Object Identification and Recognition (IV)

Introduction to Computational and Biological Vision

CS 202-1-5261

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Appearance-Based Recognition

Recognition by appearance matching

DB

Direct comparison
Appearance-Based Recognition

Abstraction - images as vectors

\[ \Rightarrow \vec{v}_I \]

\[ \Rightarrow I \]
Appearance-Based Recognition

Abstraction - images as vectors

Normalized images $\|\vec{v}_I\| = 1$
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Recognition by appearance matching

\[ \text{arg min } D(\vec{v}_{I_i}, \vec{v}_q) \]

\[ = \text{arg min } \left\| \vec{v}_{I_i} - \vec{v}_q \right\| \]

\[ = \text{arg min } \left( \hat{v}_{I_i} \cdot \hat{v}_q \right) \]
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Problems in naive appearance matching

Variability due to pose/viewing
Appearance-Based Recognition

Problems in naive appearance matching

Variability due to illumination
Appearance-Based Recognition

Problems in naive appearance matching

Image size $N \times N$ pixels, $B$ bytes/pixel

$N_V$ viewing directions per object

$N_L$ illumination directions per object

$N_o$ objects in database

$$\downarrow$$

$$N_o \cdot B \cdot N^2 \cdot N_V \cdot N_L \quad \text{bytes}$$

$N = 256$

$B = 3$

$N_V = 64 \quad \Rightarrow \quad 75GBytes$

$N_L = 64$

$N_o = 100$

Cost of representation
Appearance-Based Recognition

Problems in naive appearance matching

$$\left\| \vec{v}_{I_i} - \vec{v}_q \right\| = \sqrt{\sum_{k=1}^{N^2} \left( \vec{v}_{I_i}(k) - \vec{v}_q(k) \right)^2}$$

$O(N^2)$ operations / image

Cost of matching
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Image manifolds
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Object manifolds

Object $o_i$ under all possible viewing and illumination directions

Object $o_j$ under all possible viewing and illumination directions
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Image manifolds and PCA

PCA: Find basis which maximizes directional variance
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Eigenspace representation

Let $\vec{v}_1, \vec{v}_2, \ldots, \vec{v}_n$ be $N^2$-dimensional (image) vectors and their average vector. Let $X$ be the $N^2 \times n$ matrix

$$X = \begin{bmatrix} (\vec{v}_1 - \bar{v}) & \cdots & (\vec{v}_n - \bar{v}) \end{bmatrix}$$

then each $\vec{v}_j$ can be written as

$$\vec{v}_j = \bar{v} + \sum_{i=1}^{n} g_{ji} \cdot \vec{e}_i$$

where $\vec{e}_1, \vec{e}_2, \ldots, \vec{e}_n$, the principle components, are the eigenvectors of the covariance matrix $Q = XX^T$ corresponding to the $n$ (nonzero) eigenvalues of $Q$. 

$$\bar{v} = \frac{1}{n} \sum_{j=1}^{n} \vec{v}_j$$
**Appearance-Based Recognition**

**Eigenspace representation**

\[ \vec{v}_j \quad \Rightarrow \quad \vec{g}_j = (g_{j1}, \ldots, g_{jn}) \]

Image representation

- in natural basis

Image representation

- in eigenspace

\[ \lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_n \quad \Rightarrow \quad \vec{e}_1, \vec{e}_2, \ldots, \vec{e}_n \]

Decreasing eigenvalues

Variance maximizing eigenvectors

\[ \lambda_{i>k} \approx 0 \quad \Rightarrow \quad \vec{v}_j \approx \vec{v} + \sum_{i=1}^{k} g_{ji} \cdot \vec{e}_i \]

Vanishing eigenvalues

Compact (k-dim) image representation
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Eigenspace and PCA
Appearance-Based Recognition

\[ O(N^2) \]

Similarity in eigenspace

\[
\left\| \vec{v}_j - \vec{v}_q \right\| = \left\| \left( \vec{v} + \sum_{i=1}^{n} g_{ji} \cdot \vec{e}_i \right) - \left( \vec{v} + \sum_{i=1}^{n} g_{qi} \cdot \vec{e}_i \right) \right\|
\]

\[
\approx \left\| \left( \vec{v} + \sum_{i=1}^{k} g_{ji} \cdot \vec{e}_i \right) - \left( \vec{v} + \sum_{i=1}^{k} g_{qi} \cdot \vec{e}_i \right) \right\|
\]

\[
= \left\| \sum_{i=1}^{k} (g_{ji} - g_{qi}) \cdot \vec{e}_i \right\| = \sqrt{\sum_{i=1}^{k} (g_{ji} - g_{qi})^2} = \left\| g_j - g_q \right\|
\]

\[ O(k) \]
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Recognition in the image eigenspace
**Appearance-Based Recognition**

Appearance-based recognition in the image eigenspace

1. Obtain a training set of images of all objects of interest under variable viewing and illumination conditions
2. Construct the image eigenspace from the training set using PCA
3. Given a query image
   - Project the image to the PCA subspace (eigenspace)
   - Compute distances to training set images in the eigenspace and find object manifold $o_j$ with minimal distance $d_{\text{min}}$.
   - Unless $d_{\text{min}}$ too large, identify query image with object $o_j$. 
Appearance-Based Recognition

Example

Database = 40 pictures, 10 individuals, 4 pictures per individual.
Appearance-Based Recognition

Example

Average “object”

First three principle components
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Example

Query image (new)

Eigenspace reconstruction
(10 principle components)
Appearance-Based Recognition

Example