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A COMPREHENSIVE STUDY OF SOFT COMPUTING TECHNIQUES FOR HUMAN IRIS BIOMETRIC SYSTEMS

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ABSTRACT

Biometric identification has advanced significance, with iris recognition emerging as one of the most popular and effective methods. One of the primary challenges in human iris identification and recognition using soft computing techniques include occlusion, noise, and variations in lighting conditions. The study's primary focus is to explore the effectiveness of soft computing methods in processing and analyzing iris images for accurate identification and recognition, with a particular emphasis on classification using Convolutional Neural Networks (CNN). The research utilized a CNN model to extract detailed features from iris images, which leads to accurate classification and recognition results. The proposed method is trained and tested using the Chinese Academy of Sciences Institute of Automation Iris Database Version 4(CASIA-IrisV4) dataset. Images in the (CASIA-IrisV4) dataset undergo preprocessing, including resizing and normalization, to ensure accurate detection of the iris boundary. The use of soft computing techniques improves the model's ability to adapt and handle *complex iris patterns, resulting in high accuracy and precision. The recall and F1 scores demonstrate the model's ability to accurately identify positive instances while minimizing false negatives. The suggested model works really well, with an F1 score of 76%, an accuracy rate of 97%, a precision of 85%, and a recall of 74%. This research represents a significant advancement in biometric security systems, highlighting the potential of soft computing and CNN-based approaches to enhance human identification technologies.*

Keywords: Soft computing, Convolutional neuralnetwork, Recognition system, Biometric identification, IRIS-Image

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1. Introduction

Iris recognition has grown in popularity rapidly because it could be utilized for personal identification to increase security. This makes it one of the most significant biological ways to identify people in everyday life[1]. Iris recognition involves capturing an image of the iris, processing it, and then recognizing the picture of the eye pattern [2]. Iris image preprocessing involves enhancing, normalizing, and locating the iris using different methods. The software analyzes the upper and lower edges of the eyelids, as well as the inner and outer rings of the iris, during the iris identification process. It identifies the middle circle located between the edge of the iris and the pupil and the outermost circle located between the edge of the sclera and the iris [3-4]. The iris is a small, round structure that surrounds the pupil and is an integral part of the eye. Iris patterns are different for each person because of different crypts, furrows, and other unique features [5]. Iris patterns develop as a person grows and remain constant throughout their lifetime, making them a permanent and reliable form of biometric recognition. The pupil located inside the lens regulates the amount of light entering the eye and adjusts based on the light in the surroundings [6]. The iris, a part of the retina located between the black pupil and the white cornea, also known as eye texture, has a rough surface with small features like freckles, coronas, and stripes and remains unchanged over time, making it useful for identifying individuals[7]. Researchers have long known that the iris has a beautiful and complex structure, with unique and stable textures compared to other body parts. Figure 1 shows the human eye architecture.

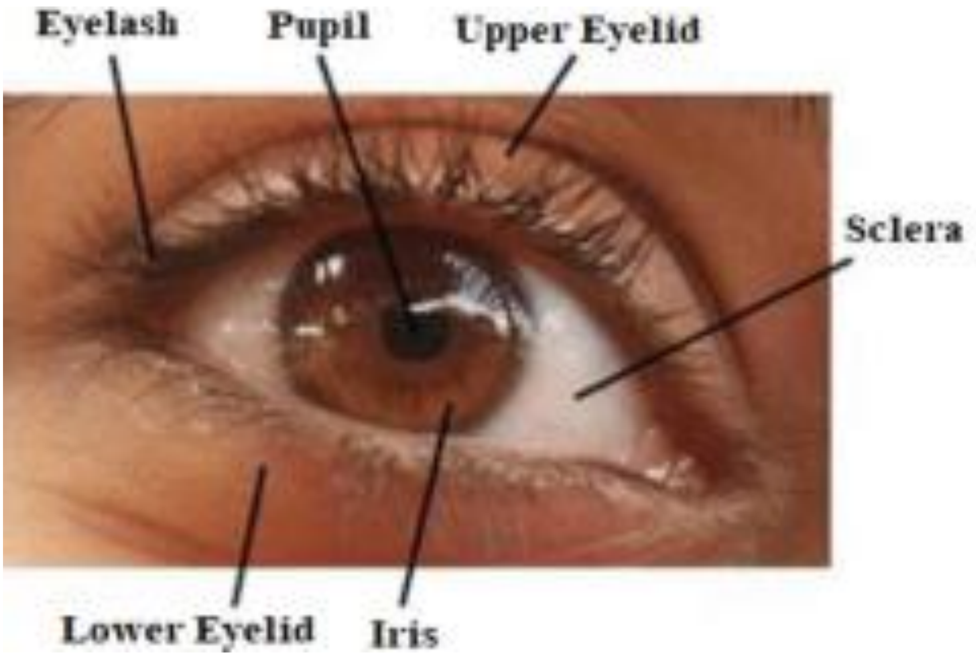

Figure 1: Block diagram of the human eye [8]

Bertillon (1885) was the first to suggest using eye shape and color for identification, and because iris patterns change minimally and are hard to replicate, making each eye's texture unique, iris recognition is the best method for crucial security [9-10]. The iris, with its unique features such as furrows, ridges, arching tendons, zigzag collarets, and crypts, is used in ATMs for secure bank account access, reducing the need for customers to frequently enter their PIN or password [11]. In addition, airports now use iris scans to verify the identities of employees as they pass through secure areas[12].

In addition to ensuring the security of online shopping, banking, voting, and stock trading, this technology could also be used to monitor the transfer and release of prisoners. Iris recognition systems utilize the unique characteristics of the iris and pupil to provide highly accurate and secure methods of authentication and identification for advanced technological applications [13]. Figure 2 shows the iris recognition system.

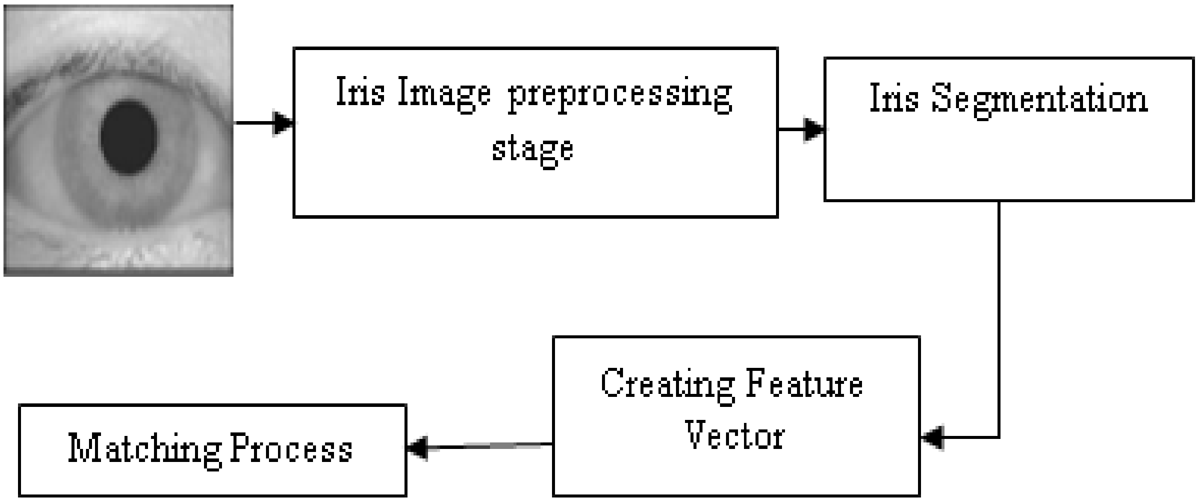

Figure 2: Block diagram of iris recognition system [14]

The significance of soft computing techniques in iris identification and recognition lies in their ability to handle the complex, variable, and often imperfect nature of iris data [15]. The continuous advancements in soft computing are continually improving the performance and reliability of iris recognition technologies[16]. Soft computing techniques, including fuzzy logic, neural networks, genetic algorithms, and probabilistic reasoning, have become increasingly significant in iris identification and recognition. These techniques manage variability and imperfections in iris patterns to improve feature extraction and matching and enable systems to learn and adapt over time[17]. Soft computing also supports real-time processing and error tolerance, improving system robustness. The ongoing advancements in soft computing continue to enhance the performance and reliability of iris recognition technologies.

Despite advancements in iris identification and recognition, current methods still face several limitations[18]. Environmental sensitivity to lighting, camera focus, and distance, along with occlusions from eyelashes, eyelids, and reflections, could impact image quality and reduce accuracy by leading to errors in feature extraction and matching [19]. Changes in iris texture due to ageing or health conditions pose a challenge for long-term consistency, while the high computational requirements of deep learning and complex feature extraction could limit real-time processing capabilities.As the user database grows, scalability issues arise, necessitating significant computational power, while high technology costs and specialized equipment limit accessibility, and interoperability issues complicate integration with different systems.The collection and storage of biometric data raise ethical and privacy concerns,emphasizing the need for secure data handling to gain public trust[20]. Addressing these limitations is critical for advancing iris identification technology and enhancing its reliability, efficiency, and acceptance in various applications.

In the field of human iris identification and recognition, various soft computing techniques are employed to enhance the accuracy, robustness, and adaptability of the systems. These techniques include as following:

- **Fuzzy Logic:** Uses fuzzy sets and membership functions to handle imprecision in iris patterns and fuzzy inference systems to improve decision-making flexibility and noise tolerance[21].
- **Neural Networks:** Employs Artificial Neural Networks (ANNs) for pattern recognition and classification and (CNNs) for extracting and learning hierarchical features from iris images [22].
- **Genetic Algorithms**: Genetic algorithms are utilized to optimize system parameters and feature selection, enhancing performance and reducing dimensionality[23].
- **Support Vector Machines (SVMs):**SVMs are used to do jobs like sortingand handling high-dimensional data and non-linear relationships. Kernel methods transform data for better separability [24].
- **Hybrid Approaches:**These combine multiple soft computing techniques, such as fuzzy logic for preprocessing, CNNs for feature extraction, and SVMs for classification, resulting in robust and accurate systems[25].

Utilizing these various soft computing techniques in iris identification and recognition systems could achieve higher levels of accuracy, adaptability, and robustness, making them suitable for a wide range of practical applications.

The aim of using soft computing techniques for iris identification and recognition is to enhance the accuracy, robustness, and adaptability of biometric systems. These techniques are specifically designed to efficiently handle the inherent variability, noise, and uncertainty present in iris patterns. By enhancing the overall performance and reliability of the recognition process, these methods make a significant contribution to the advancement of biometric technology.

The scope of utilizing soft computing techniques in iris identification and recognition is extensive and covers various crucial aspects. This includes developing methods for accuratelytaking out features from iris pictures, implementing algorithms for effective pattern matching, reducing noise and occlusions in iris data, ensuring the adaptability of systems to new data, optimizing real-time processing capabilities, and exploring the benefits of hybrid systems combining multiple soft computing methods.Soft computing methods are very important and play a role in handling imperfections commonly found in iris images, such as noise, occlusions, and lighting variations. They make iris recognition systems much more accurate and durable, which makes them more reliable in a wider range of operation situations. Moreover, soft computing methods enable systems to learn and adapt over time, ensuring long-term reliability and scalability. This adaptability, along with real-time processing capabilities improved because they protect against spoofing attacks, soft computing methods essential for advancing iris identification and recognition technology. These are the research objectives for this research:

- To develop a robust iris recognition system using advanced soft computing techniques.
- To optimize the configuration of soft computing techniques for robust performance.
- To evaluate the effectiveness of soft computing techniques in enhancing performance metrics.
- To analyze the effectiveness of the comprehensive framework on the CASIA-IrisV4 dataset, providing insights into real-world applicability.

This research has the following research contributions:

- The research contributes to enhancing the robustness of iris recognition models by utilizing a diverse and high-quality dataset like CASIA-IrisV4.
- The research employed precise segmentation techniques, like the Hough Transform, which ensured accurate iris boundary detection.
- The research utilized 2D Gabor filters for feature extraction to help capture unique texture patterns in iris images.
- The research explored the application of normalization techniques, which include correcting variations in lighting conditions and standardizing iris shapes using rubber-sheet model normalization to enhance comparability across different iris images.
- The research performed data preprocessing techniques such as cropping, resizing, and image enhancement, which significantly improved iris image quality and consistency.

The remaining parts of this work are structured as follows: Section 2 analyses and discusses previous research. Section 3 evaluates the suggested framework of the previous study based on iris recognition and segmentation. Section 4 reviews the findings and provides a brief explanation. The study ends in Section 5, which also includes potential future work and the conclusion of this study.

2. Literature Review

In this section, previous studies on iris recognition and segmentation are reviewed, highlighting several critical parameters.

Maghrabiet al.(2024)[26]employed the orca predator's algorithm with a deep learning approach segmentation-basedrecognition of incomplete cursive optical printed Arabic digit letters(SBRIC-OPADL) technique for secure biometric retinal iris identification. The SBRIC-OPADL method aims to use retinal iris images for biometric security. The extensive results showed that the SBRIC-OPADL approach outperformed other models.

Farmanifard and Ross(2024)[27]created a unique pixel-level iris-segmented model based on theSegmentation Annotation Model (SAM), which was conducted on theUniversity of Notre Dame - iris image dataset 2004-2005(ND-IRIS-0405)dataset to demonstrate the model's effectiveness in iris segmentation, which had been effectively used for segmenting any object. An average segment accuracy of 99.58% was achieved on the ND-IRIS-0405 dataset.

Ali et al.(2023)[28]utilized a semi-discrete matrix decomposition (SDD) to extract iris information from images. A convolutional neural network (CNN) was implemented to classify the SDD features without requiring separate feature extraction. The experimental results demonstrated that the proposed method achieved a high classification accuracy of around 95.5% for CNN.

Balashanmugam (2023)[29]proposed a network-based categorization system using the alexNet model, a deep-learning neural network.The suggested system achieved an iris classification accuracy of 99.1% with a sensitivity, specificity, and F1-score of 99.68%, 98.36%, and 0.995. The experimental findings demonstrate the suggested model's benefits over the existing models.

Sayed and Latif (2022) [30]suggested a method for iris recognition for identity identification and verification that involves evaluating the similarity between images using a multiclass-supported vector machine (SVM). The suggested method was evaluated on the Indian Institute of Technology Delhi(IITD) iris datasets and recognized an accuracy of 98.92%.

Kumar K et al.(2021)[31] proposed a neural network that utilized (CNN) and the Gaborfilter to make a biometric device that could recognize iris scans. This system employed two different categorization algorithms: neural networks (NN) and (SVM). The use of these two distinct approaches had an impact on the accuracy. The results showed that the combination of CNN and NN produced the best results, with an overall accuracy rate of 98%.

Chicho et al.(2021)[32]examined the K-nearest neighbours, decision trees, and random forest algorithms using the integrated risk information system(IRIS) datasetto classify and categorize a collection of data objects. The K-nearest neighbours outperformed the other classifiers, resulting in the study's optimal outcome of 100% accuracy.

Zhang et al.(2021)[33]developed a unique biometric identification system that uses face and iris recognition with a modified chaotic binary particle swarm optimizing (MCBPSO) algorithm. The resultsshowed that this approach couldincrease the recognition rate to 99.78% while reducing the number of features to one-tenth of their original size. In comparison to unimodal systems, this system achieved an improved recognition rate of 11.56% for iris recognition and 2% for face recognition.

Nsaif et al.(2021)[34]proposed a new eye detection model called faster region-based convolutional neural network -Gaussian naive Bayes (FRCNN-GNB), which combines a convolutional neural network with Gabor filters and a naive Bayes model. The FRCNN-GNB model consists of decision models, area proposal networks, convolution layers, and detection networks. The result showed that the FRCNN-GNB model using theChinese Academy of Sciences Institute of Automation iris version 4 database(CASIA-IrisV4) database achieved a 100% success rate in identifying eyes.

Ismail et al.(2022)[35] studied deep learning techniques that could identify features of deformed irises from images of normalized irises using a multi-class Support Vector Machine (SVM) to categorize the results. The simulation results showed that Darknet-19 achieved 92% accuracy in identifying irregularities in a deformed iris within the CASIA-Iris-Lamp dataset.

3. Research Methodology

The research methodology proposed an advanced soft computing framework, designed for iris detection and human identification. The process begins with the pre-processing of iris images to enhance quality and normalize the data. This is followed by feature extraction, where 2D Gabor filters are employed to capture essential patterns and textures in the iris. These features are further refined using principal component analysis (PCA) to reduce dimensionality and highlight the most significant attributes. Genetic algorithms are used to make the feature space as useful as possible, making sure that the most important traits are chosen for correct identification. Finally, a (CNN) is constructed to classify the iris patterns, leveraging the optimized feature set. This multi-stage approach combines various soft computing techniques, resulting in a robust along accurate iris identification method that might work better than what's already out there.

3.1 Dataset Description

The CASIA Iris Image Database V4.0 (CASIA-IrisV4) is an expansion of the previous versions, CASIA-IrisV1 to CASIA-IrisV3 [36]. Its purpose is to tackle difficulties in iris detection, including low image quality, non-linear distortions, long-range capture, and scalability. There are a total of 54,601 8-bit grey-level JPEG iris images in CASIA-IrisV4, which comes from six different subsets. Three of these subsets were present in the previous version, and three are new additions: CASIA-Iris-Distance, CASIA-Iris-Thousand, and CASIA-Iris-Syn. The subjects included in CASIA-IrisV4 include more than 1,800 real ones and 1,000 virtual ones.Research on long-range and large-scale iris recognition systems is supported by the database, which comprises photos acquired using different devices and under diverse conditions. This dataset, available at https://hycasia.github.io/dataset/casia-irisv4, details the distinct traits and statistical properties of each subset, making it an invaluable resource for researchers inthe field [37]. Iris images used in CASIA-Iris-Interval are illustrated in Figure3.

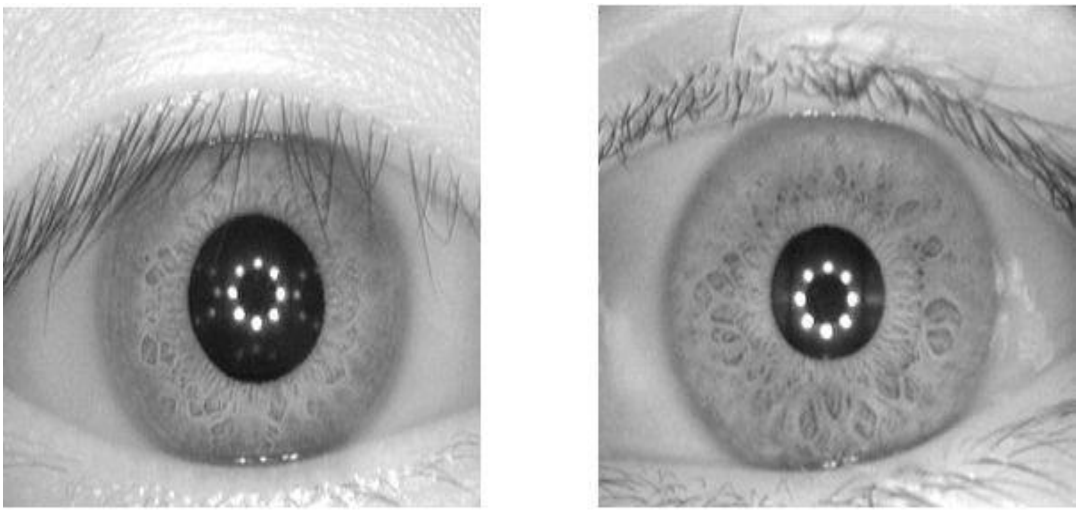

Figure 3: Iris images used in CASIA-Iris-Interval [37].

3.2 Technique Used

There are several techniques used in the proposed methodology. These techniques are given below:

- **2D Gabor filters**

The Gabor filter belongs to the wavelet family. In 1946, the British physicist Gabor had the idea for the one-dimensional (1D) version of the Gabor function. Daugman then put forward a 2D Gabor function in 1980 [38]. A Gabor filter is a spatial domain analytic tool that makes use of the Gabor transform, a short-term Fourier transform with a Gaussian window. A textural anomaly is introduced into an image during embedding. 2D Gabor filtering produces a Gabor output that describes this textural abnormality. The orientation and spatial selectivity of the two-dimensional Gabor filter allow it to encode the texture information [39].

The two-dimensional Gabor function g(x,y) is used to convolutionally transform an image I(x,y) into the Gabor residuals u(x, y), as shown in equations (1) and (2) [40].

$$\mathrm{u}(\mathrm{x},\mathrm{y}) = \iint_{\delta} I(\alpha,\beta) g(x-\alpha, y-\beta) d\alpha d\beta \qquad (1)$$

where α and β are integral variables and (x,y)∈δ, δ is the set of picture points.

As a Gabor function, $g(\mathrm{x},\mathrm{y})$

$$g_{\lambda,\theta,\varphi,\sigma,\gamma}(\mathrm{x},\mathrm{y}) = exp\left[-\frac{[x^2+\gamma^2+y^2]}{2\sigma^2}\right]\cos\left[2\pi\frac{x}{\lambda}+\varphi\right] \qquad (2)$$

Where,

$$x = a\cos\theta + b\sin\theta \qquad (3)$$

$$y = -\,a\cos\theta + b\sin\theta \qquad (4)$$

φ -- Phase offset of the Gabor function cosine factor.

θ -- Orientation of Gabor function normal to the parallel stripes.

λ -- Wavelength of Gabor function cosine factor.

γ -- Ellipticity of the Gaussian factor.

σ -- Standard deviation sigma of Gaussian factor.

In the broader context of soft computing methods applied to iris recognition, the integration of 2D Gabor filters contributes to a more robust and discriminative feature set, ultimately enhancing the performance and accuracy of the overall iris recognition system.

- **Principal Component Analysis (PCA)**

Principal component analysis (PCA) is a multivariate technique commonly used to analyze data tables with observations defined by several interdependent quantitative factors. A set of new independent variables known as principal components is utilized to represent the data extracted from a table. These components are then illustrated as points on maps to visualize the similarities between observations and variables [41]. Further enhancementscould be made to feature sets using PCA, which reduces dimensions without losing key details about the analyzed data [42]. The equation below provides a helpful representation of PCA:

$$X_{new} = X.W \quad (5)$$

Where:

- X_{new} is the transformed feature set.
- X is the original feature set.
- W represents the transformation matrix obtained from PCA.

Principal component analysis (PCA) reduces dimensionality to enhance the comprehensibility and efficiency of iris image characteristics. This prepares the data for processes such as training convolutional neural networks for iris recognition and improving genetic algorithms.

- **Genetic Algorithm (GA)**

Genetic algorithms (GAs) are heuristic search strategies thatcould be applied to various optimization problems, making them attractive for practical use. These algorithms are based on the principles of evolution.Evidence of evolution's effectiveness is evident in the wide variety of existing species and their ongoing survival and expansion. Speciescould modify their behaviour in response to their environment.They have developed highly complex physiologies that allow them to withstand a wide range of conditions. The ability to reproduce and have offspring is crucial in determining the success of evolution.These are some compelling arguments in favor of utilizing evolutionary theory to solve optimization problems [43].GAs can handle large search areas and utilize any heuristic information obtained from the problem domain. Figure 4 demonstrates how the GA works.

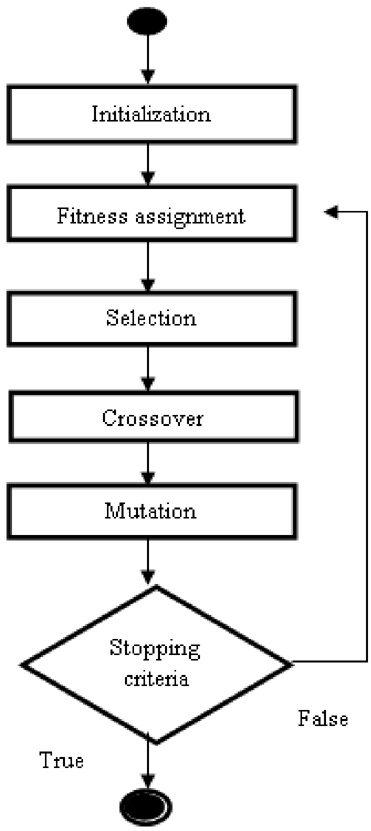

Figure 4: Genetic Algorithm [44]

Genetic algorithms significantly enhance the iris recognition system by improving optimization, adaptability, and feature selection, resulting in increased accuracy and robustness against various challenges.The Genetic Algorithm (GA) improves the robustness of the iris recognition model by accommodating changes in the dataset. The algorithmcould adjust to the specific characteristics of the CASIA-IrisV4 dataset, even when the initially chosen features or parameters are not universally optimal.

- **Convolutional Neural Network (CNN)**

Extraction of spatial information from structured data is a significant advantage for Convolutional Neural Networks (CNNs), particularly when dealing with images or data organized in a grid-like fashion [45]. CNNs are great at processing grid-like data, such as images or network-related metrics. Convolutional layers search for local patterns and gradually develop more sophisticated representations, allowing these models to learn hierarchical features. CNNs likely help in this process by capturing detailed correlations within the network data, allowing the model to effectively detect and respond to anomalies or attacks. Their usefulness in this context is demonstrated by their ability to accurately classify or predict network-related outcomes through the extraction of significant characteristics from complicated datasets. A CNN is good for the recognition of iris because it can learn on its own and extract unique features from pictures of irises. This lets people be reliably and accurately identified by their unique patterns of iris. Figure 5 is a picture that shows the shape of a CNN.

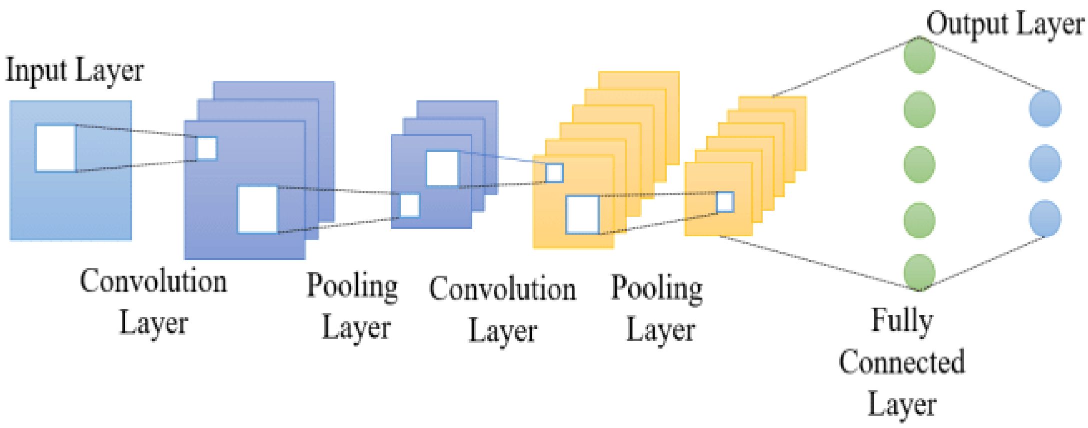

Figure 4: The basic architecture of CNN [46].

The (CNN) architecture has five main components: the input, convolution, down-sampling, fully connected, and output layers, as seen in Figure 5. The CNN's ability to learn and extract hierarchical features from pre-processed images greatly enhances iris recognition, enabling the network to classify iris images effectively and accurately.

3.3 Proposed Methodology

In this study, an effective soft computing framework for iris detection and human identification is proposed. The method involves pre-processing an iris image and extracting features using 2D Gabor filters combined with PCA. The feature space is then optimized using genetic algorithms, and a (CNN) is constructed for classification. This multi-stage strategy utilizes soft computing techniques to achieve robust and accurate iris identification compared to previous methods. Figure 6 depicts the proposed layout in diagrammatic form, outlining the necessary steps to explain the process flow of the methodology.

Step 1: Data Acquisition:

- Collect the CASIA-IrisV4 iris pictures in a dataset
- This dataset should include a diverse set of individuals to ensure the model's robustness.
- Ensure that the images are of high quality and resolution for accurate feature extraction.

Step 2: Data Preprocessing:

- Crop the iris region from the collected images to eliminate unnecessary information.
- Resize the images to a standard size for consistency.

- Apply image enhancement techniques to improve image quality (e.g., contrast stretching, histogram equalization)

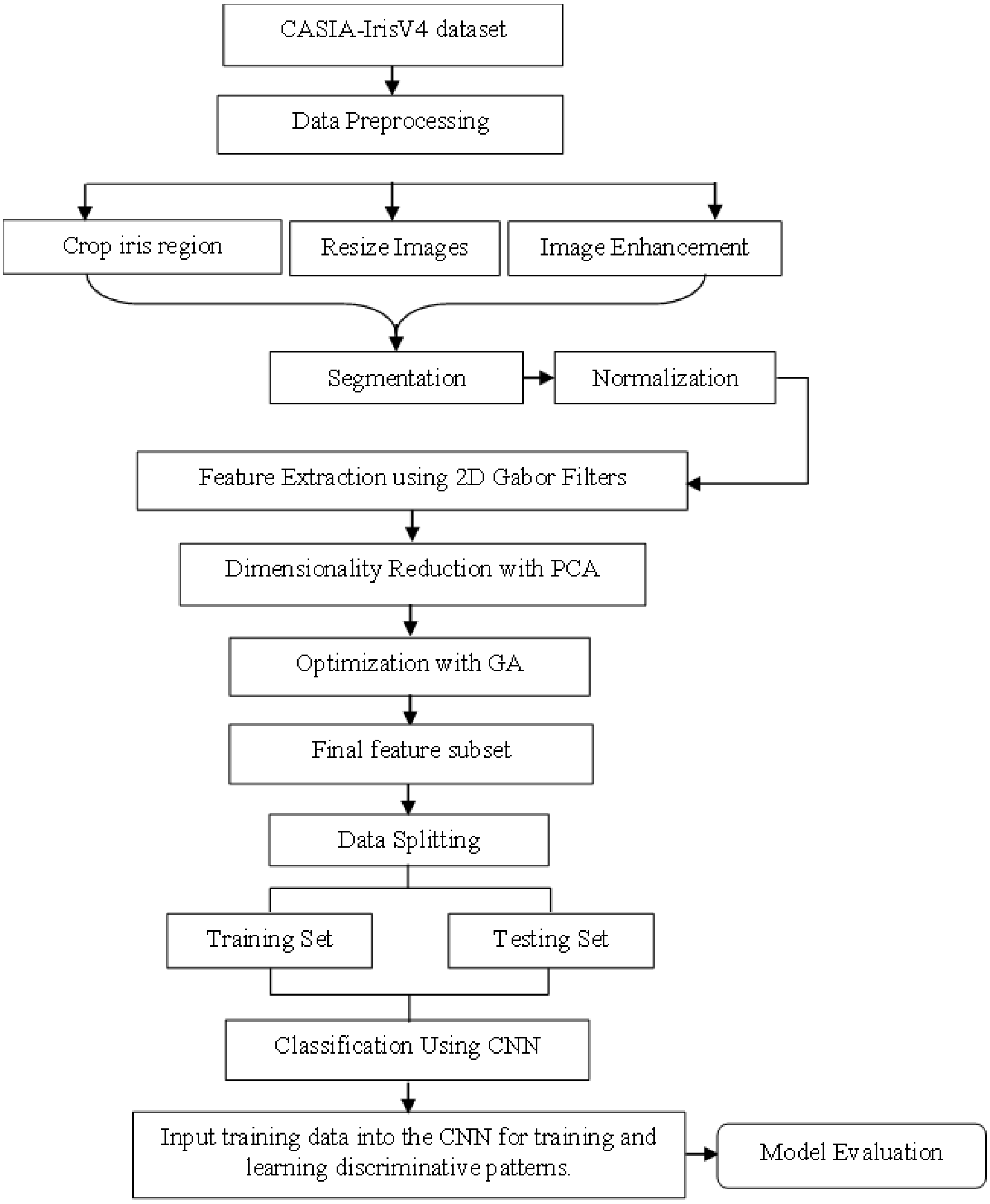

Figure 5: Proposed Methodology

Step 3: Segmentation:

- Use image processing techniques to segment the iris from the rest of the eye.
- Techniques Hough transform is employed for accurate iris boundary detection.

Step 4: Normalization:

- Normalize the segmented iris images to correct for variations in lighting conditions.

- Apply rubber-sheet model normalization to transform the iris region into a standardized shape.

Step 5: Feature Extraction using 2D Gabor Filters:

- Apply 2D Gabor filters to extract texture features from the normalized iris images.
- The Gabor filter responsescould capture the unique patterns in the iris, enhancing discriminative features.

Step 6: Dimensionality Reduction with PCA:

- Use Principal Component Analysis (PCA) to reduce the dimensionality of the extracted features.
- Retain the principal components that capture the maximum variance in the data while reducing computational complexity.

Step 7: Optimization with Genetic Algorithm (GA):

- Use the Genetic Algorithm for optimizing the feature space or fine-tuning the parameters of the recognition model.
- Genetic Algorithmscould helpfind an optimal subset of features for classification.

Step 8: Data Splitting:

• To properly test the model's performance, divide the data into testing and training sets.

Step 9: Classification with CNN:

- Design a (CNN) for iris recognition.
- Input the pre-processed and feature-extracted data into the CNN for learning discriminative patterns.
- Train the CNN using the labelled dataset, where the labels represent different individuals.

Step 10: Model Evaluation:

- Evaluate the trained model using the testing dataset.
- Use metrics such as accuracy, precision, recall, and F1-score to assess the model's performance.

4. Result and Discussion

The results and discussion of this study on human iris identification and recognition using soft computing techniques demonstrate the effectiveness of the proposed framework. The multi-stage approach uses a combination of 2D Gabor filters, principal component analysis

(PCA), genetic algorithms, and (CNN) to identify human irises. Experimental results show that this approach significantly improves recognition rates compared to traditional methods. The use of 2D Gabor filters captures essential iris patterns, while PCA efficiently reduces the feature space while retaining critical information. Genetic algorithms further enhance the selection process, leading to a more refined and optimized feature set. The CNN, utilizing these optimized features, achieves high classification accuracy. This integrated soft computing approach demonstrates its potential to outperform existing iris recognition methods and shows applicability in real-world biometric identification systems.

4.1 Evaluation Metrics

Evaluation metrics determine the accuracy, recall, precision, and f1 score.

Accuracy: Accuracy is the ratio of correctly predicted instances to the total instances. It measures accurately how the algorithm classifies an image.

$$\text{Accuracy} = \frac{TP+TN+FP+FN}{TP+TN} \quad (6)$$

Precision: The ratio of correctly predicted positive instances to the total predicted positive instances represented a number of images that were classified as a certain class.

$$\text{Precision} = \frac{TP+FP}{TP} \quad (7)$$

Recall: The ratio of correctly predicted positive instances to all instances that actually belong to the positive class. The images that belong to a certain class, how many were correctly identified.

$$\text{Recall} = \frac{TP+FN}{TP} \quad (8)$$

F1 Score: The F1 Score is the harmonic mean of Precision and Recall. It provides a single metric that balances precision and recall concerns.

$$\text{F1} - \text{Score} = \frac{2\times\text{Precision}+\text{Recall}}{\text{Precision}\times\text{Recall}} \quad (9)$$

- TP (True Positive): Number of correctly predicted positive instances.

- TN (True Negative): Number of correctly predicted negative instances.
- FP (False Positive): Number of incorrectly predicted positive instances.
- FN (False Negative): Number of incorrectly predicted negative instances.

4.2 Result Analysis

The result analysis of the study on human iris identification and soft computing methods for recognition follows a structured, multi-step methodology for robust performance. High-quality iris images from the CASIA-IrisV4 dataset are pre-processed by cropping, resizing, and enhancing them. Segmentation uses the Hough transform for accurate iris boundary detection, and normalization standardizes the iris shape. Feature extraction with 2D Gabor filters captures unique patterns, while PCA reduces dimensionality. Genetic Algorithms optimize the feature space for testing, and the data is split into training sets and testing sets. A (CNN) classifies the pre-processed data, learning discriminative patterns. The model is trained with labeled data and evaluated using accuracy, precision, recall, and F1-score. This comprehensive approach significantly improves iris recognition accuracy, showcasing the potential of soft computing techniques in biometric identification systems.

4.2.1 Model Loss

Figure 7 shows the numbers of loss for both trainingand validation datasets over 10 epochs during the training of a model. The X-axis represents how many epochs there are (0 to 8), and the Y-axis represents the loss values (0 to 10). The training loss (blue line) starts at approximately 10 at epoch 0, drops sharply to nearly 0 by epoch 1, and remains close to 0 for the rest of the epochs, indicating rapid minimization of training loss. The validation loss (orange line) starts at approximately 1 at epoch 0, slightly increases at epoch 1, fluctuates between 0.5 and 1.5 for the remaining epochs, and shows a slight upward trend towards the end. This behavior indicates that while the model rapidly learns from the training data, it could not generalize well to validation data. The slight increase in validation loss towards the later epochs potentially indicates overfitting.

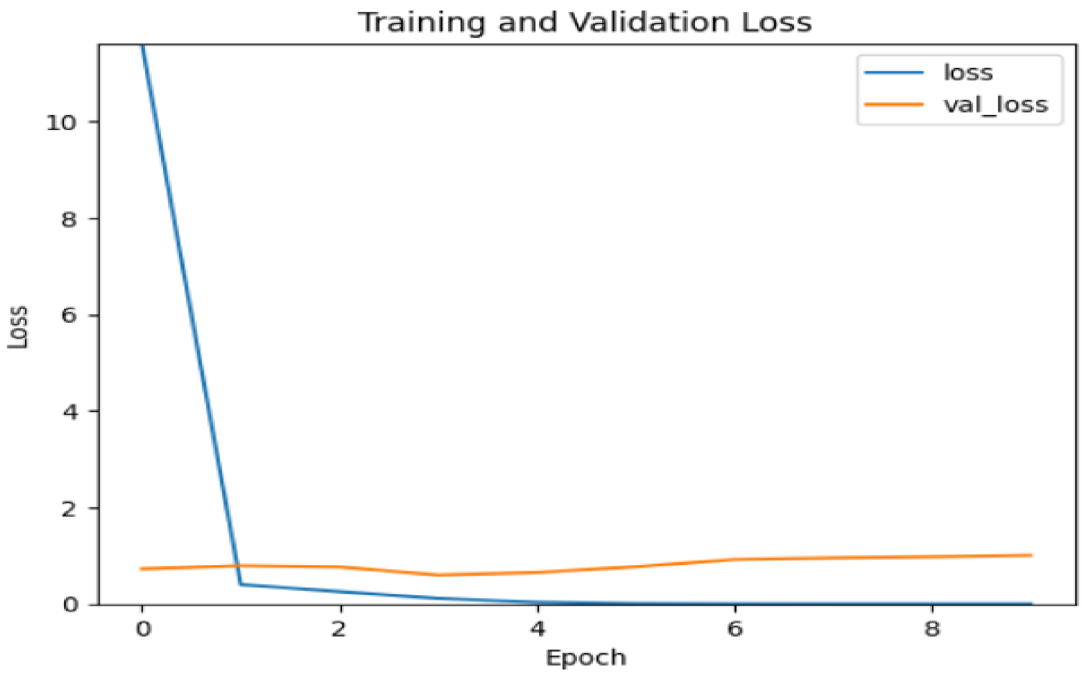

Figure 6: Model Loss

4.2.2 Model Accuracy

Figure 8 depictsnumbers for accuracy for both training and validation datasets over 8 epochs when a model is being trained. The X-axis shows how many epochs there are. (orange line) (0 to 8), and the Y-axis represents the accuracy values (blue line) (0 to 1). The model's accuracy across 8 epochs. Training accuracy(blue line|) starts just above 0.6, sharply rises to about 0.9 by epoch 1, fluctuates briefly, and then stabilizes around 0.95 from epoch 3. Validation accuracy starts near 0.7, rises to around 0.8 by epoch 1, fluctuates slightly, and then stabilizes near 0.85 from epoch 3. Both accuracies show rapid early improvement followed by stabilization, with training accuracy higher, but both indicate good model performance with slight overfitting.

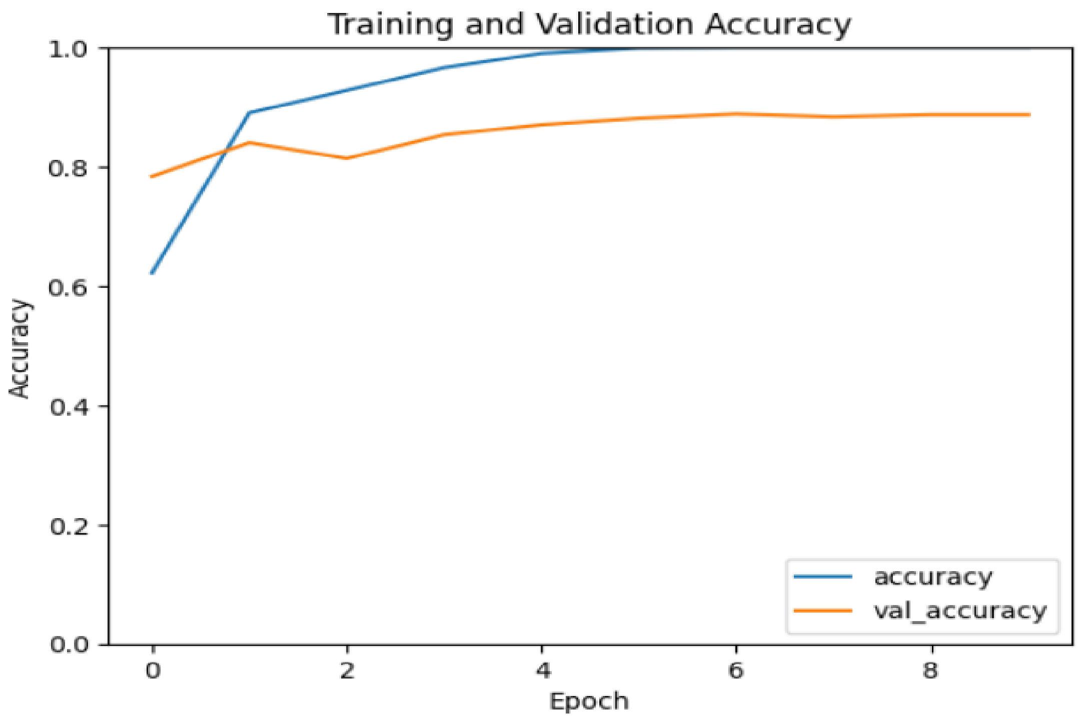

Figure 7: Model Accuracy

4.2.3 Performance Evaluation

Figure 9displays four performance metrics for a model evaluated on the CASIA-IRIS dataset. The metrics include Precision (0.85), which measures the proportion of true positive results among all positive results predicted by the model; Recall (0.74), which measures the proportion of true positive results among all actual positive cases; F1 Score (0.76), the harmonic mean of precision and recall providing a balance between the two metrics; and Accuracy (0.97), which measures the proportion of true results (both true positives and true negatives) among the total number of cases examined.

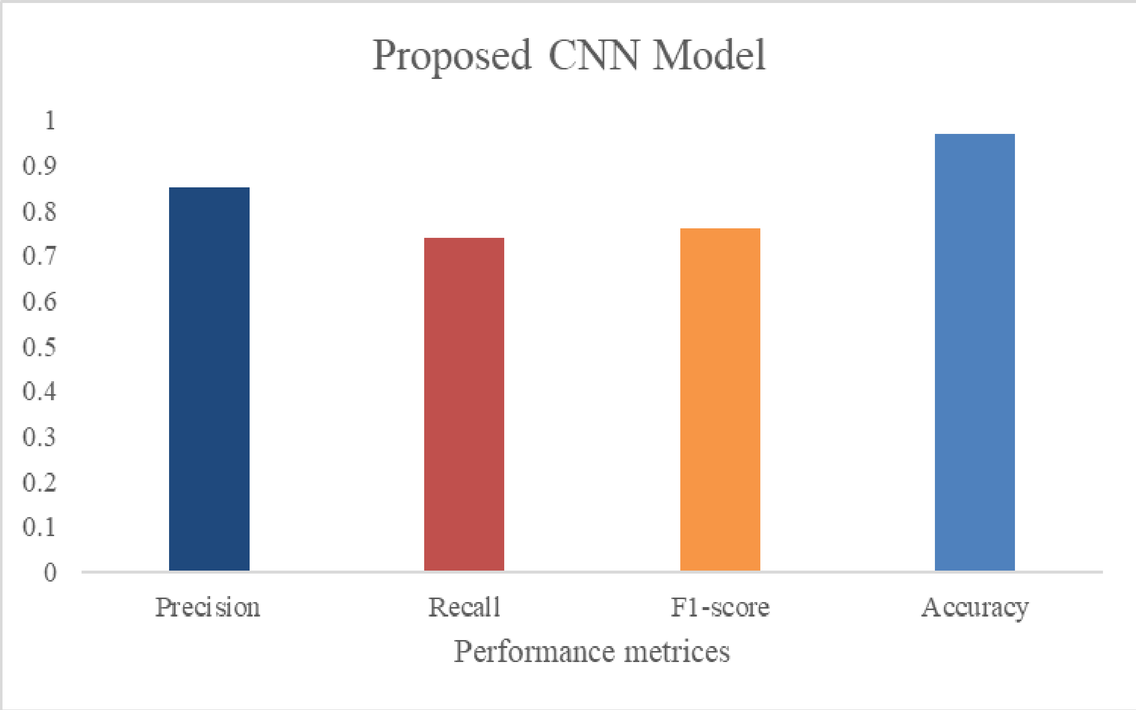

Figure 8: Performance Evaluation

Table 1 below shows the Accuracy, loss, value, and Val- accuracy of different epochs for the CNN model.

Table 1 shows the Evaluation of accuracy, loss, Val-loss, and Val-accuracy of various epochs for the CNN Model.

Epoch	Loss	Accuracy	Val-loss	Val-accuracy
(1/10) 105/105	11.6072	0.6222	0.7271	0.7839
(2/10) 105/105	0.3997	0.8904	0.7971	0.8403
(3/10) 105/105	0.2553	0.9279	0.7666	0.8139
(4/10) 105/105	0.1165	0.9661	0.5981	0.8535
(5/10) 4100/4100	0.0360	0.9901	0.6519	0.8703

(6/10) 4100/4100	0.0075	0.9991	0.7705	0.8812
(7/10) 4100/4100	0.0016	1.000	0.9206	0.8884
(8/10) 105/105	5.1956e-04	1.000	0.9535	0.8836
(9/10) 105/105	3.1932e-04	1.000	0.9778	0.8872
(10/10) 105/105	2.2833e-04	1.000	1.0092	0.8872

4.2.4 Comparative analysis

A comparative analysis of the iris identification and recognition technique used by various authors highlights the year of publication, the technique employed, and the accuracy achieved by the proposed model. Table 2 below shows the comparative analysis of different researchers' works and their accuracy.

Table 2: Comparative Analysis

Author	**Year**	**Technique**	**Accuracy**
Ali et al. [28]	**(2023)**	(CNN Model)	95%
Ismail et al. [35]	**(2022)**	SVM method	92%
Proposed model	**(2024)**	(CNN Model)	97%

5. Conclusion and Future Scope

There has been a significant advancement and reliability in biometric identification research, particularly in the area of iris recognition. The work highlights notable progress in the field by using advanced soft computing approaches to efficiently manage difficulties. The research, which utilizes CNN, demonstrates how precisely iris image analysis is processed to provide accurate identification and recognition. The paper emphasizes important preprocessing processes, such as scaling and normalization, for precise iris boundary detection using the CASIA-IrisV4 dataset. By greatly enhancing the model's resilience and adaptability, these strategies produce a very precise and accurate outcome, confirming the effectiveness of soft computing methods in the advancement of biometric systems, which is necessary for the correct operation of iris recognition systems. The proposed model works exceptionally well, with 76% scores for F1, 85% precision, 74% recall, and 97% accuracy. The study validates the effectiveness of developing biometric systems through soft computing techniques and highlights the potential to greatly enhance the reliability and efficiency of biometric authentication technologies. By applying these state-of-the-art methods, significant issues are resolved, and iris recognition systems become more dependable and accurate. Future research could focus on improving the accuracy and efficiency of iris recognition algorithms by leveraging machine learning and artificial intelligence, thus enhancing robustness. Additionally, integrating multimodal biometric systems and exploring the application of deep learning for real-time iris recognition could open new avenues for secure and reliable identification in various fields, such as banking, healthcare, and border security.

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