



# AUTOMATIC CONTROL THEORY VIRTUAL EXPERIMENT SYSTEM BASED ON MATLAB GUI

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## ABSTRACT

Virtual laboratory based on MATLAB GUI to complement the teaching of the course, to help teachers explain the curriculum theory better, and enhance students' understanding of the course. In this paper, listed common experiment in "Automatic Control Theory", and given the GUI panel design and program design. Given the corresponding parameter can get curves and data in applications, to further analyze the influence of different parameters on the system. The method has a friendly interface, easy operation, precise and intuitive image data, make up for deficiencies in the traditional teaching, help to improve the quality of teaching and student understanding of "Automatic Control Theory" course.

**Keywords:** *MATLAB, GUI, Automatic Control Theory, Virtual Experiment*

## 1. INTRODUCTION

"Automatic Control Theory", many colleges and universities Electric Automation class view it as a professional basic course, occupies a very important position in teaching. The course of the basic concepts of the theory of control theory, basic analysis methods and practical applications. Due to the abstraction of the concept of curriculum theory, involving cumbersome mathematical theory and derivation of the teaching process, teachers need to draw a lot of curves on the blackboard, when analyzing large number of factors, it is always difficult to separate them with a limited number of color and guarantee the accuracy of the curve, thereby it affects the students' ability of understanding and receptivity and enable students to be difficult to grasp the basic issues, ideas and methods. Therefore, the use of computers and software to achieve in the process of teaching drawing and image analysis could improve the teaching quality of teachers, and then students also could have a intuitive understanding of curriculum theory, therefore makes teaching reform come true.

MATLAB is launched by Mathworks Inc, USA in the mid-1980s, which is high-performance numerical software and is mainly used for algorithm development, scientific computing, and interactive program design. The graphical user interface (GUI) is the element which is created in a graphical interface and enable customers use some methods (such as a mouse or keyboard) to achieve a

specific function and can return results data show in the corresponding display area of the program interface. GUI is composed of windows, menus, buttons, and text description. It can not only embed in existing simulation program, but also be able to present the result of simulation to the customer through a dynamic way of human-computer interaction, which gives customers a deep impression, at the same time the simulation code is not visible, make it possible for the people who are not familiar with MATLAB to operate it.

Virtual Test Bench is an experimental platform designed on the base of MATLAB GUI; it achieves the desired effect by GUI design panel and calling the MATLAB program for simulation<sup>[1]</sup>. This will greatly save the drawing analysis teach time, improve teaching quality of teachers, enable students to be more intuitive and easy to understand about the basic concepts of the control system, the basic theory and analysis methods, and will also save a lot of experimental equipment and funds, to avoid the problems for lacking of equipment.

Section 2 presents the overall design of the system. In section 3, we introduced the correction theory. In section 4, introduced detailed design steps of the correction system. Section 5 gives a conclusion to the whole paper.

## 2. PROGRAM OVERALL DESIGN

The main of the design is the use of MATLAB GUI function to realize Virtual Experiment

platform which are common in "Automatic Control Theory" course. It mainly includes the following eight experiments:

Experiment 1: Virtual Experiment platform for time domain typical form of a first order system based on the MATLAB GUI.

Experiment 2: Virtual Experiment platform for time domain transient response of a second-order system based on the MATLAB GUI.

Experiment 3: Virtual Experiment platform for linear system in time domain stability analysis based on the MATLAB GUI.

Experiment 4: Virtual Experiment platform for linear system of the root locus analysis based on the MATLAB GUI.

Experiment 5: Virtual Experiment platform for linear system of the frequency domain analysis based on the MATLAB GUI.

Experiment 6: Virtual Experiment platform for system correction based on the MATLAB GUI.

Experiment 7: Virtual Experiment platform for discrete system analysis based on the MATLAB GUI.

Experiment 8: Virtual Experiment platform for nonlinear system analysis based on the MATLAB GUI.

Control Theory" course. You can choose according to need, enter the sub experiment system. The flow chart of the program overall design is shown in figure 1.

You can enter the system interface, in which users can conveniently choose to the running system what they want, and can return to the interface after the experiment in order to carry next experiment. The interface is shown in figure 2.

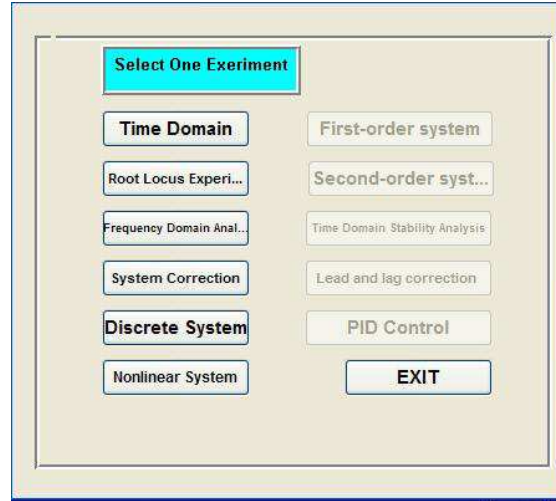


Figure 2: The Main Interface

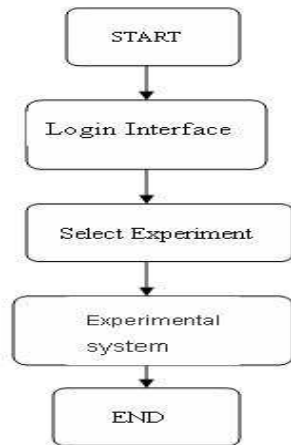


Figure 1: The Flow Chart

It adds the system login interface and system experiment selection interface in order to manage the data effectively, because of the large number of procedures involved. After correct landing, into the system experiment selection interface, which contains all of common experiments in "Automatic

The system includes multiple experiments, the designed process of correction system virtual test bench to illustrate the designed process of systems experiment is listed below.

### 3. DESIGN PRINCIPLE OF VIRTUAL BENCH OF CORRECTION SYSTEM<sup>[2,3]</sup>

#### 3.1 Series Leading Correction of The frequencies Law

The basic principle of using the lead network or PD controller series corrected is using the advance characteristics of the phase angle of a lead network or PD controller. By choosing the lead network as long as the cut-off frequency of both sides of the system to be corrected and selecting the appropriate parameters  $\alpha$  and T, then you can make revised cutoff frequency and phase margin meet the desired performance requirements and thereby improve the dynamic performance of the closed-loop system. The stability of closed-loop system performance requirements are ensued by selecting corrected open loop gain of the system. Stepping ahead correction network design frequency methods are as follows:

- (1) According to the requirements of the steady-state error, determine the open-loop gain K.



(2) According to determined the open loop gain K, plot the frequency characteristic curve ( $L_0(\omega)$ ,  $\varphi_0(\omega)$ ) of the number of pairs of the original system and calculate its stability margin  $\gamma_0$ ,  $L_{g_0}$ .

(3) Determine the correction value of the cutoff frequency  $\omega_c'$  and network of the system  $\alpha$  after corrected.

①IF it gives prior request for the cutoff frequency  $\omega_c'$  of the corrected system, and then we can choose  $\omega_c'$  according to the value of requirement. Then search the value of  $L_0(\omega_0')$  of original system in BODE diagram, make the sum of logarithmic amplitude and frequency values of former network  $L_c(\omega_m) = 10 \lg \frac{1}{\alpha}$  and  $L_0(\omega_0')$  be zero, so it's  $L_0(\omega_0') + 10 \lg \frac{1}{\alpha} = 0$ , then we could get the value of  $\alpha$  of former network.

②IF it does not give prior request for the cutoff frequency  $\omega_c'$  of the corrected system, you can obtain the maximum lead angle  $\varphi_m$  of former network through the following empirical formula from the given phase margin requirements  $\gamma$ :  $\varphi_m = \gamma - \gamma_0 + \Delta$  ( $\Delta = 5^\circ \sim 10^\circ$ ). In the formula  $\varphi_m$  is the network's biggest lead angle;  $\gamma$  is the phase margin which the corrected system required;  $\gamma_0$  is phase margin of uncorrected system;  $\Delta$  is the amount of compensation of result of the phase margin of introduced the cutoff frequency; The value of  $\Delta$  s based on the size as the original system in the vicinity of the phase frequency characteristic shape, in general  $\Delta = 5^\circ \sim 10^\circ$  could satisfy the requirement.

After obtained the value of  $\varphi_m$  of network lead angle of former network, then we can obtain the value of  $\alpha$  according to following formula; then on a characteristic curve of the uncorrected system detects that its amplitude is equal to the frequency corresponding and so is the corrected cutoff frequency. And  $\omega_m = \omega_c'$ .

$$\alpha = \frac{1 - \sin \varphi_m}{1 + \sin \varphi_m}$$

(4) Determining correcting the transfer function of a network.

According to the value of  $\omega_m$  and  $\alpha$ , we can determine the time constant for

$$T = \frac{1}{\omega_m \sqrt{\alpha}}$$

You can write the transfer function of the correction network for  $G_c(s) = \frac{Ts + 1}{\alpha Ts + 1}$ .

(5) The draw correction system after logarithmic frequency characteristic curve.

(6) The checksum corrected after the system meets the requirements of a given indicator.

(7) Determining the values of the various electrical components of the network depending on the value of the lead network parameters a and b.

### 3.2 Serial Lag Correction

The fundamentals of the reason why make use of lag network or PI controller to conduct series correction is their high frequency attenuation characteristics.

It will obtain the phase margin which meet requirements, by using the characteristics to reduce the cutoff frequency of the corrected system.

Therefore, the maximum lag angle of lag network should be not chosen at the place which is near the System cut-off frequency.

Generally, it considers using Series lag correction, when a system prefers to high suppression noise level performance rather than high response speed.

It can design a lag network with frequency method as follows:

Determine the open loop gain K, base on the steady-state error requirement.

Draw the original system's logarithmic frequency characteristic curve  $L_0(\omega)$ ,  $\varphi_0(\omega)$  and compute its stability margin  $\gamma_0$ ,  $L_{g_0}$ , base on the determined open loop gain K.

Determine the correction system of cut-off frequency  $\omega_c'$ .

It can choose the  $\omega_c'$  according to the required value, if it makes request to correction system of cut-off frequency  $\omega_c'$  in advance.

It can use the following empirical formula to find a new phase margin  $\gamma(\omega')$  which based on the requirement of the given phase margin, if it does not make request to correction system of cut-off frequency  $\omega_c'$  in advance.

$$\gamma(\omega_c') = \gamma + \Delta \quad (\Delta = 5^\circ \sim 15^\circ) \quad (1)$$

In (5),  $\gamma(\omega_c')$  is the phase margin at the new cut-off frequency  $\omega_c'$  of the original system. It is not only considering the given requirements and considering the lag network side effects and proposed a new phase margin.  $\gamma$  is required phase margin,  $\Delta$  is phase Angle added for compensating lag correction device side effects .it usually take  $5^\circ \sim 15^\circ$ .

According to the  $\gamma(\omega')$ , find the corresponding frequency of  $\gamma(\omega')$  in the original system phase frequency characteristic curve. And the above frequency is new cut-off frequency of the correction system.

Find  $\beta$  in lag network. Find the log magnitude-frequency  $L_0(\omega_c')$  at  $\omega_c'$  of original system, and get the value of  $\beta$  with the following formula.

$$L(\omega_c') - 20 \lg \beta = 0 \quad (2)$$

Determine the transfer function of corrective network. Choosing the second corner frequency of corrective network as

$$\omega_2 = \frac{1}{T} \approx \left(\frac{1}{10} \sim \frac{1}{5}\right)\omega_c' \quad (3)$$

From this, it can figure out T and  $\beta T$ , and get the network's transfer function as

$$G_c(s) = \frac{Ts + 1}{\beta Ts + 1} \quad (4)$$

Draw the log frequency characteristic curve of the correction system.

To verify whether the corrected system could meet the given index. If it meets the requirement, it can shift  $\omega_c'$  further left and then recalculate until fully satisfied the given index.

Determine the element numerical of the electrical network, according to the  $\beta$  and T of lag network.

### 3.3 PID Correction

PID regulator, also known as PID control, proportional, integral, differential regulation referred to. PID regulator, also known as PID control, proportional, integral, differential regulation referred to. The PID correction is a negative feedback loop control. The PID corrector usually connected in series with the controlled object, set prior to the passage in the negative feedback loop control.

Respectively under the action of the PID regulator, the proportional, integral, differential operation of the error signal e (t), and then summing the three components, use it as a control signal to the controlled object.

PID regulator of differential equations for

$$u(t) = K_p \left[ e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt} \right]$$

In the function, u (t) is the output signal of the PID regulator, the signals are sent to the controlled object; system error signal is defined as: e (t) = r (t) - c (t), r (t) is given, (t) is the system of the amount charged input signal;

PID regulator transfer function model is :

$$G_c(s) = K_p \left( 1 + \frac{1}{T_i s} + T_d s \right) \quad (5)$$

## 4. CORRECTION SYSTEM VIRTUAL TEST BENCH

### 4.1 Features

The system for the automatic control principle, system calibration of virtual test bench. Divided into three subsystems, respectively as series lead correction system, series lag correction system and PID correction system. Given system parameters will generate a logarithmic frequency characteristic curve and a unit step response curve, and returns the corresponding system parameters to check the calibration results.

4.2 Interface Design<sup>[4]</sup>

Start MATLAB, into the GUI interface, and establish a panel and main control, which are shown in figure 3, figure 4 and figure 5.

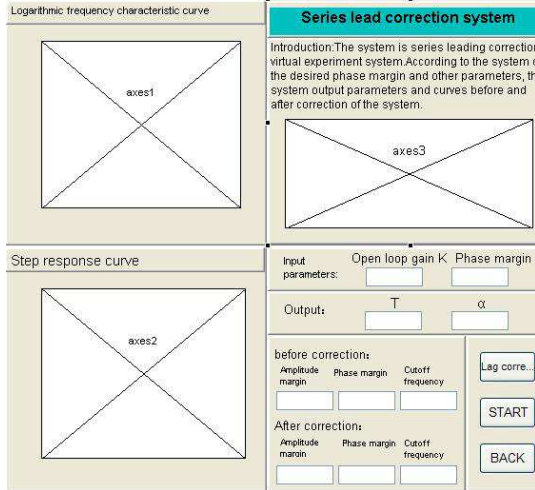


Figure3: Series Lead Correction System Panel

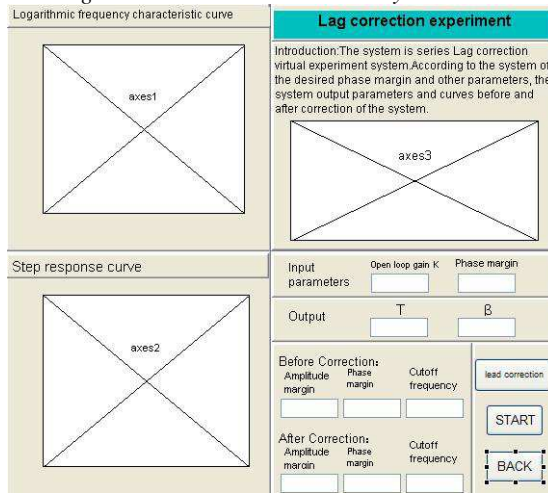


Figure4: Series Lag Correction System Panel

After the system parameters set, click on the "start" button and an image produced. The Callback function of the series lead correction system's "start" button is as follows:

```
K=str2double(get(handles.edit1,'String'));
gama=str2double(get(handles.edit2,'String'));
den=[1 1 0];
sys0=tf(K,den);
axes(handles.axes1);
bode(sys0)
grid on
[gm1,pm1,wg1,wp1]=margin(sys0); %For before
correction parameters
set(handles.edit5,'String',20*log10(gm1));
set(handles.edit6,'String',pm1);
set(handles.edit7,'String',wp1);
ph=gama-pm1+10;
phim=36*pi/180;
```

```
a=(1-sin(phim))/(1+sin(phim));
set(handles.edit4,'String',a);
[mag,phase,w]=bode(sys0); %Calculation cut-off
frequency
[mu,pu]=bode(sys0,w);
adb=20*log10(mu);
am=10*log10(a);
wc=spline(adb,w,am);
T=1/sqrt(a)/wc; %calculate T
set(handles.edit3,'String',T);
nc=[T 1];
dc=[a*T 1];
```

```
sysc=tf(nc,dc);
sys=sys0*sysc; %Calculate correction system
hold on
```

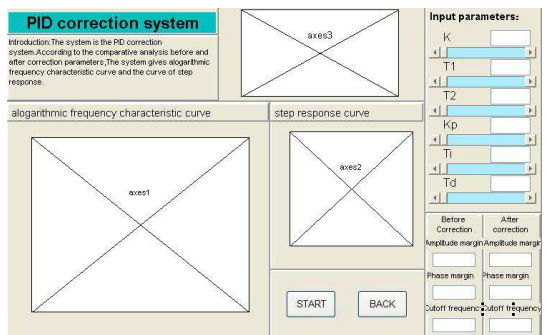


Figure 5: PID Correction System Panel

```
bode(sys)
[gm,pm,wg,wp]=margin(sys); %After adjustment
for parameters
set(handles.edit8,'String',20*log10(gm));
set(handles.edit9,'String',pm);
set(handles.edit10,'String',wp);
sys1=feedback(sys0,1);
sys2=feedback(sys,1);
axes(handles.axes2);
```

step(sys1)

grid on

hold on

step(sys2)<sup>[5,6]</sup>

Input the parameters according to the experimental requirements and run the system, we can easily get various curves as well as indicators parameters which are very convenient for us.

5. CONCLUSION WORDS

We design the principle of automatic control of the virtual test bench; solve the difficulties in class and experimental teaching. And all of these are based on the MATLAB GUI platform. This experiment system based on MATLAB language and GUI interface, with friendly interface, friendly interface, easy to operate and flexible, it is appropriate to grasp, and has good scalability, convenience of experimental simulation. It will provide students with a more intuitive understanding of the analysis of automatic control theory approach, more in-depth grasp of the course content, once used for the experimental teaching<sup>[7]</sup>.

REFERENCES:

- [1] Fan Shoukang, LabVIEW/MATLAB Mixed Programming Technology, Machinery Industry Press, 2012
- [2] Li Suling, Automatic Control Theory (Third Edition) Machinery Industry Press, 2012
- [3] Xiong Xiaojun. Automatic control principle experiment tutorial[M]. Machinery Industry Press.2009
- [4] Luo Huafei, Study Of MATLAB GUI (2nd Edition), Beijing: Beijing University of Aeronautics and Astronautics Press. 2011
- [5] Wang Zhenglin, MATLAB / Simulink and Control System Simulation (2nd Edition) Electronic Industry Press, 2008
- [6] Zhao Jianfeng, Wu Jiping, virtual experiment system of Automatic Control Theory based on LabVIEW, Journal of Electrical and Electronics 2007 (1) :85-87
- [7] Gao Xingquan, Wang Binggang, He Feng, development of a virtual experiment system of Automatic Control Theory based on LabVIEW , Journal of Jilin Institute of Chemical Technology 2009 (4) :63-66

4.3 The Operation Results Of System Simulation

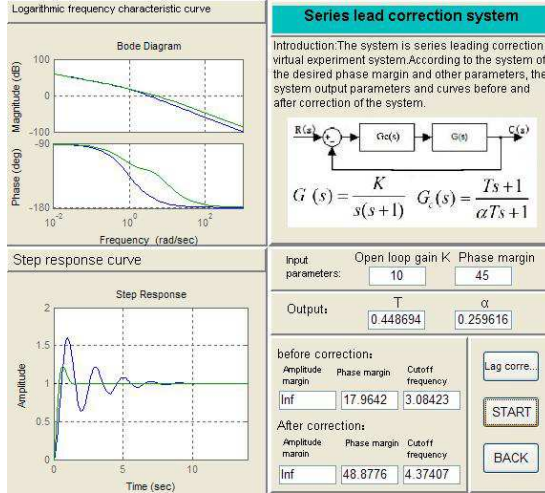


Figure 6: Results of Series Lead Correction

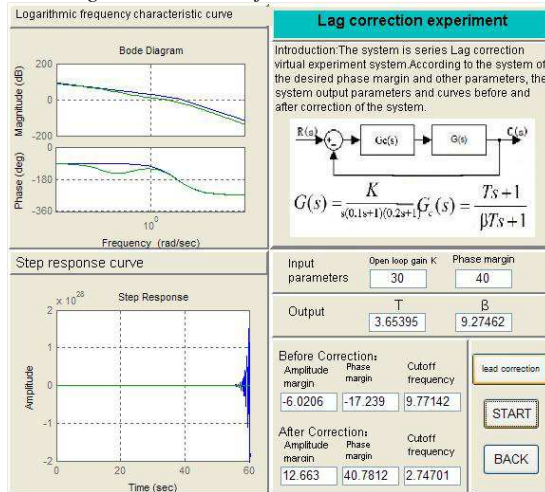


Figure 7: Results Of Series Lag Correction

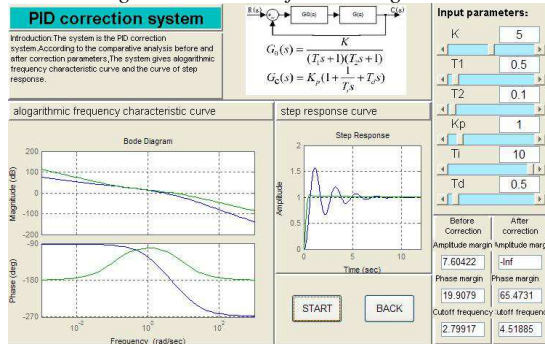


Figure 8: Results Of PID Correction