Virtual practicum for research of mathematical algorithms using Digital Signal Processing

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Abstract

The article describes an approach to the organisation of a virtual laboratory practicum for research in the Digital Signal Processing (DSP) field. Such an approach may be useful in implementing a part of the educational process in a distant mode. The laboratory setting simulation method based on LabVIEW software was used to solve the research tasks.

It is advisable to create and implement this integrated educational solution – virtual laboratory practicum – in the educational process of universities that train engineers. It will allow students to have laboratory and practical training to improve specialists’ qualifications and carry out control activities. Using such an environment will allow extension course students, teachers, and trainees to perform assigned tasks without time limit, both in virtual form and in the form of training before working with real equipment. It will also allow students to carry out additional research on their own in the Digital Signal Processing sphere, which will increase their interest.

Keywords: virtual laboratory practicum, LabVIEW programming, Digital Signal Processing, discrete Fourier transform, amplitude measurement error.

1. Introduction

Virtual laboratory practicum has been gaining popularity in recent years as a tool for conducting research and experiments in various fields, including digital signal processing. Labview, a virtual laboratory software, provides a versatile platform for conducting experiments and simulations in a controlled environment. Its ease of use and flexibility make it an ideal tool for students, researchers, and engineers to learn and explore digital signal processing principles.

With LabVIEW, researchers can simulate real-world scenarios, collect data, analyze signals, and evaluate the performance of their digital signal processing algorithms [1-3]. This approach offers a number of advantages, including reduced costs, increased accessibility, and the ability to conduct experiments without being limited by physical resources. As a result, LabVIEW has become an essential tool in the field of digital signal processing research, providing researchers with the flexibility to design and test complex systems efficiently.

A virtual laboratory practicum using LabVIEW is an increasingly popular approach for students to learn signal processing techniques and complete laboratory assignments. As numerous publications demonstrate, virtual laboratory practicum using LabVIEW is becoming an increasingly popular approach for students to learn signal processing techniques and complete laboratory assignments. For example,
the process of data acquisition and signal processing using LabVIEW is described \[4\], using illustrative examples, the process of developing simple and functional virtual tools that can maintain data acquisition and post-processing in a laboratory environment is demonstrated. Some examples are the basis for subsequent execution in a modestly equipped laboratory.

The article \[5\] explores the application of e-learning in a laboratory workshop for the course «Measuring Instruments and Radio Engineering Devices». It analyzes the structure of the e-learning organization and provides a description of some of the workshop activities.

The article \[6\] discusses the prevalent issues of a growing demand for professional engineers in the field of electronic science and the outdated teaching methods being used presently. The authors explore a new approach to group teaching based on the Virtual Instrument technique, using a specialized course on «Virtual Instrument technique and LabVIEW program». The article outlines the specific measures and implementation procedures adopted for this teaching mode, as well as its resultant impact.

A virtual laboratory \[7\] for DSP has been developed utilizing LabVIEW. The laboratory is a network-based edition that is comprised of three functional modules: virtual experiment table, information management, and network communication. The virtual experiment table includes two sub-modules: resource & document and simulation experiment. The information management module includes four sub-modules: database, user registration, security verification, and system management. The network communication module is implemented by LabVIEW Web Server. The DSP Virtual Laboratory is ideal for experimental teaching in subjects such as Digital Signal Processing, Signals & Systems. The virtual laboratory has been designed to offer users a remote virtual experimental platform without time and space constraints.

The design goal was to develop a virtual laboratory practicum designed to study measurement methods using mathematical algorithms based on the discrete Fourier transform (DFT).

2. Main part

The aim of this article is to present a methodology for investigating mathematical algorithms related to digital signal processing, in particular the discrete Fourier transform, using the Labview features.

In general, a virtual practicum contains a theory module (‘electronic textbook’ or tutorial), a laboratory practice module and a knowledge and skills test module, supplemented if necessary by other modules, for example, an electronic task book. The purpose of an electronic textbook is to provide the necessary theoretical and methodological support for self-study of the course's theoretical units. The purpose of a virtual laboratory practicum is to ensure the necessary ground for training practical skills adequate to the professional requirements of the chosen specialty or specialisation. The student operates with mathematical models of harmonic signals and makes notes of the required characteristics. The task of the knowledge testing electronic unit is to provide an automated knowledge testing routine, which allows the student to objectively estimate the achieved subject study level.

Each virtual practical training laboratory is presented with a description and a downloadable program. The description contains theoretical statements, study steps, methodological guidelines, requirements for report completion, and control questions for self-checking.

The laboratory practicum program contains a list of experiments to be made with the studied object, the list of parameters to be recorded during the research of an object, and values to be calculated based on the experimental data processing and given in the completion report.

The virtual laboratory practicum includes a series of laboratory activities, presented below.

Fig. 1 shows the user interface of the laboratory work «Measuring the amplitude of the model signal using the discrete Fourier transform». The purpose of work is to measure the amplitude of the model signal using the DFT; to evaluate the amplitude measurement error caused due to finite measurement time,
due to absence of synchronization, and due to influence of the initial phase of the model signal; to evaluate the effectiveness of amplitude correction of the harmonic signal. The amplitude correction $U_0$ is calculated from the formulas:

$$U_0 = g_{mm} \cdot \frac{x}{\sin x},$$

where:

$$x = \pi \cdot \frac{Z}{1 + Z},$$

$$Z = \frac{g_m}{g_{mm}},$$

where:

- $g_m$ is the sample in the signal spectrum that is neighbour to the maximum sample (greater value in amplitude);
- $g_{mm}^{\text{max}}$ is the maximum amplitude sample in the signal spectrum.

So, to obtain an $U_0$, the two largest neighbouring DFT samples must be taken. Then the maximum of the two samples is multiplied by $\frac{x}{\sin x}$.

The oscillogram (Fig. 1) shows the amplitude spectra of the harmonic signals.

Fig. 2 shows the user interface of the laboratory work «Measuring the phase difference of the model signals using the discrete Fourier transform». The purpose of work is to measure the phase difference of the model signals using DFT; to estimate the error of phase difference measurement due to finite measurement time, due to absence of synchronization, and due to the initial phases of the model signals’ influence.

The oscillogram (Fig. 2) shows a curve of the phase difference estimation error (in degrees) depending on the frequency of the signals, expressed as a number of periods. Thus, the influence on the phase difference measurement accuracy of the values of the initial phase signals and the values of the measured phase difference, as well as the influence of the synchronisation absence, is seen. To research the effect of synchronisation, the integer and decimal parts of the ratio $T/T_0$ are taken into consideration in the expression below:

$$f_0 \cdot T = n + \lambda,$$

where:

- $n$ and $\lambda$ are the integer and decimal parts of the ratio $T/T_0$;
The period of harmonic signals $x(t)$ and $y(t)$ on the time interval $T$ of harmonic signal analysis is $T_0 = 1/f_0$.

The frequency of harmonic signals is $f_0$.

Fig. 3 and Fig. 4 show the user interface of the laboratory work «Measurement of amplitude of model signal on Gaussian noise background using discrete Fourier transform». The purpose of the work is to measure the amplitude of the model signal on Gaussian noise background using DFT; to estimate the error of amplitude measurement, signal-to-noise ratio, and required measurement time for providing filtering coefficient.

The window (Fig. 3) is used to calculate the parameters of the amplitude spectrum.

The below oscillogram (Fig. 4) shows a plot of the signal-to-noise ratio $\Lambda$ (in decibels) for signals $x(t)$ and $y(t)$ on the number of samples $N$, calculated by the formula:

$$\Lambda = 10 \cdot \log \left( \frac{U_{\text{amp,har}}^2 \cdot N}{2 \cdot \sigma_s^2} \right)$$

where:

- $U_{\text{amp,har}}$ – the value of the amplitude harmonic component in the spectrum of signals $x(t)$ and $y(t)$ at the fundamental frequency;
- $\sigma_s^2$ – noise dispersion.

Thus, the fact that the amplitude error decreases with an increase in the samples number (i.e., with an increase in the measurement time) and with an increase in the signal-to-noise ratio is confirmed. It also confirms that the signal-to-noise ratio increases with an increase in the samples number (i.e., with an increase in the measurement time).

Similarly, Fig. 5 and Fig. 6 show the user interface of laboratory work «Measuring phase difference of model signals on Gaussian noise background using discrete Fourier transform». The purpose of the work is to measure the phase difference of model signals on Gaussian noise background using DFT. Another aim is to estimate the error of phase difference measurement, signal-to-noise ratio, and required measurement time for providing filtering coefficient.
The oscillogram (Fig. 6) shows the dependence of the phase difference estimation error (in degrees) from the measurement time.

The following was confirmed as a result of data analysis: the signal-to-noise ratio increases when the error in phase difference measurement decreases, and the required measurement time for providing the required error also increases. The value of the required measurement time is influenced by the noise level.

The student sets the values of input parameters of harmonic signals (sampling frequency, number of samples, frequency, amplitudes, and initial phases of signals) and noise to make measurements in the mode of determining the given metrological characteristics. The main metrological characteristics to be measured are amplitude-frequency response, phase-frequency response, amplitude, and phase errors. They are calculated from the results of measuring the informative parameters of the harmonic signal (i.e. amplitude and phase) using DFT and measurement error correction algorithms [8-9]. The virtual laboratory is based on the principle of functioning and exploitation of the automated metrologist workplace [10].

It should be noted that in describing these laboratory works, only a part of the virtual laboratory practicum windows was employed. The other windows contain data, operations on which allow us to research other important tasks, to organize more and more virtual laboratory experiments.

3. Conclusions

The following tasks were solved during the implementation of the virtual laboratory practicum:

- measurement of signal phase differences and amplitudes, with and without background noise;
- simulation of errors caused due to measurement of signals phase and amplitude differences;
- determining the required signal-to-noise ratio;
- determining the measurement time for the filtering coefficient according to the required accuracy for phase and amplitude difference measurements;
- simulation of correction algorithms to improve the accuracy of phase difference and amplitude measurements.
References

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