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Machine Learning with Eigenvector-Based Feature Representation: A Mathematical Analysis Using SVM for Robust Face Recognition

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INTRODUCTION & AIM

Face recognition remains one of the most important applications of computer vision and machine learning. However, the performance of recognition systems often degrades in the presence of noise, illumination variations, and high-dimensional image representations. Principal Component Analysis (PCA) and Support Vector Machines (SVMs) have been widely employed for facial image analysis due to their ability to reduce dimensionality and perform accurate classification.

Despite their popularity, conventional PCA-based approaches select eigenvectors solely according to the amount of retained variance, which does not necessarily guarantee optimal class discrimination. This limitation motivates the development of a more discriminative feature extraction strategy capable of enhancing recognition performance under challenging imaging conditions.

OBJECTIVE

The objective of this work is to develop a robust face recognition framework that combines:

• Discriminative eigenvector-based feature extraction.
• Adaptive dimensionality reduction.
• Kernel-aware SVM optimization.
• Improved generalization in noisy environments.

The proposed framework aims to maximize class separability while preserving the most informative facial characteristics.

PROPOSED METHODOLOGY

The proposed approach consists of four main stages.

First, facial images are preprocessed and transformed into a high dimensional feature space. PCA is then applied to compute eigenvectors describing the principal facial variations.

Unlike traditional Eigenfaces methods, eigenvectors are not selected solely according to their variance contribution. A discriminative criterion is introduced to identify components that maximize inter-class separability while minimizing intra-class variability.

The selected feature vectors are subsequently used to train Support Vector Machine classifiers. Several kernels, including Linear, Polynomial, and Radial Basis Function (RBF), are evaluated through systematic hyperparameter optimization.

Finally, cross-validation is employed to determine the optimal configuration and improve model generalization.`

MATHEMATICAL FRAMEWORK

Given a set of facial images represented by vectors x_i ,PCA projects the data onto a lower-dimensional eigenspace:

$$y = W^T(x - \mu)$$

where:

• W is the eigenvector matrix,
• μ is the mean image,
• y is the reduced feature vector.

The SVM classifier determines the optimal separating hyperplane:

$$f(x) = sign(w^T x + b)$$

while maximizing the margin between classes.

Kernel functions enable nonlinear decision boundaries and improve classification performance in complex feature spaces.

RESULTS & DISCUSSION

EXPERIMENTAL SETUP

Experiments were conducted using the Extended Cohn–Kanade (CK+) facial expression dataset.

To evaluate robustness, several degradation scenarios were simulated, including:

• Additive image noise.
• Illumination variations.
• High-dimensional feature representations.

Performance was compared against:

• Standard PCA + SVM.
• Raw-feature SVM.
• Proposed Discriminative Eigenvector + Optimized SVM framework.

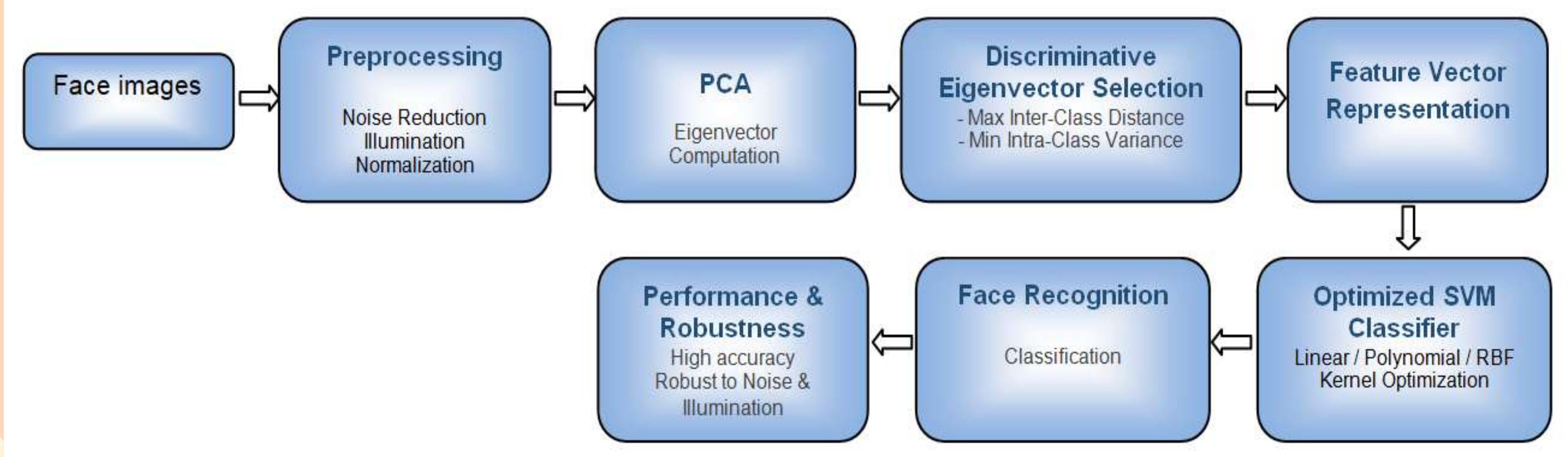
RESULTS AND DISCUSSION

The proposed framework consistently outperformed conventional approaches across all experimental settings.

Classification accuracy exceeded 97% on the CK+ dataset, demonstrating the effectiveness of discriminative eigenvector selection. The optimized SVM kernels produced more stable decision boundaries and improved resistance to image degradations.

Experimental results further revealed that controlling support vector sparsity reduces overfitting and enhances generalization performance. These findings confirm that the interaction between feature-space structure and margin-based learning plays a crucial role in robust face recognition.

Figure. Proposed Face Recognition Frame work



CONCLUSION

This work presents an enhanced machine learning framework for face recognition that integrates discriminative eigenvector-based feature extraction with optimized SVM classification. By combining adaptive subspace selection and kernel-aware learning, the proposed approach significantly improves recognition accuracy and robustness under challenging conditions.

The obtained results demonstrate that classical machine learning techniques can still achieve competitive performance when supported by appropriate mathematical optimization strategies.

FUTURE WORK

Extension to deep hybrid architectures.

• Integration with Kernel PCA and manifold learning techniques.
• Evaluation on larger and unconstrained face datasets.
• Real-time deployment in intelligent surveillance systems.
• Investigate numerical stability of the obtained solutions.

REFERENCES

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