8

Conclusions and Future Work

8.1 Conclusions

In this work, based on the neural network and feedback linearization techniques, a novel method to design robust control for a class of MIMO discrete-time nonlinear uncertain systems is proposed. This method includes four different control schemes, which can be applied depending on the state vector measurement viability:

a) The first designed robust *direct* neural control scheme is based on the backstepping technique, approximated by a high order neural network. On the basis of the Lyapunov approach, the respective stability analysis, for the whole closed-loop system, including the extended Kalman filter (EKF)-based NN learning algorithm, is also performed.
b) The second robust *indirect* control is designed with a recurrent high order neural network, which enables to identify the plant model. A strategy to avoid specific adaptive weights zero-crossing and conserve the identifier controllability property is proposed. Based on this neural identifier and applying the discrete-time block control approach, a nonlinear sliding manifold with a desired asymptotically stable motions was formulated. Using a Lyapunov functions approach, a discrete-time sliding mode control that makes the designed sliding manifold to be attractive was introduced.

Both the first and second control schemes require only the plant model structure knowledge, but the plant state vector must be available for the measurement. In the case when only the plant output is measured, some plant parameters are needed to design an observer.

c) For nonlinear plants whose mathematical model is assumed to be unknown and the only output vector can be measured, the third robust control scheme was designed. This strategy includes an adaptive recurrent neural observer, which estimates the state vector of the unknown plant dynamics. This observer has a Luenberger structure and is based on a recurrent high

E.N. Sanchez et al.: *Discrete-Time High Order Neural Control – Trained with Kalman Filtering*, Studies in Computational Intelligence (SCI) **112**, 95–96 (2008)
www.springerlink.com

order neural network (RHONN) trained by the EKF learning algorithm. Using the separation principle, stability conditions for the complete closed-loop system were derived.

d) Based on the above proposed RHONN observer, two *trajectory tracking* control policies were formulated. The first one was achieved by using the backstepping technique, while the second version was designed implementing the block control linearization approach techniques. The respective stability analysis carried out for the neural observer trained by the EKF learning algorithm and block controller has proved robustness of the closed-loop system.

Effectiveness of all the proposed schemes was illustrated via design, computer simulation, and real-time implementation of four discrete-time controllers designed for an induction motor. It was established that

e) For the controllers based on the first two proposed schemes ((a) and (b)), only the rotor loop parameters are needed to design the rotor flux nonlinear observer. The obtained flux estimates were then used in the *direct* backstepping high order neural network controller (a) and to train the RHONN identifier in the *indirect* controller (b).
f) For the controllers based on the RHONN observer ((c) and (d)), the knowledge of the motor parameters is not required.

The simulation and real-time implementation of the schemes proposed in this book are presented, validating the theoretical results, using a benchmark for a three phase induction motor.

The experimental results illustrate the robustness of the designed controllers with respect to motor parameter variations and the load torque (external disturbance).

8.2 Future Work

As a future work, it is worth to mention the following:

- Design robust controllers for electric power system using the developed in the book robust control method
- Design a discrete-time indirect control scheme of speed and limited current for an induction motor
- Design discrete-time neural observers of reduced order for nonlinear uncertain systems
- Design a sensorless neural observer in the benchmark of an induction motor
- Design of a bounded neural controller based on the backstepping technique