Computer-aided instruction of mechanical engineering test technology and signal processing based on the use of MATLAB

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ABSTRACT: This article highlights several of the problems in teaching and studying based on many years' experience of teaching and practice, with a focus on a mechanical engineering test technology and signal processing course. MATLAB engineering software was introduced into the course, and it enabled the content of error theory and data processing to be strengthened while retaining the course's traditional contents. Four typical instruction examples are given and analysed in this article. The analysis and results show that the examples are fit for class teaching and extracurricular practice study.

INTRODUCTION

Mechanical Engineering Test Technology and Signal Processing is one of the key specialized courses among the specialisations within the mechanical engineering discipline, which include vehicle engineering, mechatronics engineering, and mechanical design, manufacture and automation. This course plays an important role in the formation of students' knowledge structure and the cultivation of their ability.

The architecture and knowledge content of the course are rather fixed in universities in many countries [1-6], and the overall composition of a test system is shown in Figure 1 [7][8]. The test system includes several key components: transducers (always including a sensor and other circuits), signal conditioning, signal processing, and so on. The course mainly focuses on the key components and the test system itself.
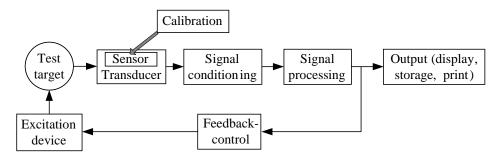

Figure 1: Overall components of a general test system.

Overall, the course can be divided into three parts: fundamental theory and knowledge, typical applications and modern test technology. The fundamental theory and knowledge part almost appears in every test technology textbook. The largest differences between textbooks concern the second and the third parts. Even so, the measurement of vibration and of stress, strain and torque are necessary content across all textbooks.

PROBLEMS IN TEACHING AND STUDYING

As teachers of the course, the authors regularly hear from students that the course is more tedious and difficult than interesting and easy, and from other teachers that there is overall dissatisfaction with the teaching. After years of teaching and practice, several problems have been identified, including:

1. The test technology course is multidisciplinary, covering topics such as electricity, complex functions and probability statistics. Any deficiencies in knowledge may make students lose faith in themselves. For example, in sections about sensors, signal conditions and conversions, and typical applications, there are some circuits and electronic chips. The students have a keen interest in these electro-mechanic applications, but they are always disappointed by the difficulties they encounter.
2. There are too many complex and tedious formulas, such as frequency spectrum analysis for periodic and arbitrary signals in the signal processing section, response characteristics of second-order systems and transfer functions in the section on measurement system behaviour.
3. The limited class time reduces the time available for practical classes. In many universities, only four or eight hours out of 32 or 40 hours for the overall course are devoted to experiments. Moreover, deficiencies in the equipment provided make teaching and studying more difficult for the teacher and students.
4. Even with multimedia teaching software, the amount of knowledge, complex graphs and curves make demonstration in classes difficult.
5. Students of some specialties in the mechanical engineering discipline would prefer more knowledge of basic measurement, such as error theory and data processing methods.

Given the problems outlined above, the content of error theory and data processing was introduced to the course, while retaining the traditional content and using MATLAB to the fullest extent possible.

INSTRUCTION EXAMPLES AND ANALYSIS

Static Measurement Data Outlier Detection

The measurement series data are 28.53, 28.52, 28.50, 29.52, 28.53, 28.53, 28.50, 28.49, 28.49, 28.51, 28.53, 28.52, 28.49, 28.40, and 28.50. Detect the outliers using the three-sigma rule, and compute the mean value and standard deviation.

Solution: The mean value $\overline{x}$ and standard deviation s can be computed from the n measurement data $x_1, x_2, x_3, \cdots x_n$. To three-sigma rule, if $|x_i - \overline{x}| > 3s$ $(i = 1, 2, 3, \cdots, n)$, then, x_i is an outlier, and should be removed. If an outlier is removed from the data, the detection procedure should be done again using the remaining data to find another outliers. So the MATLAB code is as follows.

```
x=[28.53, 28.52, 28.50, 29.52, 28.53, 28.53, 28.50, 28.49, 28.49, 28.51, 28.53, 28.52, 28.49, 28.40, 28.50];
disp('********Computing results*************')
while(1)
   meanx=nanmean(x);
   vx=x-meanx;
   stdx=nanstd(x);
   [maxvx,Index]=nanmax(abs(vx));
   if maxvx>3*stdx
      disp(['No.', num2str(Index), ' data ', num2str(x(Index)), ' is an outlier.'])
      x(Index)=NaN;
   else
      break;
   end
end
disp(['After the outliers are removed,'])
disp(['the mean value is ', num2str(meanx),','])
disp(['and the standard deviation', num2str(stdx), '.'])
disp('***********************************')
```

The running results are as follows.
********Computing results*************
No.4 data 29.52 is an outlier.
No.14 data 28.4 is an outlier.
After the outliers are removed,
the mean value is 28.5108,
and the standard deviation0.016564.
****

Spectrum Analysis of Periodic Signal

A periodic function $x(t)$ with the angular frequency ω_0 can be represented by a trigonometric series, such that for any t:

$$x(t) = A_0 + \sum_{n=1}^{\infty} \left(A_n \cos n\omega_0 t + B_n \sin n\omega_0 t \right) \qquad (1)$$

and also be represented as:

$$x(t) = A_0 + \sum_{n=-\infty}^{n=\infty} C_n e^{jn\omega_0 t} \qquad (2)$$

The coefficients A_0, A_n, B_n and C_n can be determined with $x(t)$ known.

The Fourier coefficients can be computed easily in MATLAB using symbolic functions, such as integration function *int* and symbolic substitution function *subs*. The MATLAB code for spectrum analysis of the periodic square pulse signal is as follows, and running results are shown in Figure 2.

```
syms t n T tao A
T=4;A=1;tao=1;
f=A*exp(-j*n*2*pi/T*t);
fn=int(f,t,-tao/2,tao/2)/T          % Compute Fourier coefficients formulas
fn=simple(fn)                       % Simplify
n=[-20:-1,eps,1:20]
fn=subs(fn,'n',n)                   % Compute Fourier coefficients value
stem(n,fn,'filled')                 % Draw amplitude spectrum
line([-20 20],[0 0])                % Draw coordinate lines
title('Amplitude spectrum of periodic square pulse')
t=-4:0.1:4;
xt=zeros(1,length(t))
for k=n
     xt=xt+fn(k+21)*exp(j*k*2*pi/T*t);
end
figure
    plot(t,xt)
```
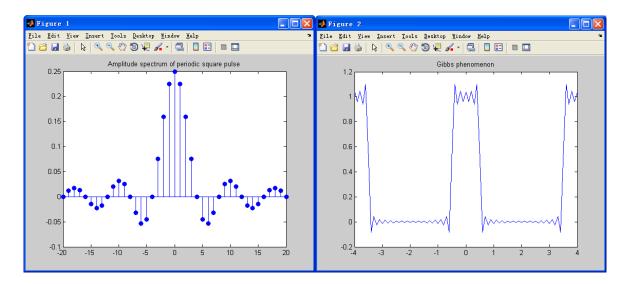

Figure 2: Spectrum analysis of periodic square pulse signal.

Decomposition of Periodic Signal Using Filter

The simulation model was built in MATLAB/Simulink, as shown in Figure 3a. The Pulse Generator block was used to generate the periodic signal, so the block parameters are set as follows: Amplitude: 1, Period (seconds): 4, Pulse width (% of period): 25, and Phase delay (seconds): -0.5. The analog filter design block designs and implements a Butterworth, Chebyshev type I, Chebyshev type II, or elliptic filter in a highpass, lowpass, bandpass or bandstop configuration.

The simulation model uses 6 Butterworth filters. One is a low pass filter; the other five are bandpass filters. Filter order of all six filters has been set at 20. The pass edge frequency (rad/s) of the low pass filter is set as 2*pi*0.022; the lower and upper passband edges frequency (rad/s) of the bandpass filters responding to the fundamental, second, third, fifth, sixth harmonic are set as (2*pi*0.023, 2*pi*0.27), (2*pi*0.48, 2*pi*0.52), (2*pi*0.73, 2*pi*0.77), (2*pi*1.23, 2*pi*1.27) and (2*pi*1.48, 2*pi*1.52). The simulation result is shown in Figure 3b.
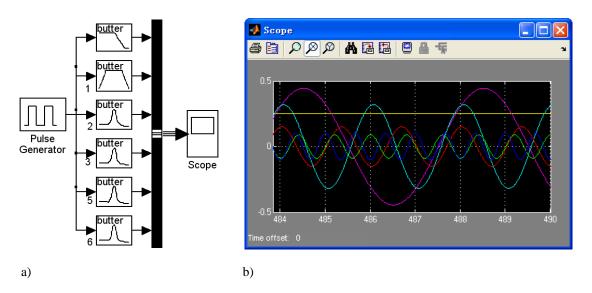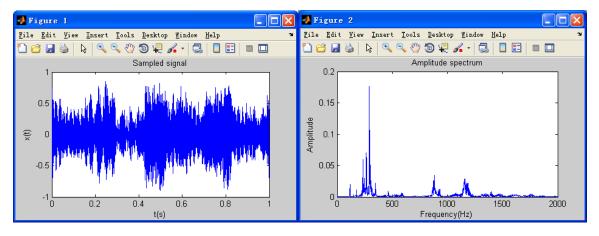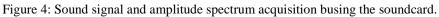
Figure 3: Decomposition of the periodic signal using the filter: a) simulation model; and b) simulation results.

Acquisition and Analysis of a Sound Signal Using Soundcard

The method for acquisition of a signal in MATLAB based on the sound card has been amply discussed in the literature [9][10]. The only hardware required is a computer and a microphone. The procedure is simple, so it is an excellent example for the teacher and student to use in class and in extracurricular practice. The code is shown as follows and the result is shown in Figure 4.

```
ai = analoginput('winsound');  addchannel(ai, 1);
T=1;fs=44100;N=T*fs;   set(ai,'sampleRate',fs);
set(ai,'SamplesPerTrigger',T*fs);   start(ai); data=getdata(ai);
t=(0:N-1)*1/fs;
plot(t,data);  xlabel('t(s)');      ylabel('x(t)'); title('Sampled signal')
stop(ai);  delete(ai);
fn=fft(data); fn=fn/N;f=0:min(N/2,2000);
figure
plot(f,abs(fn(1:min(N/2,2000)+1))*2)
xlabel('Frequency(Hz)'); ylabel('Amplitude')
title('Amplitude spectrum')
```


Figure 4: Sound signal and amplitude spectrum acquisition busing the soundcard.

CONCLUSIONS

The Mechanical Engineering Test Technology and Signal Processing course has many complex and tedious formulas, requires multidisciplinary knowledge, and there is limited class time. It would, therefore, appear that multimedia technology and engineering software could be used to improve the impact of teaching. In this article, five important problems were presented, based on years of teaching and practice. To solve these problems, MATLAB was fully introduced into the course, and the content of error theory and data processing were strengthened. Four typical instruction examples were given and analysed. These examples are appropriate for class teaching and extracurricular practice studying.

The problems and examples discussed here have several advantages. First, the teachers can prepare lessons, demonstrate course knowledge with great facility and make classroom activities more informative. Second, the students can make full use of teaching resources for extracurricular exercises in topics, such as programme code, simulation models and experimental systems. Third, the students are exposed to engineering software applications, which cultivates students' consciousness and ability to solve practical problems using the computer. If some creative, inventive and on-limits design projects or experiments are developed and introduced into teaching activities, the students' creativity can be enhanced. This will be examined in future work.

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