INTRODUCTION

Face recognition under variations in illumination and pose has been recognized as a difficult problem with pose appearing somewhat more challenging to handle than variations in illumination (Zhao et al., 2003).

What’s Known About Illumination:

- Subject illumination cone is linear (Belhumeur & Kriegman, 1998) and low-dimensional (Basi & Jacobs, 2003).
- Illumination face spaces are idiosyncratic (Chang et al., 2006).

What’s Known About Pose:

- Subject pose manifold is nonlinear.
- Linear methods perform poorly on this problem (e.g. SVD-based).

Past Approaches:

- Illumination cone (Georghiades et al., 2001).
- Light-fields (Gross et al., 2004).
- 3D Morphable Model (Blanz & Vetter, 2003)

Past Classification Method:

- Comparing distances of a single incidence of the probe class with a single or multiple incidence(s) of the gallery classes.
- Euclidean or statistical measure of similarity.

PROPOSED METHOD

- We propose to use set-to-set comparison paradigm for face recognition where we assume multiple images of each subject are available.
- This paradigm naturally induces classification on the Grassmannians (definition is given below), where well-established metrics (Edelman et al., 1999) are available for classification (examples given below).
- Any attempt to construct a unitarily invariant metric on the Grassmann manifold will yield something that can be expressed in terms of principal angles.

Definition

The Grassmannian $G(k,n)$ or the Grassmann manifold is the set of $k$-dimensional subspaces in an $n$-dimensional vector space $K^n$ for some field $K$, i.e.,

$$G(k,n) = \{ W \subset K^n | \dim(W) = k \}.$$  

Arc length (Geodesic) $d_{arc}(X,Y) = \|X - Y\|_2$

Fubini-Study $d_{FS}(X,Y) = \cos^{-1} (\prod \cos \theta)$

Chordal (Projection F) $d_c(X,Y) = \sin \theta$}

RESULTS

- Extended Yale Face Database B (YDB) (Georghiades et al., 2001).
- 28 subjects, 9 poses, 65 illumination conditions
- The “illum” subset of CMU-PIE database (Sim et al., 2003).
- 67 subjects, 13 poses, 21 illumination conditions

Table 1. Average recognition error rate for Experiments I, II, and III using the first principal angle. Poses c07, c09, c25, and c31 are excluded in Experiment III of the CMU-PIE.

<table>
<thead>
<tr>
<th></th>
<th>Database</th>
<th>Experiment I</th>
<th>Experiment II</th>
<th>Experiment III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended YDB</td>
<td>0.05</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMU-PIE</td>
<td>0.01</td>
<td>26.9</td>
<td></td>
<td></td>
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</tbody>
</table>

DISCUSSIONS

- Set-to-set paradigm is done by realizing sets of images as points on a Grassmann manifold and employ a geometric perspective for computing metrics that compare subspaces and extract neighborhood information.
- Sufficient sampling of the variation is critical and in the illumination and pose problem, it is more important for pose than illumination.
- No geometric normalization and preprocessing is required.
- Most of the computation is done off-line, therefore making the method efficient. See Table 2 for a short comparison of the speed.

<table>
<thead>
<tr>
<th></th>
<th>30X3M</th>
<th>Illumination Cone</th>
<th>Set-to-Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set used</td>
<td>Lights of PIE</td>
<td>YDB</td>
<td>“illum” of PIE</td>
</tr>
<tr>
<td>Image pixel size</td>
<td>256 x 300</td>
<td>256 x 300</td>
<td>256 x 300</td>
</tr>
<tr>
<td>Identification time for one probe</td>
<td>2.5 min</td>
<td>2.5 sec</td>
<td>0.65 sec</td>
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Table 2: Computational speed of the two state-of-the-art face recognition algorithms and the proposed set-to-set algorithm.