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# Experiments on Neural Control of a Flexible Manipulator

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# Abstract

Applications of neural networks (NN's) in the fields of identification, state estimation, and control of nonlinear dynamic plants have been recently developed [1] [2] [3]. Several neural models have been proposed to the aim of better replicate the dynamical behaviour of such systems [4] [5] [6] . Infact is well known that, given a sufficient number of training examples, NN's can learn a wide class of nonlinear mappings.

In this paper a multilayer neural network [7] is considered for the identification of a flexible robot arm. Measuring the position and the speed of a "sufficient" number of points along the link is feasible the reconstruction of the state space rapresentation of the arm (rigid and elastic variables). Adequately exciting the system is then possible to obtain a training set including evolutions of sampled inputs and states. This set, opportunely scaled, is to be considered for feeding the NN. The resulting mapping is then used in a reverse way, to produce a suitable control to drive the robot along a trajectory, from an equilibrium point to an other, with fast modal damping characteristics.

Many problems arise when dealing with this particular mechanical system due to the presence of an unstable and unobservable dynamics: the transfer function between the torque applied at the joint level and the position of the end effector presents infact a non minimum phase structure [8]. Using the nonlinear regulator theory [10], it can be shown that exact tracking of a trajectory with internal stability admits only one evolution for the state variables. This leads to the impossibility of imposing a trajectory for the state without knowing the explicit form and the exact values of the parameters of the model.

After a short review of the model properties [9] it is shown in the paper how the series-parallel formulation for the identification model [1] is adequate. In this case its state $Y_P$ is assumed depending from the previous states and from the input $u$ of the real system:

$$Y_P(k+1) \doteq \Phi[Y_P(k), Y_P(k-1), Y_P(k-2)] + u(k). \tag{1}$$

Given the above structure the NN can be trained to learn the nonlinear mapping between the delayed values of the plant states and the control input (see fig. 1). In this way th NN learns to emulate the inverse plant: when the desired state evolution is presented as its input, the NN computes a suitable plant control input. This approach

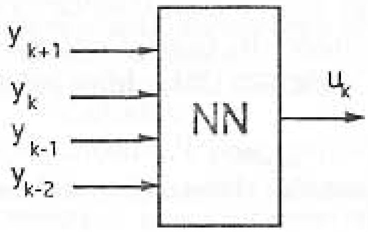


Figure 1: Training scheme

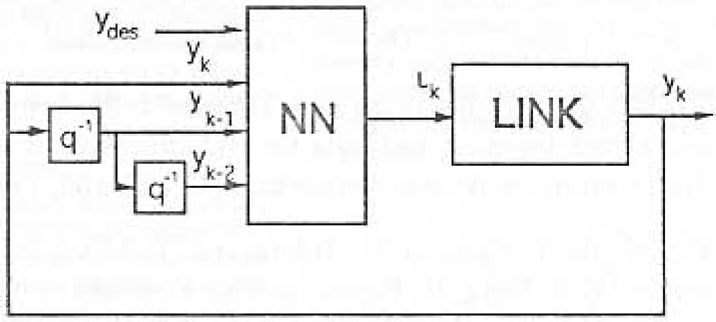


Figure 2: Control scheme

stress the nonlinear aspects of these control systems and their ability to work with a "black box" representation of the plant.

Using now the NN to control the link movement the scheme shown in fig 2 can be succesfully adopted if the future desired state is fully known. In our case this model reference approach cannot be directly used becouse is not possible to impose an evolution for the whole state without knowing the admissible one. So we can ask to the system only to have some properties, relaxing the condition of exact traking.

The proposed control scheme has been implemented on the flexible arm available in the Robotics Laboratory at DIS [11] and experimental results are reported.

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