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Face Recognition Utilizing Generative Adversarial Networks and Fuzzy Logicfor Angle Classification

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Face Recognition Utilizing Generative Adversarial Networks and Fuzzy Logic for Angle Classification

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Abstract: Face recognition involves programming computers to identify human faces, with various authors employing different methods to tackle this challenge. The classification of the images needed to collect the required information to be used by the law enforcement for one of the major applications of image processing which involves extensive processing of image data. Moreover, pose verification is another challenging problem faced in face recognition systems. The challenge lies in recognizing faces even when there are sudden variations in the orientation of image data. The orientation-based approach to pose recognition is applied in our proposed system. The main aim of this paper is to develop an adaptive Fuzzy-GAN using the angle's orientation in face recognition. The proposed system will be able to adaptively generate Low, Medium, and High angle orientation membership functions like clockwise and anti-clockwise orientations from normalized angle face.
Keywords: Angles based Face image Classification, Adaptive Fuzzy GAN, Image Processing etc.
1.Introduction: Computer vision is a well-known approach of Artificial Intelligence (AI). It can enable machines to interpret visual information extracted from videos and images. The capability is achieved through image processing and AI algorithms in which facilitate image recognition and pattern recognition. Images process involves to manipulate through digital image methods such as geometric transforms, histogram equalization, and noise reduction [1, 2]. These processes include feature extraction through edge detection and description. Recent breakthroughs in computer vision, fueled by deep learning, highlight the rise of Convolutional Neural Networks (CNN) and Generative Adversarial Networks (GAN) [3]. The application of fuzzy logic can enhance the training of GANs by providing advanced decision-making and learning techniques. Integrating fuzzy techniques into this process enables GANs to effectively manage the uncertainty and vagueness inherent in real-world data [4].

The process of face unearthing is based on the identification of specific face characteristics within an image or video to recognize a person. This is done using the principles of machine learning and deep learning whereby specific facial characteristics are encoded in numbers for accurate comparison [5]. This technique is proved to be effective for real-time security applications and flexible enough for adapting variations in illumination, pose, or facial expression. It includes face detection, alignment, feature extraction, and matching for identity verification. Fuzzy logic improves facial recognition techniques by successfully solving problems of ambiguity and vagueness of data. It helps in making better decisions in different situations and improves recognition performance in unfavorable conditions [6].

Face Recognition is a forensic AI system that confirms identity using physical features. The face recognition process includes detecting, analyzing, encoding, and comparing. While it has been mainly applied to serve identification purposes, the technology is fraught with ethics issues of consent, bias, and mass surveillance. For this reason, several countries have biometric privacy laws [7-8]. This paper presents the mathematical formulation of the Fuzzy-GAN Face Recognition System, which

integrates Generative Adversarial Networks (GAN) for feature generation and increase the reliability, fuzzy logic for angle-orientation classification [11], and a face recognition matching process.

2.Proposed Work: In image processing application, where there is a huge volume of data processing, it is crucial to classify data needed for extracting useful information that is relevant to the application's targeted output [9]. Similarly, in face recognition applications, a significant challenge is the problem of pose verification [14-16]. This challenge involves recognizing faces despite sudden changes in the direction of input image data. Our proposed model addresses this issue by employing an angle-oriented pose recognition system [10], which classifies the image dataset obtained from input devices using a semicircular model.

- The goal is to develop an adaptive Fuzzy-GAN framework for angles-based face recognition. This system will automatically learn Low, Medium, and High angle-orientation membership functions, such as clockwise and anti-clockwise classifications, from normalized angles face. As a result, it aims to improve recognition accuracy, make the process easier to interpret, and increase robustness to extreme angle variations.

2.1. Face Images Using Generative Adversarial Network (GAN): Ian Goodfellow proposed the deep learning framework known as GAN, in 2014. It makes use of the Generator and Discriminator neural networks, which are in competition with one another. In an attempt to produce realistic-looking photographs, the Generator generates synthetic image data. The Discriminator attempts to distinguish between generated and actual images in order to categorize them as authentic or fraudulent.

$$\text{GAN} = \min_{GR}\max_{DR} V(DR, GR) = \text{E}_{I\sim px_{data}(I)}[\log DR(I)] + \text{E}_{q\sim px_z(z)}[\log(1 - DR(GR(q)))]$$

where GR= Generator, DR= Discriminator, I= Real Angles of Images, q= Random Noise Vector, $px_{data}(I)$= Real data distribution, $px_q(Q)$= Noise distribution.

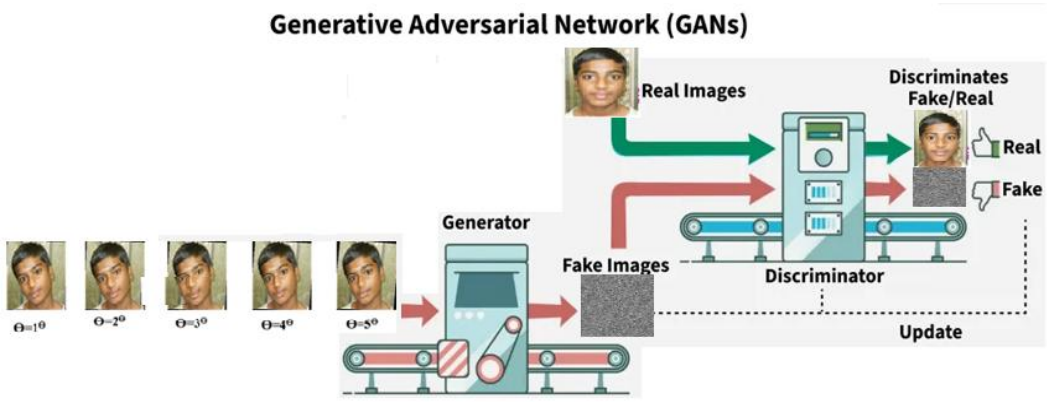


Figure-1: Develop a GAN Model of Angles of Image Framework

GANs are important in face recognition [12] for generating and augmenting angles of face images, normalizing poses, adding data, handling occlusions, and improving accuracy under different lighting and angles [15-18]. In a Fuzzy-GAN Face Recognition System, GANs produce or augment facial features, while fuzzy logic classifies posture orientations (Low, Medium, High) to improve recognition performance.

2.2. Methodology: The Fuzzy-GAN angle-oriented Face Recognition System methodology [13] integrates a mathematical framework that employs Generative Adversarial Networks (GAN) to generate and enhance features. It utilizes fuzzy logic for classifying angle orientation and supports face recognition matching. The following process steps are as follows

Step-1: Image Normalization: Let the pose angle of a face input 'I' image be normalized to the range $[0, 1]$:

$$I_n = \frac{I - I_{\min}}{I_{\max} - I_{\min}}$$

where:

- I= original face pose angle
- I_n= normalized angle value

Step-2: Role of Fuzzy Membership:

Low Direction:

$$\mu_{Low}(I_n) = \begin{cases} 1, & I_n \le a \\ \dfrac{b - I_n}{b - a}, & a < I_n < b \\ 0, & I_n \ge b \end{cases}$$

Medium Direction:

$$\mu_{Medium}(I_n) = \begin{cases} 0, & I_n \le a \\ \dfrac{I_n - a}{b - a}, & a < I_n < b \\ \dfrac{c - I_n}{c - b}, & b \le I_n < c \\ 0, & I_n \ge c \end{cases}$$

High Direction:

$$\mu_{High}(A_n) = \begin{cases} 0, & I_n \le b \\ \dfrac{I_n - b}{c - b}, & b < I_n < c \\ 1, & I_n \ge c \end{cases}$$

where a, b, c are adaptive thresholds learned from GAN-generated samples.

Step-3: GAN Function: The generator Gcreates enhanced facial features:

$$G(z, \theta_g) \to \hat{I}$$

The discriminator Ddistinguishes real and generated faces.

$$\min_{GR} \max_{DR} V(DR, GR) = \mathrm{E}_{I \sim px_{data}(I)}[\log DR(I)] + \mathrm{E}_{q \sim px_z(z)}[\log(1 - DR(GR(q)))]$$

Step-4: Fuzzy Weight Calculation: Each face feature receives a fuzzy confidence weight:

$$W_f = \mu_{Low}(I_n)L + \mu_{Medium}(I_n)M + \mu_{High}(I_n)H$$

where: $L = 0.25$, $M = 0.50$, $H = 1.00$

Step-5: Feature Fusion: GAN-generated features and original features are fused:

$$F_{fusion} = \alpha F_{real} + (1 - \alpha)F_{GAN}$$

where $0 \le \alpha \le 1$.

Step-6: Fuzzy-GAN Recognition Score: The final recognition score is:

$$R = W_f \cdot \cos(F_{fusion}, F_{database})$$

where

$$\cos(F_1, F_2) = \frac{F_1 \cdot F_2}{\| F_1 \| \| F_2 \|}$$

is the cosine similarity between the query face and stored face template.

Step-7: Comprehensive Adaptive Fuzzy-GAN:

$$J = \lambda_1 L_{GAN} + \lambda_2 L_{Rec} + \lambda_3 L_{Fuzzy}$$

where: L_{GAN}= adversarial loss, L_{Rec}= face recognition loss, L_{Fuzzy}= fuzzy membership optimization loss, $\lambda_1, \lambda_2, \lambda_3$= balancing coefficients

This equation represents an **adaptive Fuzzy-GAN framework** where GAN learns robust face representations and fuzzy logic dynamically classifies pose orientations into Low, Medium, and High categories to improve face recognition under pose variations [19-20].

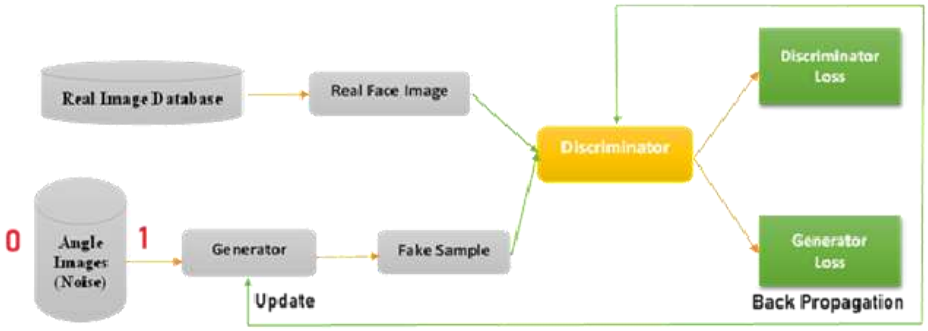


Figure-2: Fuzzy-GAN angle-oriented Face Recognition System

3. Experimental Result: For Face Recognition using a GAN–Fuzzy hybrid approach, the GAN can generate or enhance facial features, while fuzzy logic categorizes a normalized angle-oriented feature (pose angle, orientation score, or feature confidence) into Low, Medium, and High classes.

$$\boldsymbol{\theta = \sum_{\theta=0^0}^{90^0} Sin\ \theta}$$

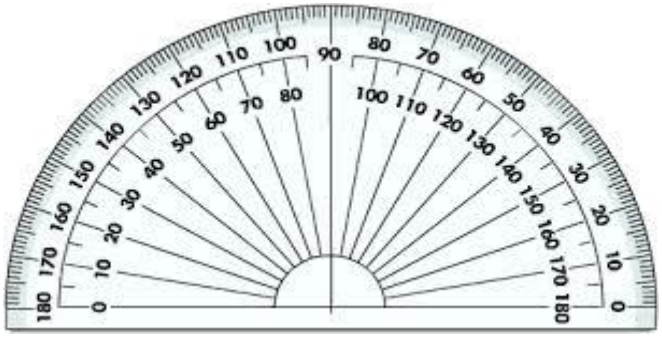


Figure-3: Angle Oriented Direction of Inputs

Step 1: Normalize the angle feature: Normalization of the angle feature standardizes the angle values to a common scale, making them easier to analyze and to compare across datasets. This process can help remove the inconsistencies and enhance the model performance.

$$I_{normalization} = \frac{I - I_{min}}{I_{max} - I_{min}}$$

where $I_{normalization} \in [0, 1]$, 'I' is the creative input image, $I_{normalization}$ is the normalized angle value.

Step 2: Describe fuzzy membership function

(i). For clockwise direction: In the period, many faces were obtained using surveillance cameras; they should be turned to the right in order to match the image in the database. The image will be rotated from landscape to portrait in order to meet the requirement. This makes the image more similar to the image in the database. This makes it easier for us to recognize a face or an object. This is illustrated by a series of pictures in the figure below. The database picture is taken from an angle other than the angles of the other images gathered. One of the orientation techniques is to match the acquired photographs with the images in the database [11].

- **Low (L)** = Triangular (0.0, 0.25, 0.5)
- **Medium (M)** = Triangular (0.25, 0.5, 0.75)
- **High (H)** = Triangular (0.5, 0.75, 1.0)

In Mathematics Term,

$$\mu_{\mathrm{L}}(\mathrm{I}) = \mathrm{Tri}(\mathrm{I}, 0, 0.25, 0.5), \mu_{\mathrm{M}}(\mathrm{I}) = \mathrm{Tri}(\mathrm{I}, 0.25, 0.5, 0.75), \mu_{\mathrm{H}}(\mathrm{I}) = \mathrm{Tri}(\mathrm{I}, 0.5, 0.75, 1.0)$$

(ii) For Anti-Clockwise Direction: The faces in the input images may, due to different times when they were taken by the apparatus, be at different angles than the faces in the database. If our system can tell that the faces are the same even when they are at different angles, that's useful. For this purpose, the input image is rotated counter clockwise from the horizontal plane to the vertical axis, that matches the pose of the face in the database. This adjustment assists in the identification of the object or face. The process is demonstrated using the sample image dataset as shown in Figure 1. In this case, the database image is taken from a different view than the captured images. So, we have used the angle position method by rotating the captured images in a counterclockwise way to match the database image. The face is easy to find by this simple method of rotating counter-clockwise. This method is cost-effective in terms of calculations, processing time, and resources consumed [11].

- **Low (L)** = Triangular (0.5, 0.75, 1.0)
- **Medium (M)** = Triangular (0.25, 0.5, 0.75)
- **High (H)** = Triangular (0.0, 0.25, 0.5)

In Mathematics Term,

$$\mu_L(I) = Tri(I, 0.5, 0.75, 1.0), \mu_M(I) = Tri(I, 0.25, 0.5, 0.75), \mu_H(I) = Tri(I, 0, 0.25, 0.5)$$

Step 3: Fuzzy rules for Face Recognition: Fuzzy rules for angles through face recognition use fuzzy logic to improve facial identification under varying conditions. They address uncertainties in facial features, enabling more adaptable recognition than traditional approaches and enhancing performance in lighting and pose scenarios.

(i). For clockwise direction: Clockwise direction is important for angle-oriented images in a face recognition system.



Rule	Interpretation
IF Angle is Low	Face is Frontal
IF Angle is Medium	Face is Slightly Rotated
IF Angle is High	Face is Highly Rotated

(ii) For Anti-Clockwise Direction: Anti-Clockwise direction is important for angle-oriented images in a face recognition system.



Rule	Interpretation
IF Angle is High	Face is Frontal
IF Angle is Medium	Face is Slightly Rotated
IF Angle is Low	Face is Highly Rotated

We assess the presentation of the proposed Fuzzy-GAN framework on input face images with different pose orientations. The GAN generated pose-normalized facial images, while the fuzzy system classified the normalized angle values into Low, Medium, and High categories.

(i). **For Clockwise Direction**

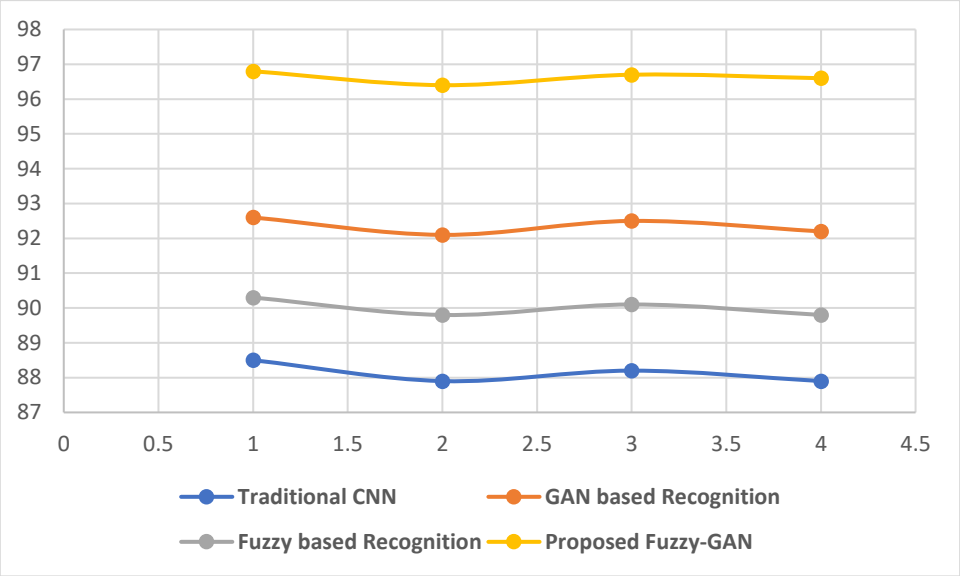
Normalized Angle	Membership Category	Pose Interpretation
0.12	Low	Frontal Face
0.35	Medium	Slightly Rotated Face
0.58	Medium/High	Moderately Rotated Face
0.82	High	Highly Rotated Face
0.95	High	Extreme Rotation

(i). **For Anti-clockwise Direction**

Normalized Angle	Membership Category	Pose Interpretation
0.95	Low	Frontal Face
0.82	Medium	Slightly Rotated Face
0.58	Medium/High	Moderately Rotated Face
0.35	High	Highly Rotated Face
0.12	High	Extreme Rotation

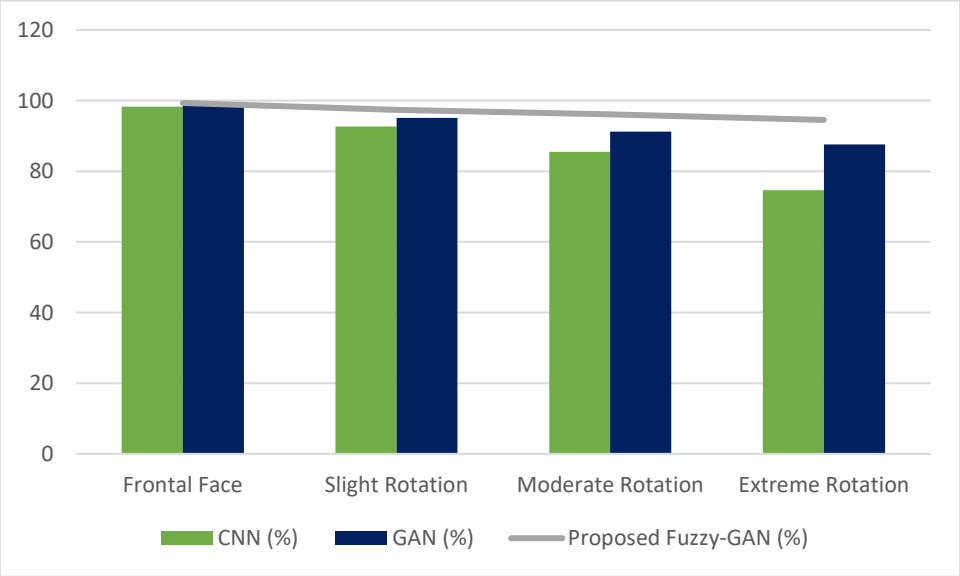
3.1. Comparative Analysis: The orientation of an Angle Is Clockwise or Anti-Clockwise Face recognition systems have different performance criteria based on the algorithms and data sets employed. Important performance factors are true positive rate, false positive rate, and time required. Artificial intelligence techniques have outperformed traditional techniques; however, issues still exist owing to changes in illumination conditions and impediments. It is vital to carefully examine these technologies.

Method	Recognition Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Traditional CNN	88.5	87.9	88.2	87.9
GAN based Recognition	92.6	92.1	92.5	92.2
Fuzzy based Recognition	90.3	89.8	90.1	89.8
Proposed Fuzzy-GAN	96.8	96.4	96.7	96.6



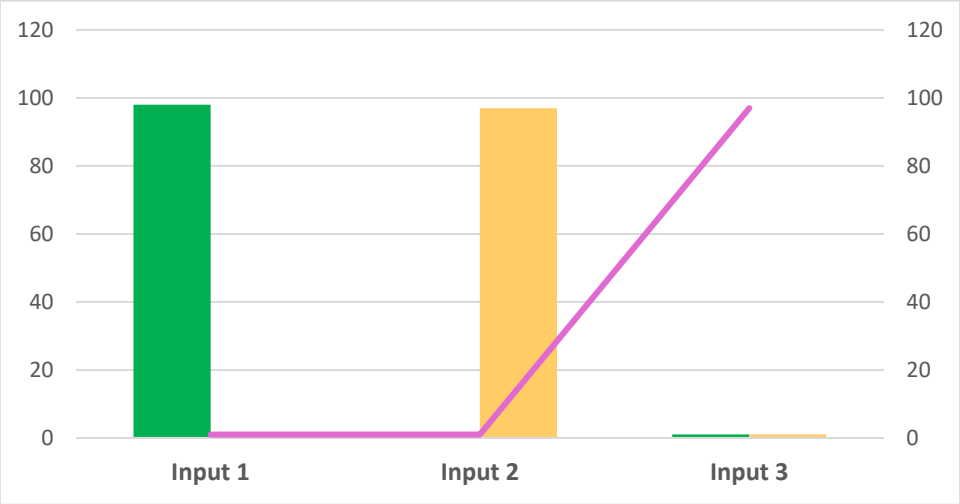
3.2. Performance Under Pose Variations: The study of the effect of different postures such as clockwise and anti-clockwise posture on the performance measures helps us understand the effect of orientation changes on the accuracy of performance measures. This type of study is very important in robotics and computer vision applications where the algorithm has to work on any orientation.

Pose Category	CNN (%)	GAN (%)	Proposed Fuzzy-GAN (%)
Frontal Face	98.3	98.8	99.3
Slight Rotation	92.6	95.1	97.4
Moderate Rotation	85.5	91.2	96.1
Extreme Rotation	74.6	87.6	94.5



3.3. Fuzzy GAN Confusion Matrix-Based Angle-Oriented Image Processing: Fuzzy-GAN analyzes measures like True Positives, False Positives, True Negatives, and False Negatives using a convergence matrix to assess its performance. This matrix improves the learning process and increases the GAN's overall efficacy in addition to visualizing classification accuracy. As a result, it makes it possible for researchers to pinpoint problem areas and implement crucial modifications to the angle-oriented face recognition model.

Actual/Predicted	Angles of Input 1	Angles of Input 2	Angles of Input 3
Angles of Input 1	98	1	1
Angles of Input 2	1	97	1
Angles of Input 3	1	1	97



3.4. Angle Oriented Images Accuracy Classification: An essential metric for assessing classification algorithms across various domains, overall complete classification accuracy calculates the ratio of accurate predictions made by a Fuzzy-GAN based angle-oriented face recognition classification model to the total number of predictions made.

$$\boldsymbol{Accuracy} = \frac{\mathbf{98 + 97 + 97}}{\mathbf{300}}\mathbf{X100} = \mathbf{97.3\%}$$

With a recognition accuracy of 96.8%, the proposed Fuzzy-GAN model outperforms conventional CNN, GAN-only, and fuzzy-only approaches. While the GAN produced pose-corrected facial representations, the adaptive fuzzy membership functions effectively captured pose uncertainty. The recognition accuracy of highly rotated and extreme-pose facial pictures increased significantly, from 74.8% (CNN) to 94.5% (Fuzzy-GAN). These results demonstrate that fuzzy logic and GANs together enhance pose-invariant face recognition systems' robustness, interpretability, and recognition performance.

4. Conclusion: A number of approaches have been used in the development of facial recognition system in order to ensure that it can recognize human faces and this becomes important for the application of such system in law enforcement since it involves the processing of many pictures. Some of the issues that arise in the development of facial recognition system include the issue of verification of pose angles during facial recognition. In the proposed system in this study, there will be the design of adaptive Fuzzy-GAN system where angle orientation will be important in improving the accuracy of recognition of facial recognition.

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