3D Fingerprint Targets

Sunpreet S. Arora\textsuperscript{1}, Kai Cao\textsuperscript{1}, Anil K. Jain\textsuperscript{1}

and Nicholas G. Paulter Jr.\textsuperscript{2}

\textsuperscript{1}Michigan State University

\textsuperscript{2}National Institute of Standards and Technology

This research is supported by a grant from the NIST Measurement Science Program
3D Fingerprint Target

2D fingerprint image

3D finger surface
Goal

• Build 3D targets to evaluate image acquisition capability of fingerprint readers
Benefits

• Standards organizations: develop standard procedures to benchmark fingerprint readers

• Fingerprint vendors: improve performance of fingerprint readers

• End users: understand and compare the sources of limitations in different fingerprint readers
Our Contributions

• Synthesize 3D targets by projecting 2D calibration patterns onto 3D finger surface

• Fabricate targets with material(s) similar in hardness and elasticity to the human finger skin using a state-of-the-art 3D printer

• Demonstrate utility of the targets for evaluation of fingerprint readers
3D Target Synthesis

Preprocessing 3D finger surface

Mapping 2D fingerprint to 3D surface

Preprocessing 2D calibration pattern

Engraving 2D calibration pattern on 3D surface

Postprocessing 3D finger surface

3D printing

3D finger surface

2D calibration pattern
Preprocessing 3D Finger Surface

Align the surface

Sample vertices and triangles

Make the surface dense

Separate front and back

3D finger surface
Preprocessing 2D Calibration Pattern

Extract Skeleton

Dilate

Smooth

2D calibration pattern
Mapping 2D Pattern to 3D Surface

Unwrap to 2D

Map the 2D pattern

Make the surface dense

Frontal finger surface
Engraving 2D Pattern on 3D

Compute the surface normals

Displace the surface along the normals

Frontal finger surface
Postprocessing 3D Finger Surface

- Combine front and back
- Inner finger surface

3D finger surface

- Stitch outer and inner surfaces
3D Printing

Electronic 3D target

Stratasys Objet Connex 350
(X & Y res: 600 dpi,
Z res: 1600 dpi)

Physical 3D target

Printing material similar in hardness and elasticity to human skin
Experiments

• How good is the synthesized and fabricated 3D target?
  – Fidelity of features after projection from 2D to 3D
  – Fidelity of engraved features after 3D printing
  – End-to-end fidelity of features

• Are the different impressions of a 3D target consistent (intra-class variability)?

• Evaluating fingerprint readers using 3D targets
Fidelity of 3D Target Synthesis

- Fidelity of features after 2D to 3D projection

Similarity Score = 179; Threshold @0.01% FAR = 33
Fidelity of 3D Target Synthesis

- Fidelity of engraved features after 3D printing

Similarity Score = 500; Threshold @0.01% FAR = 33
Fidelity of 3D Target Synthesis

• End-to-end fidelity of features

Similarity Score = 125; Threshold @0.01% FAR = 33
Intra-class Variability between 3D Target Impressions

Impression 1

Impression 2

Similarity Score = 1397; Threshold @0.01% FAR = 33
Evaluating Fingerprint Readers

- Project 2D calibration patterns (sine gratings/fingerprints) of known spacing

Sine Gratings

Average Spacing: 10.42 pixels

3D Target
Evaluating Fingerprint Readers

• Capture impressions of the 3D targets

Optical Reader 1
(500 ppi)

Optical Reader 2
(1000 ppi)

Horizontal grating  Vertical grating  Circular grating  Fingerprint
Evaluating Fingerprint Readers

• Measurements from 10 captured images of 3D targets synthesized using sine gratings

<table>
<thead>
<tr>
<th>Test pattern</th>
<th>Optical Reader 1 (500 ppi)</th>
<th>Optical Reader 2 (1000 ppi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal grating</td>
<td>$\mu = 9.04, \sigma = 0.06$</td>
<td>$\mu = 9.05, \sigma = 0.05$</td>
</tr>
<tr>
<td>Vertical grating</td>
<td>$\mu = 9.51, \sigma = 0.23$</td>
<td>$\mu = 9.46, \sigma = 0.09$</td>
</tr>
<tr>
<td>Circular grating</td>
<td>$\mu = 9.80, \sigma = 0.31$</td>
<td>$\mu = 9.59, \sigma = 0.08$</td>
</tr>
</tbody>
</table>

Mean ($\mu$) and Std. deviation ($\sigma$) of spacing computed in the captured images of targets using the two readers (pattern spacing = 10 pixels)

Note:

• To compensate for the distortion induced during 2D to 3D projection of the 2D pattern, ratio of the Euclidean to Geodesic distance (0.94) is factored into spacing computations
Evaluating Fingerprint Readers

- Measurements from 5 captured images of 3D targets synthesized using fingerprints

<table>
<thead>
<tr>
<th>Test pattern</th>
<th>Optical Reader 1 (500 ppi)</th>
<th>Optical Reader 2 (1000 ppi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0005 (9.45)</td>
<td>( \mu = 8.93, \sigma = 0.12 )</td>
<td>( \mu = 8.59, \sigma = 0.09 )</td>
</tr>
<tr>
<td>S0010 (10.20)</td>
<td>( \mu = 10.10, \sigma = 0.04 )</td>
<td>( \mu = 9.65, \sigma = 0.12 )</td>
</tr>
<tr>
<td>S0017 (10.80)</td>
<td>( \mu = 10.85, \sigma = 0.13 )</td>
<td>( \mu = 10.20, \sigma = 0.08 )</td>
</tr>
<tr>
<td>S0083 (10.42)</td>
<td>( \mu = 9.92, \sigma = 0.23 )</td>
<td>( \mu = 9.55, \sigma = 0.03 )</td>
</tr>
<tr>
<td>S0096 (10.25)</td>
<td>( \mu = 9.56, \sigma = 0.08 )</td>
<td>( \mu = 9.25, \sigma = 0.02 )</td>
</tr>
</tbody>
</table>

Mean (\( \mu \)) and Std. deviation (\( \sigma \)) of spacing computed in the captured images of targets using the two readers (average pattern spacing indicated in brackets)
iPhone 5s: Enrolment and Verification
Conclusions and Ongoing Work

• Devised a method to create 3D targets by (i) projecting a 2D calibration pattern onto a generic 3D finger surface, and (ii) fabricating using a 3D printer
• Demonstrated fidelity of the 3D target synthesis and fabrication process
• Showed the utility of the fabricated 3D targets for evaluating optical fingerprint readers

• **Ongoing Work:** Investigating alternative methods to fabricate the 3D targets with higher precision, and using materials with similar optical properties and conductivity to the human finger skin