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Application of a computer sound card for measurement of mechanical vibrations

(Aplicação de uma placa de som de computador para medição de vibrações mecânicas)

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This paper presents a data acquisition and analysis system based on a computer sound card for measuring and processing random vibration signals. This system turns the computer into a two-channel measurement instrument which provides sample rate, simultaneous sampling, frequency range, filters and others essential capabilities required to perform random vibrations measurements. An easy-to-use software was developed for vibration monitoring and analysis, including facilities for data recording, digital signal processing and real time spectrum analyzer. Since the tasks of vibration data acquisition frequently require expensive hardware and software, this versatile system provides students a very accurate and inexpensive solution for experimental studying mechanical vibrations.
Keywords: data acquisition system, vibrations, computer sound card.

Este trabalho apresenta um sistema de aquisição e análise de dados baseado em uma placa de som de computador para a medição e processamento de sinais de vibração. Este sistema transforma o computador em um instrumento de medição de dois canais, disponibilizando taxa de amostragem, amostragem simultânea, faixa de freqüência, filtros e outros recursos essenciais necessários para realizar medições de vibrações aleatórias. Um software com facilidades de utilização foi desenvolvido para o monitoramento e análise de vibrações, incluindo recursos para gravação de dados, processamento dos sinais e analisador de espectro em tempo real. Uma vez que as tarefas de aquisição de dados de vibração geralmente requerem hardware e software de custo elevado, este sistema versátil oferece aos estudantes uma solução precisa e barata para o estudo experimental de vibrações mecânicas.
Palavras-chave: sistema de aquisição de dados, vibrações, placa de som de computador.

1. Introduction

Mechanical vibrations can occur in many engineering designs and their characterization usually involves several concepts and equipment. The instrumentation systems and techniques for vibration measurement are key factors to ensure the quality of the measured data and therefore there are many practical implications that must be taken into account as pointed out by Ref. [1]: the systems that perform measurement and analysis comprise a broad variety of prices, configurations and characteristics, making more difficult the choice of a specific measurement system. Both measurement and analysis are determined by many factors like available budget; already present computer and measurement systems; type, amount, frequency range, amplitude range and location of the measurements; personnel skill and experience of the analysts; and current relation with hardware and software vendors.

In the context of undergraduate laboratory instructions, experimental practices related to mechanical vibrations have been performed in order to provide opportunities to enhance the knowledge and technical skills of students. In the work presented in Ref. [2], the forced vibrations of rigid and flexible cantilever beams clamped in one end, are studied. An experiment useful to the study and analysis of the damages caused by an unbalanced machine in a given system when the machine presents a vibration frequency near the char-

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acteristic resonance frequency of the system is reported in Ref. [3].

However, for undergraduate laboratory instructions, the cost for data acquisition systems can be prohibitive and for this purpose, the use of computer sound card as data acquisition device can be a very accurate and inexpensive solution for experiments. Usually, computer sound cards provide 2 input channels, 16 bit resolution, and maximum sample rate of 44.1 kHz per channel with simultaneous sampling on both channels for general data acquisition. These data acquisition capabilities combined with other technical aspects summarized in Ref. [4] are adequate and very useful for vibration measurements and give an alternate way for undergraduate student laboratory purposes.

Data acquisition using computer sound card have been reported for a variety of experimental practices. For example, in Ref. [5] the authors studied the rapid changing electromagnetic phenomena in the undergraduate physics laboratory. They used computer sound card to measure electromagnetic phenomena like EMF and damped oscillations. In Ref. [6], computer sound card was used as data acquisition system in the undergraduate laboratory to record Doppler shifted sound from a moving source. In Ref. [7], computer sound card was used for data acquisition and analysis of Geiger–Müller tube pulses, an instructive piece of equipment in undergraduate physics laboratories. In Ref. [8], the experiment using computer sound card to acquire sound data, demonstrated both the Doppler effect and spectral broadening in the undergraduate physics laboratory. In Ref. [9], the authors presented an experiment with the help of a personal computer that works at the same time as a function generator, an oscilloscope, a spectrum analyser and an analogical/digital converter.

This paper presents a data acquisition and analysis tool based on the computer sound card for sampling random vibration signals at constant frequency. The software, developed in Laboratory Virtual Instrument Engineering Workbench (LabView) programming language, can provides a low cost solution for motivating students to validate theories related to mechanical vibrations.

2. Software description

Vibe Tools shown in Fig. 1 (with labels and buttons in Portuguese) is an easy-to-use tool developed for vibration monitoring and analysis which uses computer sound card for random vibration data acquisition. The hardware and software requirements involve a Personal Computer running Microsoft Windows® operating system with 15.6 MB of free space in the hard disk and 256 MB of Random Access Memory (RAM). The software is not commercially available since it was designed and implemented according to local needs. Similarly, the code is not open-source since specific routines have been exclusively developed.

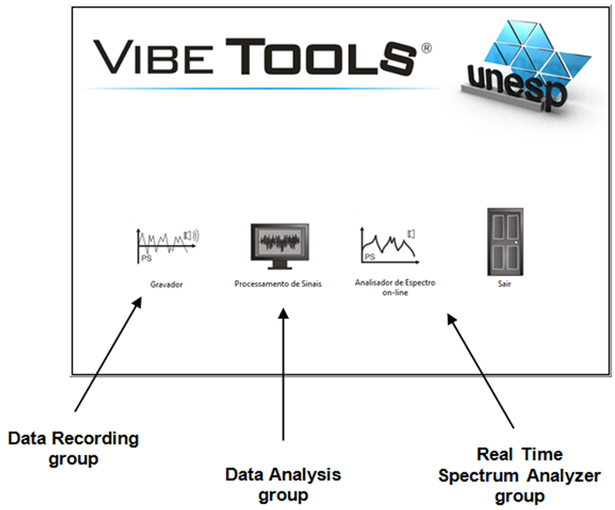

Figure 1 - The Vibe Tools groups.

Vibe Tools provides facilities for data recording, digital signal processing and real time spectrum analyzer as illustrated in the workflow in Fig. 2.

2.1. Data Recording group

The measurement process is initiated by selecting the Data Recording group. This group shown in Fig. 3 allows the user to select the appropriate measurement parameters including number of channels; sampling frequency; time span of each capture frame; trigger characteristics (trigger level, slope direction and time delay) and transducer sensitivity.

The sensitivity value for each input channel is established using a vibration reference source (for example PCB Piezotronics model 394C06 handheld calibrator) and the accelerometer connected to the channel. When the reference acceleration level (expressed in grms) is typed and the reference signal generated by the calibrator is well positioned within the full scale voltage range of the input channel, the program supervises the measurement and the current value for input channel sensitivity (expressed in mV/EU) is automatically returned, as illustrated in Fig. 4.

Following the measurement process, the data acquisition may be initiated by pressing the start button indicated in Fig. 3, and replaced by the stop button. When the process is finished, saving and exporting measurements tools allows the user to eliminate the DC component of measured signals before to save and export all measured data in American Standard Code for Information Interchange (ASCII) files or Universal File Format (UFF) for other application programs.

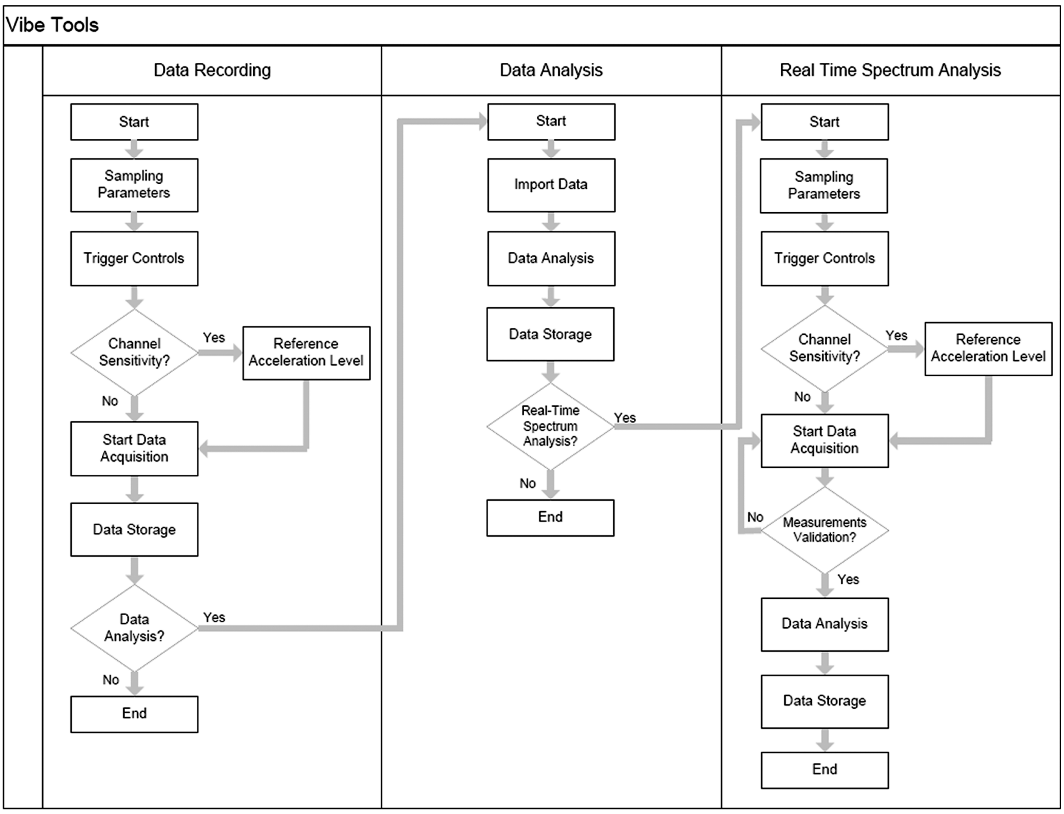

Figure 2 - Processes flow diagram.

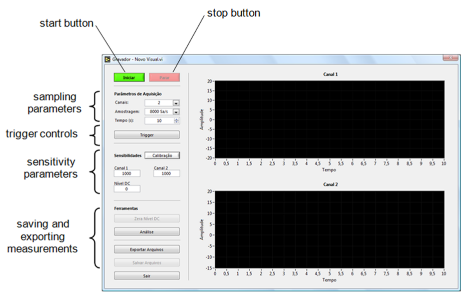

Figure 3 - The Data Recording group.

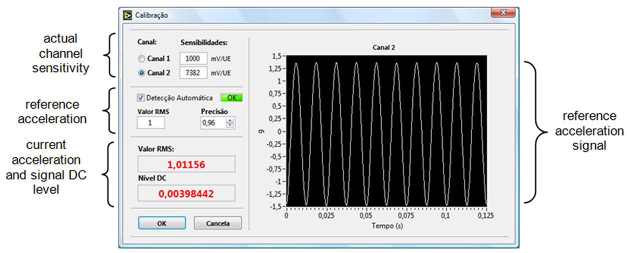

Figure 4 - Channel sensitivity panel.

2.2. Data Analysis group

The post-processing repertoire shown in Fig. 5 provides the facilities for the recovery and analysis of ASCII or UFF data files. This group provides statistical estimators (rms value, kurtosis, minimum and maximum values), filter options (Butterworth, Chebyshev and elliptic filter) and spectral analysis (fast Fourier transform - FFT, power spectrum and power spectrum density) that may be applied to a signal for detailed analysis. Additionally, the zoom analysis facility applied to the time axis of a signal displayed in the graph window is also provided to isolate specific regions of interest in zoom graph window. The recorded signal analyzed may be restored in both ASCII or UFF format.

2.3. Real Time Spectrum Analyzer group

This group shown in Fig. 6 combines the facilities of the both data recording and data analysis groups, and provides simultaneous analysis and real time recording of vibrations signals through the computer sound card input channels. All input signals may be recorded simultaneously and subsequently be analyzed in time domain and frequency domain, including the following functions: history time, auto power spectrum, power spectral density, cross spectrum density, transfer function and coherence function. The user may select the appropriate parameters related to measurement such as sampling frequency, frequency resolution, number of channels, trigger, sensitivity, number of averages and overlap weighting function applied to time-data prior to performing an FFT. This group also provides graph windows for the analysis signal selected, including zoom analysis facility applied to the time axis, double cursor to mark the start and stop times for analysis, auto scaling for the axis, linear and logarithmic scales.

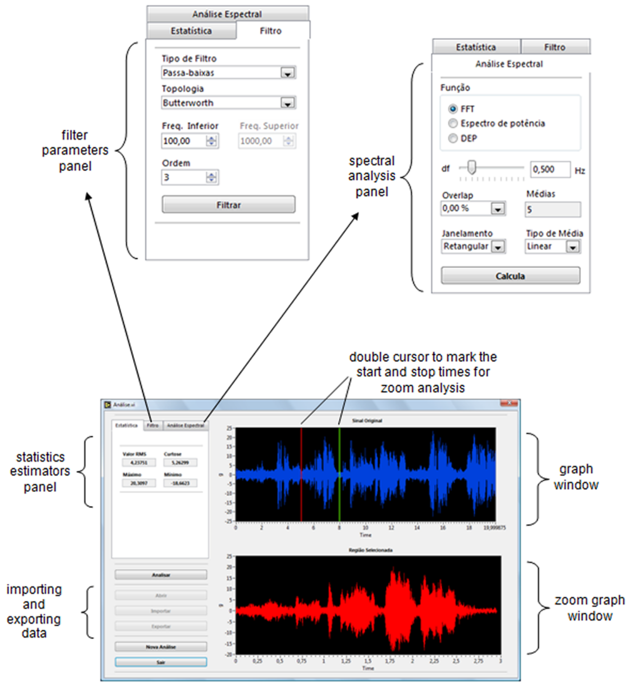

Figure 5 - The Digital Signal Processing group.

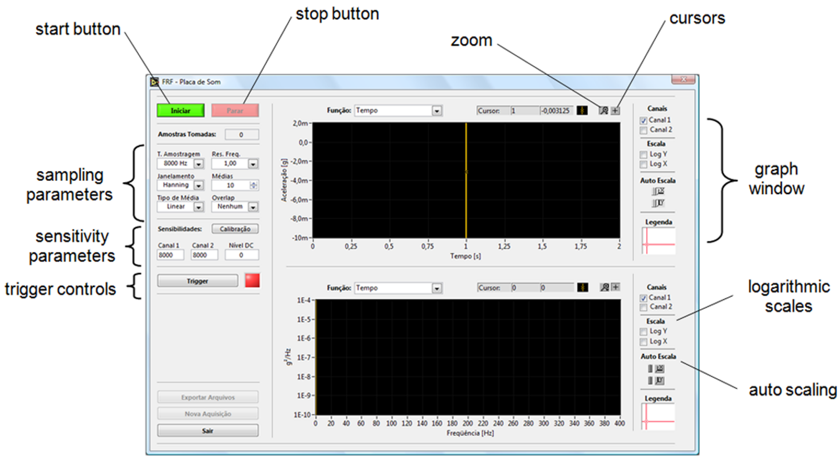

Figure 6 - The Real Time Spectrum Analyzer group.

3. Application to response of cantilever beam

To validate the developed tool for random vibration measurement and analysis, we present an example of a typical experiment shown in Fig. 7, used for characterization of the dynamic behavior of the beam. The purpose of this case study is to characterize the acceleration transmissibility function of the system. An aluminum 2024-T3 flexible cantilever beam of dimensions 340 mm x 1 mm x 20 mm was horizontally clamped to a LDS V201 shaker that provides the transverse random base excitation of the beam. The Brüel and Kjaer 1049 signal generator with the LDS TPO25 power amplifier provide power in the form of voltage and current to the shaker. Input acceleration was monitored through two Brüel and Kjaer 4517-002 accelerometers, used with Brüel and Kjaer 2694 conditioning amplifiers, positioned on the beam clamping fixture and on the free end of the beam, where the maximum displacement occurred. The first input accelerometer provided the base acceleration input and the planar response of the beam was measured with the second input accelerometer. In the experiment we performed an acquisition to obtain the transfer function by setting the following measurement parameters on the Real Time Spectrum Analyzer group: sampling frequency: 1024 Hz; frequency resolution: 0.25 Hz; window function: Hanning; number of averages: 100; average type: linear; overlap weighting function: not applied. The first five natural frequencies of the beam experimentally obtained are 4.75 Hz, 31.25 Hz, 89 Hz, 181.75 Hz and 302.75 Hz.

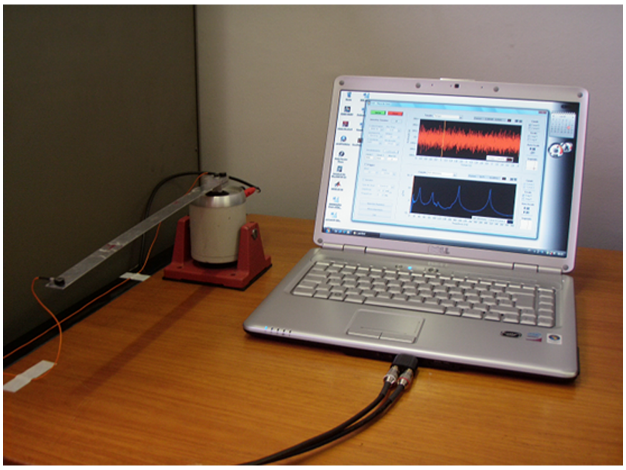

Figure 7 - General view of the experimental setup.

Following the validation process, the response of the beam was also evaluated numerically. The excitation (a prescribed acceleration) was applied in a beam tip and the acceleration response calculated for the other tip. The numerical model used consists of 6 linear Euler-Bernoulli beam elements. The mass of the accelerometer placed on the beam's tip (0.7 g) was taken into account. No damping was considered in the calculation of the frequency response. The two response curves (numerical and experimental) are displayed in Fig. 8 below. The reasonable agreement among the three results can be noticed and the experimental results shown to be as expected. The largest discrepancy in the natural frequencies obtained is lower than 5.8% and occurs for the fourth natural frequency of the beam. A more refined model using elements with higher order shape functions would certainly provide even better results but these tasks are beyond the scope of this work.

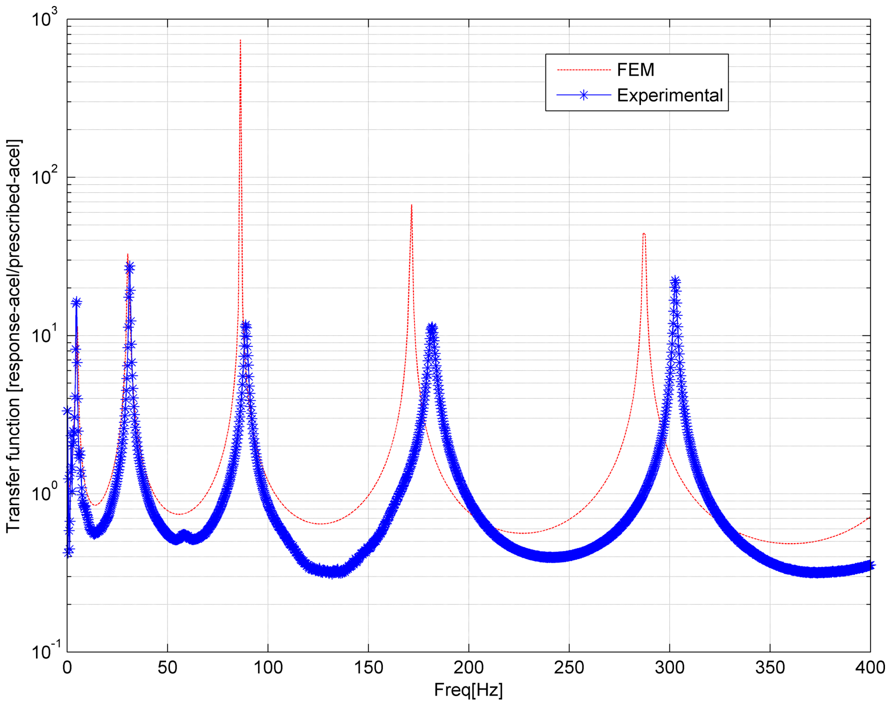

Figure 8 - Comparison between experimental results and finite element analysis.

4. Conclusions

Excitation systems, transducers, measurements and analysis systems are needed for investigating the dynamics of structures. In the context of measurements systems, data acquisition systems are available in a wide variety of prices and capabilities. However, for undergraduate laboratory instructions, the cost for such systems is an unfortunate aspect. This paper presented a versatile and low cost data acquisition and analysis system based on the computer sound card for measuring and processing random vibration signals, which can be used in experiments on free and forced vibration analysis. This system turns the computer into a two-channel dynamic signal analyzer which provides sample rate, simultaneous sampling, frequency range, filter and other essential capabilities required to perform vibrations measurements. To validate the system, the dynamic behavior of a flexible cantilever beam excited with a transverse random base motion was observed. Experimental results indicated that this data acquisition system and the easy-to-use developed software can be used to teach students most of the practical aspects of mechanical vibrations analysis.

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