AC 2011-1877: ASSESSING THE IMPACT OF A BIOMETRICS COURSE ON STUDENTS' DIGITAL SIGNAL PROCESSING KNOWLEDGE

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Assessing the Impact of a Biometrics Course on Students' Digital Signal Processing Knowledge

Introduction

A biometric refers to a physiological or behavioral trait which can be used to identify a person. Most people use signature (a behavioral trait) daily in making credit or debit card purchases, and are familiar with fingerprinting (a physiological trait) from any number of detective shows where fingerprints are used to identify a criminal. There has been a rapid increase in the use of a variety of biometrics to enhance security over the last decade which has been prompted by a number of high profile terrorist attacks that may have been averted through better security. Among the most widely used technologies are face and fingerprint recognition systems[1]. Face recognition systems have the advantage that facial images can be collected at a distance (e.g., by closed circuit television cameras) while fingerprint data must be collected from a scan of a person's finger. However, fingerprint recognition systems are more accurate than face recognition systems[2]. These biometric systems rely on the use of efficient algorithms to extract the key information from the input data and to search through large databases potentially considering millions of matches. Courses in biometric technology have predominantly been taught at the graduate level due to the mathematical background required for research in the area. As part of our NSF CCLI project[3], we have designed a course in Biometric Signal Processing which allows junior and senior level undergraduate students in Electrical and Computer Engineering (ECE) to explore these important technologies.

Our course, which consists of traditional lectures and hands-on laboratories with biometric sensors and software, introduces students to biometric systems and pattern recognition while also giving students another opportunity to more fully grasp the fundamental concepts of Digital Signal Processing (DSP). Students are first introduced to biometric systems through the development of a speaker recognition system which ties nicely into the one-dimensional signal processing theory that they have already learned. Then students use image processing methods in designing a face recognition system and working with a fingerprint recognition system. This is students' first introduction to image processing and sampling, filtering, and frequency analysis in two dimensions are covered.

The application of signal processing methods to these important and fun technologies should motivate students to increase their understanding of core signal processing concepts. Moreover, students work with two-dimensional signals (images) as well as one-dimensional signals (speech) in the course and this should give students a deeper understanding of signal processing concepts. We decided to use the Discrete Time Signals and Systems Concept Inventory (DT-SSCI) exam[4] before and after the course as an objective student learning assessment tool. In the past, DT-SSCI has been used to assess student learning in introductory courses, so our project represents a novel application of this tool since students have already been exposed to the material in a previous course. Using the results from the DT-SSCI as detailed in this paper, we have been able to determine what areas of DSP have been positively impacted by the course and what areas can be better addressed in future offerings. We also collected survey data from students to determine how they viewed the course content and what aspects of the course they found most/least interesting.

This paper first briefly outlines the format of the course and the material covered in the course. Then, we describe the Discrete Time Signals and Systems Concept Inventory (DT-SSCI) exam and the different aspects of DSP which it covers. We conduct an in-depth analysis of the results obtained from the DT-SSCI Pre-Test and Post-Test exams. The results from an informal survey of students at the end of the course are also described. We conclude with some thoughts on how future course offerings will be modified to further enhance student understanding of DSP concepts.

Course Topics and Format

The Biometric Signal Processing course consists of 3 lecture sessions which are 65 minutes in length and a 175 minute laboratory each week. In lectures, background theory for each of the applications is covered while in laboratories students have the opportunity to experiment with the biometric signals and build biometric identification systems. All students who take the class have taken a continuous time signals course and a discrete time signals course in their sophomore year as well as a computer programming course.

In the first part of the course, we describe a speaker recognition system which naturally leads to the review of some signal processing concepts such as sampling, convolution, and filtering. Since speech is a one-dimensional signal, this material is already familiar to students but the application to speaker recognition systems is new. The speech is modeled using an all-pole model and this leads to a review of pole-zero models and an illustration of how these systems are used to model the vocal tract. The parameters of the all-pole model form the features of the pattern recognition system and a Dynamic Time Warping (DTW) algorithm is detailed in class and used to compensate for different speaker rates.

In the second part of the course, we describe face and fingerprint recognition systems. We cover the fundamentals of image processing in lectures so that students understand how images can be manipulated to facilitate recognition. In particular, topics such as sampling, filtering, and frequency analysis in two dimensions are covered. While students have covered these topics in their prior signal processing courses using one-dimensional signals, image processing offers a new way of visualizing the effects of sampling, aliasing, and filtering. Filtering is carried out in the spatial and the frequency domains so that it is clear to students that both domains can be used for this operation.

In laboratory sections, students are presented with different clues which they must solve by building fully operational biometric systems. This presents students with the challenge of successfully identifying a person from a number of possible suspects (on the order of 100), and the background theory required to build the systems has already been covered in lectures. We omit the details of the laboratories as these have been covered in a prior publication[5].

Discrete Time Signals and Systems Concept Inventory (DT-SSCI)

The Force Concept Inventory (FCI) was developed to quantify how students' understanding of physics concepts is changed from the beginning to the end of an introductory course[6]. While homework and exams capture whether students can successfully solve problems, these may only partially answer whether students have understood the underlying concepts. The Signals and Systems Concept Inventory (SSCI) was developed with NSF support[4] and sought to create a similar assessment tool for electrical and computer engineering students who take signals and systems courses. The exam is given to students at the start of the course (Pre-Test) and the end of the course (Post-Test) and the differences in the scores obtained are used to assess how students' understanding of core concepts has improved by taking the course.

Two separate exams were developed as part of the SSCI effort: one that focused on Continuous Time (CT) concepts and the other on Discrete Time (DT) concepts. Since the systems we had students develop used discrete time signal processing, we had the students take only the DT-SSCI exam. This exam has 25 questions in total and the students are given 1 hour to complete the exam. Each question assesses students' conceptual understanding of a core concept rather than students' ability to perform mathematical calculations. The questions have been carefully designed and modified over time so that the distracters (alternate answers) can very often reveal the reasons for students' confusion[4]. We used version 5.0 (released in 2010) of the DT-SSCI.

The SSCI-DT exam covers concepts in 6 different categories[4]: mathematical background, linearity and time invariance, convolution, transform representations, filtering, and sampling. Since there are 4 questions which cover pole-zero plots, we decided to split the transform representations category into two different categories and separately assess students' knowledge of this transform domain representation. The students were given the Pre-Test exam on the second day of classes and the Post-Test on the last day of classes. Students completed the exams anonymously and our analysis, which is documented in the sections below, is based on the aggregated scores.

DT-SSCI Assessment Results

Overall Performance

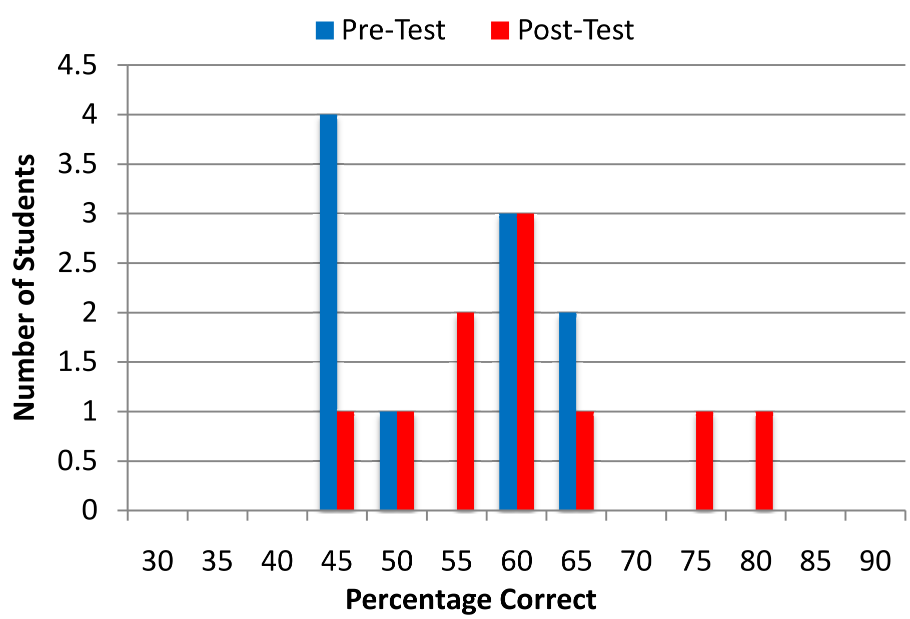

Figure 1. Histogram of Percentage Correct Answers on Pre-Test and Post-Test

The number of students that took both the Pre-Test and the Post-Test was 10 and the results are based on their answers. The percentage of questions that each student answered correctly in the Pre-Test and the Post-Test was determined, and are percentages are shown in the histogram in Figure 1. The Pre-Test histogram shows that there is a distinct peak (comprising 4 students) at 44%. This peak has been removed in the Post-Test histogram where the percentage of correct scores is increased overall. In the Pre-Test, the two highest scores were 64% while in the Post-Test the two highest scores increased to 76% and 80%.

The statistics associated with the data shown in Figure 1 are given in Table 1.

	Mean	Std. Dev.	Gain
Pre-Test	52.8	8.8	12
Post-Test	58.4	10.2	

Table 1. Pre-Test and Post-Test Statistics along with the Percentage Gain

In the last column of Table 1, the percentage gain is calculated[7] as

$$Gain = 100 \times \frac{Post - Pre}{100 - Pre}.$$

This gives a measure of the percentage improvement in students' learning of signal processing concepts from the start to the end of the course. There is a gain of 12% which shows a positive increase in understanding. This result must also be seen in light of the fact that students have already had continuous time and discrete time signals courses thereby making it more difficult to change students' minds on concepts which they may have already misunderstood.

Category Analysis

As previously detailed, the questions on the DT-SSCI exam covers 6 different categories (as previously discussed, we split out the Pole Zero questions to create a 7th category) and the answers to these sets of questions can be aggregated to determine how the course impacts students' understanding in each of these categories. Table 2 details the number of questions from each category where our categorization largely follows the original paper[4] although we have updated the categories to reflect the questions given on the newest version 5.0 of the DT-SSCI test.

Category	**# Questions**
Mathematical Background (B)	5
Linearity and Time Invariance (LTI)	4
Convolution (C)	3
Transform Representations (T)	5
Filtering (F)	2
Sampling (S)	2
Pole Zero Plots (PZ)	4

Table 2. DT-SSCI Concept Categories and the Number of Questions in each category

In Figure 2, we show the mean score obtained by students in each of the categories in the Pre-Test and Post-Test. The results show that there is an increase in score across all categories except for the Transform Category (T) where there is a slight decrease.

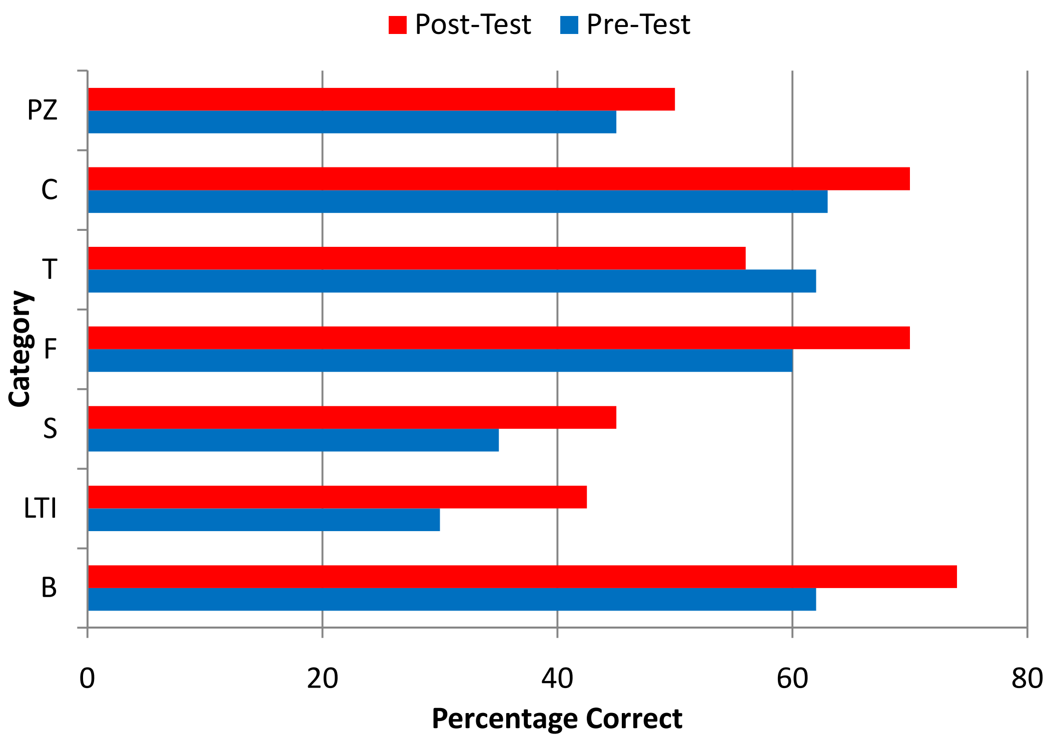

Figure 2. Percentage Correct on Pre-Test and Post-Test by Category

Question by Question Analysis

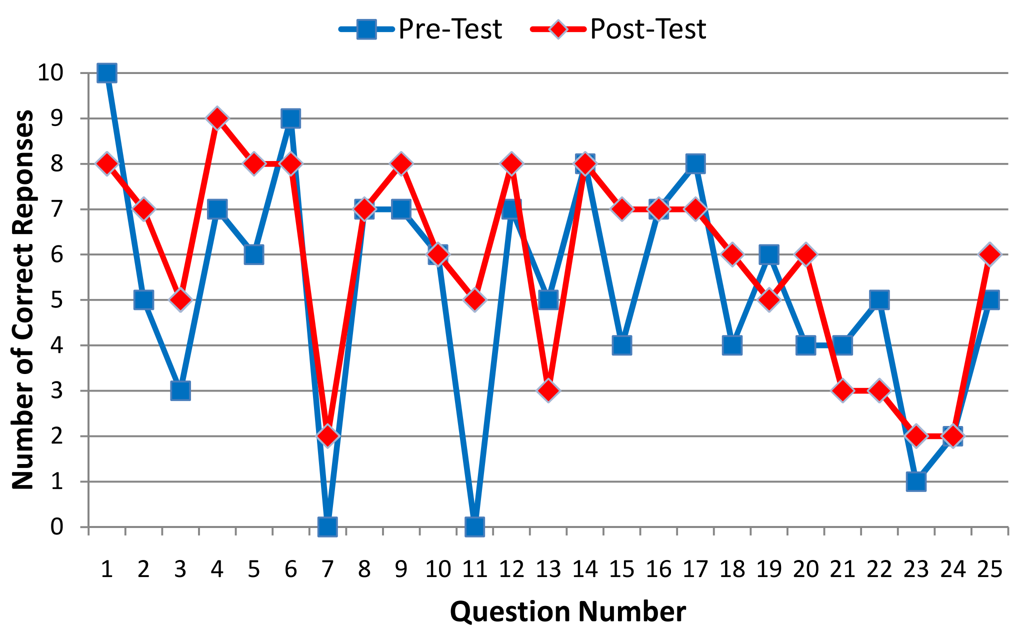

Figure 3. Number of Correct Responses to Each DT-SSCI Question on Pre-Test and Post-Test

In Figure 3, we present the number of correct responses to each of the 25 DT-SSCI questions received on the Pre-Test and Post-Test. This allows us to further analyze where student understanding has been increased or decreased. We highlight 3 questions from this analysis which show the most pronounced differences between Pre-Test and Post-Test:

- Question 7 did not have any correct answers on the Pre-Test and only 2 on the Post-Test. This question asks students to identify the sampling rate from a figure which shows the samples of a continuous time signal $x(t) = \sin(2\pi(3)t)$ over 2 periods. 8 students on the Pre-Test and the Post-Test exams chose distracter answer C which indicates that they believe the sampling rate is determined by the number of samples in 1 period which is true but they forgot to account for the frequency of the signal which is 3 Hz.
- Question 11 also did not have any correct answers in the Pre-Test but there were 5 correct answers in the Post-Test. This question gives the possible outputs of a linear time-invariant (LTI) system to a sinusoidal input. On the Pre-Test, half the students chose distracter answer A where the output was the absolute value of the input but no students chose this option on the Post-Test. On the Post-Test, students who answered incorrectly chose the distracter which has the same amplitude and almost the same frequency as the input – there are 1.5 cycles shown instead of 2 cycles.
- Question 22 shows a decrease in performance from the Pre-Test to the Post-Test. Students are given the output of a system and the frequency response as $H(e^{j\omega}) = e^{-j\omega n_0}, -\pi < \omega \leq \pi$. 4 of the incorrect answers on the Pre-Test and the Post-Test chose distracter answer A which is the output waveform weighted by an exponential value e^{-n_0}.

DT-SSCI Discussion

There was an overall gain in student knowledge of core concepts in DSP of 12% which is significant given that the students have already taken two courses in signals and systems and many of their misconceptions may already be engrained and thus difficult to change.

When the different categories of questions were considered separately, there was an increase in the number of correct answers in 6 of the 7 categories and a slight decrease in a single category (Transform Representations) as shown in Figure 2. This may be explained by the fact that class lectures and homework did not review Fourier Transform properties (as examined in Question 22) and this will be remedied in the next version of the course.

Most of the students took close to the full hour to complete the Pre-Test but completed the Post-Test more rapidly with some students finishing in under a half hour. This may indicate that students more readily answered some questions on the Post-Test or that students just wanted to finish the exercise (which has no credit associated with it) and leave the final class early. In part, this may explain the results from questions 7 and 22 where students perhaps did not take the time to read the question carefully. To ensure students do not rush through the Post-Exam, we intend to give the exam a week earlier in the future and impress on students the need to take their time and carefully read each question.

Post Course Informal Survey Results

In consultation with an external evaluator, we designed a survey that we gave to students after the last class which asked the following questions:

- *What was the most interesting part of the course?*
  Students found the most interesting part of the course to be Labs (2 students), Projects (2 students), and Case Study (2 students) while 4 students identified "learning about different biometric systems" as the most interesting part of the course.
- *What was the least interesting part of the course?*
  Students thought that the least interesting part of the course was the mathematical computations (3 students) and review of DSP material (2 students) while 5 students did not identify any part of the course as least interesting.
- *After graduation, are you considering working/studying in the field of*
  (a) Forensics (b) Applied Signal Processing (c) Biometrics (d) Other
  6 students were considering one of the first 3 choices as an option while 3 others had already decided on a different area (robotics, power electronics, and patent law) and 1 student was undecided.

Students really enjoyed the application area of Biometrics and the labs, project, and case study were very well received. Students found the lecture material, which mainly considered the theoretical aspects of the biometric systems, less interesting although applets were used in many lectures to enliven the presentation. While students' knowledge of core DSP concepts improved, these survey results point towards trying to more fully integrate the DSP theory and laboratory elements of the course and splitting up the laboratory experiments into smaller segments which can be accommodated into a lecture session time period rather than waiting for a longer series of experiments in one laboratory session at the end of a week. Some students would prefer not to have any mathematics in the presentation, but in truth we sought to keep this to a minimum in presenting the course material and felt that it was important to have students realize that mathematical analysis and core signal processing theory form the foundation of biometric systems. However, we will review the presentation of the mathematics and try to incorporate more examples as well as more closely tie the theory to the applications.

Conclusion

We have described our assessment of an undergraduate upper level elective in Biometric Signal Processing. The course covered speaker, face and fingerprint recognition systems using lectures to cover the theoretical background material and laboratories, projects, and a case study to give students hands-on experience with implementing biometric systems. We used the Discrete Time Signals and Systems Concept Inventory (DT-SSCI) exam before and after the course as an objective assessment tool. This represents the first use of this tool in an applied signal processing course where students taking the course have already taken a couple of signals courses as prerequisites.

Our analysis of the results from the DT-SSCI Pre-Test and Post-Test showed that there was an overall gain of 12% in student understanding of DSP concepts. Analysis of the question categories on the exam showed a gain in 6 of the 7 categories and a slight drop in 1 category. We will address this drop by including some exercises on transform properties in the homework the next time the course is offered. By analyzing the answers to each of the questions we were able to pinpoint the current areas of improvement and how the course could be altered in the future to improve student learning. We also gave students an informal survey to ascertain what parts of the course they found the most and least interesting. We will use this to modify the course and try to more closely intertwine the theory and hands-on laboratories by dividing the laboratories into more manageable sections which can be incorporated into the lecture presentation. While applets were used to illustrate some concepts, we will try to include more applets in future versions of the course to enhance students' understanding of DSP concepts.

Students very much enjoyed the course and found the material fun and interesting. At the end of the course, the majority of students indicated that they would like to pursue further work in the areas of applied signal processing or biometrics which is a very positive sign that their interest in the area has been increased through taking the course. We hope that future modifications to the course will further increase students' interest in this important and exciting area of signal processing.

Acknowledgement

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Bibliography

1. J.R. Vacca, *Biometric Technologies and Verification Systems*, Butterworth-Heinemann, 2007.
2. A.K. Jain et al., Biometrics: Personal Identification in Networked Society, Kluwer Academic, Boston, Mass, USA, 1999
3. S. F. Cotter, "CSI Union: understanding forensic and biometric technologies", NSF CCLI Award DUE-0837458, June 2009
4. K. Wage, J. Buck, C. Wright, T. Welch, "The signals and systems concept inventory", *IEEE Transactions on Education*, Volume 48, Issue 3, pp. 448-461, Aug. 2005.
5. S.F. Cotter, "Laboratory exercises for an undergraduate biometric signal processing course", Proc. ASEE Conference, Session 1359, Louisville, June 2010
6. D. Hestenes, M.Wells, and G. Swackhamer, "Force concept inventory", *Phys. Teacher*, vol. 30, pp. 141-159, Mar. 1992
7. R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses", *Amer. J. Phys*., vol. 66, no. 1, pp. 64-74, Jan. 1998