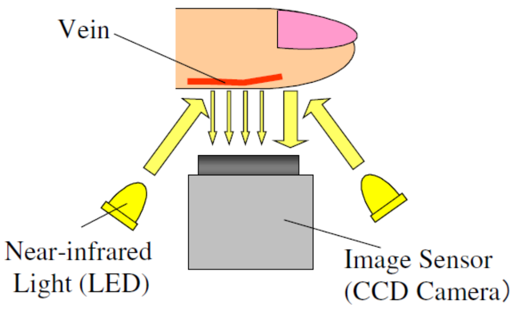
- Bimodal Systems
  - Simultaneous Imaging, Single Shot
  - Finger Imaging $\rightarrow$ Fingerprint and Fingervein
  - Finger Imaging $\rightarrow$ Fingerprint and Finger Knuckle
  - Hand Imaging $\rightarrow$ Palmprint, Finger Geometry and Hand Geometry
  - Face Imaging $\rightarrow$ Face and Periocular, Iris and Periocular, … Obscured or Changed

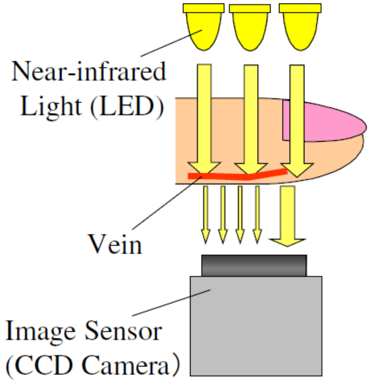
Finger Vein Biometric

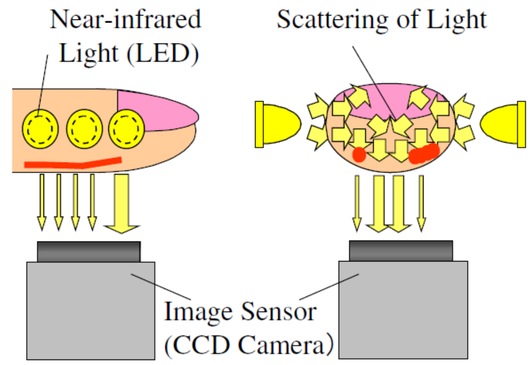
- Key Advantages
  - Orientation Large, Robust and Hidden Biometric Feature
  - Vascular Structure → Unique and Private Identifier
  - Identical Twins → Different Vein Structure
  - Not Intrusive
  - Not Easily Damaged, Obscured or Changed
  - Highly Stable and Repeatable
  - Extremely Difficult to Fake

Vascular Imaging

- ➢ Finger Vein Imaging

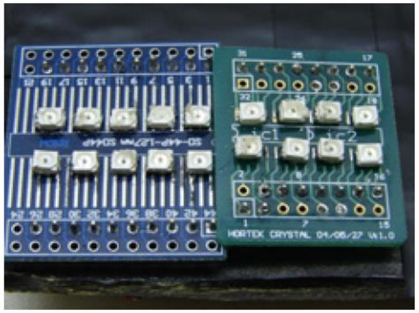






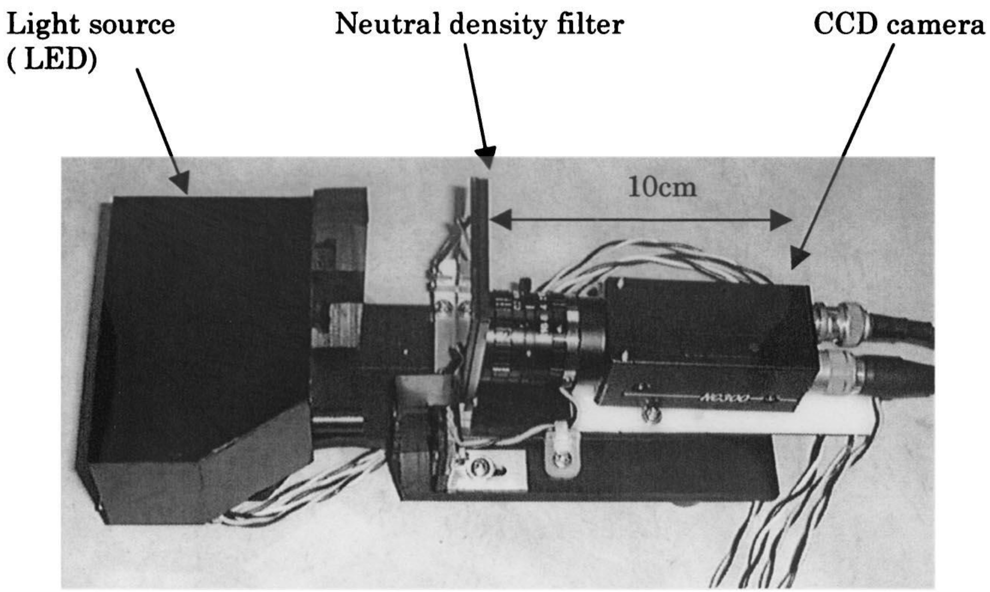
(a) Side View (b) Front View

- ➢ Imaging Hardware



Earlier Work

- Imaging and Illumination (810nm)



M. Kono, H. Ueki, and S. Umemura, “A new method for the identification of individuals by using of vein pattern matching of a finger,” *Proc. 5th Symp. Pattern Measurement*, pp. 9–12 (*in Japanese*), Yamaguchi, Japan, 2000.

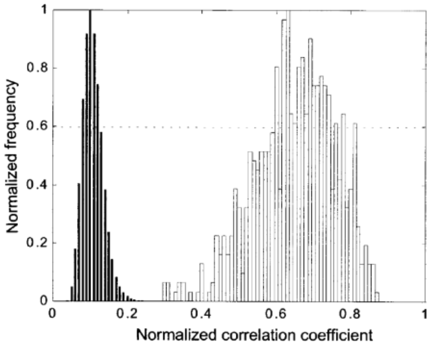
M. Kono, H. Ueki, and S.-i. Umemura, “Near-infrared finger vein patterns for personal identification,” *Applied Optics,* vol. 41, no. 35, pp. 7429-7436, December, 2002

- Preprocessing
  - Matched Image → Registration
  - Orientation Alignment using Finger/Images Shape

Normalized Cross-Correlation Coefficient

- Matching Finger Vein Images (aligned ROI)
  - Similarity Score → Cross-Correlation Coefficient
  - $y_{i,j}$ = IFFT2 [♣FFT2(p) ∗FFT2(q)], i, j = 1…N
  - ♣ → complex conjugate; ∗ → element-by-element multiplication
  - Normalized Cross Correlation → $C = \max[Y_{i,j}]^{1/2}$

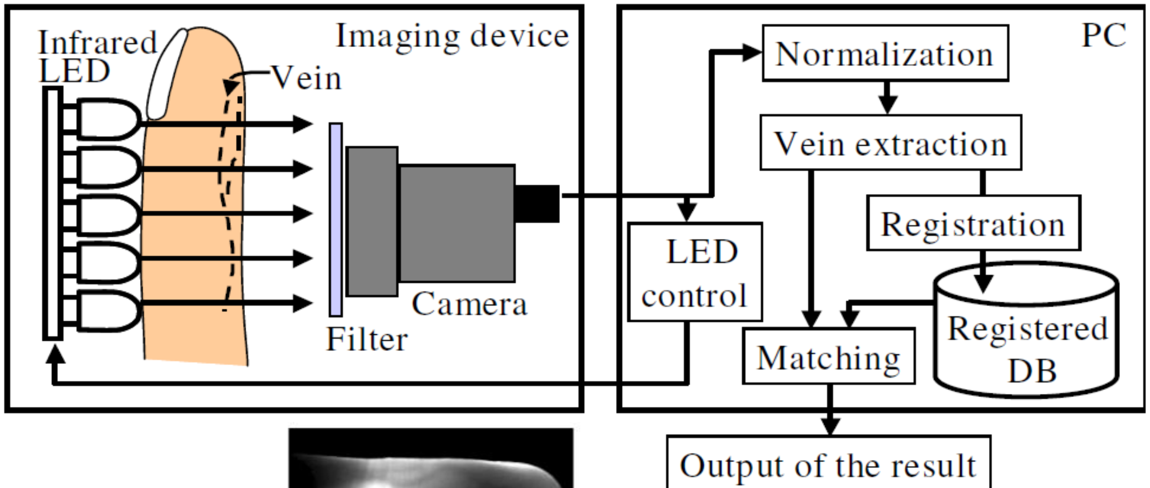
- Experimental Results
  - Database → 678 volunteers, 2 images/person
  - Genuine → 678, Impostors → 229, 503 (678×677×1/2)
  - *"All 678 individuals were perfectly identified"*

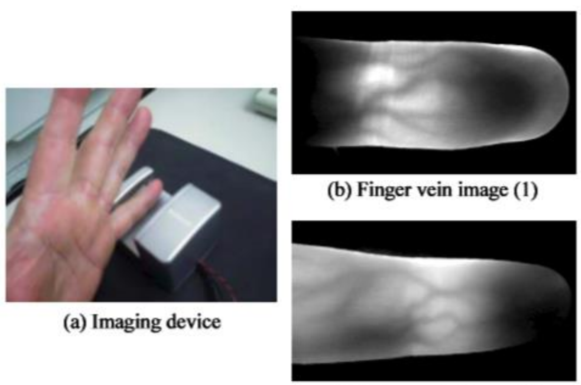


- Limitations
  - Proprietary database → Lack of reproducibility
  - Only 2 images/person → Reliable? Commercial Interests?

Repeated Line Tracking (2004)

- Line Tracking
  - Improved Imaging, System





(a) Imaging device

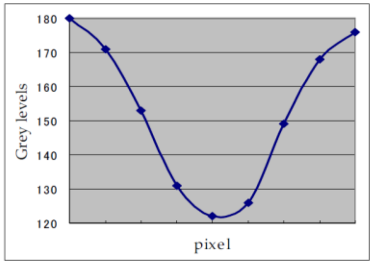
(b) Finger vein image (1)

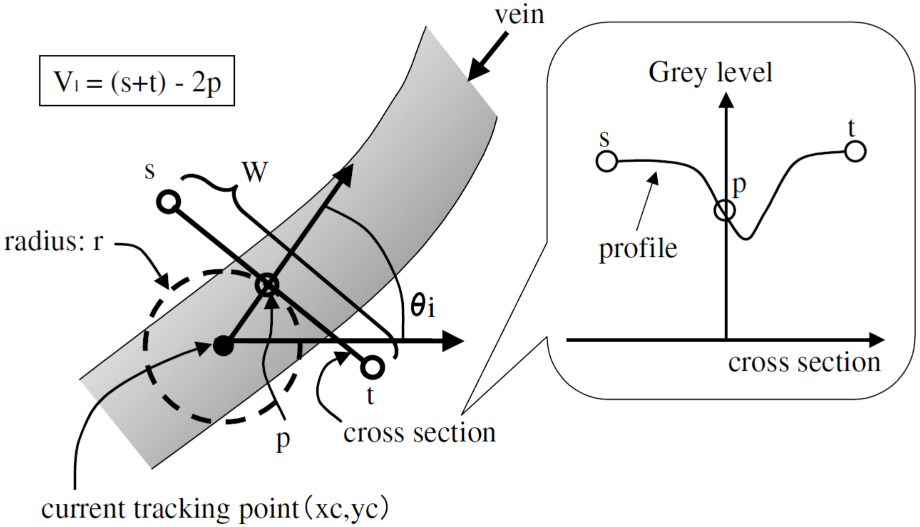
(c) Finger vein image (2)

N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

Repeated Line Tracking

- Line Tracking



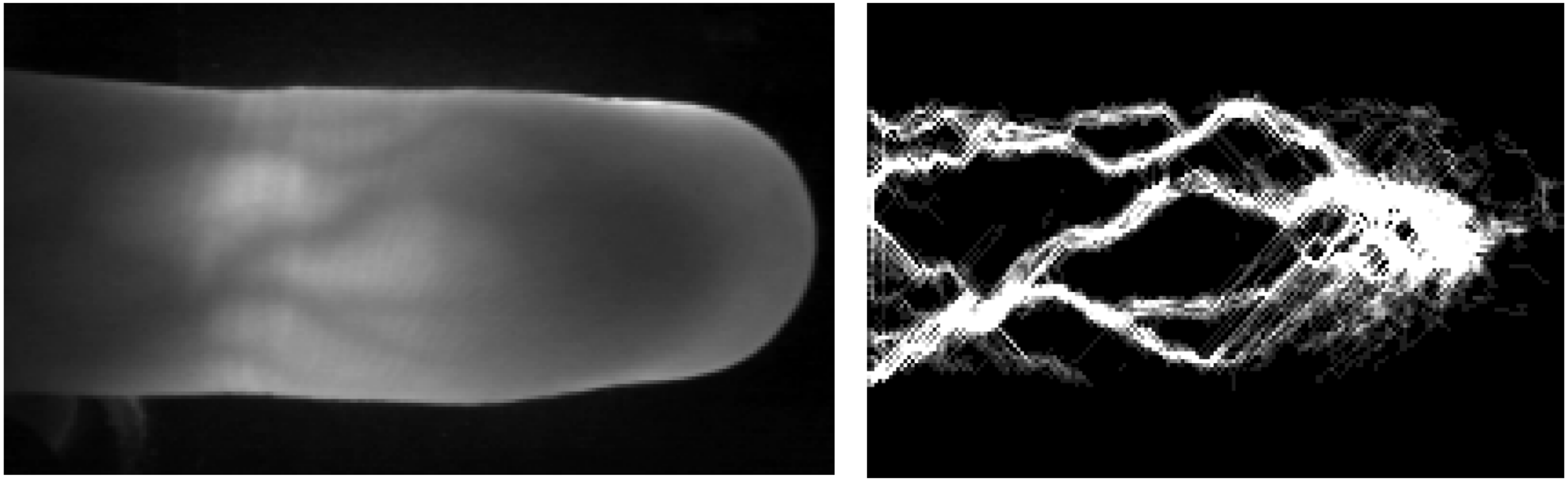


- Small No of Repetitions → *Insufficient* feature extraction
- Large No of Repetitions → *High* computational cost
- At least → 3000 (lower limit)

N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

Repeated Line Tracking

- Tracking Results
  - Number of times a pixel has been tracked

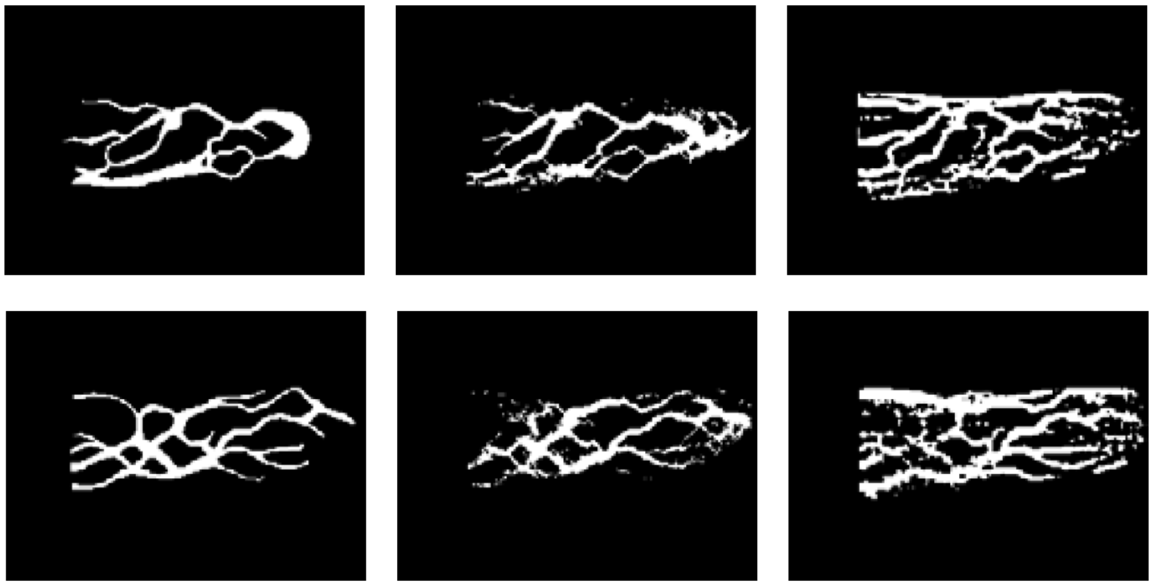


Infrared image (left) and value distribution in the tracking space (right)

N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

Repeated Line Tracking

- Tracking Results
  - Comparisons



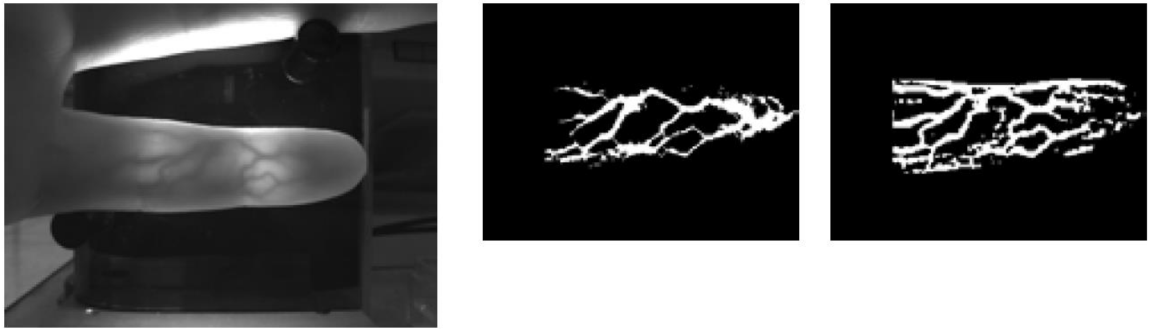
Manually Labelled, *RLT Method*, *and using Matched Filter*

26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26
26	8	-18	-32	-18	8	26

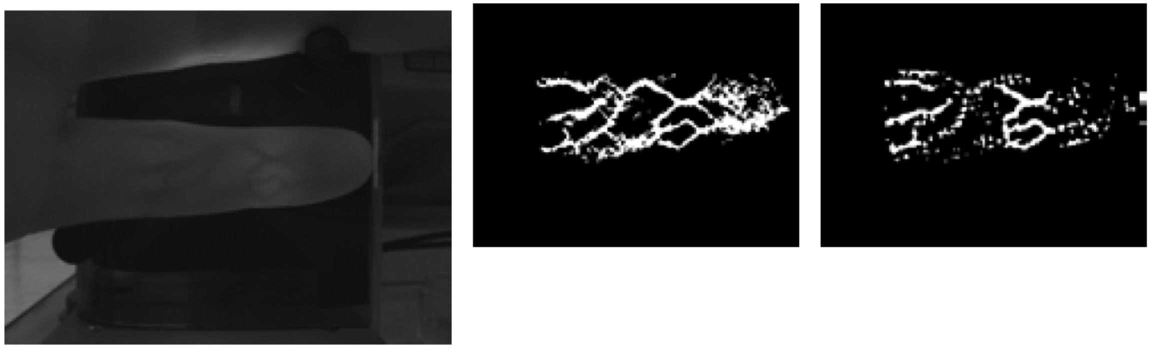
N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

Repeated Line Tracking

- Tracking Results
  - Comparisons



Bright Sample: Repeated Line Tracking and using Matched Filter



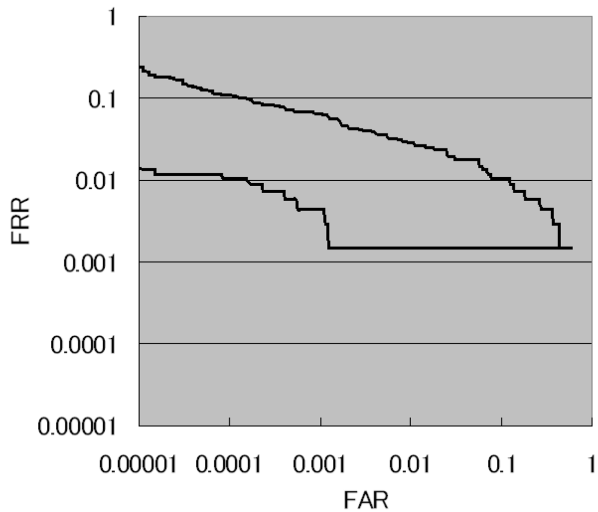
Dark Sample: Repeated Line Tracking and using Matched Filter

N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

Repeated Line Tracking

➢ Matching Binarized Images

- Downsampling, Translation and Matching → Highest Score
- Mismatch Ratio (Normalized by vein pixels in two images)
- Database → 678 Volunteers (Same)
- EER → 0.145%



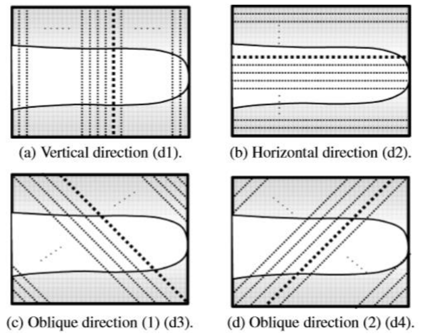
➢ Limitations

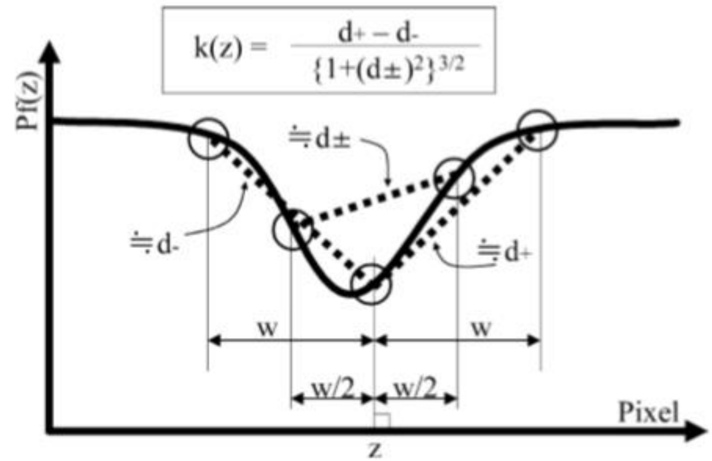
- No comparison with earlier (Hitachi) work
- Proprietary database → Lack of reproducibility
- Only 2 images/person → Least reliable, Commercial

N. Miura, A. Nagasaka, and T. Miyatake, "Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification," *Machine Vision and Applications*, pp. 194-203, Jul. 2004.

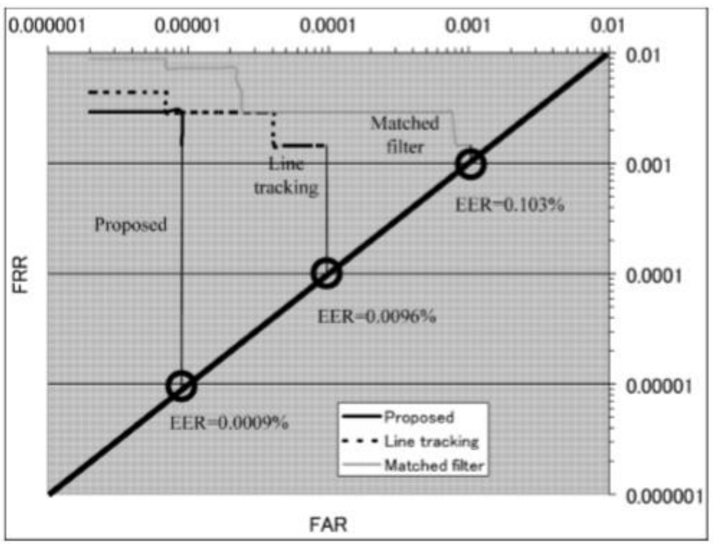
Local Maximum Curvature (2007)

- Multiple Profiles





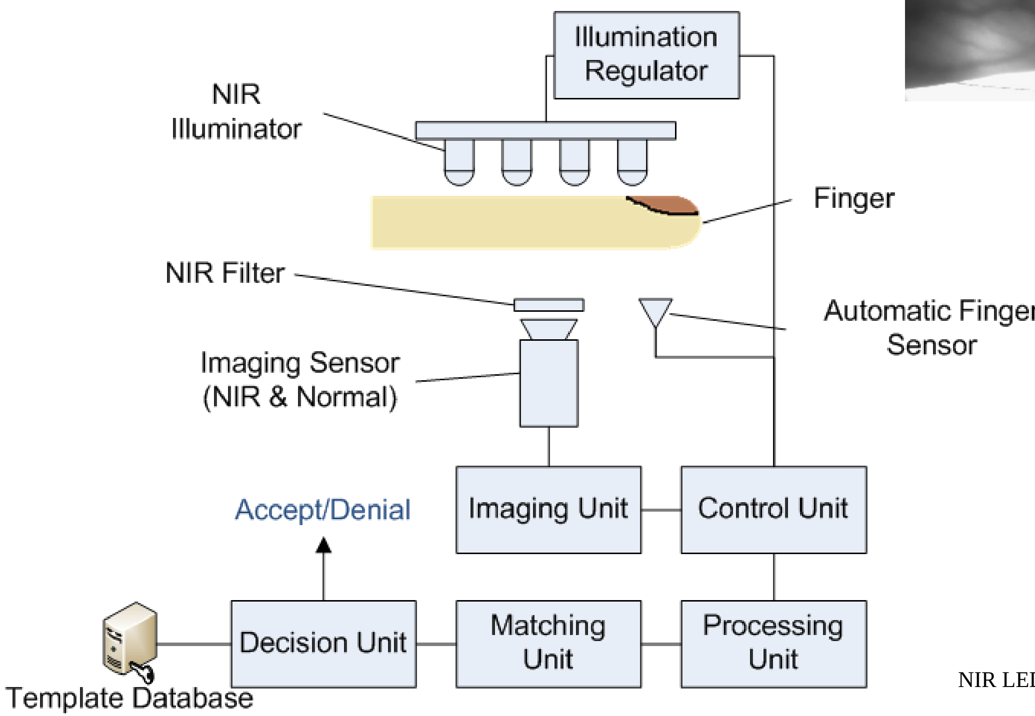
- Computing Curvature
  - Discrete Lines
  - Binarization → Otsu's Method
  - Same Dataset (678 Subjects)

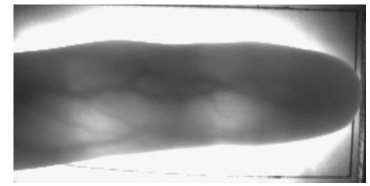


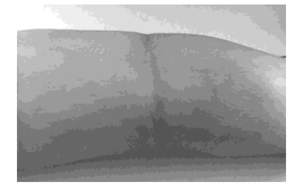
N. Miura, A. Nagasaka, and T. Miyatake, "Extraction of finger-vein patterns using maximum curvature points in image profiles," *ICICE Transactions*, August 2007.

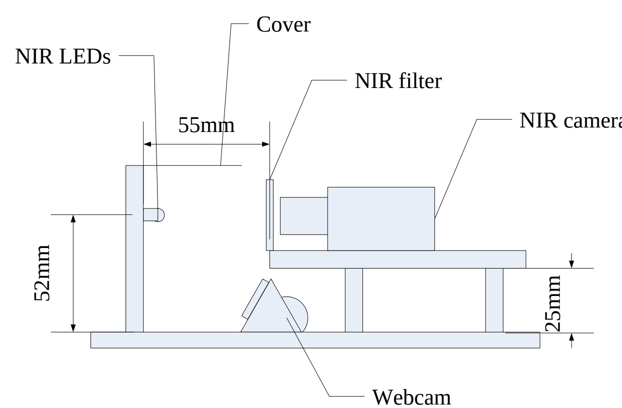
Finger Vein Imaging

- Imaging Setup





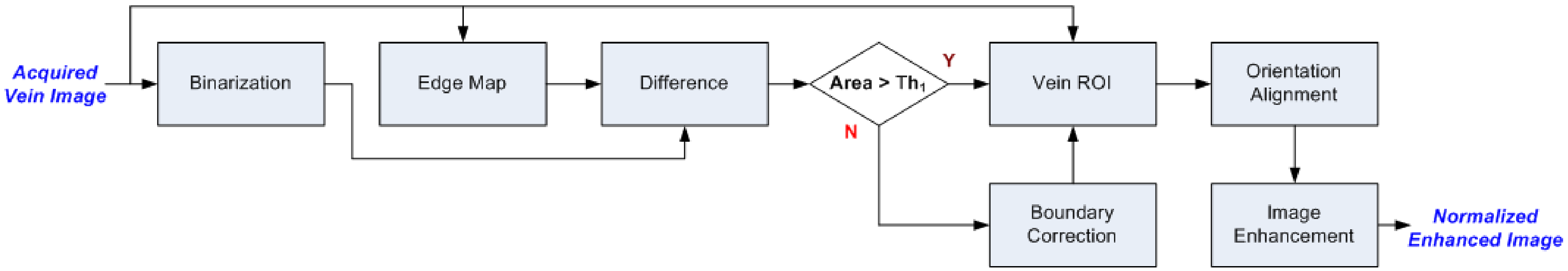




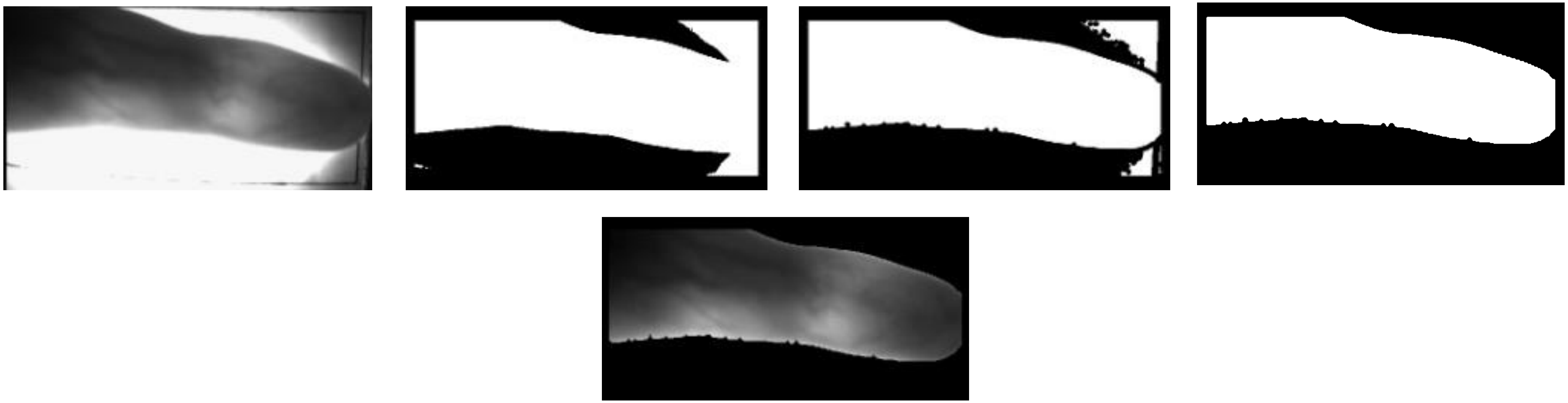
- World’s First Publicly Available FingerVein Images Dataset

Region of Interest Segmentation

- Pre-Processing

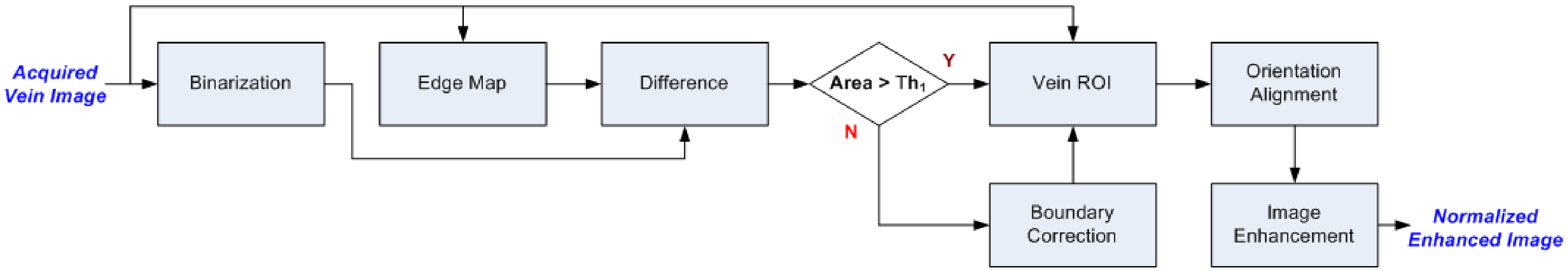


- Sample Example
  - Acquired image to segmented ROI

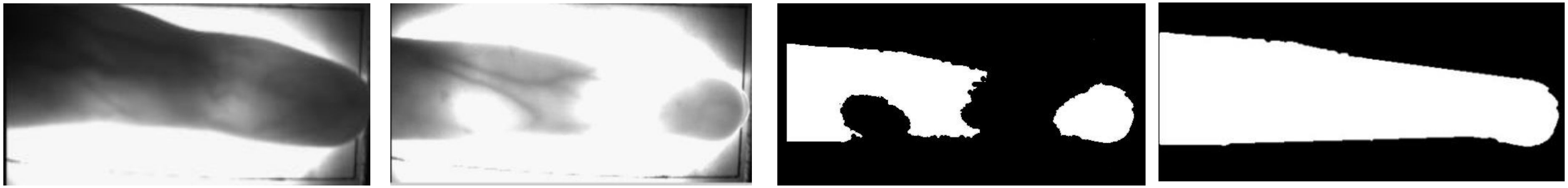


Region of Interest Segmentation

- Pre-Processing



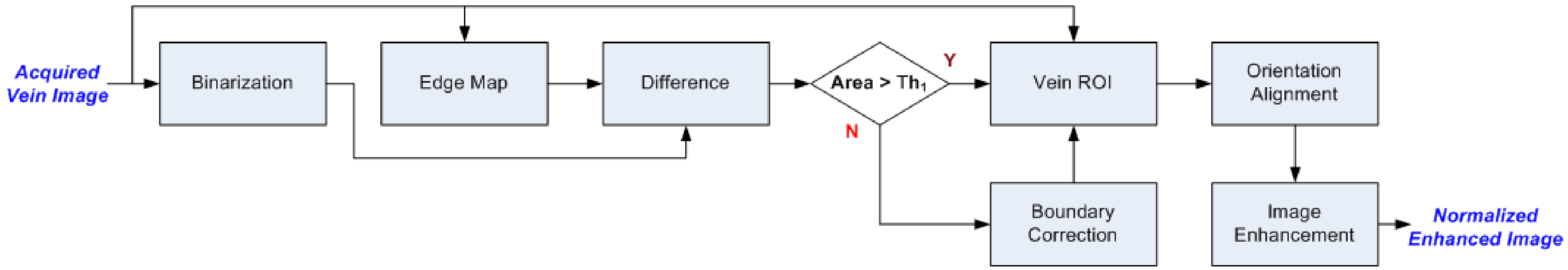
- Sample Example (Poor Quality)
  - Acquired image to segmented ROI



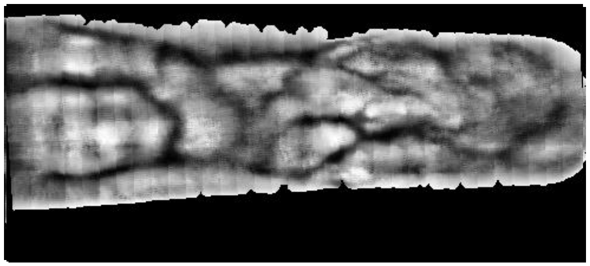
  - Mask → Estimation of Orientation (centroid & moments)
  - Rotational Alignment of ROI

Region of Interest Enhancement

- Pre-Processing



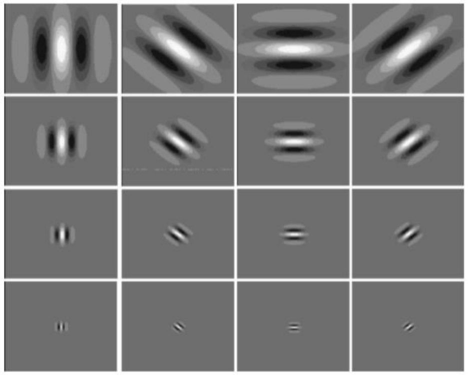
- Image Enhancement
  - Method → *HistEq* (*Img - Avg Background Illumination*)
  - Sample Results

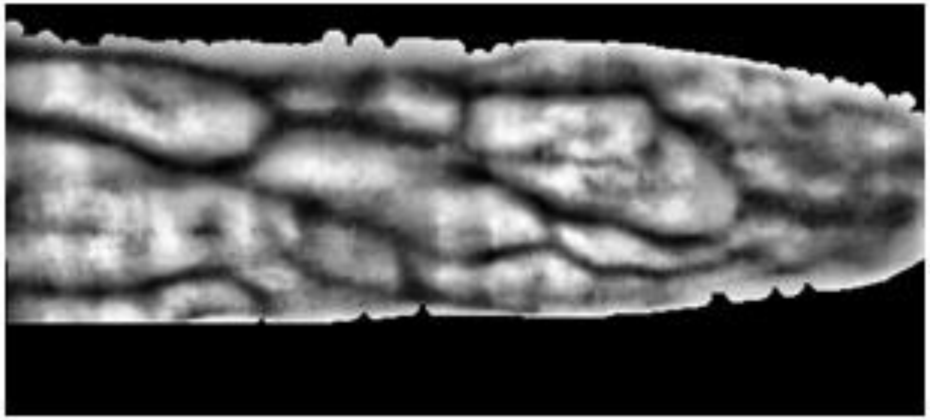



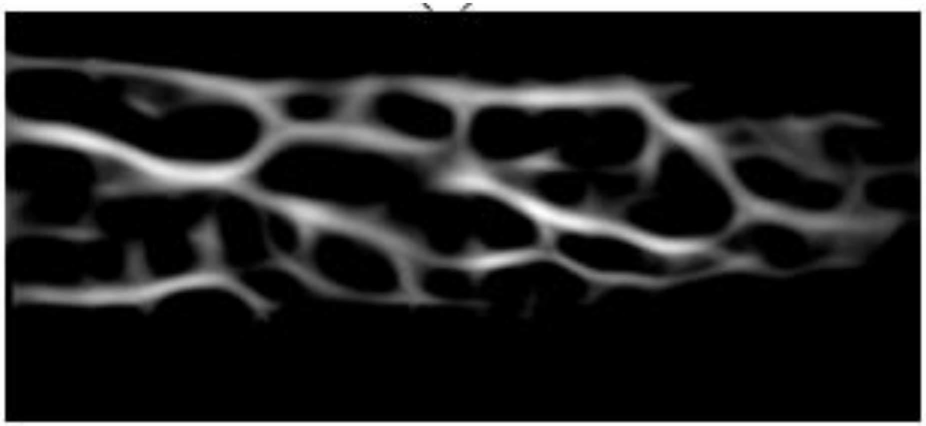
Feature Extraction

Gabor Filter and Morphological Processing

- Set of Filters → Extract Vein Structure
- $f(x,y) = \max_{\forall\, n=1,2,..\Omega} \{\acute{h}_{\theta_n}(x,y) \star v(x,y)\}$





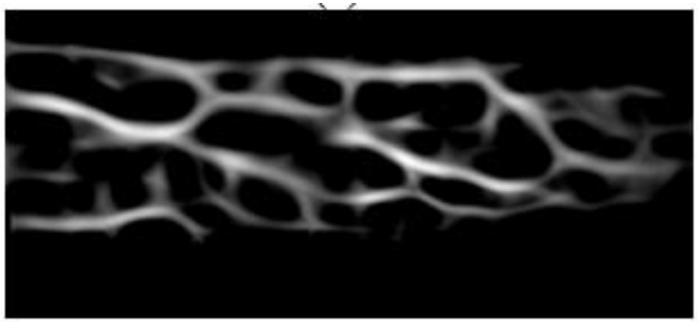


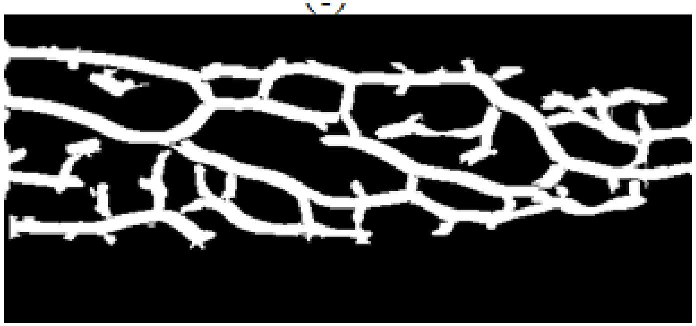
Feature Extraction

- Morphological Operations and Feature Encoding
  - Morphological Operations → Enhance clarity of vein patterns

$$z(x,y) = f(x,y) - (f(x,y) \ominus b) \circledast b$$

  - SE → *b*, Grey scale erosion/dilation, top-hat operation





  - Feature Encoding
  - $R(x,y) = \begin{cases} 255 & if \;\; z(x,y) > 0 \\ 0 & if \;\; z(x,y) \leq 0 \end{cases}$

Generating Match Score

- Finger Vein Match Score
  - Robust → Accommodate translational and rotational variations
  - Binarized feature map R and T → Match score

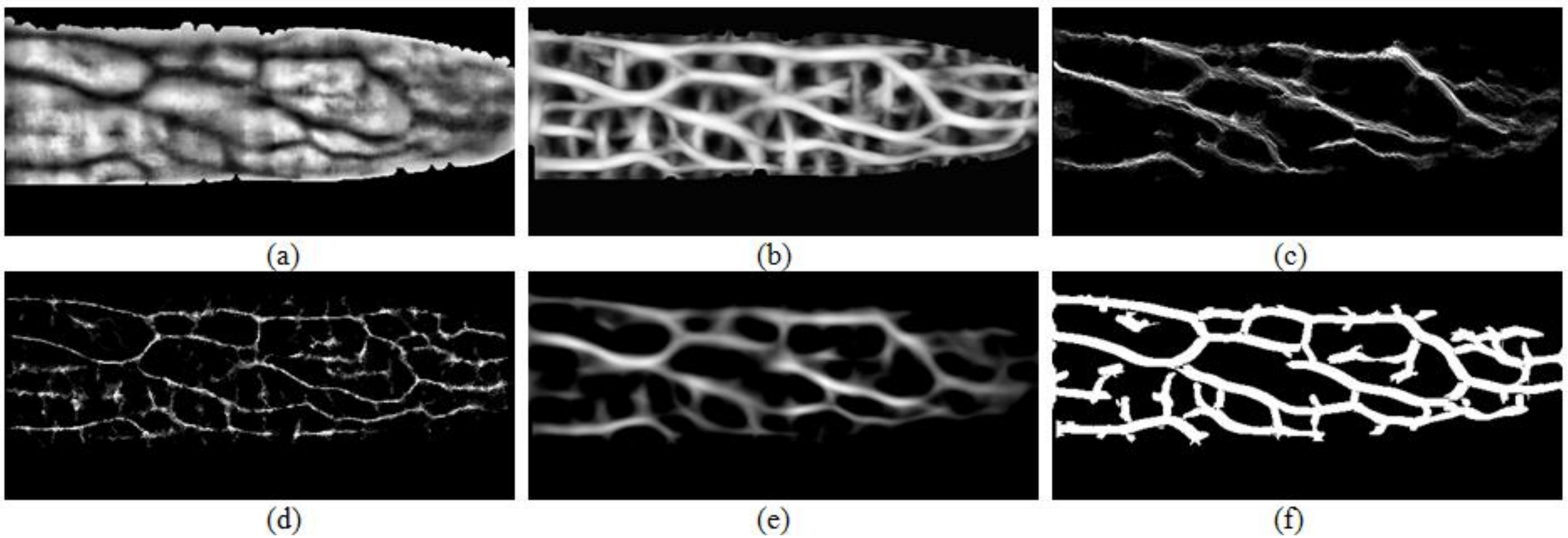
$$S_v(R,T,M_R,M_T) = \min_{\forall i \in [0,2w], \forall j \in [0,2h]} \left(\frac{\sum_{x=1}^{m} \sum_{y=1}^{n} \odot \left(\hat{\boldsymbol{R}}(x+i, y+j), \boldsymbol{T}(x,y), M_R(x+i,y+j), M_T(x,y) \right)}{\sum_{x=1}^{m} \sum_{y=1}^{n} M_R(x,y) \cap M_T(x,y)} \right)$$

  - Masks → M_R, M_T, Automatically generated

$$M = \left\{ (x,y) \middle| \forall (x,y) \in I, I(x,y) \neq I_{bg} \right\}$$

Experiments and Results

- Sample Results



Sample results from different feature extraction methods: (a) *enhanced* finger vein image, (b) output from matched filter, (c) output from repeated line tracking, (d) output from maximum curvature, (e) output from Gabor filters, and (f) output from morphological operations on (e)

Experiments and Results

HK PolyU Fingervein Database

- World's First Publicly/Freely Accessible Database
- Two Session Database, 6264 Images
- First Session → 156 Subjects, Second Session → 105 Subjects
- Six Images → Each from Index and Middle Fingers

Two Session Experiments (Protocol A)

Three Sets→ Individual Fingers and Combination

- Genuine Scores → 630 (105 × 6)
- Imposter Scores → 65,520 (105 × 104 × 6)

- Combination → Index and Middle Finger. 210 Class
- Genuine Scores → 1260 (210 × 6)
- Imposter Scores → 263,340 (210 × 209 × 6)

Experiments and Results

- Two Session Experiments (Protocol A)

Comparative Results→ Individual Fingers and Combination

Table 1: Performance from finger vein matching with various approaches without mask

Approach	Index Finger	Middle Finger	Index and Middle Finger
Even Gabor with Morphological	7.14%	12.39%	9.31%
Repeated line tracking [5]	15.28%	18.59%	16.70%
Maximum curvature [6]	15.41%	18.06%	16.61%
Matched filter	8.60%	11.87%	10.00%
Even Gabor	6.50%	10.12%	8.10%

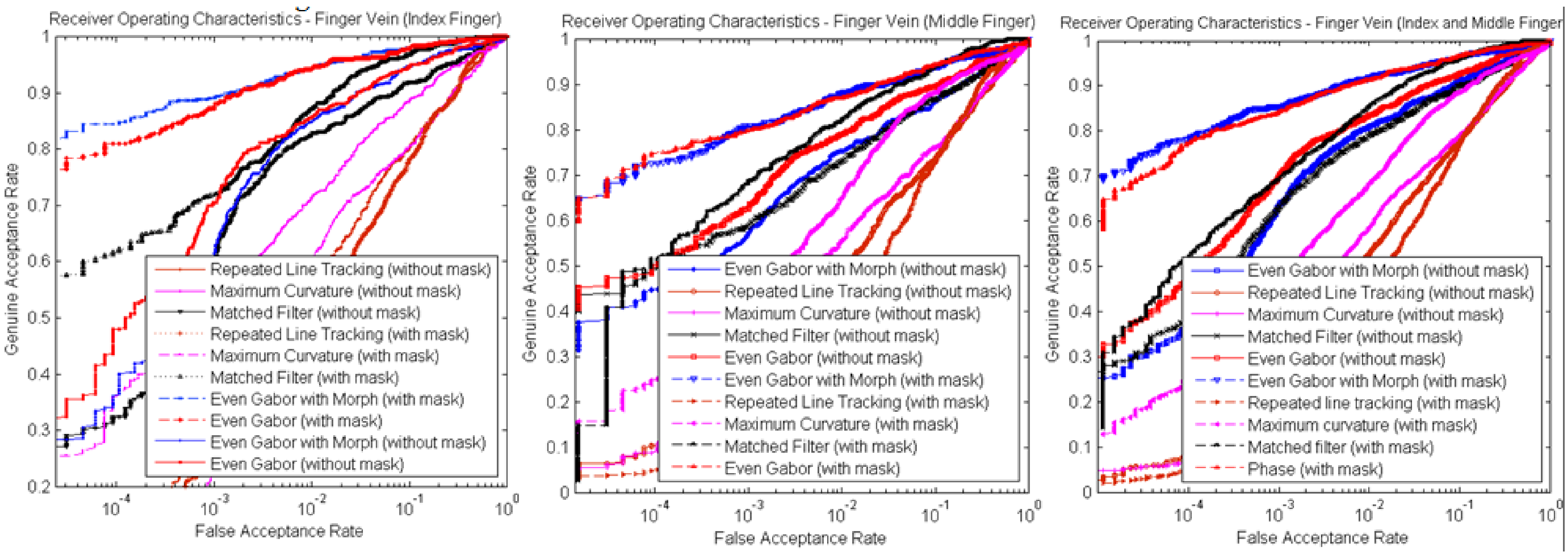
Table 2: Performance from finger vein matching with various approaches with mask

Approach	Index Finger	Middle Finger	Index and Middle Finger
Even Gabor with Morphological	**3.33%**	**6.99%**	**4.91%**
Repeated line tracking [5]	15.60%	18.18%	16.43%
Maximum curvature [6]	10.96%	11.08%	10.99%
Matched filter	4.84%	7.81%	5.31%
Even Gabor	3.82%	7.08%	4.61%

Experiments and Results

- Two Session Experiments (Protocol A)

Comparative Results→ Individual Fingers and Combination



A. Kumar and Y. Zhou, "Human identification using finger images," *IEEE Trans. Image Processing*, vol. 21, pp. 2228-2244, April 2012

Experiments and Results

➢ Single Session Experiments (Protocol B, Larger Subjects)

Comparative Results→ Individual Fingers and Combination

Table 4: Performance from finger vein matching with various approaches without mask

Approach	Index Finger	Middle Finger	Index and Middle Finger
Even Gabor with Morphological	1.16%	2.24%	1.71%
Repeated line tracking [5]	5.57%	7.77%	6.38%
Maximum curvature [6]	2.59%	3.73%	3.27%
Matched filter	1.70%	1.75%	1.71%
Even Gabor	0.89 %	1.71%	1.22%

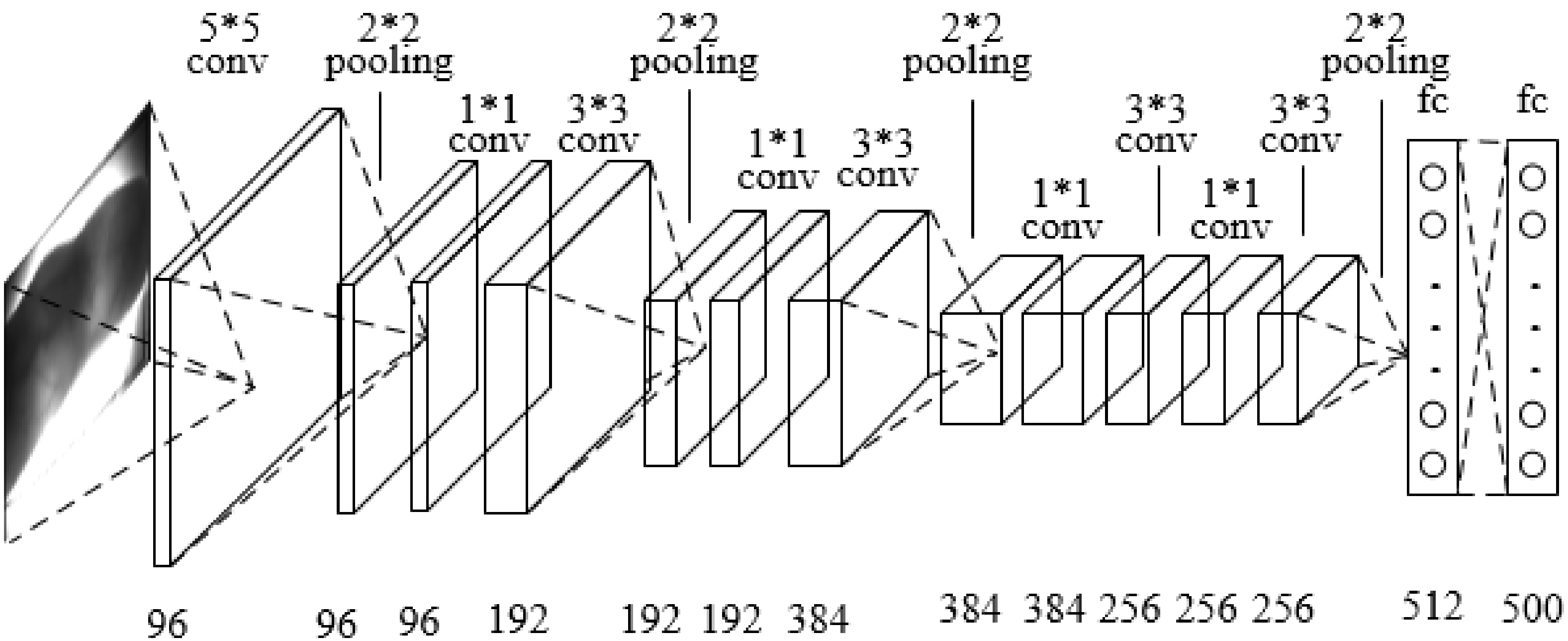
Table 5: Performance from finger vein matching with various approaches with mask

Approach	Index Finger	Middle Finger	Index and Middle Finger
Even Gabor with Morphological	**0.43%**	**0.96%**	**0.65%**
Repeated line tracking [5]	6.54%	9.95%	8.25%
Maximum curvature [6]	2.20%	3.13%	2.65%
Matched filter	1.88%	2.10%	1.89%
Even Gabor	0.54%	1.16%	0.80%

Experiments→Convolutional Neural Network

- Two Session Experiments (Protocol A, using CNN)

- Lightened CNN Architecture

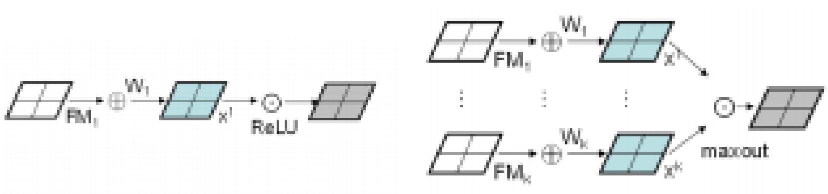


C. Xie and A. Kumar, "Finger Vein Identification using Convolutional Neural Networks," *Technical Report No. COMP-K-25*, The Hong Kong Polytechnic University, Dec. 2016.

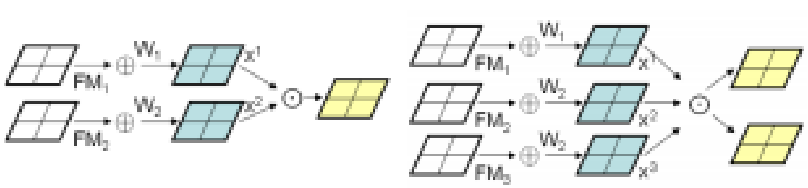
Experiments→Convolutional Neural Network

➢ Light CNN Architecture

- Light CNN introduced in [A]
- Maxout → less parameters
- MFM (Max Feature Map)



(a) ReLU: $h(x)$=max(0, x^1) (b) Maxout: $h(x)$=max(x^i)



(c) MFM 2/1: $h(x)$=max(x^1, x^2) (d) MFM 3/2: $h^1(x)$=max(x^i), $h^2(x)$=median(x^i)

Type	Filter Size /Stride	Output Size	#Params
Conv1	$5 \times 5/1, 2$	$128 \times 128 \times 96$	2.4K
MFM1	-	$128 \times 128 \times 48$	-
Pool1	$2 \times 2/2$	$64 \times 64 \times 48$	-
Conv2a	$1 \times 1/1$	$64 \times 64 \times 96$	4.6K
MFM2a	-	$64 \times 64 \times 48$	-
Conv2	$3 \times 3/1, 1$	$64 \times 64 \times 192$	165K
MFM2	-	$64 \times 64 \times 96$	-
Pool2	$2 \times 2/2$	$32 \times 32 \times 96$	-
Conv3a	$1 \times 1/1$	$32 \times 32 \times 192$	18K
MFM3a	-	$32 \times 32 \times 96$	-
Conv3	$3 \times 3/1, 1$	$32 \times 32 \times 384$	331K
MFM3	-	$32 \times 32 \times 192$	-
Pool3	$2 \times 2/2$	$16 \times 16 \times 192$	-
Conv4a	$1 \times 1/1$	$16 \times 16 \times 384$	73K
MFM4a	-	$16 \times 16 \times 192$	-
Conv4	$3 \times 3/1, 1$	$16 \times 16 \times 256$	442K
MFM4	-	$16 \times 16 \times 128$	-
Conv5a	$1 \times 1/1$	$16 \times 16 \times 256$	32K
MFM5a	-	$16 \times 16 \times 128$	-
Conv5	$3 \times 3/1, 1$	$16 \times 16 \times 256$	294K
MFM5	-	$16 \times 16 \times 128$	-
Pool4	$2 \times 2/2$	$8 \times 8 \times 128$	-
fc1	-	512	4,194K
MFM_fc1	-	256	-
Total	-	-	5,556K

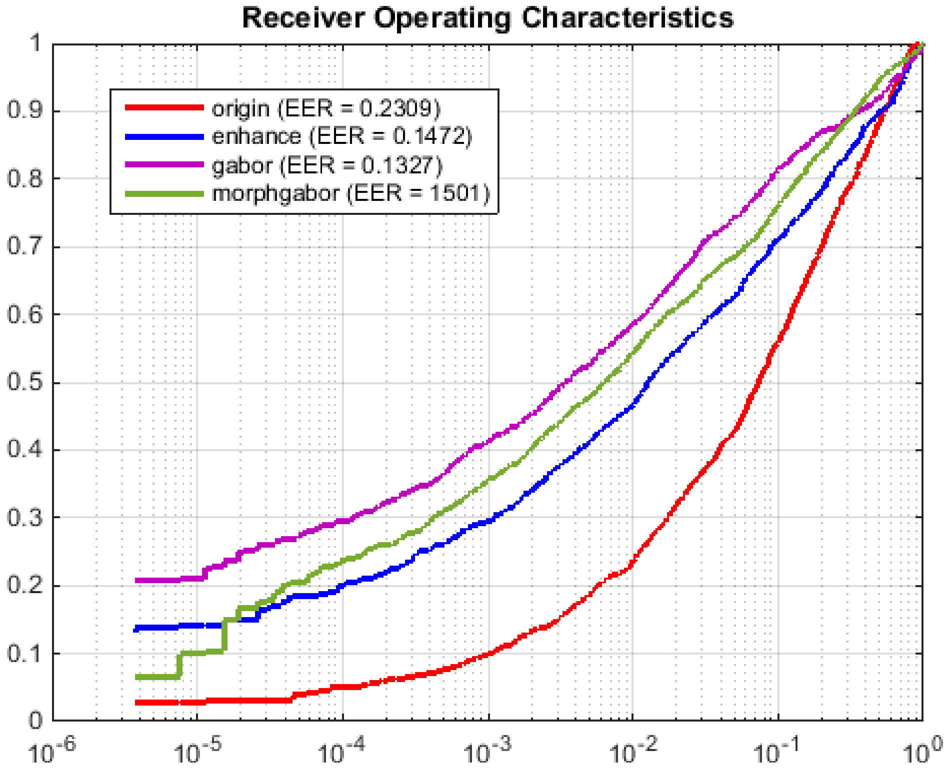
[A] X. Wu *et al*., "A Light CNN for Deep Face Representation with Noisy Labels," https://arxiv.org/abs/1511.02683 Nov. 2016

C. Xie and A. Kumar, "Finger Vein Identification using Convolutional Neural Networks," *Technical Report No. COMP-K-25*, The Hong Kong Polytechnic University, Dec. 2016.

Experiments→Convolutional Neural Network

- Experimental Results using Light CNN

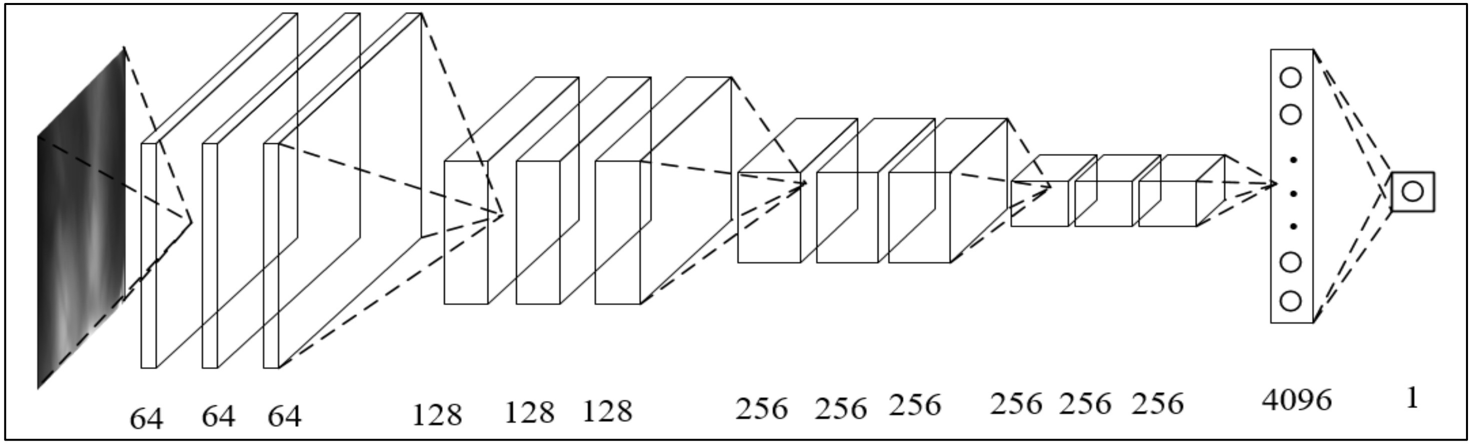
- EER of 13.27% (Independent Second Session Test Data)

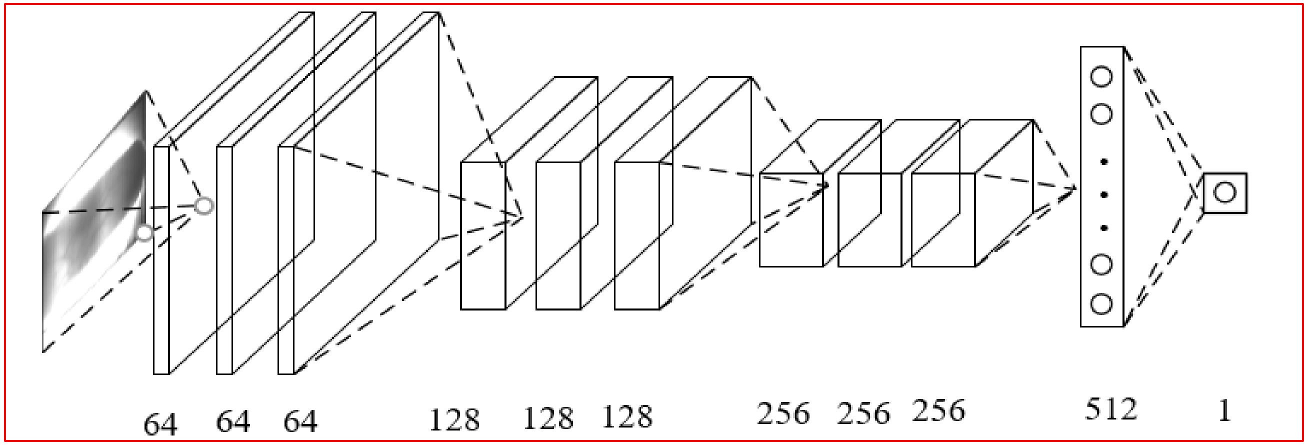


[A] X. Wu et al., "A Light CNN for Deep Face Representation with Noisy Labels," https://arxiv.org/abs/1511.02683. Nov. 2016

Experiments→Convolutional Neural Network

- DCNN (VGG) with cross entropy loss
- Architecture



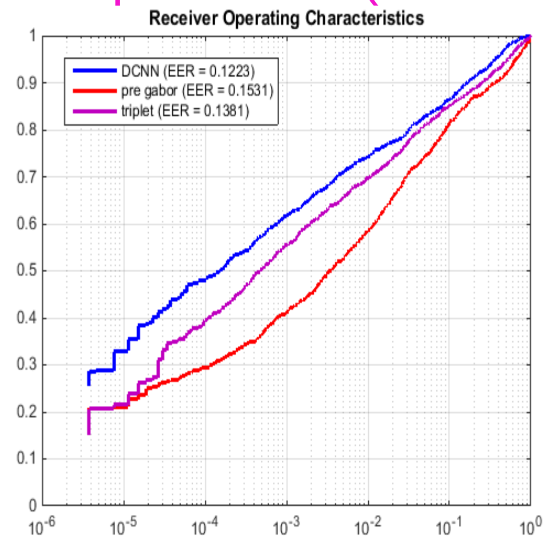


K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," *Proc. ICLR, 2015*.

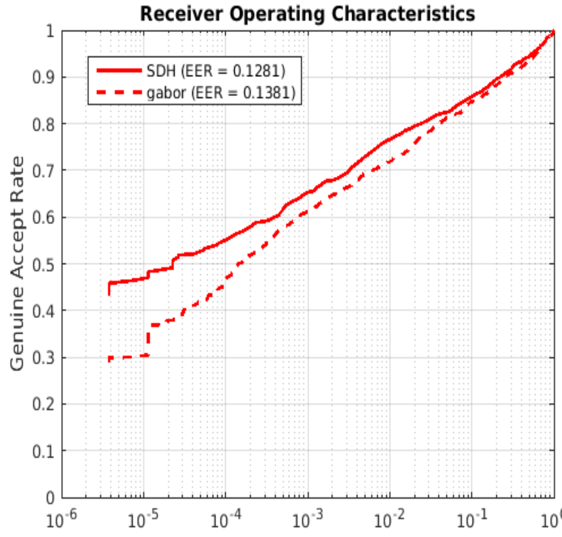
Results→Convolutional Neural Network

- Two Session Experiments (Protocol A, Comparative Results)

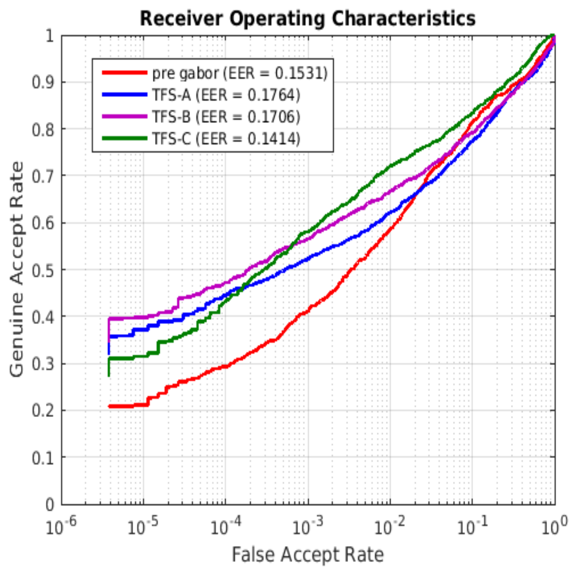
DCNN



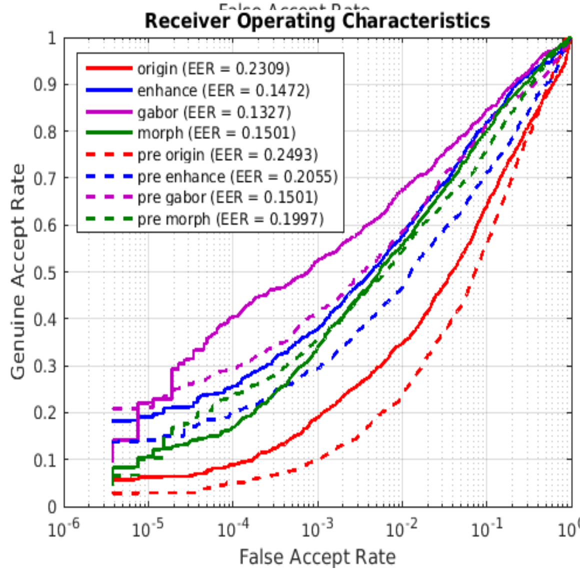
Triplet



TFS (log)



Joint Bayesian



Experiments→Convolutional Neural Network

➢ Two Session Experiments (Comparative Results using Public Database)

Key Conclusions

- Generally SDH delivers superior performance (better ROC and also notable improvement in EER)
- DCNN with cross entropy loss has similar effect on SDH, but cannot combined with SDH directly
- Log scale and the modified TFS structure can improve performance (evident from ROC but less noticeable for EER)
- Triplet loss has similar effect as TFS
- State of art (TIP2012) →GAR of over 0.6 @FAR of 1e-05 (slide 24)

In summary, achieved accuracy fails to match those from using the method detailed in TIP 2012 reference

(more details available in the following reference)

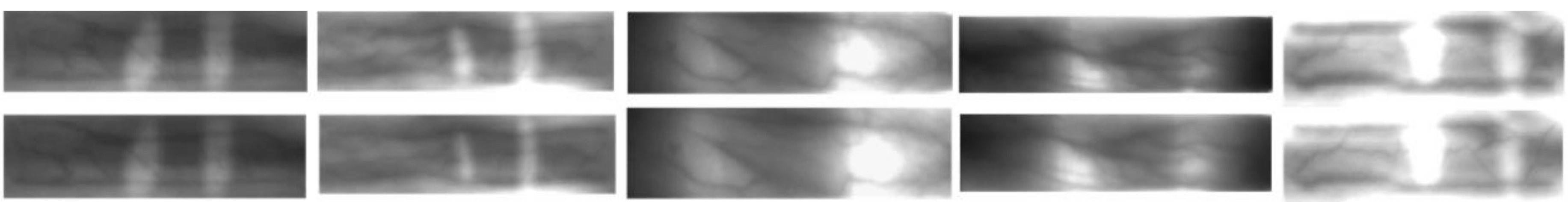
C. Xie and A. Kumar, "Finger Vein Identification using Convolutional Neural Networks," *Technical Report No. COMP-K-25*, The Hong Kong Polytechnic University, Dec. 2016.

Synthesizing Finger Vein Images

➢ Summary of Public Databases

Database	Ref.	Size	Sessions	Public
Hong Kong Polytechnic University	[KZ12]	6264 images from 156 subjects, 2 fingers per subject	2	Yes
SDUMLA-HMT	[YLS11]	3816 images, 6 fingers per subjects	1	Yes
University of Twente	[TV13]	1440 images of 60 subjects	2	No
FV-USM	[MASR14]	5904 images of 123 subjects, 492 different finger classes	2	Yes
CFVD	[ZLL+13]	1345 images of 13 subjects, 130 different fingers	2	No

Which is Real? Which is Synthesized?



F. Hillerström and A. Kumar, “On generation and analysis of synthetic finger-vein images for biometrics identification,” *Technical Report No. COMP-K-17*, June 2014, http://www.comp.polyu.edu.hk/~csajaykr/COMP-K-17.pdf

Finger Knuckle Identification

- Motivation
  - Limitations of Traditional Biometrics
  - Multimodal Biometrics, Identification At-A-Distance
  - Anatomy of Hands → Uniqueness of Knuckle, Correlation with DNA



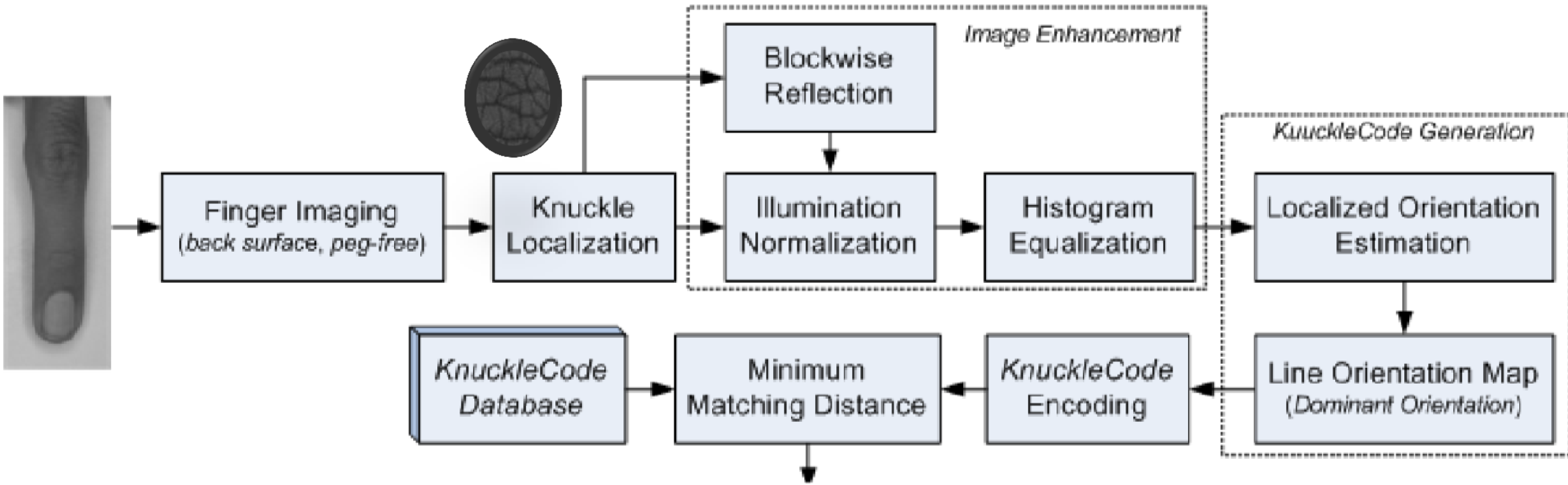
  - Forensic Identification → Only Piece of Evidence from Suspects



Online Finger Knuckle Identification

- KnuckleCodes (BTAS 2009)

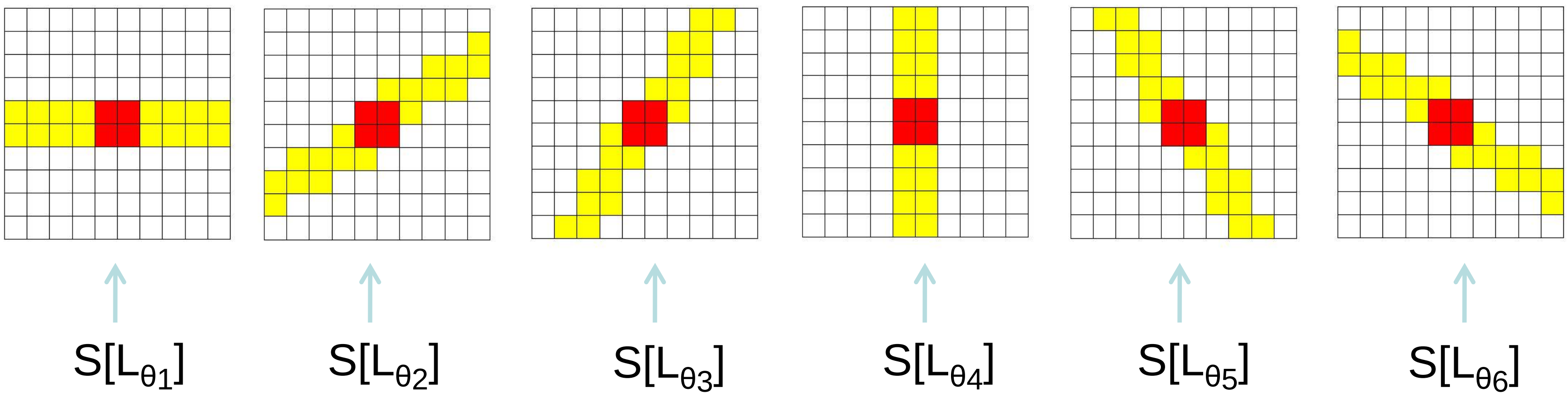
Automated Segmentation → Efficient ROI Matching using KnuckleCodes



A. Kumar and Y. Zhou, "Human identification using knucklecodes," *Proc. 3rd Intl. Conf. Biometrics, Theory and Applications*, BTAS'09, pp. 147-152, Washington DC, USA, Sep. 2009

Feature Extraction

➢ Localized Radon Transform



Select the direction which results in minimum (maximum) magnitude

Match Score Generation

- Matching KnuckleCodes
  - Partially Matching Knuckles $\rightarrow$ Translation and Rotation of Fingers
  - Matching Score for two Z-bit KnuckleCodes

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

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

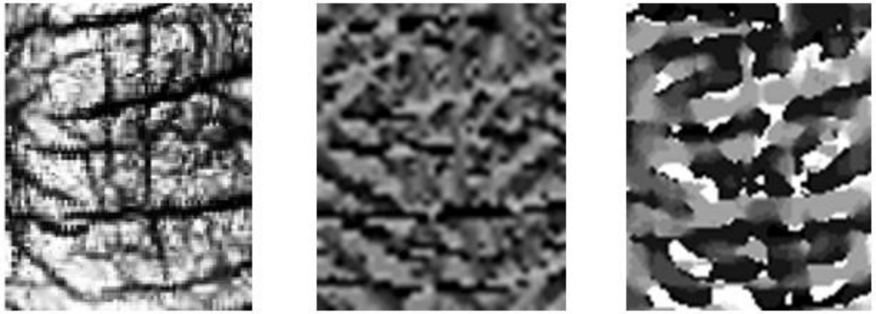
$$\hat{\mathbf{R}}(\mathrm{x},\mathrm{y}) = \begin{cases} \mathbf{R}(x-w, y-h) & x \in [w+1, w+\mathrm{m}],\ \ y \in [h+1,\ h+\mathrm{n}] \\ -1 & \text{otherwise} \end{cases}$$

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

  - Size of KnuckleCodes $\rightarrow$ 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

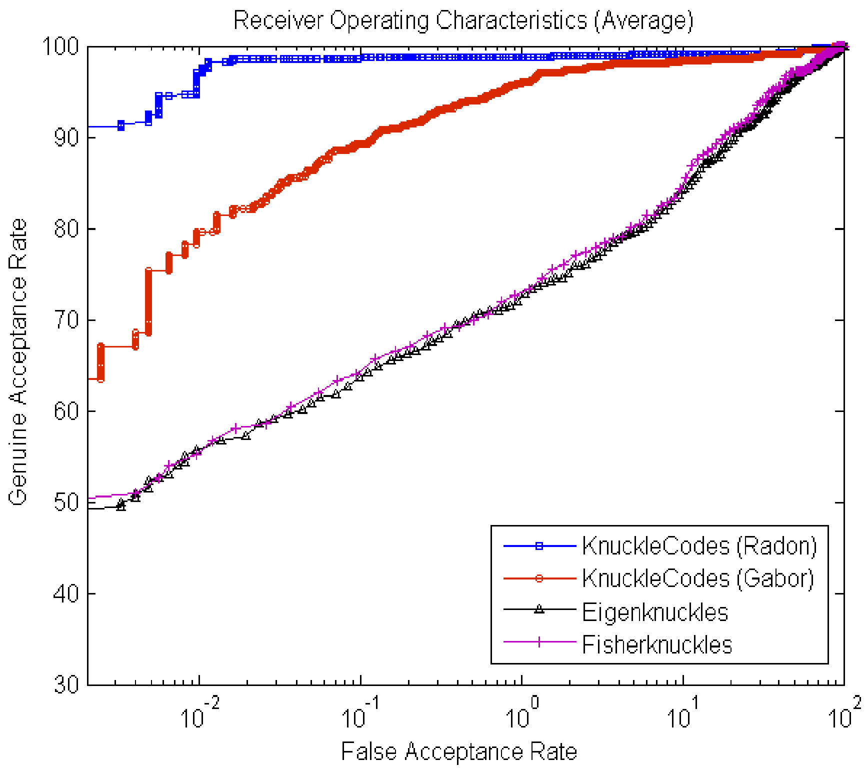


(a) (b) (c)

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



Experimental Results

- Results
  - Performance Analysis

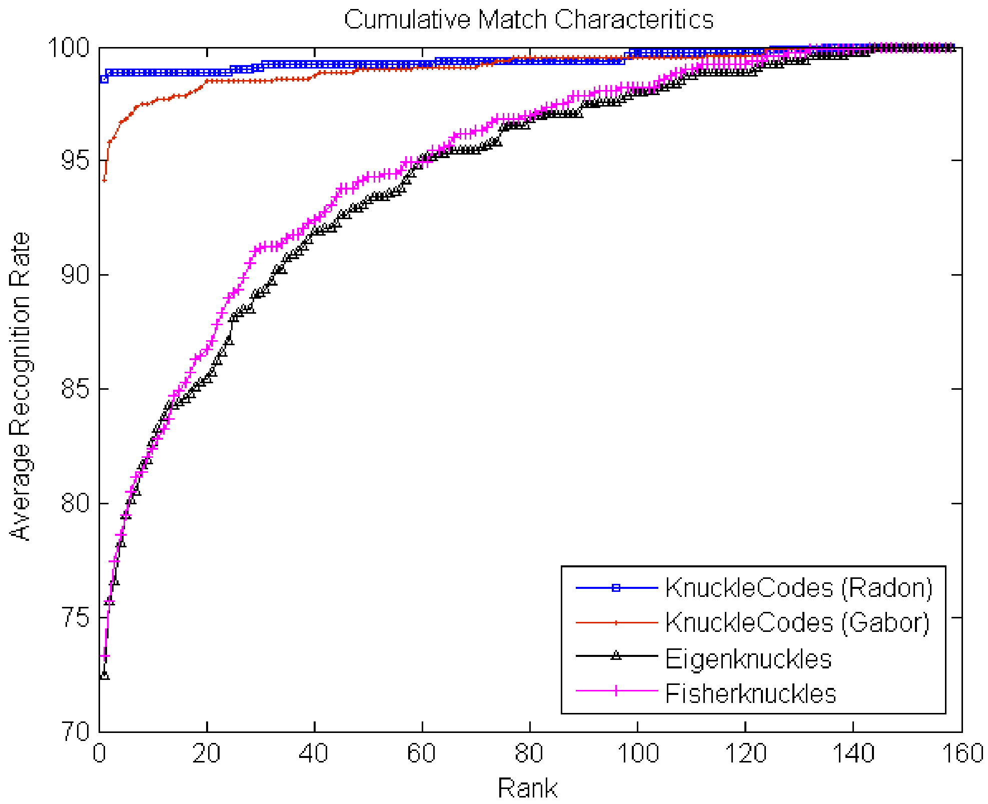
	Equal Error Rate					
X_p	1		2	3		4
l	13	15	14	13	15	14
Mean (%)	1.15	1.15	**1.08**	2.78	2.53	6.96
Std deviation (%)	1.57	1.57	1.08	0.96	1.48	0.9

		Equal Error Rate					
D (Intervals in 0-π)		6	8	10	12	14	16
KnuckleCodes (Radon)	Mean (%)	2.03	**1.08**	1.29	1.14	1.27	1.29
	Std deviation (%)	1.37	1.08	1.59	1.37	1.60	1.24
KnuckleCodes (Gabor)	Mean (%)	4.18	11.14	5.82	**2.66**	3.29	7.59
	Std deviation (%)	2.31	1.88	1.04	1.81	2.26	2.24

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

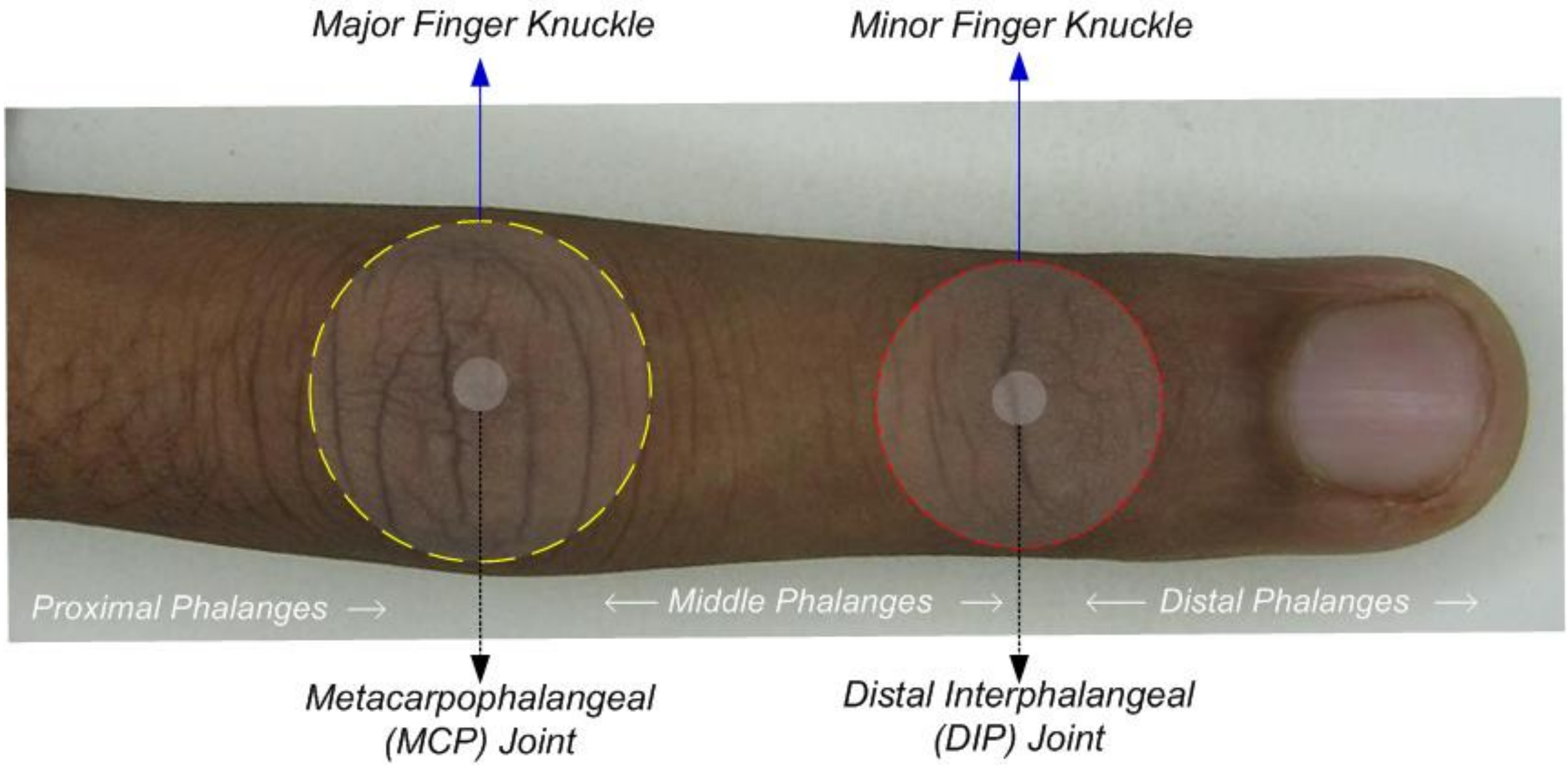
Experimental Results

- Results
  - Cumulative Match Characteristics



Minor Finger Knuckle

- Forward Motion of Fingers
  - First Minor Finger Knuckle



  - Second Minor Finger Knuckle?

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.

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  - Yingbo Zhou
  - Zhihuan Xu
  - Bichai Wang
  - Cihui Xie
  - Ch. Ravikanth

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Thank You !