3D Fingerprint Phantoms

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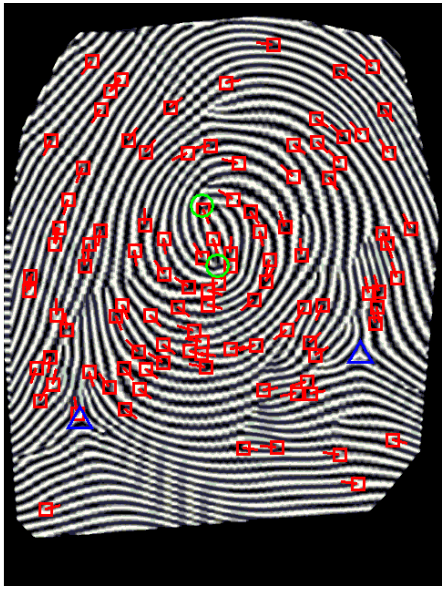
3D Fingerprint Phantom

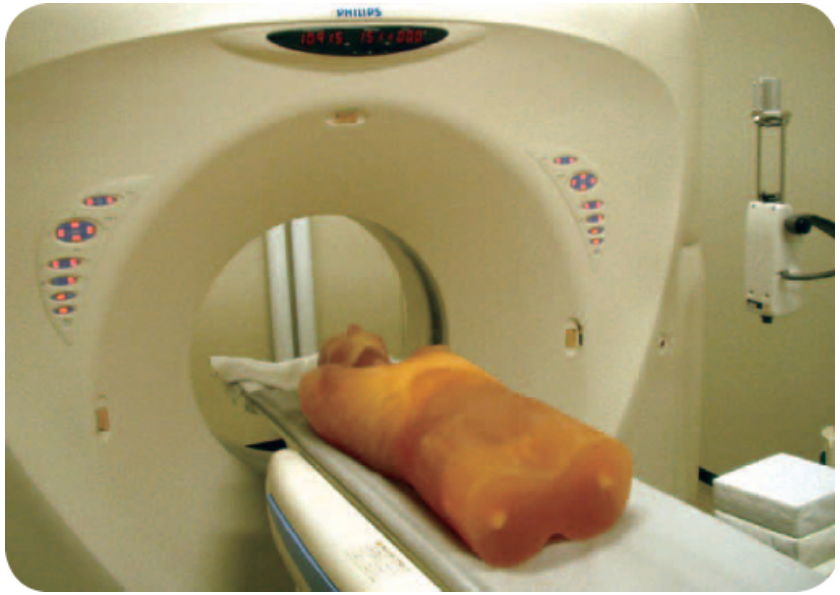


2D synthetic fingerprint image with known features

Generic 3D finger surface

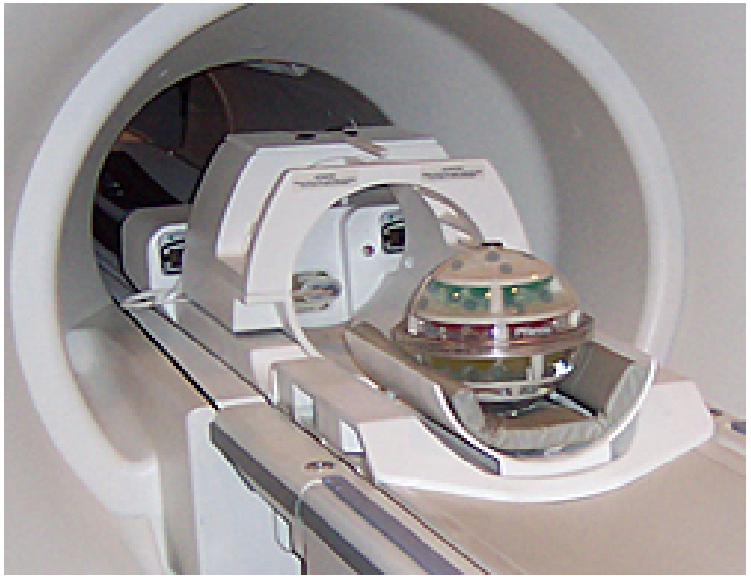
Imaging Phantoms

- Specially designed artifacts with known properties to evaluate the performance of imaging devices



Torso Phantom to calibrate CT Scan machines

https://www.kyotokagaku.com/products/detail03/ph-4.html



“Phannie”, a phantom to calibrate MRI machines developed at NIST

http://www.nist.gov/pml/electromagnetics/phannie_051110.cfm

3D Fingerprint Phantoms

- 3D synthetic fingerprints with known features (cores, deltas, ridge flow, ridge frequency, minutiae) for evaluating fingerprint recognition systems

Fabricated 3D synthetic artifacts of different finger sizes and hardness

Motivation

- **End-to-end evaluation** of fingerprint systems

Use Case	2D synthetic fingerprints [1] [2]	3D fingerprint phantoms
Fingerprint sensors	No	**Yes**
Feature Extractors	Yes	**Yes**
Matchers	Yes	**Yes**
End-to-end evaluation	No	**Yes**

[1] R. Cappelli, “Sfinge: an approach to synthetic fingerprint generation,” in International Workshop on Biometric Technologies, 2004
[2] Q. Zhao, A. Jain, N. Paulter, and M. Taylor, “Fingerprint image synthesis based on statistical feature models”, BTAS, 2012

Motivation

- Benchmark **touchless fingerprint scanners**

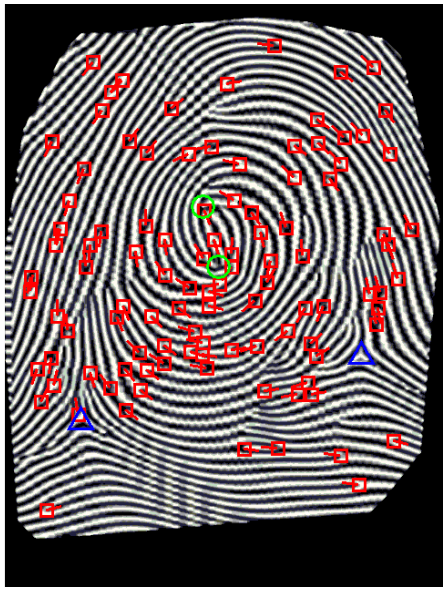
ONEprint touchless fingerprint reader
http://www.idairco.com/products/

FlashScan3D touchless fingerprint sensor
http://www.flashscan3d.com/

AIRprint touchless fingerprint sensor
http://www.idairco.com/products/

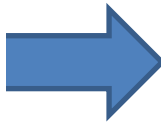
Design of 3D Fingerprint Phantom

- Input: 2D fingerprint image with known features and a generic 3D finger surface as a triangular mesh
- Output: 3D fingerprint phantom



2D synthetic fingerprint image with known features

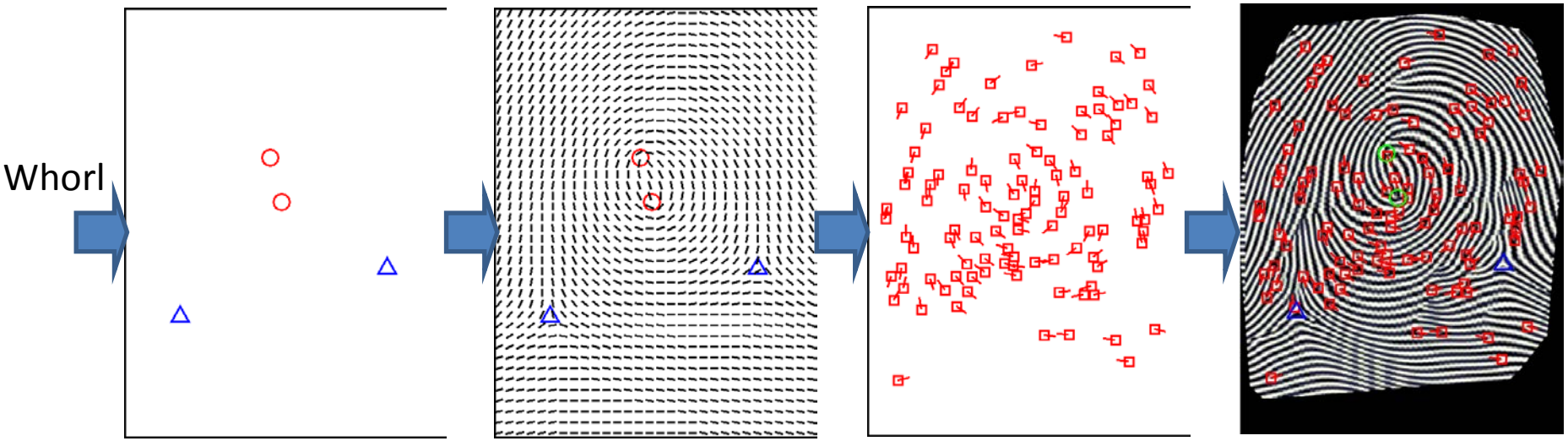
Generic 3D finger surface



3D fingerprint phantom

Generation of 2D synthetic fingerprint

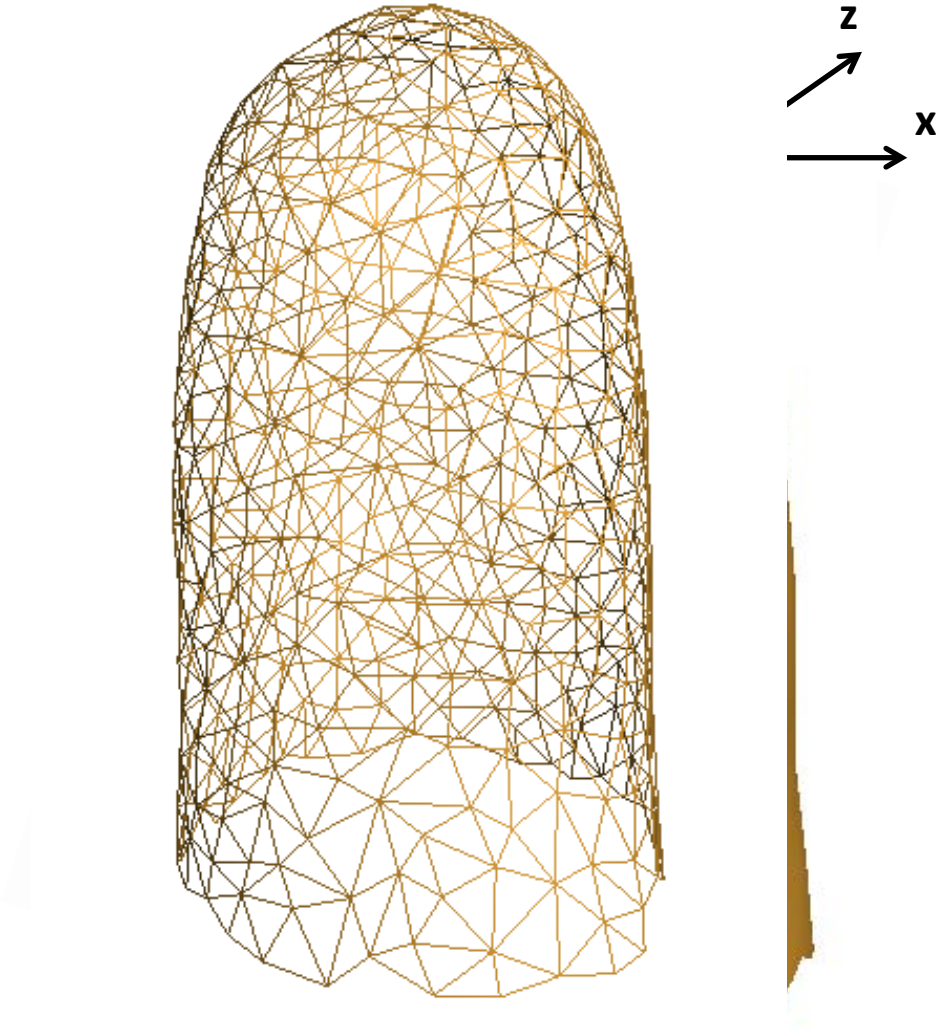
- Input: Fingerprint type (whorl, loop, arch)
- Output: 2D synthetic fingerprint [2]



[2] Q. Zhao, A. Jain, N. Paulter, and M. Taylor, "Fingerprint image synthesis based on statistical feature models," BTAS, 2012

Preprocessing 3D Finger Surface

- Align the finger surface
- Surface triangulation
- Surface re-meshing [3]
- Regularize the finger surface [4]
- Separate front and back

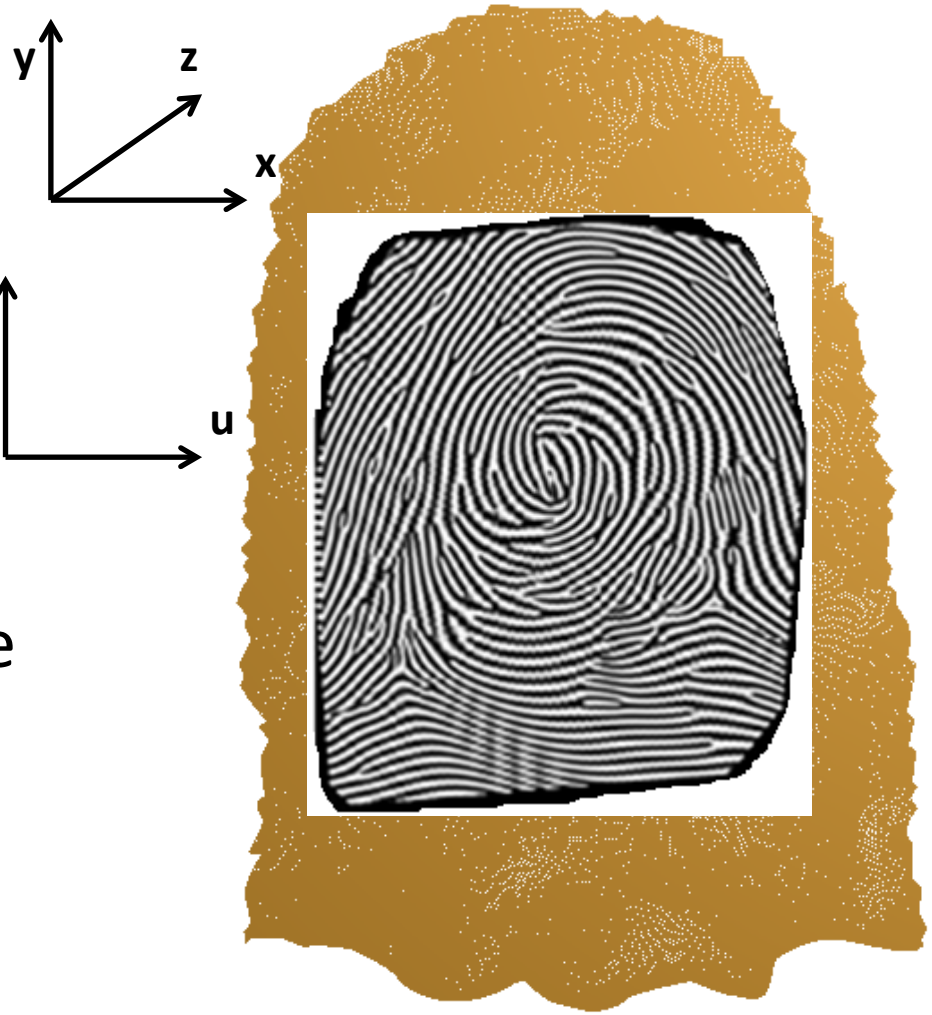


3D finger surface

[3] G. Peyré, and L.D. Cohen. "Geodesic remeshing using front propagation." International Journal of Computer Vision , 2006
[4] C. Loop, "Smooth subdivision surfaces based on triangles.", 1987

Mapping 2D fingerprint to 3D surface

- 3D to 2D projection [5]
- Translation, rotation and flip correction w.r.t reference coordinates
- Make the surface dense
- Determine one-one correspondence

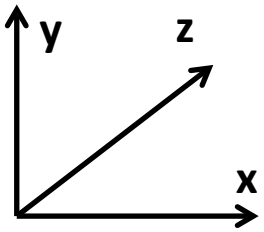


Frontal finger surface

[5] J. B. Tenenbaum, V. de Silva, J. C. Langford, "A global geometric framework for nonlinear dimensionality reduction", Science, 2000

Engraving ridges and valleys

- Compute the surface normals
- Displace the surface along the surface normals
- Displacement proportional to mapped intensity value



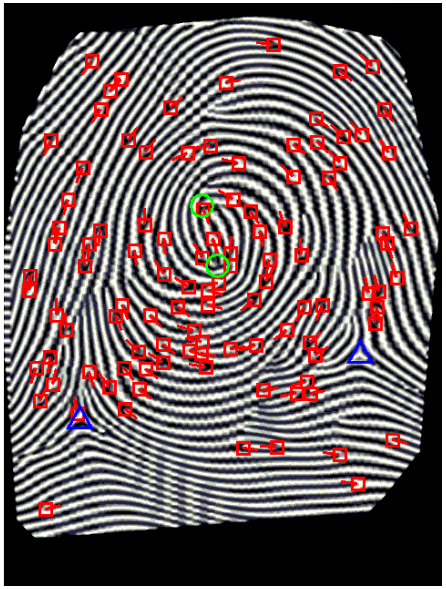
Frontal finger surface

Postprocessing 3D finger surface

- Combine front and back
- Create inner surface
- Stitch outer and inner surfaces to create a watertight solid surface

3D finger surface

3D Fingerprint Phantom



2D synthetic fingerprint image with known features

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3D Fingerprint Phantoms

2D fingerprint image

3D Fingerprint Phantoms

3D Printing

- Phantoms fabricated using a 3D printer (X & Y resolution: 16 microns, Z resolution: 30 microns)
- Printing material based on finger skin properties

Property	Human skin [6] [7]	Material A	Material B
Shore A hardness	20-41	26-28	35-40
Tensile strength (MPa)	5-30	0.8-1.5	1.3-1.8
Elongation at Break (%)	35-115	170-220	110-130

[6] C. Edwards and R. Marks, "Evaluation of biomechanical properties of human skin" *Clinics in dermatology,* 2005
[7] V. Falanga and B. Bucalo, "Use of a durometer to assess skin hardness" *J. American Academy of Dermatology, 1993*

Evaluation of 3D Fingerprint Phantom

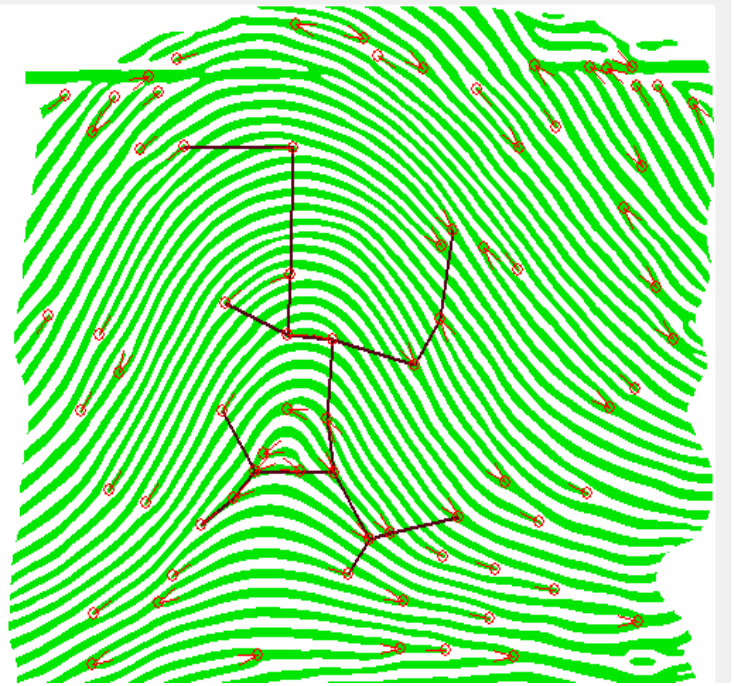
- Two fingerprint sensors (500 ppi and 1000 ppi) used to capture impressions of 3D phantoms
- A commercial fingerprint SDK used for matching

Experiments with 3D Fingerprint Phantom

- How good is the mapping from 2D to 3D?
  - Match the original 2D fingerprint image to impressions of 3D phantom
- Are multiple impressions of the 3D phantom consistent (small intra-class variability) ?
- Evaluation of fingerprint recognition systems using 3D phantoms (to be done)

Evaluation of 2D to 3D Mapping

- Match captured impressions of 3D phantom to the original 2D fingerprint image



Original 2D fingerprint image

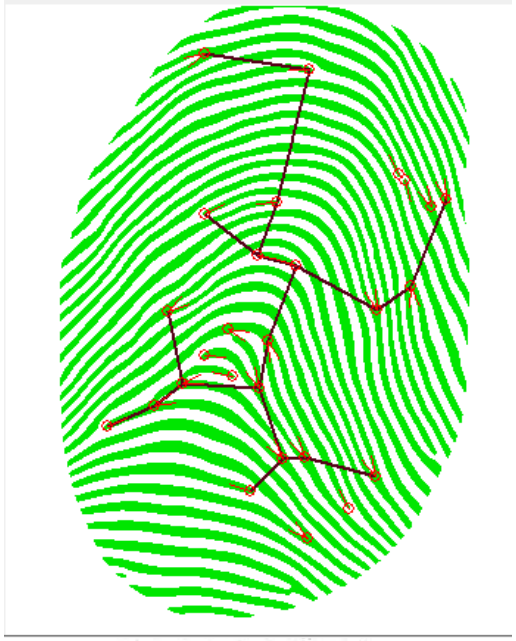
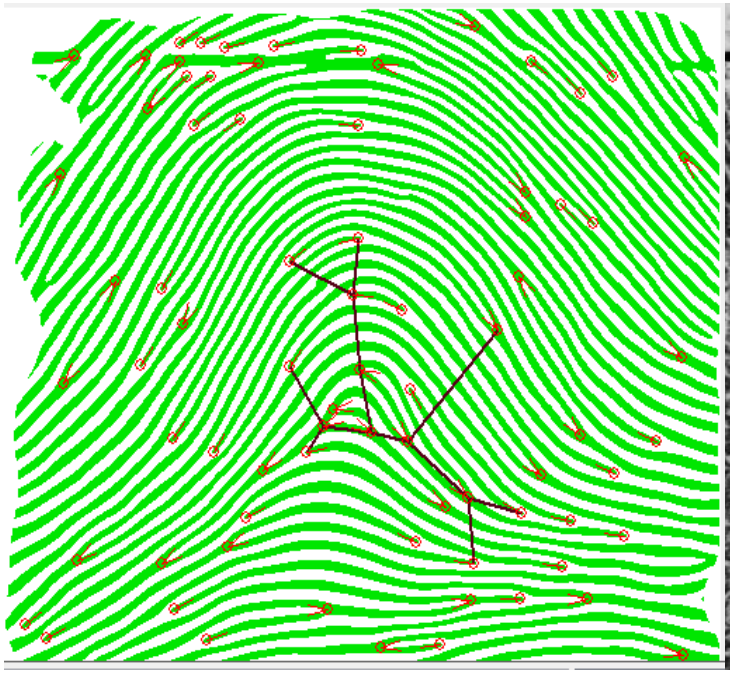


Image of 3D phantom using 1000 ppi scanner

Match score: 180; threshold at FAR=0.01% is 33

Evaluation of 2D to 3D Mapping

- Match captured impressions of 3D phantom to the original 2D fingerprint image



Original 2D fingerprint image

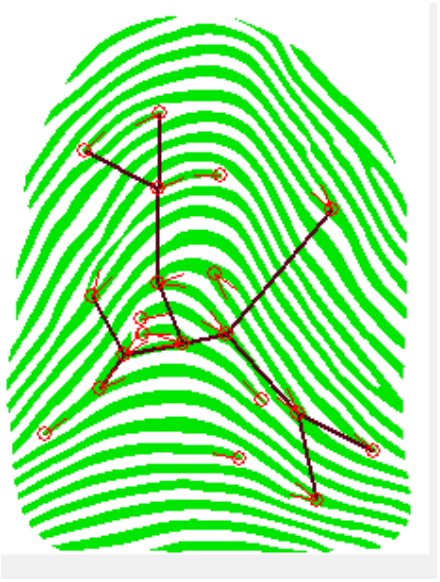
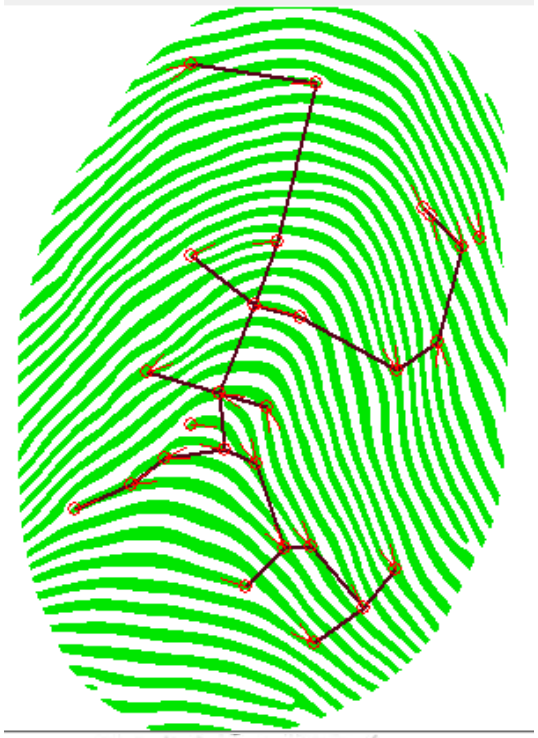


Image of 3D phantom using 500 ppi scanner

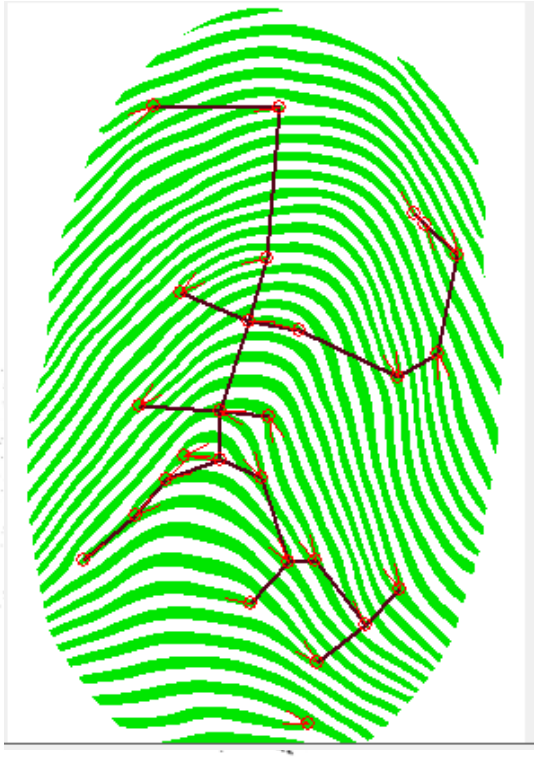
Match score: 153; threshold at FAR=0.01% is 33

Intra-class Variability of 3D Phantom Impressions

- Match different impressions of the same 3D phantom



Impression 1 of phantom using the 1000 ppi sensor

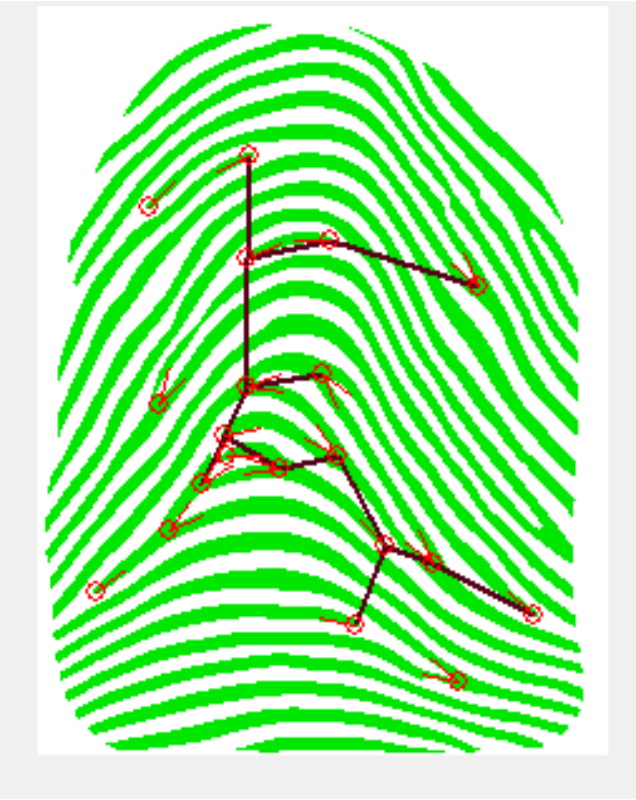


Impression 2 of phantom using the 1000 ppi sensor

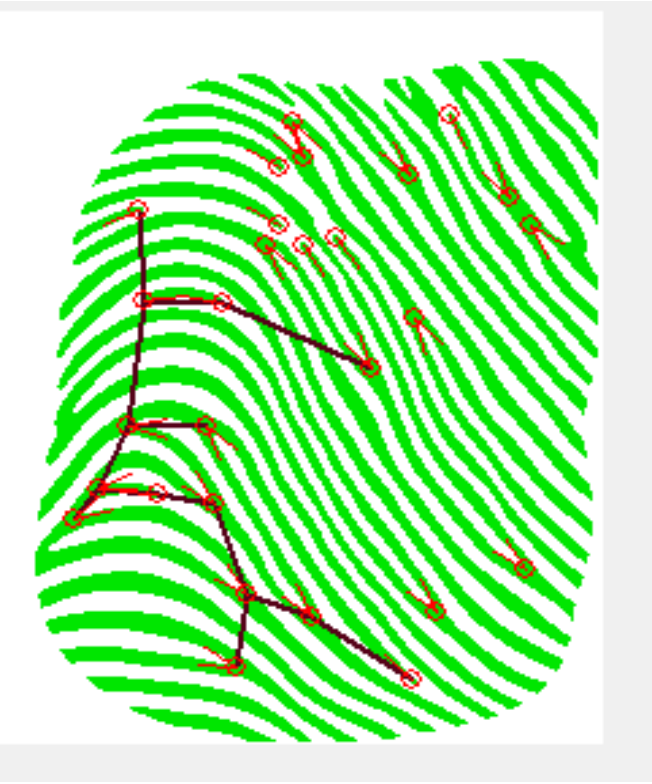
Match score: 878; threshold at FAR=0.01% is 33

Intra-class Variability of 3D Phantom Impressions

- Match different impressions of the same 3D phantom



Impression 1 of phantom using the 500 ppi sensor



Impression 2 of phantom using the 500 ppi sensor

Match score: 410; threshold at FAR=0.01% is 33

Evaluation of Fingerprint Recognition Systems (to be done)

- Feature extractors
  - Capture several different impressions of the same 3D phantom
  - Compute the average number of missing and spurious minutiae w.r.t. ground truth minutiae
  - Compare feature extraction capabilities
- Matchers
  - Given the same set of extracted features, how good is the fingerprint matching module?
  - Statistical validation of match score distributions

Summary and Conclusions

- 3D fingerprint (electronic and physical) phantoms created by (i) projecting any 2D fingerprint onto a generic 3D finger surface, and (ii) fabrication using a commodity 3D printer
- We can print a 3D fingerprint phantom using materials with finger-like properties and known fingerprint features
- Such fabricated 3D fingerprint phantoms can be used for evaluating and comparing fingerprint sensors, feature extractors and matchers
- **Future Work:**
  - Evaluate the 3D electronic and physical artifacts independently
  - Conduct extensive experimentation for end-to-end fingerprint system evaluation
  - Add a conductive layer after fabrication in order to calibrate solid state sensors