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Design of Signal and System Virtual Simulation Experiment System

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Abstract: A lot of relevant mathematical theories is involved in the course of signal and system, which are relatively strong in theory. It is abstract and boring to learn, so students are not very interested in learning it. Through the MATLAB development platform, this virtual simulation experiment system is developed by making full use of its GUI interface design, so that the abstract and boring theoretical knowledge becomes vivid and students have a certain perceptual understanding, thus stimulating students 'interest in learning, improving students' academic performance and teaching effect.

Keywords: Signal and system, virtual simulation, experiment System, GUI, MATLAB.

1. Introduction

Signal and System is a compulsory course for the major of Measurement and Control Technology and Instrument, and it can also be a compulsory or elective course for the majors of Electrical Engineering, Automation and Information. Through the study, students will master the basic theory and analysis and processing methods of signals and systems, and cultivate the ability of solving engineering practice problems with theoretical knowledge, which will lay a foundation for the following professional courses and graduation design. A lot of relevant mathematical theories is involved in the course, and the theory is so strong that learning is more abstract, boring, obscure and difficult to understand, and students' learning interest is not very high. A wide range of signal processing functions and user interface design capabilities is provided with MATLAB software and it is easier to use MATLAB for auxiliary teaching of signals and systems [1-8]. In order to stimulate students' interest and improve their learning effect, a virtual simulation experiment system for the important knowledge points of signals and systems is designed and developed on Matlab platform.

2. Overall System Design

The signal and processing virtual simulation experiment system is divided into two modules, namely, the continuous time signal and system simulation and the discrete time sequence and system simulation. Five main modules are included in the continuous time signal and system simulation part: the time domain properties of basic signals, convolution, Fourier transform of signals, Laplace transform and system frequency response, Fourier transform and communication system. And there are five modules in the discrete time series and system simulation part, namely, the convolution of discrete time signals, the Z-transform of basic functions, the basic properties of Z-transform, the frequency characteristics of discrete time systems, and the properties of discrete Fourier transform.

3. Detailed Design

Each simulation experiment in the Signals and Systems Virtual Simulation Lab is designed according to the following methodology: First, analysis and understanding of the relevant theory; second, development of the corresponding program code; and finally, design and debugging of the GUI interface. The detailed design for the Sampling Theorem and the Convolution of Discrete-Time Signals is elaborated as below.

3.1. Design and Debugging of the Sampling Theorem Simulation Experiment

(1) Theoretical Background

The Sampling Theorem is of fundamental importance in communication and information theory. A bandlimited signal $f(t)$ with a maximum frequency of ω_m can be uniquely represented by its sample values taken at uniformly spaced intervals T_s, where $T_s \le \frac{1}{2f_m}$. To recover the original signal $f(t)$ from its sampled version $f_s(t)$, the following two conditions must be satisfied:

The signal $f(t)$ must be bandlimited, whose spectral function is zero for $|\omega| > \omega_m$.

The sampling frequency shall not be too low; it must satisfy the condition $\omega_s \ge 2\omega_m$ (or equivalently, $f_s \ge 2f_m$, $T_s \le \frac{1}{2f_m}$). Otherwise, aliasing will occur.

The minimum allowable sampling frequency $f_s = 2f_m$ is generally called the Nyquist rate, and the maximum allowable sampling interval $T_s = \frac{1}{2f_m}$ is referred to as the Nyquist interval. According to the sampling theorem, a bandlimited signal whose spectrum is limited to $|\omega| < \omega_m$ is uniquely determined by its samples if the sampling rate is at least the Nyquist rate of $2f_m$ [9].

(2) Program

```
set(handles.Ts_slider,'visible','on');
set(handles.text2,'visible','on');
set(handles.text3,'visible','on');
set(handles.text4,'visible','on');
```

```
set(handles.start_pushbutton,'visible','off');
Ts=get(handles.Ts_slider,'Value');
n=-300:300;
t=-7:0.005:7;
w=-10:0.005:10;
N=round(20*Ts/(2*pi));
handles.N=N;
ft=12*cos(2*t)./(-4*t+pi)./(4*t+pi);
Fw=3*cos(1/4*pi*w).*(heaviside(w+2)-heaviside(w-2));
fst=12*cos(2*n*Ts)./(-4*n*Ts+pi)./(4*n*Ts+pi);
```

(3) GUI Design and Debugging

In the time-domain sampling theorem interface design, the sampling period, sampling frequency, and signal bandwidth are all user-configurable. With a fixed signal bandwidth, users can validate the sampling theorem by modifying the sampling frequency. The demonstration process is shown in Figure 1. By adjusting the "Sampling Period" control, the sampling frequency is altered, leading to three distinct outcomes:

1) When the sampling frequency f_s is greater than $2f_m$, the aliasing in the sampled signal's spectrum is absent.

2) At the Nyquist rate (i.e., when the sampling frequency is exactly twice the maximum signal frequency), the spectrum is on the verge of aliasing.

3) When the sampling frequency f_s is less than $2f_m$, the aliasing in the sampled signal's spectrum is clearly exhibited.

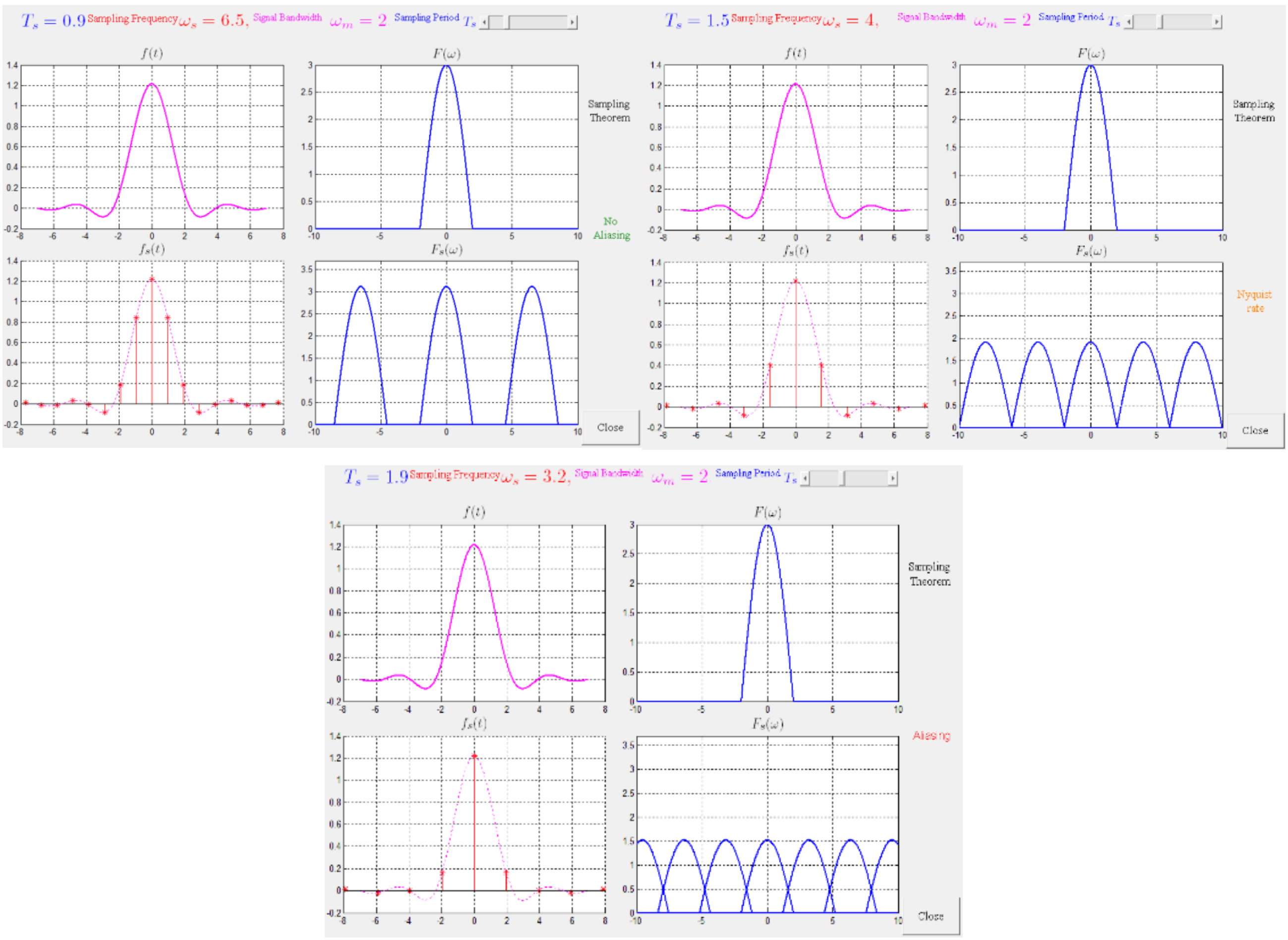

Figure 1. Sampling Theorem

3.2. Design and Implementation of a Discrete-Time Signal Convolution Simulation Experiment

(1) Theoretical Background

The graphical method is an effective technique for determining the convolution sum of simple sequences. To compute the convolution sum of $f_1(k)$ and $f_2(k)$ using the graphical method, the following five steps are involved in the procedure:

1) Variable Substitution: Substitute the independent variables of $f_1(k)$, $f_2(k)$ with i, transforming them into $f_1(i)$, $f_2(i)$.

2) Folding: Reverse the sequence $f_2(i)$ to obtain $f_2(-i)$.

3) Shifting: Shift the sequence $f_2(i)$ along the positive i-axis by k units to obtain $f_2(k-i)$.

4) Multiplication: Multiply the sequences point-by-point to obtain the product $f_1(k)f_2(k-i)$.

5) Summation: For a given value of k, sum the product $f_1(k)f_2(k-i)$ over all i.

By using the graphical method, students can understand the process of solving the convolution sum and deepen their understanding of this part of the knowledge.

(2) Program Module

```
handles.b=-handles.Nh+1:0;
c=4;
handles.b=handles.b+c;
axes(handles.axes3);
stem(handles.b,handles.h,'r');
```

```
hold on
stem(handles.n,handles.x)
grid on
hold off
axis([-10 30 0 1.2])
axes(handles.axes4);
for i=0:4;
    stem(i,handles.y(i+1));
    hold on
end
axis([-10 30 0 8]);
grid on
hold off
```

(3) GUI Design and Debugging

For the discrete-time convolution sum interface, the following two sequences were chosen: a power function sequence and a rectangular pulse sequence. The operational steps are: (1) Folding, (2-5) Shifting, and (6) Display of the convolution result. This process is demonstrated in Figure 2.

Through the convolution sum simulation experiment, students gained a more intuitive understanding of the computational process, developed a clearer grasp of the concept, and showed increased interest in learning.

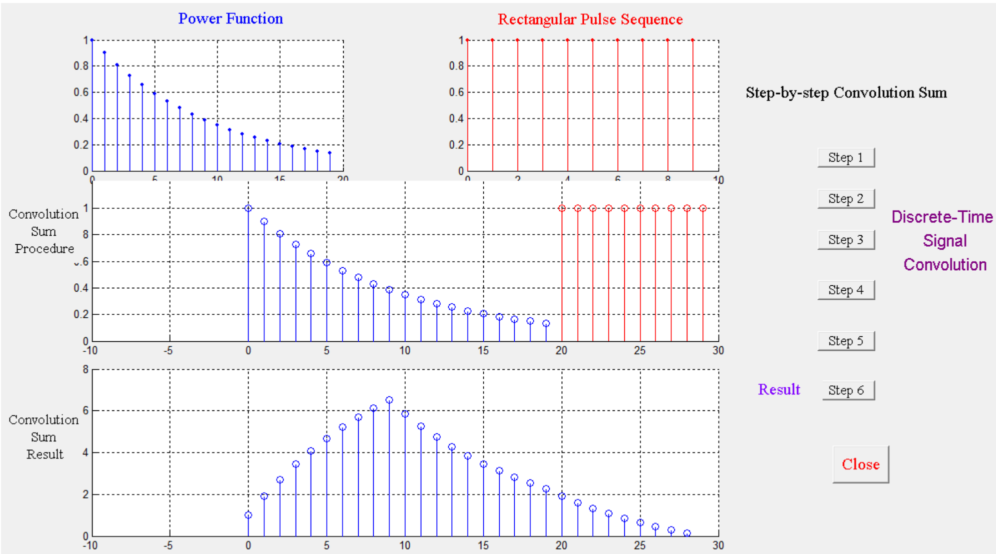

Figure 2. Interface for Discrete-Time Signal Convolution Simulation

4. Conclusion

By the development of this Signals and Systems virtual simulation laboratory, abstract and dry theoretical knowledge is transformed into vivid and interactive content, which provides students with an intuitive understanding, thereby continuously stimulating their interest and enthusiasm for learning, and fostering a comprehensive grasp of the relevant subject matter. The implementation of this virtual simulation system has yielded excellent results, with students showing a measurable improvement in their learning effectiveness and a significant boost in their academic scores.

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