Head Pose Estimation by Imperceptible Structured Light Sensing
Jingwen Dai and Ronald Chung
Dept. of Mech. & Automation Engineering, The Chinese University of Hong Kong

1. Introduction
This article describes a method of determining all the 6 DOFs of head pose in space by the use of an imperceptible structured light system. We employ projection that appears as white light (and thus is less annoying) to humans, but underneath actually embeds coding patterns that can facilitate 3D reconstruction. The method tracks 3D salient feature points on human face accurately without the need of going through prior training. Firstly, through an elaborate pattern projection strategy and camera-projector synchronization, a pattern-illuminated image and the corresponding scene-texture image are captured. Then in the point cloud generated by structured light sensing, the facial feature points in the scene-texture image — all localized by AAM — will have their 3D positions interpolated. Correspondences between such facial features in 3D with those associated with the previous or reference image frame can then be constructed. Finally, from such point pairs in 3D, the head orientation and translation are determined. Extensive experiments show that the proposed method is effective, accurate, and fast in determining the 6 DOFs of the head pose, making it suitable for use in real-time applications.

2. Method
- Pattern Projection Strategy for Imperceptible Structured Light Sensing
  
  Here one capture-projection cycle, illustrated in Fig. 1, is used to describe the strategy of pattern projection. To achieve imperceptible structured light projection, the frequency of projection must exceed the flicker fusion threshold, which is 75 Hz for most of the people.

3. Experimental Results
To assess the feasibility of the proposed head pose estimation method using imperceptible structured light sensing, we conducted an accuracy evaluation experiment.

3.1. Experimental Setup
- Facial Feature Localization
  - Locating 2D Positions of Key Facial Feature Points in Scene-texture Image
    
    Firstly, Adaboost face detection method is employed to extract the position of the face in the image. Then AAM method is applied to locate the facial features in the segmented face image, as shown in Fig. 2(a).

  - Determining 3D Positions of Grid Points in Pattern-illuminated Image
    
    Color coding scheme is used to determine the 3D position of the grid points in the pattern-illuminated image.

  - Inferring 3D Positions of Key Facial Features
    
    3D positions of the key facial feature points are derived by a combined use of the 2D facial feature points in the scene-texture image that are localized by AAM, and the point cloud generated by structured light sensing. The interpolation process is illustrated in Fig. 2.

- 6-DOF Head Pose Estimation
  
  Head orientation and translation are estimated by SVD of a correlation matrix that is generated from 3D point pairs between consecutive frames.

\[
H = \sum_{i=1}^{N} p_i p_i^T = U \Lambda V^T, \\
\hat{R} = UV^T, \\
\hat{T} = \hat{p} - \hat{R} \hat{p},
\]

where \( p_i \) = \( \bar{p} - \bar{p} \), \( \bar{p}_i = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} p_i \), \( \bar{p} = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} p_i \).

Experimental results at some frames of a subject are presented in Fig. 3. In each sub-figure the AAM-located feature points are indicated by yellow circles in the corresponding scene-texture image. The inset image at the bottom-right corner of each sub-figure shows the corresponding pattern-illuminated image, while the inset image at the top-right represents a qualitative description of the estimated head pose, in which the ground-truth and the estimated head pose are implied by a blue circle (or ellipse) and a red arrow respectively.

The mean absolute estimation error of the proposed method, along with those of three other systems, are shown in Table I. The comparison should be considered as a reference only, since the evaluation data-sets and the systems used to obtain the ground-truth are not exactly the same.

<table>
<thead>
<tr>
<th>Method</th>
<th>Sensing</th>
<th>Mean Absolute Error (°)</th>
</tr>
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<tbody>
<tr>
<td>Murphy-Chutropian</td>
<td>Monocular</td>
<td>3.39</td>
</tr>
<tr>
<td>Morency</td>
<td>[7]</td>
<td>Stereo</td>
</tr>
<tr>
<td>Jimenez</td>
<td>[8]</td>
<td>Stereo</td>
</tr>
<tr>
<td>Our method</td>
<td>ILS</td>
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Contact email: jwdai@cuhk.edu.hk