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DESIGN AND PERFORMANCE EVALUATION OF A BIOMETRIC IRIS VERIFICATION SYSTEM

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DESIGN AND PERFORMANCE EVALUATION OF A BIOMETRIC IRIS VERIFICATION SYSTEM

ABSTRACT

This paper describes an iris verification project focused on design and performance evaluation under both matched and mismatched training and testing conditions. Training is always performed on clean iris images. Testing is performed on both clean and noisy iris images. This project is part of a senior undergraduate course on biometric systems. In implementing an iris recognition system, students go through each step, namely, preprocessing, feature extraction, classification (training and use in rendering a decision) and performance evaluation. The Chinese Academy of Sciences - Institute of Automation (CASIA) eye image database known as the CASIA-Iris-Interval-v3 database is used to show students that robustness to mismatched training and testing conditions is a significant practical issue.

INTRODUCTION AND MOTIVATION

Biometrics is the science of recognizing and authenticating people using their physiological features. Border and immigration control, restricted access to facilities and information systems, cybersecurity, criminal investigations and forensic analysis are just a few of the primary application areas of biometrics used by commercial, government and law enforcement agencies. There is much research interest in different biometric systems, notably, iris recognition.

Two important applications of iris recognition include airport security, for recognizing passengers, employees and flight crews and especially for matching an individual against a watch list [1]. The second is for recognition in a coal mine where face and fingerprint modalities may not provide adequate image quality due to the working conditions [1]. In this case, iris recognition can supplement the face and fingerprint modalities. Other applications of iris recognition include physical access control, internet security, forensics, electronic commerce, the transportation industry and automobile ignition and unlocking as an anti-theft measure.

The advantages of iris recognition are [1][2][3]:

- Permanence: The unique features of the iris are formed by 10 months of age and change very little over a person's lifetime. Subjects need only to be trained once during an entire lifetime. Face, signature and speech features are not permanent and change as a person advances in age.
- Unique: The probability of the irises of two different people being the same or resulting in the same biometric features is nearly impossible. The irises of twins can be distinguished.
- Easy integration: Iris recognition technology can easily be integrated into existing security systems or operate as a standalone. No special purpose hardware other than a simple Web camera is needed for integration to a personal computer. This is also true of speech and face based systems.
- Cannot be spoofed: The iris images or features are not susceptible to theft, loss or compromise. They cannot be artificially duplicated. This is not true of the face, speech and fingerprint modalities that can be spoofed.
- Non-Invasive and Quick: Iris recognition does not involve any contact and is quick to give a result. The verification time is a few seconds. This is also true of face, speech and fingerprint systems.
- Very high accuracy making it a method of choice for airport security and other biometrics applications.

Disadvantages of iris recognition exist but are becoming less of an issue [1][2][3]:

- Much memory required for data to be stored.
- Very expensive, but the cost is coming down.
- User acceptance is low but becoming better.
- There is performance degradation due to mismatched training and testing conditions. This is an issue that also affects speech, fingerprint and face based systems and is a very important area of biometrics research.

The motivation of the work presented in this paper is to make students aware of the performance degradation due to mismatched training and testing conditions in iris verification. In [4], the effects of image compression on iris verification are studied. Another type of mismatched condition occurs when the gaze is different between training and testing [1]. In this paper, the Iriscode algorithm [5] and its associated MATLAB code [6] is used as a starting point. The task is for students to simulate communication channel errors at various bit rates and observe the effects on iris recognition performance. Training is performed on clean iris images.

The assessment results are based on faculty formulated rubrics.

IRIS RECOGNITION SYSTEM

Figure 1 shows the block diagram of the iris recognition system [4].

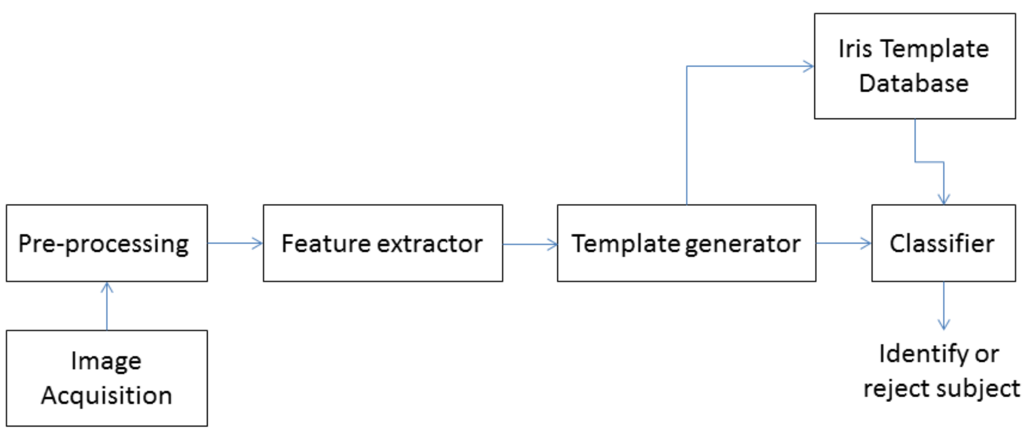


Figure 1. Block diagram of the iris recognition system

In general, an iris recognition system consists of six components:

1. An image acquisition system that collects and converts the eye image to digital format.

2. Pre-processing algorithms that remove artifacts from the digital output obtained from the image acquisition system. These algorithms usually enhance, segment, and normalize the digital images.
3. A feature extractor that extracts significant features.
4. A template generator that generates a template, which provides a discriminating representation of the features.
5. A storage component, i.e. the database that stores the templates.
6. A classifier that compares the generated template with the other stored templates for recognition. This result will be used to identify or reject the subject.

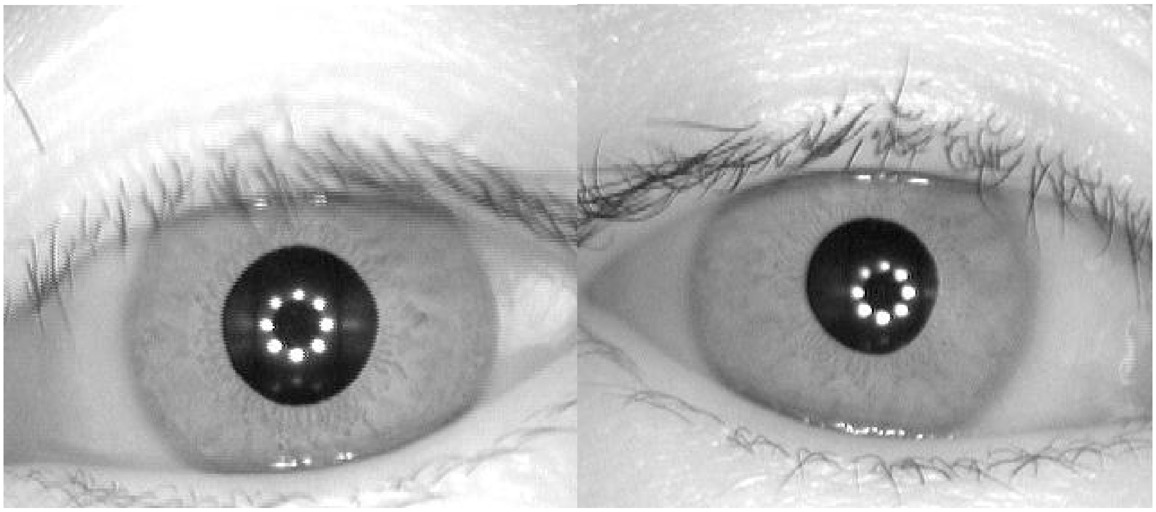
Based on the block diagram shown in Figure 1, several subsystems are needed for the iris recognition system. Since the CASIA eye image database is used in this experiment, the image acquisition subsystem does not need to be developed. The MATLAB-based tools for the other subsystems are publicly available [6]. These include pre-processing with the Hough transform based segmentation and Daugman's rubber sheet model-based normalization, 1-D log-Gabor filter-based feature extraction, bit-wise biometric template generation, and fractional Hamming distance (FHD) calculation between the templates for subject identification. Students have to write their own code to plot the receiver operating characteristic (ROC).

DATABASE

To test the developed iris recognition system, the Chinese Academy of Sciences - Institute of Automation (CASIA) eye image database [7], CASIA-Iris-Interval-v3, was used. This database contains 2,639 greyscale eye images with 395 unique eyes or classes and 5 different images of each unique eye. Images from each class are taken from two sessions with a one month interval between sessions. The images were captured especially for iris recognition research using specialized digital optics developed by the National Laboratory of Pattern Recognition in China. The eye images are mainly from persons of Asian descent, whose eyes are characterized by irises that are densely pigmented, and by dark eyelashes. Due to specialized imaging conditions using near infra-red light, the features in the iris region are highly visible and there is good contrast between pupil, iris and sclera regions.

In the CASIA eye image database, there are 249 subjects (persons). The subdirectories 001 to 249 in the database refer to the subject number. In each subdirectory, there is an information file and two additional subdirectories, namely, L and R. The L refers to iris images of the left eye. The R refers to iris images of the right eye. The filenames are very convenient to interpret. For example, the file S1012R02.jpg is interpreted as follows: The

‘S1’ is a common prefix for every file. The ‘012’ refers to subject 12. The ‘R’ refers to an image of the right eye. The ‘02’ refers to image number 2 of the right eye. Note that the number of images is not necessarily the same for each subject. Also, some subjects do not have any left eye images and some subjects do not have any right eye images. For example, subject 22 has no right eye images. Figure 2 shows an example of a left eye and right eye iris image for subject 9.



(a) Left Eye (b) Right Eye

Figure 2 – Left Eye and Right Eye Iris Images (S1009L01.jpg and S1009R01.jpg)

LEARNING OUTCOMES

The student learning outcomes of the project include:

- Enhanced application of math skills
- Enhanced software implementation skills
- Enhanced interest in biometrics
- Enhanced ability to analyze experimental results
- Enhanced communication skills
- Comprehension of the importance of vertical integration in that students realize that their experiences are part of a flow that contributes to a unified knowledge base.

SPECIFIC OBJECTIVES OF LABORATORY PROJECT

The objectives of this experiment are to

- develop and implement an iris recognition system using a standard iris database and open-source tools
- verify its performance with clean eye images

- verify its performance when the images are transmitted over a communication link
- quantitatively evaluate the performance

LABORATORY PROTOCOL

The laboratory protocol includes both supplied MATLAB code and code that has to be written by the student. This experiment is briefly described in [8]. More detail and assessment results are given here. In this experiment, 40 subjects numbered 001 to 040 will be used for iris recognition. Both the left and right eye images for each subject will be used in the experiment. Each student group will implement an iris recognition system using the open-source iris recognition tools and the CASIA eye image database.

This section continues by giving the laboratory instructions as it was presented to the students. The word 'you' as used in the laboratory protocol below addresses the student groups. Also, sentences written in the 'imperative' format also address the student groups.

A zip file having the CASIA-Irisv3-Interval eye image database and the iris recognition MATLAB based tools will be emailed to you. Upon unzipping the file, there will be a main directory called 'iris' which will be referred to as C:\iris (although one can have it on any drive). There will be three subdirectories, namely,

- C:\iris\CASIA-IrisV3-Interval
- C:\iris\FHD_Results
- C:\iris\utility

Also, the directory C:\iris will have m-files that are to be used. Check that all of these have been obtained.

Iris recognition – Generating the Templates

Set the current folder to C:\iris. The following lists the tasks to be completed.

- Run the MATLAB code 'iristemplates.m' to generate templates for all the eye images corresponding to subjects 001 to 040. This includes the templates for the clean iris images (subjects 001 to 040) and the noisy iris images (subjects 021 to 040). Demonstrate your understanding of the code 'iristemplates.m' by writing a few sentences about it.

- Examine the templates files and view the iris images (in the CASIA-IrisV3-Interval subdirectory) of several subjects from 001 to 020 (clean images only).

Note that the template files are merely binary files (Iriscode) from which the fractional Hamming distance (FHD) values are calculated. View the iris images of several subjects from 021 to 040 (clean and noisy images).

Iris recognition – Training the System on Clean Images

- Run the MATLAB code 'irisFHDIntraclass.m' (with option = 0) to calculate the FHD between the templates of all pairs of images of the same subject, except of course between two identical images for which the FHD is 0. Using an option of 0 calculates the intraclass FHD for subjects 001 to 020 (training data). The MATLAB code 'gethammingdistance.m' is called by 'irisFHDIntraclass.m'. Demonstrate your understanding of the programs 'irisFHDIntraclass.m' and 'gethammingdistance.m' by writing a few sentences about each. Note that after running this program, the file 'trainingFHDIntraClass.txt' appears in the FHD_Results subdirectory. This file contains all the obtained FHD values.

- Run the MATLAB code 'irisFHDInterclass.m' (with option = 0) to calculate the FHD between the templates of all pairs of images of different subjects. Using an option of 0 calculates the interclass FHD for subjects 001 to 020 (training data). The MATLAB code 'gethammingdistance.m' is called by 'irisFHDInterclass.m'. Demonstrate your understanding of the program 'irisFHDInterclass.m' by writing a few sentences about it. Note that after running this program, the file 'trainingFHDInterClass.txt' appears in the FHD_Results subdirectory. This file contains all the obtained FHD values.

- Run the MATLAB code 'irisClassificationThreshold.m' to plot the probability density function (pdf) of the FHD values obtained (both intraclass and interclass). Demonstrate your understanding of the code by writing a few sentences about it. Note that after running this program, the files 'pdfTraining.tif' and 'ThresholdTable.txt' appears in the FHD_Results subdirectory. Examine the value of the variable BestThreshold and discuss how it was chosen? What information is conveyed in the file 'ThresholdTable.txt' (open using Wordpad)? What do you observe regarding the probability density functions of the intraclass and interclass FHDs?

- Write your own MATLAB program to plot the ROC curve for the training data. Use thresholds from 0.1 to 0.9 in steps of 0.005. Find the best estimate for the Equal Error Rate (EER) of the system. This gives an estimate of the EER for the training data. What threshold results in this EER? Compare the best threshold found for the EER and the Total Error Rate (sum of the False Accept and False Reject rates). Is it fair to compare the EER with the smallest Total Error Rate and the EER or are the two pieces of information essentially different?

The students plot the probability density function of the intraclass and interclass FHD values as a histogram. This plot is shown in Figure 3. There is a clear separation between the two sets of FHDs.

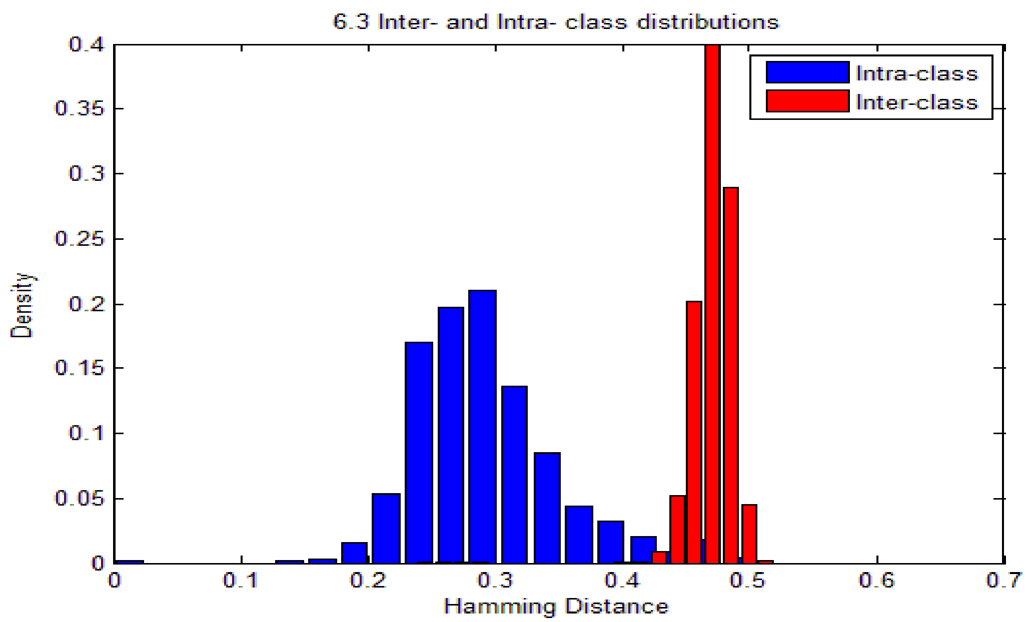


Figure 3 – Intraclass and Interclass Fractional Hamming Distance Histograms

Iris recognition – Performance Evaluation on Clean Data Not Part of the Training Set

- True trials: Run the MATLAB code ‘irisFHDIntraclass.m’ (with option = 1 and no bit errors) to calculate the intraclass FHD for subjects 021 to 040 (clean test data). Note that after running this program, the file EvaluationFHDIntraClass.txt appears in the FHD_Results subdirectory. What does this file contain?

- Impostor trials: Run the MATLAB code ‘irisFHDInterclass.m’ (with option = 1 and no bit errors) to calculate the interclass FHD for subjects 021 to 040 (clean test data). Note that after running this program, the file EvaluationFHDInterClass.txt appears in the FHD_Results subdirectory. What does this file contain?

- Plot the probability density function of the intraclass and interclass FHD values obtained. How does it compare to the plot resulting in the previous case (Figure 3). Comment on the differences.

- In this step, it is assumed that the threshold is picked for the best Total Error Rate from the training data (subjects 1 to 20). For the evaluation data (subjects 21 to 40), what is the false accept rate (FAR), false reject rate (FRR) and Total Error Rate for the BestThreshold found for the training data? Compare with the previous results.

- In this step, it is assumed that the threshold that led to the EER from the training data (subjects 1 to 20) is picked for the evaluation data. For the evaluation data (subjects 21 to 40), what are the FAR, FRR for this threshold? Compare with the previous results.

- Write your own MATLAB program to plot the ROC curve for the clean evaluation data. Use thresholds from 0.1 to 0.9 in steps of 0.001. Find the best estimate for the Equal Error Rate (EER) of the system? This gives an estimate of the EER for the evaluation test data. Compare the EER with that found for the training data.

Iris recognition – Performance Evaluation on Data Corrupted by Bit Errors

- Follow the relevant steps to calculate the intraclass FHD, interclass FHD for the clean evaluation data (subjects 021 to 040) corrupted by communication distortion corresponding to bit error rates of 1e-07, 1e-03 and 1e-01. The iris images for these bit error rates are noisy and have been configured earlier.

- Write your own MATLAB program to plot the ROC curve for the clean evaluation data corrupted by communication distortion corresponding to bit error rates of 1e-07, 1e-03 and 1e-01. Use thresholds from 0.1 to 0.9 in steps of 0.001. Compare the EER for the three bit error rates and with those that were found for the clean data? How does the performance of the system compare for clean and noisy iris images?

ASSESSMENT RESULTS

Rubrics used to quantify student achievement of project instructional outcomes were developed. For each instructional outcome, four levels of achievement were designated. A score of 1 to 4 was given based on the project lab report. The advantages of using rubric based assessment are that it gives a quantitative judgment of student knowledge, requires little extra work in the grading process, requires no additional training for faculty to use, and avoids complete reliance on student self-reporting through surveys [9][10]. Table 1 gives the outcomes and levels of achievement for the iris verification project. Table 2 gives the statistics.

Indicator	4	3	2	1
Students are able to (1) train the system on clean images, (2) understand the supplied MATLAB code and (3) plot and interpret the probability density functions for the intraclass and interclass FHDs.	All the work was done correctly.	The supplied MATLAB code was run and interpreted correctly. There are minor mistakes in the interpretation of the probability density functions.	The supplied MATLAB code was run and interpreted correctly. There are major mistakes in the interpretation of the probability density functions..	The work had many major mistakes.
Students were able to write MATLAB code to plot an ROC curve and determine	All work was done correctly.	The code was written and the EER was determined	There were mistakes either in the MATLAB	Students did not attempt this.

the EER correctly for the cases of clean images both part and not part of the training set.		but no explanation of the results given.	code and/or determination of the EER.	
Students were able to write MATLAB code to plot an ROC curve and determine the EER correctly for the cases of images corrupted by bit errors.	All work was done correctly.	The code was written and the EER was determined but no explanation of the results given.	There were mistakes either in the MATLAB code and/or determination of the EER.	Students did not attempt this.

Table 1 – Rubrics for Iris Verification Project

Outcome	Mean, Median
Training and probability density function	3.88, 4
ROC and EER for clean data	3.63, 4
ROC and EER for data corrupted by bit errors	3.52, 4.

Table 2 – Rubric Statistics

SUMMARY AND CONCLUSIONS

This lab project was successful in teaching the basic principles of biometric verification using the iris as the modality and enabling the students to understand that an important issue in iris recognition is the mismatch between training and testing conditions.

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