3D Object Recognition Based on Canonical Angles between Shape Subspaces

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Goal and Solutions

Our goal is to realize a framework for 3D object recognition, which is invariant to camera rotation and object motion.

How was the framework achieved?

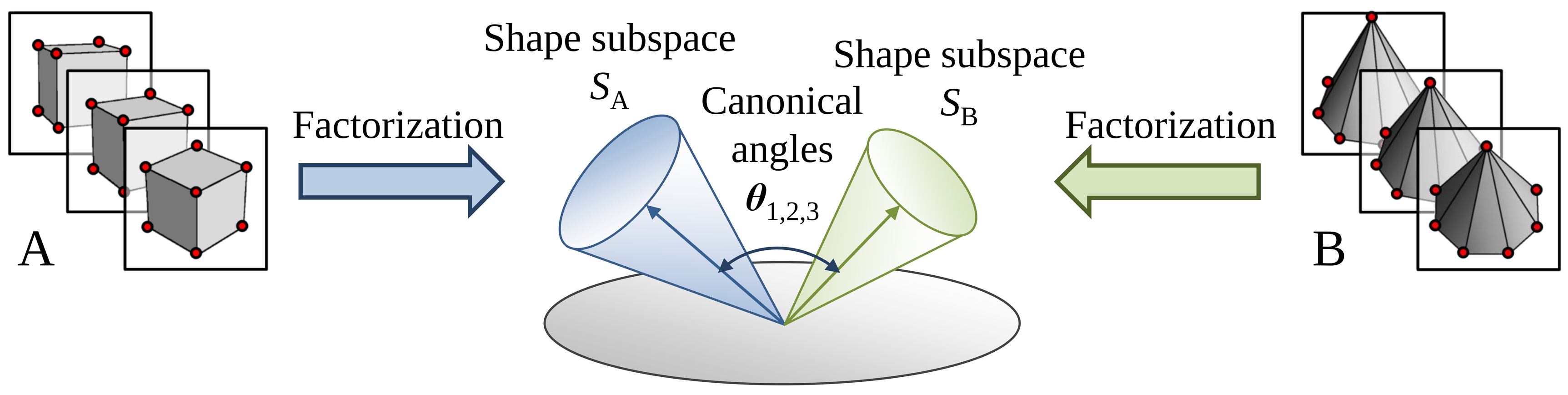
We establish an index of shape similarity by measuring the geometrical relation between two shape subspaces using canonical angles.

To obtain a similarity, we must solve the point matching problem.

We introduce a new method to solve the problem by comparing the orthogonal projection matrices of two shape subspaces.

Concept of our framework for 3D object recognition

(1) The feature points are tracked through image sequence for each object.
(2) The shape subspaces are derived from the sets of the tracked feature points by the factorization method.
(3) Canonical angles between the shape subspaces are calculated and used to construct a measure of shape similarity.



1. Calculation of shape subspace with factorization of an image sequence

The measurement matrix $\mathbf{W}$ is factored into the product of three matrices.

$$\mathbf{W}_{2F\times P} = \mathbf{U}_{2F\times 3}\Sigma_{3\times 3}\mathbf{V}^T_{P\times 3}$$

F: num of frames
P: num of points

The column vectors of ***shape matrix*** $\mathbf{V}$ span ***shape subspace***.

2. Similarity based on canonical angles between shape subspaces

Let $\mathbf{Q}_A$ and $\mathbf{Q}_B$ denote the orthogonal projection matrices of the shape subspaces S_A and S_B. Then, $cos^2\theta_i$ for the canonical angle θ_i is equal to the i-th largest eigenvalue of $\mathbf{Q}_A\mathbf{Q}_B$. We define the shape similarity Sim as follows.

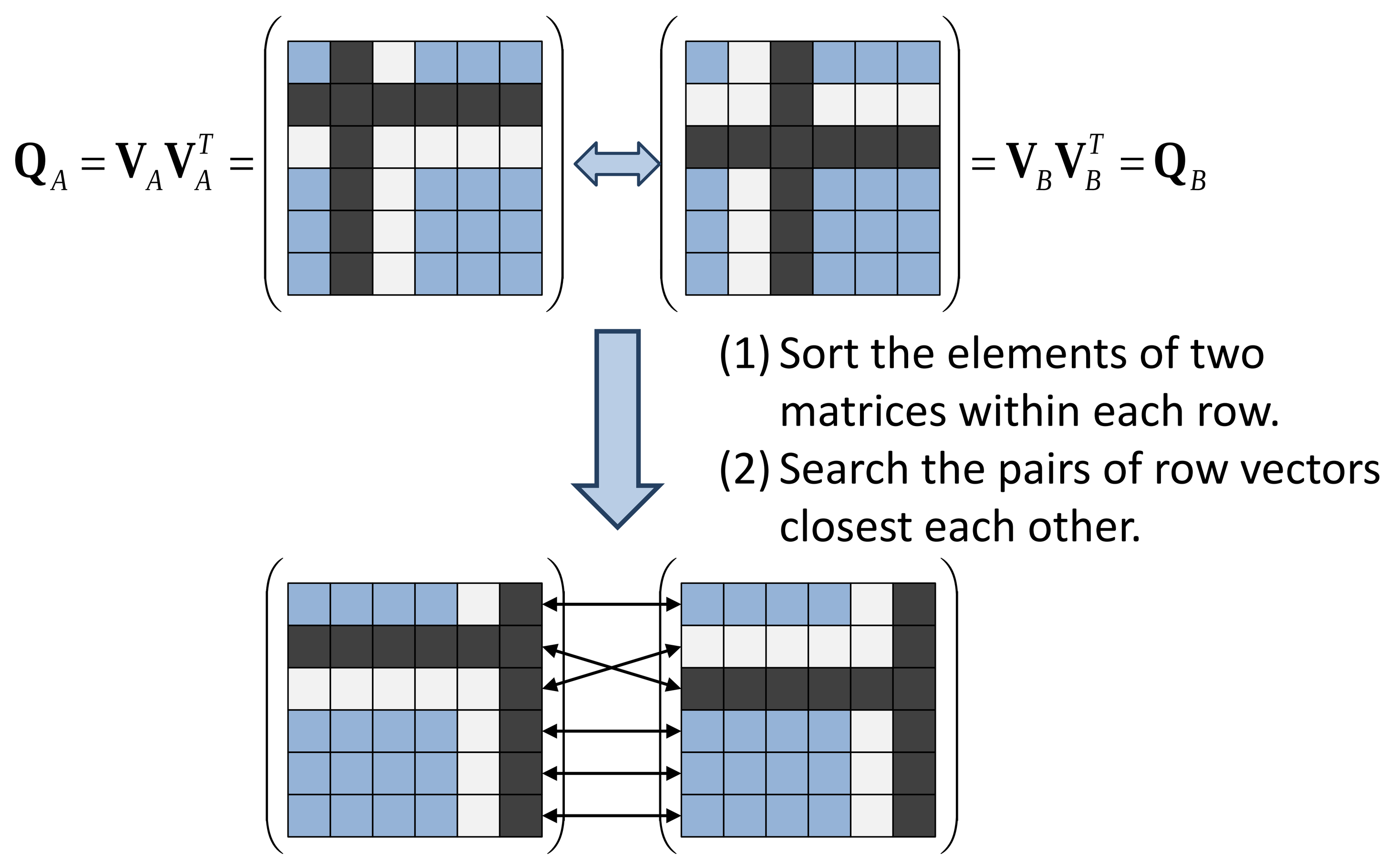
$$Sim = \frac{1}{3}\sum_{i=1}^{3}\cos^2\theta_i\ ,\quad 0.0 \le Sim \le 1.0$$

Matching points using orthogonal projection matrices

If the order of feature points changes, the shape subspace corresponding to them also changes. Therefore, we need to match the feature points.

How are the sets of feature points matched?

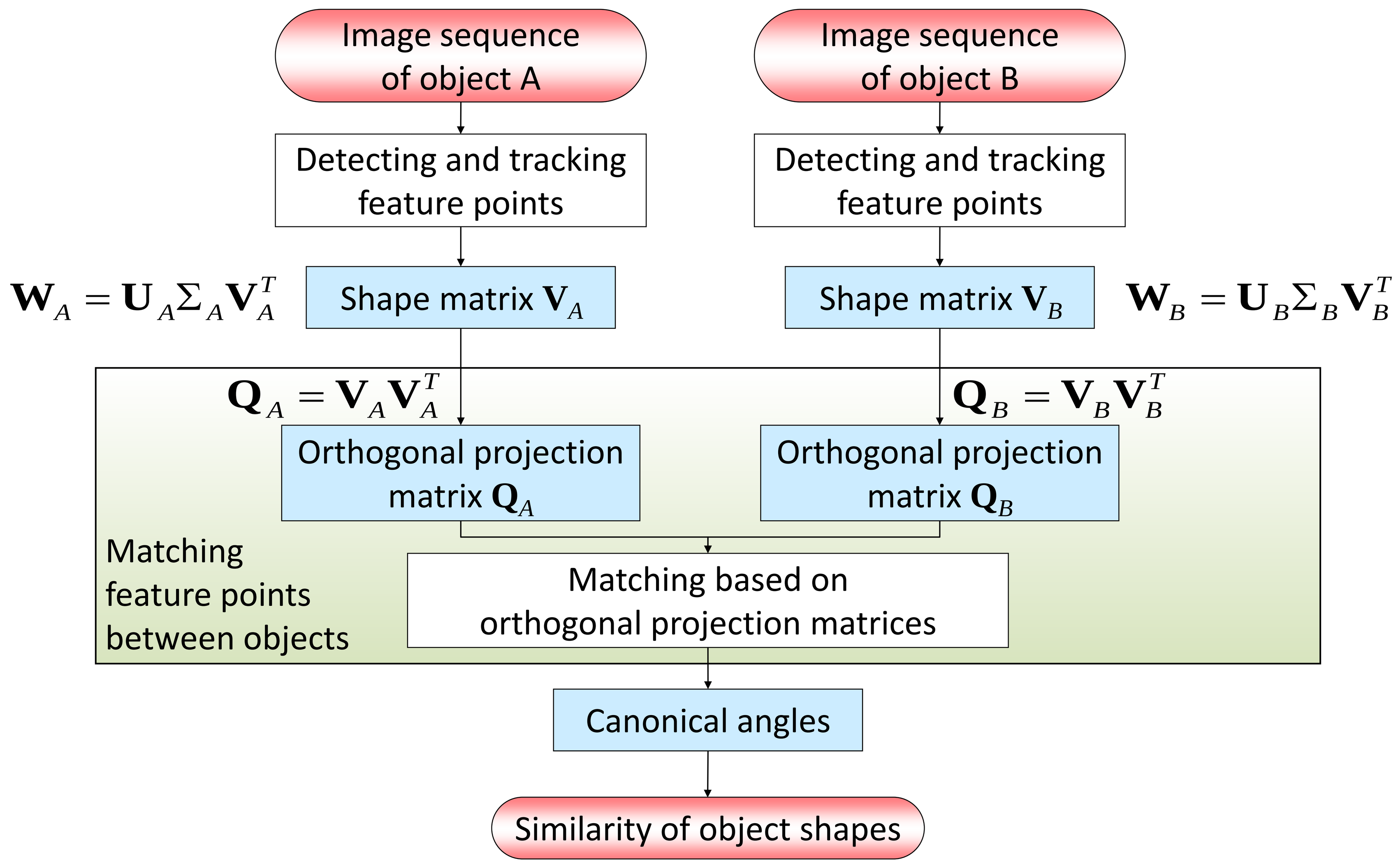
(1) Shape matrix is just one set of basis vector of a shape subspace. Then we can not use the shape matrices to match the feature points.
(2) The orthogonal projection matrix is unique to a shape subspace.
(3) So we match the feature points sets by rearranging the rows and columns of the orthogonal projection matrices.



References

[1] Z. Wang, et al., "Dimension-free affine shape matching through subspace invariance," CVPR2009.
[2] K. Fukui, et al., "Facial feature point extraction method based on combination of shape extraction and pattern matching," Systems and Computers in Japan, 1998.

Flow of the proposed object recognition

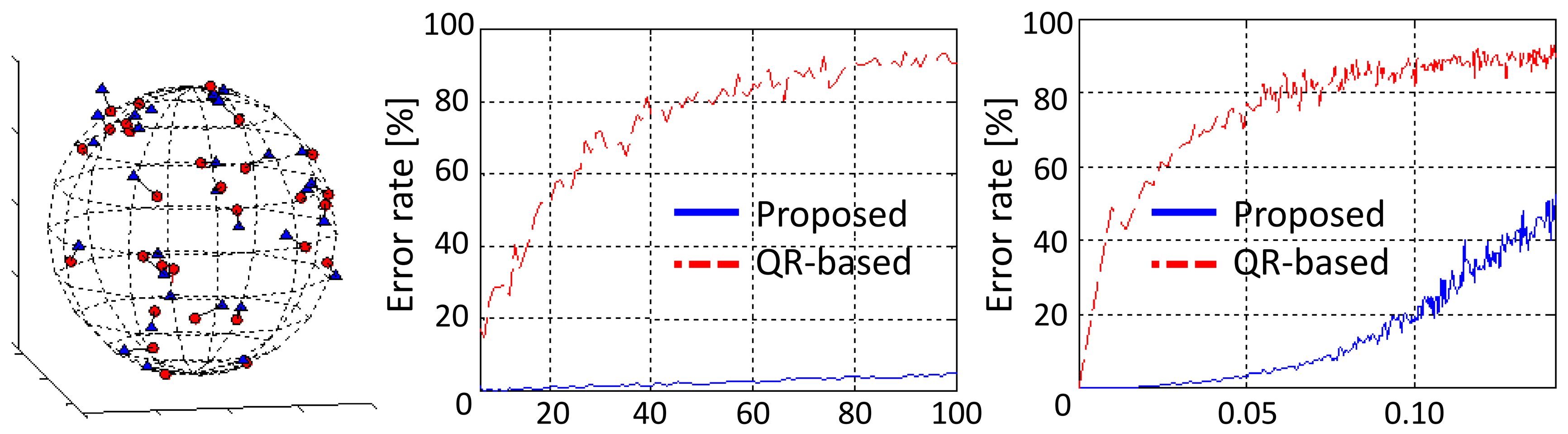


Experimental results

1. Matching feature points using synthetic data

We evaluate the robustness of the proposed matching method using synthetic 3-dimensional data sets. We compared the proposed method with the QR-based method[1].

(1) One is a set of P randomly generated points on an unit sphere. The other is with added Gaussian noise of standard derivation σ.
(2) For each of the parameters, 200 independent experiments were run.



Proposed (P = 30, σ = 0.1) | Num of points: P (σ = 0.0316) | Standard derivation: σ (P = 30)

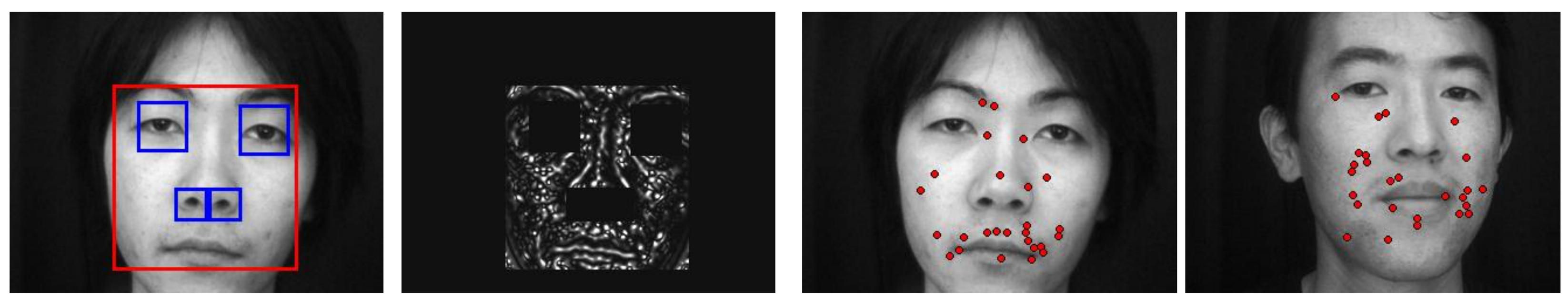
2. Face recognition

Input

(1) Capture **300 image sequences** for each of **22 subjects**.
(2) Apply face detection and circular separability filter[2].
(3) Detect and track **26 points** from the 300 separability maps by KLT tracker.
(4) The 300 image sequences were **divided into sets of 30 frames** for each subject.

Recognition

(1) Compare the proposed method with QR-based matching in terms of classification.
(2) NN method was used as classifer and the rate was estimated by Leave-One-Out.



Face detection | Separability map | Detecting and tracking feature points

Matching feature points between two sequences by proposed method

Matching	Recognition rate	EER
Proposed	99.5% (219/220)	2.60%
QR-based	94.1% (207/220)	17.30%