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 interwoven with anticipation concept [8].

The principal idea of NARMA-L2 (Nonlinear Auto-regressive – 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:

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

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

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

The model used for the plant implementation is described as:

\[ u(k) = G[y(k), y(k - 1), \ldots, y(k - n + 1), y_r, (k + d), u(k - 1), \ldots \ldots \ldots \ldots u(k - m + 1)]. \] (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]:

\[ y(k + d) = f[y(k), y(k - 1), \ldots, y(k - n + 1), u(k - 1), \ldots u(k - m + 1)] + g[y(k), y(k - 1), \ldots, y(k - n + 1), u(k - 1), \ldots u(k - m + 1)]u(k); \] (3)

here, the next controller input \( u(k) \) is not contained in the nonlinearity. The resolving controller input has the form:
\[ u(k) = \frac{y(k + d) - f[y(k), y(k - 1), \ldots, y(k - n + 1), u(k - 1), \ldots u(k - m + 1)]}{g[y(k), y(k - 1), \ldots, y(k - n + 1), u(k - 1), \ldots u(k - n + 1)]} \]. (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:

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

\[ u(k + 1) = \frac{y(k + d) - f[y(k), \ldots, y(k - n + 1), u(k), \ldots u(k - n + 1)]}{g[y(k), \ldots, y(k - n + 1), u(k), \ldots u(k - n + 1)]} \] (6)

where \( d \geq 2 \).

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

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.

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

\[ G(s) = \frac{\Omega(s)}{V_a(s)} = \frac{S(s)}{E(s)} = \frac{K_s}{1 + \tau_m s} \] (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 \( \tau_m=1 \) sec

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.

References


7. Theriou N, Tsirigotis G. The construction of an anticipatory


Neuroniniai tinklai dėl daugiausiausu skirtingo perseptrono aпроksимavimo galimybęs įžadėti populiarių įrankių modeliuojant netiesines sistemas ir išdėstiant netiesinius valdiklius. Vienas iš jų, skirtingų prognozavimų ir valdymų, yra valdiklis NARMA–L2 (arba grijžtamojo ryšio linearizacijos Valdiklis).

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


Neural Networks, due to their approximation capabilities of Multilayer Perceptron (MLP) are promising to become a popular tool for modeling nonlinear systems and implement 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).