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Cross-Spectrum Thermal-to-Visible Face Recognition

Shuowen (Sean) Hu, Ph.D.
Nathan Short, Ph.D.
US Army Research Laboratory
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**Objective:** Develop techniques exploiting multi-spectrum facial signatures for robust face recognition in challenging scenarios (nighttime, extended range)

**Motivation:**
- Enable nighttime face recognition at extended standoff distances for intelligence gathering
- Utilize thermal imaging, which acquires naturally emitted radiation from skin tissue
- Recognize individuals in thermal images from a visible face watch list (interoperability with existing databases)

**Key technical challenges:**
- Substantial differences in thermal and visible face signatures due to phenomenology
- Limited facial details in images for distant individuals

**Community context:**
- Limited work in thermal-to-visible face recognition (West Virginia U, Michigan State U)
- No prior work on polarimetric thermal face recognition
The Nation’s Premier Laboratory for Land Forces
Preprocessing Results

Visible

1 m

2 m

4 m

MWIR

LWIR
Note: Face images represent HOG feature vectors that are actually used during PLS model building.
• **Rank-1 identification rate (48 subjects)**
  – Gallery: 2 VI images per subject at 1m range
  – Probes: 2 MW/LW/VI images per range

<table>
<thead>
<tr>
<th></th>
<th>1m Range</th>
<th>2m Range</th>
<th>4m Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-to-VI</td>
<td>92.7%</td>
<td>81.3%</td>
<td>64.6%</td>
</tr>
<tr>
<td>LW-to-VI</td>
<td>82.3%</td>
<td>70.8%</td>
<td>33.3%</td>
</tr>
<tr>
<td>VI-to-VI</td>
<td>N/A*</td>
<td>100%</td>
<td>99.0%</td>
</tr>
</tbody>
</table>

* Used for gallery, not available for probe

• MW-to-VI achieves higher performance than LW-to-VI at all ranges
• LW-to-VI performance deteriorates precipitously from 2m to 4m
Recognizing low-resolution thermal probe image from high resolution visible gallery

- Down-sampled imagery to simulate extended range for cross-spectrum face recognition
- MWIR consistently outperforms LWIR at higher resolution
- Robust performance down to 30% (52×52 pixels) of original size
Advantage: Polarimetric thermal provides key textural and geometric facial details not present in conventional thermal signature

Polarimetric characteristics:
- Polarimetric image measures emission intensity at different polarization-states, which extracts information about surface texture and orientation of surface normal with respect to viewing angle (line of sight).
- Stokes vectors describe preferred polarization-state of captured light. Degree of Linear Polarization (DoLP) approximates amount of linearly polarized light emitting from a source.

Stokes Vectors:

\[
S_0 = I_0 + I_{90} \left( \frac{w}{sr cm^2} \right)
\]

\[
S_1 = I_0 - I_{90} \left( \frac{w}{sr cm^2} \right)
\]

\[
S_2 = I_{45} - I_{-45} \left( \frac{w}{sr cm^2} \right)
\]

\[
DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}
\]
Polarimetric LW-IR
- 640x480
- 7.5 - 11.1 µm
- Cooled
- 10.6 x 7.9 deg FOV

LW-IR
- 640x480
- 7.5 - 13 µm
- Uncooled
- 24 x 18 deg FOV

VISIBLE x 4
- 658x492
- 400-920nm
- 5, 17, 34, 53 deg FOV
Exploiting polarization-state information for face recognition

- Stokes images contain complementary information about facial features
- Should be able to provide more information for cross-spectrum matching
- Innovation: combine Stokes features into a composite feature set

Visible

<table>
<thead>
<tr>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>DoLP</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Image of S0]</td>
<td>![Image of S1]</td>
<td>![Image of S2]</td>
<td>![Image of DoLP]</td>
<td>![Image of Composite]</td>
</tr>
</tbody>
</table>
Results:

- 5 test sets: conventional thermal, $S\downarrow 1$, $S\downarrow 2$, DoLP, composite features
- 100 probe searches per test set
- 1070 subjects in the visible gallery
- Composite feature set substantially outperforms all other features

Summary highlighting key CMC data points:

<table>
<thead>
<tr>
<th>Input</th>
<th>Rank-1 ID</th>
<th>Rank-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S\downarrow 0$</td>
<td>60%</td>
<td>84%</td>
</tr>
<tr>
<td>$S\downarrow 1$</td>
<td>49%</td>
<td>80%</td>
</tr>
<tr>
<td>$S\downarrow 2$</td>
<td>47%</td>
<td>83%</td>
</tr>
<tr>
<td>DoLP</td>
<td>41%</td>
<td>85%</td>
</tr>
<tr>
<td>Composite</td>
<td>82%</td>
<td>94%</td>
</tr>
</tbody>
</table>
Covert, nighttime person identification

Indoor

Outdoor (Night)

DOLP within center region of face
Indoors Low-Light

Visible Scene

View from visible camera

View from thermal camera

View from polarimetric camera
Visible and Polarimetric faces

- Same subject
- All conditions

<table>
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<tr>
<th>Original</th>
<th>Nighttime</th>
<th>Low Resolution</th>
<th>Aging (3 Months)</th>
<th>Indoor/no-light</th>
<th>Indoor/low-light</th>
<th>Indoor/shadow</th>
</tr>
</thead>
</table>
**3D Face Reconstruction Technique**

- 3D face surface can be reconstructed from polarization state of emitted thermal radiation
- Combine Stokes images by Fresnel relations to extract surface normal \((\theta, \phi)\) at each pixel
- Integrate normals to generate 3D surface

**Challenges**

- \(\theta\) solved numerically using Kirchhoff radiation law in conjunction with Fresnel relations
- Inherent \(\pi\) ambiguity in azimuth angle \(\phi\)

Polarization state information can be exploited to reconstruct 3D face – address pose variations through “frontalization”
1. Thermal and polarimetric imaging sensors provides unique face recognition capability with following benefits:
   - Relatively invariant to illumination
   - Polarimetric enables 3D reconstruction → robustness to pose
   - Mitigates impact of cosmetics disguises & makeup

2. Challenges remain
   - Automated detection of facial points
   - Improved exploitation/fusion of Stokes vectors
   - Extended standoff range operation

3. **Goal:** Day and night unconstrained face recognition capability for the Warfighter based on polarimetric thermal imaging.
Dr. Nathaniel J. Short
NIPRNNT: Nathaniel.J.Short2.ctr@mail.mil
Phone: 301-394-0437

Dr. Shuowen (Sean) Hu
NIPRNNT: Shuowen.Hu.civ@mail.mil
Phone: 301-394-2526