A Review of Iris Scanning: From Fundamentals to Real-world Applications

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Abstract- *Iris scan is a biometric recognition technology, which has high accuracy and a non-forging nature. This review paper provides an overview of the workings of iris scanning technology and a few models which is used for the recognition systems. The system of Iris recognition depends on the patterns found in the iris part of the eye to recognize people and verify them. Iris recognition is a valuable tool for security, access control, verification, and authentication. Also, the iris scanning technology can be used in applications in healthcare, and border control, to increase security. Iris has features like unique patterns and longterm stability throughout the lifespan of a person, making it more secure and reliable than other recognition biometrics like fingerprint and face recognition. Integration of AI and Hybrid models (Use of traditional models like Daugman's rubber sheet model with deep learning) is also making it more secure and faster as technology is evolving.*

Keywords - *Iris scan, image processing, CNN, IRS.*

I. Introduction

Iris scanning is one of the growing biometrics in secure methods for personal identification and authentication. "The iris is a colored part of the eye surrounding the pupil and has unique and stable patterns that recognize individuals" [1]. Using the unique patterns of the iris, iris scan bio-metric can be used in a wide range of applications from security access control to identity verification at different places. The iris provides a higher level of accuracy, stability, and reliability than other bio-metrics such as fingerprints, voice recognition, or facial recognition. The unique and complex nature of iris patterns makes it difficult to change surgically without affecting vision or forging identity. Iris recognition technology provides crucial security in various sectors, including government, finance, healthcare, military installations, and many more. Iris scanning is increasingly integrated into diverse systems, iris scanning plays a crucial in border crossing in daily life for identifying persons and working as a passport or identity card in open border countries. Table 1 shows the difference between different bio-metrics recognition systems.

Table 1:Comparison of Different Bio-Metrics [1]

Bio-Metrics	Ease of use	Uniqueness	Circumvention	Acceptability
Iris	Medium	High	Low	Medium
Fingerprint	High	High	Medium	High
Face	Medium	Medium	High	High
Voice	High	Low	High	High
Retinal	Low	High	Low	Low
Hand Geometry	High	Medium	Medium	Medium

High
Medium
Low

A. General Description of IRS

The IRS (Iris Recognition system) has normally ten steps in verifying or identifying an individual or enrolling an individual into the system. These steps are as follows:

Image acquisition: The first step of iris recognition it includes capturing a high-quality image of the human iris, which works as the raw data for input and further processing in the iris recognition system. The quality of the visual representation of the iris directly influences the accuracy and reliability of the whole process.

Eye Image: In iris recognition, the second step, the eye image is the raw input captured by a camera in the first step, and it serves as the basis data for identifying a person based on the unique patterns present in the iris. Crypts, furrows, and freckles are part of the iris that are unique to each person.

Pre-processing: In iris image recognition, this step includes a series of image enhancement and correction techniques that are applied to the captured iris images before they are used for further processing of the recognition system. Pre-processing is mainly used to increase the quality and reliability of iris images, making them more suitable for accurate and robust identification by their unique patterns.

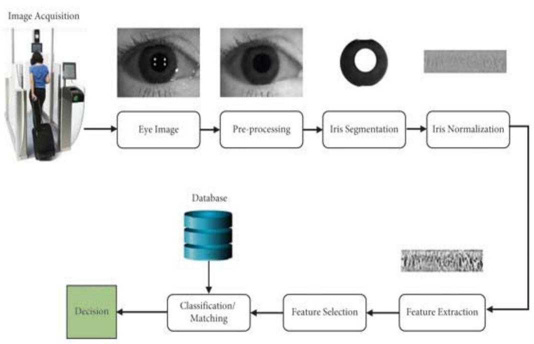

Figure 1: Process of the IRS [2]

Segmentation: The process of segmentation of the iris is a crucial and the fourth step in process of the iris identification, in which the objective is to isolate the iris region (Colored part of the eye) from the input image of the eye. This process is essential because only the iris part of an eye contains unique patterns that are used for identification in iris recognition systems. Segmentation allows for a focused analysis of the iris patterns for further process in the system.

Iris normalization: Normalization of the iris is a crucial step in a traditional system of recognizing the iris that involves transforming the iris part from its original polar coordinates to a standardized Cartesian coordinate system or in other words transforming a circular image into rectangular form.

Feature extraction: Feature extraction for iris recognition this step involves the process of selecting and presenting the "unique characteristics of the iris that is used for the identification or verification of an individual" [2]. After iris normalization, feature extraction algorithms analyse the patterns and textures within the iris to create templates of the iris patterns also called the compact representation of the iris. These extracted features are then used in the feature selection process to reduce the feature space.

Feature selection: Feature selection from the image in iris recognition is done by the process of choosing relevant features from the extracted features to improve the effectiveness and efficiency of the IRS. Its purpose is to collect the most discriminative and informative features while reducing the feature space. Feature selection is necessary for increasing the performance, and computational efficiency of iris recognition systems.

Classification and Matching: In iris recognition, classification and matching are the final steps in the process of verifying or identifying an individual. In this step of the process, the templates of the input iris image are compared to the previously stored templates to find whether it match any template of the enrolled persons or not and send the findings to the next step of the process that shows whether the individual is identified or not.

Database: Database is a structured collection of templates or images representing the unique iris patterns of individuals registered in the system. The database will be used in the future for verification and identification of the individual.

Decision: In iris recognition, decision making is the final step in process that involves determining whether the input of the iris matches any of the stored templates of the iris in the database or not and shows that the individual is identified or not, it shows that the new person is enrolled depends on request.

B. Hamming Distance:

In iris recognition, it is used to describe the distance between two iris patterns that are represented by binary iris codes. IrisCodes are compact and unique representations generated during the coding phase of iris detection algorithms, including Daugman's algorithm.

- **IrisCode Generation:** During the enrolment process, the iris pattern of an individual is identified and analysed by an IrisCode-generating algorithm. The IrisCode is a binary representation of the iris pattern.

- **Binary Representation:** The IrisCode is a sequence of binary digits ("0s" and "1s") that represents the specific characteristics of an iris pattern. Every bit of the IrisCode represents a specific characteristic or feature of an iris.

- **Hamming Distance Calculation:** The next step is the Hamming distance. Hamming distance measures the difference in the number of places where the corresponding bits of two different IrisCodes diverge. A low Hamming Distance indicates that two IrisCodes have a high degree of similarity. This is indicative of the likelihood of the two IrisCodes being from the same individual in the context ofIR. Conversely, a high Hamming Distance indicates a greater degree of dissimilarity. A higher Hamming Distance in Iris Recognition indicates a lesser possibility of two IrisCodes belonging to the same individual.

- **Usability:** Iris recognition systems usually use a threshold value. "The threshold value is the difference between a false positive and a false negative" [4]. If the calculation of the Hamming distance (the distance between two IrisCodes) between an IrisCode and an IrisCode stored in the "Iris Codes system is less than or equal to the threshold value, then the match is declared and the person is identified" [4].The threshold is a key factor in determining the sensitivity and specificity of an IRS. By adjusting the threshold, the system can achieve the desired balance between false positives and false negatives.

  Calculation

$$\boldsymbol{H(x,y)} = \frac{\boldsymbol{1}}{\boldsymbol{M}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(A_i \oplus B_i) \quad [4] \qquad (1)$$

Where: A_i and B_i are the bits at position $i$in the two binary strings.$\oplus$ represents the XOR (exclusive OR) operation.

C. Models

Iris recognition models can be specified into the three main groups based on their advanced technologies: Deep Learning, Machine Learning, and AI-based models.

Daugman's model: The rubber sheet model, "is a conceptual and mathematical representation of iris patterns used for iris recognition purposes" [5]. It is designed to normalize and standardize the representation of an iris pattern in order to provide a consistent and comparable pattern for accurate recognition. This model is based on the concept of a rubber sheet, which is a mathematical representation of a rubber sheet. This model is designed to address the variability of iris images caused by pupil dilation and eye rotation, as well as other factors.

The segmented part of iris is transformed into a rectangle image. It's like drawing circles of pixels in an iris image, where you take the pixels from an oval iris and fill it linearly like a rectangle [5]. You can do this by taking the first upper circle of pixels in your iris (the size of the diameter of your iris at 360°) and arranging them in a straight row. Then you take the diameter of the first circle and divide it by one. You can do the same with the second line of pixels until you get to the pupil. If you take the first circle and step 1, the resulting rectangle is 360° wide and the height is the difference between the radius size of your iris and your pupil.

CNN: "CNN is one particular class of the neural networks techniques that has ability to automatically learn picture feature representations" [1]. Models of neural networks rely on layer computation and have a hierarchical data representation. Because NN models are sequentially implemented, the output from one layer will be the input for the subsequent layer. Each layer provides a single representation level, and the layers are specified by a set of weights [6]. Additionally, it is mentioned that a set of biases and weights connect the input and output units. The weights in CNN are shared locally, meaning that the weights are the same at every input point. The weights associated with the comparable output form the filter. Locally connected convolutional layers are arranged in alternating layers within a CNN. There are the same number of filters in each tier. Fully connected layers and down sampling layers function as a classifier.

Three ideas underpin the CNN architecture weight sharing, down sampling processes, and local receptive fields. Every neuron in the local receptive field receives input from a tiny area of the layer above. Additionally, it is the same size as a convolution filter. Layers that use convolution and down sampling take advantage of local receptive fields. The convolutional layer is supposed to share the weight to manage "capacity and decrease the complexity of the model".

- **The convolutional Layer:** Convolutional layer is first in CNN that uses a set of randomly generated learnable filters that are trained via the back-propagation technique as its weights. "Every filter that convolved over the entire image produced the feature map. Additionally, the feature maps in that layer have the same number of applied filters".
- **The pooling layer:** This layer reduces the spatial size of the convolutional layers by implementing a down sampling process. Prior to being applied at the pooling layer, the size of the pooling mask and the type of pooling operation must be decided.The pooling process is applied to the values of the pixels that the "pooling mask captures, multiplied by a trainable coefficient, and then added to a trainable bias" [7].
- **Fully connected layers:** "CNNs use the fully connected layer to create the appropriate classifications for the images. Once the images have been flattened, each value is given a vote through one or more than one fully connected layer"[7].

ANN: "Artificial Neural Networks (ANNs) for Iris Recognition are computational models that are inspired by the human brain's structure and functioning". These models are capable of automatically learning and recognizing unique patterns in iris images. This is a common biometric authentication process, and an ANN model for Iris Recognition leverages its capacity to learn and adjust to complex patterns. The success of an ANN for Iris Recognition is dependent on its architecture, the appropriate hyperparameter selection, and the accuracy of its training data [8].

- **Input Layer:** The first layer of an ANN is made up of the features that are extracted from an iris image. Every node in the first layer represents a particular element or pixel value in the iris data set.
- **Hidden Layers:** The hidden layers enable the processing of the input data to generate sophisticated patterns and representations. Each node within the hidden layers computes a weighted summary of its inputs and then applies an activation function, such as a ReLU or a sigmoid. The number of layers and nodes within each layer is dependent on trial and error and the difficulty of the task.
- **Activation Functions:** The activation function introduces nonlinearities into the model, allowing it to process and extrapolate complex mappings in the data. Generally, "Rectified Linear Units (RLUs) are used for the hidden layers, and sigmoids or softmaxes are used for the output layers, according to the classification challenge" [9].
- **Output Layer:** Output layer outputs the final iris recognition results. The output layer for iris recognition usually consists of a single node with sigmoid activating function for binary class (genuine/implantation) or a multiple node with softmax activating function for a multidimensional class (identifying unique individuals).

D. Advantages and Disadvantages

Advantages:

- **High Accuracy:** Iris recognition is well-known for its precision in recognizing people. Iris patterns offer a unique and stable biometric feature.
- **Non-interfering:** The process of iris photography is non-disturbing and does not involve any physical contact.
- **Spoofing proof:** Due to the complexity and random nature of the iris pattern, it is difficult to imitate or falsify and the impossibility of surgically modifying the iris without risk of the vision [5].
- **Integration with Other Technologies:** Iris recognition system can also be combined with different biometric technologies or security systems, resulting in multi-modal solutions that improve precision and dependability.
- **Stability:** Iris patterns are stable throughout a person's life, making Iris Recognition suitable for use in the long term.

Disadvantages:

- **Cost:** Installing an iris recognition system can be a costly process. Specialized hardware, including high-resolution cameras and advanced algorithms, can add to the overall cost.
- **Environmental Factors:** Iris image quality can be affected by environmental elements, such as lighting conditions.
- **Limited Range:** Iris recognition system requires a person to stand relatively close to the system for capture for high accuracy.
- **Template Size:** The amount of iris data in a template can be large, so it can be hard to store it in small systems.
- **Vulnerability:** The iris may experience slight alterations as a result of cataracts, Myopia, or other eye diseases, which

may affect the accuracy of recognition over a long period.

E. Real life Applications of Iris Recognition

There are many applications of an iris recognition system in different sectors which include: Border Crossing, Security, citizen identity proof, forensics science, the health sector, and many more.

- **Border control:** Iris applications are used in national border control, where an iris is like a living passport to the security checkpoint at the border. This task is linked to the entry and exit of the country of the nationals and foreign nationals as part of daily trade with the rest of the world [5].
- **The health Sector:** Integrate Iris Recognition into Health Insurance Cards to Reduce Fraudulent and Unauthorised Access to Insurance Benefits. Iris Recognition can be utilized to authenticate participants in research data to maintain the integrity of the data and the confidentiality of the participants.
- **Forensics science:** Forensics science uses a variety of sciences to solve problems that are important to the legal system, like verifying identities of people, government documents, official papers, etc., verifying "rights to services" like birth certificates, tracking missing or wanted people, and identifying missing people who don't remember where they live.
- **Security:** This includes personal security as well as government or organization's confidential data and area access to checks that only authorized persons can access like Airport Security, Financial Transactions, Critical Infrastructure Protection, and Government and Military Installations.

II. Literature Review

IRS capture human eye images using a near-infrared iris sensor and transform them into an iris template by performing mainly three steps that include: "segmentation, normalization, and feature extraction. The comparison of the iris is done by calculating the Hamming distance"[10].

The researchers conducted experiments involving 54 patients with anterior segment eye diseases to determine whether such conditions could lead to failures in iris recognition. The patients' iris images were captured before and after treatment for their eye diseases. The results showed that diseases, like corneal edema, and iridotomy had little effect on iris recognition [11].

Daugman's system involves segmentation, normalization, and feature extraction using Gabor wavelets, and matching using the Hamming distance.The article also discusses the work of Boles, who proposed an iris recognition system that can handle noisy conditions and variations in illumination and camera-to-face distance [12].

Iris recognition algorithms are used to "match iris images from the dataset of iris images". Iris Recognition at Airport security and Border-Crossings used for passport-less immigration control, expedited check-in, and security screening, airport employee access control, and watch-list screening for arriving travellers [13].

AI-based autonomous security robots at airports autonomously patrol airport premises, monitor suspicious activities, and interact with passengers to provide information and assistance. Smart CCTV systems are also a key component of airport security, as they analyze passenger data, traffic flow, and other critical information in real-time [14].

In Polar transformation, the iris image is mapped into a polar coordinate system. John Daugman's transformation formula uses wavelets to code iris information, providing "a high level of security and distinctiveness". The odds of two different irises returning identical iris codes are discussed, emphasizing the system's robustness [15].

There are multiple matching algorithms one of them is IriTech's matching algorithm which uses a "multi-sector analytic method that selects and uses only the unique portions of the captured image, even if the image is affected"[16] by environment variables like light, or other variables like eyeglasses, and contact lenses.

Deep learning approaches are used for improving segmentation and feature extraction. The paper give priority to the need for research to address various challenges, and it concludes by discussing the strengths and limitations of iris recognition systems and their future prospects[2].

Iris recognition system has two approaches to store data which are "non end-to-end and end-to-end approaches. In the non-end-to-end approach", pre-processing, feature extraction, and matching are separate steps, often involving techniques like the Hough transform for segmentation and traditional handcrafted features or deep learning features for feature extraction. In contrast, end-to-end approaches use specialized neural networks and achieve high accuracy[17].

The iris is a colored part of an interior organ eye that is well-safe. On the other side, fingerprints can be problematic in identifying after a long time of manual work or dust on fingers or cut from sharp objects. The iris is stable which makes it work accurately for a long period[19].

Multiple researches are performed for the Iris recognition which conclude that DCNN, CNN, Capsule networks shows good results compared to similar research. Researchers discuss two methods for feature transformation: invertible transformation uses techniques such as salting and bio-hashing to transform template features using a function specified to a particular user; and noninvertible transformation uses one way functions such as hash functions.To keep iris template databases secure, LSB steganography can be used [20].

Table 2: Review Literature

S. N.	Author	Technique	Data
1.	Raghavendra, R., Raja,and Busch, C.(2016).[21]	OSIRIS (Open Source for IRIS),twocommercial algorithms - VeriEye SDK and Morpho	ICS dataset
2.	Abu-Zanona, [22]	Transfer learningtech.using ImageNet	MIMU iris database
3.	Hu, Q., Yin,and Huang, Y. (2020). [23]	"An End to I Neural Network based on CNN".	CASIA iris V4 database,
4.	Ak, T. A., Steluta, A., et al. (2021).[24]	"New method of iris localization and using an eyelid detection method"	"CASIA-V1.0, CASIAV4.0 Lamp, SDUMLA HMT dataset"
5.	Zhou, W., Ma, X., and Zhang, Y. (2020).[25]	ICASIA.v4-distance, UBIRIS.v2 ris segmentation, Deep learning	"CASIA-Iris-Interval, CASIA-Iris-Thousand, UBIRIS.v1 database iris segmentation; deep learning"
6.	"Wang, C., Muhammad, J., Wang, Y., He, Z., and Sun, Z. (2020)"[26].	IrisParseNet	"CASIA.v4-distance, UBIRIS.v2, and MICHE-I"
7.	Garg, M., Arora, A., and Gupta, S. (2021). [27]	The Back Neural Network (BPNN)	"CASIA database version 3.0"

8.	"Malgheet, J. R., Manshor, N. B., Affendey,(2021)"[2]	Traditional approach and the Deep learning approach.	CASIA-IrisV4, MICHE, or UBIRIS
9.	Nanayakkara, Meegama, R. (2020).	Machine Learning [20]	CASIA and LEI
10.	Nguyen, K, Proen ca, H, (2022).[18]	Deep Learning	MICHE and UBIRIS
11.	"Desoky, A. I., Ali, H. A., and Abdel-Hamid, N. B. (2012)"[28].	Daugman's (conventional) method	MMU1

III. Future Scope and Conclusion

The Future of Iris Recognition. Iris recognition has great potential in many areas. As technology advances, its capabilities and applications will continue to grow. The future of Iris recognition is in the integration of AI and ML algorithms, which will improve the accuracy and effectiveness of IRS. In the near future, we can expect to see the introduction of Touchless boarding at airports, as well as widespread use of Iris-based systems in healthcare to identify patients securely and to monitor biometric health. We can look forward to exploring new applications such as Human-Computer Interaction and Iris-based Authentication for emerging technologies.

In conclusion, Iris Recognition (IR) is a powerful biometric technology that offers remarkable benefits in terms of precision, non-intrusion, and resistance to counterfeiting. Its existing applications in access control and security, as well as in healthcare, demonstrate the clear advantages of this technology. Nevertheless, it is essential to address issues related to privacy, ethics, and technological compatibility. By continuing to research, innovate, and implement iris recognition responsibly, it is likely to play a major role in creating a safer, more efficient, and more technologically advanced future. In this paper review, we have determined that the device's image acquisition range is limited to a maximum of 1 metres, which is a significant issue related to Iris Recognition.

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