DC Motor Controller Design with NeuFuz™

National Semiconductor
Application Note 958
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FEATURES

- Provides accurate Motor Control based on NeuFuz algorithm
- Reduces design time
- Requires minimum hardware
- Existing control solutions can be duplicated
- Low power consumption during normal operation
- Firmware extremely modular, and is designed to be either embedded stand alone unit or slave to host
- Firmware for new motor type is possible without writing any microcontroller code
- Solution valid under varying load conditions

INTRODUCTION

This application note focuses on a design based on National Semiconductor's patented NeuFuz based Neural-Fuzzy technology to arrive at a motor control scheme implemented on National Semiconductor's low-cost COP8™ microcontroller. NeuFuz technology allows for the automated generation of a fuzzy logic control engine based on training data. In this case, the training data was taken from the motor characteristics obtained from the open loop response. The NeuFuz based design methodology followed here allows for tailoring the controller to suit different motor characteristics without having to rewrite the code.

Motor control for accurate positioning and speed is a very important function in many applications. Whether a small induction motor is used for proper autofocus in a camera or camcorder, or a servo motor is used for proper positioning of the head in a high-speed hard disk, the algorithm for motor control is the key to the success or failure of the product.

HARDWARE CONFIGURATION

The motor controller board consists of a COP8 series microcontroller, an A/D converter, an RS-232 driver, and a DAC. The COP8 series microcontroller used in the motor control application is a National Semiconductor COP884EG. The COP884EG is one of a family of fully static 8-bit CMOS microcontroller's built around the common COP8 core. The analog to digital converter is a National Semiconductor ADC0841. The ADC0841 is a CMOS 8-bit successive approximation converter. The National Semiconductor DS14C232C is an integrated RS-232 driver and receiver with built in power supplies that generate the required RS-232 voltages from the 5V supply line. The digital to analog converter is a National Semiconductor DAC0890. The DAC0890 is a complete dual 8-bit DAC that can operate on a single 5V supply.

The ADC0841 is used to determine the speed of the motor. The motor is mechanically connected to the generator.

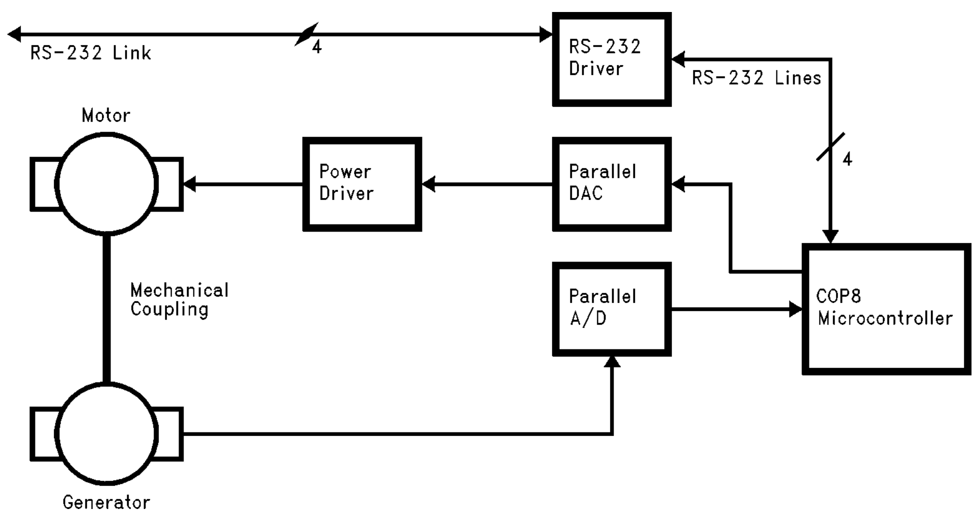

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FIGURE 1. NeuFuz Based Motor Controller Block Diagram

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Since the output voltage of the generator is directly proportional to the speed of the generator shaft, reading the generator voltage gives a proportional indication of the speed of the motor. The generator produces an output voltage of 0 VDC to +130 VDC, corresponding to a rotor speed of 0 RPM to 2500 RPM. By using a divider bridge constructed from three resistors, the generator voltage is attenuated to a signal ranging from 0 VDC to +5 VDC. The voltage step-down is required since the ADC0841 has an input operating range of 0 VDC to +5 VDC. Since the ADC0841 has 8-bit resolution, each bit corresponds to 2500 RPM/(2^8 bits) = 9.766 RPM/bit. This conversion indicates that, for example, a reading of A2 hex (162 dec) from the A/D indicates a speed of 9.766 RPM*162 = 1582 RPM. The conversion also indicates that 8-bit accuracy corresponds to a speed resolution of a little less than ten RPM, which is sufficient for most control applications.

An RS-232 port is included in the design with minimum effort. The COP888EG has a built in serial port that can be controlled in software to provide all standard features, such as start bits, stop bits, and parity. The baud rate of the port is controlled in software. The only component needed to implement the serial port is a line driver and a receiver chip, the DS14C232C. The DS14C232C has on-chip power circuitry to generate both +12 VDC and −12 VDC. The RS-232 interface is used to connect to a PC which has a monitoring and display program.

The DAC0890 8-bit DAC is used to provide a speed control signal that ranges from 0 VDC to +10.2 VDC. The speed control signal is used to drive a power amplifier that provides a motor drive signal that ranges from 0 VDC to +130 VDC. The relationship between the speed control signal and the motor drive signal is linear. The resolution for the motor drive voltage is 9.766 RPM, the same value as the speed resolution.

Firmware Modules

The firmware for the motor controller is extremely modular. It can therefore be tailored to design a system with a mix and match of needed features.

The complete Neuro-Fuzzy development cycle to create the motor control algorithm consists of the following steps:

— Determine input and output variables.

— Define the data set by studying motor parameters.

— Preprocess the data set to tailor it to the hardware.

— Configure the NeuFuz neural network.

— Train the neural network.

— Find an optimized fuzzy representation.

— Generate code for the fuzzy module.

— Integrate code with other code in the target system.

Data Set Definition

The first step in motor design is to decide on the input parameters, which represent the internal state of the motor control transfer function. The parameters chosen should be easy to measure, using a low cost sensor and an A/D converter. The data set should contain information about nonlinearities in the motor characteristics and more data points are needed around the critical nonlinear portions of the characteristics, and areas of operation where precise control is desired.

Preprocess the Data Set

Once these parameters are known, a table containing the values and corresponding outputs are made. It is recommended that sufficient data points are available to account for the nonlinearities of the system. The input data points must span the entire range. This table must be in the form of an ASCII flat file. The NeuFuz user's manual provides useful information on preparing the ASCII file.

Configure the Neural Net

The configuration parameters for training the neural net, the number of fuzzy membership functions desired and the absolute accuracy desired from the system need to be defined.

Train the Neural Network

Training the neural network is an iterative process. This requires the user to study the error generated during training and to modify the neural network's training parameters.

Find An Optimized Fuzzy Representation

The fuzzy logic solution obtained from the trained neural network needs to be verified for accuracy and size. Verify the accuracy of the solution over the entire range of input space. This fuzzy logic solution can be further optimized directly from NeuFuz using a deletion factor to eliminate some of the less significant rules, with minimal effect on the accuracy of the solution.

Generate Code

Once the neural network has been trained and the accuracy of the fuzzy logic solution found acceptable, the NeuFuz package automatically generates COP8 code. The code generated by NeuFuz comprises of relocatable COP8 assembly code. The code generated also includes the definitions for the RAM requirements. A ''log'' file indicating the amount of RAM and ROM used for this algorithm is also generated. The COP8 code includes some general purpose math routines for multiplication and division and can be shared by other firmware modules.

Integrate Code with Other Firmware Modules

To integrate the NeuFuz generated fuzzy logic assembly code with the rest of the code is required to pre-process the inputs and output externally. In this application, it was required to process the input data acquired from the A/D converter and scale it. The scaled input is an 8-bit value and is stored in RAM. The fuzzy logic algorithm reads data from these RAM locations and writes the output in RAM.

One of the most significant benefits of using the fuzzy logic assembly code produced by NeuFuz is that the RAM used by it can be reused by other assembly modules.

Should the NeuFuz generated code be interrupted during execution, it is necessary to protect all the contents of RAM used by NeuFuz. Special care must be taken not to overwrite the RAM locations that NeuFuz uses.

Performance

The NeuFuz solution compares favorably to a conventional PID approach. To illustrate the superiority of NeuFuz, step response tests can be performed to evaluate the performance of the two control functions for the same application. For a test case, tests were run with input speed settings from 500 RPM to 2500 RPM in 500 RPM increments. These tests show that the NeuFuz controller demonstrates reduced overshoots and settling time at start up, while maintaining approximately the same rise time. The rise time is defined as the time it takes for the motor speed to go from 10% to 90% of the desired speed. Maximum overshoot is defined as the maximum positive deviation of the motor speed from the desired speed. This is represented in the table as a percentage of the desired speed.

The motor and the generator used in this application has the following characteristics: maximum operating speed of 2500 RPM, a maximum power of ⅛ HP, input voltage range from 0 VDC to +130 VDC and a motor time constant of 0.90.

Performance of NeuFuz and PID Control Algorithms

Desired Speed	PID Rise Time	NeuFuz Rise Time	PID Overshoot	NeuFuz Overshoot
500	360 ms	400 ms	20%	2%
1000	360 ms	360 ms	18%	0%
1500	480 ms	480 ms	19%	1%
2000	480 ms	480 ms	20%	1%

The results obtained from the tests performed on the two solutions are summarized in the performance table. In both the NeuFuz case and the PID case, the controllers provide a zero steady state error. The overshoots at start up in case of the conventional solution can be reduced by increasing the damping factor of the controller. However, increasing the damping factor of the PID controller will increase the rise time.

NeuFuz Design Implications

Neural networks and fuzzy logic are highly suitable for modeling nonlinear, time-variant system behavior. Conventional linear control can only perform a linear approximation of a nonlinear behavior. This approximation may be sufficient for some applications, but not suitable for all, especially when a high degree of of accuracy is desired. Neural networks and fuzzy logic have proven to be highly suitable for such applications. Although these two technologies individually suffer from certain drawbacks, when combined as in NeuFuz, these disadvantages can be successfully filtered out, maintaining all the advantages. NeuFuz allows the designer to take advantage of the learning capability of neural networks, at the same time providing a cost-effective fuzzy logic implementation of the system. It offers a high level of automation in the design process, significantly reducing design time. It allows the designer to concentrate on the system configuration and performance hiding all the error prone, cumbersome mathematical manipulations. It offers more control over the design by introducing an added feature to specify the accuracy of the fuzzy system, as well as better modeling of nonlinear behavior. The result is improvement in performance. The advantages of NeuFuz based design make it a clear choice for microcontroller based motor control.

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