A Multidisciplinary Junior Level Laboratory Course in Dynamic Data Acquisition

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Abstract

This paper describes a Junior-level multidisciplinary laboratory course concerning industrial applications of dynamic data acquisition and analysis. The course, developed as part of the NSF Foundation Coalition and initially targeted for electrical, mechanical, and industrial engineers, consists of four weeks of introductory material followed by four modules, each concerning a specific application of signal acquisition and analysis. The modules emphasize qualitative understanding of concepts and are designed to illustrate the principles involved in data acquisition and analysis, to demonstrate industrial applications of engineering concepts, to exploit the varied experiences of the individuals within the multidisciplinary student teams, and to introduce students to the equipment and processes necessary to take meaningful measurements and interpret their significance. Each application-specific module is designed to be independent, and the modules may be taken in any order. By employing a modular structure, the class can be easily modified in the future to accommodate additional disciplines, such as aerospace engineering.

Introduction

This paper describes a Junior-level multidisciplinary course centered around industrial applications of dynamic data acquisition and analysis. Developed for the University of Alabama (UA) Foundation Coalition (FC), this course will be offered to FC and non-FC students for the first time in Fall 1996. The semester long course will contain classroom and laboratory components and will consist of four weeks of introductory material followed by four modules, each concerning a specific application of signal acquisition and analysis (speech encoding and enhancement, machinery sound power measurement, machine condition monitoring, and motor condition monitoring). The course will conclude with a three week culminating design project. Funding for instrumentation for this course was provided by an NSF Instrumentation and Laboratory Improvements (ILI) grant and University of Alabama matching funds.

Course Structure

This three-credit-hour course will be one semester long and will consist of both classroom activities and laboratory exercises. The classroom activities will be interactive, making use of PC-based demonstrations and team-based exercises. Spectrum analyzers, custom-built machinery, sound cards equipped with microphones and speakers, and color printers will be utilized in these exercises. MATLAB will be the primary computing platform, and spreadsheets such as EXCEL will also be used. The laboratory exercises will involve use of laboratory instrumentation to capture, process, and evaluate data. In addition to analyzing data captured using laboratory instrumentation, the students will also use the WWW to acquire data from existing databases [1]. Supporting literature for the course will include portions of textbooks (e.g. [2, 3]), application notes from various manufacturers [4, 5], manufacturers' catalogs (both in paper form and via the WWW), and interactive tutorials (which will be made available to the students via WWW).

Students will work in teams of maximum size 4, consisting of individuals from two or more disciplines (e.g. mechanical, electrical, and industrial engineering). Teams are intended to group students with complementary interests and skills and, further down the line, enable cooperative, multidisciplinary senior design projects.

Course Content

This course will begin with an introductory module covering the fundamentals of digital data acquisition and analysis. This will be followed by a series of independent laboratory modules centered around specific industrial and commercial applications of dynamic data acquisition and analysis. The course will conclude with each team performing a three-week culminating project, requiring a written report, based on one of the application modules.

Representatives from industry have provided input on course content and will review course materials for accuracy and relevance. Each application-specific module is designed to be independent, and thus these modules may be taken in any order. The modular structure of the course also allows for the addition or deletion of application modules in response to incorporation of other engineering disciplines (such as aerospace engineering) or changes in industry.

Introductory Module

The introductory module will consist of four weeks of interactive lectures and exercises designed to teach the basic concepts of data acquisition and digital signal processing. Topics will include sensors, sampling and reconstruction, aliasing, linear and nonlinear quantization, windowing and digital filtering, the Fast Fourier Transform, transfer functions, and auto and cross-correlations. These concepts will be reinforced through illustrative lab experiments and through MATLAB exercises using both pre-recorded data files and data gathered by the students. Students will also learn how to use laboratory instrumentation such as dynamic signal analyzers and data acquisition cards.

Application-Specific Modules

At present, four industrial and commercial application modules are planned - speech encoding and enhancement, machinery sound power measurement, machine condition monitoring and diagnostics, and motor condition monitoring and diagnostics.

Speech Encoding and Enhancement

The objective of this module is to demonstrate data acquisition principles and certain signal processing techniques used in speech encoding and enhancement. Digital speech encoding and enhancement has many commercial and industrial applications, including new-generation digital cellular telephones, speech encryption devices for privacy, and compact disks. The module will consist of three different experiments - performance evaluation of various speech encoding techniques, use of digital signal processing to reduce background noise, and use of digital signal processing to enhance speech.

Using a PC-based data acquisition system, students will begin the module by making digital recordings of their voice, both in a quiet environment and with background noise. Using the “quiet” recordings, students will investigate various speech encoding techniques, including Pulse Code Modulation (PCM) at 64 kbits/sec and Delta Modulation (DM) at 16 kbit/sec. Students will then examine the performance of each encoding technique in terms of speech quality, computational complexity, and encoding rate.

Next, students will examine the recordings made with background noise. Various processing techniques, including additional filtering and adaptive noise cancellation will be evaluated. As with speech encoding, the noise reduction techniques will be rated in terms of computational complexity and improvement to speech quality.

For the final experiment in this module, students will use speech generated by speaking-impaired individuals and will employ speech enhancement techniques to improve the intelligibility and quality of the handicapped person’s speech. This experiment will be performed in conjunction with University of Alabama faculty (and possibly students) from the College of Communications with expertise in communicative disorders.

Specialized equipment used in this module will include electronic filters, PC-based data acquisition boards and sound cards, and a two-channel, FFT-based dynamic signal analyzer.

Sound Power Measurements

In this module, students will gain an understanding of why machinery sound power measurements are needed (hearing protection and annoyance issues) and how sound power data is utilized by engineers. Specifically, sound power will be measured and evaluated for office machinery. Decibels, 1/3-octave and octave band levels, human hearing, and A-weighting will be covered. Students will be introduced to applicable standards (ASA, ANSI and ISO) and various accepted methods of sound power measurement will be discussed. The use of free-field (outdoor or hemi-anechoic room) sound pressure measurements to calculate radiated sound power will be covered. The reverberation room method, utilizing the comparison of sound levels with those generated by a calibrated sound power source, will also be discussed. Finally, although not yet accepted in the European Union for the qualification of sound power radiated by office machinery, sound intensity measurements will be covered. The relative merits of these three methods will be discussed.

Equipment for this module includes a calibrated sound source, sound intensity probes, phase matched microphones, a sound intensity calibrator, and two portable two-channel real time spectrum analyzers with 1/3 octave, octave, and FFT capabilities. In addition, reverberation time and sound intensity software will be used. Laboratory exercises will involve measurements of sound power radiated by typical office machines using the scanning method of sound intensity. Students will see firsthand the effects of time averaging, microphone spacing, and microphone diameters on the validity of measurements in different frequency ranges.

Machine Condition Monitoring and Diagnosis

The objective of this module is to teach students how vibration measurements are utilized for machine condition monitoring and diagnostics. Conditions reflected in order-related spectral components (1X running speed and higher harmonics) including imbalance, misalignment, and loose coupling will be examined. Non-order-related vibrations will also be examined. Topics covered will include sensors (proximeters, velocimeters, and accelerometers), optimal sensor location and mounting, normalization of frequency scales in terms of multiples of the base RPM (i.e., orders), the use of bin or band levels for data trending, and database aspects. Machinery diagnostics covered will be limited to the more basic methods involving the trending of spectral levels, although reference will be made to more sophisticated and / or complex analyses utilized for gear and bearing diagnostics (e.g., the so-called "envelope averaging method" and cepstral methods used for bearing analysis). Students will be taught the basic "rules of thumb" that are used to identify imbalance, out-of-alignment, and shaft looseness conditions.

A machine incorporating a motor, coupled shaft(s), bearings, and gears is currently under design for this laboratory. Experiments will involve the acquisition and analysis of data acquired on laboratory machinery both with and without component faults. Students will also be made aware of other methods employed in predictive and preventive maintenance (e.g., oil analysis and gear box chip detectors). Instrumentation will include industrial accelerometers and an accelerometer calibrator. Two dual-channel combination data loggers/real time analyzers with tachometer inputs will be used. Analyzer capabilities include those required for run-up and run-down testing, time synchronous averaging, FFT, octave and 1/3-octave analyses, time waveforms, frequency response functions, zoom analysis, and machinery balancing software.

Motor Condition Monitoring and Diagnosis

The main objective of this module is to acquaint students with various techniques and methods for using electrical measurements to monitor condition and classify faults in electric machinery. This module will also familiarize students with the dynamic performance and transient response of energy conversion systems. Students will study the mechanical and electrical interactions in electric machinery resulting from load changes, voltage changes, and distribution system faults. Techniques will be introduced for detecting motor failure modes such as winding insulation breakdown, rotor bar open-circuits in induction motors, and bearing wear.

Hall effect transducers will be used for current sensing, and resistive voltage dividers will be used for potential measurement. Substantial emphasis will be placed on data collection and processing methods that are consistent with current industrial practice.

An understanding of motor condition monitoring will well prepare students for industrial careers. Current trends are to reduce motor maintenance costs by performing less maintenance, and the ability to monitor condition will enable scheduled maintenance on demand rather than maintenance caused by forced outage.

This module will use the same analyzers and database software as that used for the machine condition monitoring module.

Culminating Project

At the end of the semester, each team will perform a small (three-week) culminating project. These projects will be based on one of the application modules and, preferably, will involve measurements in an actual industrial environment. Each team will choose from a list of available projects and, upon completion of the project, each team will be responsible for submitting a written report. Several possibilities are foreseen for the project list, including

a) Having students take measurements of radiated sound power on a product manufactured by local industry, or
b) Having students visit a large plant or power generation station, inventory the number and types of machines and their criticality to the production process, and then design a preliminary plan for the implementation of a predictive maintenance program.

At the beginning of the project, each team will select a team leader and, together with the team leader, will develop a detailed outline of the report. The team leader and instructor will jointly review this outline. Team members will be tasked with developing specific sections of the report. Drafts of these sections will be submitted to the team leader, who will review them with the instructor. The team leader will be responsible for editing and assembling the revised drafts into a final, coherent report.

Multidisciplinary Senior Design Projects

In their senior year, mechanical and electrical engineering students at UA must perform a senior design project. The ME and EE courses are currently separate, but the UA Foundation Coalition is considering a multidisciplinary senior design project course structured to follow the Dynamic Data Acquisition course. Given the multidisciplinary teams formed in the Dynamic Data Acquisition course, and given the course's broad range of application-specific modules, the course can easily serve as a springboard for multidisciplinary senior design projects.

Student Performance Assessment

Throughout the course, students will be given individual quizzes on the fundamentals and application-specific topics covered in class. For each laboratory module, teams will be expected to present their results in oral and/or written reports. As discussed earlier, a written report is also expected from each team concerning the culminating project. Expectations for the quality and format of these presentations will be clearly defined at the beginning of the course, and students will be shown videotapes of their oral presentations in order to help them improve their presentation skills. Certain laboratory modules may also require the students to take individual practical examinations. Student grades will be determined on the basis of exam scores, written reports, anonymous end-of-term reviews by fellow team members, presentations, and participation.

Course Assessment

Course assessment will be performed by three groups - students, instructors, and industrial representatives. For the course as a whole, as well as for each laboratory module, a list of key principles and learning objectives will be developed. At the end of the course, students will be given an anonymous course evaluation form with a series of detailed written questions to assess the effectiveness of the course in teaching the key principles. The questionnaire will also ask what aspects of the course the students found most difficult, most beneficial and/or enjoyable, and what they would suggest to improve the course. Students will also be asked to provide any general comments or opinions concerning the course. Additionally, student comments will be solicited during the interactive class time throughout the course, and a portion of the final class will be dedicated to an open critique of the course.

Representatives from industry will be asked to assess the content and methods of the course on the basis of the course syllabus, laboratory experiments, student reports, and student presentations. The course instructors will keep a log of their day-to-day class experiences, noting which teaching techniques are effective and which areas need improvement. The instructors will also convene after the course is completed and draft a joint report describing their experience and evaluating the course.

Conclusions

This paper describes a Junior-level multidisciplinary laboratory course concerning industrial applications of dynamic data acquisition and analysis. The course, developed as part of the UA Foundation Coalition and initially targeted for electrical, mechanical, and industrial engineers, consists of an introductory module followed by four independent, application-specific modules and a culminating project. Details are given concerning contents of each of the modules, and methods for assessing student performance and course effectiveness are discussed. This course will demonstrate industrial applications of engineering concepts and, it is hoped, can serve as a springboard for a multidisciplinary senior design course and for other interactions among students of different engineering disciplines.

References

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