Vein Recognition
Biometric Systems (DTU 02238)

Christoph Busch

Session 9

Overview Vein Recognition

Structure of this session

- Anatomical foundations
- Vein sensor technology: near infrared imaging
- Preprocessing and registration
- Feature extraction techniques
- Comparison design
- Additional information
- Applications

Why Vein Recognition?

Fingerprints can be captured with a camera

- this is good, if the capture subject wants this !
  (e.g. Smartphone authentication)
  https://www.dasec.h-da.de/research/biometrics/mbassy/

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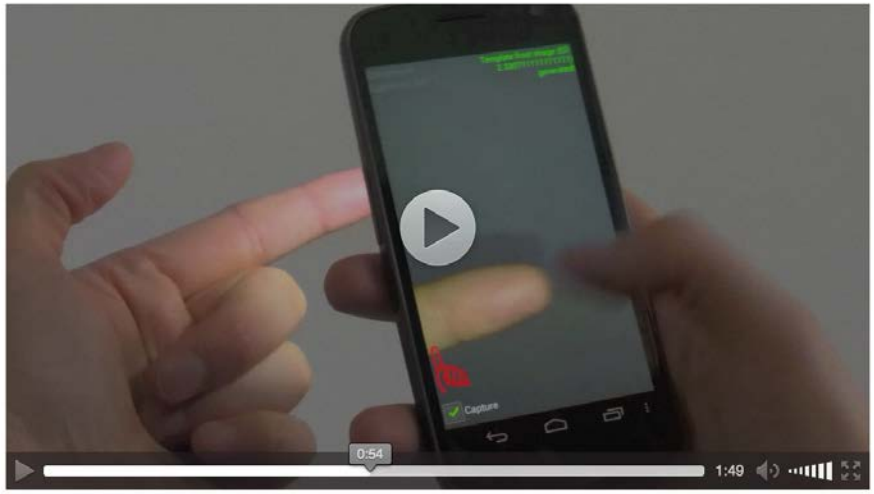
MBASSy (Modular Biometric Authentication Service System)

Since the introduction of the iPhone, the number of smartphone users is steadily increasing. Because a variety of personal or
on smartphones, an increased need for information protection arises compared to traditional mobile phones. Current authenti
devices use knowledge-based methods, where the PIN is the dominant approach. Since passwords and PINs are often forgo
perceived as disturbing, the research and development of user-friendly authentication solutions is an important task.



Why Vein Recognition?

Fingerprints can be captured with a camera

- this is bad, if the capture subject doesn‘t wants this! (e.g. impersonation)
  http://www.bbc.com/news/technology-30623611

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29 December 2014 Last updated at 12:43 GMT

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Politician's fingerprint 'cloned from photos' by hacker

By Zoe Kleinman
Technology reporter, BBC News

German defence minister Ursula von der Leyen's fingerprint was cloned just from photos, the hacker claims

Vein Characteristic

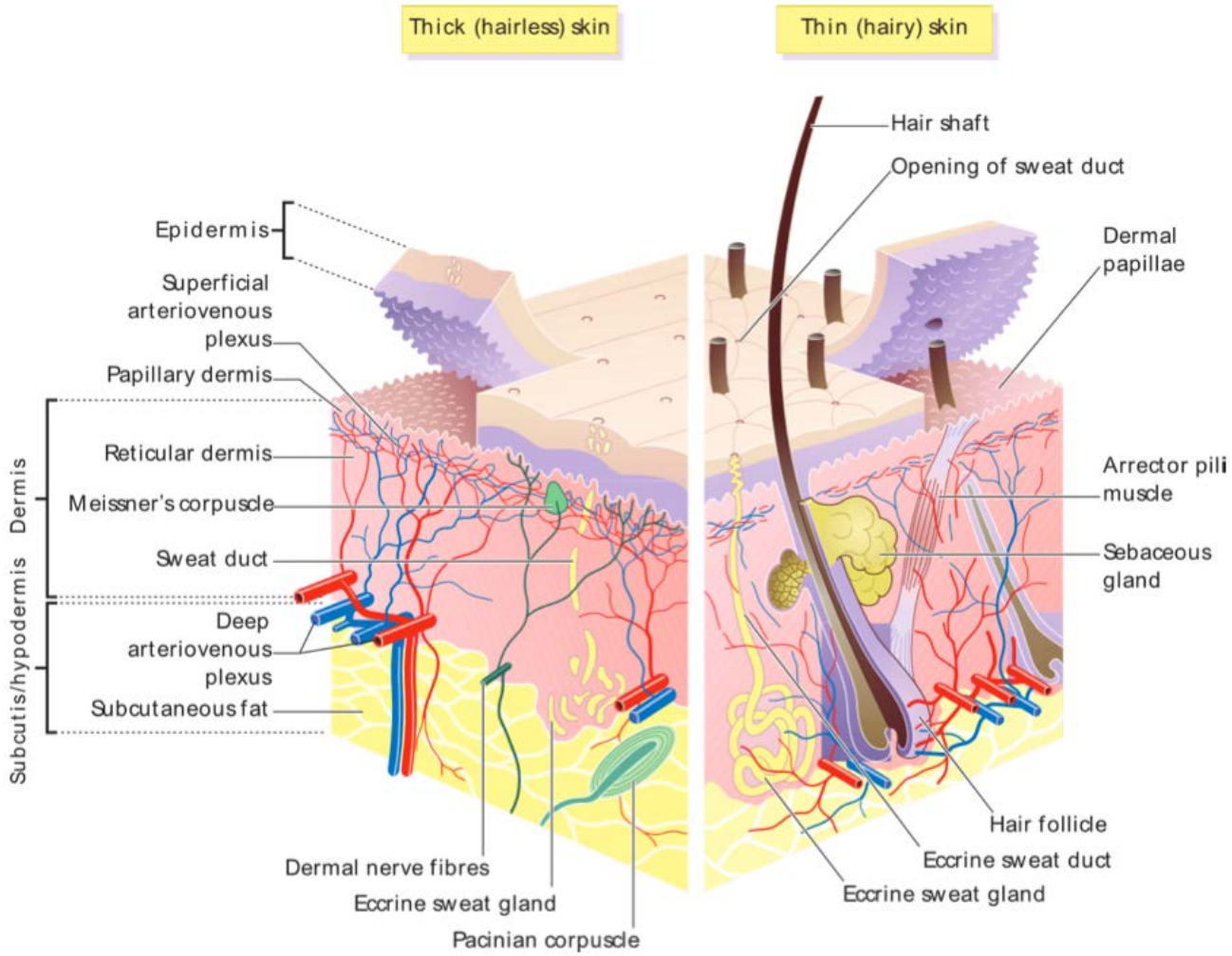
Description of vascular biometrics

- Location and intersection points of the veins inside the body (available at every healthy human)
- Palm, back of hand or fingers are easily accessible
- Retina and sclera also contain vascular meshes
- Highly discriminative:
  - patterns differ even for identical twins
- Stable during life-time
  - persistence claim (from industry):
    „*the pattern of blood veins in the palm is unique to every individual, and apart from size, this pattern will not vary over the course of a person's lifetime*“ (Fujitsu)

Veins as a Biometric Characteristic

Location of the Veins

Skin cross-section:



Why Vein Recognition?

Expectations

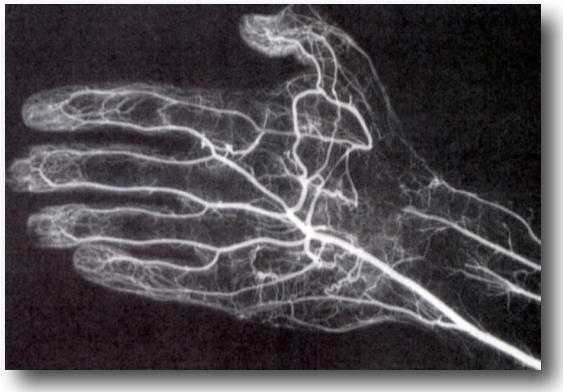
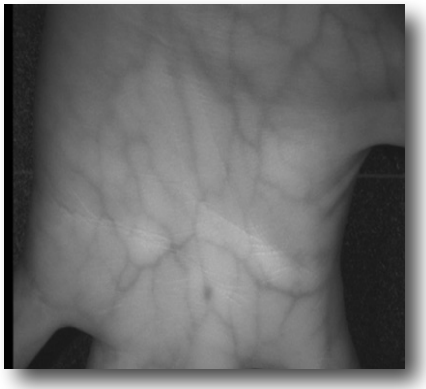
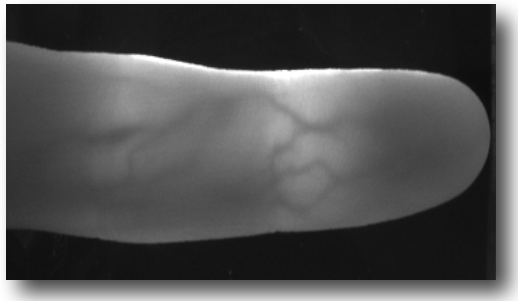
- Good biometric performance.

Vein recognition has reached product state

- Simple capture devices on the market
- Sony, Fujitsu, Hitachi, Techsphere

Observed body parts:

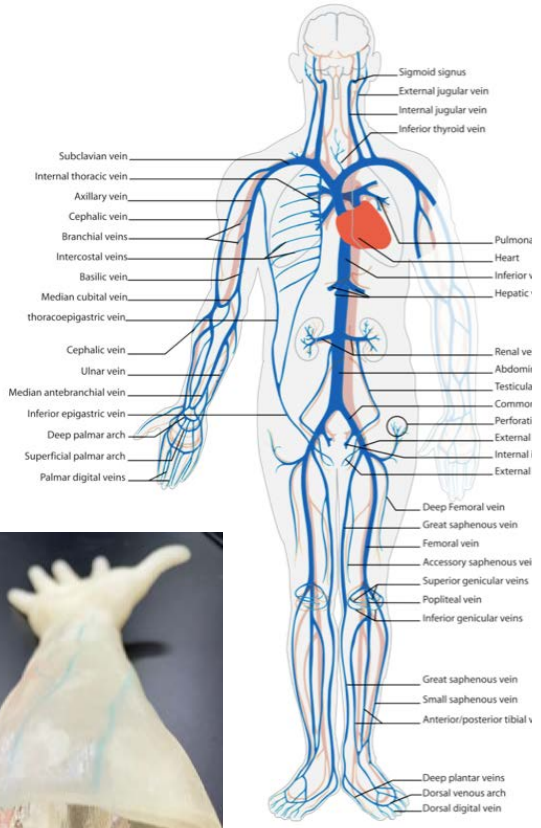
- Identifying the subcutaneous (beneath the skin) vein pattern
  The characteristic is hidden inside the body

Facts

Hard to circumvent

- Not left unintentionally - no latent prints
- Difficult to acquire in daily life
  - not public, no unnoticed capture
- Hard (if not impossible) to replicate
- Presentation attack detection capabilities
  - liveness measure: blood circulation



High acceptance level:

- „*Clean*”: Contact-less capturing process by infra-red light
- Not related to criminal prosecution

Vein Capture Devices

Vein Recognition

Capture devices

- Finger: Hitachi, Sony, NEC, FIT Design, XGZX (China)
  Palm: Fujitsu, Techsphere (Korea)
- Hybrid systems: NEC (finger) and Fujitsu (hand)
- Problem: black boxes due to intellectual property protection
  - or due to limited performance ?

Hitachi finger vein scanner

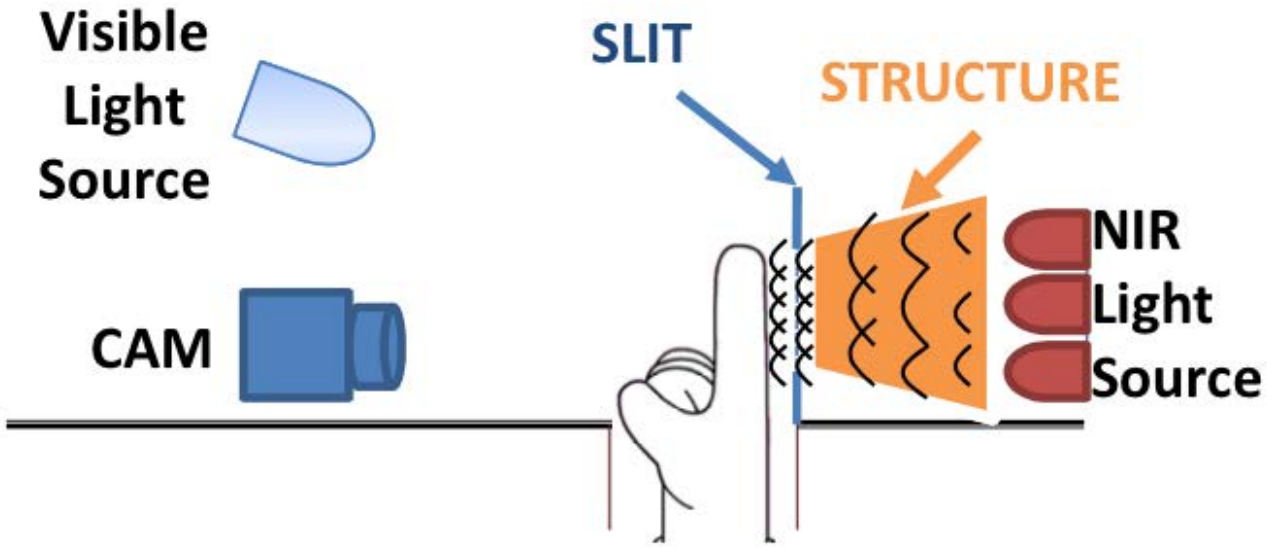
Sony/Mofiria finger vein scanner

Fujitsu palm vein scanner

NEC fingerprint-
fingervein scanner

Vein Recognition

- Problem solved: white box developed at NBL
  - actually it is our blue box



Layout of the fingerprint and finger vein capture device

Camera

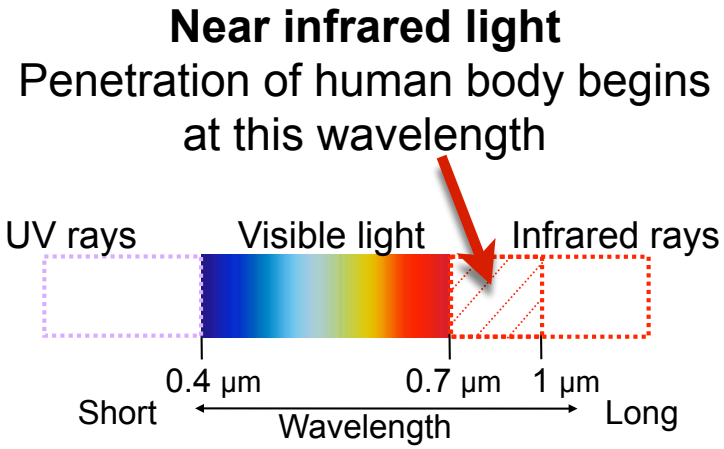
LED source

[RRSB14] R. Raghavendra et al.: „A low-cost multimodal Biometric Sensor to capture Finger Vein and Fingerprint “, Proceedings IJCB, (2014)

Capture Principle

Vein imaging

- Currently widespread:
  - near-infrared (NIR) optical systems
  - 700 - 1.000 nm
- Principle:
  - illuminate region of interest with NIR light source
  - veins generally serve to return deoxygenated blood to the heart
  - deoxygenated hemoglobin in the red blood cells absorbs NIR rays
  - other tissue does not absorb the rays
  - capture the reflected light (vein pattern) with NIR sensitive device
    - CCDs are commonly used

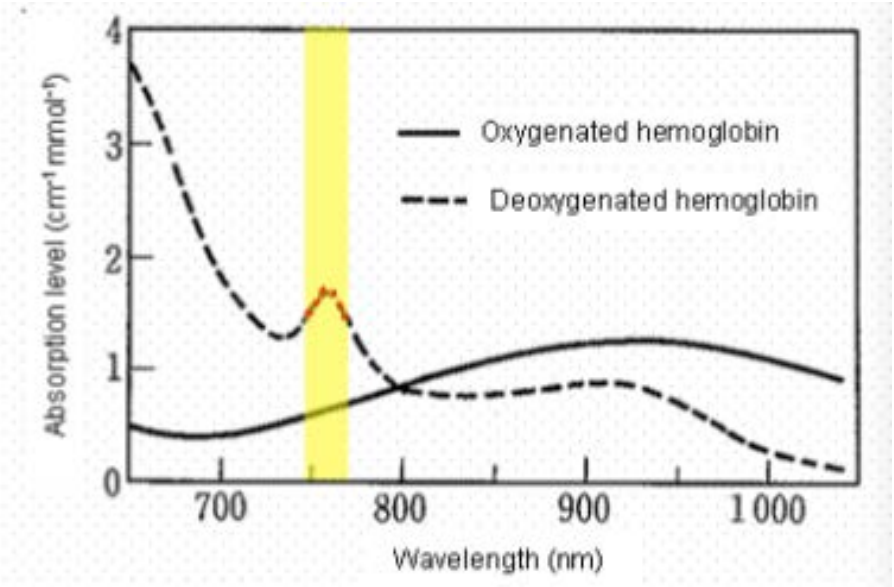


Iron-containing oxygen-transport metalprotein

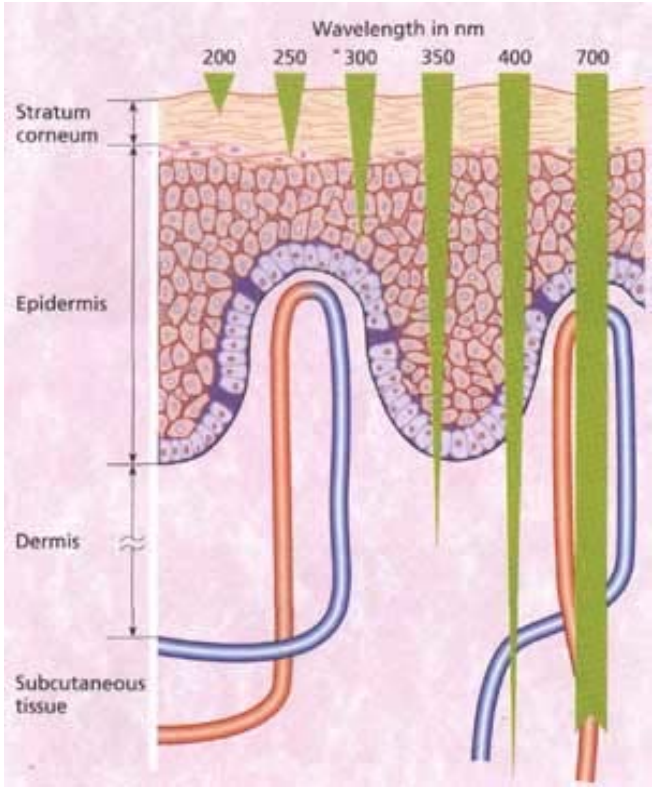
Penetration Depth

Penetration depth of the sensor

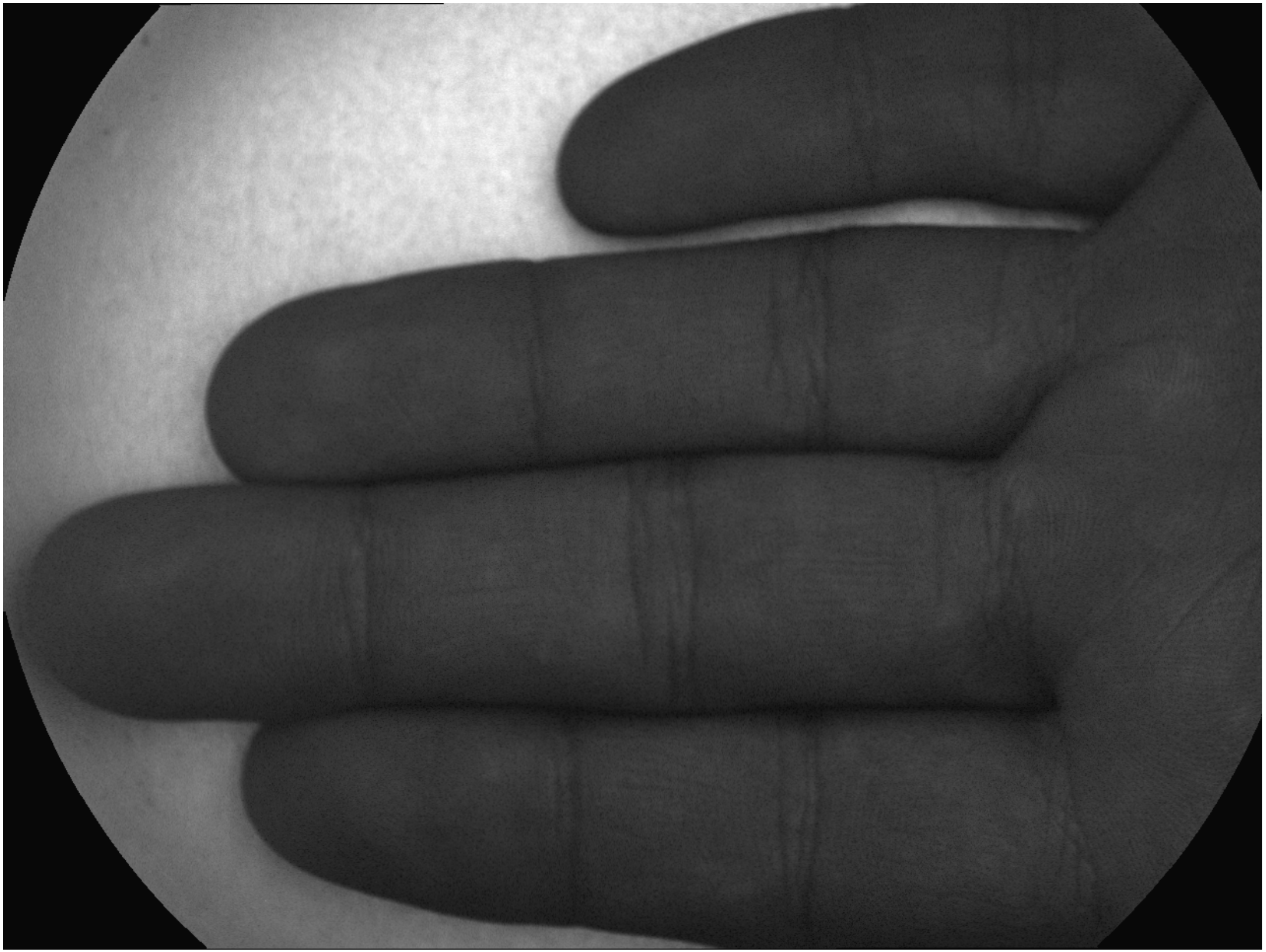
- 760 nm is required to reach the subcutaneous tissue layer
- Deoxygenated blood transported in veins
- Oxygenated blood transported in arteries



Source: Bio-Informatics Visualization Technology (1997)

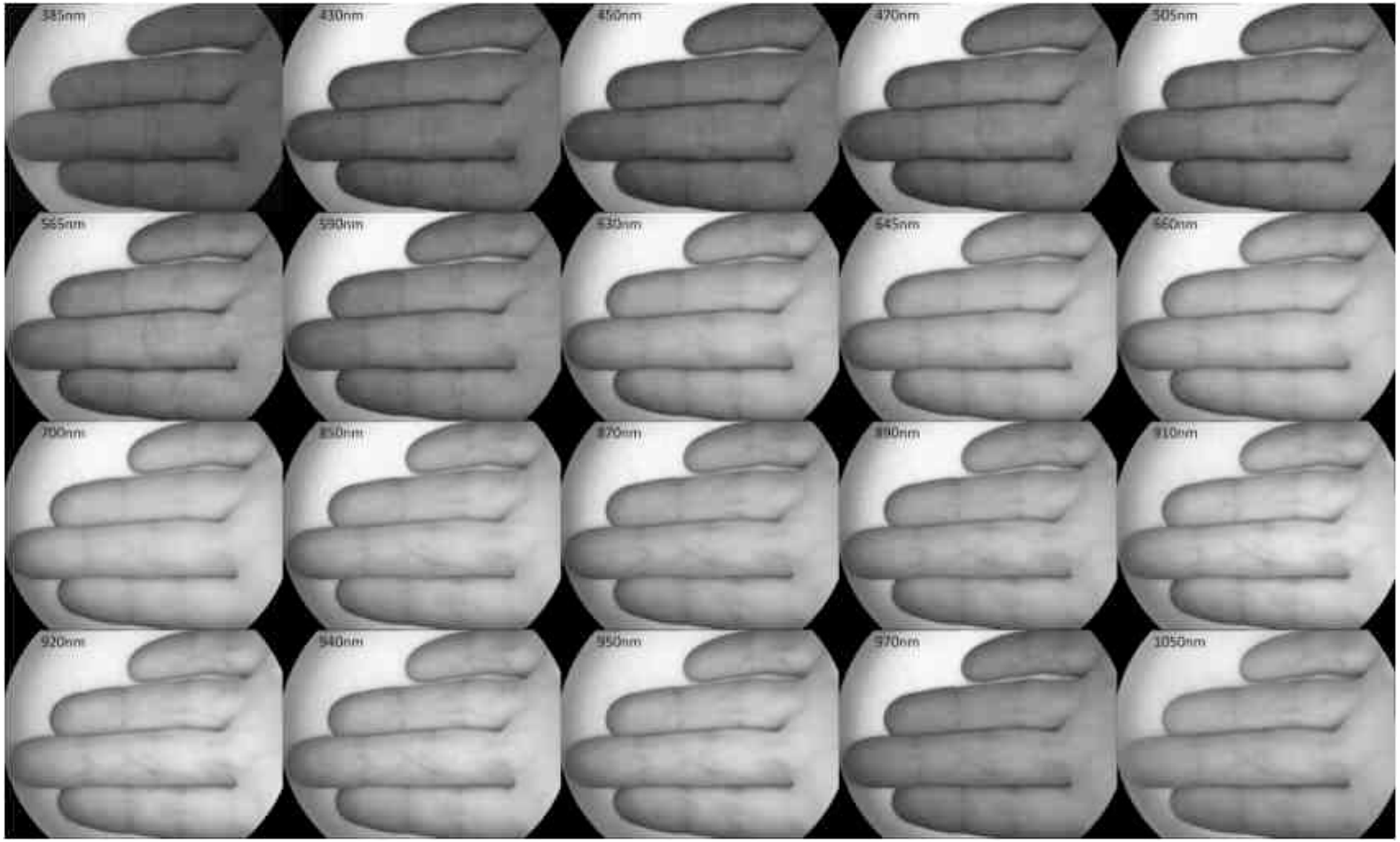


Penetration from 385nm to 1050nm



Source: Martin Olsen (DTU Videometerlab)

Penetration from 385nm to 1050nm

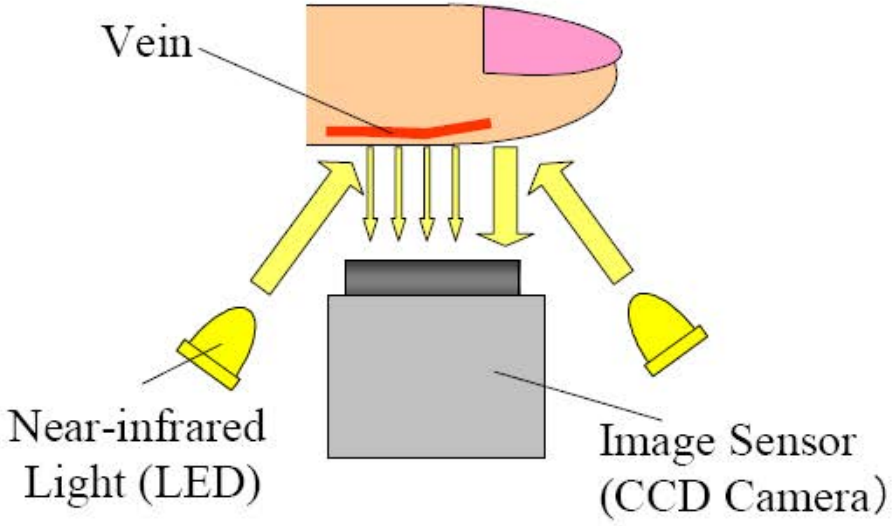


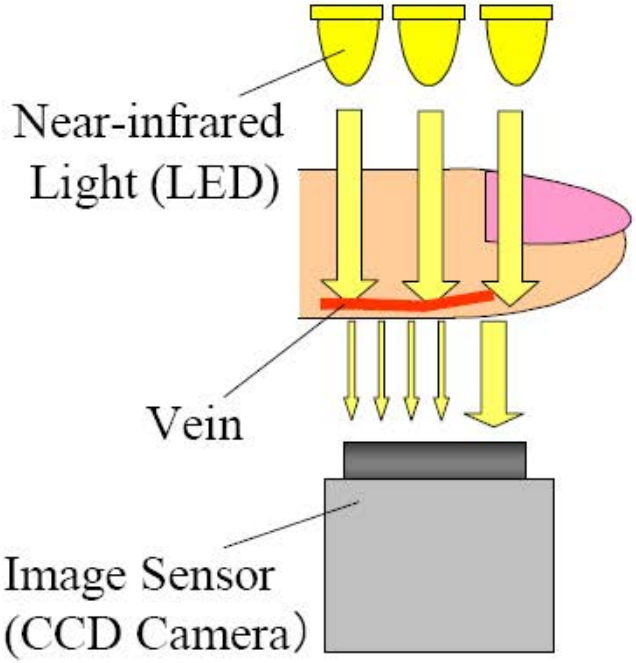
Source: Martin Olsen (DTU Videometerlab)

Capture Principle

Capture devices focusing on the ventral veins (i.e. the inner part of the finger

- Reflection method
- Transmission method





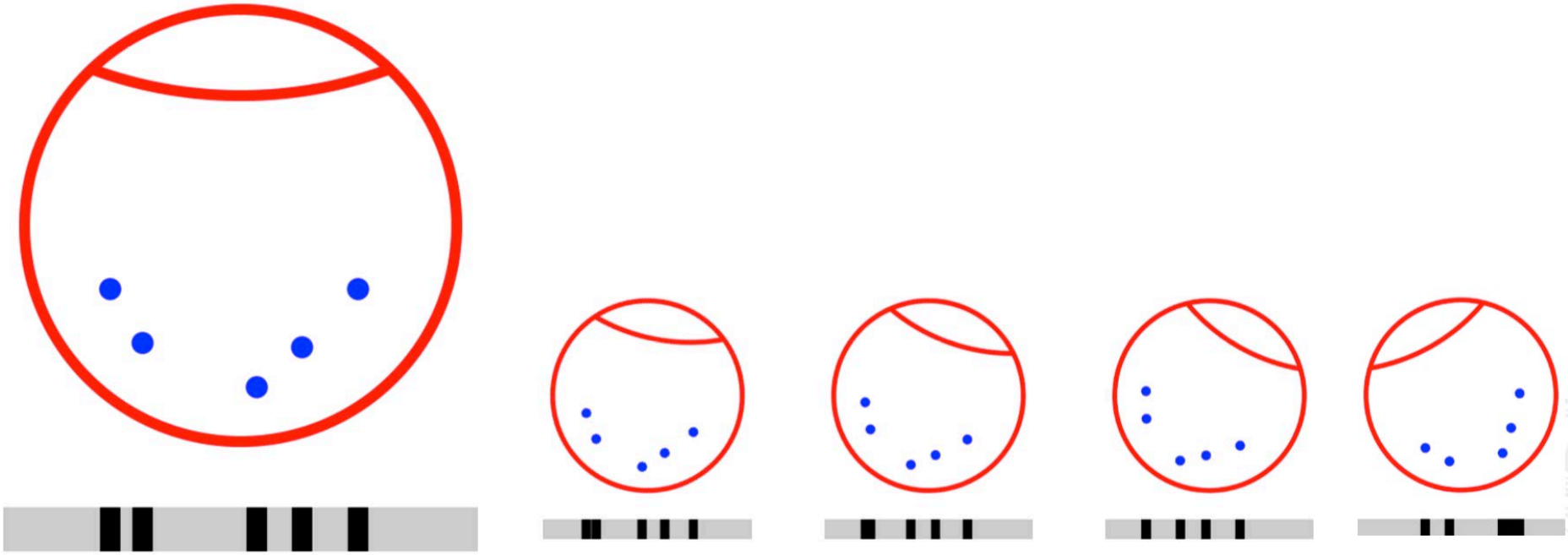
Source: Hashimoto 2006

[Hashi2006] J. Hashimoto: "Finger Vein Authentication Technology and Its Future", in Symposium on VLSI Circuits, (2006)

Capture Principle

Problem with 2D capture devices

- Impact of finger rotation

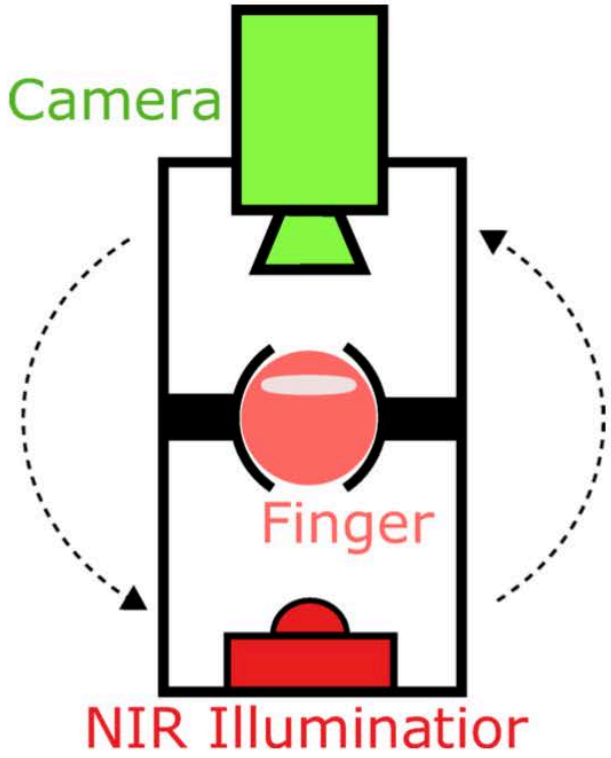


Source: Uni Salzburg 2018

Capture Principle

3D capture cevice - University Salzburg

- Sensor is rotating with 360 degrees around the finger
- Stepsize one degree



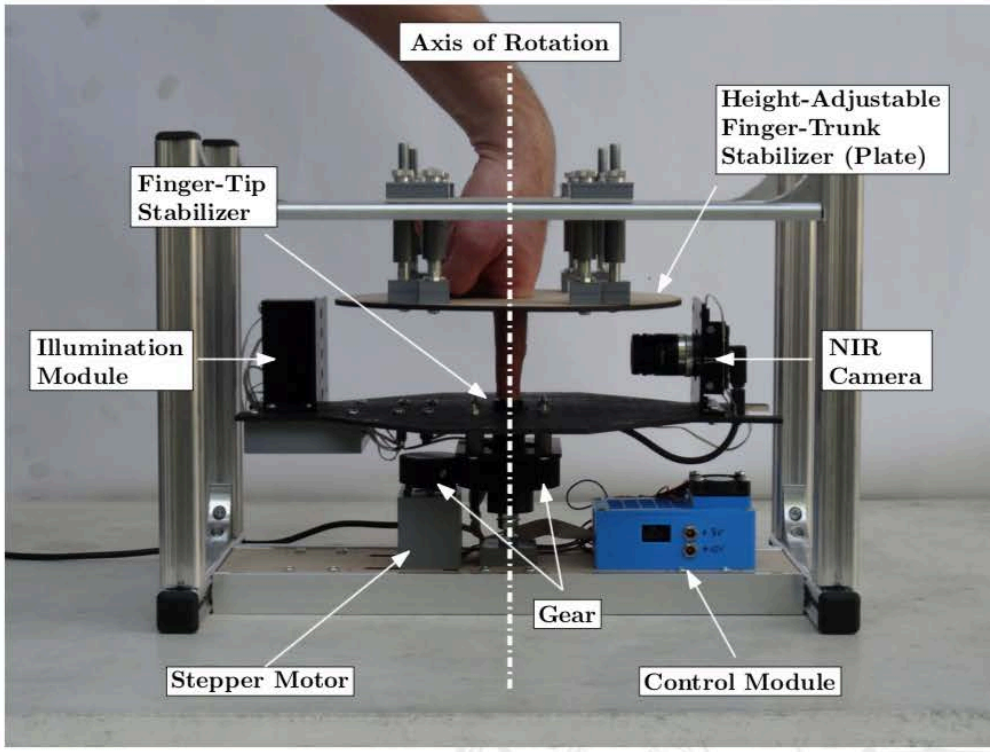


Image Source: Uni Salzburg 2018

[Prom2018] B. Prommegger, C. Kauba, A. Uhl: „Longitudinal Finger Rotation in Finger-Vein Recognition“, in proceedings BIOSIG, (2018)

Capture Principle

3D capture device - University Salzburg

- Sensor is rotating with 360 degrees around the finger
- Stepsize one degree

0 degree

60 degree

120 degree

180 degree

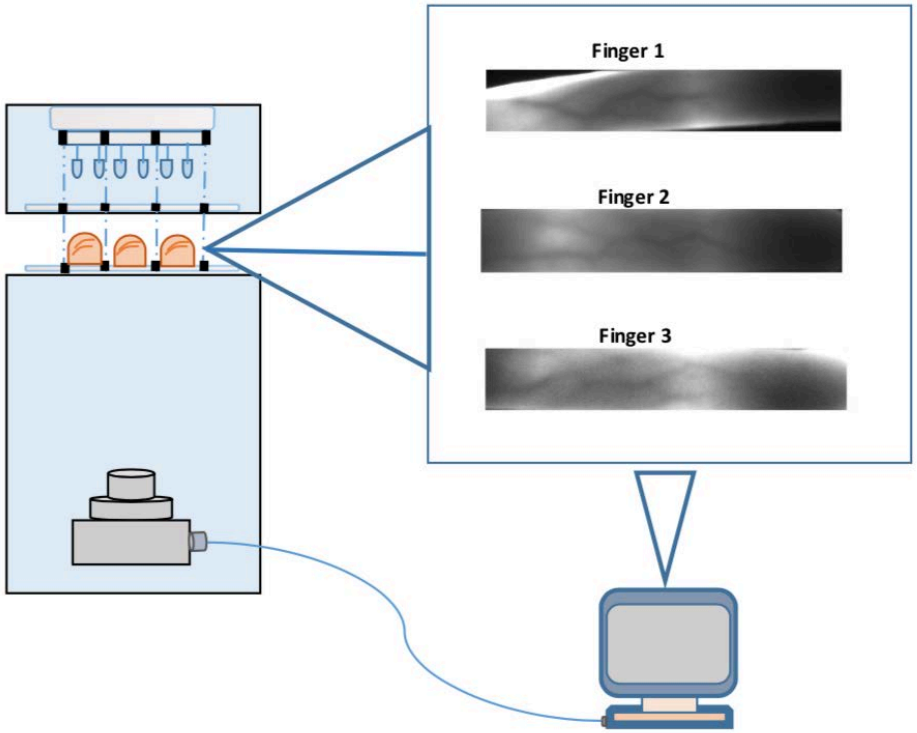
Image Source: Uni Salzburg 2018

[Prom2018] B. Prommegger, C. Kauba, A. Uhl: „Longitudinal Finger Rotation in Finger-Vein Recognition“, in proceedings BIOSIG, (2018)

Capture Principle

Multi-finger capture device - NBL@NTNU

- Three fingers are captured - frontal view is enforced



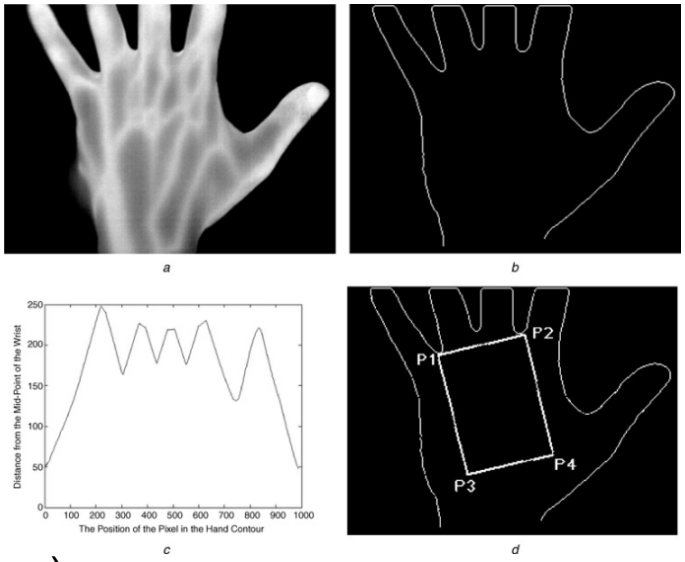
[Ragh2018] R. Raghavendra, S. Vekatesh, K. Raja, C. Busch: „A low-cost mutli-fingervein Verification System“, in proceedings SITIS, (2018)

Preprocessing and Registration

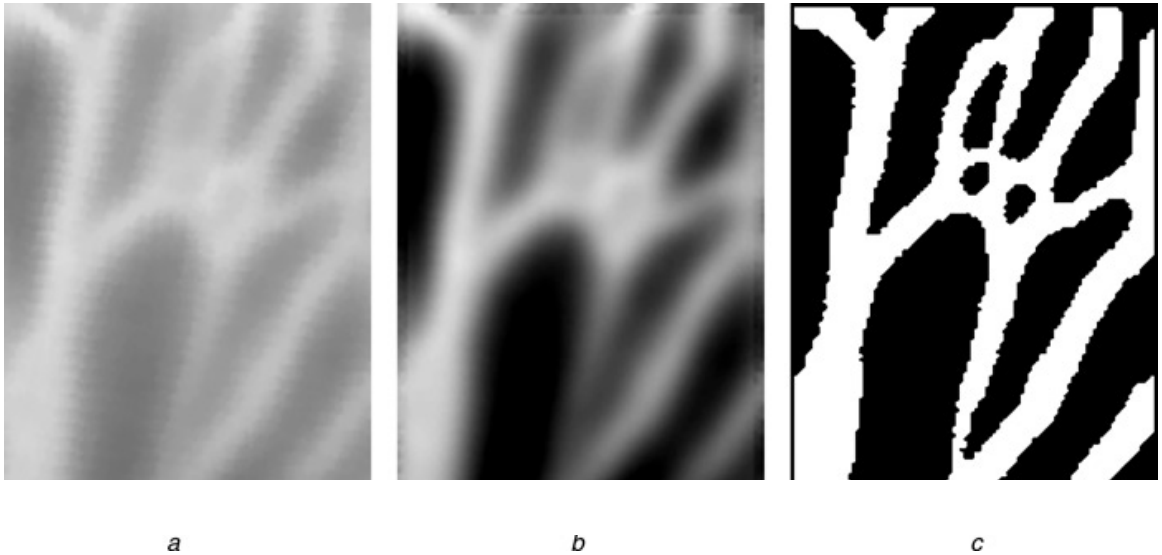
Processing

In general we have to do three steps
from the captured image to the features

- a) Select region of interest and
  register the image to reference coordinate system
- b) Reduce noise and optimize contrast
  - CLAHE, Fourier based filtering, Gabor filter
- c) Apply feature extraction algorithm



a)



b)

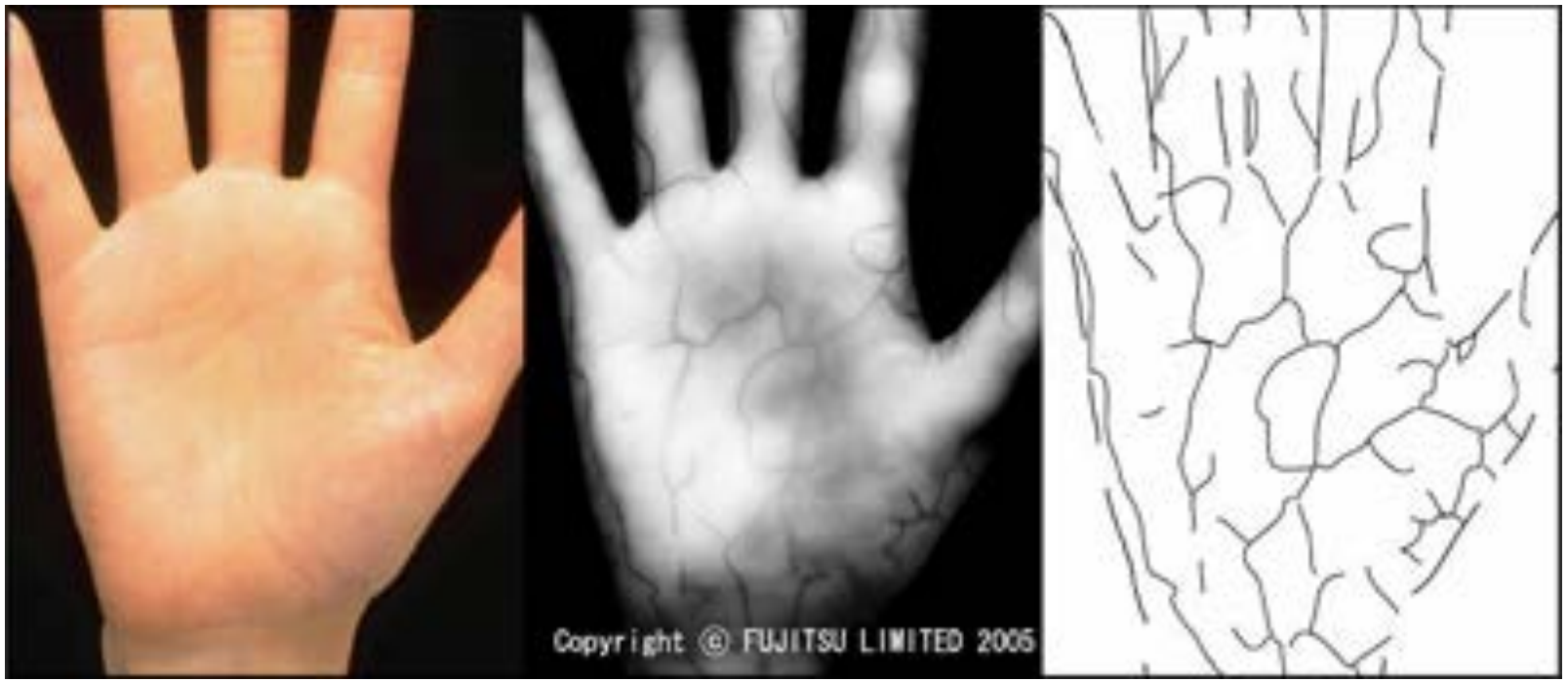
c)

Source: Wang 2007

Processing

Approach

- Extraction of skeleton
- „Vein minutia“ extraction



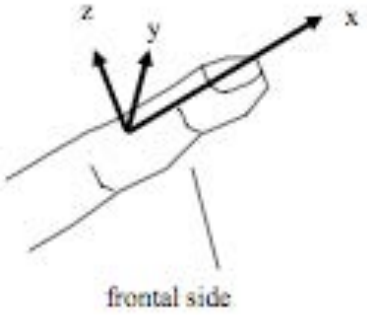
Palm photo NIR scan Extracted features

Source: Fujitsu Limited

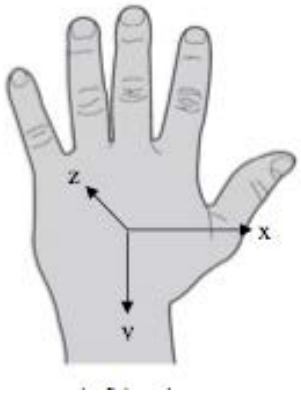
Image Coordinate System

Standardised image orientation (ISO/IEC 19794-9)

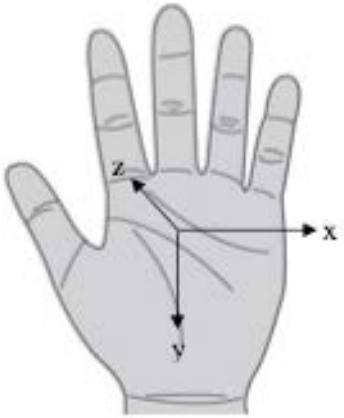
- Finger
  - Combined with Fingerprint



- Back of hand



- Palm
  - Large number of veins

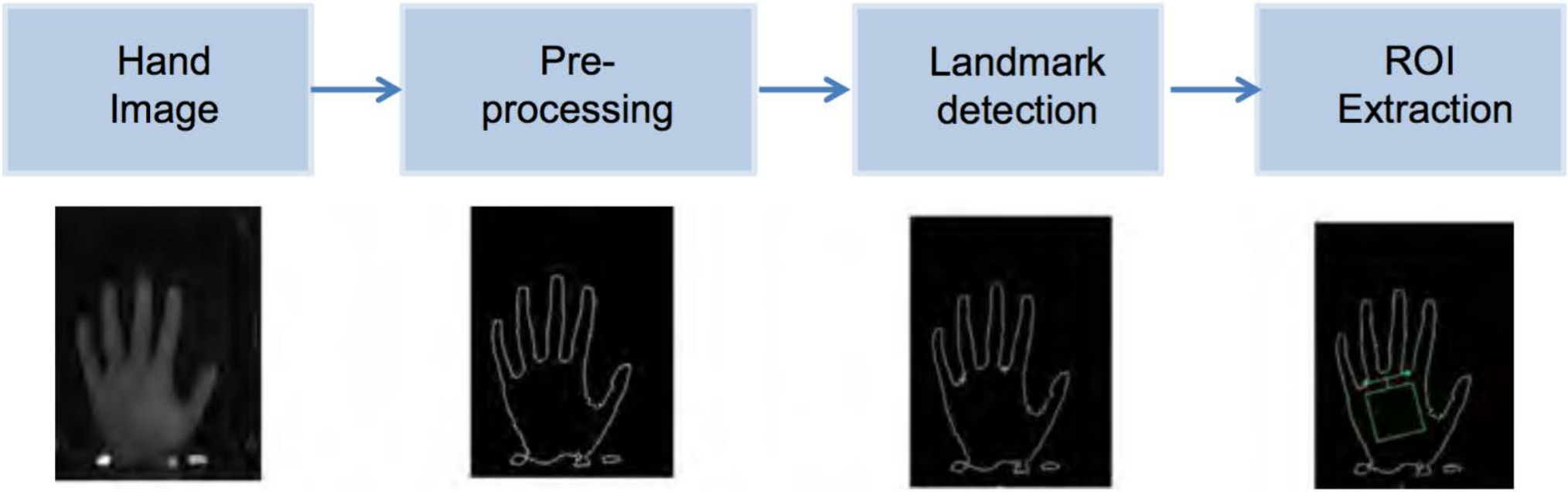


Source: ISO/IEC 19794-9

  - No hair on the palm of hand

ROI Registration - Overview

Processing steps to extract the ROI

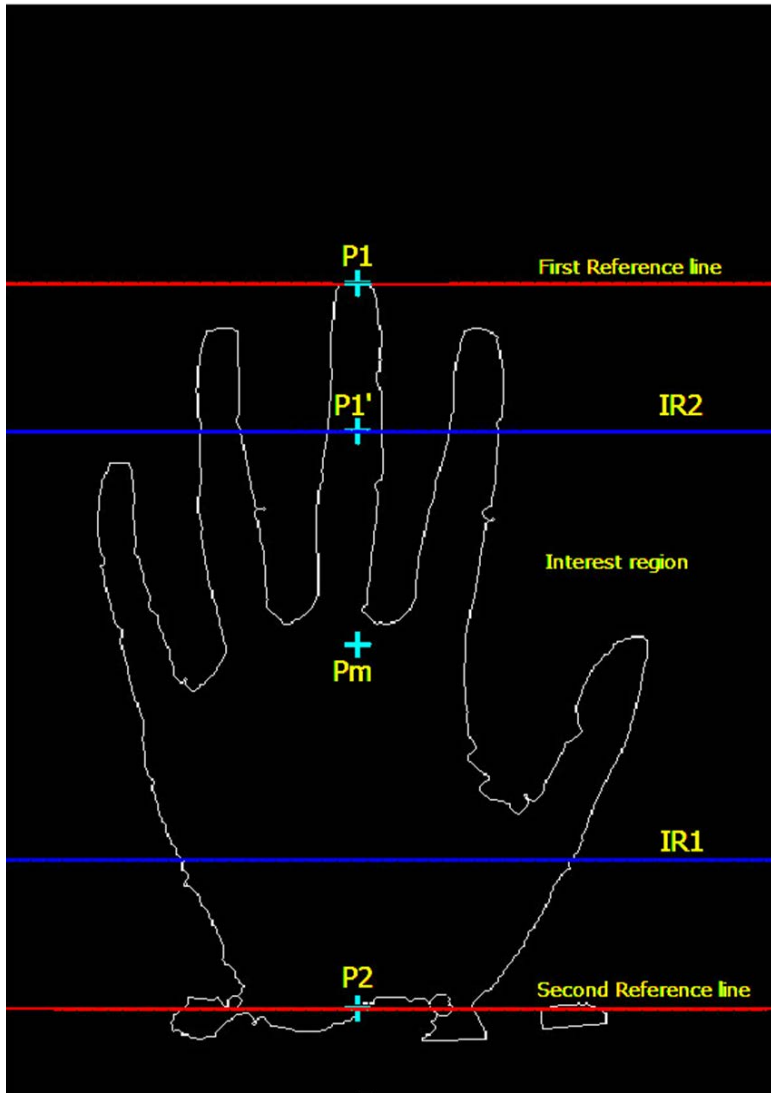


[RB2014] R. Raghavendra, C. Busch: "Novel image fusion scheme based on dependency measure for robust multispectral palmprint recognition",
in Elsevier Pattern Recognition Journal, (2014)

ROI Registration

Procedure for localizing the Region of Interest

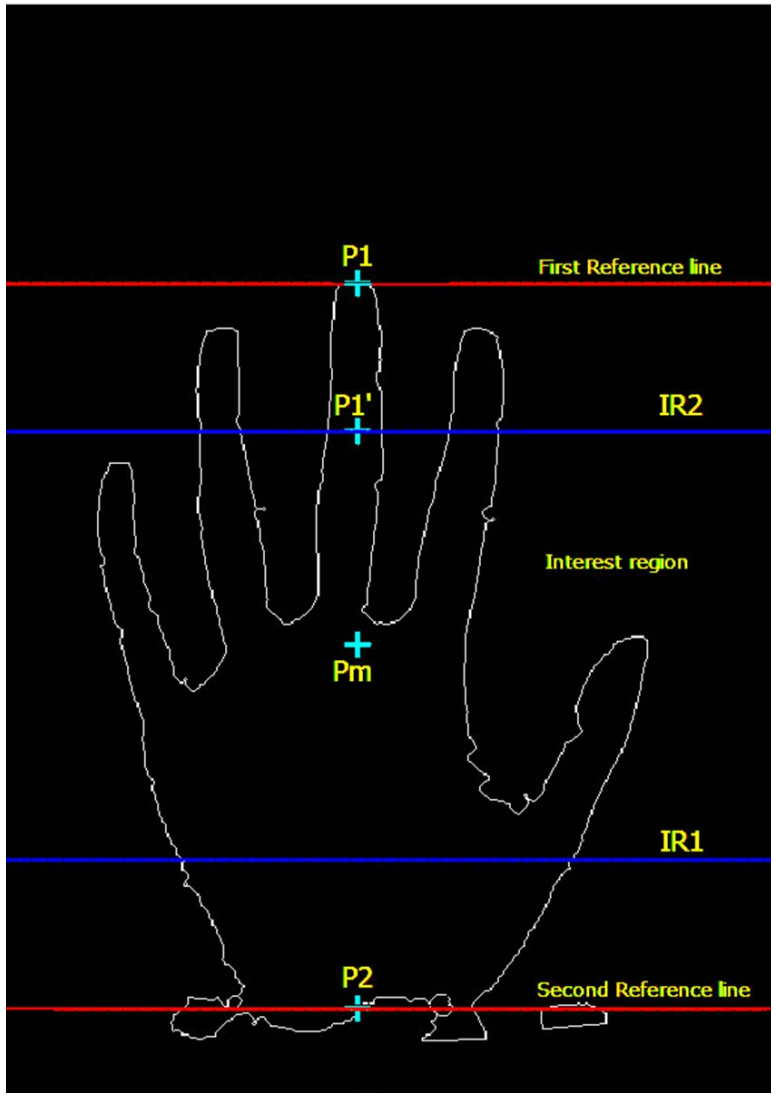
- Binarise the edge image
- Start from first column (e.g. top left) and search for binary discontinuity
- Choose the index that corresponds to the lowest value of the row irrespective of columns that is: *P1*
- Upper point *P1* represents an edge corresponding to one of the fingers
- *P1* will be used as reference
- Seek binary discontinuity corresponding to the largest row index value as our second point *P2*
- Seek *Pm*, which is the midpoint in the column connecting *P1* and P2



ROI Registration (2)

Procedure for localizing the interest region

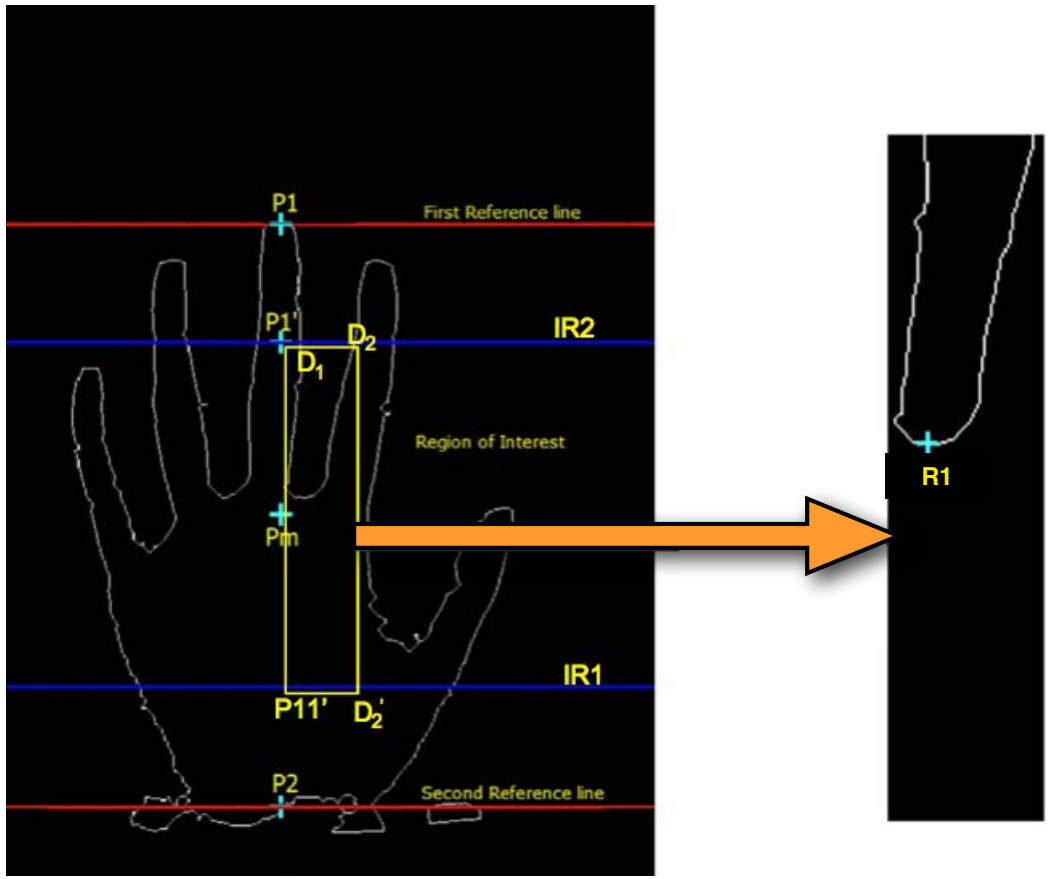
- Seek interest region (IR) between blue lines that lie between *Pm*+150 rows (*IR1*) and *Pm*-150 rows (IR2)
- Project *P1* along column onto row *IR2* and let this projected point be *P1'*



ROI Registration (3)

Procedure for landmark identification

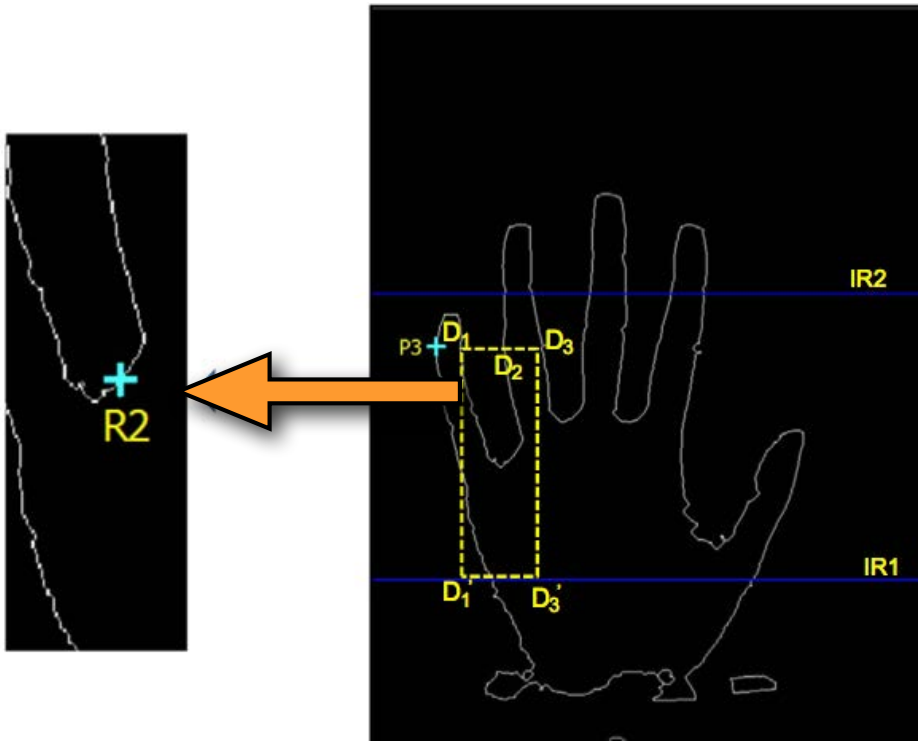
- For middle finger: Seek valley *R1*
- Starting from point *P1'* obtain the discontinuities by scanning the boundary region in both directions and locate D_1 and D_2
- Project *P1'* and D_2 onto the interest region boundary *IR1*
- Segment the region limited by points *P1'*, D_2, D'_2 and *P11'*
- Locate the landmark point *R1* as the midpoint in the segmented valley between middle and index finger



ROI Registration (4)

Procedure for landmark identification

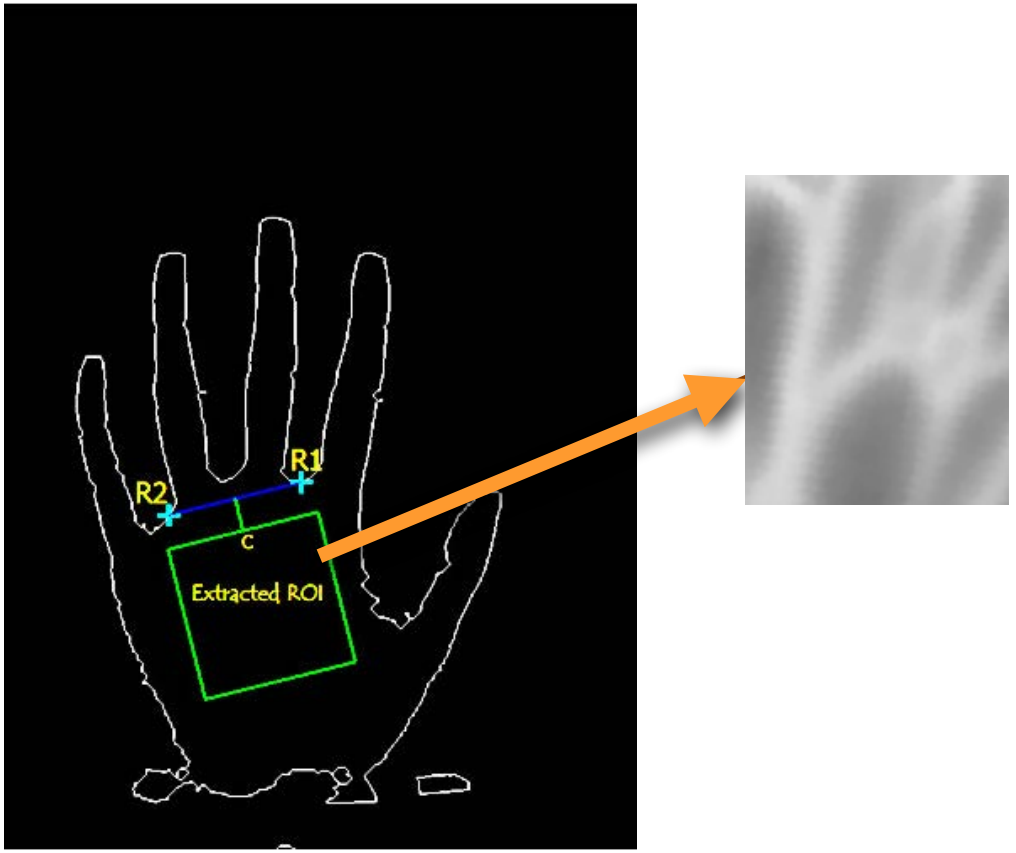
- For middle finger: Seek valley *R2*
- Locate the point P3
- Find the corresponding boundary discontinuity D_1, D_2, D_3 and projected points D'_1 and D'_3.
- The landmark point *R2* is located as the midpoint point in the segmented region defined by the points D_1, D_3, D'_1 and D'_3



ROI Registration (5)

Segmenting the Region of Interest

- Draw reference line between *R1* and *R2*
- Obtain midpoint between *R1* and *R2*
- Traverse perpendicularly towards palm region for 15 pixel and let this point be *C*
- Starting from C draw a rectangle of width 120x120 pixel

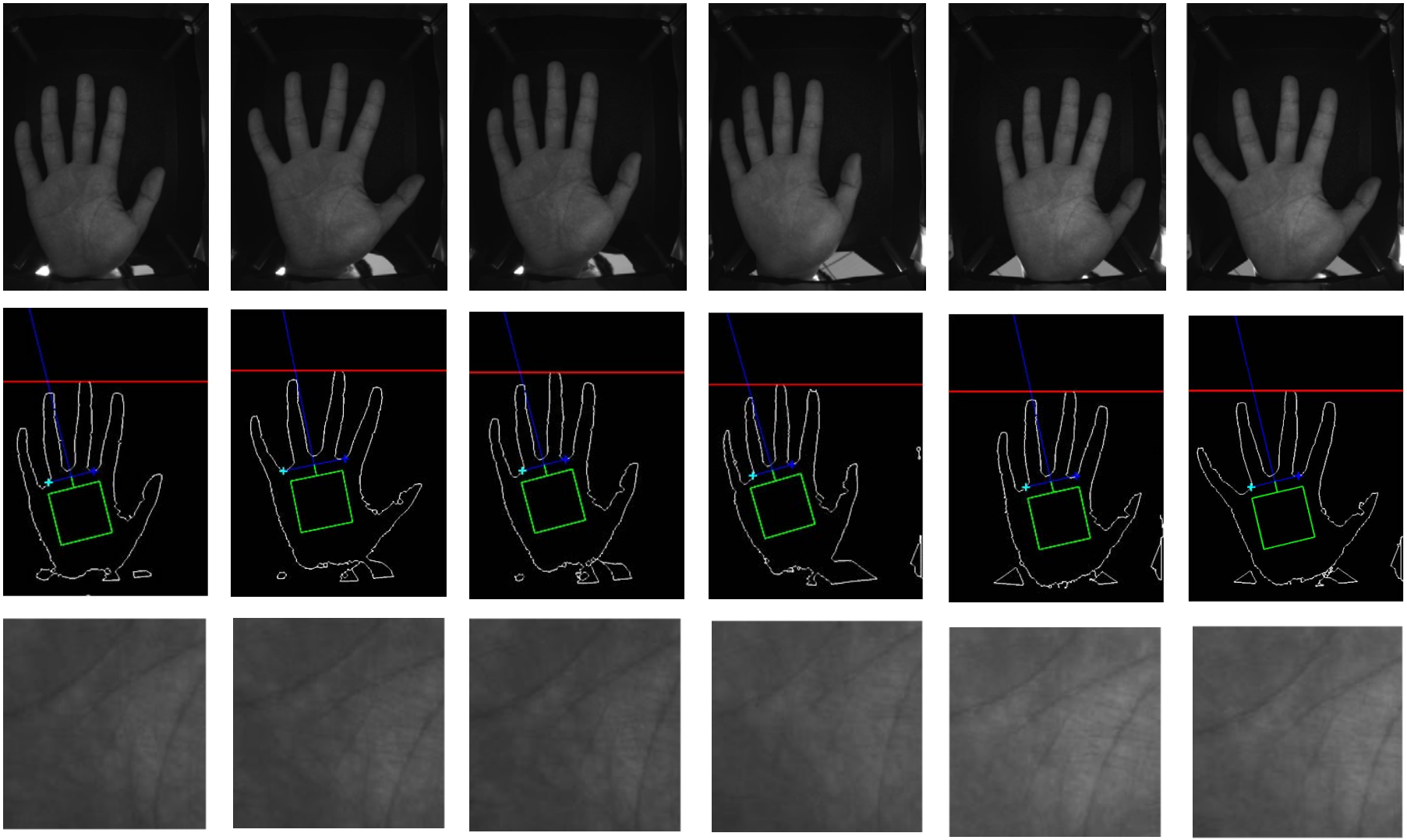


- Note: settings (e.g. 15 pixels) are determined empirically

ROI Registration - Evaluation

Testing the steps to extract the ROI

- Reproducible result of hand-crafted approach



Feature Extraction Techniques

Feature Extraction

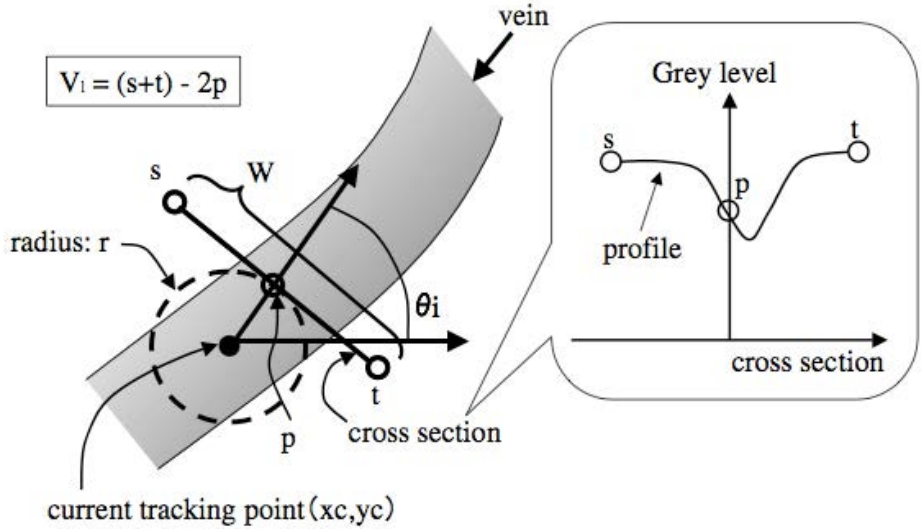
Methods

- Line Tracing
  - N. Miura et al.: *An extraction of finger vein patterns based on repeated line tracing* (2004)
- Curvelets and neuronal networks
  - Z. Zhang et al.: *Multiscale Feature Extraction of Finger-Vein Patterns Based on Curvelets and Local Interconnection Structure Neural Network* (2006)
- Maximum Curvature Points
  - N. Miura et al.: *Extraction of Finger-Vein Patterns Using Maximum Curvature Points in Image Profiles* (2007)
- Wide Line Detector
  - B. Huang et al.: *Finger-Vein Authentication Based on Wide Line Detector and Pattern Normalization* (2010)
- Spectral Minutia representation
  - D. Hartung et al.: *Spectral Minutiae for Vein Pattern Recognition* (2011)

Feature Extraction

Line Tracing

- Choose random starting points from finger root
- Choose neighborhood-based tracking point following high contrast and limited curvature until end of finger is reached
- Repeat those steps *N* times (N > 3000)



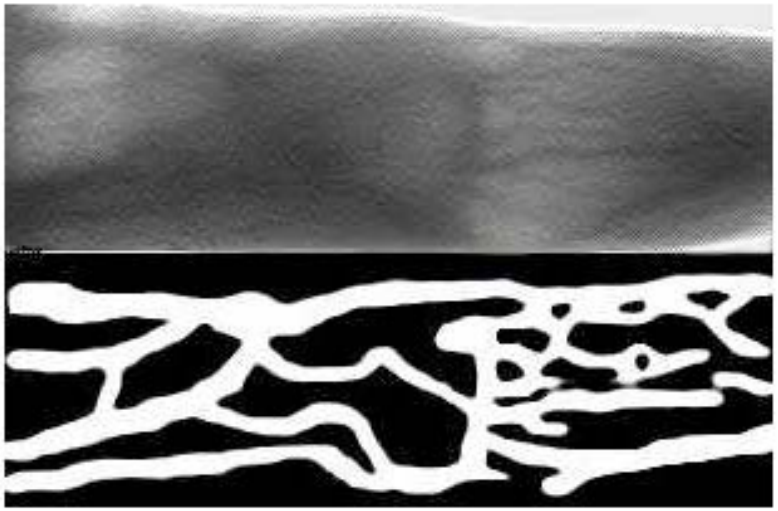
Source: Miura 2004

[Miura2004] N. Miura et al.: “Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification” in Machine Vision and Applications, (2004)

Feature Extraction

Curvelets and neuronal networks

- Extended wavelet transformation of the vein image
  - Represents line singularities of the image
  - Additional direction selection
- Train neuronal network structure
  - Detect straight lines in small regions
  - Rotate receptive field of the neuronal network is seeking for straight lines at different angles



Source: Zhang 2006

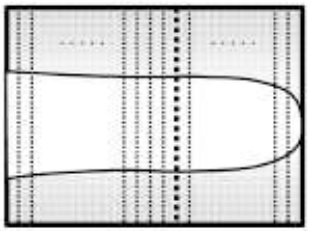
[Zhang2006] Z.B. Zhang et al.: “Multiscale Feature Extraction of Finger-Vein Patterns Based on Curvelets and Local Interconnection Structure Neural Network” in 18th International Conference on Pattern Recognition (ICPR), (2006)

Feature Extraction

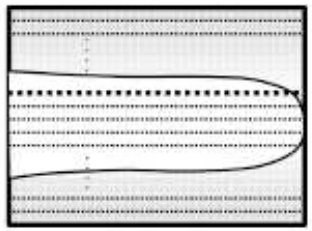
Maximum Curvature Points

- Find center of veins
  through analysis of the vein image in 4 directions
  - Horizontal
  - Vertical
  - +/-45 degree

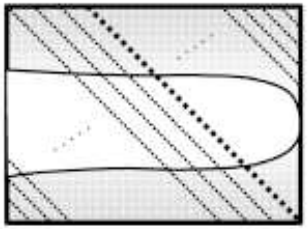
  from root to fingertip



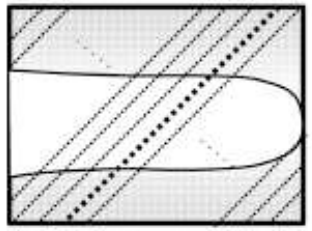
(a) Vertical direction (d1).



(b) Horizontal direction (d2).



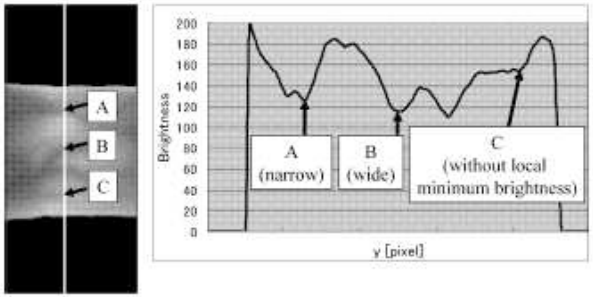
(c) Oblique direction (1) (d3).

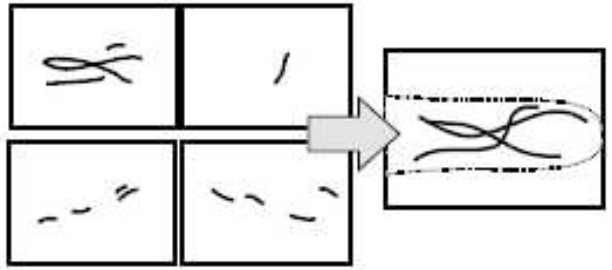


(d) Oblique direction (2) (d4).

Source: Miura 2007

- Contrast changes indicate high possibility of vein center





Source: Miura 2007

Obtain vein pattern by combining four directions

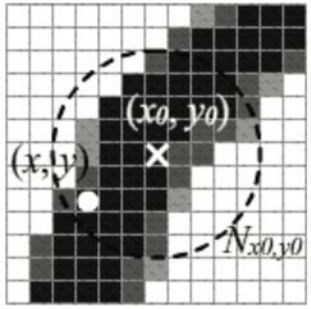
- Connect adjacent points over the whole finger image

[Miura2007] N. Miura et al.: “Extraction of Finger-Vein Patterns Using Maximum Curvature Points in Image Profiles” in IEICE Trans on Information and Systems, (2007)

Feature Extraction

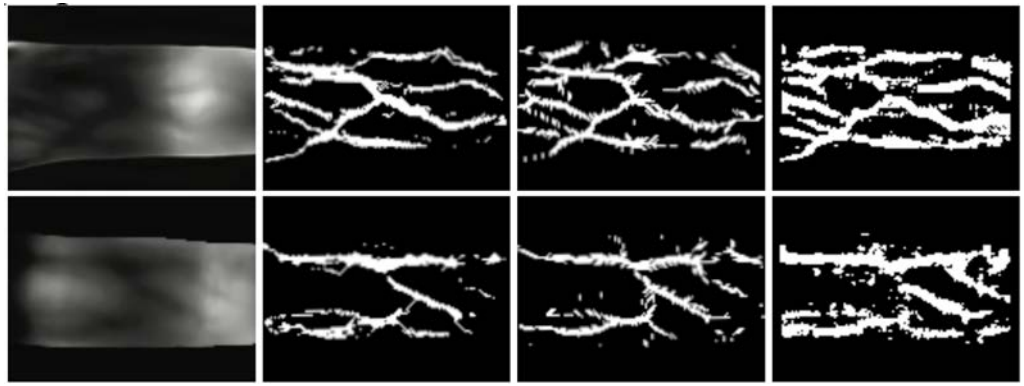
Wide Line Detector

- Veins are represented by lines with different width
  - detector groups pixels whose brightness is similar to the brightness at the center of the mask
  - summation within the circular mask gives the mass
  - the smaller the mass s, the larger the feature response



circular neighborhood

$$s(x, y, x_0, y_0, t) = \begin{cases} 1, & \text{if } |I(x,y) - I(x_0,y_0)| \leq t \\ 0, & \text{if } |I(x,y) - I(x_0,y_0)| > t \end{cases}$$



Original Line tracking MCP Wide Line Detector

Source: Huang 2010

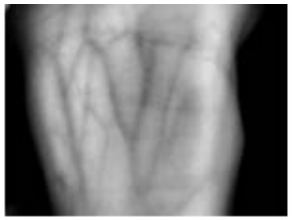
[Huang2010] B. Huang et al.: “Finger-Vein Authentication Based on Wide Line Detector and Pattern Normalization” in International Conference on Pattern Recognition (ICPR), (2010)

[Liu2007] L. Liu et al.: “Detecting Wide Lines Using Isotropic Nonlinear Filtering” in Transactions on Image Processing (TIP), (2007)

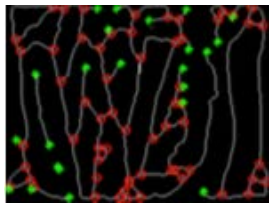
Feature Extraction

Spectral Minutiae

- Find skeleton

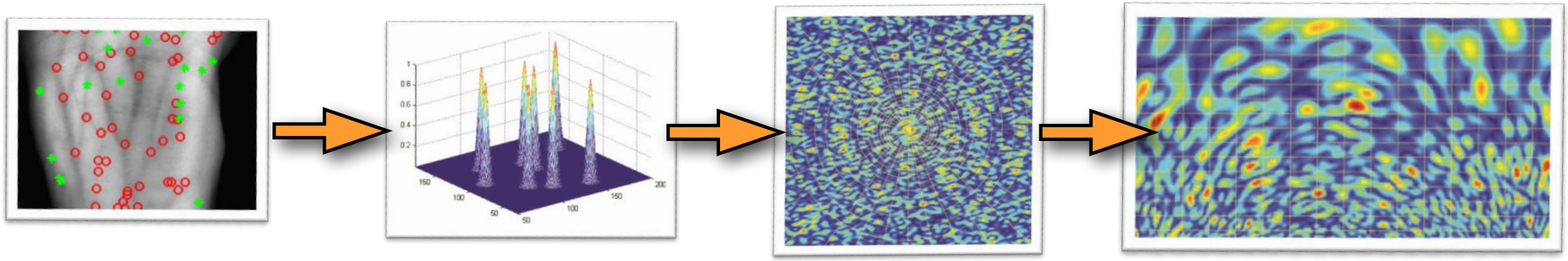


- Detect minutia points



overlay of extracted minutiae points and skeleton.
Green stars: endpoints,
red circles: branch points

- Spectral minutiae representation
  - robust against translations



Fourier spectrum sampled on a polar- logarithmic grid.

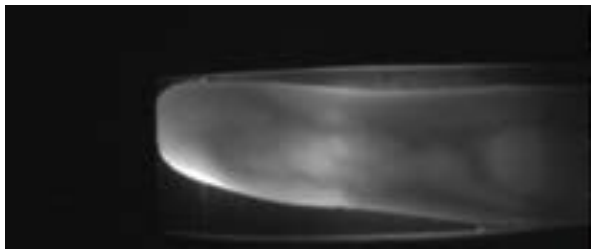
[Hartung2009] D. Hartung et al.: “Spectral minutiae for vein pattern recognition” in International Joint Conference on Biometrics (IJCB), (2011)

Testing and Applications of Vein Recognition

Biometric Performance

Academic testing

- Test results indicate the suitability of the approach
  - NBL Blue Box (2014)



Modality	Algorithms	EER(%)
Finger vein	Repeated line tracking[6]	7.86
	Gabor enhancement [4]	12.45
	Maximum Curvature [7]	2.21
	SMR [2]	3.47
	Proposed Scheme	**1.74**
Fingerprint	MINDTCT with SMR [14]	6.83
Fusion	Weighted Sum rule	**0.78**

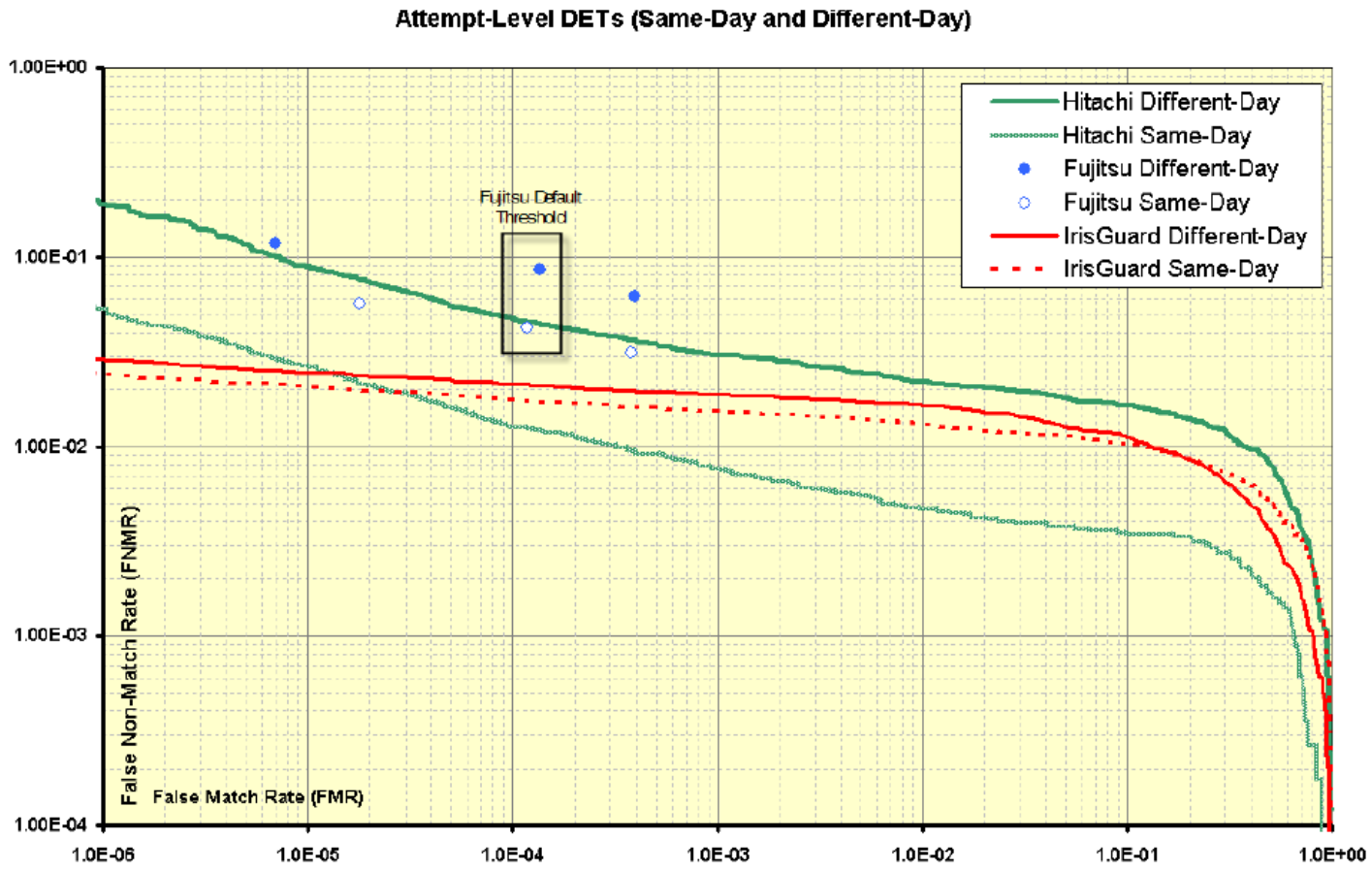
Source: R. Raghavendra

[RRSB2014] R. Raghavendra et al.: „A low-cost multimodal Biometric Sensor to capture Finger Vein and Fingerprint“ in Proceedings IJCB-2014

Biometric Performance

Industry Benchmark iris recognition vs. vein recognition

- IBG 6th report 2006
- Indicates that recognition rates are competitive



Challenges

Registration of the body part

- Reliable alignment (for finger vein)
- Capture device must ensure that the same area of the body part is captured
  - construction requirement

Source: Techspere

Environmental impact

- Change of vein image with temperature or climatic conditions
  - in the cold veins are contracted and harder to capture
  - palm less sensitive to cold temperature due to larger number of thick vein vessels
- Change of vein image after nicotine consumption
- Change due to health conditions

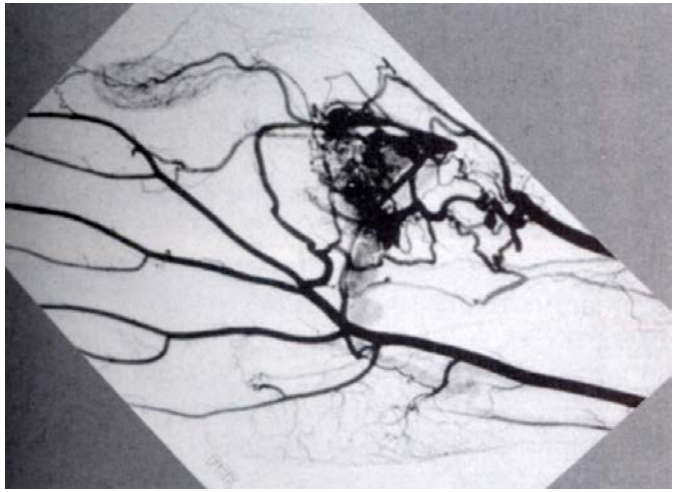
Additional Information

Change of vein image when oxyglobine is in the blood

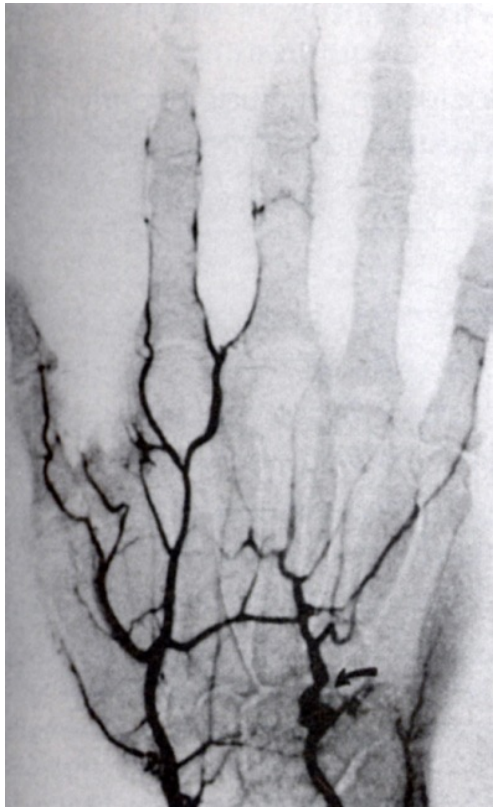
- „Doping-Detector“?

Biometric sample will reveal medical information in case of

- Infection and thrombosis
- Arteriovenous malformation
- Hypothenar hammer syndrome



Arteriovenous malformation



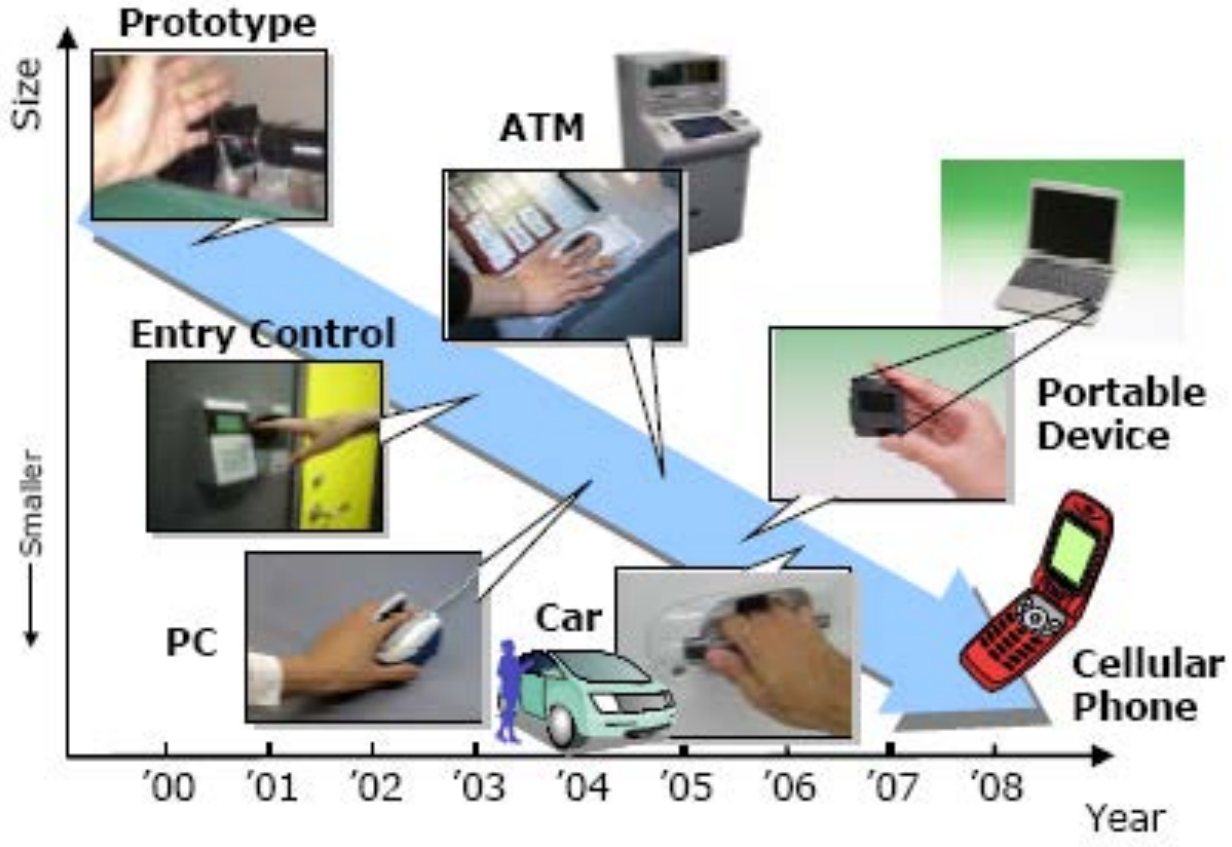
Hypothenar hammer syndrome

Applications

Integration of vein recognition

- In ATMs today
- Future use in doorknobs (car, vault, door) and mobile devices

Hitachi Ltd.

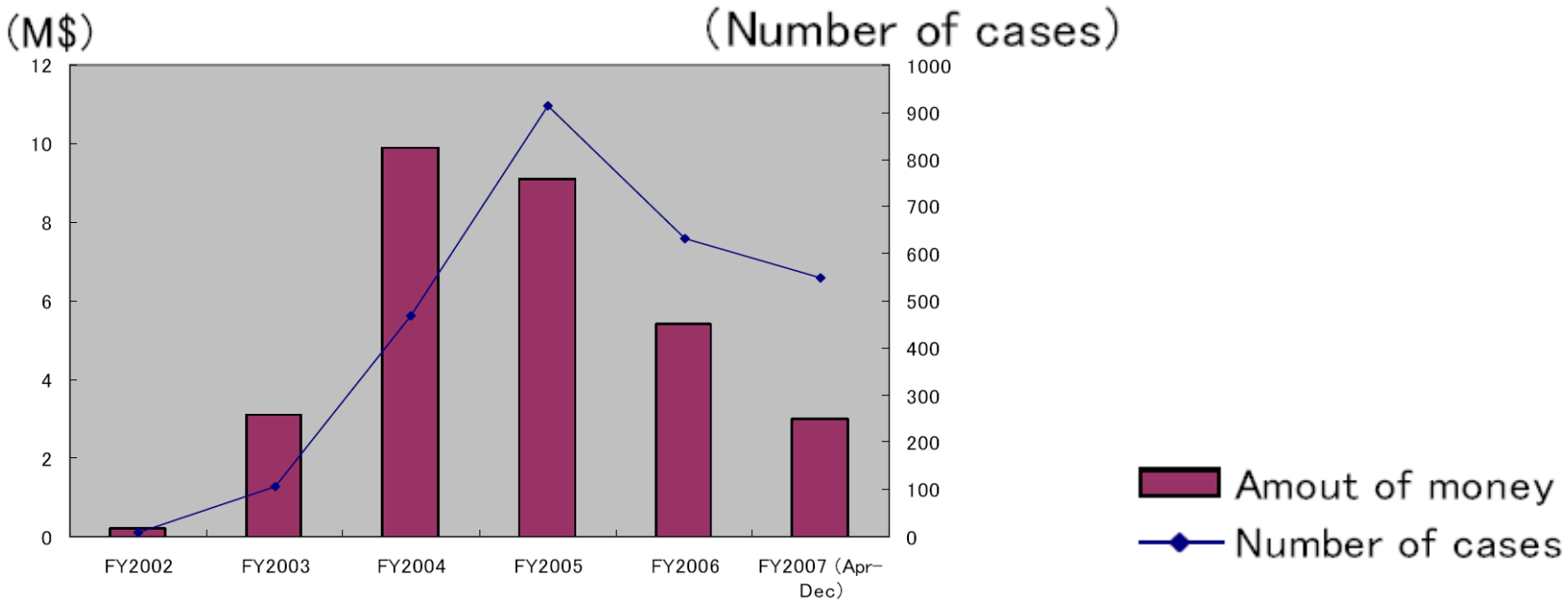


Source: Hashimoto 2006

Applications

Enhanced security at ATMs in Japan

- Countermeasure against illegal transaction with stolen cards since September 2004 in Japan:



Japanese Financial Services Agency's report

- Law for the protection of depositors (effective Feb. 10, 2006)
  - liability fell to banks

Other Applications

Hitachi

- Vein recognition behind the steering wheel

Fujitsu

- Laptop and PDA access control

References

Web

- Daniel Hartung - PhD Thesis (NBL - 2012)
  http://www.christoph-busch.de/files/Hartung-PhD-Thesis-2012.pdf
- Handbook of Vascular Biometrics (2019)
  https://link.springer.com/book/10.1007/978-3-030-27731-4
- University Salzburg - Vein Capture Device and SDK
  http://www.wavelab.at/sources
- Bram Ton - vein recognition implementations
  http://se.mathworks.com/matlabcentral/profile/authors/1836574-bram-ton

Complementary reading

- A. Uhl: “State of the Art in Vascular Biometrics“, Handbook of Vascular Biometrics (2019)
- R. Raghavendra et al.: “A low-cost multimodal Biometric Sensor to capture Finger Vein and Fingerprint“, in Proceedings IJCB, (2014)
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- L. Wang: “Infrared imaging of hand vein patterns for biometric purposes” in Journal CV IET, (2007)