Research on Iris Feature Extraction and Recognition Technology Based on Deep Learning

Yufei Chen
School of Computer Science and Engineering
Xi'an Technological University
Xi'an, 710021, China
E-mail: 18092589395@qq.com

Bing Zhao
School of Computer Science and Engineering
Xi'an Technological University
Xi'an, 710021, China
E-mail: 1574186102@qq.com

Yiyang Zhao
School of Computer Science and Engineering
Xi'an Technological University
Xi'an, 710021, China
E-mail: 2389369622@qq.com

Hao Wei
School of Computer Science and Engineering
Xi'an Technological University
Xi'an, 710021, China
E-mail: 3129943413@qq.com

***Abstract*—Certain biological information or behavioral information of a person can achieve the effect of characterizing an individual, and by combining the computer to extract the corresponding information, identity authentication is achieved. In a variety of biometrics, iris relative to fingerprints, handwriting and face, belongs to the structure within the human eye, if you want to steal is very difficult, in order to improve the safety factor, so the iris is used for authentication to achieve iris recognition. This study is based on deep learning iris recognition matching, in order to be able to effectively improve the accuracy of iris recognition, experiments are carried out. Evaluation metrics are performed through Hamming distance to calculate the correct recognition rate to ensure that the iris information can be accurately represented. This study mainly uses the improved PCHIP-LMD algorithm and CNN algorithm, the LMD algorithm is more context-aware, has better generalization ability, flexibility and scalability, while the CNN algorithm has the advantages of local awareness, parameter sharing and automatic parameter learning. In this study, we compare the correct recognition rate of iris recognition between improved PCHIP-LMD and CNN algorithms and get the conclusion that the correct recognition rate of the improved PCHIP-LMD algorithm is only 78%, which is much smaller than that of the CNN algorithm which is 92%, and we get the conclusion that LMD algorithm is suitable for iris recognition with few samples, and it is more suitable to use CNN algorithm when the sample images are too many. CNN algorithm. With the development of technology, the application of iris recognition will be more and more, I believe that soon will be widely popularized in daily life and work.**

Keywords-Iris Recognition; Deep Learning; Normalization; Feature Extraction; LMD; CNN

I. INTRODUCTION

Today, with the rapid development of science and technology, biometric identification has begun to enter people's daily life and work. Biometric identification is a technology that collects the user's biometric features by means of modern technology and extracts the features through specific recognition algorithms, converts them into coded representations within the computer, and realizes identity authentication. Iris recognition is widely used in the field of identification by virtue of its uniqueness, stability and anti-counterfeiting features. Compared with other biometric identification, iris recognition is more secure, and is useful for safeguarding personal privacy and information security. Outstanding performance

In this paper, the iris feature extraction method based on traditional methods is firstly categorized into single feature and multi-feature fusion. Single feature is mainly for the acquisition of features in the frequency domain, air domain, etc. Multi-feature fusion is based on single feature extraction, and multiple features are comprehensively extracted by using weighted summing or machine learning algorithms.

Secondly, the matching of iris recognition based on deep learning is added, which mainly includes distance recognition algorithms and neural network classification methods, which can use the Hamming distance, Euclidean distance, cosine distance, etc. to measure the distance between different iris image features, convert the extracted iris features into digital features, and compare the distance similarity with the template iris in order to determine the category. The neural network method is to input the extracted iris features into the network (e.g., BP, RBF, etc.), and then use the relevant classification function to complete the determination of the iris image category. In this paper, by comparing experiments on the CASIA-Iris-Syn dataset and CASIA-Iris Thousand dataset, which are commonly used in iris recognition tasks, we verified that the CNN test method can effectively improve the accuracy of iris recognition and achieve a low error rate.

Subsequently multi-feature fusion hierarchy is added. Depending on the different sources of data, the multi-feature fusion hierarchy can be categorized into, pixel hierarchy, feature hierarchy, matching hierarchy, and decision hierarchy.

Finally, iris feature matching test is performed. When recognizing the matching, the loss function layer of the network is removed, the rest of the network structure is retained, and the feature images extracted from the training model are expanded into one-dimensional feature vectors. The experimental results show that different iris feature vectors can be successfully extracted and the processed iris images are compared with those in the database for subsequent iris matching and recognition.

II. RELATED WOEKS

In 2014, Zhen Nan Sun et al. encoded the texture of the captured iris images with a new representation of the texture, which brought together the advantages of vocabulary tree and local constraint line coding, resulting in further performance improvement over the previous one. In 2020, Bill Zeng regarded the iris recognition task as an iris classification task, and explored the effectiveness of various strategies on iris classification. In 2020, as the Belt One Road Policy is deeply implemented, Chinese iris vendors with independent intellectual property rights start to export iris technologies and solutions, and become the main suppliers for foreign iris universal registration programs.2021, Ding tong designs a multi-connected residual network can obtain feature maps of different scales in training, realizing multi-dimensional extraction of iris features.

Nowadays, deep learning algorithms are also different from traditional algorithms. In iris recognition, traditional algorithms still have certain dilemmas, in the use of traditional iris recognition algorithms, the need for the user to take the initiative to cooperate with a very high degree, requiring the user to follow the instructions for recognition; in the process of using the user experience is very poor. But deep learning has a different solution, compared to traditional feature recognition algorithms, deep learning methods in the premise of improving the recognition accuracy, but also improves the model of the image noise of the interference and resistance to the ability as well as the ability to generalize. This deep learning technique is data-driven, allowing the iris recognition system to be less demanding on image quality, than traditional algorithms. In the process of recognition, by adding different angles of eye posture and other changes, so that the system can recognize the iris features in different states, to ensure the system recognition efficiency, but also to improve the user experience.

In recent years, along with the continuous growth of computing power in China, deep learning has also been rapidly developed in the trend of the times, especially in the field of biometric identification systems, for example, the accuracy rate of face recognition technology based on deep learning has far exceeded that of human beings themselves.

III. MODEL AND METHOD

A. Iris

The iris is a part of the human eye, a flat, circular membrane located in the middle layer of the eye wall, between the cornea and the lens, visible through the cornea, commonly known as the "black eye". There is a small round hole in the center, called the pupil, from which light enters the eye. The iris is composed mainly of connective tissue containing pigment, blood vessels, and smooth muscle. The color of the iris varies depending on the amount and distribution of the pigment, and is generally black, blue, gray, and brown. Individual irises are biologically distinct and can therefore be used as an identifier.

Figure. 1. The human eye

A complete iris recognition system consists of an acquisition device for collecting iris images and a recognition algorithm for extracting iris texture features. The iris image is first acquired by a high-precision iris capturing device, next the collected iris image samples are preprocessed, then the preprocessed iris image is feature extracted, followed by encoding the extracted texture features of the iris, and finally the features are saved in a database for subsequent recognition control.

B. Iris Recognition Key Technology

The acquisition of iris images is crucial because the image quality directly determines the accuracy of the recognition. The human iris and pupil are very close to a circle, and the iris is a region enclosed by the outer boundary of the pupil and the inner boundary of the sclera, which is a relatively small target, so a lot of work needs to be invested in the iris image acquisition part of the iris recognition research as well. The earlier algorithm used for iris image recognition is LMD and the recognition process is shown in Fig. 2.

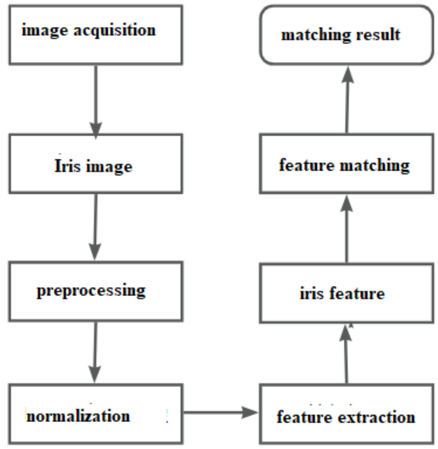


Figure. 2. Flowchart of iris recognition

C. Data sets

The more commonly used iris libraries in iris recognition related algorithms and systems are CASIA, UBIRIS, JLU iris library, IITD iris dataset, and MMU database. Among them, CASIA iris database is a free iris database provided by the Institute of Automation of Chinese Academy of Sciences (IAAS), which is acquired by the remote multimodal biometric feature acquisition and recognition system (LMBS) independently researched and developed by CASIA, and this device can capture images from a distance of 3 meters, and it is also one of the main databases applied to iris research in the world at the present time.

So far, the CASIA iris database consists of four versions, i.e., CASIA-V1~CASIAI-V4. The fourth version, CASIA-V4, was selected for this study.

CASIA-V4 contains a total of 54,601 iris images from more than 1,800 real people and more than 1,000 virtual people. All images are 8-bit grayscale images captured under near-infrared light and saved in JPEG format. CASIA Database Figure 3 shows two example iris images in CASIA-V4.

(a)CASIA-Iris-Thousand (b)CASIA-Iris-Syn

Figure. 3. Example of two iris images

D. Modeling Principles

The LMD model is a recognition algorithm that centralizes preprocessing, feature extraction, model training, and recognition in a single unit, and traditional LMD algorithms will show good performance on small datasets.

It has good recognition rate in iris recognition, which decreases in poor lighting, blurred images and too much test data. For this reason, the continuous improvement of the LMD method, named PCHIP-LMD, the flow of the algorithm is shown in Fig. 4, using this algorithm ensures the continuity and smoothness of the polynomial derivatives coming at each point, and improves its robustness and conformality.

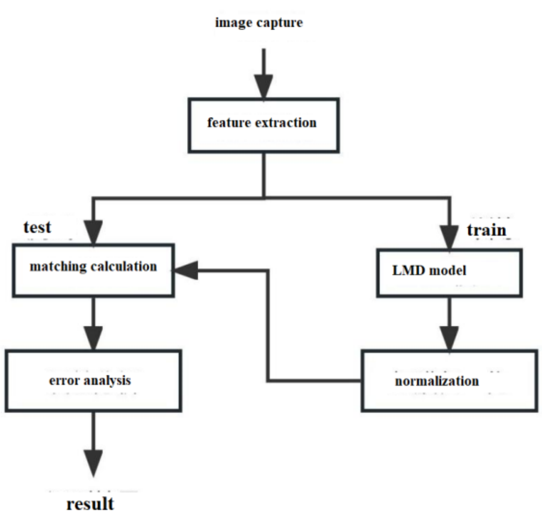


Figure. 4. Flow of LMD improvement algorithm

Let there be a sequence of nodes ($x_i, i=0,1,2,...,n$) on the interval $[a,b]$, $a = x_0 < x_1 < ... < x_n = b$, whose corresponding function is y_i , $\int f'(x_i) = m_i, h_k = x_{k+1} - x_k, h = \max h_k$.

The segmented cubic interpolation function $I_h(x)$ satisfies.

$$I_h(x) \in [\alpha, \beta] \tag{1}$$

On any small interval $[x_{k+1}, x_k](k = 0,1,...,n-1)$, $I_h(x)$ is a cubic polynomial.

Satisfy the interpolation conditions $I_h'(x_i) = m_i$, $i = 0,1,2,...,n$.

In the interval $x \in [x_{k+1}, x_k]$, the PCHIP function expression is

$$I_h(x) = y_i + c_{k,3}(x-x_k)^3 + c_{K,2}(x-x_k)^2 + (x-x_k)^3 \tag{2}$$

Among them,

$$\begin{cases} c_{k.1} = m_i \\ c_{k.2} = (\frac{3}{h_k}(y_{k+1} - y_k) - 2m_k - m_{k-1.1})\frac{1}{h_k} \\ c_{k.3} = (m_{k+1} + m_k - 2\frac{y_{k+1} - y_k}{h_k})\frac{1}{h_k^2} \\ x \in [x_k, x_{k+1}], (k = 0,1,...,n-1) \\ h_k = x_{k+1} - x_k, m_k = f'(x_k) \end{cases} \tag{3}$$

It decomposes the image into different frequency sub bands to extract the structural and textural information of the image. The PCHIP-LMD algorithm combines PCHIP interpolation and LMD decomposition, which can be used for image processing tasks such as image enhancement, denoising, and image synthesis.

PCHIP-LMD (Piecewise Cubic Hermite Interpolating Polynomial-Local Median Decomposition) algorithm is an algorithm used in the field of image processing and computer vision. The core idea of the algorithm is to combine PCHIP interpolation and LMD decomposition to achieve the tasks of image enhancement, denoising, and synthesis. PCHIP-LMD guarantees that the interpolated curves between two neighboring points are monotonic, which means that the curves will not have strange fluctuations or discontinuous parts.

LMD is an image decomposition technique that decomposes the input image into multiple frequency sub bands. This decomposition can be used to extract image structure and texture information for better handling and utilization of image features in subsequent processing.

In this study PCHIP-LMD algorithm combines two techniques PCHIP interpolation and LMD decomposition. First, the input image is smoothed and interpolated by PCHIP interpolation to obtain a smooth image representation. Then, LMD decomposition is applied to this smoothed image to decompose it into different frequency sub bands. The structure or texture of the image can be enhanced and the noise of the image can be reduced by adjusting the enhancement parameters of the different frequency sub bands. In this study, PCHIP-LMD is used for better feature image extraction, enhancing the robustness of the image and ensuring that the interpolation curve is smooth and monotonic between neighboring data points. The accuracy of the image matching results is improved.

E. Faster R-CNN

The Faster R-CNN model integrates feature extraction, frame extraction, frame regression and classification into one network, which greatly improves the overall performance of target detection. Compared with the traditional iris localization methods, the Faster R-CNN model for iris localization not only improves the accuracy of iris localization, but also adapts better to different lighting conditions and image quality.

The basic flow of Faster R-CNN model is shown in Fig. 5. Firstly, the input to the detection sample image is used to extract features by CNN mentioning the input image, and then several proposal windows are generated by RPN (Region Proposal Network) and the proposal windows are mapped to the last layer of CNN to convolve the feature maps. Finally, a fixed-size feature map is generated for each ROI through the ROI pooling layer, and the classification probability and edge regression are jointly trained.

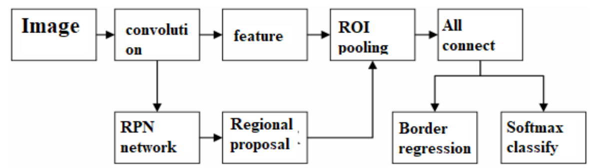


Figure. 5. Basic flow of Faster R-CNN model

When applying the Faster R-CNN model to iris detection, the training data need to be selected for labeling first. In order to better identify and locate the iris region in the test set, when labeling the iris images in the training set, the information of other objects in the labeling box should be minimized. When labeling, the outer boundary of the iris is labeled with a circle The ROI pooling layer labels the boundary of the pupil with a circle, and the outer rectangle of the pupil labeling circle is also labeled.

Combining the iris localization obtained from Faster R-CNN model detection and traditional iris localization and region segmentation algorithms can improve the localization and segmentation accuracy without decreasing the detection speed, which better solves the contradiction between accuracy and speed.

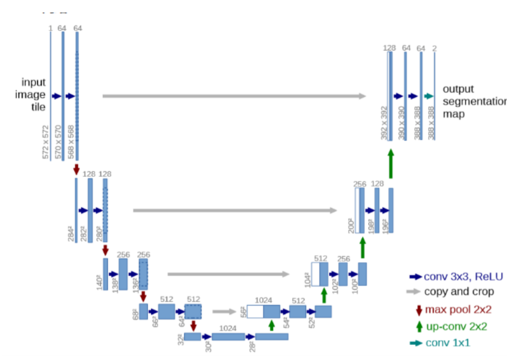


Figure. 6. U-net network structure

The U-net network structure is shown in Fig. 6. It is built using a U-shaped structure, and the hierarchy uses an encoding-decoding pattern, where the encoding part reduces the size while aggregating the image features, and the decoding part enlarges the size while mapping the image features. The encoding module aggregates the iris feature information through layer-by-layer convolution, which includes important feature information such as texture and pixel relationships. The decoding module gradually reduces the iris feature map to the original image size through up-sampling while mapping the iris semantic information to the corresponding locations in the original image.

Meanwhile, Hamming distance is used as a comparison method for error analysis by setting J and K as the feature codes of two different iris images, respectively:

$$\mathrm{HD} = \frac{1}{N}\sum_{i=1}^{N} J_i \oplus K_i \quad (4)$$

Where N is the total number of bits encoded in the image and $\oplus$ is a different-or-relative operation, which is 0 when J and K are the same and 1 when they are different. The encoding of the same iris is similar with a small Hamming distance, while the encoding of the different iris is very different with a large Hamming distance, which can be used as a criterion for distinguishing whether the two iris images are the same iris or not. The experiment is set that if the Hamming calculated value is less than or equal to 0.2, then the scanned image matches with the iris that already exists in the database, and if the Hamming calculated value is greater than 0.2, then the scanned image cannot be matched with the iris that already exists in the database.

F. Evaluation indicators

On the basis of the whole iris recognition system, in order to determine the recognition performance of different recognition algorithms, it is necessary to determine the corresponding judgment standard, in the whole process of experimental analysis, the evaluation index will have an impact on the performance of the algorithm. The evaluation index of iris recognition algorithm is Correct Recognition Rate.

Correct Recognition Rate (CRR) indicates that a higher CRR during a single iris recognition indicates that the system is more capable of recognizing and making accurate judgments about the attribution of iris information. The correct recognition rate is calculated as shown in Equation X, which represents the ratio of the number of correctly recognized samples to the total number of samples in a recognition task using a classifier. The correct recognition rate is a good response to the accuracy of the recognition algorithm and a good measure of whether the extracted features can accurately represent the iris information.

$$\mathrm{CRR} = \frac{N_{correct}}{N} \times 100\% \quad (5)$$

IV. EXPERIMENT AND ANALYZE

The software used in this study includes Python 3.7.13 and Matlab R2016a, the operating system used is Windows 10 Professional, and the hardware configuration of the computer is NVIDIA GeForce RTX 2060 graphics card, Intel(R) Core(TM) i5-10400F processor, 16GB of RAM and 6GB of discrete graphics memory. Intel(R) Core(TM) i5-10400F processor, 16GB of RAM and 6GB of discrete video memory.

In this study the advantages and disadvantages of two languages Python and MATLAB for iris recognition are compared along with the tools and libraries they provide.

Python is an interpreted language with rich scientific computing, deep learning and image processing libraries such as PyTorch, Keras and OpenCV. These libraries provide efficient data processing and analysis capabilities, and can help this study to achieve tasks such as training and optimization of iris recognition models, as well as image processing and feature extraction. At the same time, Python has GPU acceleration support, which can greatly improve the training and inference speed of deep learning models and help to improve the real-time performance of iris recognition. Python also has rich community support and open source code, which can help researchers to quickly develop and debug deep learning models. Python is used to implement the R-CNN model algorithm.

In contrast, Matlab is a specialized language for scientific and engineering computation, with powerful mathematical computation and matrix operations, as well as rich toolboxes, such as the image processing toolbox, the signal processing toolbox and the control system toolbox. These toolboxes can easily implement a variety of scientific computing and engineering computing tasks, and can help this study to implement tasks such as segmentation, denoising, and enhancement of iris images. Matlab also provides some powerful visualization tools that can help this study to better understand and analyze the data. In addition, Matlab's syntax is simple and intuitive, easy to learn and use, and easier for researchers who do not have a programming background. The LMD model is implemented on Matlab.

A. *Experimental data set*

All the models in this paper are validated and compared uniformly on the CASIA-Iris-Syn dataset and the CASIA-Iris-Thousand dataset, where the CASIA-Iris-Syn dataset contains a total of 200 people, each of whom contains an iris image of the left and right eye, totaling 400 images, and the dataset is divided according to the ratio of 6:1. The CASIA-Iris-Thousand dataset contains a total of 50 people, in which each person contains 10 images of the left and right eyes, totaling 500 images, and the dataset is also divided according to the ratio of 6:1, and only the left eye image is used for Python based training and testing, and the dataset is divided as shown in Table 1.

TABLE I. COMPARISON OF THE CONTENT OF THE TWO DATASETS

	Training Set	Test Set	Training Set	Test Set
Number of categories	50	8	45	6
Number of images/classes	20	20	10	10
Total number of images	342	58	342	58

The research in this paper aims to investigate the face recognition technology based on iris images. For this purpose, the iris images of the left and right eyes of 150 people, totaling 400 images, were randomly selected from CASIA V4.0 iris library as test samples for this experiment. On this basis, the experiment utilized the following research steps, the

First, this experiment normalizes the original captured iris images to obtain the feature maps. Next, the feature map is input into the convolutional neural network as the original sample for training and testing. Finally, a threshold value of 0.200 is set in the experiment, and the recognition is performed according to this threshold value, and the recognition results are obtained as shown in Table 2 and Figure7.

TABLE II. ANALYSIS OF EXPERIMENTAL DATA

Test Methods	Training Set	Test Set	Number Of Correct Identifications	Recognition Rate % (Crr)
CNN	400	60	56	92
LMD	400	60	47	78

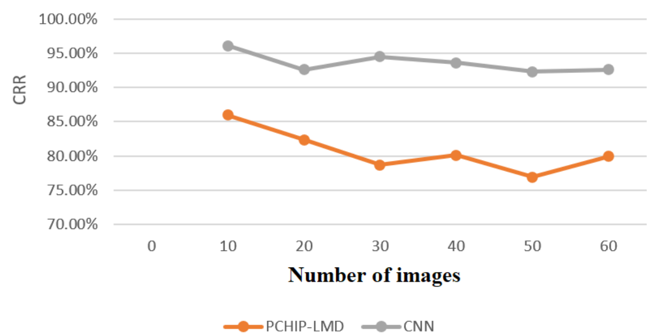


Figure. 7. CNN recognition result rate

Based on the analysis of the above results, it is concluded that the CNN algorithm yields a relatively high recognition rate of more than 90%, while the traditional LMD algorithm has a lower recognition rate of less than 80%.

B. *Visualization of experimental results*

The running code schematic is shown in Figure 8.

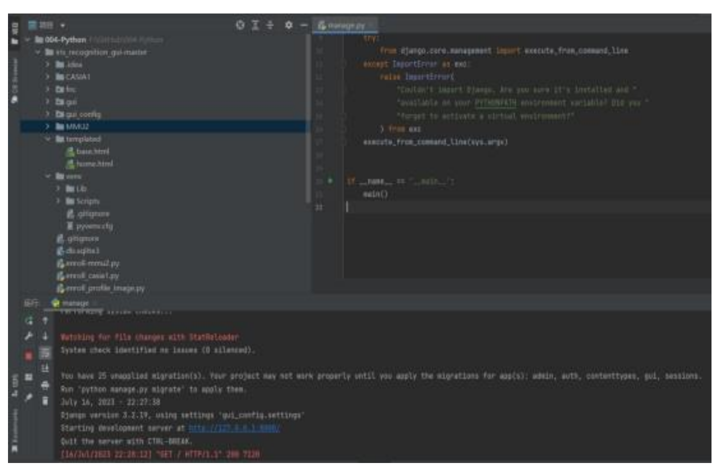


Figure. 8. Code Run Diagram

Figure 8 shows the R-CNN model implementation is based on Python3.7.13 Djanjo framework to realize the front-end interface, in the running results are displayed in the terminal interface will generate the local server address. The two html files in the middle are the iris interface administrator registration diagram and iris recognition system front-end interface diagram. The recognition function implements the iris verification function of an iris recognition system. The system is able to verify the input iris image by extracting iris features and performing iris matching to determine whether it matches the enrolled iris sample. First, the main function is set up, which obtains the path of the input image, the path of the template directory and the matching threshold from the command line parameters, and extracts features from the input iris image by calling the feature extraction related function to obtain its iris features. Then the matching function is called to match the extracted iris features with the registered iris samples. Finally, according to the matching result, the corresponding information is returned.

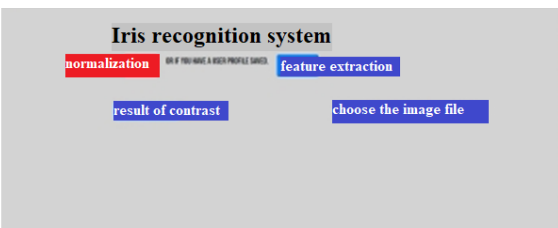


Figure. 9. Front-end page display

Figure 9 shows the front-end page display diagram with five visualization functions, which normalize the collected images, feature extract the iris image at different angles, and extract different iris feature vectors for subsequent iris matching and recognition. Comparison of database images, the processed iris images are compared with those in the database, and the matching results are shown in Fig. 10, if there is a matching image in the database, it shows successful recognition. The database is added, you can click to select the file to add the un-deposited figure iris image, and the addition process is shown in Figure 11.

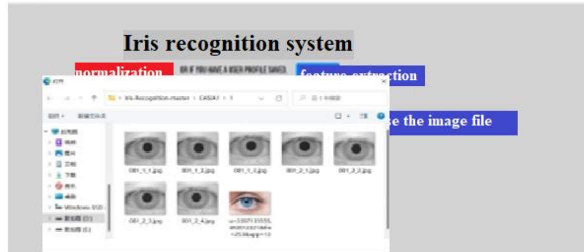


Figure. 10. Selecting the iris image to be matched against the image in the database

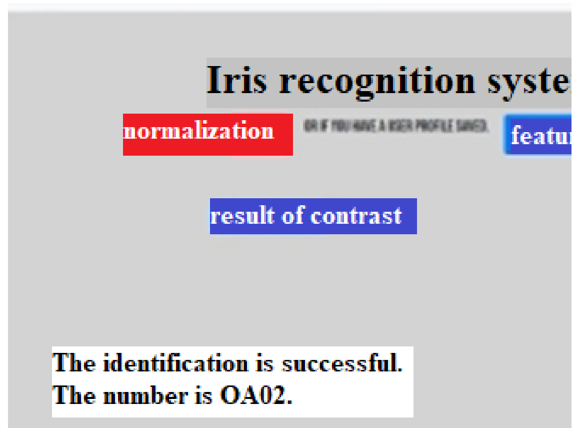


Figure. 11. Image matching demonstration

C. *Matlab-based experimental analysis*

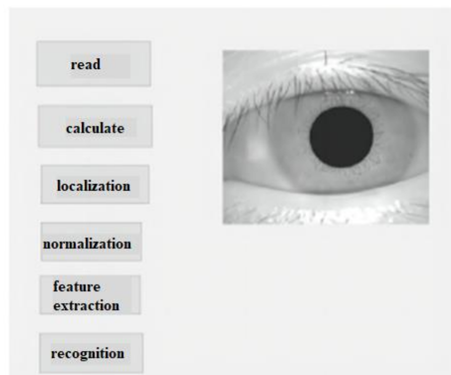
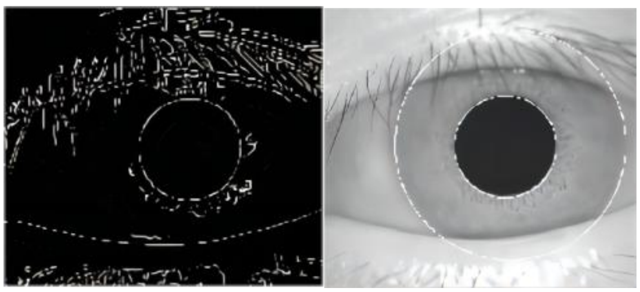


Figure. 12. Interface display

The experiment of LMD algorithm is based on Matlab R2016a for iris localization, extraction and recognition. Fig. 12 shows the runtime interface presentation, which contains the option of reading the image, selecting the image that you want to compare, and the image operation option, respectively. Canny edge detection algorithm is used for experimental implementation. The Matlab programming language was used to detect the edges of the image by combining techniques such as Gaussian filtering (to remove noise), Sobel operator (to compute the gradient of the image). Moreover, different parameter settings are experimented and analyzed in the experiment to get the best edge detection results.

The result of the operation is shown in Fig. 13. The experiment implements an iris localization function. It obtains the positional information of the iris and pupil by reading an eye image, segmenting it into iris regions, and then drawing a localization circle on the image.



(a) canny edge extraction (b) localizing iris image

Figure. 13. Edge extraction to obtain iris

D. Localization

In terms of normalization process, this experiment consists of saving the normalized iris image and the noise array. Normalization removes distortion and rotation from the image by converting the original iris image into polar coordinate representation. The normalized image is displayed in the image control and saved in picture format. The noise array is also saved for subsequent processing. This step helps to improve the accuracy and stability of iris recognition system. The normalized image is shown in Fig. 14(a). Subsequently, the normalized iris image is subjected to feature extraction and coding method. The image is first processed using Gabor filtering to obtain a set of results. By processing the results, a biometric feature template consisting of binary values is obtained. In order to ensure the accuracy of the template, pixels with small amplitude are labeled as noise parts to reduce their effect on the template. With the method proposed in this paper, feature extraction and encoding of iris images can be performed accurately. The obtained feature extraction map is shown in Fig. 14(b)

(a) Normalized image (b) Image after feature extraction

Figure. 14. Image after normalization and feature extraction

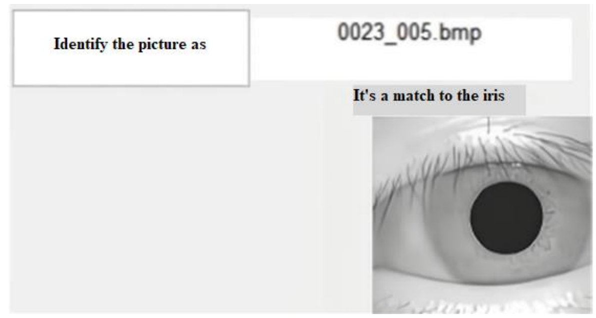


Figure. 15. Matching successful image

Figure 15 presents the interface of successful matching. The design of this experiment not only obtains good experimental results, but also provides a convenient user interface.

In this study, two languages, Python and MATLAB, are used to implement the iris recognition system, giving full play to their advantages and achieving good experimental results. Both Python and MATLAB have their own advantages and applicable scenarios. If deep learning model training and optimization are needed, or large-scale data processing and analysis are needed, Python is a better choice. If you need to perform scientific and engineering computing tasks, and need to visualize and analyze data, Matlab is also a good choice. Of course, the choice of language should also take into account the personal experience and proficiency of the researcher, as well as the specific needs of the project.

In research work, choosing the right language and tools is important for the development and implementation of iris recognition systems. Both Python and MATLAB have their own advantages and can provide efficient support for the development and implementation of iris recognition systems. By fully utilizing their advantages, the accuracy and real-time performance of iris recognition can be improved to better meet the practical needs.

In terms of modeling, the data performance of the LMD model is not as good as the R-CNN model, but the burden of its model, the complexity of its algorithm is relatively low, and appropriate algorithms and implementation paths are selected under different requirements.

V. CONCLUSIONS

Iris recognition is one of the most convenient and accurate of the current bio-information recognition technology; this paper combines the deep learning and applies the cutting-edge technology of deep learning to iris recognition. This paper mainly combines the convolutional neural network technology of deep learning with iris feature extraction and classification in iris recognition system, and uses this as the basis to introduce iris recognition based on CNN model. The current research status related to iris recognition technology at home and abroad clarifies the current research content and subject needs, and determines the research program of the subject. Combined with the iris recognition in recent years, the iris region is used as the input of the model based on the convolutional neural network model, and at the same time has a high recognition rate. It further promotes the development of iris recognition technology related fields. Iris has more advantages than others in terms of security and anti-counterfeiting, and the development prospect is getting broader and broader, so this research has great significance.

In this paper, we try to use the model generated by convolutional neural network in deep learning in iris recognition, and although we have achieved some results, there are still some deficiencies and shortcomings. For iris preprocessing, the traditional grayscale algorithm is still used for preprocessing, which may increase the computational difficulty. Therefore, future research can explore more advanced iris preprocessing techniques to improve the accuracy and real-time performance of iris recognition.

In addition, this paper selected the existing database CASIA v4.0 with a small amount of selected data and generated simulated iris images that can be used for network training. However, this may lead to data errors that affect the accuracy and generalization ability of the iris recognition model. Therefore, future research can continue to collect more iris datasets and explore more data enhancement techniques to improve the generalization ability and robustness of iris recognition models.

Future research can explore more deep learning models and algorithms to improve the accuracy and real-time performance of iris recognition. In addition, more iris image preprocessing techniques can be explored to improve the robustness and generalization ability of iris recognition models. Through continuous improvement and optimization, iris recognition technology will have an advantage over other technologies in terms of security and anti-counterfeiting, promoting the development of related fields.

ACKNOWLEDGEMENT

This research is partially funded by the Project funds in Shaanxi Province University Student Innovation and Entrepreneurship Fund Project (S202210702081).

REFERENCES

[1] Mach. IntelH. Proenca, S. Filipe, R. Santos, et al, The UBIRIS.v2: A database of visible wavelength iris images captured on-the-move and at-a- distance[J]. IEEE Trans. Pattern Anal, 2010, 32(8):1529-1535.

[2] Fawzi A, Samulowitz H, Turaga D, et al. Adaptive data augmentation for image classification[C].2016 IEEE International Conference on Image Processing (ICIP). IEEE,2016.

[3] Carl M , Goldberg R .Iris biometrics: from segmentation to template security[J].Computing reviews, 2013, 54(11):672-673.

[4] Hu J, Shen L, Sun G. Squeeze-and-excitation networks; proceedings of the Proceedings of the IEEE conference on computer vision and pattern recognition, F, [C] Salt Lake City, UT, USA 2018.

[5] Ibrahim M T, Khan T M, Khan S A, et al. Iris localization using local histogram and other image statistics[J]. Optics & Lasers in Engineering, 2012, 50(5):645-654.

[6] Chen Y, Wu C, Wang Y. T-center: a novel feature extraction approach towards large-scale iris recognition [J]. IEEE Access, 2020, 8: 32365-32375.

[7] Leonard Flom, Aran Safir. Iris recognition system [P]. United States Patent No. 46413491987.

[8] Liu M, Zhou Z, Shang P, et al. Fuzzified image enhancement for deep learning in iris recognition [J]. IEEE Transactions on Fuzzy Systems, 2019, 28(1): 92-9.

[9] Zhao Z, Kumar A. Towards more accurate iris recognition using deeply learned spatially corresponding features; proceedings of the Proceedings

of the IEEE international conference on computer vision, F, [C] The Hong Kong Polytechnic University 2017.

[10] Nguyen K, Fookes C, Ross A, et al. Iris recognition with off-the-shelf CNN features: a deep learning perspective [J]. IEEE Access, 2017, 6: 18848-55.

[11] Lei Songze, Zhang Boxing, Wang Yanhong, et al. Object Recognition using Non-negative Matrix Factorization with Sparseness Constraint and Neural Network. information [J], 2019, 10(37):1-17(EI).

[12] Othman N, Dorizzi B, Garcia-Salicetti S. OSIRIS: An open source iris recognition software [J]. Pattern Recognition Letters, 2016, 82: 124-31.

[13] Raja K B , Raghavendra R , Vemuri V K , et al. Smartphone based visible iris recognition using deep sparse filtering[J]. Pattern Recognition Letters, 2015, 57:33-42.

[14] Mengjia Wang, Research on iris recognition algorithm based on deep learning [D]. Jilin University, 2022.

[15] Qi Zhao, Research on Iris Recognition Algorithm Based on Deep Learning [D]. Xidian University, 2020.

[16] Liu N, Zhang M, Li H, et al. Deepiris: Learning pairwise filter bank for heterogeneous iris verification [J]. Pattern Recognition Letters, 2016, 82: 154-61.

[17] Alinia Lat R, Danishvar S, Heravi H, et al. Boosting Iris Recognition by Margin-Based Loss Functions [J]. Algorithms, 2022, 15(4): 118.

[18] Roy K, Bhattacharya P Iris recognition with support vector machines[J]. Lecture Notes in Science. 2006, 3832: 486-492.

[19] Gangwar A, Joshi A. DeepIrisNet: deep iris representation with applications in iris recognition and cross-sensor iris recognition; proceedings of the 2016 IEEE international conference on image processing (ICIP), F, [C]. IEEE 2016.