Session 1609

Design of a module for teaching/learning spectral analysis

Natalie T. Smith, Julie E. Greenberg
Electrical Engineering and Computer Science, Massachusetts Institute of Technology/Harvard-MIT Division of Health Sciences and Technology/ Research Laboratory of Electronics, Massachusetts Institute of Technology

Abstract

This work concerns the design of a module for teaching/learning spectral analysis with emphasis on biomedical applications. The module design is based on the principles of the "How People Learn" framework as embodied in the STAR Legacy model. This model includes components aimed at providing context and motivation, facilitating exploration, developing in-depth understanding, and incorporating opportunities for self-assessment. In the spectral analysis module, this is accomplished by augmenting traditional teaching methods (lectures, laboratory exercises, and homework problems) with small group discussions, peer-to-peer learning, and novel interactive exercises. These interactive exercises consist of a web-based tutorial accompanied by an interactive demonstration of spectral analysis. This demonstration performs spectral analysis of cosine, ECG, and speech signals, and allows user selection of key parameters. The tutorial questions are designed to promote exploration and understanding of key concepts and to encourage constructive use of the interactive demonstration (as opposed to 'fiddling' with parameters). Links to general text summaries of key concepts, a glossary, specific hints, and general tips accompany the tutorial questions. Plans for assessment of the module's effectiveness are briefly discussed.

I. Background on Teaching Spectral Analysis

Spectral analysis is an important concept relevant to many electrical and biomedical engineering applications, including speech analysis, speech processing, magnetic resonance imaging, and analysis of clinical biomedical signals such as the ECG, EEG, and EMG. The motivation for developing this module comes from the second author's experiences teaching spectral analysis in a course titled Biomedical Signal and Image Processing. Senior undergraduates and first-year graduate students with diverse engineering backgrounds typically take this semester-long course. It meets for two ninety-minute lectures and one four-hour lab session each week.

In the past, the fundamentals of spectral analysis were covered in one lecture and one homework problem, with subsequent application in portions of two lab exercises. Two additional lectures, covering the speech signal and cardiac electrophysiology, provided background for those lab exercises. Performance on quizzes indicated that many students had difficulty mastering the fundamentals of spectral analysis, presumably due to the complexity of interactions among the relevant variables. Results from lab reports indicated that even students who did master the fundamentals typically managed to succeed in the lab exercises by fiddling with parameters, rather than by applying the fundamentals previously learned. These experiences motivated the current work, with the goal of developing a module to assist students in learning the fundamentals of spectral analysis and applying those concepts to a variety of biomedical applications.

II. Background on Model for Module Design

The goal of this work is to develop a module to facilitate student understanding of spectral analysis. The module design is based on principles of the "How People Learn" framework[1], which specifies four qualities of effective learning environments:

1. *Learner-centered* environments consider students' previous experiences and prior knowledge as a basis for future learning.
2. *Knowledge-centered* environments present new material with rationale and relevant connections, in order to facilitate understanding, to develop accessible knowledge that can be applied appropriately, and to promote transfer of concepts to new situations.
3. *Assessment-centered* environments include opportunities for self-assessment, feedback and revision.
4. *Community-centered* environments increase students' opportunities and motivation to interact with faculty and peers, receive feedback, and learn.

The STAR Legacy model[2,3] provides a systematic approach to designing learning environment based on the principles of the "How People Learn" framework. The model organizes a set of learning activities around complex technical challenges. This is accomplished with explicit learning cycles consisting of multiple components; each of these components corresponds to an important phase of exploring the challenge. The major components of the STAR Legacy cycle are described here:

1. *The Challenge* poses a complex goal to students. The purpose of the challenge is to motivate students and to provide them with opportunities to explore new material while exercising problem solving and inquiry skills.
2. *Generating Ideas* allows students to explore their initial thoughts about the challenge, making explicit and documenting any naïve preconceptions or misconceptions.
3. *Multiple Perspectives* provide expert insights into the challenge. This component exposes students to advanced thinking on multiple aspects of the challenge, without providing a direct solution.
4. *Research and Revise* consists of resources and learning activities that help students develop expertise to effectively approach multiple aspects of the challenge.
5. *Test your Mettle* consists of opportunities for formative assessment, allowing students to reflect on what they have learned thus far and to identify any weaknesses in their current understanding.
6. *Go Public* is the final, summative assessment of students' understanding of the material at the

end of the module.

The STAR Legacy model is quite versatile and can be applied to the design of instructional modules used in contexts ranging from elementary to post-graduate education, spanning time frames ranging from a few hours of class time to semester-long projects. The spectral analysis module exemplifies how the STAR Legacy model can be applied to material covered in a few hours of an advanced-undergraduate or graduate subject.

With appropriate software, STAR Legacy cycles can be implemented entirely on-line. However, the spectral analysis module consists of a combination of in-class and on-line components and does not utilize any specific STAR Legacy software.

III. Design of Spectral Analysis Module

The design of the module strives for efficiency with respect to both development time and classroom time. As a result, the traditional methods of teaching spectral analysis (lectures, lab exercises, and homework problems) are reorganized in accordance with the STAR Legacy model and augmented by additional elements. In addition to providing students with a wide variety of learning environments, the reuse of existing educational materials meets the objective of reducing development time. In order to accommodate new components introduced by the STAR Legacy model, one additional lab session is devoted to this material.

For this module, the components of the STAR Legacy model are as follows:

1. *The challenge* is to design a system for monitoring a patient's ECG signals in a hospital setting. The system should sound an alarm when a life-threatening ventricular arrhythmia occurs. While failure to detect an arrhythmia is obviously undesirable, false alarms are also quite problematic, as hospital staff are likely to ignore systems with frequent false alarms. The background for this challenge is introduced in the lecture on cardiac electrophysiology. The challenge itself is described in the lab handout that students are expected to read before coming to lab, and will be further described at the start of lab itself.
2. Immediately following presentation of the challenge in lab, students break up into small groups (of three or four students) to *generate ideas.* They discuss how to approach the challenge, based on their preliminary understanding of spectral analysis. Each group prepares their ideas into an informal presentation for the other groups in their lab session.
3. Next, the class reconvenes to hear *multiple perspectives.* Each small group presents their ideas to the class. Depending on the breadth of ideas presented, the instructor may also introduce additional perspectives. The instructor then solicits student reactions to the various ideas and moderates a discussion to identify their strengths and weaknesses. The instructor may also provide expert reactions and insights to the students' ideas and perspectives.
4. Students *research* spectral analysis and *revise* their understanding using novel interactive exercises developed for this module. Lab time is provided to begin this process, but the on-line exercises remain available outside the scheduled lab hours. These exercises consist of a

web-based tutorial accompanied by an interactive demonstration of spectral analysis, and are described in more detail in Section IV. In addition, students attend a 90-minute lecture on spectral analysis. This is essentially the same lecture used previously, but in the past it was the students' first exposure to the topic. In the current module, it is delivered after students have been exposed to spectral analysis and had extensive hands-on experience with the on-line exercises. It is expected that this later placement of the lecture will allow students to further revise their developing understanding of spectral analysis.

5. Students *test their mettle* using two previously existing instructional materials. Homework problems provide one opportunity for students to apply what they have learned about spectral analysis in slightly different contexts. In addition, students attempt to solve the cardiac monitoring challenge during a full lab session. This is done in groups of two, which provides opportunities for peer-to-peer learning.
6. Students *go public* using two previously existing assessment tools, the lab report and the quiz. Although students work with a partner in solving the challenge in lab, each student writes his/her own report.

IV. Interactive Exercises

The main goal of the module in general, and the interactive exercises in particular, is to guide students as they develop an understanding of key concepts in spectral analysis. These concepts include the effect of window length, window shape, and DFT length on both frequency resolution and amplitude resolution. After completing these exercises, students should be able to analyze the frequency content of an arbitrary signal and to interpret a given frequency representation.

The exercises developed for the *research and revise* portion of the module consist of a web-based tutorial accompanied by an interactive demonstration of spectral analysis. The tutorial consists of a series of questions, accompanied by links to resources that may be useful in answering the questions. These resources include general text summaries of key concepts, a glossary of terms, hints specific to a particular question, tips for using the interactive demonstration, and the interactive demonstration itself.

The interactive demonstration (http://web.mit.edu/6.555/www/matweb/demo.html) is implemented using the MATLAB® Web Server. It performs spectral analysis of cosine, ECG, and speech signals. The input window displays a block diagram illustrating the steps of the processing and allows user selection of key parameters such as window length, window shape, and DFT length. The output window displays the DTFT (continuous frequency representation) of the selected window and the windowed signal, as well as the actual DFT (discrete frequency representation) resulting from the processing. Additional options permit the user to display time-domain signals, compare and contrast multiple parameter sets, and generate spectrograms (using the same parameter set) when the input is a speech signal.

The tutorial questions are designed to promote exploration and understanding of key concepts and to encourage constructive use of the interactive demonstration (as opposed to ‘fiddling’ with parameters). The tutorial includes true/false, multiple choice, and short answer questions. Some of the tutorial questions explicitly direct students to use the interactive demonstration in certain ways, especially for comparison and contrasting of different parameter selections. Other tutorial questions are more concept-oriented, and may be answered with or without optional use of the interactive demonstration. After responding to a question, the student has the option of checking his/her answer, accessing hints and other resources for review as necessary, and then trying again. After the student has settled on a final answer, he/she may view the correct answer and an explanation.

The tutorial questions are organized sequentially to cover the following topics:

1. Diagnostics
   a) window length and mainlobe width
   b) window length and sidelobe peak amplitude
   c) window shape
   d) sampling in time (Nyquist Sampling Theorem and aliasing)
2. Frequency resolution
   a) Effect of window length
   b) Effect of window shape
3. Amplitude resolution
   a) Effect of window shape
   b) Effect of window length
4. Combined effects of window length and window shape
5. DFT as frequency samples of underlying DTFT
   a) Spacing of samples and zero-padding in time
   b) Placement of samples and frequency-dependent artifacts
6. Speech spectrograms

V. Future work

Future work includes testing of the interactive exercise, followed by assessment of the module’s effectiveness. Preliminary student feedback will be collected using a “talk aloud” procedure to observe students’ reactions as they interact with the tutorial and spectral analysis demonstration. This information will be used to modify the tutorial questions and the interface to the interactive demonstration as necessary.

The overall effectiveness of the module will be assessed in several ways. Student satisfaction surveys and performance on lab reports and quizzes for students having used the module will be compared with results from previous years for students not using the module. Moreover, the module design is expected to facilitate development of a more mature understanding of spectral analysis *before* the material is presented in lecture. Therefore, current efforts are aimed at developing a method to assess the frequency and depth of student questions during lecture, in order to test that hypothesis.

Acknowledgements
This work was supported by the NSF Engineering Research Centers Award Number EEC-9876363, by the Harvard-MIT Division of Health Sciences and Technology's John F. and Virginia B. Taplin Awards Program, and by MIT/Microsoft Research Project I-Campus. The authors are grateful to Dinh-Yen Tran and Jeffrey Steinheider, who participated in the development of the interactive demonstration of spectral analysis.

Bibliography

1. Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds*.). How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press (1999).
2. Schwartz, D.L., Lin, X., Brophy, S., & Bransford, J.D. Toward the Development of Flexibly Adaptive Instructional Designs. In C. Reigeluth (Ed.), *Instructional-Design Theories and Models: A New Paradigm of Instructional Theory*. Mahwah, NJ: Erlbaum (1999).
3. Brophy, S.P. Guidelines for modular design. VaNTH Engineering Research Center Technical Report No. VANTHLSSPB200001V1. Nashville, TN: Vanderbilt University (2000).

NATALIE SMITH
Natalie Smith is a graduate student at the Massachusetts Institute of Technology. She received a S.B. in Electrical Engineering from the Massachusetts Institute of Technology in June 2000 and expects to complete her M.Eng. in Electrical Engineering in June 2001.

JULIE GREENBERG
Julie Greenberg is a Lecturer in the Harvard-MIT Division of Health Sciences and Technology and a Research Scientist in the Research Laboratory of Electronics at the Massachusetts Institute of Technology. She received a B.S.E. in Computer Engineering from the University of Michigan 1985, a S.M. in Electrical Engineering from the Massachusetts Institute of Technology in 1989, and a Ph.D. in Medical Engineering from the Harvard-MIT Division of Health Sciences and Technology in 1994. She has been involved in teaching Biomedical Signal and Image Processing since 1993. During the 1999-2000 academic year, Dr. Greenberg was a John F. and Virginia B. Taplin Faculty Fellow in Health Sciences and Technology. She is a member of the ASEE and the IEEE.