3D Fingerprint Phantoms

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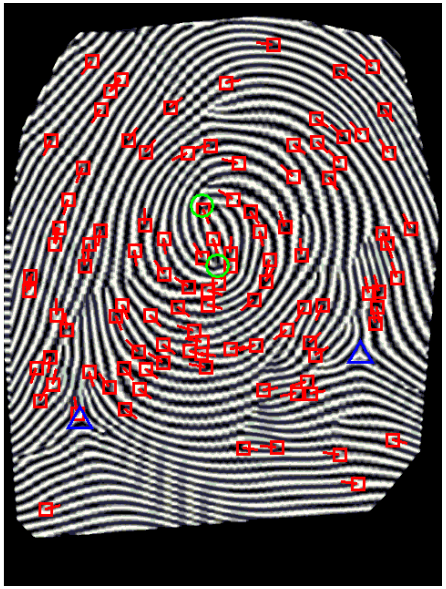
This research is supported by a grant from the NIST Measurement Science Program

3D Fingerprint Phantom

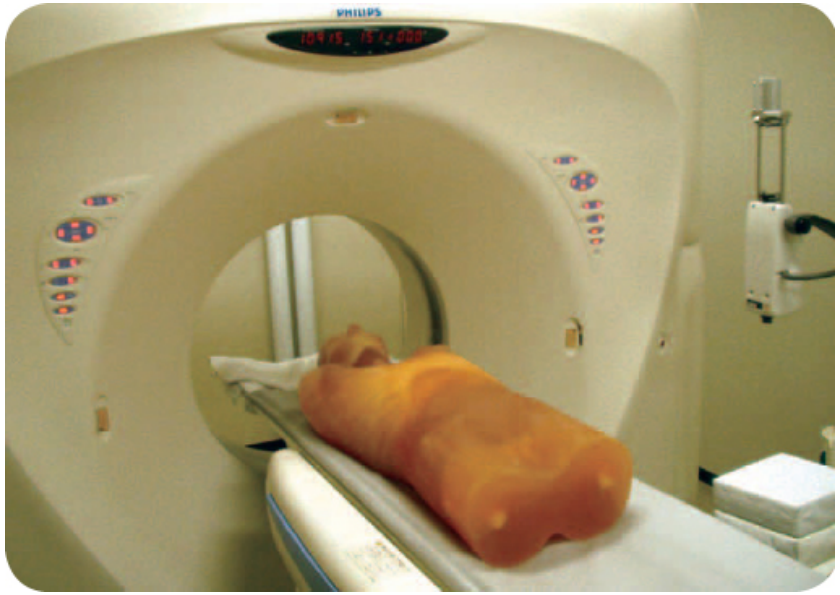


2D synthetic fingerprint image with known features

Generic 3D finger surface

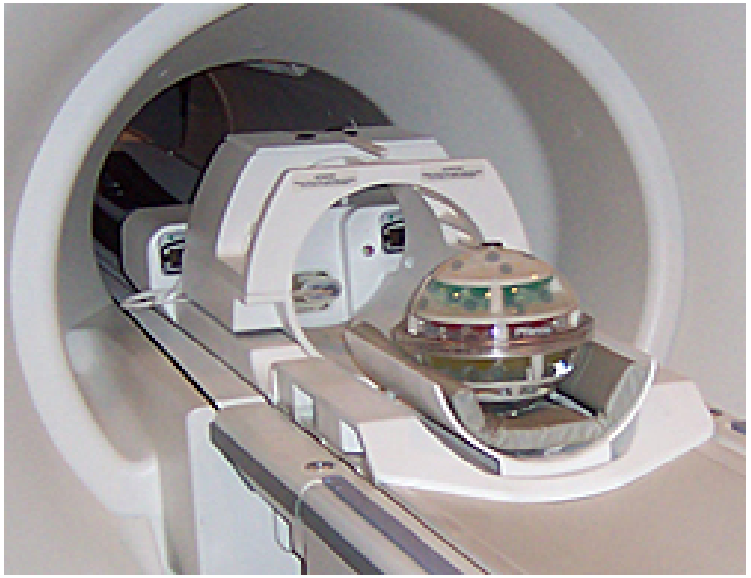
Imaging Phantoms

- 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**

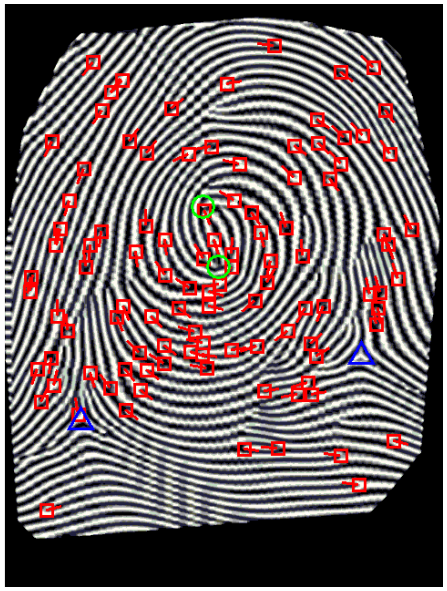
ONEprint touchless fingerprint reader
http://www.idairco.com/products/

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

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

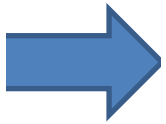
Design of 3D Fingerprint Phantom

- 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

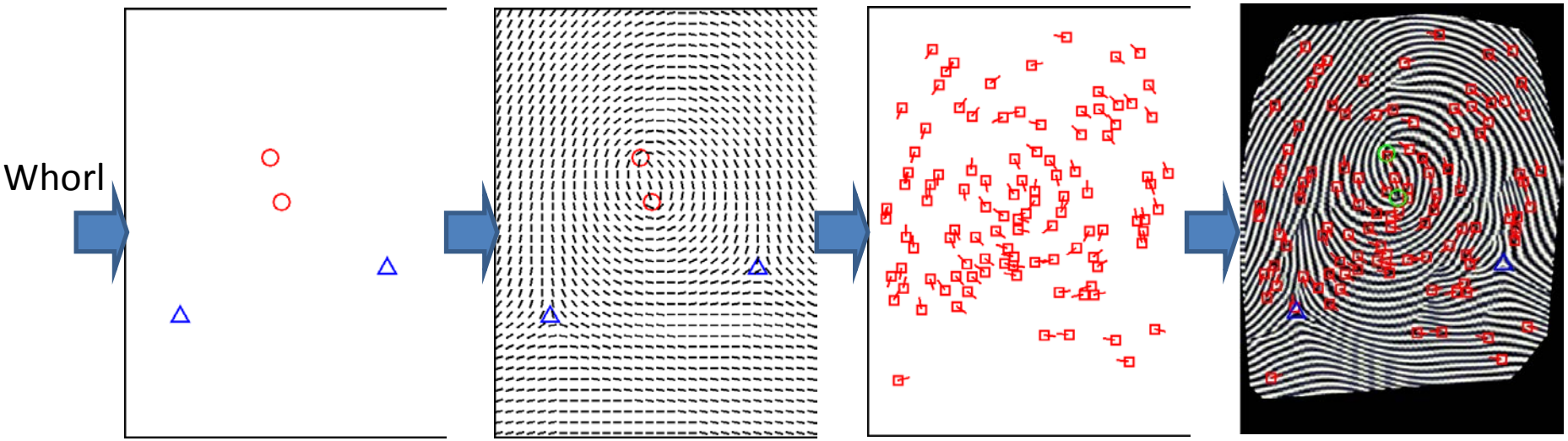
Generic 3D finger surface



3D fingerprint phantom

Generation of 2D synthetic fingerprint

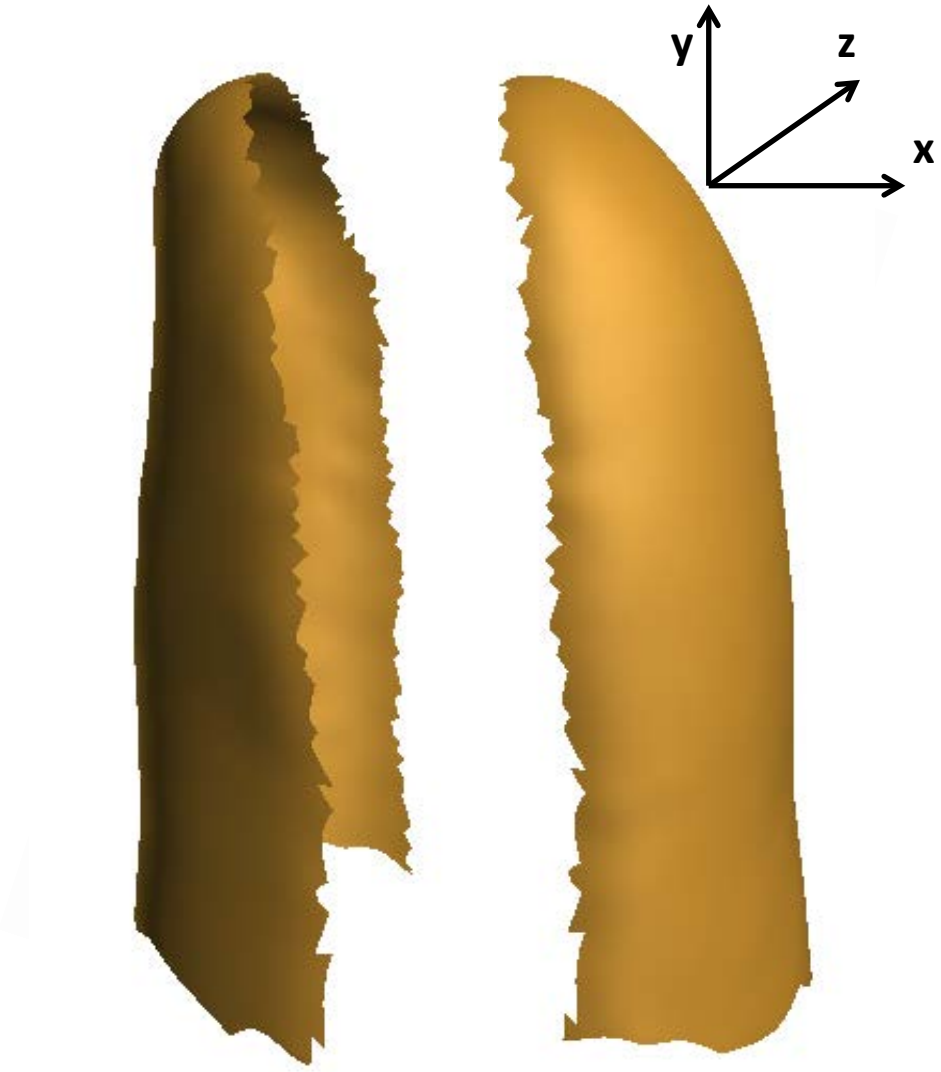
- Input: Fingerprint type (whorl, loop, arch)
- Output: 2D synthetic fingerprint [2]



[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

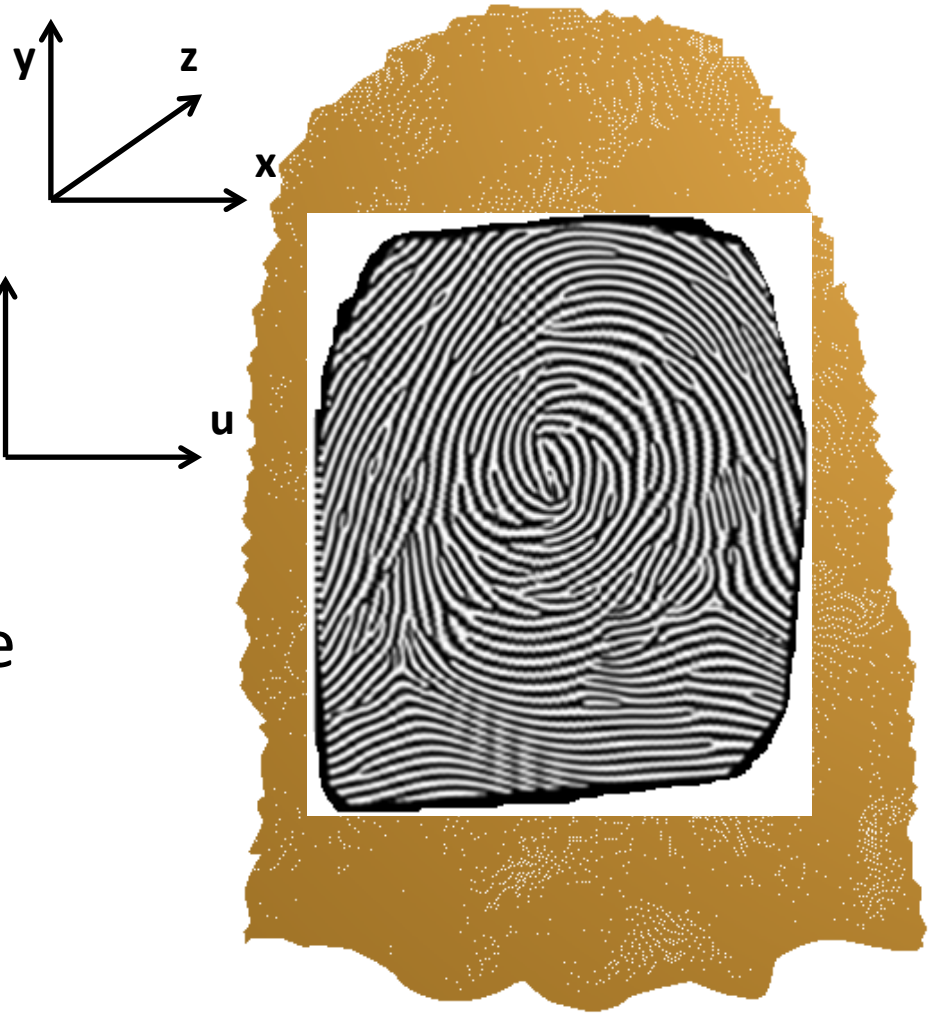


3D finger surface

[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

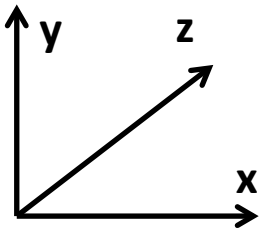


Frontal finger surface

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

Engraving ridges and valleys

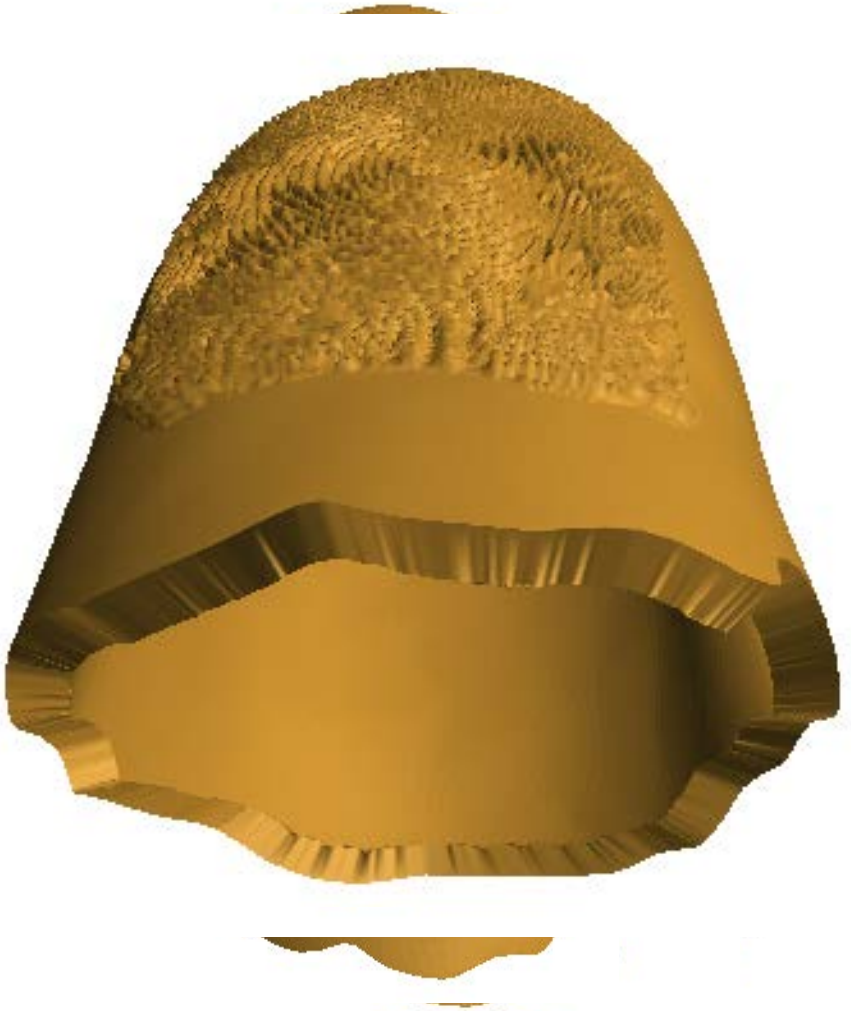
- Compute the surface normals
- Displace the surface along the surface normals
- Displacement proportional to mapped intensity value



Frontal finger surface

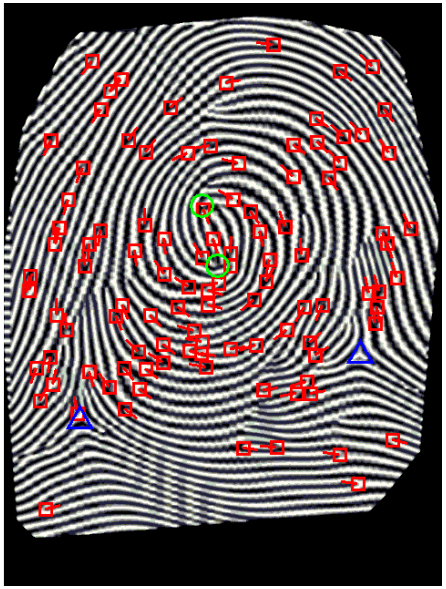
Postprocessing 3D finger surface

- 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

Generic 3D finger surface

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

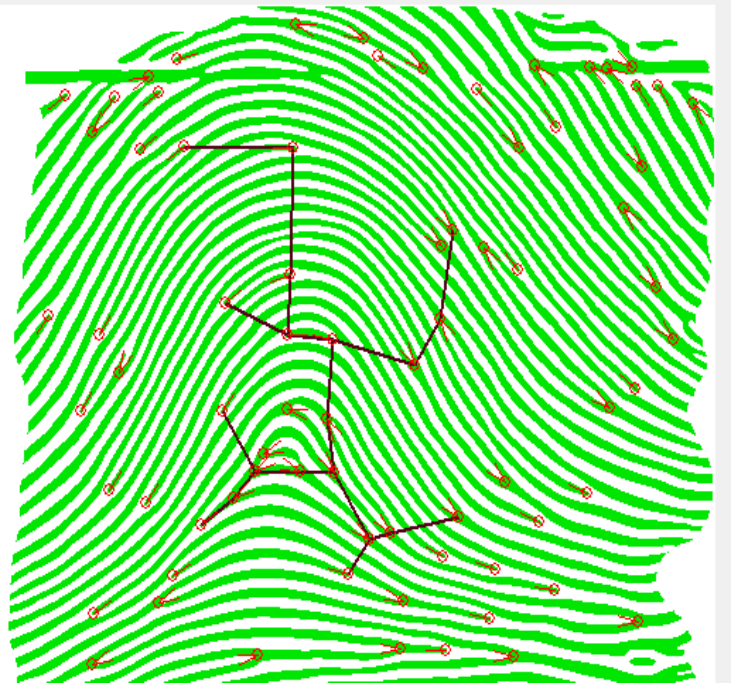
- Two fingerprint sensors (500 ppi and 1000 ppi) used to capture impressions of 3D phantoms
- A commercial fingerprint SDK used for matching

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

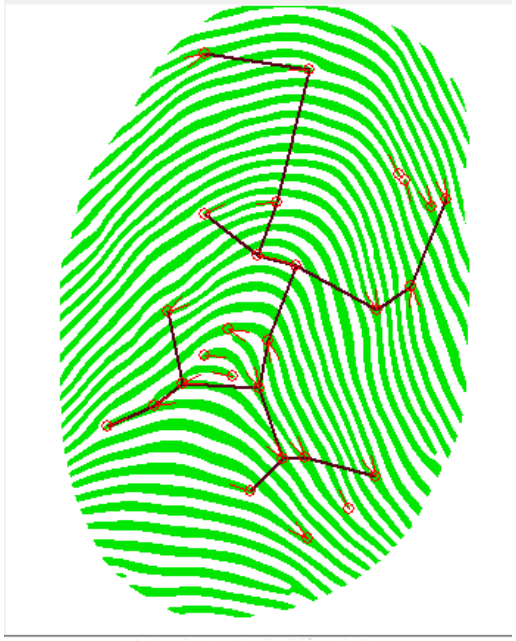
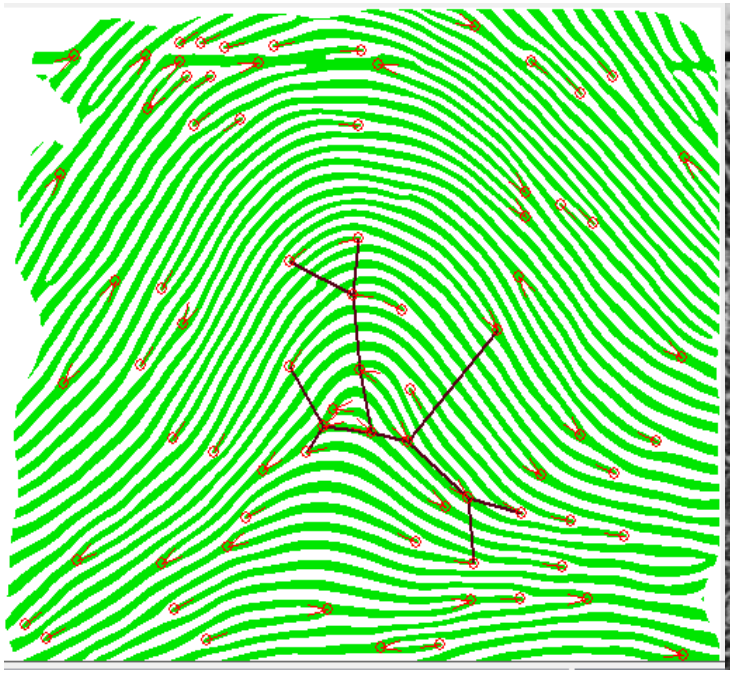


Image of 3D phantom using 1000 ppi scanner

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



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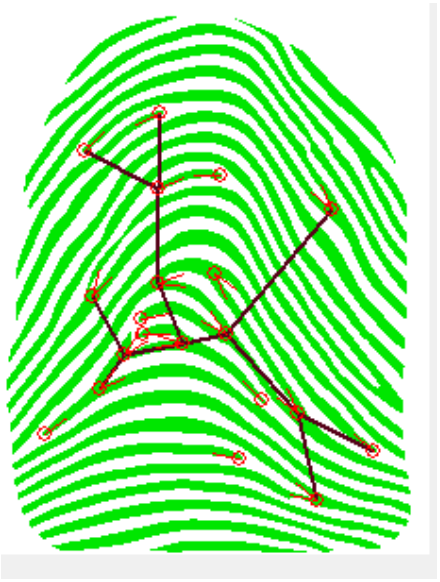
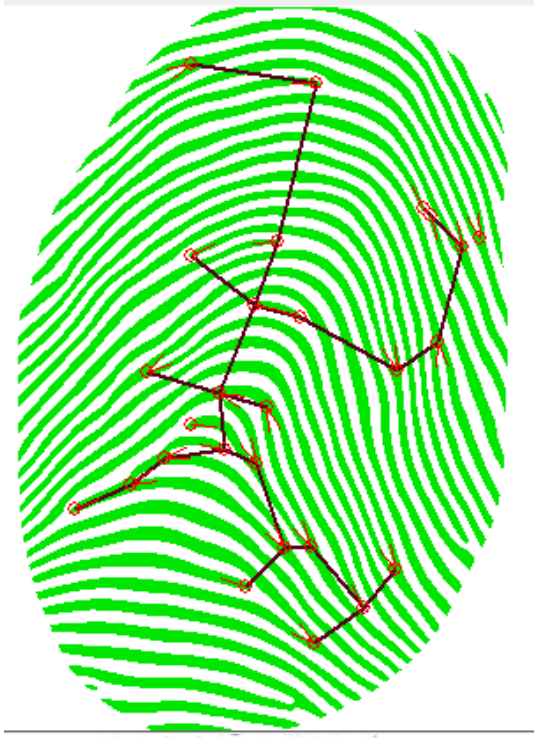


Image of 3D phantom using 500 ppi scanner

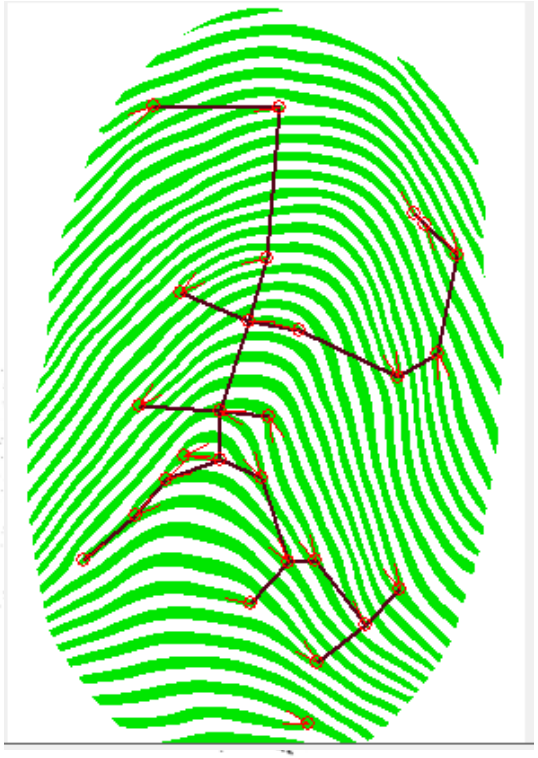
Match score: 153; threshold at FAR=0.01% is 33

Intra-class Variability of 3D Phantom Impressions

- Match different impressions of the same 3D phantom



Impression 1 of phantom using the 1000 ppi sensor

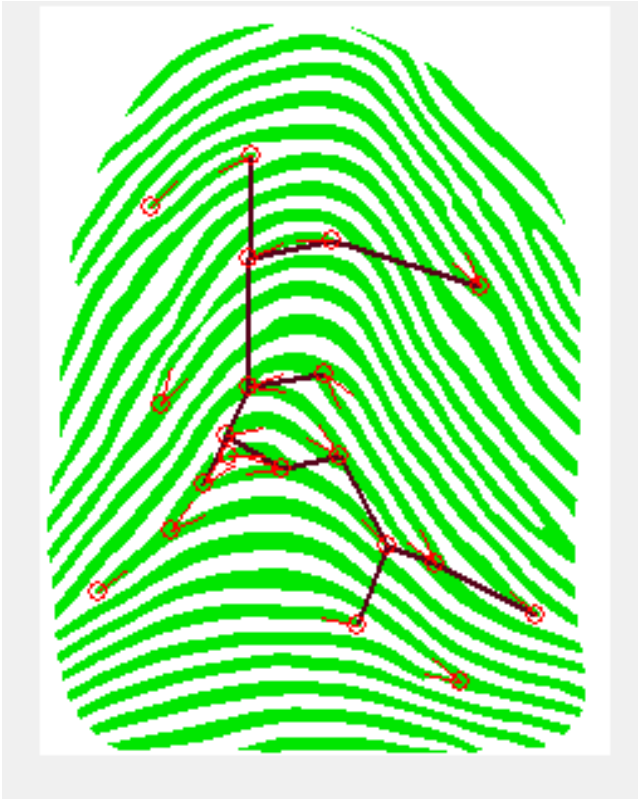


Impression 2 of phantom using the 1000 ppi sensor

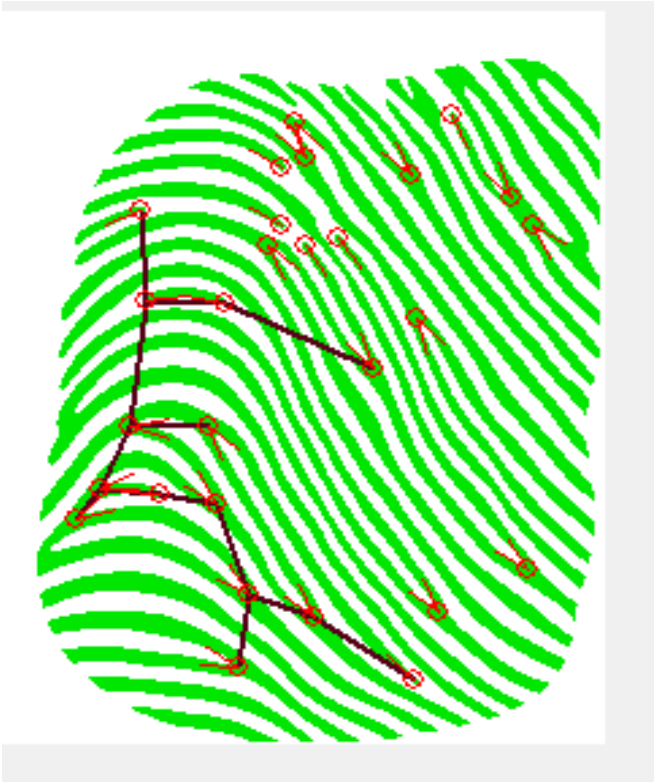
Match score: 878; threshold at FAR=0.01% is 33

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