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Fuzzy Based Face Recognition System using Machine Learning Algorithms

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ABSTRACT: Face recognition is a hard computer vision problem with increasingly more applications in finance, healthcare, and security. Yet, being insensitive to varying illumination, facial expressions, poses, and occlusions is still a hard problem. Current systems are non-robust and generalize poorly due to poor feature extraction and inefficient classifier performance. Experiments have to be performed with the implementation of strong feature extraction methods and high-performance classifiers to enhance system performance. Hybrid methods using the combination of various features may possess potential for accomplishing higher recognition accuracy and reliability. This paper provides a comparative analysis of ANN, SVM, and RF classifiers using HOG, fuzzy FIS, and hybrid combinations of features for face recognition. The proposed model indicates that fuzzy-based feature extraction and hybrid features improve the system's robustness, accuracy, and reliability when tested on the ORL dataset.

KEYWORDS: Face Recognition, Artificial Neural Networks (ANN), Support Vector Machine (SVM), Random Forest (RF), Histogram of Oriented Gradients (HOG), Fuzzy Inference System (FIS), Hybrid Feature Extraction.

I. INTRODUCTION

Face recognition technology is currently an important application in most industries such as security, health, and finance. The technology can identify and verifying individuals according to their faces, and thus it is an important application in systems such as surveillance systems, biometric identification, and interactive customer service. As technology keeps advancing, face recognition systems will increasingly provide accurate and consistent responses in varying environments.

Even with these developments, face recognition continues to be vulnerable to lighting, expression, and pose changes. Conventional approaches based on feature extraction methods like edge detection or texture mapping do not work when exposed to such variability. It is therefore important to create more resilient techniques that can effectively handle such complexities.

This paper emphasize evaluating various feature extraction techniques and classification algorithms in an attempt to offer improved accuracy and reliability in face recognition systems. It addresses performance using classifiers such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Random Forest (RF) and various feature extraction techniques such as Histogram of Oriented Gradients (HOG) and fuzzy-based feature extraction and combining hybrid models combining both aforementioned.

The approach is to utilize the ORL dataset, which has 40 subjects with 10 images per subject, under varying lighting and facial expression conditions. The dataset is split into training and test sets in an 80-20 ratio. The second one is the face feature extraction by three different ways: Histogram of Oriented Gradients (HOG) to extract gradient-based texture features, fuzzy-based face feature extraction for obtaining soft variations in facial features, and hybrid way that makes use of both HOG as well as fuzzy features to acquire stronger

robustness of the system. The face features are extracted and then run through Principal Component Analysis (PCA) for reduction in dimension. Three classifiers ANN, SVM, and RF are next trained on extracted features and their performance is compared by accuracy, confusion matrices. This method tries to identify the optimal feature-classifier combination for maximum face recognition performance under different conditions.

II. LITERATURE SURVEY

Utilization of different techniques for image processing and classification has been at the center of the creation of effective recognition systems. This literature review covers research on Fuzzy Inference Systems (FIS), Histogram of Oriented Gradients (HOG), Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Random Forests (RF), with emphasis on their discoveries and contributions toward classification and recognition processes.

Kumar and Sundaresan (2015)[1] suggested a fuzzy inference system for edge detection, which applies fuzzy membership functions to adaptively detect edges in images. Their approach solves the problems of varying illumination and noise, providing enhanced edge detection accuracy. This fuzzy-based technique set the stage for more research on fuzzy-based classification methods.

Khanam et al. (2020)[2] proposed a fuzzy-based facial expression recognition model. Fuzzy logic was used in the study to process facial features and classify expressions, proving its strength in emotion recognition under various conditions. Their research showed the potential of fuzzy systems in dealing with intricate recognition tasks such as facial expression detection.

Li et al. (2021)[3] discussed the application of Histogram of Oriented Gradients (HOG) features for face recognition. Through their research, they proved how HOG retains edge features important for face recognition in different conditions. The paper proved that HOG, when coupled with other methods, offers a suitable solution for face recognition, thus making it a common feature extraction method within image processing.

Cheng et al. (2022)[3] suggested an improved SVM-based face recognition model using SVM with HOG features. Their performance demonstrated better results in recognition, especially in the management of large databases and varying light conditions.

Sharma et al. (2020)[5] discussed the function of activation functions in artificial neural networks (ANNs). Their research emphasized the significance of selecting an appropriate activation function to improve network performance and accelerate convergence. Through a comparison of different activation functions, the paper illustrated how they affect the capacity of neural networks to learn intricate patterns, which is essential for enhancing recognition accuracy in deep learning models.

Zhou et al. (2018)[6] concentrated on the use of Random Forests (RF) for object recognition and classification processes. The paper proved how the ensemble method of RF, in its use of an array of decision trees, was effectively usable for classifying pictures and working with noisy data. The merger of decision trees helped RF maintain its strong performance of classification for multiple datasets and reflected its importance for complicated work such as facial and object identification.

In summary, these works provide significant contributions to the utilization of fuzzy inference systems, HOG, SVM, ANN, and RF in multiple recognition and classification applications. Their works point out the advantages of each method and the continued improvements in image processing and machine learning.

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III. PROPOSED METHODOLOGY

The architecture of facial recognition system is modular from pre-processing of images to feature extraction through methods such as HOG and fuzzy logic-based features. PCA is employed for dimension reduction of features. Features are utilized in model training using classifiers such as ANN, SVM, and Random Forest. Performance is measured against standards such as accuracy, confusion matrix. It is modular and scalable in design to enable flexibility towards future development with the possibility of being configured towards a new feature extraction algorithm. Olivetti Research Laboratory (ORL) face dataset is utilized. Below figure 1 shows a sample of 10 faces from ORL dataset.

Figure 1: ORL dataset images of 10 people.

1. Dataset Loading and Pre-processing

The first thing to do is to load the ORL face database (400 images of 40 people). Images are loaded and resized. The data is then split between test and train sets. The operation is done in a way where 80% of data is utilized for model training and 20% for model testing. Normalization of pixel values is also included during pre-processing in order to further refine feature extraction and model performance.

2. Feature Extraction

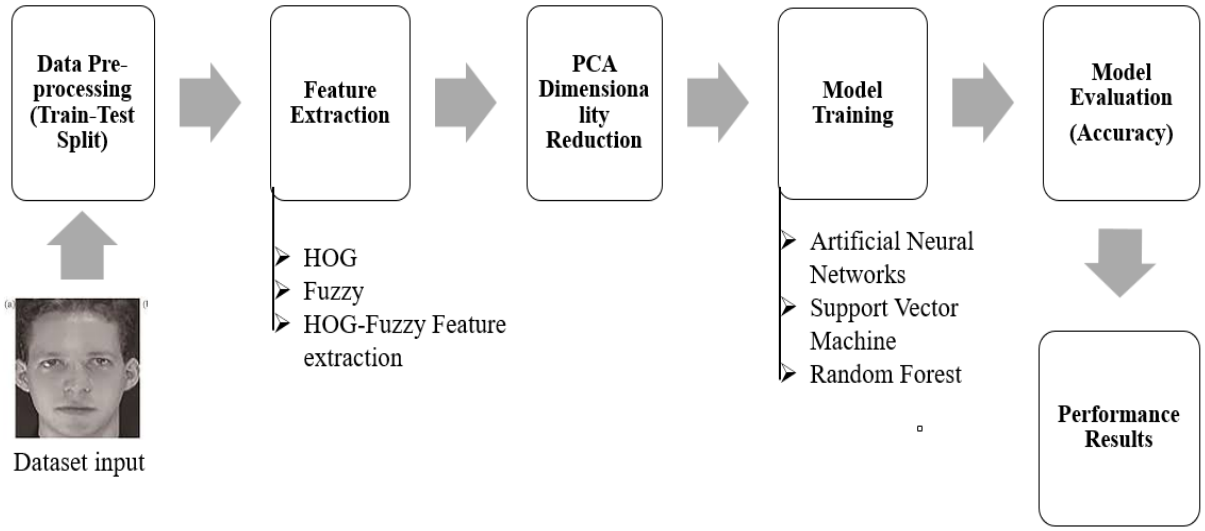
Feature extraction is a critical step of image classification. Three major approaches are employed in feature extraction: Histogram of Oriented Gradients (HOG), Fuzzy and HOG - Fuzzy hybrid feature extraction.

HOG approach achieves edge features by segmenting the image into tiny spatial areas and calculating the gradient direction histograms. Resizing each image to a 64 × 64 pixels image, applying HOG with 3 orientations, 8×8 pixel cells, and 1×1 block configuration, one gets a 41-dimensional feature vector after PCA dimensionality reduction.

The fuzzy-based approach uses a Canny edge detector and histogram equalization to generate edge and texture maps. Sigmoid and Gaussian membership functions are utilized to fuzzify them. Semantic features, smooth and sharp are computed from statistical means of the fuzzified edge and texture maps through a fuzzy inference system (FIS). The whole fuzzy feature vector is then mapped by PCA to 246 dimensions. The Fuzzy-HOG hybrid feature extraction is obtained by concatenating fuzzy and HOG features with the resulting 287-dimensional vector. These extracted features are then utilized in classification models for face recognition.

3. Model Training and Evaluation

Model training and evaluation occur after feature transformation and extraction via PCA. Artificial Neural Network (ANN), Support Vector Machine (SVM), and Random Forest (RF) are trained using PCA-transformed features according to this method. These classifiers are used to study the performance of various algorithms in facial image classification depending on the application of various feature extraction methods. Once a model is trained, accuracy, confusion matrices are generated to make a prediction regarding what each classifier is going to perform. These do everything in their power to produce a prediction on what each



classifier is going to do with varying sets of features.

Figure 2: Block diagram for proposed methodology.

4. Results and Analysis

The plot of the different classifiers (SVM, ANN and RF) and feature extractors (HOG, Fuzzy, Fuzzy-HOG) work best against the other. Accuracy-wise, the best accuracy was with the use of Fuzzy -HOG hybrid feature and SVM classifier was 95%. Below table 1 and figure 3 shows the accuracy of all 3 models.

Feature Type	Classifiers		
	ANN	SVM	RF
HOG	82.5	91.25	78.75
Fuzzy	90.0	95.0	83.75
Fuzzy-HOG	92.5	95.0	90.0

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Table 1: Comparison of Classification Accuracy for HOG, Fuzzy, and Fuzzy-HOG Features Using ANN, SVM, and RF.

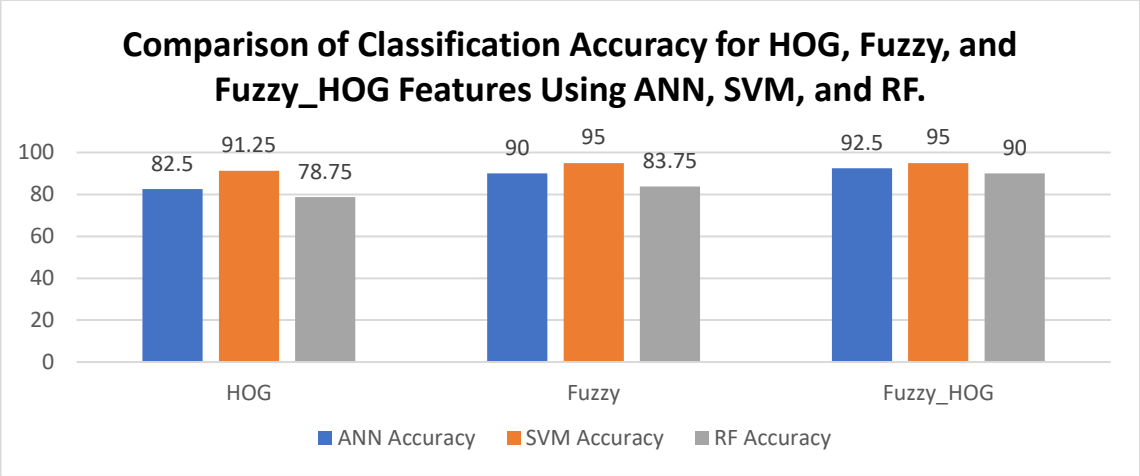

Figure 3: Comparison plot of Classification Accuracy for HOG, Fuzzy, and Fuzzy-HOG Features Using ANN, SVM, and RF.

Apart from accuracy, additional statistics like Precision, Recall and F1-Score are calculated by using macro and weighted metrices. These readings present a more detailed picture of the performance. Below table 2 gives the summary of additional metrices calculated.

Feature and Model	Macro Metrices			Weighted Metrices		
	Precision	Recall	F1-Score	Precision	Recall	F1-Score
HOG with ANN	84%	87%	82%	87%	82%	83%
HOG with SVM	93%	93%	90%	95%	91%	90%
HOG with RF	78%	83%	74%	87%	79%	78%
Fuzzy with ANN	91%	93%	88%	96%	90%	91%
Fuzzy with SVM	97%	97%	95%	97%	95%	94%
Fuzzy with RF	83%	88%	79%	91%	84%	83%
HOG-Fuzzy with ANN	92%	95%	91%	96%	93%	92%
HOG-Fuzzy with SVM	97%	97%	95%	97%	95%	94%
HOG-Fuzzy with RF	92%	91%	88%	94%	90%	89%

Table 2: Classification Metrics (precision, recall, f1-score)

The outcome of this comparison is that SVM can be employed to its full potential using the Fuzzy-HOG feature set and that it is more accurate. But the ANN and Random Forest are also doing reasonably well but are not as accurate as SVM while utilizing the Fuzzy-HOG feature set. Overall, this systematic framework provides a high-level description of the face recognition system to balance well classifier performance and accuracy. Confusion matrix depth and performance measure will be of highest importance in ensuring improvement and

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evolution, and resulting system will be effective and robust for actual implementation. Below Figure 4 shows the confusion matrix of SVM with HOG-Fuzzy combination.

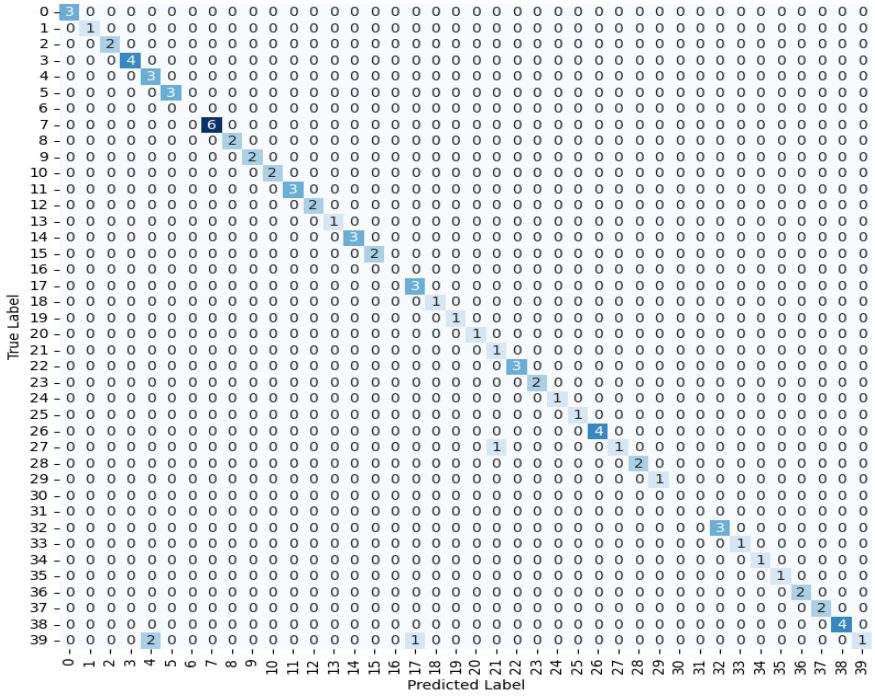

Figure 4: Confusion matrix of Fuzzy-HOG feature with SVM combination.

IV. Testing and Results

The extracted features are given to the models and get trained and validated. Three classifiers SVM, ANN and RF were attempted on different features: HOG features, fuzzy features, and fuzzy-HOG hybrid features. SVM classifier performed better than all combined, most notably with the fuzzy-HOG hybrid features, with 95% accuracy. ANN also had competitive performance, the fuzzy-HOG combination providing it 92.5% accuracy. Random Forest, while lower, did significantly better with the hybrid features at 90% accuracy. The results show that the combination of fuzzy logic-based descriptors and HOG features significantly improves the power of classifiers in discriminating different classes, especially with SVM.

V. CONCLUSION

This paper focused on building an efficient face recognition system through exploration of various feature extraction techniques and classifiers on the ORL database. Experimental results showed that fuzzy-HOG hybrid feature out-performed other approaches invariably and learned texture and edge detail better. Specifically, the SVM classifier produced its optimal rate of 95% after it was trained by the fuzzy-HOG hybrid features, the power of fusion between fuzzy logic-based descriptors and HOG features being attested. The method of hybrid achieved a tremendous boost over the traditional methods, its fusion of conventional methods with the fuzzy feature extraction proving to significantly enhance discriminability and model performance. In general, the proposed methodology forms a good foundation for future face recognition systems that require not only accuracy but also reliability.

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