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The Open Cybernetics & Systemics Journal, 2015, *9*, 329-334 329

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Virtual Digital Control Experimental System

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Abstract: Digital control experiments are important parts of electrical engineering course in modern electrical schools. A virtual digital control experimental system is developed for undergraduates to learn digital control principals and to practice online. Based on the digital control hardware experiment platform, the practical circuit model is developed. And some digital control algorithms are employed for virtual digital control operations, these algorithms include PID and some varies algorithms, Smith predictor algorithm, Dahlin algorithm and Kalman algorithm. The development of the Kalman filtering algorithm in the virtual experimental system is detailed. The experimental parameters of the plant and the controller can be flexible configured by the users in the terminal online, and the control results can be quickly displayed online. The virtual digital control experimental system is efficient for undergraduates to pre-practice the digital control experiments and to learn the control principals.

Keywords: Digital control, kalman filtering, virtual experiment.

1. INTRODUCTION

Digital control experiments are important parts of electrical engineering course in modern electrical schools. Undergraduates in colleges and universities need more practical experiments to improve their ability for analysis practical engineering problems to give the solutions. Meanwhile the personalized education is emphasized to improve the learning efficient. The traditional experimental system is hard to do more for this. Digital control course is a practical engineering course with very strong engineering background, and the experimental training is an important link between knowledge learning and practical applications [1]. With the development of computer application technology, including the web technology, software technology and mobile communication technology, the virtual experimental system can be developed for undergraduates to pre-practice experimental system and to learn principals. This is very important for breaking the breakthrough and limitation of the traditional hardware experimental resources, such as computers and experimental hardware box. A virtual experimental system for digital control is developed in Harbin Institute of Technology at Weihai. The mixed programming of advanced programming language, including MATLAB and VB, is used to develop the experiment platform and simulate the circuit hardwire. Based on the digital control hardware experiment platform, the practical circuit model is developed. And some digital control algorithms are employed for virtual digital control operations, these algorithms include PID and some varies algorithms, Smith predictor algorithm, Dahlin algorithm and Kalman algorithm. The experimental parameters of the plant and the controller can be flexible configured by the users in the terminal online, and the control results can be quickly displayed online.

2. EXPERIMENTAL SYSTEM DESIGN OF HARDWARE

The digital control experiments often use the traditional hardware circuit for plant simulation and PC for controller design and results display [2]. The hardware and the experimental device often produce some errors. To improve the measurement accuracy, Kalman filtering algorithm is employed in our system. As an optimal regression data processing algorithm to solve the problem of dynamic error of the system with optimal performance, Kalman filter is known as the optimal recursive data processing algorithm [3]. In recent years, Kalman filtering algorithm is widely used in signal processing applications, and it is employed in our experimental system.

Digital control experimental system constructs hardware devices with computer, PC bus driver card, data channel interface board, computer control experiment platform and the op-amp circuit board. Computer is used to measure signal and control signal input and output. Computer also provides man machine interface, especially the essential output results, such as the experimental waveforms. The plant platform is equipped with the op-amp circuit, resistance and capacity element to simulate a variety of characteristics of controlled plant. Kalman filtering algorithm is coded after circuit board embedded hardware platform. The digital signal and analog signal is conversed by an interface board that is inserted in bus expansion slot of experiment platform to provide minimization design and flexible configuration for the basic, comprehensive and innovative experiments. To reduce the hardware link errors, Kalman filtering algorithm is employed to improve measurement accuracy. The overall architecture of the digital control experimental system is illustrated in Fig. (**1**).

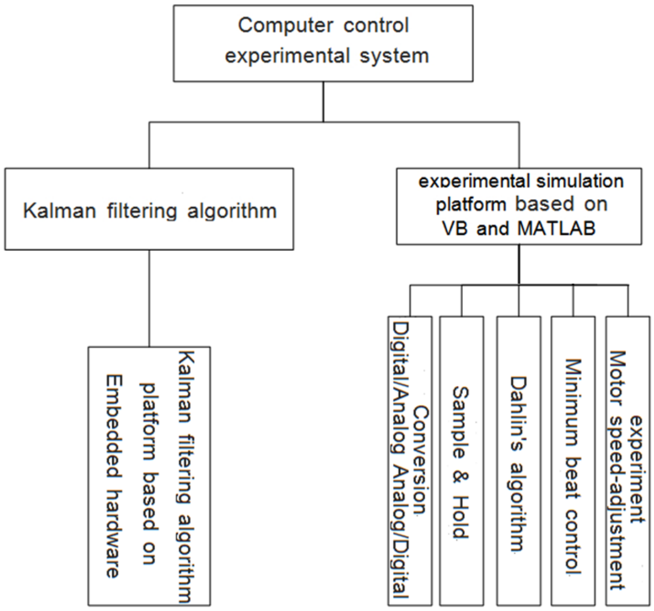

Fig. (1). The architecture of the digital control experimental system.

The flow chart of Kalman filter algorithm is shown in Fig. (**2**). Next we will give the detail of the Kalman filtering algorithm implementation. A typical digital control plant is consisted of a RCL series network as illustrated in Fig. (**3**). Then we can calculate the input $i_L(t)$ and output $u_c(t)$ of its state space equation. Let $i_L(t_0)$ and $u_c(t_0)$ be the initial.

Variables, voltage $u(t)$ is given, $i_L(t)$ and $u_c(t)$ can be used to describe the network of motion state. $i_L(t)$ and $u_c(t)$ can be used as a set of state variables of the given network. We can also use the network of independent energy storage

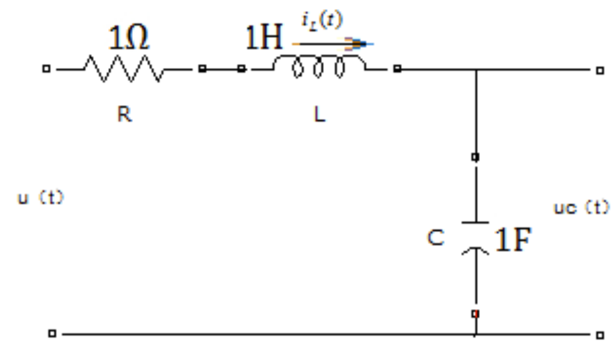

Fig. (3). RCL series network.

component inductance L and capacitance C to determine the state variable. When we choose inductor current $i_L(t)$ and capacitor voltage $u_c(t)$ as state variables, we can obtain the equation

$$L\frac{di_L(t)}{dt}+Ri_L(t)+u_c(t)=u(t)$$
$$C\frac{du_c(t)}{dt}=i_L(t) \qquad (1)$$

Let $x_1(t)=i_L(t)$, and $x_2(t)=u_c(t)$, first order matrix differential equation can be obtained as follows

$$\begin{bmatrix}\dot{x}_1(t)\\ \dot{x}_2(t)\end{bmatrix}=\begin{bmatrix}-\frac{R}{L} & -\frac{1}{L}\\ \frac{1}{C} & 0\end{bmatrix}\begin{bmatrix}x_1(t)\\ x_2(t)\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}u(t) \qquad (2)$$

For the output, we can get the system equations

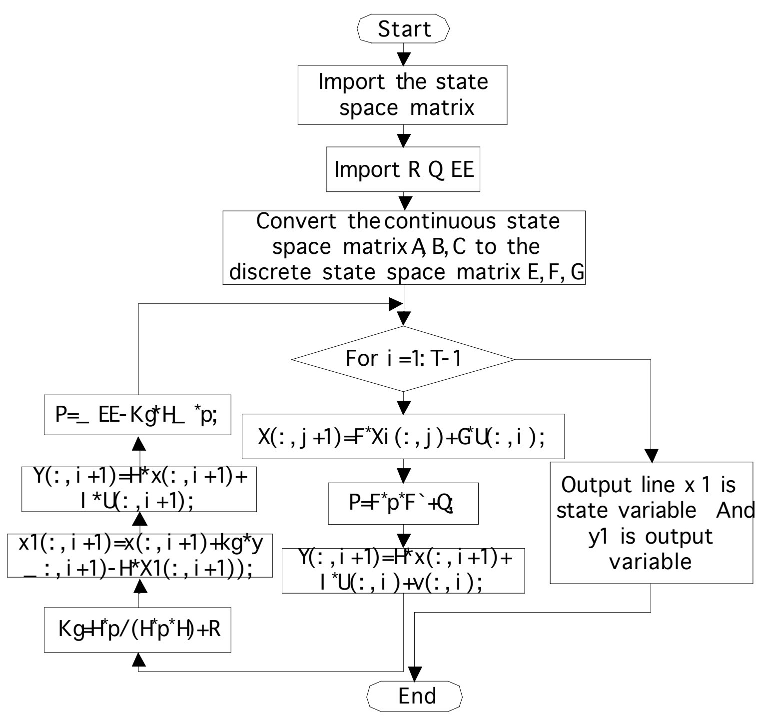

Fig. (2). Flow chart of Kalman filtering algorithm.

$$y(t) = u_c(t) = [0 \quad 1]\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} \tag{3}$$

We write (2) and (3) as the matrix equation form

$$\dot{x}(t) = Ax(t) + Bu(t)$$
$$y(t) = Cx(t)$$

$$x(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} \quad A = \begin{bmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{bmatrix} \quad B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \tag{4}$$

Now we give an example. For the state space expression of RLC networks, we assume that R=1, L=1, C=1 in the RLC series network, then we can get the state space equation

$$A = \begin{bmatrix} -1 & -1 \\ 1 & 0 \end{bmatrix} \quad B = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \tag{5}$$

The state space equation is

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ 1 & 0 \end{bmatrix}\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t) \tag{6}$$

$$y(t) = u_c(t) = [0 \quad 1]\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} \tag{7}$$

When the random noise of 0~1 is appeared, we have

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ 1 & 0 \end{bmatrix}\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t) + W \tag{8}$$

$$y(t) = u_c(t) = [0 \quad 1]\begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + V \tag{9}$$

The state variable curve of a constant input 30V without Kalman filter algorithm is shown in Fig. (**4**). After applying Kalman filter algorithm, the curve is shown in Fig. (**5**). The output variable curve without Kalman filter algorithm is shown in Fig. (**6**). And the output variable curve with Kalman filter algorithm is shown in Fig. (**7**). The result of these comparisons indicates that Kalman filter can obviously reduce the experimental measurement error.

3. VIRTUAL EXPERIMENTAL SYSTEM DESIGN

3.1. Implementation Scheme

In our implementation, mixed programming technology is used. The advanced language Visual Basic is used for the project, and MATLAB is used for the control algorithm simulation.

Experimental simulation system is developed with VB to create friendly man machine interface [4]. VB language is object-oriented structured high-level programming language, and it is efficient and powerful for graphical interface work [5]. MATLAB is very smart and flexible to develop control

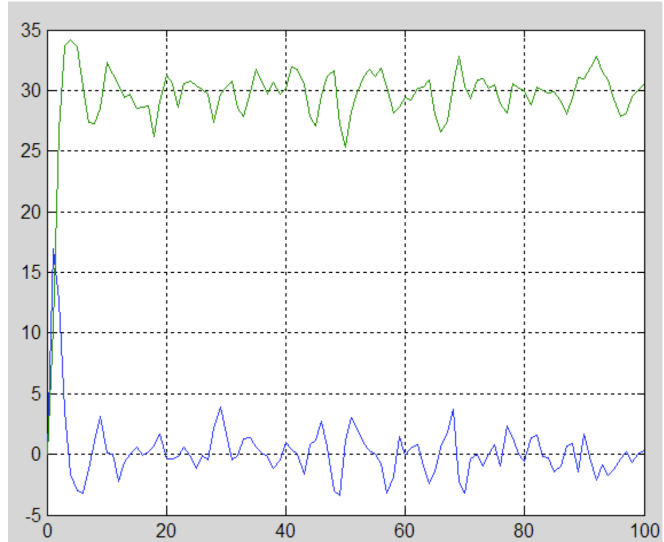

Fig. (4). The state variable without Kalman filter algorithm.

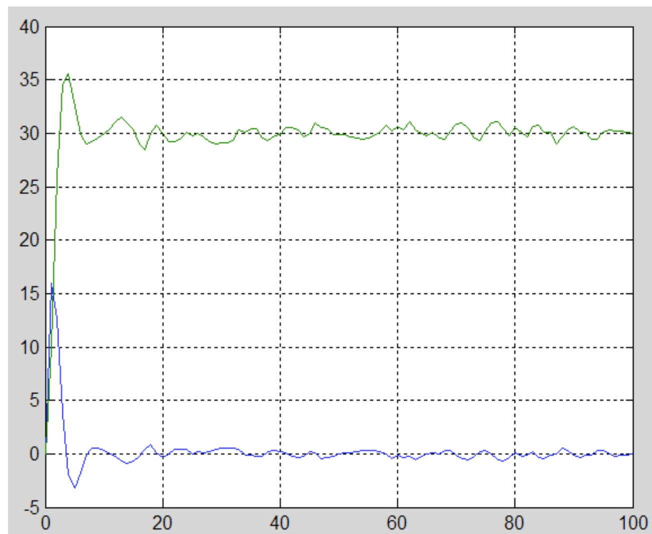

Fig. (5). The state variable with Kalman filter algorithm.

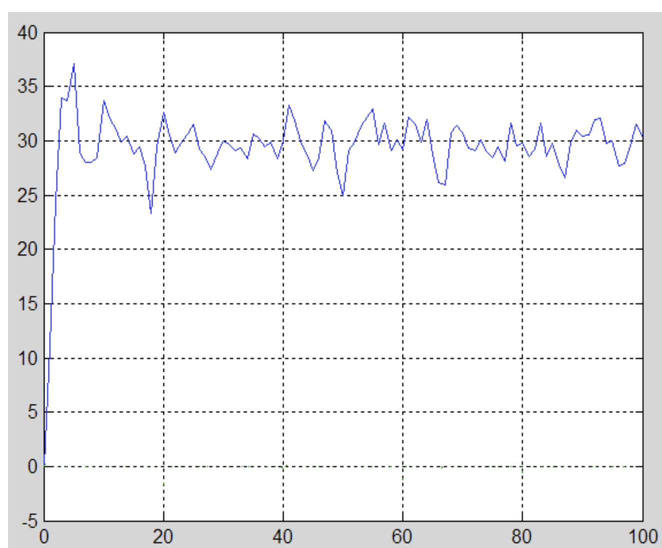

Fig. (6). The output variable without Kalman filter algorithm.

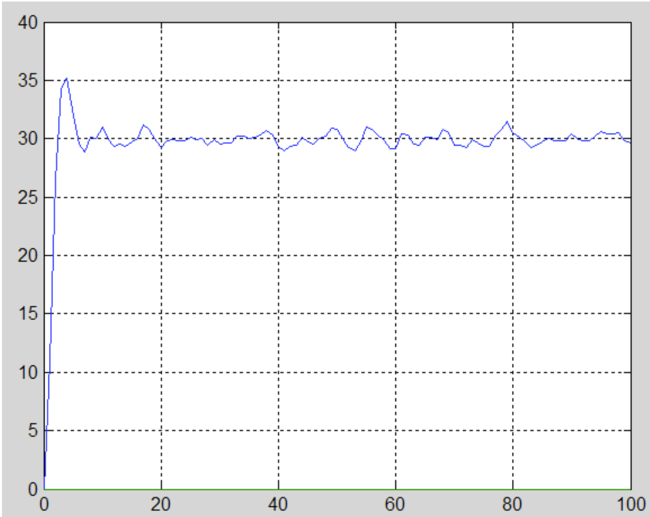

Fig. (7). The output variable with Kalman filter algorithm.

system and simulate control strategy [6, 7]. And the network experimental environment is developed for the undergraduates can visit the application in the lab web through the campus network.

The key technology in the development of this virtual digital control experimental system is the interface problem between VB and MATLAB. We use ActiveX control to solve this problem. The ActiveX control is called Matlab procedures in the application to access matrix or work space. ActiveX object in the Windows registry is defined as the following statement.

Dim a As MLApp.MLApp = New MLApp.MLApp

When a connection is established with MATLAB, VB application can communicate with MATLAB. The various ways to call the application object can be used. These common methods are BSTR command and variable passing method. BSTR command can be sent and followed a single string receiving. MATLAB output information is in the string, and can be used to display for the users. Variable passing method uses two functions for data transfer, function.

void GetFullMatrix(

[in] BSTR Name,

[in] BSTRWorkspace,

[in, out] SAFEARRAY (double)* pr,

[in, out] SAFEARRAY (double)* pi)

and

void PutFullMatrix(

[in] BSTR Name,

[in] BSTR Workspace,

[in]SAFEARRAY (double) pr,

[in] SAFEARRAY (double) pi)

These two functions can carry matrix variables in MATLAB to VB in the array or send data with inverse directions. More details can be found in the Matlab AcviveX references. For example, we can send the input of resistance and capacitance from the man machine interface of the web page and received the data in the server. Then these parameters are sent from VB to Matlab to get the corresponding simulation result curves.

3.2. The Experimental Simulation Implementation

Based on the system modular design method, simulation module for virtual online digital control experimental system is developed. The user operation interface is simple and friendly. When users logged into the system, a main menu is showed according the user class and the experiments to be

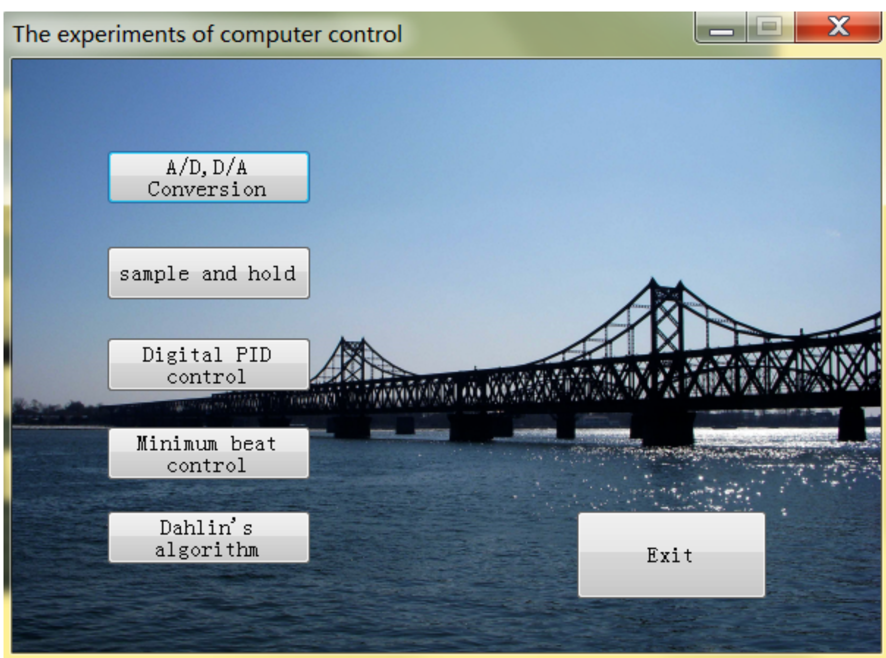

Fig. (8). Main menu for users according to the user class.

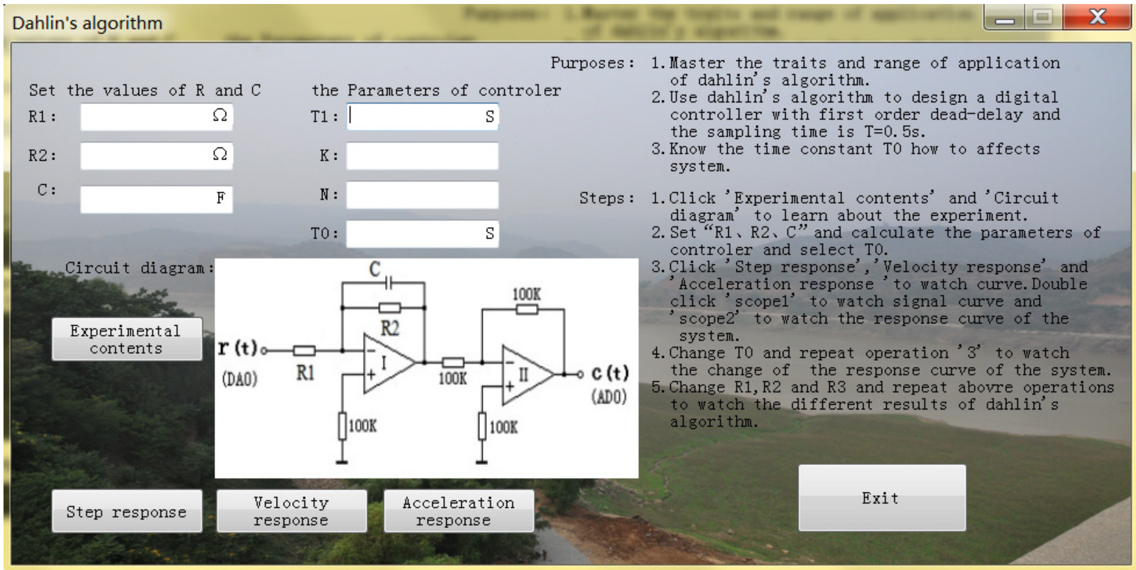

Fig. (9). Experimental interface.

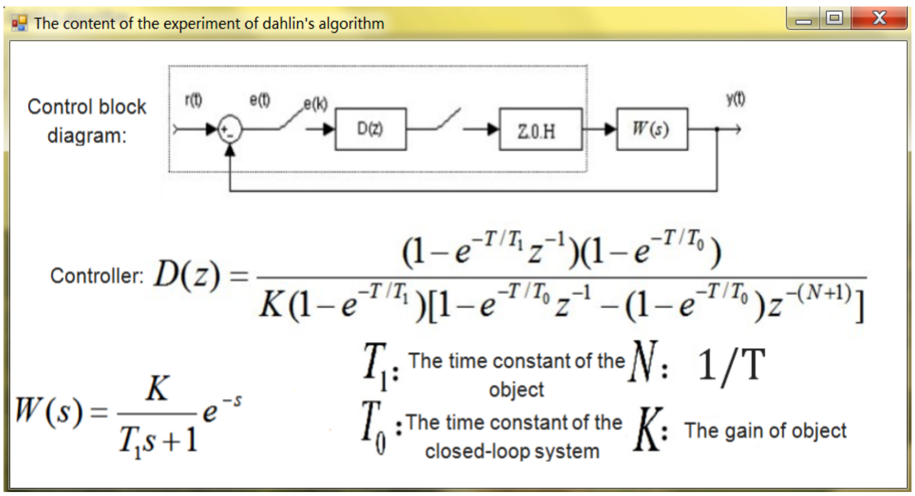

Fig. (10). Controller and parameter selection interface.

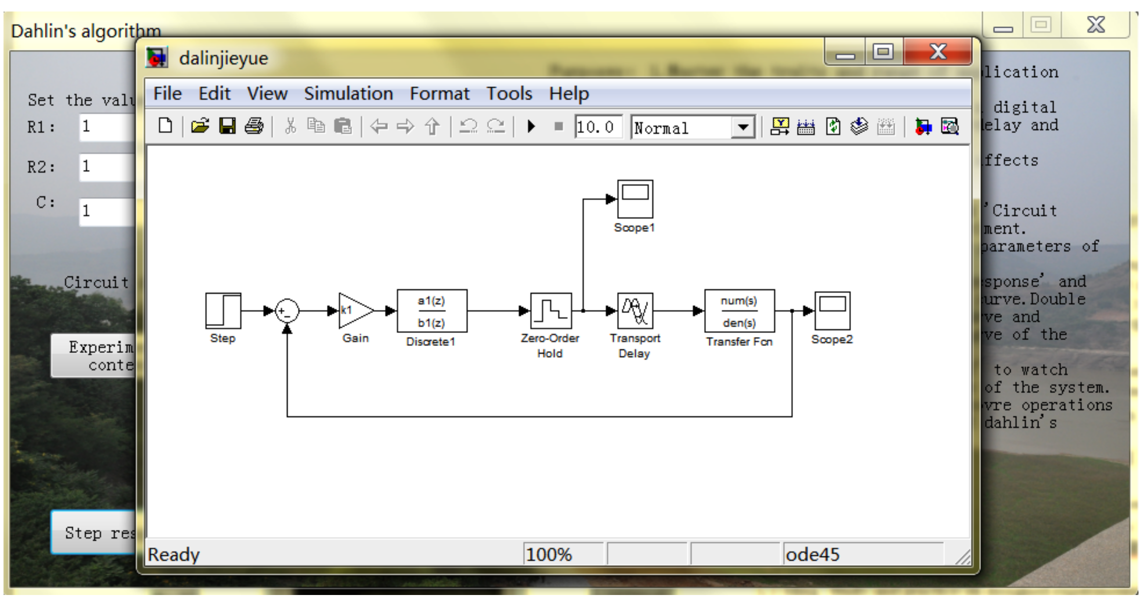

Fig. (11). Typical diagram of the control system.

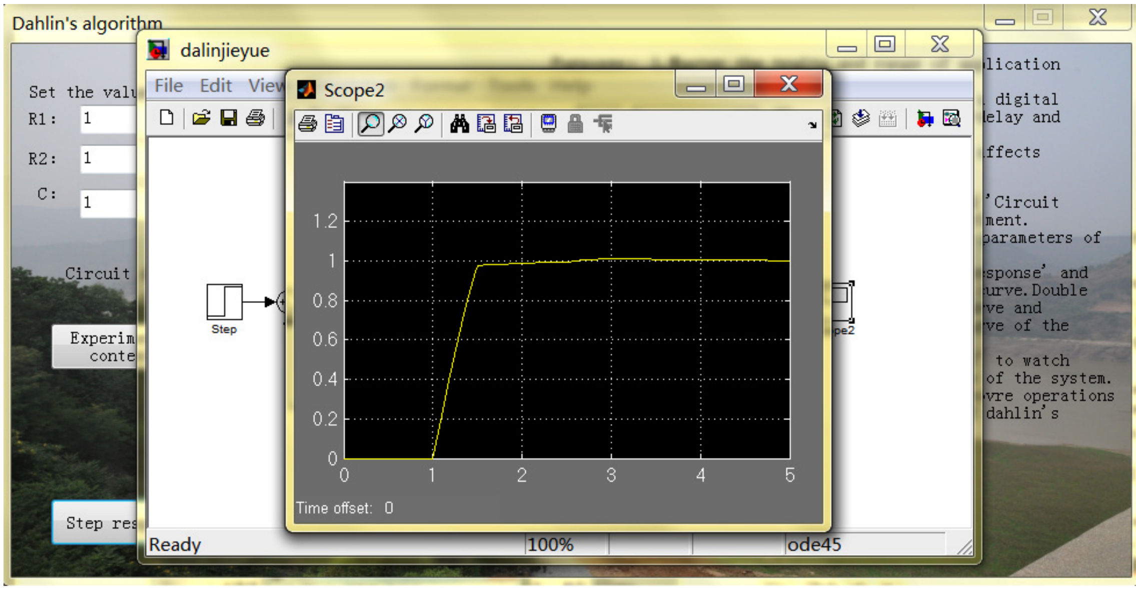

Fig. (12). The system output interface.

learned as shown in Fig. (**8**). After the user select an experiment, the experimental interface is shown as illustrated in Fig. (**9**). The controlled plant parameters and the controller model can also be selected or typed into as shown in Fig. (**10**). Meanwhile the typical model of the control system can be showed as in Fig. (**11**). And the output information can be obtained as illustrated in Fig. (**12**).

CONCLUSION

A virtual digital control experimental system is developed and it has been successfully applied in our class and lab for one year. The system has a powerful function to extend the experimental content and control theory. The open architecture and the network environment provide more easy used ability. Based on the digital control hardware experiment platform, the practical circuit model is developed. And some digital control algorithms are employed for virtual digital control operations, these algorithms include PID and some varies algorithms, Smith predictor algorithm, Dahlin algorithm and Kalman filtering algorithm. It is easy to use for pre-practicing the experiments and simulating the control engineering theory. And many undergraduates like to verify the virtual experimental results in the practical hardware platform, and most of them are familiar with the models very much after their using the virtual experimental system.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work is partially supported by Shandong Provincial Natural Science Foundation (ZR2011FM005), Shandong Provincial Promotive Research Fund for Excellent Young and Middle-aged Scientists (BS2010DX001), and Key Lab Open Fund of Harbin Institute of Technology (HIT.KLOF.2012.078).

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Received: September 16, 2014 Revised: December 23, 2014 Accepted: December 31, 2014