ISSN 1392 – 1215 ELEKTRONIKA IR ELEKTROTECHNIKA. 2004. Nr. 6(55)

T 170 ELEKTRONIKA

Comparative Control of a Nonlinear First Order Velocity System by a Neural Network NARMA-L2 Method

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Introduction

Since their appearance, Neural Networks found a vast field of applications in almost all sections of science and technology. They constitute original solutions in different kinds of recognition problems, as well as in forecasting and anticipation [1-7]. Electronic, Electrical and Control Engineering is one of the most privileged domains of their applications.

As in real world of control engineering the nonlinearities are an unavoidable problem that necessitates the development of controllers with special capabilities in solving the nonlinearity problems. Neural Networks have been proved a successful method in identification and control of dynamic systems. Their approximation capabilities of Multilayer Perceptron (MLP) made them a popular choice for modeling nonlinear systems and for implementing general – purpose nonlinear controllers. For this purpose, different control algorithms and architectures are implemented. One of them, among others, for prediction and control is the NARMA–L2 (or Feedback Linearization) controller. In this work we test its capabilities in a first order velocity control system as compared with classic PID control.

NARMA L2 architecture

In all Neural Networks architectures used for control two steps are involved: System Identification and Control Design.

In the system identification step, a neural network model, of the plant under control, is developed, and in the control design step this plant model is used to train the controller, which is a simple rearrangement of the plant model.

One can say that Neural Network learns the plant behavior, in different kind of inputs signals, which occur from its physical construction and then, by possessing this "knowledge", anticipates the appropriate control to apply.

The overall description transforms the classic control system into an anticipatory system, as it "posses" a model of its own behavior, characteristic which is interweaved with anticipation concept [8].

The principal idea of NARMA-L2 (Nonlinear Autoregressive – Moving Average) controller is to transform nonlinear system dynamics into linear, by canceling the nonlinearities.

The model used for the plant implementation is described as:

$$y(k+d) = N[y(k), y(k-1), \cdots] \\ \cdots, y(k-n+1), u(k), u(k-1), \cdots u(k-n+1); \qquad (1)$$

where: $u(k)$ and $y(k)$ are the system input and output respectively.

The Neural Network training, during the identification phase, is realised in order to approximate the nonlinear function N.

If the system follows a desired reference trajectory y_r then the nonlinear controller must be of the form:

$$u(k) = G[y(k), y(k-1), \cdots, y(k-n+1), y_r(k+d), u(k-1), \cdots \\ \cdots u(k-m+1)]. \qquad (2)$$

The Neural Network training (minimisation of Mean Square Error) is to create the G function of the controller [9].

The NARMA-L2 controller approximate model is in companion form [10]:

$$\hat{y}(k+d) = f[y(k), y(k-1), \cdots, y(k-n+1), u(k-1), \cdots u(k-m+1)] + \\ + g[y(k), y(k-1), \cdots, y(k-n+1), u(k-1), \cdots u(k-m+1)]u(k); \qquad (3)$$

here, the next controller input $u(k)$ is not contained in the nonlinearity. The resolving controller input has the form:

$$u(k)=\frac{y_r(k+d)-f[y(k),y(k-1),\cdots,y(k-n+1),u(k-1),\cdots u(k-m+1)]}{g[y(k),y(k-1),\cdots,y(k-n+1),u(k-1),\cdots u(k-n+1)]}.\quad(4)$$

For realisation problems of this equation (control input *u(t)* calculation is based on the same time output *y(k)*) is more realistic to use instead the following equations:

$$y(k+d)=f[y(k),y(k-1),\cdots,y(k-n+1),u(k),u(k-1),\cdots u(k-m+1)]+ \\ +g[y(k),\cdots,y(k-n+1),u(k),\cdots u(k-n+1)]u(k+1),\quad(5)$$

$$u(k+1)=\frac{y_r(k+d)-f[y(k),\cdots,y(k-n+1),u(k),\cdots u(k-n+1)]}{g[y(k),\cdots,y(k-n+1),u(k),\cdots u(k-n+1)]};\quad(6)$$

where $d\geq 2$.

The NARMA-L2 controller, which realises this function, is shown in Figure 1.

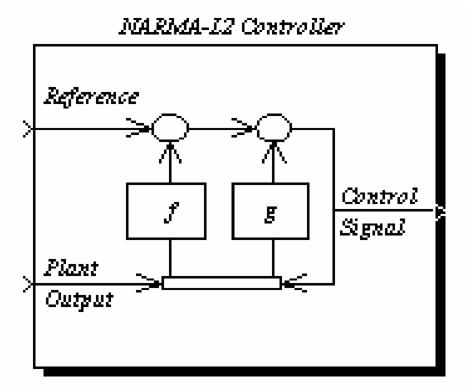

Fig. 1. NARMA-L2 controller

The velocity control system

The system to control is a classic first order closed loop rotational velocity control system, with D.C motor, having dead zone type nonlinearity, in armature control mode, using the classical PID controller. The motor with its electrical representation is shown in Figure 2.

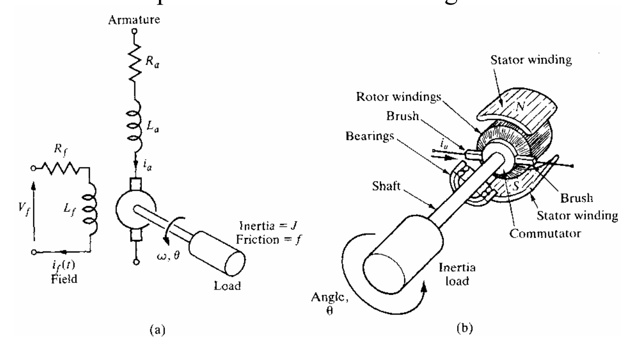

Fig. 2. DC motor

The Transfer Function describing the output rotational velocity of the motor as a function of armature applied voltage input is of the form:

$$G(s)=\frac{\Omega(s)}{V_S(s)}=\frac{S(s)}{E(s)}=\frac{K_S}{1+\tau_m s}\quad(7)$$

and the classic PID control system for Feedback® DC motor application is shown in Figure 3.

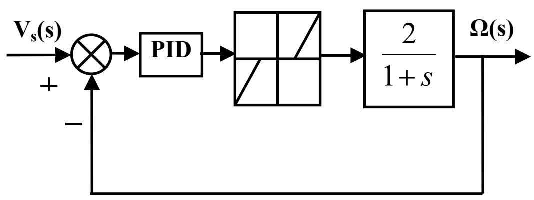

Fig. 3. First order nonlinear system: Motor Gain K_s=2, time constant τ_m=1sec

The overall system with NARMA-L2 controller is realized with Matlab Simulink® software and it is shown in Figure 4.

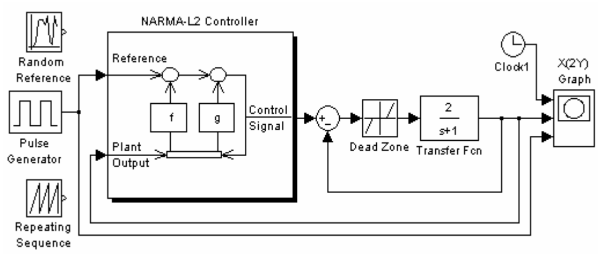

Fig. 4. NARMA-L2 controlled system

The Random Reference input (figure 5) is to train the network (plant identification), Pulse Generator and Repeating Sequence inputs are for testing the performance of NARMA-L2 controlled system for first and second order inputs.

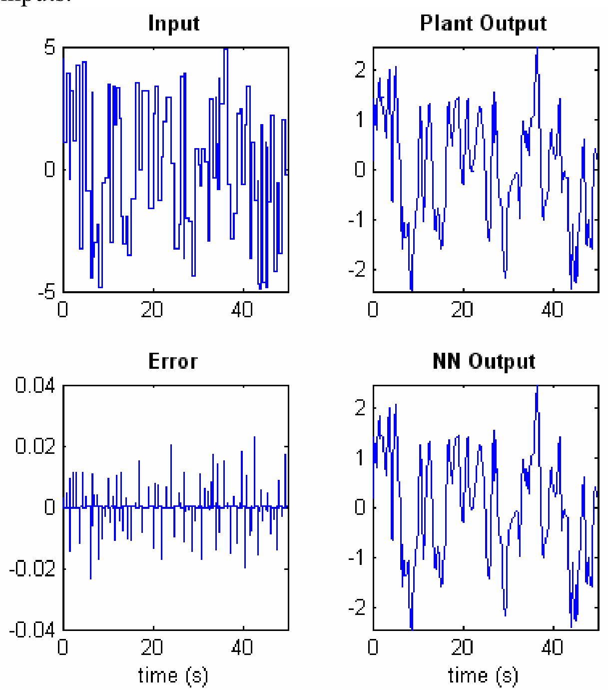

Fig. 5. Training data for NARMA-L2

Results

After identification phase of the controller, realized for some thousands of learning cycles, the system responses, for different kind of control modes and inputs, are shown in following figures.

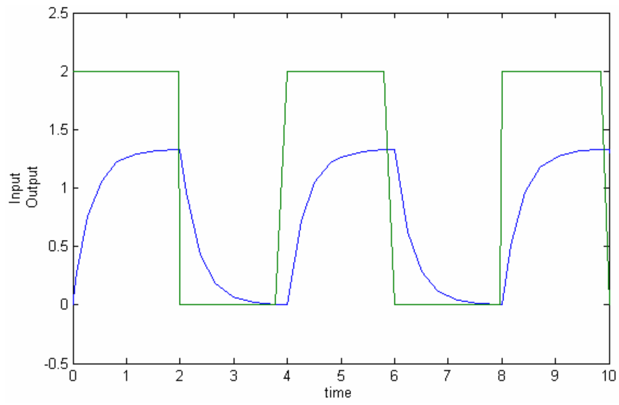

Fig. 6. Step input response of non controlled system

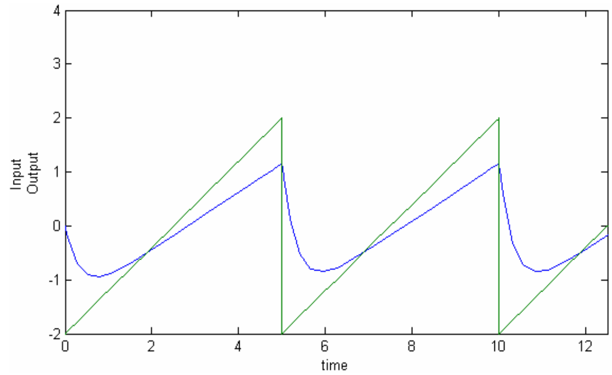

Fig. 7. Ramp input response of non controlled system

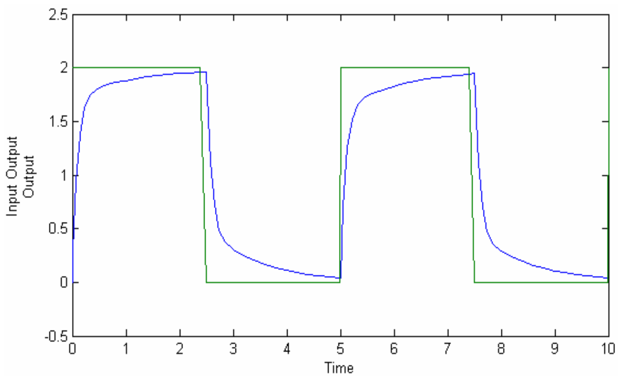

Fig. 8. Step input response of PID controlled system

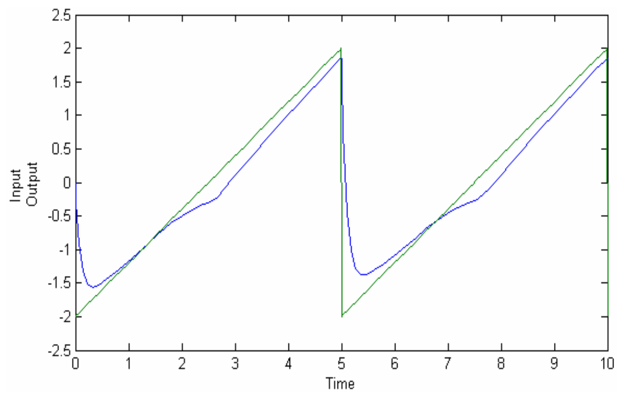

Fig. 9. Ramp input response of PID controlled system

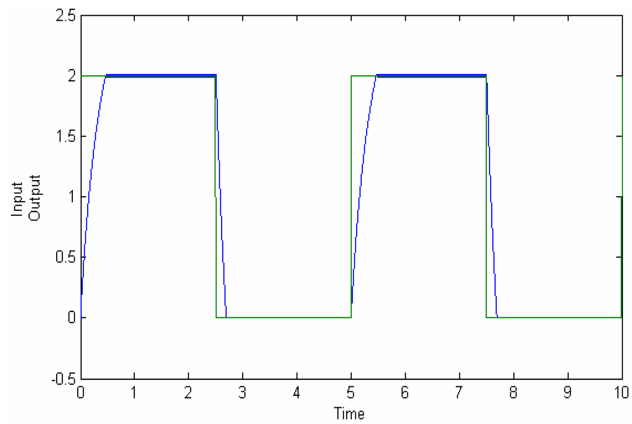

Fig. 10. Step input response of NARMA-L2 controlled system

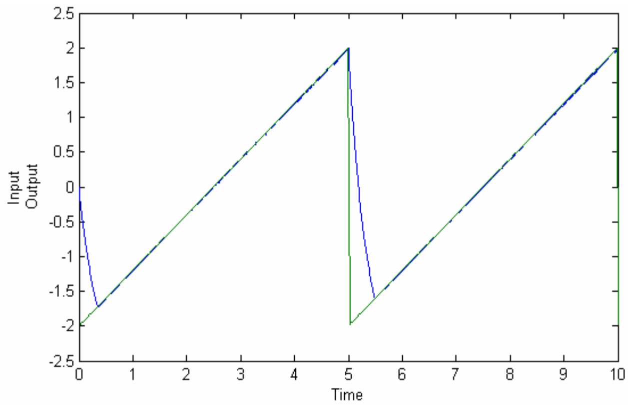

Fig. 11. Ramp input response of NARMA-L2 controlled system

Conclusion

Comparison between system responses, controlled with PID and NARMA-L2 controllers, clearly shows that NARMA-L2 controller gives the best control results for both kind of inputs (step or ramp), hereby minimising the steady state final errors of response and, at the same time, improving its velocity.

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Pateikta spaudai 2004 08 25

G. Tsirigotis, D. Bandekas, D. Pogaridis, J. L. Lázaro. Netiesinės greičio sistemos lyginamoji kontrolė taikant neuroninių tinklų NARMA-L2 metodą // Elektronika ir elektrotechnika. – Kaunas:Technologija, 2004. – Nr. 6(55). – P. 5-8.

Neuroniniai tinklai dėl daugiasluoksnio perceptrono aproksimavimo galimybių žada tapti populiariu įrankiu modeliuojant netiesines sistemas ir įdiegiant netiesinius valdiklius. Vienas iš jų, skirtas prognozavimui ir valdymui, yra valdiklis NARMA–L2 (arba grįžtamojo ryšio linearizacijos Valdiklis).

Bandomos šio valdiklio galimybės pirmos eilės greičio valdymo sistemoje, atliktas palyginimas su klasikine PID kontrole. Sistemų palyginimas rodo, kad valdiklis NARMA–L2 duoda geresnius valdymo rezultatus abiem įėjimo (laiptuoto ir nuoseklaus) atvejais, taip minimizuojamos nuolatinės būsenos reakcijos paklaidos, o tuo pačiu metu padidinamas greitaeigiškumas. Il. 11, bibl. 10 (anglų kalba; santraukos lietuvių, anglų ir rusų k).

G. Tsirigotis, D. Bandekas, D. Pogaridis, J. L. Lázaro. Comparative Control of a Nonlinear First Order Velocity System by a Neural Network NARMA-L2 Method // Electronics and Electrical Engineering. – Kaunas: Technologija, 2004. – No. 6(55). – P. 5-8.

Neural Networks, due to their approximation capabilities of Multilayer Perceptron (MLP) are promising to become a popular tool for modeling nonlinear systems and implementing general – purpose nonlinear controllers. One of them, for prediction and control, is the NARMA–L2 (or Feedback Linearization) controller.

In this work its capabilities are tested, in a first order velocity control system, and compared with classic PID control. The comparison between system responses, clearly showed that NARMA-L2 controller gives the best control results for both kind of inputs (step or ramp), hereby minimising the steady state final errors of response and, at the same time, improving its velocity. Ill. 11, bibl. 10 (in English, Summaries in Lithuanian, English, Russian).

Г. Тсириготис, Д. Бандекас, Д. Погаридис, Х.Л. Лазаро. Контроль скорости системы первой степени, используя метод нейронных сетей NARMA–L2 // Электроника и электротехника. – Каунас: Технология, 2004. – № 6(55). – С. 5-8.

Нейронные сети, использующие аппроксимации многослойного персептрона, являются популярным приспособлением для моделирования систем и при реализации нелинейных контроллеров. Одним из них, предназначенный для прогнозирования и контроля, является контроллер NARMA–L2 (или контроллер линеаризации возвратной цепи).

Исследованы возможности контроллера в системе первой степени контроля скорости и сопоставлены с классическим PID контролем. Исследования показали, что контроллер NARMA–L2 дает лучшие результаты в обеих случаях входного сигнала (ступенчатого или постепенного), таким образом минимизируются погрешности постоянного состояния и в то же время улучшается быстродействие. Ил. 11, библ. 10 (на английском языке; рефераты на литовском, английском и русском яз.).

DOI: 10.5755/j02.eie.10887