SYSTOOL — AN ONLINE LEARNING TOOL FOR SIGNALS AND SYSTEMS

Rudolf Rabenstein

University of Erlangen-Nuremberg
Telecommunications Laboratory
Cauerstr. 7, D-91058 Erlangen, Germany
rabe@LNT.de

ABSTRACT

SYSTOOL is an online learning tool for real or virtual courses in signals and systems. It provides a collection of Java applets for interactive simulation and visualisation of linear systems. While based on a traditional textbook, SYSTOOL is accessible online though the Virtual University of Bavaria. This article describes structure and content of this learning tool and presents selected modules.

1. INTRODUCTION

Signal processing education starts with a solid introduction to continuous and discrete signals and systems. Teaching this subject at an early stage poses a major educational challenge: How to introduce the students to abstract entities like systems, impulse responses, the frequency domain, or poles and zeros? In face to face teaching, abstract signals and systems theory can be brought alive by classroom experiments and computer demonstrations. Im virtual teaching, probes and oscilloscopes, push buttons and monitor screens have to be replaced by interactive simulation and visualisation.

This article describes a virtual signals and systems course that focusses on student interaction with various forms of virtual systems and their associated input and output signals. It is based on a textbook [1] which presents the theory and a large number of worked examples. The virtual course consists of a number of custom designed Java applets, each representing a specific kind of system description. Students only need a standard computer with Internet access and a standard browser with Java enabled. No hardware or commercial software is required.

The virtual course on signals and systems consists of a number of HTML–pages and a collection of Java applets for interactive simulation. The web pages review the respective portion of the theory and describe the use of the applets. The purpose is not to expose the students to a step-by-step instruction, which they have to follow. The idea is rather to trigger their imagination by providing them with a set of tools for system simulation and to let them explore the topic on their own.

Access to the course is given by the a Virtual University of Bavaria (vhb). This Virtual University is active since May 2000. It provides students of Bavarian universities a curriculum in five different schools including the School of Computer Science and the School of Engineering. In addition to their regular curriculum, Bavarian students may add virtual courses to broaden their education.

This paper gives at first a short introduction to the Virtual University of Bavaria. Then the learning tool for signals and systems is presented along with a detailed description of some selected modules. Some student responses to this novel way of learning conclude the paper.

2. THE VIRTUAL UNIVERSITY OF BAVARIA

The Virtual University of Bavaria (vhb) is a joint institution of the Bavarian universities and technical colleges. Its purpose is the development of multimedia teaching and learning tools as support for traditional courses and for Internet applications in student education as well as for lifelong learning [2].

The vhb started in May 2000 with more than five hundred students in five different schools: computer science, engineering, medicine, business and administration, key qualifications. Enrollment doubled to more than thousand students in the winter semester 2000/01, where the five schools offered a total of 48 virtual courses. Currently 47 new courses are in development and new applications are under review. Also new schools are introduced.

During the winter semester 2001/02, the school of engineering offered courses in microelectronics, design of digital systems, signals and systems, image coding, computer networks, civil engineering, quality and environmental management, and technology-oriented entrepreneurship, with 13 new courses in development.

The focus in the development of virtual courses is to fully exploit the technical possibilities of web-based information exchange. Rather than just providing course material in printable or click-able format, each course facilitates

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student interaction with online teaching elements. Examples are:

- The course on computer networks provides interactive access to setup and operation of real-world network components.
- The course on design of digital systems provides access to professional design software for integrated circuits.
- The course on signals and systems provides a collection of Java applets for interactive experiments with virtual systems and their associated input and output signals.

The following section gives a detailed description of the signals and systems learning tool.

3. SYSTOOL — AN ONLINE LEARNING TOOL

The online learning tool SYSTOOL is intended for students who take a course in signals and systems either in classroom or by self study. It is based on the text book [1] or on the corresponding German edition; but it can also be used with most other standard text books. The full version of SYSTOOL is accessible for students of the vhb [2], a somewhat restricted public version is found at the author's home page [3].

3.1. Structure and Content

SYSTOOL consists of a number of modules, each comprising a few HTML pages and one or more Java applets. Each module reviews the basic theory, explains the usage of the corresponding applet and gives access to the applet itself.

The following modules a currently available:

- System Representations
  Explore the interrelations between standard form block diagrams, state space descriptions, and pole zero diagrams. Available for continuous and discrete signals.
- Convolution
  A graphical tool to demystify the convolution integral. Available also for discrete convolution.
- Fourier Transformation
  Build your own magnitude and phase functions and view the corresponding impulse responses.
- Hilbert Transformation
  - Experiment with various time functions and view their Hilbert transforms.
  - Do the same for the spectra of analytic signals.
  - Learn to apply the Hilbert transformation building block to sample bandpass signals and for modulation/demodulation.
- Sampling
  - Experiment with band limited continuous signals, sampling rates, pulse trains, and aliasing.
  - Learn how to recover a continuous signal from its samples.
- Wiener Filter
  - Mix signals and noise and design a Wiener filter for optimal signal recovery.
  - Listen to noisy signals and assess the improvement in audio quality by Wiener filtering.

Finally, a collection of problems shows the students how to link theory and computer experiments. Some problems require to solve a textbook problem first, then to use one of the virtual systems to verify the solution. Other problems let the students explore the system behavior on their own and makes them discuss their findings.

3.2. Description of selected modules

3.2.1. System Representations

Common descriptions of linear time-invariant systems are block diagrams, state space descriptions, and pole-zero diagrams. The interrelations between graphical representations, differential equations and the complex frequency plane appears to the novice students as puzzling as the Bermuda triangle. The module about system representations lets the user enter this triangle at either corner and explore further from there. One of the possible starting points is the interactive block diagram shown in Fig. 1. Block diagrams in different structures and orders (up to 7) can be specified. The coefficients as well as the initial states can be entered by the user or loaded from a menu. Also the input signal can be chosen from a list of common functions (sine and cosine, impulse, step, triangle, and alike). The students may modify these settings to their content, compute the corresponding output signals, and try all over again.

The structure of the block diagram and the values of the coefficients can be exported into the applet on state space description. It calculates the state space matrices, allows modifications, computation of the output signal, as well as converting the state space matrices back into block diagrams.

Pole-zero diagrams constitute the third corner in this triangle. They can be computed either from a block diagram or from a state space description. A sample result is shown in Fig. 2. Again, poles and zeros can be modified either by drag-and-drop with the mouse or by editing their values. Having added or deleted poles and zeros or changed the values, the pole-zero diagram can be converted back to a block diagram or a state space representation.

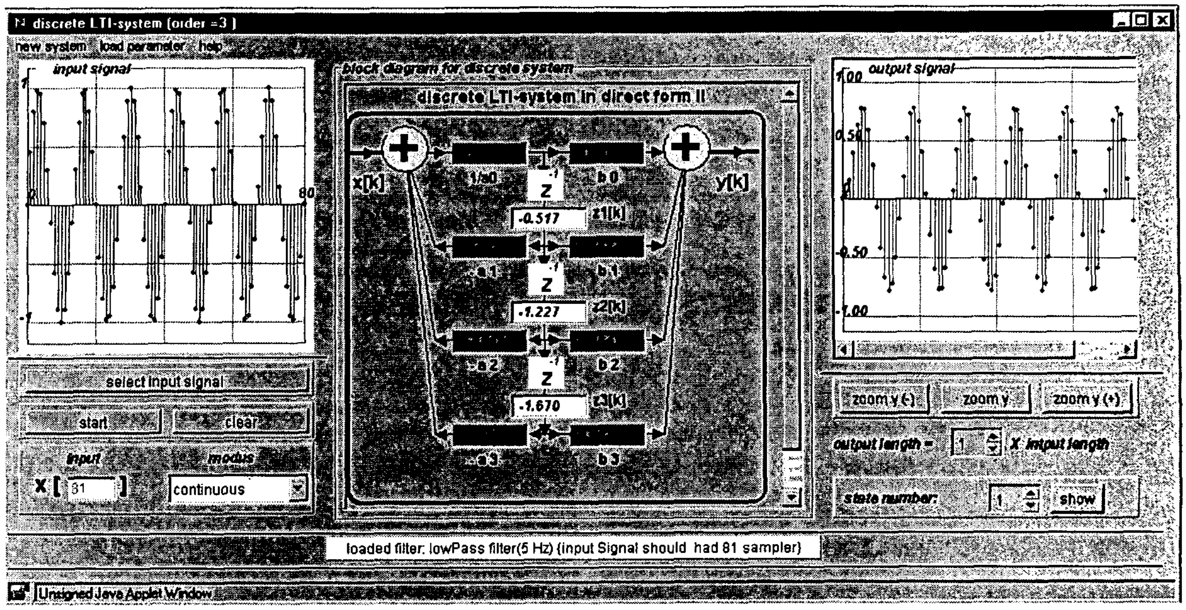

Fig. 1. Interactive block diagram with input and output signals.

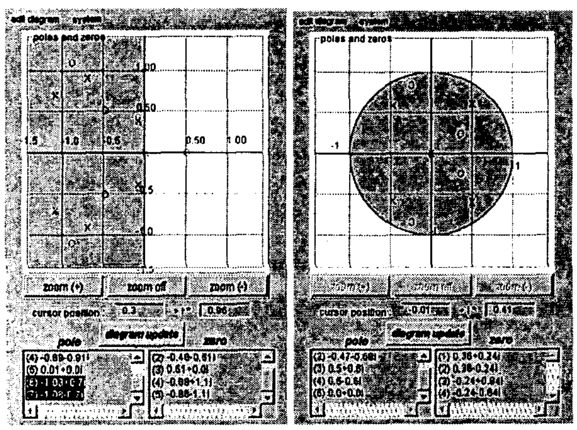

Fig. 2. Pole-zero diagrams for continuous and discrete systems.

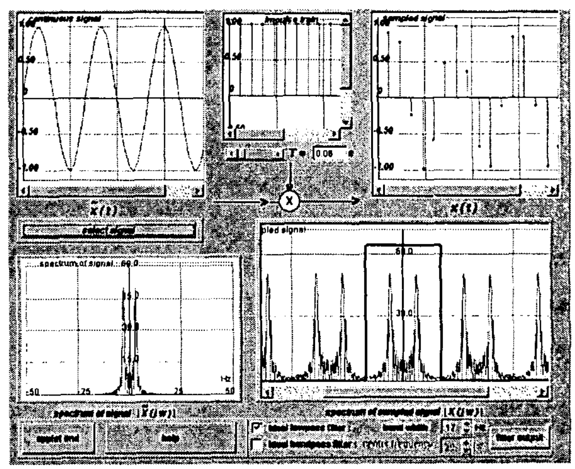

Fig. 3. Sampling of a continuous signal. Continuous signal (top left), pulse train (top center), discrete signal (top right), spectrum of the continuous signal (bottom left), periodic spectrum of the discrete signal (bottom right)

3.2.2. Sampling

Sampling and reconstruction of continuous signals is a key element of any signals and systems course. With no previous exposure to the subject, it seems natural that reconstruction works the better the higher the sampling rate is chosen. How can we convince students, that perfect reconstruction of bandlimited signals is possible at a moderate sampling rate? In addition to derivations of the theory and cleverly designed drawings, Fig. 3 shows an applet for the interactive visualisation of the effects of sampling in the time and frequency domain.

For the choice of the continuous signal (top left), similar functions as in Fig. 1 are available. After specifying the input signal, the sampling pulse train is determined (top center). The resulting discrete-time signal is shown on the right. The corresponding spectra are given at the bottom. By experimenting with various input signals and sampling frequencies, the students can explore ideal sampling and aliasing effects. Finally, ideal reconstruction filters (low pass and band pass) can be specified. By comparing the original signal and the reconstruction from its samples, the effect of aliasing can be assessed in the time domain.

3.2.3. Wiener Filter

The examples considered so far were based on deterministic signals. The module on Wiener filtering introduces the notion of stochastic signals. Its purpose is to complement the theoretical elements like ensemble and time averaging, autocorrelation functions and power density spectrum by intuitive examples. Rather than dealing with these elements of stochastic signals directly, the idea of signal and noise is presented by audio signals and their power density spectra.

Fig. 4 shows the corresponding setup. The input signal in the left can be picked from a menu of different audio signals. The wave form is shown in the window above. In a similar way, a noise signal can be chosen from a selection of low, high and band pass filtered noise. Also the noise gain can be adjusted by the user. The wave form of the original signal corrupted by noise is shown on the window on the right. By estimating the power density spectra of signal and noise, the frequency response and the output signal of the Wiener filter is computed.

There are two ways to assess the effect of the Wiener filter on the noisy signal: Inspecting the power density spectra of signal, noise, noisy signal, and reconstructed signal (the acadmic way) or listening to audio examples of the signal, the noisy signal and its reconstruction (the intuitive way).

An example for the inspection of the power density spectra is shown in Fig. 5. While the original signal is limited to a few frequency bands in the lower range, the contribution of the noise signal is found mainly in the high frequency region. This situation allows to separate signal and noise components by a suitable designed Wiener filter. By insepction of the power density spectra in Fig. 5 and listening to the corresponding audio signals, students can grasp the idea of optimal filtering.

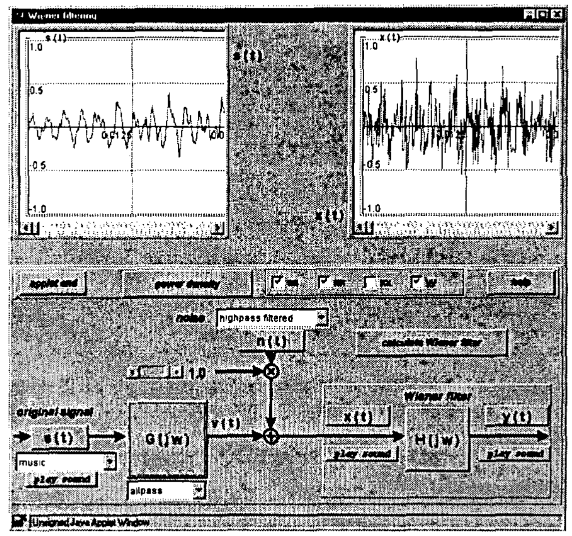

Fig. 4. Wiener Filter. Interactive block diagram and waveforms of original and noisy signal.

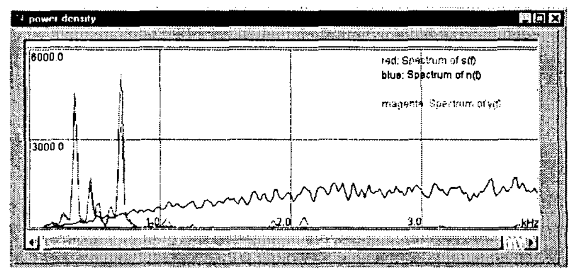

Fig. 5. Wiener Filter. Power density spectra for orignal signal, noise, and reconstructed signal.

4. STUDENT RESPONSE

The response of the students to SYSTOOL has been evaluated in two ways. At first, the student evaluation sheets of the classroom course on signals and systems contained also questions pertaining SYSTOOL. Secondly, SYSTOOL has been part of the online evaluation of all vhb courses.

The response of the classroom students was ambivalent. Since the use of SYSTOOL was not mandatory, some did not care about this innovative teaching tool at all. However, those who had tried it once, came back for more and reported increased insight into and even fun with signals and systems.

The response of the online evaluation to the use and benefit of SYSTOOL was equally positive. A point of criticism was the complicated regristration procedure imposed by the administration of the vhb.

5. REFERENCES

[1] G. Girod, R. Rabenstein, and A. Stenger, *Signals and Systems*, J. Wiley & Sons, Chichester, England, 2001.

[2] `http://www.vhb.org`, Virtuelle Hochschule Bayern (vhb, Virtual University of Bavaria).

[3] `http://www.LNT.de/~rabe`, Author's home page with link to SYSTOOL.