System Development for Education and Design of a Nonlinear Controller with On-Line Algorithm

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Abstract: The education system in this paper is used to demonstrate and educate the effects of electromagnetic induction. Placing an aluminum ring over the core and switching on AC source causes the ring to jump in the air due to induced currents in the ring producing a magnetic field opposed to that produced in the core. To control the position of the ring by only the current, it is to require nonlinear control algorithm and control board that is composed of photo sensors, decode circuit, computer communication, and power electronics circuit. This paper provides the development for education system in detail and the effects of dynamic neural networks for nonlinear control with on line is studied.

Keywords: Education system, dynamic neural unit, real time control.

1. INTRODUCTION

The education system described in this study is a "jumping ring system." This system demonstrates the principle of electromagnetic induction, producing a force from AC sources, Lenz's law of repulsion and transformer. This principle can be demonstrated when the switch, closed thė ring is usually positioned around the extended core of the coil, and is then thrown upwards into air [1]. Elihu Thomson discovered the force effects of AC currents [2]. The effects of repulsion force on the ring was first demonstrated by him at the American Institute of Electrical Engineers in New York in 1887 and subsequently in Paris in 1889 [3]. However, Fleming first published it in 1891 [4], after his discourse at The Royal Institution of Great Britain on March 6th of the same year. Here he demonstrated what is known as the jumping ring experiment. The jumping ring experiment is shown in Fig. 1. A conducting aluminum ring is levitated above a coil excited by an AC source. The AC source is amplitude modulated to ensure that the ring stays in a stationary levitated position. To design and manufacture the education system, the Maxwell 2D simulator and ANSYS version 5.3 tool is used. To jump the ring at desired position, it is to need a precise controller. After the ring's height is measured by a sensor, control law to generate modulate signal to follow reference position. Placing an aluminum ring over the core and switching on AC voltage causes the ring in the air to jump. This is due to the fact that induced currents in the ring produce magnetic field opposed to that produced in the core. If the AC current is slowly increased from zero or if the ring is placed over the core when AC is already flowing, the ring will float due to the balance between its weight and the upward electromagnetic force [1]. It is not easy to find operating point between the force and the control variable because flux density is not available and the ring is heating in control processing, sensor error is include, and ring is vibrate, etc.

This paper develops education system to control real system with on line, show how controller act and utilize test system for comparing controller's performance. Also, we propose dynamic neural mode to control education system and connect dynamic mode to series or parallel to better control goal.

This paper is organized into seven sections. Calculating the force on a ring is described in Section 2. The design of a jumping ring system and manufacturing is described in Section 3. Real time control is introduced in Section 4. Dynamic neural unit model and neural units are proposed in 5. In Section 6, experiments are conducted to validate the controllers performances and display the results. Discussions and conclusions are drawn in the last section.

2. FORCE ON THE RING

Consider the jumping ring apparatus as shown in Fig. 1, a distance z up from the end of the core and length of core l and parameters as shown. Let the height from the top of the coil be z. The ring is free to move up and down on the core with zero friction between itself and the core. The core is made from laminated soft iron ferrous metal bars and the ring is

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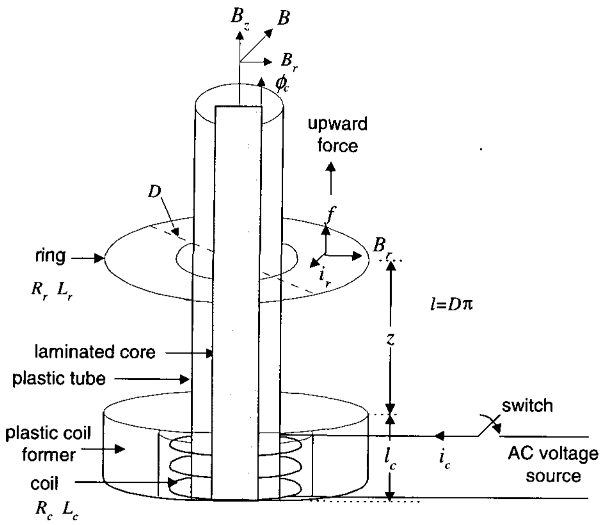

Fig. 1. Jumping ring apparatus.

made from an aluminum. Apply a sinusoidal current $I_c \sin wt$ to the coil flowing in it. Then the flux density is directed along the axis of the core depending upon the coil parameters and the peak value of the current in the coil. Let B be the peak value of the flux density in the core at the height z up from the top of coil, with a vertical component B_z and a radial component B_r.

The upward force f is derived from Fleming's left-hand rule and electromagnetic force is given as

$$f = B_r \; i_r \; l. \tag{1}$$

Here, B_r is the flux density in the ring, i_r is the current of ring and l is the total length of the core, namely

$$B_r = \frac{1}{l}\frac{\partial \phi_c}{\partial z} \quad \text{and} \quad i_r = \frac{v_r}{|z_r|} = \frac{MwI_c}{|z_r|}\cos(wt - \theta_r),$$

where

ϕ_c flux generated by i_c flowing in the core;

v_r induced voltage in the ring;

z_r impedance in the ring;

M mutual inductance between the coil and ring;

θ_r ring phase shift($= \tan^{-1}\dfrac{wL_r}{R_r}$).

The induced voltage in the ring is given as

$$v_r = -\frac{d\lambda_r}{dt} = -\frac{dMi_c}{dt} = MwI_c \cos wt. \tag{2}$$

Here λ_r represents the flux linkage of the ring. Because not all of the flux passing through the center of the core will pass through the ring, as some flux lines will exit the core along the coil and between the coil and the ring. Critically, some flux lines will exit through the ring itself. Consider the Fig. 2, the leakage flux plus the linkage flux represents ϕ_c.

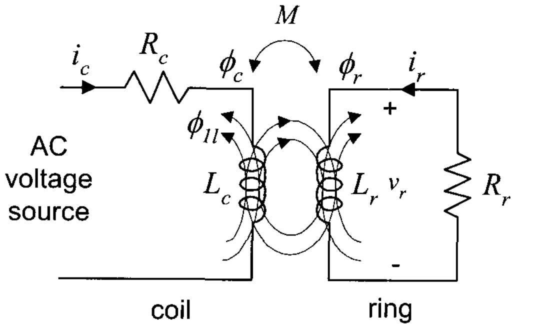

Fig. 2. Equivalent circuit of jumping ring apparatus.

$$\phi_c = \phi_{1l} + \phi_{12}. \tag{3}$$

Here ϕ_{12} represents the linkage flux on the ring by flux producing by i_c, through the ring and producing linkage flux $\lambda_r = M\; i_c$.

The linkage flux is affected in the ring and changed with the height of ring. The variation prime flux has an effect on the ring and is given as

$$\frac{\partial \phi_c}{\partial z} = \frac{\partial}{\partial z}(\phi_{1l} + \phi_{12}) = \frac{\partial}{\partial z}(\phi_{12}) = \frac{\partial}{\partial z}(M\; i_c). \tag{4}$$

Using the equation (1) and (4), the upward force is given by

$$f = \frac{\partial \phi_c}{\partial z} i_r = i_c\; i_r \frac{\partial M}{\partial z}. \tag{5}$$

The force has the levitated distance in its expression and is derived from the change in stored magnetic energy.

3. THE DESIGN OF A JUMPING RING SYSTEM AND MANUFACTURING

The laminated core was made from soft iron ferrous bars each 2.5mm in diameter. The radius of the core was 2.51cm, giving a fill factor of 80% for the core. The coil was made of 14000 turns of 1.2mm diameter enameled copper wire with a resistance of 13Ω. The frequency of operation was modulated at 120Hz. Fig. 3 shows the design parameter to a jumping ring experiment and aluminium ring.

Table 1 shows the upward force, induced current and ring inductance depending upon ring position. When the voltage across the coil is first turned on the ring will experience a large impulsive force due to the increase of voltage in a short time. The education system as shown in Fig. 4 was implemented by three photo sensors placed at 120°, encode circuits, decoder circuits, LED displayer and microprocessor.

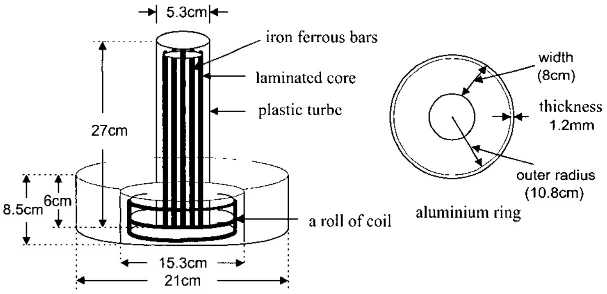

Fig. 3. Sketch of jumping ring apparatus.

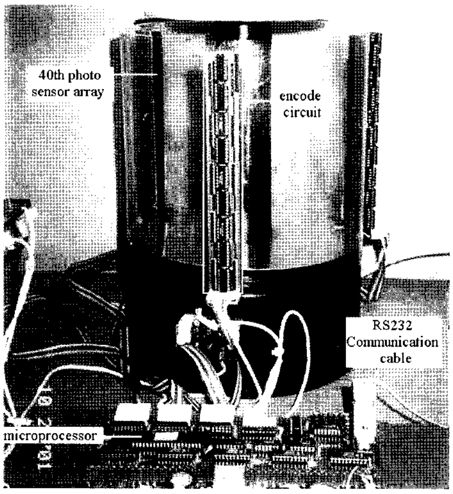

Fig. 4. Picture of the levitated ring, encode circuits, sensor mountings, and RS232 cable.

Table 1. Force, current and inductor using maxwell 2D simulator with ring's position.

f, i_c, L_r / ring position	Force	Current [RMS]	Inductor
2mm	3[N]	1049[A]	0.27[H]
100mm	0.58[N]	517[A]	0.38[H]
190mm	0.09[N]	214[A]	0.41[H]

4. REAL TIME CONTROL

To control the height of levitation by the ring, determine the levitation of the ring with respect to control voltage over (0, $u_{\max}$). Using three photo sensor array, 8 to 3 encoder (74hc148), buffer, 3 to 8 decoder (74HC138), NAND gates, and five D/A converter, the height of levitation of the ring is calculated to 8bit signal and entered to 89C51 microprocessor in Fig. 5. The heights of ring at each of the three different phase sensors are shown as connect cables with markers (A, B, C). Each of the sensor arrays is composed of forty 5mm photo interceptor. There are six decoders to detect the sensor signal and calculate the height of the rings. Also, sensor arrays is composed of forty 5mm

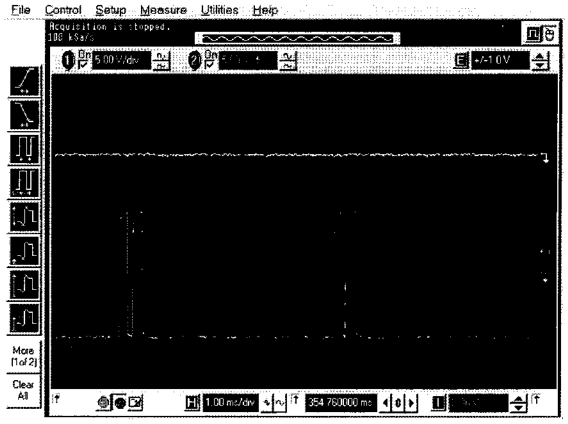

Fig. 5. 8 bit D/A signal sending to CPU with 4.16ms speed.

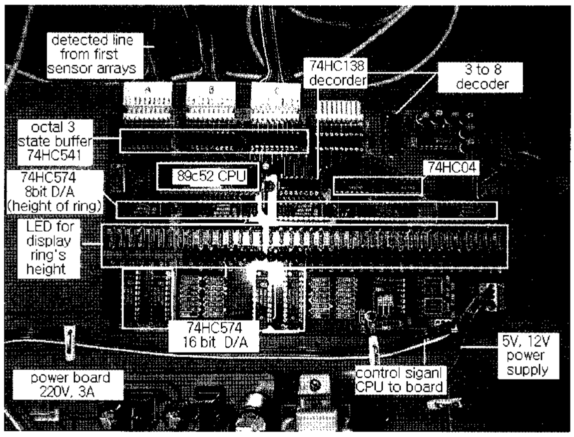

Fig. 6. Photo sensor signal and D/A control signal.

photo sensor arrays is composed of forty 5mm photo interceptor. There are six decoders to detect the sensor signal and calculate the height of the rings. Also, three NAND gates are used to find out which decode output are selected and used. These signals are transferred to microprocessors. This calculated height is transferred to a control PC through a communication port. As Fig. 6 shows, the average height of sensor arrays are transferred to 8 bit D/A signal on 4.55ms speed through RS232 port. Main computers with touch screen modulate control signal by real time program that generate digital control signal. The control digital signal is calculated by a nonlinear controller and sent to 89C52 CPU back through RS232 port. The CPU received a 16bit D/A control signal and sent it to a power board. This control signal in Fig. 5 is implemented to a DC voltage below +5[V]. As Fig. 6 shows, the power board is composed of power IC (TRAIC), TCA785, Op-amplifier (LM324) and electric devices. Comparing this control signal with a ramp signal in the power board, those regions higher than control are selected and the fire angel of the power IC is changed.

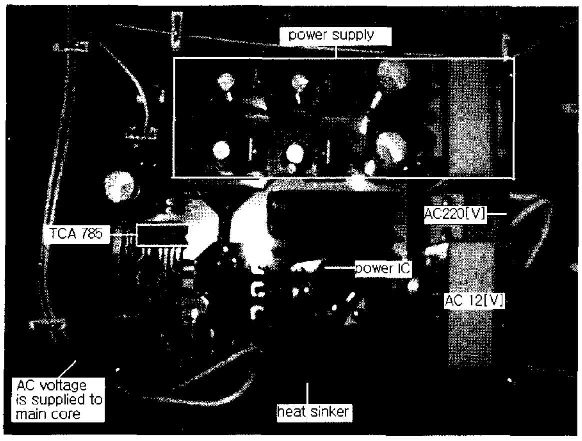

Fig. 7. Power IC, phase control IC and electronic circuit.

Thus, the PWM signal is made of a high frequency square oscillator and a control range. According control ranges, AC source voltage is supplied to a jumping ring apparatus. Fig. 7 shows the power board and electronic circuits. Here TCA 785 is used to control phase control IC. This phase control IC is intended to control thyristors, triacs, and transistors. The trigger pulses can be shifted within a phase angle between 0° and 180° . TG25C60, TRIAC is used to control AC source.

5. DYNAMIC NEURAL UNIT MODEL AND NEURAL UNITS

The conventional neural network models are a parody of biological neural structures and are very slow learning. In order to emulate some dynamic functions, such as learning and adaptation, and to better reflect the dynamics of biological neurons, M.M. Gupta and D.H. Rao have developed a dynamic neural model [6]. Proposing similar dynamic neural model structures but better stabilized performances, identify function approximation and good track nonlinear function. A proposed neural unit (DNU) model is used to introduce some dynamics to the neuron transfer function, such that the neuron activity depends on internal states [7]. The dynamic structure of proposed DNU, as shown in Fig. 8. The dynamic elementary processors (DEP) has a second order structure that can be described by the following state space representations [8,9].

$$\begin{bmatrix} s_1(k+1) \\ s_2(k+1) \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} x(k), \quad (6)$$

$$v_1(k) = \begin{bmatrix} c_1 & c_2 \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} + d_0 x(k). \quad (7)$$

Here $x(k) = \sum_{i=1}^{P} w_i I_i(k)$ and $v_1(k)$ are the scalar

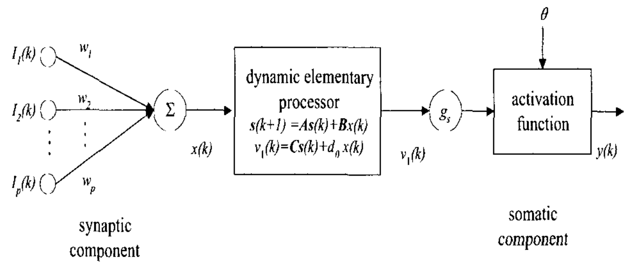

Fig. 8. Proposed dynamic neural unit.

input and output of the DEP, $s_1(k)$ and $s_2(k)$ are the state and k is the discrete time index, respectively. And $I_i(k)$ is the input vector of the DNU.

In order to stabilize the proposed DEP, it is necessary to derive the stability condition for a parameter of (6-7). To obtain the necessary and sufficient condition that the state coefficient matrix A converges in the steady state as follows:

$$\left| \lambda_i [A] \right| < 1, \quad i = 1, \ 2. \quad (8)$$

Applying the Lyapunov theorem, parameters of DEP are stable, and update optimally. All eigenvalues of A have magnitudes less than 1 if and only if for any given positive definite Hermitian matrix Q with the property A, Q observable.

$$P - A^T P A = Q. \quad (9)$$

The proposed DNU consist of DEP that have minimum sensitivity structures [10]. By selecting state matrix A as follow, the minimum sensitivity structures can be composed.

$$A = \begin{bmatrix} r\cos\varphi & r\sin\varphi \\ -r\sin\varphi & r\cos\varphi \end{bmatrix}. \quad (10)$$

To minimize ratio of input variation to output variation [11], put $c_1 : c_2 = b_2 : b_1$. So, the propose DEP is given by

$$\begin{bmatrix} s_1(k+1) \\ s_2(k+1) \end{bmatrix} = \begin{bmatrix} -g_1 & -g_2 \\ g_2 & g_1 \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} + \begin{bmatrix} g_3 \\ g_4 \end{bmatrix} x(k), \quad (11)$$

$$v_1(k) = \begin{bmatrix} g_4 & g_3 \end{bmatrix} \begin{bmatrix} s_1(k) \\ s_2(k) \end{bmatrix} + d_0 x(k). \quad (12)$$

The transfer function of the DEP is described by

$$\frac{v_1(k)}{x(k)} = \frac{d_0 + K_4 q^{-1} + K_5 q^{-2}}{1 + 2g_1 q^{-1} + (g_1^2 + g_2^2) q^{-2}}, \quad (13)$$

$$K_4 = 2(g_3 g_4 + d_0 g_1),$$

$$K_5 = 2g_1 g_3 g_4 + g_2(g_3^2 - g_4^2) + d_0(g_1^2 + g_2^2).$$

The parameters d_0, g_1, g_2, g_3, g_4 are adaptable feedback and feed-forward weights respectively. The nonlinear mapping operation on $v_1(k)$ yields a neural output of the DNU.

$$y(k) = \Phi\ [g_s v_1(k) - \theta], \tag{14}$$

where $\Phi\ [\cdot]$ is a nonlinear activation function of neuron with a threshold θ. In order to extend the mathematical operations on both the positive and negative neural outputs, expand the neural activity for both the excitatory and inhibitory inputs, and suppose the activation function to be an anti-symmetric squashing function is defined as

$$\Phi[v(k)] = \tanh[g_s v_1] = \tanh[v]. \tag{15}$$

Here $v = g_s v_1$, and g_s is the somatic gain which control the slope of the activation function.

An adaptive algorithm to adjust the DNU parameter is based on a given set of input-output pairs. This determines the optimal parameter set which minimize the cost function J.

$$J = \frac{1}{2} E\left[(y_d(k) - y(k))^2\right]. \tag{16}$$

Here E is the expectation operator. The define error, $e(k)$ is the difference between the desired response $y_d(k)$ and the DNU neuron response $y(k)$. Each component of the vector $\Omega_{(\theta, g_s, d_0, g_1, g_2, g_3, g_4, w_i)}$ is adapted to minimize J using the steepest decent algorithm. This adaptation rule may be written as

$$\Omega_{(\theta, g_s, d_0, g_i, w_i)}(k+1) = \Omega_{(\theta, g_s, d_0, g_i, w_i)}(k) + dia[\mu] E\left[e(k) \frac{\partial y(k)}{\partial \Omega(k)}\right]. \tag{17}$$

Here $\Omega_{(\theta, g_s, d_0, g_i, w_i)}(k+1)$, $\Omega_{(\theta, g_s, d_0, g_i, w_i)}(k)$ are the new parameter vectors and the present parameter vectors, respectively, and $dia[\mu]\ E\left[e(k)\frac{\partial y(k)}{\partial \Omega(k)}\right]$ is an adaptive adjustment of parameter vectors. $dia[\mu]$ is the diagonal matrix of individual adaptive gains. By chain rule, the gradient of performance index with $\Omega_{(\theta, g_s, d_0, g_i, w_i)}(k)$ is obtained as

$$\frac{\partial y(k)}{\partial \Omega(k)} = \frac{\partial y(k)}{\partial v(k)} \frac{g_s \partial v_1(k)}{\partial \Omega(k)} = g_s \Phi' \frac{\partial v_1(k)}{\partial \Omega(k)}. \tag{18}$$

Therefore, the activity function is to be differentiable. Using the time shifting operator, five parameter of DEP can be obtained. To determine the change of the neuron activity depending on a parameter, the gradient has to be filtered by (13) [12].

6. EXPERIMENTS

In this section, we discuss how to control the jumping ring system with the proposed DNU. The ring is levitated by 220/220 transformer that was a 0-220[V] AC source giving a maximum current 3[A]. Since the levitated ring is slanted irregularly with an unbalance force on ring, an upward force is changed the temperature of ring. As a result, it is not easy to receive correct information for position of the ring. To measure the height of levitated ring correctly, use 3 detector points from three photo sensors placed at 120° (A,B,C). Three microprocessors are used to control the system. Generally for different communication speeds and sensor arrays, this shows that the proposed controller for modulating the force coincided well with the reference signal. Fig. 8 represents a control scheme of a block diagram. Real time control is based on the controller of the DNU, the communication speed of the interacting control PC and microprocessor. The height of levitation of the ring used in three sensor arrays is measured on line. Using a ROM writer, change communication speeds to analyze performance of the proposed DNU controller. Also, to compare original DNU controllers, program and run the control program using Visual Basic program in control PC. The proposed DNU is exploited to design a controller for nonlinear system. Different arbitrary nonlinear functions were used to evaluate the function approximation capability of the proposed DNU. The real time control is finding a control signal $u(k)$ that

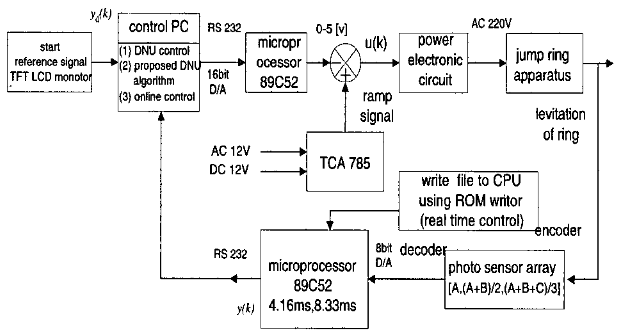

Fig. 9. Control scheme of education system on line.

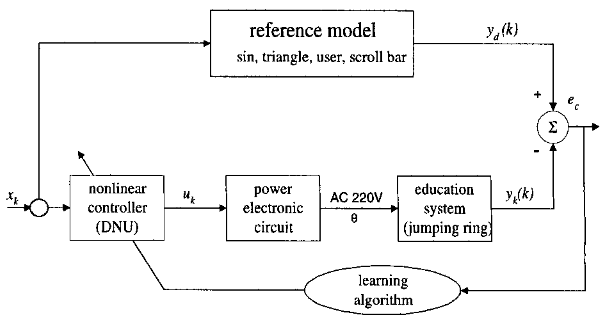

Fig. 10. Design of real time nonlinear controller.

will force the education system output $y(k)$ to track the desired output $y_d(k)$. The reference signals in the experiments have four kinds of signals shown in Fig. 11.

The control signal from DNU controller is generated from control PC to track the above reference height. To achieve control performance, the adaptation procedure is propagated with on line learning algorithm. On line adaptation algorithms are developed using the value of $y_d(k)-y(k)$ in every time steps between consecutive change DNU network parameters, and in consideration of the actual application of the network approximation. The variance of input is changed to 500 steps, and speed between encoder and the microprocessor is 4.16ms. The changed communication speeds not only provide good information on the design of the proposed DNU, but it also represents the control signal. The response of the changed communication speed experiment and input steps are shown in Fig. 11-13. For a DNU neural network, with two layers, on line learning technique is also applicable. However, the execute time will be longer and the results are less visible. Since the proposed DNU is based on a dynamic model and it is meant for the design of real time controllers, the results of experiments may be useful in some fields. The education system using control PC and LCD monitor are shown in Fig. 14. Parameters and initial values in all experiments are shown Table 2. According to on line learning algorithms, these parameters are updated to new value that minimizes error functions.

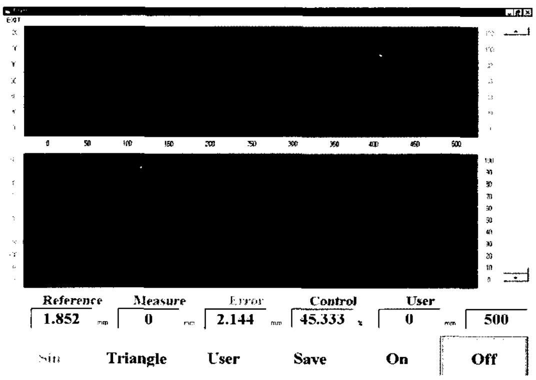

Fig. 11. Monitoring sine wave using the proposed DNU by average three sensor arrays.

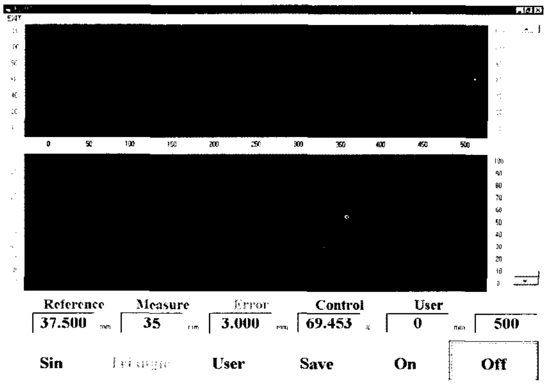

Fig. 12. Monitoring triangle signal using the proposed DNU by average three sensor arrays.

7. CONCLUSION

This paper emphasizes real system controls using dynamic neural unit models with on line learning algorithms to investigate how the DNU parameter affects the controllers performance. Real time process is present to obtain a height of the levitated ring for three different sensor arrays. Based on the education system and the proposed DNU model, the height of

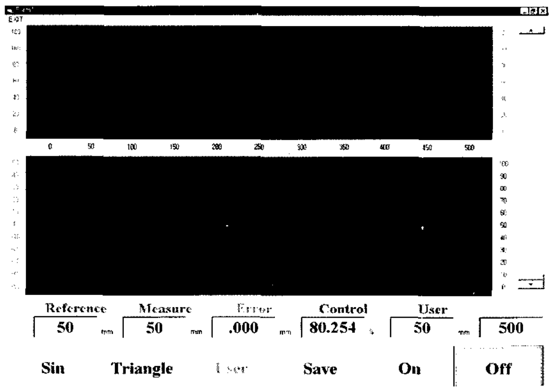

Fig. 13. Monitoring user input signal using the proposed DNU by average three sensor arrays.

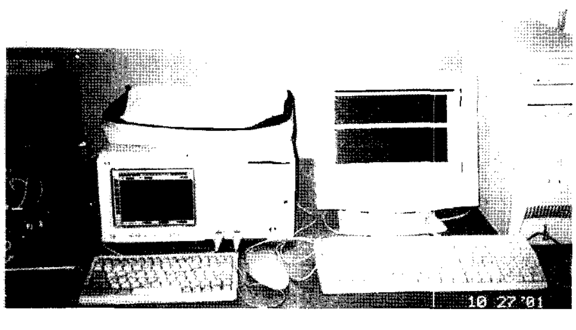

Fig. 14. Jumping ring apparatus for education using control PC and monitor.

Table 2. Parameter and initial value used in the experiments.

Method / Case study	Original DNU	Proposed DNU
sin wave	u_g=0.8,u_p=0.1,u_z=0.1,slope=1.0,theta=0.1	
triangle user input scroll bar	z[0]=0.2,z[1]=0.2 z[2]=0.2,p[0]=0.8 p[1]=0.2,p[2]=0.2	g1=p[1]/2, g2=[p[2]-g1^2]$^{1/2}$ g3=0.03, g4=0.03

levitation of the ring is controlled by reference signals. In this paper, the proposed dynamic model is used to control the height of a levitated ring by modulating the fire angles of TRAIC and supplying AC source voltage to education system. Since other applications such as linear motor and control system for education are composed of sensors, real time controllers, and communication controls with microprocessors, this approach can be applied to other classes of nonlinear controllers for an on line learning algorithm.

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