Development of an Undergraduate Course in Biometric Signal Processing

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Abstract

Using an individual's iris pattern, voice, facial characteristics or fingerprints for identification enables a high degree of certainty of a person's identity, especially when used together. This form of identifying people can be used in a variety of applications, including allowing physical access to secure sites, making financial transactions, allowing access to networked computers, or identifying a terrorist in a public place. Due to the potential for research that this relatively new field holds, and its importance to homeland defense, we have built a new Biometric Signal Processing Laboratory, and developed a new course in biometric signal processing.

This course was designed for seniors in the electrical engineering major so that they could become familiar with the basis for these new technologies. The course was organized to give the students some background in image processing, from which the identification algorithms are formulated, and had them design simple identification algorithms. The students were exposed to state-of-the-art commercial equipment, including iris scan, fingerprint and facial recognition hardware and software. The course was comprised of three lecture hours and two lab hours each week. We discuss the topics that were covered, the equipment in the lab that supported each topic, the projects that the students performed, field trips, guest lecturers and related senior design projects.

I. Background

The United States Naval Academy is a unique undergraduate institution in many ways. In addition to spending their summers flying jet fighters, driving navy ships and submarines or spending some time as a Marine, the students at the Naval Academy have the opportunity to work closely with many government agencies concerned with national defense, including the Naval Research Lab, the Office of Naval Research and various national laboratories. In addition, all of the graduates are hired into military service upon graduation, and throughout their careers will interface with the same government agencies in some manner, whether it is as a program manager for a defense research project, or testing a new weapons system on their ship. Just about everything they do relates to defending the homeland. It is important for the future leaders of the military to be aware of the capabilities, advantages and disadvantages of systems that perform biometric identification. It is also beneficial to give them insight into the design of algorithms that perform this function. This was the impetus in developing the biometric signal-processing course at the Naval Academy.

II. Coursework

The course was taught using two textbooks. First, the background of biometrics was taught using the text from Woodward, Orlans and Higgins [1]. This book provided an overview of the evolution of biometrics as used in personnel authentication, as well as the issues surrounding the use and collection of this information. Although not technical in nature, it did provide insight into how various biometric algorithms can be employed. Weekly assigned readings were drawn from this book and the students were tested on their content with quizzes. In parallel to this high-level content, the technical component of the course focused on the subject of digital image processing, as this is the basis for identification algorithms using iris scans, fingerprints and facial features, which were taught in the course.

Since the students have no background in multi-dimensional digital signal processing, the course began with learning the fundamentals of image capture and storage, including gray scale versus color, resolution, and the input/output of binary as well as formatted image data. The students were free to process the data using any computer language, however they quickly discovered that the most straightforward tools to working with the image data were available using MATLAB.

MATLAB has a relatively simple interface for users that allows for a rapid learning curve for the development of complex algorithms. The ease with which it enabled the students to input, process and display results made it possible to cover a wide range of topics in a single semester. MATLAB contains special toolboxes that can be purchased separately which provide built-in functions for specific areas of study. In particular, for this course, we relied on three toolboxes: the signal processing toolbox, the image processing toolbox, and the image acquisition toolbox. These toolboxes were loaded on all of the computers that were used in the course. The signal processing toolbox contains utilities that perform a wide variety of one-dimensional operations, such as transforms and statistical signal processing. These one-dimensional operations can also be applied to two-dimensional data (i.e., images). The image processing toolbox is more specific to formatted imagery, and allows operations such as morphology (extracting and operating on regions), geometric transformations and the reading and writing of JPEG, TIFF, and PNG files, to name a few. Finally, the image acquisition toolbox allowed the capture of video frames from commercial video cameras directly into MATLAB for processing. This toolbox was the key to understanding how a facial recognition system works.

The semester began with refreshing the students on the use of MATLAB, which had been used to varying degrees in several other electrical engineering courses they had taken. Of key importance was their ability to write code for MATLAB functions, which would be used throughout the course. They created a library of simple yet useful functions that could be applied to image data, such as one that computes and displays image statistics, one that extracts subimages, and one that normalizes the pixel values in an image for viewing. Once they were comfortable with MATLAB, the focus shifted to image processing.

The theory and methods of image processing were taught from Gonzales and Woods [2]. This is an exceptional textbook that covered all topic areas of interest. Not only does it have clear derivations and examples, but it also has a well-laid out companion website that makes instruction a lot easier. In addition, a new textbook [3] is to be published in 2004 that is based on [2] and incorporates MATLAB functions and the MATLAB image processing toolbox. The lecture portion of the class covers these major topic areas in the order stated:

- Fundamentals, including visual perception, sampling and quantization
- Spatial domain processing
- Frequency domain processing
- Restoration
- Color processing
- Morphology
- Segmentation, and
- Object recognition.

Each of the above areas was associated with a MATLAB project (done in groups), containing several functions the students needed to create in order to process an image in some manner. This sequence of topics and projects allowed the students to build on earlier topics so that by the end of the course, they were able to program simple pattern recognition algorithms. The latter part of the course had the students creating algorithms for biometric identification using image data that would accomplish:

- Fingerprint identification: detecting dots, ridge endings and bifurcations and their relationship to each other.
- Iris scan identification: detecting the iris within an image of an eye, then distinguishing the light and dark patterns within the iris.
- Facial recognition: locating the face in an image, adjusting for rotation and orientation, and extracting specific features of a face.

The features of any of these biometrics are extracted and stored in a database for each individual that is enrolled in the system. At a later time, identification occurs by capturing a biometric image (e.g., obtaining a new fingerprint, iris scan or facial image) and comparing the newly collected biometric features to each of those in the database according to some comparison algorithm. If the newly acquired features are a close enough match to a set of those in the database, identification occurs; if not, the user is not recognized. A typical use of biometrics is to allow access to authorized individuals into computer networks or secure facilities.

III. Laboratory Equipment

To support the biometrics course, we built a biometric signal processing laboratory [4]. Figure 1 shows the model of the biometric lab, which includes the following biometric systems: five iris recognition systems, four fingerprint recognition systems, one 2D face recognition system, one 3D face recognition system, three video camera systems for real-time motion detection and one server for the biometric database management. These commercial systems are used to provide the students a familiarity with state-of-the-art biometric identification equipment.

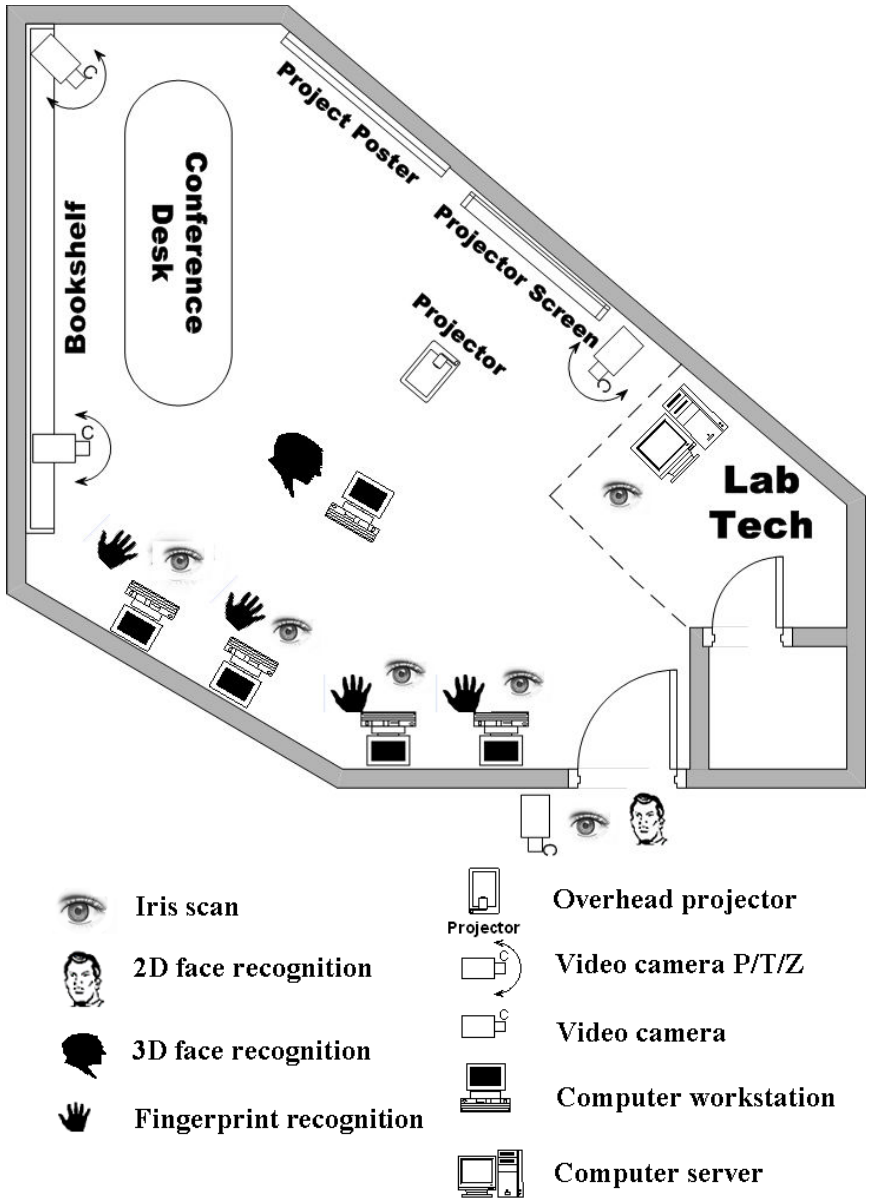

Figure 1: Biometric Signal Processing Lab Layout

Instead of combination locks, biometric systems are used for entrance access control to the lab. The door can be connected to a face recognition system (the Acsys Veraport System), or an iris recognition system (the LG IrisAccess System). In addition, the lab contains three video cameras (including a Canon VC-C4 Pan/Tilt/Zoom camera) that are mounted at three locations on the ceiling. Fingerprint (the SecuGen ® Hamster), voice recognition (which includes the Dragon NaturallySpeaking's software, the Sound Professionals SP-CMC-4 microphone and the Creative Lab Sound Blaster® Extigy external soundcard), and iris recognition systems (the Panasonic Authenticam & PrivateID system) are connected to all workstations, and the fingerprint identification is used to replace traditional username-password access control. In addition, a 3D face recognition system (the A4 Vision 3D face recognition system) is installed on one workstation. The iris scan enrollment system is installed on the server. MATLAB has been installed on all the computers and the server to allow algorithm development.

IV. Field Trips & Speakers

Field trips and guest speakers were incorporated into the course syllabus. The first field trip was to the Naval Academy's Multimedia Support Center (MSC) so that the students could discover the technology available to them that could aid in designing and creating the posters for a poster project. This tour of the MSC introduced them to such things as Adobe Photoshop, video editing software, scanning, and large-format print graphics. All of the other field trips were off-site, including a trip to the National Security Agency, the Pentagon, and to the Unisys Corporation, all of which are engaged in biometric research. The guest speakers represented some of the agencies mentioned above, as well as commercial biometric companies. These trips and speakers were designed to show the students the areas of research into biometrics at these organizations, as well as how biometrics are employed there.

V. Cooperative/Collaborative Learning

Collaborative learning played a part in this course. Although there were no homework problems assigned from a textbook, the students collaborated as lab partners in working the projects, and one grade was assigned for all members of the group. There were several possible approaches to these projects, and working in groups fostered an exchange of ideas and methods on the best way to reach a solution.

VI. Lessons Learned

Since this was the first time the course was taught, there were some lessons learned that could be used to improve the course in the future. These lessons focus primarily on hardware issues. First, current commercial biometric systems are patented, and typically do not allow access to the raw captured data. In algorithm development, it is essential to have raw data to process and experiment with. Iris data used in the course was obtained from the CASIA iris image database collected by the Institute of Automation, Chinese Academy of Sciences [5]. Fingerprint data used in this course we downloaded from the Biometric Systems Laboratory at the University of Bologna, Italy [6]. Follow-on offerings of the course should allow real-time capture of iris scan and fingerprint data for student processing. Facial images could be captured using the MATLAB Image Acquisition toolbox with the installed video cameras, but the quality of this imagery did not lend itself well to processing with inexperienced students. Some facial imagery was captured with a 4 Megapixel Canon Powershot G3 digital camera. Additionally, for this course, face imagery was supplemented with downloads from the BioID Face Database [7], and the Face Research Group at Carnegie-Mellon University [8].

Secondly, the limited number of computers available in the lab somewhat hindered the accomplishment of the projects during the lab period. Since all projects were computer oriented, it was important for each student to be able to use his/her own computer, even if working in groups. As the course grows in popularity, additional students in the classroom will require more computers. This should be corrected before the next offering of the course.

Finally, since the course is for the most part image processing and the students relied heavily on MATLAB, the next iteration of the course will use a required image processing textbook as well as one on biometrics. We feel that it was important for the students to have a technical reference as well as the high-level biometrics textbook. Our lab has a library that has a number of references available.

VII. Related Senior Projects

During their senior year, the electrical engineering majors must take a course each semester that has them design and build a senior design project. Several of these projects have been related to biometrics, and all of the students were enrolled in the biometric signal processing class. All of these students are supported by the computers and biometric equipment available in our lab.

One student designed an algorithm to identify an individual using iris scans to control access to a room. In conjunction, another student designed an algorithm to identify an individual based on speech recognition. These speech and iris identification algorithms were then combined to provide a more secure access control system. If an individual could be identified by both speech and iris, a door would unlock.

Another design project also used speech identification. Here, an array of microphones in the ceiling of the room was used to identify and track a speaker as the speaker moved about the room. Speaker identification was used to separate the individual from others in the room who might also be speaking.

VIII. Assessment

We feel that the course was a success, based on our perception and student feedback compiled at the end of the semester. 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 more complete picture of modern (and future) personal identification. The hands-on nature of the course with modern state-of-the-art equipment gave the students a refreshing look at a new and increasingly important facet of security.

IX. Conclusion

Being a new course and employing new hardware, the amount of time and effort in the planning stages for the course was significant. The introduction of commercial systems into the course played an enormous part in generating and maintaining student enthusiasm, and it is anticipated that the number of students taking the class will grow in the near future. There was some interest in the course from non-electrical engineering students, particularly from the computer science department. At some point in the future, the course may open to other majors.

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