Intelligent Control of a Stepping Motor Drive Using a Hybrid Neuro-Fuzzy ANFIS Approach

Leocundo Aguilar, Patricia MELIN, and Oscar CASTILLO
Dept. of Computer Science,
Tijuana Institute of Technology,
P.O. Box 4207 Chula Vista CA 91909, USA
pmelin@tectijuana.mx
ABSTRACT

• Stepping motors are widely used in robotics and in the numerical control of machine tools where they have to perform high-precision positioning operations.

• However, the variations of the mechanical configuration of the drive, which are common to these two applications, can lead to a loss of synchronism for high stepping rates.
In this paper, fuzzy logic is applied to control the speed of a stepping motor drive with feedback. A neuro-fuzzy hybrid approach is used to design the fuzzy rule base of the intelligent system for control. In particular, we used the ANFIS methodology to build a Sugeno fuzzy model for controlling the stepping motor drive. An advanced test bed is used in order to evaluate the tracking properties and the robustness capacities of the fuzzy logic controller.
INTRODUCTION

- Stepping motors can be viewed as electric motors without commutators [6]. Typically, all windings in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material.
Introduction cont.

- For some applications, there is a choice between using servomotors and stepping motors.
- Both types of motors offer similar opportunities for precise positioning, but they differ in a number of ways. Servomotors require analog feedback control systems of some type.
- Typically, this involves a potentiometer to provide feedback about the rotor position, and some mix of circuitry to drive a current through the motor inversely proportional to the difference between the desired position and the current position.
In this paper, the application of fuzzy logic is proposed to control the speed of a stepping motor drive. The closed-loop control scheme entails in incorporating engineering knowledge into the automatic control system by using the intuition and experience of the designer.
Moreover, this technique offers the advantage of requiring only a simple mathematical model to formulate the algorithm, which can easily be implemented by a digital computer.

These features are appreciated for nonlinear processes for which there is no reliable model and complex systems where the model is useless due to the large number of equations involved. Additionally, fuzzy logic is used more frequently for the control of electrical machines such as direct current or induction motors. Nevertheless, the main problem with fuzzy logic is that there is no systematic procedure for the design of a fuzzy controller.

For this reason, we propose in this paper the use of the ANFIS methodology to adapt the parameters of the fuzzy system for control.
BASIC CONCEPTS OF STEPPING MOTORS

- Stepping motors come in two varieties, *permanent magnet* and *variable reluctance* (there are also *hybrid* motors, which are indistinguishable from permanent magnet motors from the controller's point of view). You can distinguish between the two varieties with an ohmmeter. Variable reluctance motors usually have three (sometimes four) windings, with a common return, while permanent magnet motors usually have two independent windings, with or without center taps.
Center-tapped windings are used in unipolar permanent magnet motors [6]. Stepping motors come in a wide range of angular resolution. The coarsest motors typically turn 90 degrees per step, while high resolution permanent magnet motors are commonly able to handle 1.8 or even 0.72 degrees per step. With an appropriate controller, most permanent magnet and hybrid motors can be run in half-steps, and some controllers can handle smaller fractional steps or micro-steps.
Variable Reluctance Motors
Unipolar Motors
Bipolar Motors
DYNAMICS OF THE STEPPING MOTOR

• Each time you step the motor, you electronically move the equilibrium position $S$ radians. This moves the entire curve a distance of $S$ radians, as shown in next figure.
Dynamics of a stepping motor
Trajectory of the motor rotor
FUZZY LOGIC CONTROLLER OF THE STEPPING MOTOR

- The fuzzy logic controller provides an algorithm, which converts the linguistic control, based on expert knowledge into an automatic control strategy.
- Therefore, the fuzzy logic algorithm is much closer in spirit to human thinking than traditional logical systems.
- The main problem with fuzzy logic controller generation is related to the choice of the regulator parameters.
FUZZY LOGIC CONTROLLER OF THE STEPPING MOTOR

- For this reason, we apply the ANFIS methodology to adapt the parameters of the fuzzy controller according to real data about the problem. The experiments were made on a system described in the next Figure.
- A computer program in the PC generates the step input to the system and stores the response.
- The fuzzy controller is also contained in the PC and acts on the system according to the corresponding responses.
Block diagram of the experimental system
We now describe briefly the modules of the system

1) Motor/Driver: Micro-step motor Vexta PV266-01E with five phases and 500 steps by turn (The motor is shown in the next figure). Power driver Vexta DFR1514A with multi-resolution (Minimum: 500 steps by turn; Maximum: 125000 steps by turn).

2) Encoder: Optical encoder Bourns of 40000 steps by turn. This encoder generates two square signals with 90 degree difference. With these signals the magnitude of motor movement is determined. We use the programmable logic device (PLD) of Altera (EP5032) to determine the movement of the motor.

3) Data Acquisition Card: PCL-818 of Advantech with 8 analog inputs and 2 analog outputs (12 bits), 16 digital inputs, 16 digital outputs. The sampling time used is 0.25 ms.

4) Computer/Software: Pentium III with 733 MHz. We design a small real time kernel in C language for control and data acquisition, and the fuzzy controller was programmed in MATLAB [9].
Motor Vexta PV266-01E
Control rules

- The linguistic control rules are established considering the dynamic behavior of the stepping motor drive and analyzing the error and its variation. These control rules are expressed as follows:
  
  If Error is LP and Change_Error is LP
  then Speed = p₁*Error +q₁*Change_Error + r₁
  
  If Error is LP and Change_Error is MP
  then Speed = p₂*Error +q₂*Change_Error + r₂ ...

- This is a Sugeno fuzzy model [10] for controlling the stepping motor. We used the ANFIS methodology to estimate the parameters of the membership functions and the consequent functions. We used a fuzzy model of 9 rules and 3 membership functions for each linguistic variable. This was the fuzzy controller that gave the best results. We show in the next figure the architecture of the fuzzy system with the ANFIS approach.
Architecture of the Sugeno fuzzy system with the ANFIS approach.

System anfis: 2 inputs, 1 outputs, 9 rules
The fuzzy rules generated by the ANFIS method are shown in the next Figure

1. If (input1 is in1mf1) and (input2 is in2mf1) then (output is out1mf1) (1)
2. If (input1 is in1mf1) and (input2 is in2mf2) then (output is out1mf2) (1)
3. If (input1 is in1mf1) and (input2 is in2mf3) then (output is out1mf3) (1)
4. If (input1 is in1mf2) and (input2 is in2mf1) then (output is out1mf4) (1)
5. If (input1 is in1mf2) and (input2 is in2mf2) then (output is out1mf5) (1)
6. If (input1 is in1mf2) and (input2 is in2mf3) then (output is out1mf6) (1)
7. If (input1 is in1mf3) and (input2 is in2mf1) then (output is out1mf7) (1)
8. If (input1 is in1mf3) and (input2 is in2mf2) then (output is out1mf8) (1)
9. If (input1 is in1mf3) and (input2 is in2mf3) then (output is out1mf9) (1)
Membership functions generated by the ANFIS method
Non-linear surface of the Sugeno fuzzy model
Fuzzy rule viewer for calculating the output of the fuzzy system for specific values
EXPERIMENTAL RESULTS

- In this section, the tracking and adaptability features of the fuzzy control applied to the stepping motor are tested using simulation and experimentation.
- We first show the response of the stepping motor to a sequence of step input signals (we use 400 samples).
EXPERIMENTAL RESULTS
Stepping Motor input-output

![Graph showing input and output signals for a stepping motor.](chart.png)
Experimental Results cont.

- We show in the next Figure the results of applying the ANFIS methodology with the training data and with the testing data. We used 20 epochs for training and the final error was of 0.000001, which is very good for this application.
- We plot the predicted values by the fuzzy model and the real values for the system, and the curves are practically indistinguishable.
- Finally, we show a plot of the difference between both the real and the estimated signal by the fuzzy model.
EXPERIMENTAL RESULTS

Results of applying the ANFIS methodology to the training and testing data
EXPERIMENTAL RESULTS
Predicted values of the fuzzy model compared against the real values
EXPERIMENTAL RESULTS

Difference between the real and the estimated signal
CONCLUSIONS

- In this paper, the feasibility of fuzzy control for stepping motor drives has been proved and illustrated by simulation and experimentation.
- The best parameters for the fuzzy controller were determined by using the ANFIS methodology and also by using simulations of the stepping motor dynamics.
CONCLUSIONS

- An experimental system was used to validate experimentally the tracking ability and the insensitivity to plant parameter changes.
- The fuzzy controller presented very interesting tracking features and was able to respond to different dynamic conditions.
- Also, the fuzzy control computation is very inexpensive, and this regulator could be used for the control of machine tools and robotics manipulators [4] without significantly increasing the cost of the drive.
CONCLUSIONS

- The only extra cost is for the optical encoder. Another advantage of this method over classical quantitative controllers is that it does not require a fixed sampling time.
- Therefore, the proposed design confirms the fact that fuzzy control is relevant to the control fast of nonlinear processes such as stepping motor drives where quantitative methods are not always appropriate.