3D Fingerprint Phantoms

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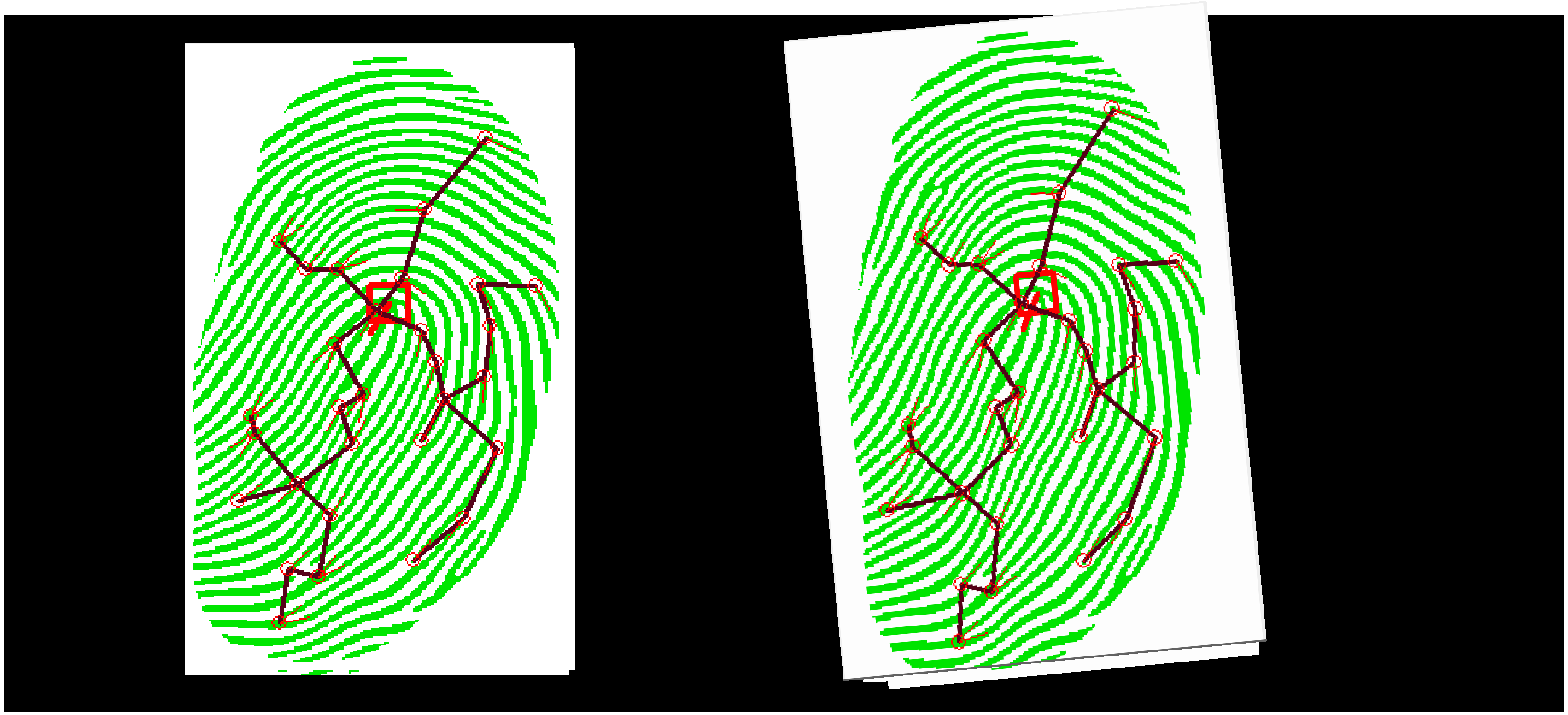
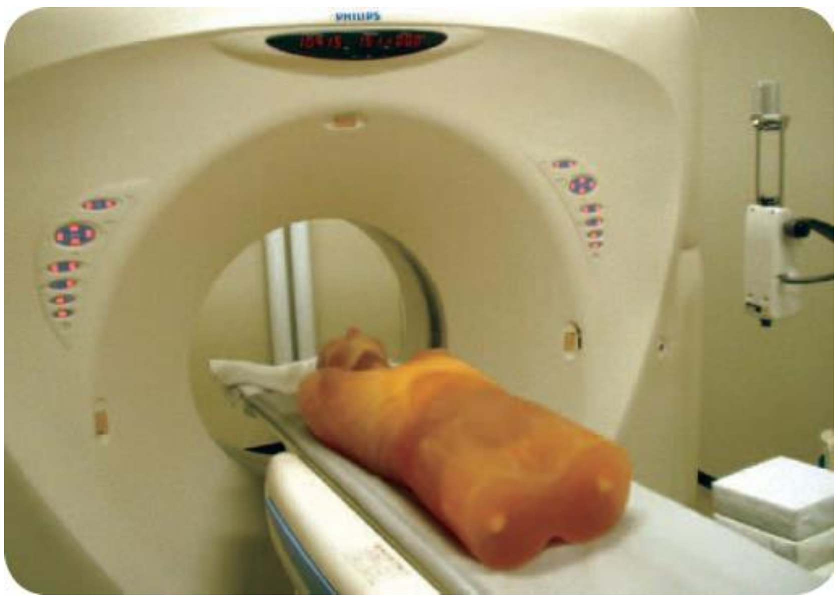
Goal

- Build 3D fingerprint phantoms/targets to calibrate fingerprint readers and evaluate feature extractors and matchers



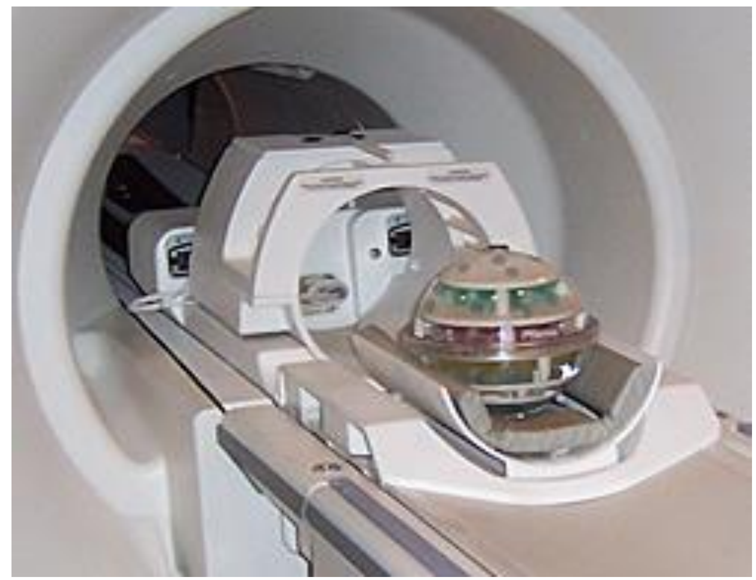
Imaging Phantoms

- 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

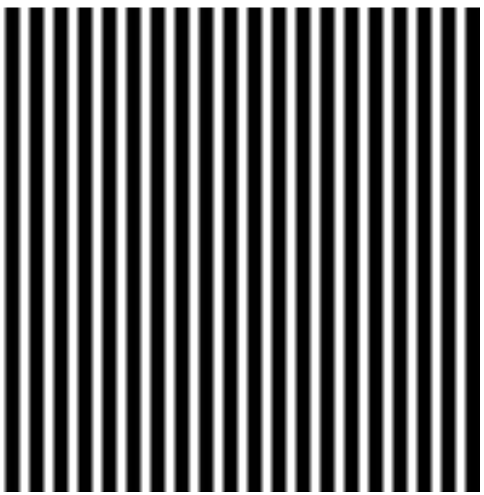


“Phannie”, a phantom to calibrate MRI machines developed at NIST

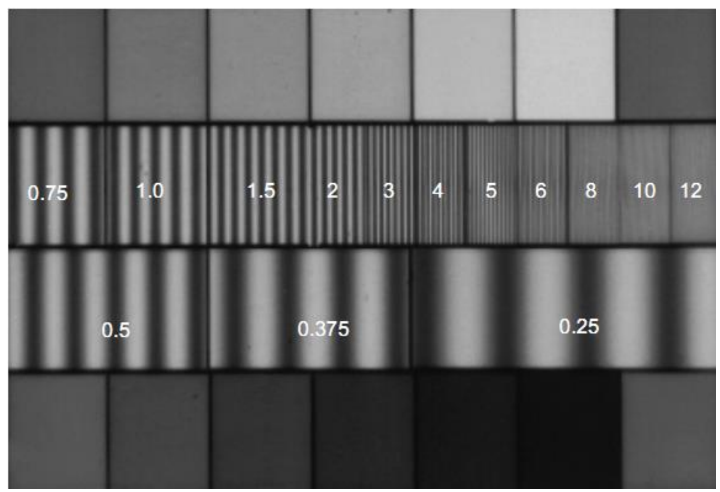
http://www.nist.gov/pml/electromagnetics/phannie_051110.cfm

Fingerprint Phantoms

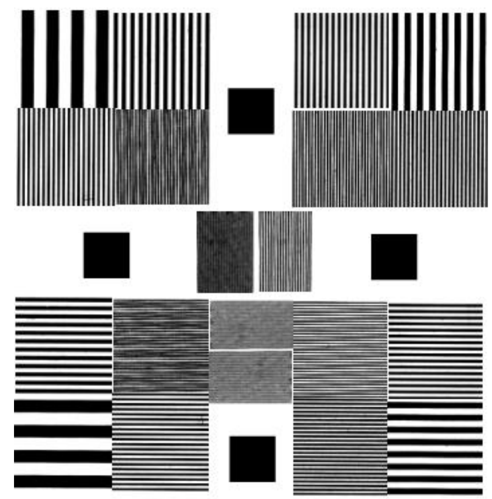
- 2D/3D artifacts recommended to measure geometric accuracy, resolution and spatial frequency response of imaging devices [1] [2]



Ronchi target



Sine wave target



Bar target

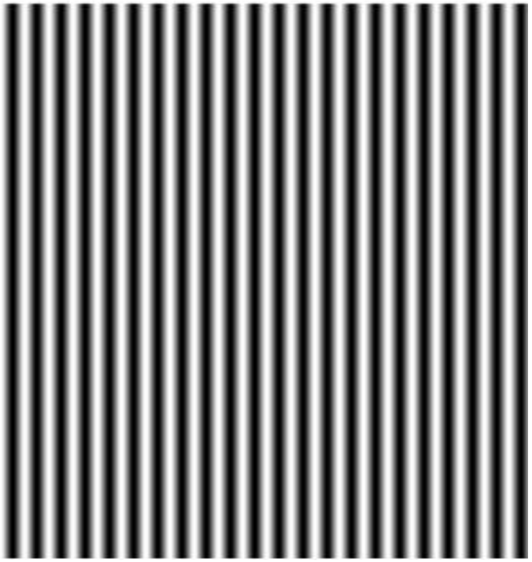
[1] Normal B. Nill, "Test procedures for verifying image quality requirements for personal identity verification (PIV) single finger capture devices." MITRE Technical Report MTR 060170, 2006.
[2] Norman B. Nill, "Test procedures for verifying IAFIS image quality requirements for fingerprint scanners and printers V 1.4" MITRE Technical Report MTR05B0016R7, 2013.

Our Contributions

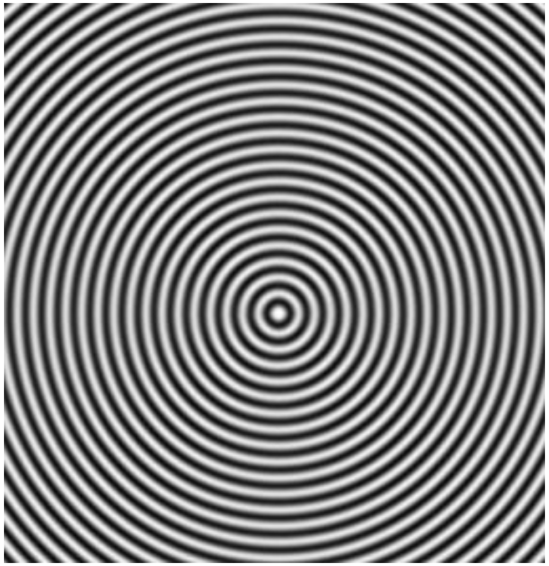
- Build 3D phantoms to calibrate optical fingerprint sensors
- Project different 2D test patterns onto 3D finger surface
- Use COTS 3D printers to fabricate 3D phantoms; the hardness and elasticity of fabrication material is similar to that of human fingers

2D Calibration Patterns

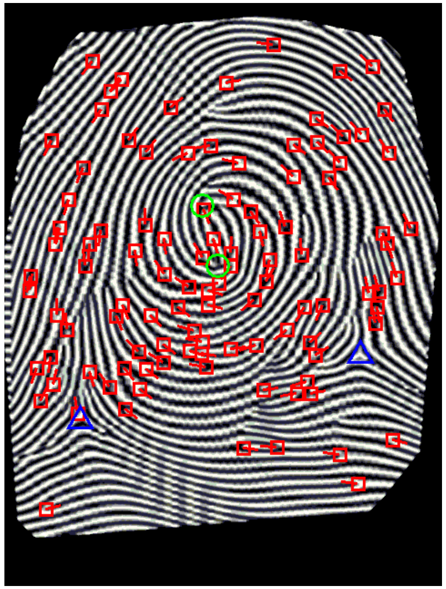
- 2D patterns with known characteristics



Vertical bars
(ridge spacing = 10 pixels)



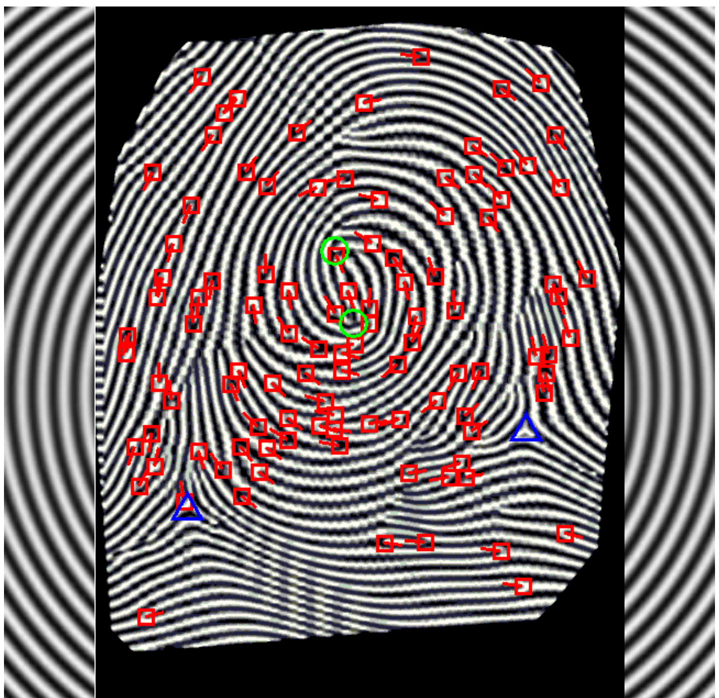
Concentric circles
(ridge spacing = 10 pixels)



Synthetic fingerprint with known features

3D Fingerprint Phantoms

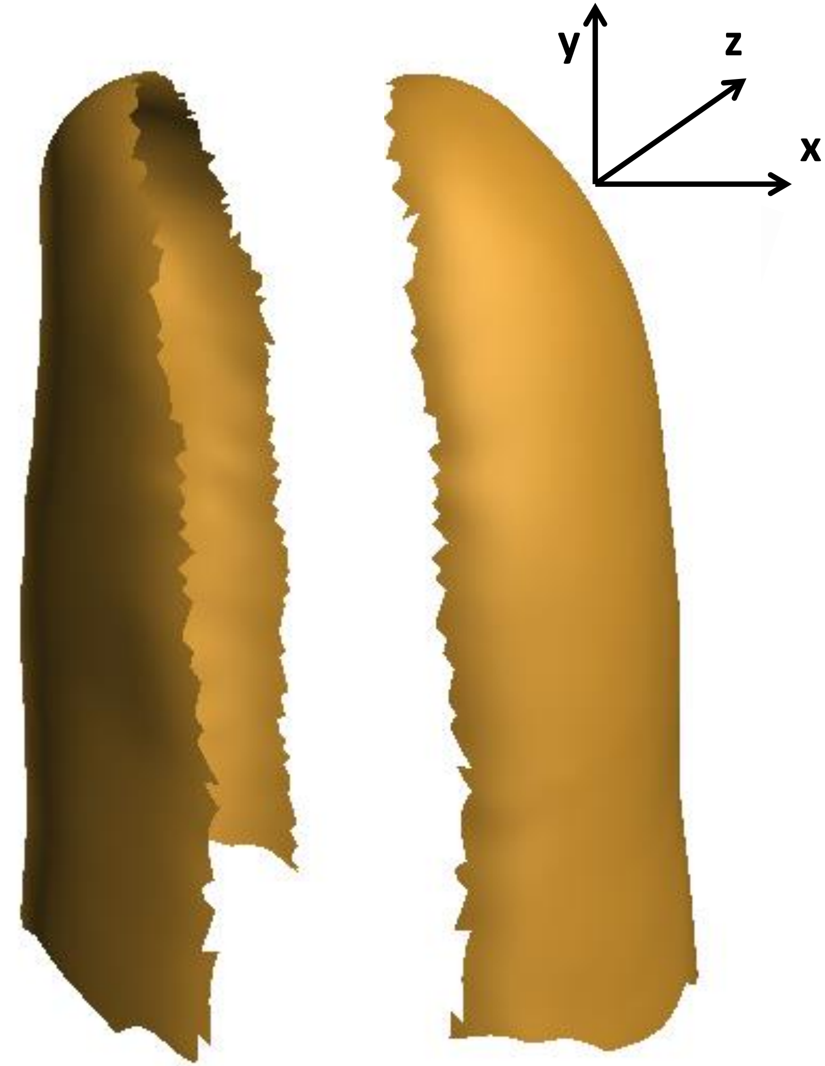
- 3D electronic and physical artifacts of known characteristics



Synthetic fingerprints with (ridge spacing = 10 pixels)

Preprocessing 3D Finger Surface

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

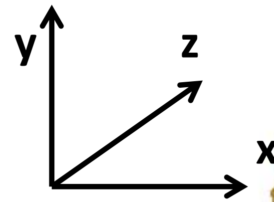


3D finger surface

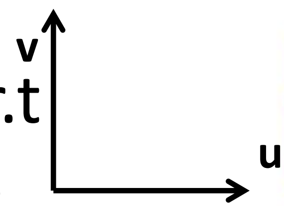
[3] G. Peyré, and L.D. Cohen. "Geodesic remeshing using front propagation." International Journal of Computer Vision , 2006
[4] C. Loop, "Smooth subdivision surfaces based on triangles.", 1987

Mapping 2D fingerprint to 3D surface

- 3D to 2D projection [5]



- Translation, rotation and flip correction w.r.t reference coordinates



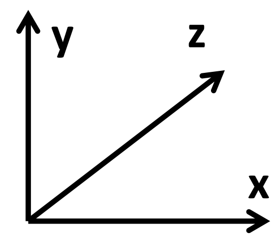
- Make the surface dense
- Determine one-one correspondence

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

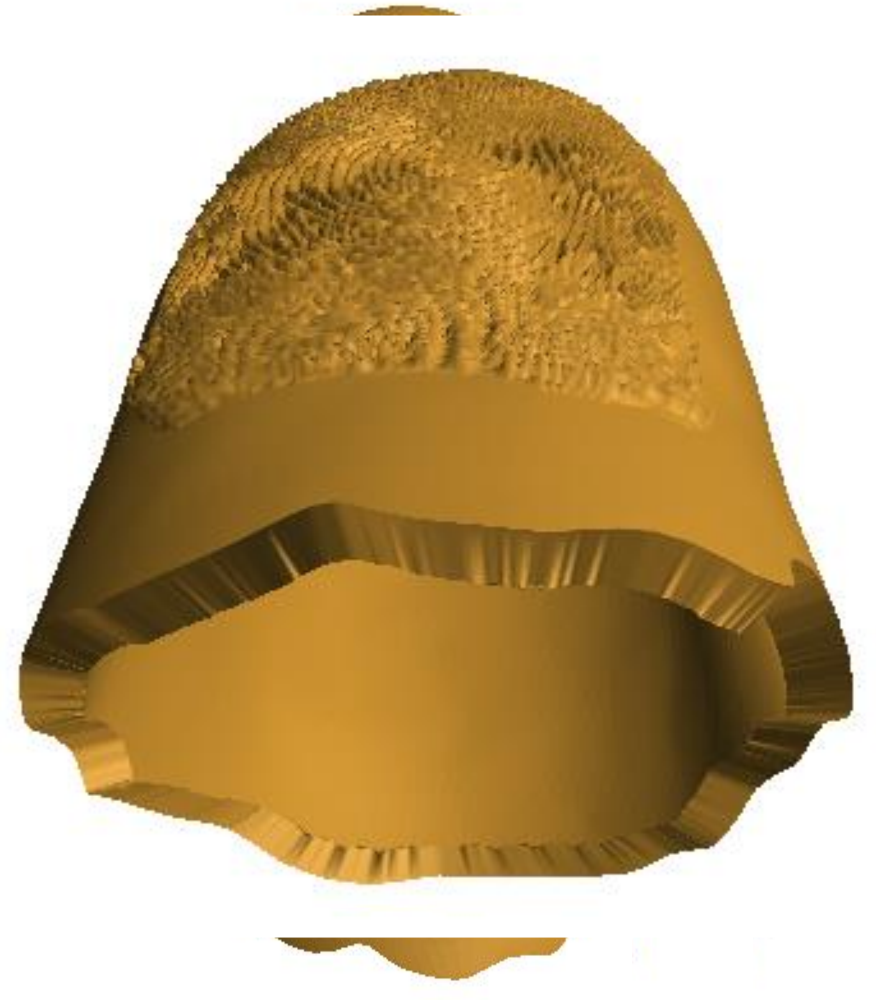
- Compute the surface normals
- Displace the surface along the surface normals
- Displacement proportional to mapped intensity value



Frontal finger surface

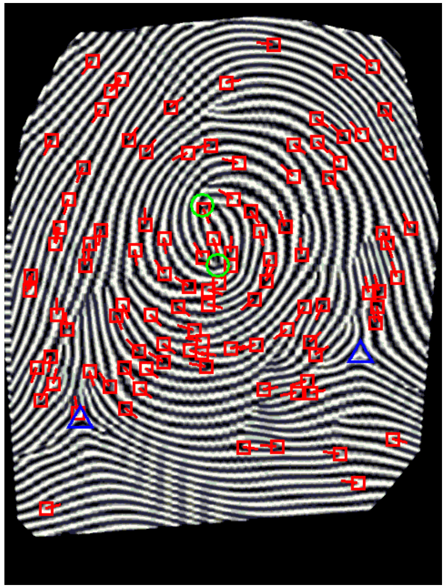
Postprocessing 3D finger surface

- 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 Phantom

3D Printing

- Phantoms fabricated using a 3D printer (X & Y res: 600 dpi, Z res: 1600 dpi) using two different materials
- 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

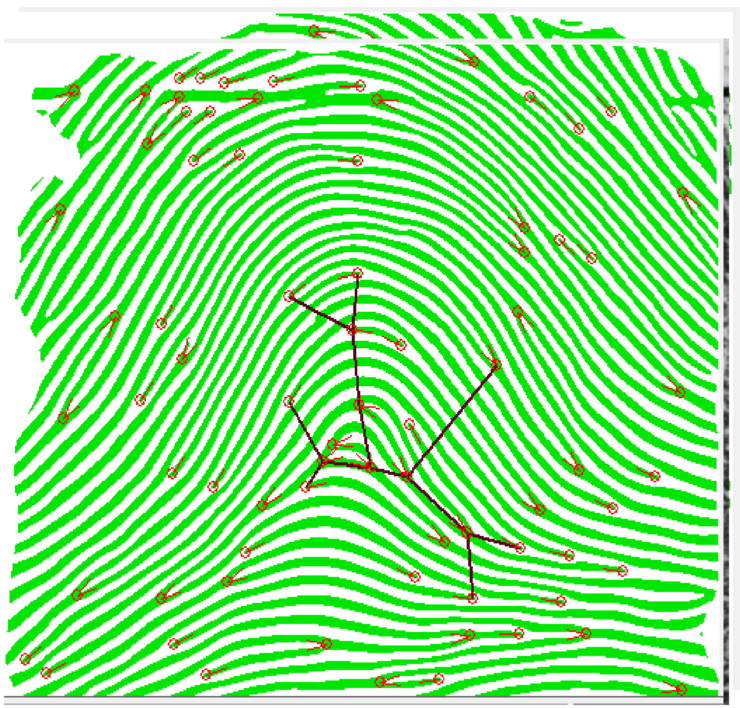
[6] C. Edwards and R. Marks, "Evaluation of biomechanical properties of human skin" *Clinics in dermatology,* 2005
[7] V. Falanga and B. Bucalo, "Use of a durometer to assess skin hardness" *J. American Academy of Dermatology, 1993*

Experiments

- 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)?
- Calibrate optical fingerprint sensors using 3D phantoms

Evaluation of 2D to 3D Mapping

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



Original 2D fingerprint image

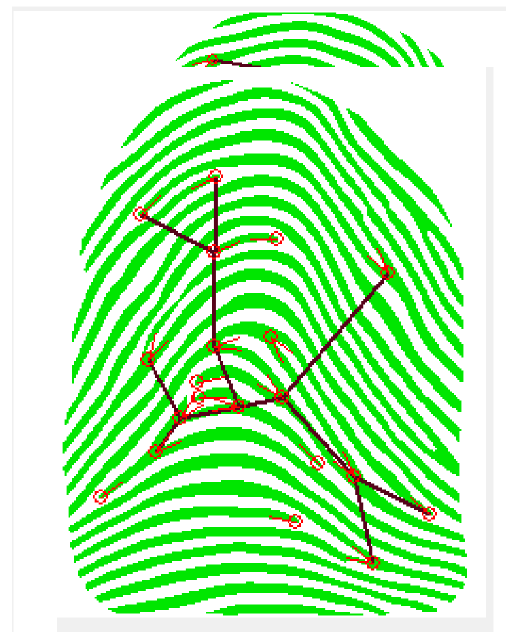
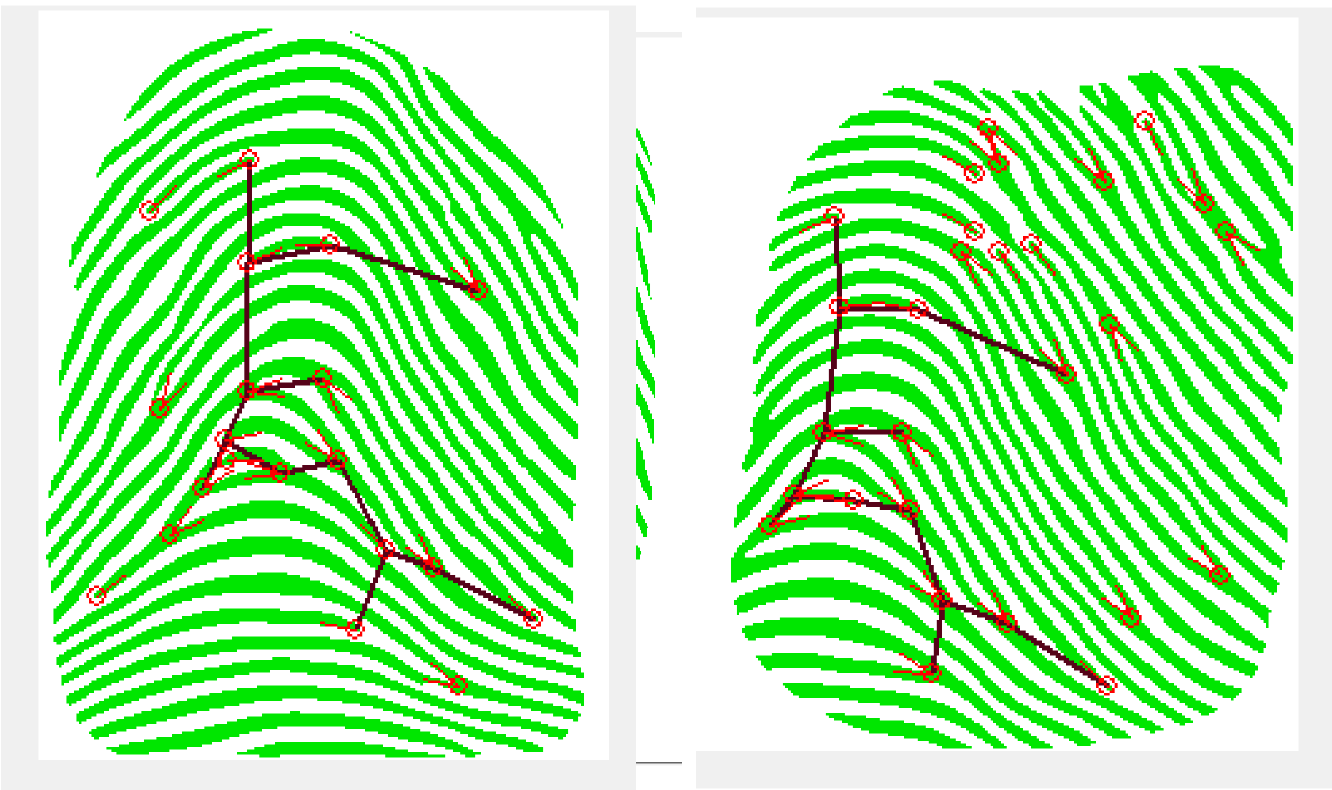


Image of 3D phantom using 1000 ppi scanner

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

Intra-class Variability of Impressions

- Match different impressions of the same 3D phantom



Match score: 870/416; threshold at FAR=0.01% is 33

Impression 1 of phantom using the 1000/500 ppi sensor

Impression 2 of phantom using the 1000/500 ppi sensor

Calibration Experiments

- Experimental Protocol
  - Capture 10 different impressions each of the three artifacts having pre-specified test patterns
  - Measure the mean and variance of ridge spacings

2D Images of 3D Phantoms

500 ppi sensor

1000 ppi sensor

Horizontal bars **Vertical bars** **Concentric circles**

Calibration Results

Test pattern	500 ppi sensor	1000 ppi sensor
Horizontal bars	Mu = 9.04, Sd = 0.06	Mu = 9.05, Sd = 0.05
Vertical bars	Mu = 9.51, Sd = 0.23	Mu = 9.46, Sd = 0.09
Concentric circles	Mu = 9.80, Sd = 0.31	Mu =9.59, Sd = 0.08

Mean (Mu) and Std. deviation (Sd) ridge spacing computed in the images acquired using the two sensors. (test pattern ridge spacing = 10 pixels)

Note:

- To compensate for the distortion during 2D to 3D projection, we use the Euclidean to Geodesic distance ratio to adjust ridge spacing

Conclusions and Future Work

- We have devised a method to create 3D fingerprint phantoms by (i) projecting any 2D test pattern onto a generic 3D finger surface, and (ii) fabricating using a 3D printer
- 3D fingerprint phantoms can be used for calibrating fingerprint sensors, and evaluating feature extractors and matchers
- Ongoing Work: (i) improve the fingerprint phantom fabrication process, (ii) study fingerprint distortion during the acquisition process