A Multidisciplinary Approach to Biometrics

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***Abstract*—Biometrics is an emerging field of technology using unique and measurable physical, biological, or behavioral characteristics that can be processed to identify a person. It is a multidisciplinary subject that integrates engineering, statistics, mathematics, computing, psychology, and policy. The need for biometrics can be found in governments, in the military, and in commercial applications. The Electrical Engineering Department at the U.S. Naval Academy, Annapolis, MD, has introduced a biometric signal processing course for senior-level undergraduate students and has developed a biometrics lab to support this course. In this paper, the authors present the course content, the newly developed biometric signal processing lab, and the interactive learning process of the biometric course. They discuss some of the challenges that were encountered in implementing the course and how they were overcome. They also provide some feedback from the course assessment.**

***Index Terms*—Active-learning, biometrics, image processing, MATLAB, signal processing.**

I. Introduction

BIOMETRICS is an emerging field of technology using unique and measurable physical, biological, or behavioral characteristics that can be processed to establish identification, to perform identity verification, or to recognize a person through automation [1]. These attributes include face, fingerprints, hand geometry, handwriting, iris, retina, and voice. Compared to the traditional identification/verification methods, such as photo or magnetic swipe identification (ID) cards, the use of biometrics is often more convenient for users, has lower costs for businesses, reduces fraud, and is more secure.

Biometric technologies are becoming the foundation of an extensive array of highly secure solutions for identification (determining a person's identity) and personal verification (verifying an individual's identity). In 2001, the *MIT Technology Review* named biometrics "one of the top ten emerging technologies that will change the world" [1]. Since September 11, 2001, the heightened awareness of security issues is driving the adoption of biometrics within numerous application environments. The need for biometrics can be found in federal, state, and local governments, in the military, and in commercial applications. Biometrics is also used in criminal justice, in United States immigration and naturalization services, and in e-commerce and e-government as passwords or keys. The US-VISIT program uses biometric technologies to help secure the nation's borders and expedite the entry/exit process [2].

A few universities in the United States have included biometrics in their regular curriculum. A Bachelor of Science in Biometrics Systems is offered at West Virginia University, Morgantown. This four-year sequence encompasses 139 credits that combines computer science, electrical, and computer engineering and an understanding of biology, physiology, and forensics that are necessary to design, build, and test automated biometric systems [3]. Some other universities that have introduced biometrics into their curriculum are the University of Notre Dame, Notre Dame, IN, with a course in their Computer Science and Engineering department entitled "Biometrics" (CSE498Q/598Q) [4], and Purdue University, West Lafayette, IN, which also has introduced biometrics in their undergraduate course "Automatic Identification and Data Capture" (IT345) under its "Industrial Technology" program [5].

The Electrical Engineering Department at the U.S. Naval Academy has developed and introduced a biometric course at the senior undergraduate level. A biometric signal processing laboratory has been designed to support this new course. The course integrates theories, practices, demonstrations, seminars, and field trips. This paper describes the curriculum, the key topics, the biometrics laboratory, the projects, and the interactive learning process. This paper also discusses some of the challenges that were encountered in implementing the biometric course.

The paper is organized as follows. Section II introduces the curriculum and key topics in the biometrics course. Section III provides an overview of the biometric signal processing laboratory. Section IV presents the interactive learning process. Section V introduces the group projects. Section VI discusses the challenges of the biometric course. Section VII shows the assessment results. Section VIII draws conclusions.

II. Course Content

The biometric course is taken as an elective by senior students in the Electrical Engineering Department as part of the communication/digital signal processing track. The prerequisite is the department's senior level course in digital signal processing, and the students are expected to have some background in using MATLAB from their other electrical engineering courses. The course is taught in three one-hour lectures and one two-hour lab period per week. Because the study of biometrics covers a very wide range of topics, the focus of this course is on image processing and its relation to biometrics. It concentrates on the use of iris scans, facial recognition, and fingerprint analysis for personnel identification. The goals of the course are four-fold:

- to give the students the analytical and computational tools to perform image processing;

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TABLE I
COURSE CONTENT

Key Topics		Lectures	Guest Lectures
Digital-Image Processing Related to Biometrics	Image fundamentals	2	
	Image enhancement in the spatial domain	2	
	Image enhancement in the frequency domain	3	
	Color image processing	3	
	Image compression and wavelets	3	
	Morphology	2	
	Image Segmentation	2	
	Pattern Recognition	4	
MATLAB	MATLAB Image Processing Toolbox	1	
	The MATLAB Graphical User Interface (GUI)	1	
Key Biometrics Technologies	Fingerprint recognition	2	1
	Face Recognition	2	1
	Iris Recognition	2	1
	Voice Recognition	1	
	Privacy, Ethical and Social Issues	1	2
*Remaining class hours were devoted to projects, exams, and field trips			

- to give the students experience in developing algorithms to analyze biometric data;
- to introduce the students to state-of-the-art biometric equipment and equipment capabilities;
- to learn the issues associated with the collection of biometric data (such as privacy).

In addition, by the end of the course the students will be able to meet the following overall course objectives:

- apply image processing techniques to digital imagery using MATLAB;
- state the privacy, policy, and legal issues associated with the use of biometrics;
- describe techniques for fingerprint, iris, facial, and voice recognition;
- describe the processes of biometric enrollment, identification, and verification;
- use commercial biometric systems for enrollment, identification, and verification;
- use MATLAB to develop code that will use fingerprint, iris, and/or facial imagery for identification or verification.

To achieve these goals and meet these objectives, lectures and in-class projects are supplemented by field trips and guest speakers.

The course was first offered in the spring 2004, with eleven students registered. The textbook used was *Biometrics* [1], discussed further in Section VI. The course content is shown in Table I. Digital image processing and pattern recognition are typically taught as stand-alone courses. However, because they form an integral part of biometric-signal processing, and since there is no room in the curriculum to add two additional courses as prerequisites, the authors devoted a large portion of the course to providing the student with a background in these areas. In addition, MATLAB provided the environment in which the students were able to practice image processing; therefore, additional time was devoted to learning how to use the MATLAB Image Processing Toolbox and graphical user interface (GUI) tools. Finally, the nontechnical issues, such as privacy, were addressed in lectures and by guest speakers. The following describes the key subjects that were covered in the course in more detail.

A. Digital Image Processing

Many physical attributes acquired by biometric sensors are stored as digital images, such as for the iris, fingerprint, and face. Since the students have no background in multidimensional digital-signal processing, the course began with learning the fundamentals of digital-image capture and storage. The following topics were also covered:

- image enhancement in the spatial and frequency domains;
- grayscale versus color image processing;
- image compression and wavelets;
- morphology;
- image segmentation and pattern recognition.

Pattern recognition is key in the use of biometrics for identification or verification. All biometric systems use pattern analysis, pattern classification, and pattern matching and recognition. Four lectures were devoted to object and pattern recognition.

B. MATLAB

MATLAB has a relatively simple interface that allows for a rapid learning curve to develop complex algorithms. All of the students had the basic skills of MATLAB in one or more courses in the Electrical Engineering Department using one-dimensional signals. However, using the Image Processing Toolbox and learning how to create a GUI in MATLAB were new to them. The biometrics course incorporated some review of the creation of functions, programs, and graphics in MATLAB and then expanded into operations on two-dimensional imagery. Wherever possible, biometric signals were incorporated into the teaching of these areas. For example, binary images of fingerprints were used to describe morphological functions.

Fig. 1. Fingerprint recognition: A digitized fingerprint image.

C. Fingerprint Recognition

Every person has minute raised ridges of skin on the inside surfaces of his/her fingers, which display a number of characteristics known as minutiae [1]. The minutiae do not change naturally during a person's life. The practice of using fingerprints as a means of identification has been an indispensable aid to law enforcement for many years, and today is being used in numerous other identification or verification applications, such as for renewing a driver's license. Fingerprint recognition systems usually include a sensor to acquire fingerprints and software for fingerprint analysis and recognition. In the biometrics course, two lectures were used to discuss fingerprint characteristics and fingerprint recognition, and the topic was covered in several of the guest lectures. Fingerprint technology was demonstrated and applied in the biometrics lab for computer log on. A digitized fingerprint is displayed in Fig. 1.

D. Iris Recognition

Iris recognition combines computer vision (the use of hardware and software to model human vision), pattern recognition, statistics, and the human-machine interface. The iris is a protected internal organ with texture that is random, stable, and very unique to an individual throughout life [6]. The random presence and location of the pits, striations, filaments, rings, dark spots, and freckles within the colored membrane (called the iris pattern) allows for high confidence recognition in very large databases.

Daugman's 2-D Gabor-wavelet approach [7], [8] for iris pattern analysis and recognition is the basis for commercial iris systems. This algorithm was introduced in the class. An example of an iris image and the resulting 2-D IrisCode is shown in Fig. 2(a). In addition, a one-dimensional iris recognition approach [9], designed by the authors was also demonstrated [Fig. 2(b)]. Two lectures were devoted to iris recognition, and several of the guest lecturers discussed this topic. Iris recognition was demonstrated using several pieces of commercial equipment available in the biometrics lab, including lab door entry control.

E. Face Recognition

Face recognition has become one of the major areas of biometric research because of its noninvasive nature and because it is a person's primary method of personal identification. The fundamental principle of face recognition is to use a special mathematical model to measure the dissimilarity of features in the face [1]. These algorithms can use features, such as distance between eyes, nose, and lips, as parameters (Fig. 3).

Three-dimensional (3-D) face recognition applies 3-D face models to the problem of robust face recognition. In particular, the 3-D face models address the two most critical and complicating factors affecting two-dimensional (2-D) face recognition performance: illumination and pose variation [10]. In the A4 Vision system, structured light is used to acquire the 3-D geometry of the face. Then, 3-D reconstruction algorithms are used to formulate the 3-D mesh surface and the surface of the face (Fig. 4), which is then used for identification.

Two lecture hours were devoted to facial recognition, and the topic was discussed in several of the guest lectures. One of the guest lecturers brought and demonstrated the latest 3-D face recognition system, generating considerable student interest. Face recognition was also demonstrated using equipment available in the biometrics lab.

F. Voice Recognition

Speech is produced as a sequence of sounds. The vibration of the vocal cords, as well as the positions, shapes, and sizes of the various articulators (such as the tongue, lips, and teeth) generate the sound being produced [11]. The characteristics of the sound vary from person to person and can be used to identify an individual. Although typically not considered as accurate as other types of biometric identification systems, a voice recognition system can be used in conjunction with other biometric systems to create a more robust recognition system [12]. Voice recognition was only covered briefly in the biometric signal processing course lectures, since it was already covered in the prerequisite digital-signal processing course. Its use was addressed by some of the guest speakers. Voice recognition algorithm development was supported using equipment available in the biometrics lab.

G. Privacy, Policy, and Legal Concerns Raised by Biometrics

Privacy, policy, and legal issues are central topics in the text used for the course. The students were assigned readings from the textbook, and supplemental materials from newspapers and the Internet about these issues were introduced in class. Two guest lecturers were invited to address these issues, including one of the authors of the course textbook. In addition, the students were encouraged to discuss these issues in the class.

To ensure privacy in the classroom, the biometrics data used did not contain any identity information about the individual. Also, when commercial biometric systems were used for demonstration or to log on to the lab network (using fingerprint recognition in this case), the information was encrypted by the commercial biometric systems. No raw data could be accessed or copied from these systems.

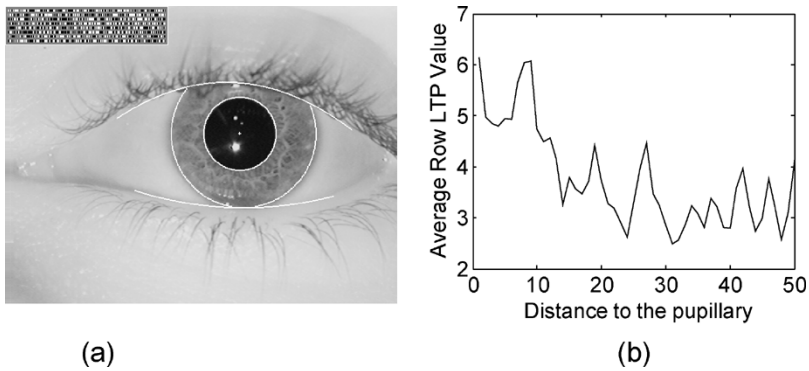


Fig. 2. Iris recognition. (a) Digitized iris with its 2-D iris code [8]. (b) One-dimensional iris code [9].

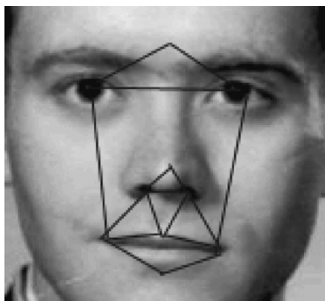


Fig. 3. Face recognition (face with feature extraction).

H. Field Trips and Guest Speakers

Field trips and guest speakers were employed to allow the students to see first-hand how biometric systems are used in more than an academic environment, and to give them different perspectives on their use. While field trips to the same sites as described below may not be possible for nonlocal educational institutions, the authors have found that many of the companies that commercialize biometric products and government institutions are more than willing to be involved in education in some way. In addition, numerous individuals who work in this area were willing to give presentations to the class. The best resource for interacting with these companies and individuals is through attendance at the Biometrics Consortium Conference, held annually in September [13].

The first field trip was a visit to the Multimedia Support Center at the Naval Academy (Section V). (A few of the student projects required multimedia support.) Additionally, a field trip was made to the National Security Agency to tour their biometrics research lab and to visit the National Cryptologic Museum.

Also, five guest speakers visited the class, representing the Unisys Corporation, the National Biometrics Security Project, Northrup-Grumman, the A4 Vision Company, and the Department of Defense Biometrics Management Office. These speakers gave both a governmental and industry perspective of the importance, the applications, and the future of biometrics. They were well received by the students, particularly those that included demonstrations of new biometric systems.

III. Biometric Signal Processing Laboratory

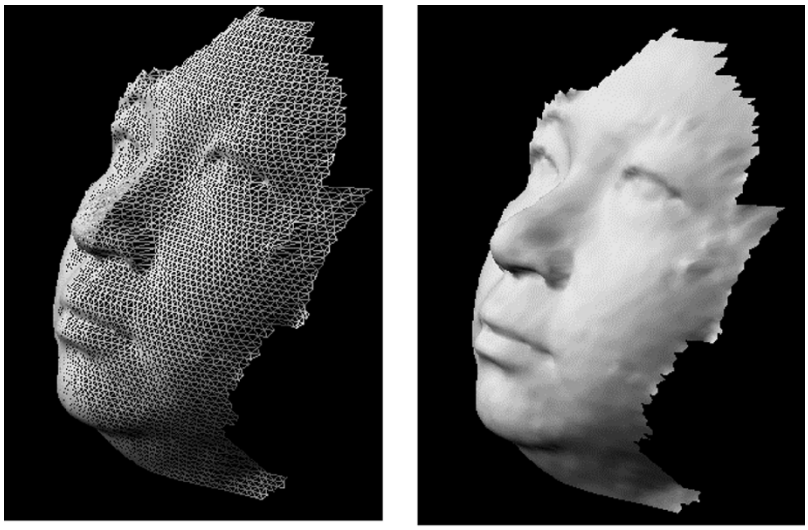
Theoretical concepts are easier to learn when the students already have hands-on experience with the real-world items that are the object of the theory [14], [15]. Therefore, a biometric signal-processing laboratory was developed and built at the Naval Academy. Fig. 5 shows the layout of the biometrics lab, which is very different from a regular classroom and was specifically designed for the biometric course and biometric research. The laboratory contains the following biometric systems to provide hands-on learning for the students: eight iris recognition systems, four fingerprint recognition systems, ten voice recognition algorithm development systems, a 2-D face recognition system, a 3-D face recognition system, four video camera systems for real-time motion detection and video capture, and one server for biometric database management.

Instead of combination locks, biometric systems are used for entrance access control to the lab. The entry door is installed with a face recognition system (the Acsys Veraport System) and an iris recognition system (the LG IrisAccess 3000 System), and either can be used for access. In addition, the lab contains four video cameras (including a Canon VC-C4 Pan/Tilt/Zoom camera) which are mounted at three corners of the ceiling inside the lab and one video camera on the entrance door. Fingerprint (the SecuGen Hamster) and portable iris recognition systems (the Panasonic Authenticam and PrivateID system) are used to replace traditional user-name, password access control to the computer workstations. A 3-D face recognition system (the A4 Vision 3-D face recognition system) is installed on one workstation. The iris-scan enrollment system is installed on the server. In addition, MATLAB has been installed on all the computers to allow for algorithm development. The systems contained within the lab are very user friendly and serve to make lab entry and computer log on easy and convenient. Fig. 6 is a collection of pictures taken of students in various sections of the lab.

IV. Interactive Learning Process

Active learning is more effective than passive learning. Felder has integrated active and collaborative learning into engineering education for more than a decade and has reported dramatic results in terms of student responsiveness, satisfaction, and problem-solving flexibility with curriculum content [16], [17].

In the biometric course, an interactive learning environment was created. Fig. 7 shows the general flow of a biometric system that includes data acquisition, a biometric database, signal processing, and decision policy. The data acquisition captures the biometric and transforms the resulting data into digital signals.



(a) (b)

Fig. 4. 3-D face recognition. (a) Structured lighting pattern is distorted by the face's surface features, allowing a mesh to be created. (b) Reconstructed 3-D surface.

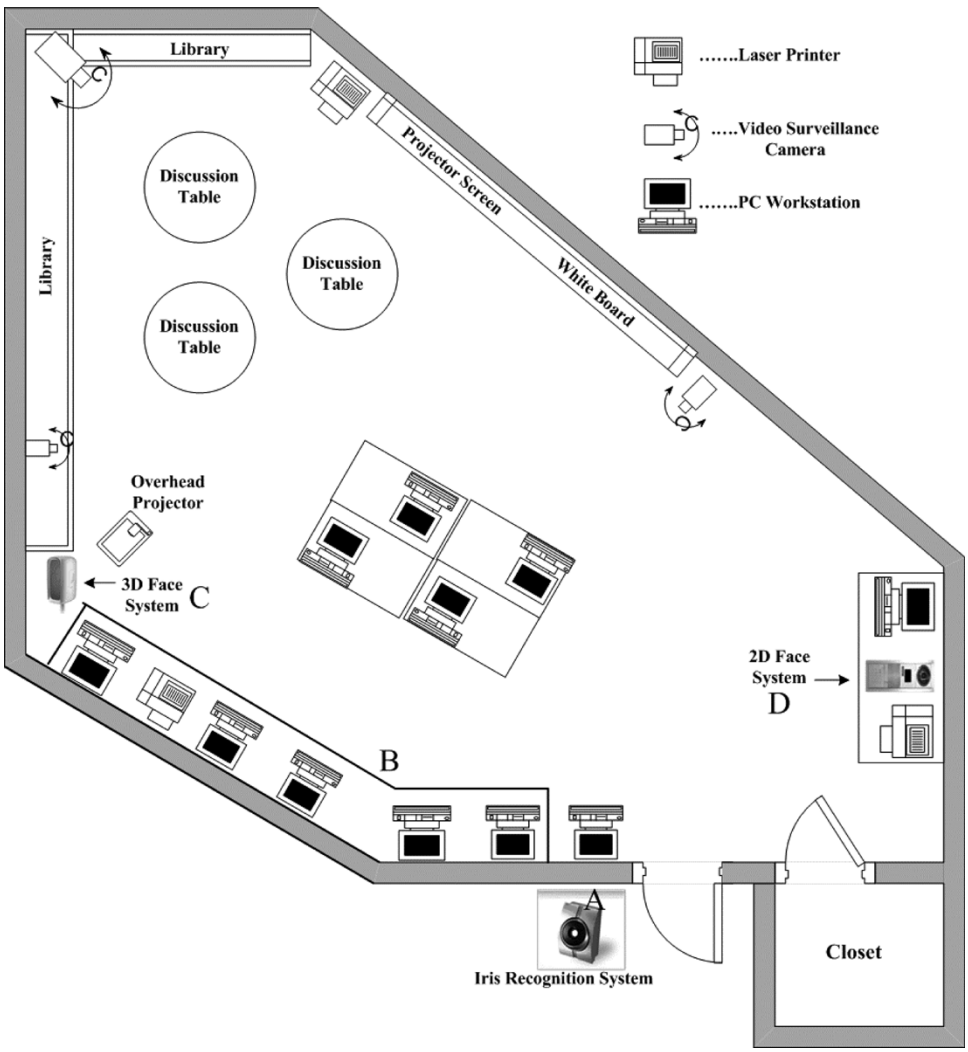


Fig. 5. Layout of the biometric lab. The letters A, B, C, and D represent the areas of the lab that appear in the pictures in Fig. 6.

The biometric database stores the enrollment data. Enrollment is the procedure in which an individual presents one or more biometric samples for processing that creates an acceptable template for future matching; the individual then becomes an

Fig. 6. Biometric signal processing lab in action. (a) Iris recognition required for entry. (b) PC workstations with fingerprint access control. (c) 3-D facial recognition. (d) 2-D facial recognition.

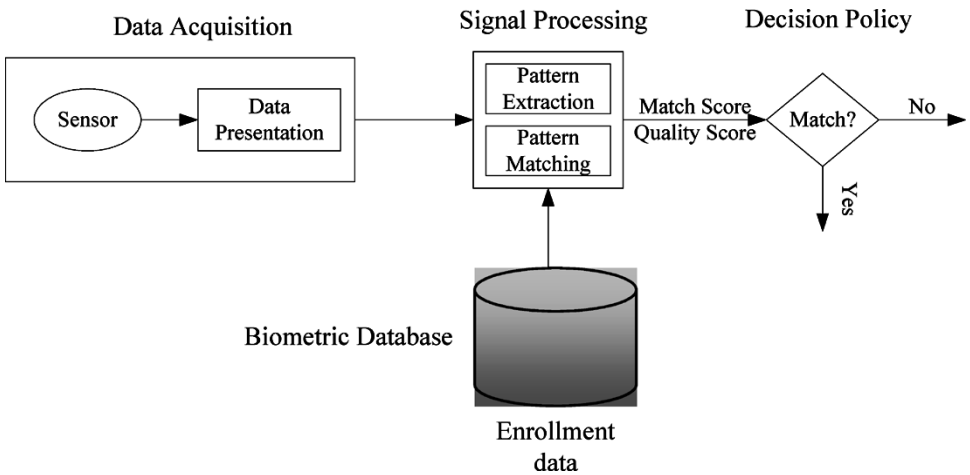
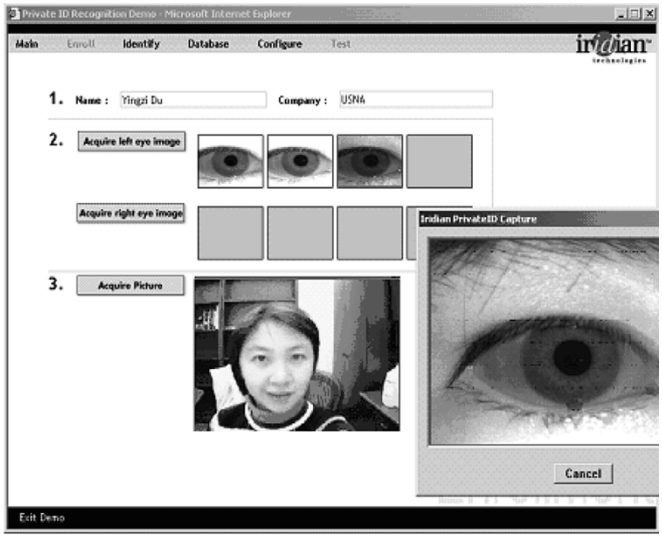


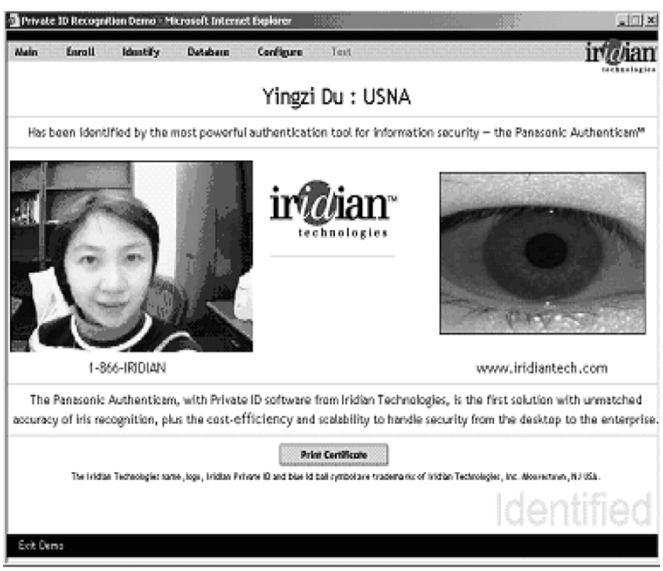
Fig. 7. Biometric system components and flow diagram.

authorized user. The signal processing extracts the patterns, matches them with the enrollment data patterns, and outputs a Match Score and a Quality Score. The decision policy will decide whether the biometric matches the database based on these scores. An iris recognition system is used as an example to demonstrate the implementation of a biometric system.

Fig. 8 illustrates the iris enrollment and identification process. In this demonstration, the Panasonic Authenticam is used to collect an iris scan and the Iridian PrivateID demonstration software is used for iris recognition and identification. Fig. 8(a) displays the computer screen while in the process of enrollment. The system requires four iris images of the same eye for enrollment. The reason for using four iris images for enrollment is to ensure the quality of the template to be used for future matching. The system also takes a picture of the user's face, which is stored with the iris data. For subsequent identification attempts, this picture will be displayed when a user's iris is recognized to show the identity determined by the system. If all four iris images are of sufficient quality, the system will allow the user to enroll; otherwise, it will reject the enrollment and give a warning and the user must enroll again. After enrollment, the system can identify the user via his/her registered iris [Fig. 8(b)]. However, for the same user, the unregistered iris (which is the other eye) could not be used to access the system. From this simple demonstra-



(a)



(b)

Fig. 8. Iris recognition demonstration. (a) Enrollment process. (b) User identified.

tion, students learn the concepts of iris recognition, enrollment, biometric database, verification/identification, and how the biometric system works. This example also demonstrated the importance of image quality, user cooperation for iris recognition, and the uniqueness of the human iris.

V. Group Projects

Biometrics is a multidisciplinary course. Many varied topics must be covered and practiced by the students, including some fundamental techniques and theories. The course is designed so that by the end of the semester, the students will be able to simulate a biometric system used for identification. To achieve this end and to support the learning process, the students are assigned multiple group projects throughout the semester. The following describes the projects in the biometrics course.

A. Poster Project

In this project, students were asked to investigate the importance and applications of biometrics. The eleven students were divided into five groups to address: Fingerprint recognition techniques, face recognition techniques, iris recognition techniques, voice recognition techniques, and the importance of biometrics to the military. Each group was tasked to create a poster that illustrated the various concepts and technologies available in their particular topic area. To support this effort, a trip to the Naval Academy's Multimedia Support Center was arranged so that the students could learn the capabilities of that organization in creating multimedia.

B. Image Processing in MATLAB

The students were exposed to the basics of image processing in a series of six projects that used MATLAB, the MATLAB image-processing toolbox, and the GUI tools. These projects included creating a set of useful functions that would be used throughout the course (such as displaying the statistics of an image, computing the mean-squared error between two images, thresholding, etc.) and input/output with both formatted (e.g., JPEG or bitmap files) and raw (unformatted) images. After mastering these basic operations, further processing of imagery was addressed: Filtering in the spatial and frequency domain, processing of color images, and processing of binary images (formed either by thresholding grayscale images or using bit planes). The imagery used in these projects was typically of people, faces, fingerprints, or irises. For example, the binary images created from bit maps were derived from grayscale iris images and were displayed in a MATLAB GUI that the students created.

After the students were comfortable processing 2-D imagery, areas that are more specifically related to a typical object-recognition system were covered. These included binary morphology, segmentation, pattern vectors and minimum distance classifiers. For example, in one project the students were given a choice of eleven photos of people, and their goal was to extract the face (only) from the rest of the image. This task was accomplished by first converting the three planes of color data (red, green, and blue) to hue, saturation, and intensity components. The students then chose the component that, after thresholding, would provide the best binary mask of the face. The binary mask was then subjected to a series of morphological operations (erosions, dilations) to enhance the mask to cover only pixels that lay on the face. Once the binary mask was finished, it was multiplied by the pixels in the original color image to extract the face. These projects were performed in groups of two to three students.

C. Presentation Project

In lieu of a midterm exam, the students were tasked with creating a PowerPoint presentation using the same groups from the poster project. The topics of these presentations were the same as for the posters, but here they were encouraged to incorporate as much multimedia (such as video, speech) as possible into their presentations. The goal of this project was two-fold: To enhance their awareness of biometrics in society today by searching for useful material, and to give them additional experience in public speaking. Each group was given 15 minutes to

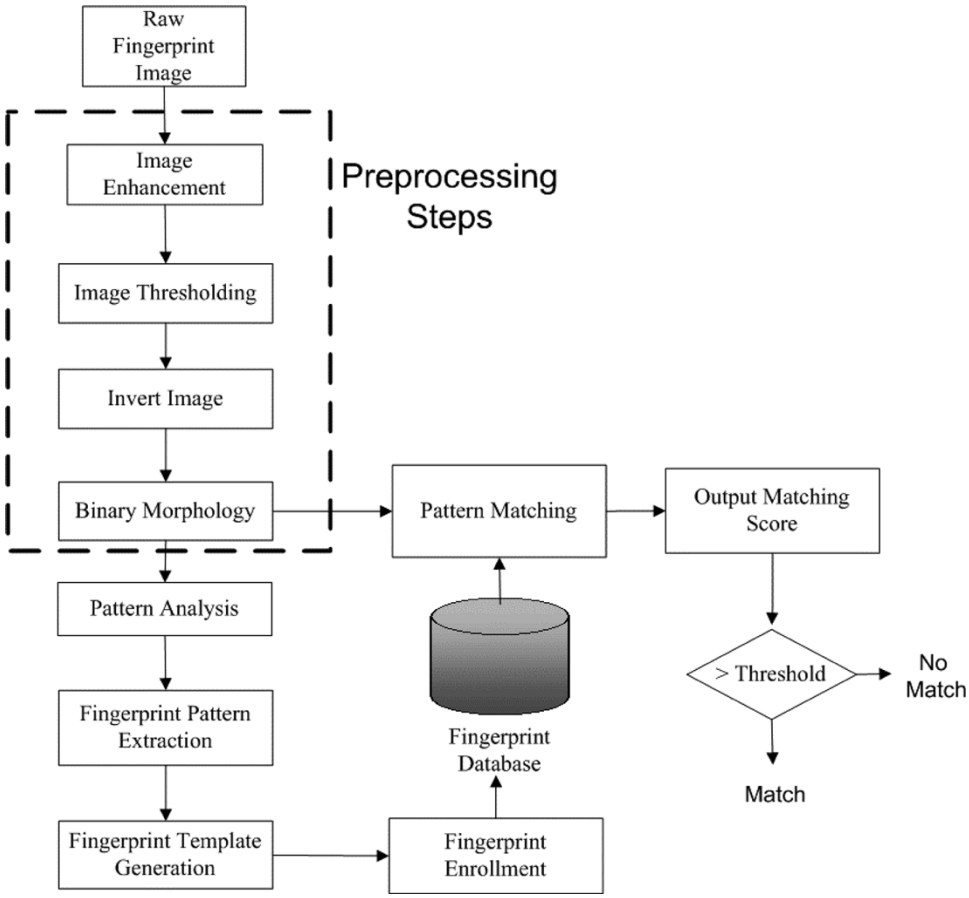


Fig. 9. Final project: Fingerprint recognition system.

present and five minutes to answer questions, and all members of each group were required to participate. Both the posters and the presentations created in this course are used for presentations on biometrics to other student groups as well.

D. Final Project: Fingerprint Recognition System

In lieu of a final exam, there was a final project. The students were tasked to create a fingerprint recognition system (Fig. 9). The fingerprint images used were downloaded from the Biometric Systems Laboratory at the University of Bologna, Bologna, Italy [18]. This system was not intended to be an automatic system because of time constraints; therefore, some operator interaction was required in the enrollment process. In addition, all of the fingerprints used had nearly the same orientation so that the issue of rotation was not considered.

The first step was to perform preprocessing on an input fingerprint image. This step included thresholding to form a binary image, inverting the result so that the finger ridges would be white instead of black, then applying binary morphology to remove noise and fill in gaps in the ridges.

To generate a template for the fingerprint database for enrollment, the students were asked to analyze visually the unique patterns of a preprocessed fingerprint image. They were to then extract five 25-by-25 pixel subimages from the fingerprint image centered at distinct minutiae (such as ridge endings, bifurcations, or dots). These five subimages formed the template for this finger stored in the fingerprint database.

For fingerprint identification, the same preprocessing steps were performed for an input fingerprint image. Then for each fingerprint in the database, its five subimage template was tested on the input fingerprint image. A binary correlation value between each subimage and the new fingerprint image was computed. If a subimage scored a correlation of at least 0.75 (meaning that 75% of the bits of the subimage match at some location in the input fingerprint image), then that subimage represented a match. If three or more of the subimages match, then the fingerprint was identified. After their system was operational, they were then free to adjust the threshold for matching and identification to improve the system performance. This final project integrated digital image processing, pattern recognition, and fingerprint recognition techniques.

VI. Challenges

Besides the inherent difficulties of developing a multidisciplinary course, there were several challenges. First, no single available textbook covered the entire scope of material that was desired to be covered. The textbook used [1] provided a high-level overview of technical and nontechnical aspects of biometrics. However, for this course, the students needed a technical reference as well as the high-level biometrics textbook; thus the technical topics were supplemented by instructor notes, papers, and Internet sources.

Second, there were issues related to the accessibility to data and algorithms. To protect user privacy and provide a more se-

cure system, the raw data is either encrypted or simply not accessible from commercial biometrics systems. This situation precluded a performance comparison of different commercial systems, or a comparison of the algorithms used in this paper with those systems. However, some biometric databases are available from the Internet. An iris database was downloaded from the Internet, collected by the Institute of Automation, Chinese Academy of Sciences (CASIA) [19]. Fingerprint data used in this course was downloaded from the Biometric Systems Laboratory at the University of Bologna, Bologna, Italy [18]. Face imagery was downloaded from the BioID Face Database [19], the Face Research Group at Carnegie-Mellon University, Pittsburgh, PA [21], and The Smoking Gun [22]. Having this data allowed the students to practice basic algorithm development. However, using these available databases did not allow complete control of the processes of data acquisition and pre-processing, nor did this use allow controlled experiments. A solution is to build a local system to collect biometric data, giving complete control over all aspects of the collection process.

Third, there were privacy issues regarding collection of data for a biometric database. A Human Subject Research proposal was submitted and approved by the USNA Institutional Research Review Board. The participants are given a verbal explanation about the research and the procedures that will be followed. They are asked to read and sign a consent and information form. To protect the privacy of the participants, no name or other identifying information will be attached to the biometric data that is stored on USNA computers.

VII. Assessment

The effectiveness of the course in meeting the course objectives (outlined in Section II) was measured using graded projects, quizzes, an exam, and presentations. Projects and the exam demonstrated their ability to perform image-processing tasks and develop algorithms for identification, while quizzes tested their understanding of the many issues surrounding the use of biometrics. Finally, presentations allowed them to describe the techniques for fingerprint, iris, facial, and voice recognition, and the enrollment and identification/verification process. Commercial systems were used at various times throughout the course, primarily from the need to log on to computers using fingerprint recognition devices and to enter the lab using iris recognition.

The course was a success, based on the professors' perceptions and student feedback compiled at the end of the semester. In addition to the standard course evaluations that are administered at the end of each semester for every class taught at the Naval Academy, the students in the biometrics class were asked to take a custom course survey primarily addressing the course content. The students found this course to be a very worthwhile experience. Most of the students stated that projects were their favorite part of the course. Many thought their MATLAB skills had been improved during the course, and that this improvement helped their senior design projects. A few believed that a course in image processing would make a good prerequisite for this course. Most students suggested using a textbook with more technical content. All of the students believed that field trips are worthwhile and thought the guest speakers were informative.

VIII. Conclusion

The authors have introduced a multidisciplinary course in biometrics in the Electrical Engineering Department of the U.S. Naval Academy. A biometrics laboratory was developed for the course to provide an interactive learning environment. The hands-on nature of the course using state-of-the art systems gave the students experience with a new and increasingly important facet of security. Since the course focused not only on the technical aspects of biometrics, but also the social impact, the students were able to experience and appreciate a complete picture of modern (and future) personal identification.

Ideally, the students should have prerequisite courses in digital signal processing, image processing, and pattern recognition for a technical course in biometrics. However, because of constraints of the undergraduate curriculum, the only prerequisite is a course on digital-signal processing, while an introduction to image processing and pattern recognition are incorporated into the course.

Although currently offered only to electrical engineers, interest in the course was expressed from nonelectrical engineering students as well, particularly from the Computer Science Department. The course may open to other majors in the future. Also in the future, the authors intend to investigate collaboration with other universities to form a virtual team [23], [24] using Internet and multimedia technologies in teaching biometrics.

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