

An Instructional Framework for Introducing Wavelet-Based Problem Solving Techniques to Advanced Civil Engineering Students

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Introduction

Wavelet-based problem solving techniques are a relatively new addition to a growing number of advanced undergraduate and graduate engineering curriculums. Traditionally, wavelet theory and methods have been taught as either a separate semester-long mathematics course or within an electrical engineering context³. While these curriculum options do provide viable pathways for learning wavelet concepts, prerequisite courses and a general lack of related application focus often make them inaccessible for civil engineering students who often do not possess a mathematical background beyond differential equations or linear algebra.

Within the civil engineering profession and its related research communities, wavelet-based techniques and applications continue to be developed. Examining the various sub-discipline areas, such as water resources^{5,2}, structures^{6,4}, transportation^{11,13}, and materials^{7,9}, results have indicated that wavelet-based techniques can often provide a unique insight into the analysis and characterization of time series data, versus classical methods.

The inherent non-stationary nature of signals that civil engineers may encounter makes a satisfactory analysis by classical spectral methods, such as Fourier analysis, very difficult or often impossible to perform; wavelets provide a solution to this problem. While wavelets are an extension along the general ideas of Fourier analysis, they do represent a new area of research in the field of engineering education. As such, teaching methods have not been developed, nor do many of the mainstream textbooks present wavelet theory and applications in a tractable manner for students without an advanced mathematical background.

Objectives

This paper presents the development of an instructional framework to introduce and assess student (learner) understanding of wavelet-based problem solving techniques within an advanced undergraduate- and graduate-level civil engineering course at Texas A&M University. The instructional framework is outlined within the following six core domains:

1. Learning Challenges and Learning Objectives
2. Authentic Scientific Inquiry
3. Embedded Information Technology
4. Assessment and Learning Products
5. Learning Experiences with Instructional Technologies
6. Strategic Planning for Implementation

The material and techniques presented here are to serve as a series of learning modules to be integrated into a course that is already established. The material does not warrant more than a few weeks of academic focus and should not be viewed as a replacement for classical methods; rather it should be treated as a supplement to the current curriculum. In other words, the learners will not become complete experts in the area of wavelets through this process alone. A more thorough treatment of wavelet theory and methods would be correctly found within a formal mathematics course. Mastering the concepts within this instructional framework, however, would likely prepare learners for a more rigorous course on the subject.

Pedagogical Concept Outline

Before the details of the core domains are presented, it is first necessary to briefly outline the basic wavelet concepts and assessment focus areas that are included in the instructional framework. The general concept outline is adapted from Walker, who makes an excellent introductory presentation of basic wavelet techniques¹². For the complete set of lecture notes and assessment materials, see Peschel⁸.

Learning Module 1: Haar Wavelets

1. The Haar Transform
2. Haar Wavelets
3. Connection to the Conservation of Energy
4. Multiresolution Analysis
5. In-Class Project: Noise Removal from Reservoir Data

Learning Module 2: Daubechies and Coif Wavelets

1. Daubechies Wavelets
2. Coif Wavelets
3. Connection to the Conservation of Energy
4. Multiresolution Analysis
5. First Learning Project: Noise Removal from Aquifer Data

Learning Module 3: Fourier-Wavelet Connection

1. Brief Review of the Discrete Fourier Transform
2. Frequency Description of Wavelets
3. Correlation and Feature Detection
4. Second Learning Project: Feature Detection within Engineering Signals

Learning Module 4: Advanced Wavelet Topics

1. Low- and High-Pass Filters
2. Two-Dimensional Wavelets
3. Wavelet Packet Transform

Instructional Framework

Learning Challenges and Learning Objectives

As outlined in the previous section, there are four primary learning components associated with this instructional framework: Haar wavelets, Daubechies wavelets, the Fourier-wavelet connection, and advanced wavelet topics. It is expected that the learners will have been exposed to basic Fourier theory and the discrete Fourier transform, preferably within the course that this instructional framework is being implemented. This is absolutely essential for the third learning component, though a brief review will be given. The Fourier approach reflects the learners' current mental model, which is assumed to not include a time-frequency representation of data. This assumption is based on the lack of exposure to wavelets in previous coursework.

Creating an optimal learning context where learners can develop a new and alternative time-frequency oriented mental model is the principle educational theme within this instructional framework. To guide the development of the new mental model, the initial question posed to the learners is: "If a signal experiences a change in frequency, how can one determine approximately when that change occurs?" In the process of developing the answer to this question, learners will be exposed to new information technologies that will allow them to critically evaluate each step involved with the wavelet-based problem solving techniques.

The learning objectives within this instructional framework are based on a subset of the Accreditation Board for Engineering and Technology (ABET) 2004-05 Criterion 3 specifications. These criteria are required components of any accredited engineering program in the United States. Specifically, this instructional framework addresses the development of critical and independent thinking, computer programming and engineering software exposure, and communication.

Authentic Scientific Inquiry

A modified scientific inquiry procedure is derived from Chinn and Malhotra to be undertaken within the instructional framework¹. Learners will initially be given the research question as stated in the previous section. While traditional experimental procedures are not involved in the instructional framework, learners will be asked to formulate a basic hypothesis with regard to the expectations of the Fourier versus wavelets results. Since the learners will be finding evidence for their own signals using a formative assessment (Learning Product Two), observations will be made that may have not necessarily been found in the presented lecture material.

Learners will be required to explain through a brief web-based report what they have found in their formative assessments; questions will be generated as a result of the findings. Learners will additionally be responsible for finding inconsistencies within the signal data sets assigned to them. Some of the data sets may be incomplete in very subtle ways (i.e. missing values). This would noticeably modify the results and the learners would be expected to report this by examining the input data beforehand. Learners will compare all final product results after they are finished. This will be very convenient due to the final product being available on the course website. Indirect reasoning and generalizations will be formulated based on all of the final

learning product results. Learners will then reflect on how what they reasoned now relates to their original hypothesis.

Embedded Information Technology

The concept of embedded information technology may be defined as computer hardware and/or software integrated into a course curriculum that is essential for the learning process, but whose specific presence and operation does not represent a primary learning objective. There are four principle categories that may be used to classify embedded information technologies: computation, visualization, communication, and presentation. These four areas of embedded information technology are used to encompass both the quantitative and qualitative aspects of learning.

Microsoft Excel is an electronic spreadsheet program used primarily for computing, analyzing, and visualizing tabular data sets. It is assumed that this will not be the learners' first practical experience with the Microsoft Excel program, or other similar spreadsheet software, therefore dilatory performance is not expected at this step. Learners will be required to obtain and work with actual signals. Often, raw signal data, such as hydrologic or temperature data sets, are not available in functional formats (i.e. they cannot be readily used for computation). Delimiters and data point ordering are two of the main problems usually found with publicly available data sets. The learners will use Microsoft Excel to correctly format the various signal data sets investigated within this instructional framework.

After valid time series have been developed, learners will utilize Matlab Release 14 for all of the wavelet computation and visualization tasks. Available from The Mathworks, Matlab R14 is an advanced computer algebra system that allows users to perform various mathematical functions, especially operations involving matrices. In addition to calculations, users may plot data, as well as write and compile stand-alone programs. Learners will have likely encountered Matlab in prior coursework; however, it will not be assumed that they will possess a high level of Matlab syntax fluency. In-class demonstrations and basic Matlab programming instructions will be posted on the course website for the learners to review while they complete the two learning products.

The learners will use Microsoft Word to communicate the results and conclusions of the first learning product. It is assumed that the learners will have gained sufficient experience with Microsoft Word, or another word processing software package, prior to this exposure. Microsoft FrontPage will be used to communicate, as well as present, the learners' results and conclusions for the second learning product. Developing effective written communication skills is an essential component within any type of educational process; unfortunately, these skills may too often be neglected in the context of engineering education. Learners will also create and communicate individual feedback while working with the different information technologies via a submission mechanism on the course website, or by email.

It is expected that the learners will develop confidence with the embedded information technologies that will promote further exploration and, ultimately lead to enhanced problem solving capabilities. Finally, it should be noted that the four recommended information

technologies given above (Microsoft Excel, Matlab R14, Microsoft Word, and Microsoft FrontPage) are not specific software package requirements for the implementation of this instructional framework. There are publicly available, alternative versions of each software package listed that are identical in function (Table 1). The recommended software was chosen solely for its presence on the existing departmental hardware that will be used by the learners. This instructional framework can be implemented with any combination of the software packages given in Table 1.

Table 1. Recommended and alternative embedded information technologies.

Recommended Information Technology	Alternative Information Technology
Microsoft Excel	OpenOffice (http://www.openoffice.org)
Matlab Release 14	Scilab (http://scilabsoft.inria.fr)
Microsoft Word	OpenOffice (http://www.openoffice.org)
Microsoft FrontPage	CoffeeCup (http://www.coffeecup.com)

Assessments and Learning Products

Due to a curriculum constraint, the implementation of the instructional framework will take place over a two-week period of time. Instruction will occur within the established course lecture time, which consists of two 75-minute lecture periods per week; therefore, only four lecture periods are available. A longer time period would be desirable, but four lecture periods should be sufficient to complete the learning objectives. The instructional framework may be inserted into an established course curriculum once Fourier theory and the discrete Fourier transform have been taught. These prerequisites are necessary for comparison purposes with the wavelet-based problem solving techniques that are introduced through the instructional framework.

The first in-class project is to apply the Haar wavelets technique and to familiarize the learners with Matlab. A series of step-wise reservoir flow measurements with unwanted environmental noise will be filtered to produce the actual signal. Learners will create their own Matlab code. This assessment will provide feedback with respect to the learners' abilities to program and synthesize based on the concepts recently learned, and to arrive at some general conclusions.

Learning product one involves the removal of noise from actual aquifer well-level data. To complete the task, the learners will use Matlab. This learning product will be assigned after the Daubechies and Coif wavelets have been introduced, and will follow the general procedures from the in-class Haar wavelets project. This learning project is a formative assessment and the learners will have approximately one week for completion. Learners will submit their results individually in the form of a brief written report.

The final learning product consists of detecting an anomalous feature hidden within an individually assigned signal. Learners will receive this summative assignment after the Fourier-wavelets connection has been introduced. The outcome of the final learning product will essentially be determined by the knowledge and abilities developed within the three previous

learning modules. Collaboration will be allowed to take place for the final learning product; however, since each learner will have a unique signal assigned, the final product is an individual effort.

Learning Experiences with Instructional Technologies

Instructional technologies are hardware and/or software used to convey course content and learning product results between the instructor and the learners, respectively. Instructional technologies are conceptually different from embedded information technologies in that they are used solely to create a medium of communication. It should be noted that within an instructional framework, the different technologies used could be classified as both embedded as well as instructional.

There are two categories of instructional technologies: instructor tools and learner tools. Within this instructional framework, the instructor tools consist of Camtasia and Microsoft PowerPoint. Camtasia is a software program available from TechSmith that allows users to create full-motion tutorials or video presentations in a real-time, streaming format (TechSmith, 2004). Microsoft PowerPoint will be used to incorporate text-based information into Camtasia for the instructional presentations. These prepared tutorials on potential topics such as how to produce an animated graphic from Matlab plots, will be produced and made available to assist the learners with the basic fundamentals of the information technologies. Microsoft FrontPage will serve an instructor tool and will be used to create a website for course information delivery and communication. External links will be placed on the course website to direct learners to related topics.

The learners will also utilize Microsoft FrontPage as an instructional technology. The results and conclusions of the final learning products are to be delivered in the form of a web page and will be posted on the course website. The final learning product is an essential knowledge-building component within the inquiry process; therefore the web page format provides the most suitable means of information distribution among the learners. As with the embedded information technologies, there are alternative software packages (with the exception of Camtasia) that are available to the public at no charge, yet have the same functionality (Table 2). Camtasia is currently available for a 30-day free evaluation.

Table 2. Recommended and alternative instructional technologies.

Recommended Instructional Technology	Alternative Instructional Technology
Microsoft PowerPoint	OpenOffice (http://www.openoffice.org)
Microsoft FrontPage	CoffeeCup (http://www.coffeecup.com)

Strategic Planning for Implementation

Since the instructional framework will be integrated within an existing course curriculum, it is essential that the motivating examples and learning product requirements be relevant to the course content. In the case of the graduate course, applications will have a hydrologic focus.

More flexibility is available for the undergraduate course, which may include students from all civil engineering specialty areas.

Within the current working implementation plan, there are four components. The first implementation task is for the instructor to develop a sufficient background in the material to adequately address not only the framework content, but also additional learner questions that may arise during the implementation process. Making the reservations for the required resources is the next component of the strategic plan. Coordination is necessary with the civil engineering department's computer system manager to ensure that the meeting room, computer resources, and the necessary software licenses are available when the course is being taught. Preparation of all lecture and project materials prior to the course being taught is the third implementation task. The final task is to ensure that timely assessments and feedback to learners is accomplished. Since the instruction period consists only of four lectures, any delays in assessment must be avoided. If the learners are unsure of their progress, uncertainty in what they are learning may be created. Further implementation tasks may be added to the strategic plan should they become necessary.

Conclusions and Future Work

This paper presents the development of an instructional framework to introduce and assess student understanding of wavelet-based problem solving techniques within an advanced undergraduate- and graduate-level civil engineering course. Results have not yet been determined since the instructional framework will not be implemented until approximately halfway through the Spring 2005 academic semester. Instructional materials and ongoing results will be placed on the course website, located at: <http://people.tamu.edu/~jmp9307/cven675/>. It is expected that at a minimum, learners will develop an awareness and basic working knowledge of wavelet-based problem solving techniques that may be applied in their current and future endeavors.

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