Experiential Noise and Vibration Education via Distance Delivery

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The Graduate Program in Acoustics and World Campus at Penn State has developed a series of software virtual instruments specifically for learning acoustics and vibration measurements. This article discusses the virtual instruments, project assignments and educational outcomes of the program.

The importance of noise and vibration continues to increase in many industries. Many companies now face noise-related issues ranging from regulatory to perception of product quality. Therefore, working professionals often find themselves thrust into technical situations requiring specialized knowledge of the noise and vibration area with little or no formal education and training. Because of the specialized nature of acoustics, courses and expertise are not generally available at most institutions of higher education. A limited number of higher learning institutions throughout the world offer a sequence of acoustics-related courses. The situation is further exacerbated, since noise and vibration analysis is often a highly experimental endeavor. Learning how to make good acoustical measurements simply takes time and experience. One must become familiar with both the equipment operation and measurement techniques. Resident instruction relies on supervised laboratory exercises to provide expert guidance to develop the skills. These issues combine to create a situation where working professional engineers may find themselves in need of training that requires an experiential-based, hands-on type of learning environment that is not available locally.

A number of professional development short courses exist that offer acoustics training. The face-to-face training provides the supervision necessary for experimental instruction. However, the nominal three- or five-day courses are so compressed that the experimental aspects of acoustical measurement and analysis can be addressed only in a limited manner. Furthermore, coverage depth is rather limited in the short-course environment due to time constraints. When in-depth knowledge is required, a more comprehensive approach is needed. Learning by distance delivery methods is an alternative and removes some of the time compression associated with short courses. The material delivery can come in the form of CD-ROM[1], web-based instruction[2] or interactive teleconferences.[3,4] The instruction can lead to a post-baccalaureate certificate or advanced degree. These delivery methods are more amenable to theoretical topics. Any experimental training is very difficult due to the prohibitive cost and logistics of making suitable testing facilities and instrumentation available to each individual student. Moreover, the distance delivery instruction mode does not lend itself to providing supervised experiential-based learning needed for experimental based activities..

Therefore, a challenge exists to provide specialized acoustics-related education to a geographically distributed group of working professionals needing a strong experimental component. To tackle this problem the Graduate Program in Acoustics and World Campus at Penn State has developed a series of software virtual instruments specifically for noise and vibration measurements. The virtual instruments are designed to mimic commercial unit operation – but with an educational bent. The virtual instruments accept and process actual acoustical data in a digital-array format. The data are usually supplied as part of an assignment or experiment. By working with actual data, the students focus on the data processing and interpretation; this is often highly experientially acquired knowledge. Since the raw data is typically supplied to the students, unfortunately a number of practical instrumentation issues (i.e, ground loops, transducer measurement positioning, signal to noise ratio, etc) are ignored. However, under the distance-delivery constraints, the approach provides an acceptable compromise while providing a realistic experimental-type component.

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In a self-paced, distance-learning environment, the students function independently. To instill the desired experience factor, the experiments must be carefully designed. The experiments must gradually start with controlled data and analysis. The important points must be obvious and analysis well behaved since the safety net of a laboratory instructor does not exist. The laboratory expectations should progressively increase in complexity, eventually arriving with open-ended decision-making and processing necessary for real-life measurements. The delivery sequence needs to be methodical in nature, constantly challenging the student, yet not overextending the experiential bounds to where the student becomes frustrated.

The purpose of this article is to explain how this approach of using actual noise and vibration data with virtual instruments has been implemented at Penn State. First, the operation and capabilities of the virtual instruments are explained. Next, several experiments are discussed, showing the increasing complexity sequencing.

Two general-purpose noise and vibration measurement instruments were created along with several more application-specific items. The general instruments consisted of a sound-level meter (VSLM) and fast-Fourier transform analyzer (VFFT). The more specialized items were for measuring room reverberation time and time-frequency analysis via the short-time Fourier transform. The SLM and VFFT are the primary focus here. Both were compiled programs written in Labview®[5] and were designed to have a similar "look and feel." Attention was paid to incorporate many of the decision-making and processing features available in commercial hardware devices. The data input format is identical, so that the same file can be analyzed with either instrument.

Virtual Sound Level Meter – VSLM

The virtual sound level meter graphical user interface is shown in Figure 1. The operation of the VSLM mimics commercially available hardware, while incorporating several features to aid instruction. The actual processing of the sound clips to determine sound pressure levels adheres to ISO standards.[6] The operation and processing controls, highlighted in Figure 1, can be summarized as follows:

Input. File format – Microsoft Windows wav monaural file data input (8 bit resolution and 22.05 kHz sample rate to increase computational speed); VSLM controls – gain adjustments for microphone sensitivity and record/playback gain adjustment.

The VSLM software does not interface to a data acquisition board, but operates on discrete data files in standard Microsoft Windows .wav format. The sound clip origin can be either supplied to or created by the user. Adjustments are available for both microphone sensitivity and variations in any signal recording-to-playback gain. Microphone sensitivity varies with make and model and the available adjustment forces the operator to recognize the associated issues and calibrate accordingly. When working with recorded sounds, a difference in the record and playback amplitude may exist. A gain control is included to compensate for any difference.

Sound Pressure Level Processing Selections. Meter response – fast (200 ms), slow (1 s), impulse peak (35 ms), peak hold and L_{eq}; weighting – Flat, A, B, C; frequency analysis – 1/3 octave.

All of the standard meter response speed and weighting options typically available in commercial hardware sound level meters are available. In addition, a 1/3-octave frequency analysis function is available if desired by the operator.

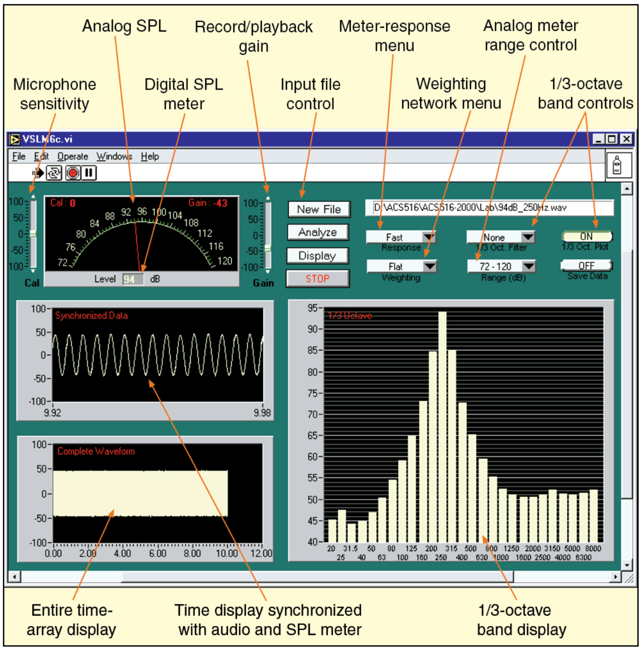


Figure 1. Virtual sound level meter with 250-Hz calibration tone.

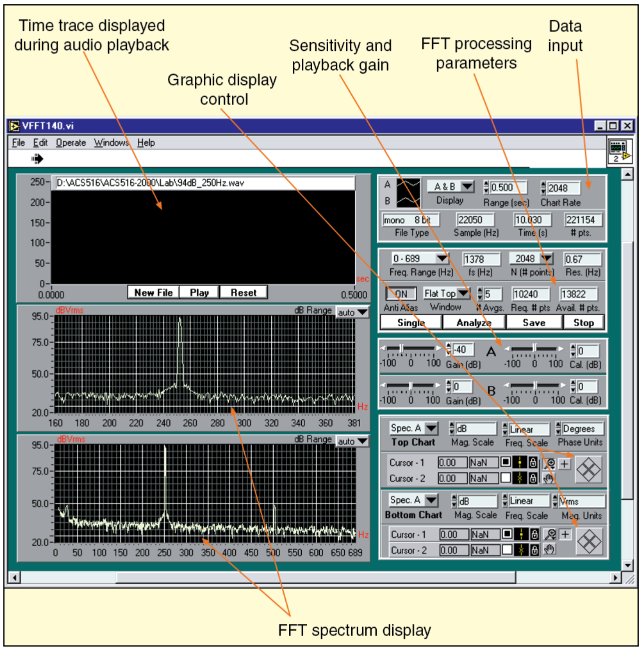


Figure 2. Virtual FFT analyzer with 250-Hz calibration tone.

The processing is performed on the entire data block before it is presented to the user. By performing the block computations, the user can easily examine the effects that a processing selection makes on the results. For example, the operator may initially select a fast meter response. Subsequently, the response may be changed to a slow setting. Since exactly the same sound data clip is processed each time, the effects of meter response on the sound pressure level readings can be readily observed. Therefore, the ability to repetitively process the same file while selectively changing the meter settings is an important feature for an independent learning environment.

Output. Analog sound pressure level meter; digital sound pressure level meter; 1/3-octave spreadsheet format output; display of entire time history; a nominal 10-ms display of time history clip synchronized with meter response.

The operator can view the time varying sound pressure level simultaneously in an analog and digital display. The analog meter allows rapidly changing levels to be observed, while the digital display provides a means to obtain accurate quantitative values.

When actually using a sound level meter, the operator highly integrates auditory and visual senses to make a reading. In other words, the user is carefully listening to the sound while observing the meter. The operator uses the auditory feedback to interpret the quantitative values. This allows the user to assess the sound pressure levels in relation to highly temporal varying sounds. Depending on the objectives of the measurement, the operator can assess issues such as range and effects (discrete events). For example, while trying to measure the exterior sound pressure from a window air conditioning unit, the sound may be contaminated by dogs barking or vehicle noise from nearby. The readings attributed only to the air conditioning unit can only be separated with the coordination of the audible feedback while monitoring the meter. To create this critically important audible feedback environment, the VSLM simultaneously plays the sound clip through the computer's speakers while visually displaying the results on the meter. The ability to observe and track the time-variant nature of sound pressure level measurements is enhanced by a running display of approximately 10 ms of the time history. The running display is also synchronized with the audio and meter displays. This combination of audio feedback with time history and meter response creates a rich learning environment.

A display of the 1/3-octave spectrum for the entire sound clip is available if desired. A synchronized real-time display of the spectrum over the course of the sound clip is not displayed (i.e., as is the SPL) due to the computational load. The L_{eq} value in each 1/3-octave is computed. The 1/3 octave spectral data can be exported to common spread sheet format for further analysis and display.

Virtual Fast Fourier Transform Analyzer

The graphic user interface for the virtual-fast Fourier transform (VFFT) analyzer is shown in Figure 2. Its purpose is to provide a form of operation similar to commercial FFT analyzers, but without the data acquisition hardware on the front end. The data to be processed are supplied as a digital data array using the same format and procedure as the virtual sound level meter. The operation and processing selections and data presentation has been designed to replicate commercially available hardware. The analyzer accepts two channels of data so that cross channel properties may be computed.

Input. File format – Microsoft Windows wav file monaural or stereo data input (8 or 16 bit resolution and 44.1 kHz or 22.05 kHz sample rate); VFFT controls – gain adjustments for microphone sensitivity and record/playback gain adjustment are provided for each channel independently.

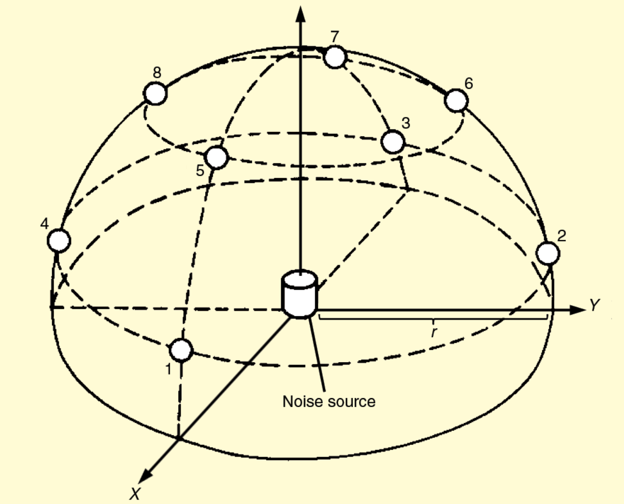
The VFFT does not interface to a data acquisition board and only processes digital data arrays in .wav format. It accepts either monaural or stereo files. For stereo files, each channel is treated as independent input. Different sample rates and discretization resolution are accepted. Adjustments are available for both transducer sensitivity and variations in any signal recording-to-playback gain.

Spectral Processing Selections. The VFFT mimics the basic processing selections in a commercial analyzer: the baseband frequency analysis range; data processing window (i.e., Hanning, flat-top, etc.); and FFT block size (i.e., 2048, 4096, etc.)

Since the VFFT operates on a prerecorded file with a fixed length, the selection of the FFT block size and frequency analysis range are not independent. Once the block size is selected, the maximum number of averages available from the array under consideration is displayed so the user can select accordingly.

Output. Display of the time traces and audible playback is provided similar to the VSLM. The data are batch processed and the user given control over display of the end results. When a stereo record is processed, the user has access to: power spectral density of both channels; frequency response function; and coherence function.

Only the power spectral density function is available for a monaural signal. The user has typical control over the graphical presentation of the results (e.g., frequency range, amplitude range, display units, etc.). The spectral data can be exported to a common spread sheet format for further analysis and display.



Mic	X	Y	Z
1	0.97*r*	0.0	0.25*r*
2	0.0	0.97*r*	0.25*r*
3	–0.97*r*	0.0	0.25*r*
4	0.0	–0.97*r*	–0.25*r*
5	0.63*r*	0.0	0.78*r*
6	0.0	0.63*r*	0.78*r*
7	–0.63*r*	0.0	0.78*r*
8	0.0	–0.63*r*	0.78*r*

Figure 3. Sound recording made around two lawn mowers at eight measuring points (top); microphone positions and radii (r) of hemisphere (below).

Experiential Learning Exercises

The learning exercises are designed to present realistic acoustic measurement scenarios. The students are required to select suitable data processing procedures consistent with the objectives of the test.

Sound Level Measurement Assignment. As a sound analysis specialist, you have been asked to characterize the sound produced by a toilet manufacturing company. The company wants to characterize the similarities and differences between the sound produced by their toilet and one of their competitor's. You have been supplied with three files for your analysis: a 94-dB calibration signal at 250 Hz; a sound clip from toilet A; and a sound clip from toilet B.

- Using the VSLM, determine a suitable measurement scheme (i.e., flat, peak, etc.) to analyze this phenomena.
- Indicate a justification for all the processing selections you make.
- Use your measurement scheme to quantify the sound emitted from the two toilets.

Spectral Analysis Analyzer Assignment. The maintenance department at a railroad has supplied you with accelerometer signals from the bearings on two separate cars. The accelerometers were mounted directly on bearing housings in the vertical direction. Based on the nominal train speed of 60 mph and the bearing specifications, the defect passage frequencies are: Axle – 9.3657 Hz; Outer Race – 96.5240 Hz; Inner Race – 118.8873 Hz; Roller – 43.9430 Hz; and Cage – 4.1967 Hz.

The maintenance director is interested in determining if any of the bearings is showing telltale signs of defect through your evaluation of the vibration spectra. Furthermore, if you suspect a bearing is defective, your guidance locating the defective component would be greatly appreciated.

Sound Power Evaluation. Sound recordings have been made around two lawnmowers at a radius of 1.5 m using a hemispherical grid as defined in Figure 3. You can assume that the section areas associated with each of eight microphone locations on the hypothetical hemispherical measurement surface are equal. Each mower was oriented along the x-axis. Position 1 is at the front of the mower, and the rear where the operator stands is toward Position 3. The measurements were made in an open grassy field on a calm quiet day. The sound recording instrumentation was calibrated with a 1000-Hz tone at 104 dB. The calibration file is available for your analysis. Each lawnmower was operated under typical cutting conditions as the sound was recorded at the eight hemispherical positions.

You have been contracted by a lawnmower manufacturer to assist in the comparative evaluation between their product and a competitor. Your expert analysis and advice is sought, and you are expected to deliver a professional report to your client.

Your client has specifically requested: sound power estimates of each mower in 1/3-octave bands; and the directivity in 1/3 octaves. Your client would like to ask your opinion in assessing the acoustical information contained in these recordings. As an expert in the area of acoustical data analysis, you have been given the latitude to examine the data using whatever method you feel is most appropriate. You have been requested to indicate your rationale and document the analysis. For the comparative product analysis, the manufacturer hopes to gain some insight into: any implications for potential hearing loss; customer annoyance; potential identification of the noise sources; guidance as to where any noise abatement treatments should be focused; and any other information you can extract from the test data.

Assignment Rationale and Expectations. In each assignment, recordings from the actual equipment mentioned are delivered to the students. The instructions are not given in a perspective form, but rather with objectives from a potential client. The students must make decisions as to the most suitable measurement and processing selections in relation to the actual data characteristics. They must reconcile the various measurement trade-offs and pragmatic issues. Throughout the exercises, they must interpret the results and adjust the analysis scheme.

Because the data are recorded, the effects of changing a processing parameter on the results can be readily evaluated and studied interactively. Through the iterative process of establishing a suitable measurement processing scheme in a realistic yet controlled environment, the students start to gain critical experience. Class discussion of the results afterward provides critical feedback to identify the finer nuances of the analysis procedure and results.

Summary

The distance-learning environment has its own set of challenges in that the students must be independent learners. The immediate availability of face-to-face assistance is not possible. The students learn to solve problems independently in this environment. The onus is on the course instructors to design class exercises that enable independent learning yet are sufficiently open-ended to promote development of critical thinking. This is always a delicate balance, but even more important in the distance-learning environment due to the limited instructor-student interaction.

The combination of virtual sound level meter and vibration measurement instruments with actual recorded data can create a rich practical learning environment. This is particularly true for many heavily experimental-based topics where experience plays a crucial aspect. The use of the VSLM and VFFT discussed in this article has proven effective in meeting this objective.

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