We proposed a method which
- estimates 2D landmarks and their visibility for a face with arbitrary pose.
- estimates both the projection matrix and 3D landmarks,
- achieves superior performances than state of the art methods.

[Image of 3D scans and 2D images]

Visible Landmarks
Invisible Landmarks

3D Face Modeling

We represent 2D landmarks $U$ as pair of projection matrix $M$ and 3D shape parameter $p$.

Prior Work

<table>
<thead>
<tr>
<th>Method</th>
<th>3D landmark</th>
<th>Visibility</th>
<th>Pose-related database</th>
<th>Pose range</th>
<th>Landmark #</th>
<th>Estimation Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCPR (ECCV2013)</td>
<td>NO</td>
<td>Yes</td>
<td>COFW, frontal w. occlu</td>
<td>19</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>CSR (ECCV2014)</td>
<td>NO</td>
<td>Yes</td>
<td>COFW-LIPFW, Helen-O frontal w. occlu</td>
<td>19, 49, 48</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>TSPM (CVPR2012)</td>
<td>NO</td>
<td>NO</td>
<td>AFW, all poses</td>
<td>6</td>
<td>11.1</td>
<td></td>
</tr>
<tr>
<td>CDM (ICCV2013)</td>
<td>NO</td>
<td>NO</td>
<td>AFW, all poses</td>
<td>6</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>OSRED (ECCV2014)</td>
<td>NO</td>
<td>NO</td>
<td>MVFW &lt; ±40°, 68</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCDCN (ECCV2014)</td>
<td>NO</td>
<td>NO</td>
<td>AFLW, AFw &lt; ±60°, 5</td>
<td>8.0, 8.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIFA</td>
<td>Yes</td>
<td>Yes</td>
<td>AFLW, AFw</td>
<td>all poses</td>
<td>21, 6</td>
<td>6.5, 8.4</td>
</tr>
</tbody>
</table>

3D Surface-Enable Visibility

- We rotate the 3D normal surface vectors according to the rotation angle indicated by projection matrix.
- The sign of z coordinate indicates 2D landmark visibility.

Experimental Results

- AFLW dataset experiments
  - 5200 images selected evenly within $[0°, 30°],[30°, 60°],[60°, 90°]$ yaw angles.
  - Randomly partitioned into 3901 training and 1299 testing images.

- AFW dataset experiments
  - 468 faces in 205 images with poses $±90°$.
  - Labeled with up to 6 visible landmarks.

- BP4D-S database experiments
  - Includes pairs of 2D images and 3D scans of 41 subjects.
  - Half of selected 1100 images for training and rest for testing.
  - The mean 3D shape is used as a baseline (after global transformation).
  - The MAPE of baseline is 5.02, while PIFA is 4.75.