Controlled Slip Design with NeuFuz™

National Semiconductor
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FEATURES

- Provides accurate slip control based on NeuFuz algorithm
- Reduces design time
- Requires minimum hardware
- Can be used to duplicate existing control solutions
- Can be used for traction control or ABS systems
- Firmware extremely modular
- Firmware for new wheel type is possible without writing any microcontroller code
- Solution valid under varying friction conditions

INTRODUCTION

This application note focuses on a design based on National Semiconductor's patented NeuFuz based neural-fuzzy technology to arrive at a slip 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 well known characteristics of controlled slip. Using the NeuFuz4 code generator, the NeuFuz based design methodology followed here allows for tailoring the controller to suit different motor and wheel characteristics without having to rewrite the code.

Drive wheel slip is defined as the difference in the tangential velocity of a rotational drive wheel and the surface being driven. In vehicular drive applications, slip is the difference in wheel speed (tangential tire velocity) and vehicle speed (speed of the vehicle). Controlling the magnitude of slip is the basis of vehicular applications such as Anti-lock Brake Systems (ABS) and controlled traction transmissions. Rather than eliminate slip totally, slip control systems are designed to provide some slip to the system. Typical automotive ABS systems attempt to control slip so that a constant 20% slip rate is maintained during ABS operation. The experimental system was constructed to investigate the slip control problem. The problem was posed as a drive wheel turning a flywheel as shown in *Figure 1.* The mechanical coupling between the drive wheel and flywheel was intentionally kept loose. If the drive wheel attempted to change the speed of the flywheel too quickly, the high inertia of the flywheel would cause it to remain at its current rotational velocity. In this case, the condition of the flywheel following the speed changes of the drive wheel too slowly is called slip. In this experiment, traction control attempted to accelerate the flywheel to a predetermined velocity while ABS braking was accomplished by reversing motor direction and attempting to reduce the flywheel speed to a lower set point. As a control problem, two inputs and one output are needed for the experimental slip system. The inputs are the drive wheel speed and the vehicle speed. The input speed values are 8-bit unsigned integers read from a counter that counts timing pulses for the two wheels. The output speed value is an 8-bit unsigned integer written to a counter that generates a PWM motor drive signal. The smaller counter values represent greater speed.

COP8 Microcontroller

The slip control application was implemented using a National Semiconductor COP884CG. The COP884CG is one of National Semiconductor's family of fully static 8-bit CMOS microcontroller's built around the common COP8 core. All COP8 microcontrollers are capable of executing the same NeuFuz4 code. For any application, the particular COP8 that offers the optimum feature set can be selected. For example, the slip control problem requires that two optical timing disks be monitored and a PWM motor control signal be generated. The COP884CG has three 16-bit counter times. For the slip control application, two counter timers are used to count timing wheel pulses and the third counter timer is used to generate a PWM control signal. For other applications which require analog inputs, the COP884CF trades off one 16-bit counter timer for an 8-bit SAR type A/D converter. NeuFuz4 and the appropriate COP8 can handle data from any source provided that the inputs can be expressed as one byte values.

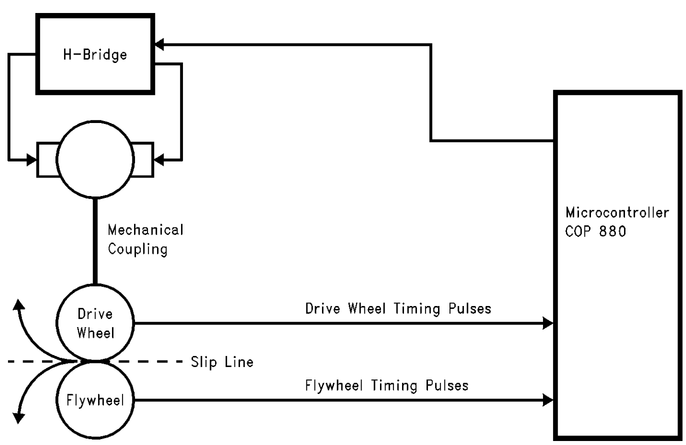

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FIGURE 1. NeuFuz Based Slip Controller Block Diagram

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NeuFuz4

NeuFuz4 is a software tool to automatically generate a control program for the COP8 microcontroller. The control program uses fuzzy logic concepts, the rules and membership functions for the fuzzy logic equations are generated automatically using the back propagation learning algorithm. The rules and membership functions are used to implement any general non-linear function of between one and four variables. Given several representative examples of the desired input and output data points, NeuFuz4 will learn a general solution. From the general solution, NeuFuz4 will generate a source code program in COP8 assembly language that can be used to implement the control function.

The data used by NeuFuz4 to generate a solution can come from many different sources. The four most common sources are a manually entered concept, the output of a simulation, a theoretical model, or collected from an existing application. A manually entered concept requires knowledge of the application. The knowledge can be either fuzzy in concept, in which case NeuFuz4 offers "A Better Fuzzy Logic than Fuzzy Logic", since NeuFuz4 can generate the required rules and membership functions knowing only the center values of the desired results. For example, a set of fuzzy rules that can be used to generate training data for the slip application can be written intuitively. A manually entered concept may also be a control surface which is well known. Both the traction control and the ABS applications have well known control surfaces. The control surfaces from available data tables give the best results and were selected for this application. Data collected by observation from simulations or theoretical models may be used to generate data that can be used for a final solution. Data collected from existing solutions may be used to reverse engineer control solutions.

Programs generated by NeuFuz4 will be predictable and reliable. Since all programs generated by NeuFuz4 are essentially identical except for tables of fuzzy logic parameters, the reliability of the code is assured. The control function can be changed by changing the fuzzy evaluation table, and leaving the main fuzzy inference program unchanged.

Programs generated by NeuFuz4 have a high level of integration. Since NeuFuz4 generates a program that maps all byte combinations of between one and four inputs to a five byte output, the need for preprocessing of data before a control algorithm is executed is drastically reduced. For the slip control application, the entire algorithm was implemented in NeuFuz4, so that no preprocessing was required.

Generating programs using NeuFuz4 shorten development time since NeuFuz4 automatically implements, in a reliable and execution efficient program, any desired control function. The development time for the slip control program using the NeuFuz4 code generator was four days for a complete solution.

Firmware Modules

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

The complete neural-fuzzy development cycle to create the slip control algorithm consists of the following steps:

— Define the data set.

— 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.

— Integrate code with other code in the target system.

Data Set Definition

The first step in a NeuFuz design is to decide on the control input parameters. In order to avoid data scaling problems, the data set is selected so that 8-bit values read directly from the speed counters are used as input to the FUZZ routine. One of the five bytes of OUT is used to directly load the PWM counter.

If No Data Exists

The best use of NeuFuz is the generation of high precision solutions from desired performance data. In the case of the slip control application, the desired performance is a well known control surface. Many applications exist where such information is not available. If very little information is known about the system to be controlled and very little data is available, the flexibility of NeuFuz4 allows it to be used as a better form of fuzzy logic. For example, in the case of the traction case of the slip control application, the rules can be intuitively stated as follows:

IF wheel speed IS small AND vehicle speed IS small
THEN slip IS small SO increase speed.

IF wheel speed IS medium AND vehicle speed IS small
THEN slip IS medium SO hold speed.

IF wheel speed IS large AND vehicle speed IS small
THEN slip IS large SO decrease speed.

IF wheel speed IS small AND vehicle speed IS medium
THEN slip IS medium SO hold speed.

IF wheel speed IS medium AND vehicle speed IS medium
THEN slip IS small SO THEN increase speed.

IF wheel speed IS large AND vehicle speed IS medium
THEN slip IS medium SO hold speed.

IF wheel speed IS small AND vehicle speed IS large
THEN slip IS large SO decrease speed.

IF wheel speed IS medium AND vehicle speed IS large
THEN slip IS medium SO hold speed.

IF wheel speed IS large AND vehicle speed IS large
THEN slip IS small SO THEN increase speed.

Conventional fuzzy logic systems require that the membership functions for large, medium, and small be fully defined. NeuFuz4 requires only that an approximate value close to the center value of the membership functions be declared. The width, height, and location of each membership function and the values of the rules will be automatically determined by the Neural Network in NeuFuz4. For the rules given above, for example, the data file can be written directly as:

 # "Better Fuzzy than Fuzzy" Data for Traction Control

# Wheel Speed	**Vehicle Speed**	**ΔPWM Counter**
0	0	+127
127	0	0
255	0	−127
0	128	0
127	128	+127
255	128	0
0	255	−127
127	255	0
255	255	+127

From this very sparse data, NeuFuz4 can generate a complete fuzzy logic solution. While conventional fuzzy logic requires extensive guess work to determine the width and height of membership functions, NeuFuz4 can interpolate between values to give a solution.

Preprocess the Data Set

Once the control input and output parameters are known, a table containing the values and corresponding output are made. It is recommended that sufficient data points are available to account for the nonlinearities of the system. The data points must span all the possibilities of input values within the input space. The table must be in the form of an ASCII file. The NeuFuz4 user 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 learning neural network's parameters when needed.

The NeuFuz4 training for both the ABS and traction control surfaces has 440 data points each. Using a learning rate of 0.1 and a learning factor of 0.01 the neural network will converge to an epsilon of 0.5 in less than 50 hours on a 486DX50. Since both the inputs and the output range between 0 and 255, an epsilon of 0.5 gives ½ LSB accuracy.

Convergence time is strongly dependent on the number of data points in the training data. For example, the rough solution given by the "Better Fuzzy then Fuzzy" data with only nine data points will converge in a few minutes on a 486DX50.

Find an Optimized Fuzzy Representation

The fuzzy logic solution obtained from the trained neural network needs to be verified for accuracy and size. The accuracy of the solution is verified over the entire range of input space. This fuzzy logic solution can be further optimized directly from NeuFuz4 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, NeuFuz4 automatically generates COP8 code. The code generated by NeuFuz4 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

In this application, the unscaled input is an 8-bit value and is stored in RAM locations IN1 and IN2. The fuzzy logic algorithm reads data from these RAM locations and writes the output in RAM locations labeled OUT1 to OUT5.

One of the most significant benefits of using the fuzzy logic assembly code produced by NeuFuz4 is that the RAM used by it can be reused by other assembly modules.

Should the NeuFuz4 generated code be interrupted during execution, it is necessary to protect all the contents of RAM used by NeuFuz4. Special care must be taken not to overwrite the RAM locations that NeuFuz4 uses.

NeuFuz Design Implications

Neural networks and fuzzy logic are highly suitable for modeling non-linear, 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 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 eliminated, 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 and significantly reduces design time. It allows the designer to concentrate on the system configuration and performance while hiding all the error prone, cumbersome mathematical manipulations. It provides 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 and reduction in cost. the advantages of NeuFuz based design make it a clear choice for microcontroller based slip control.

Results

The COP8 slip controller is able to perform both the ABS and traction control functions better than a human operator. The slip control circuit can be completely implemented with two chips, a COP884CG microcontroller and an LM12298 H-bridge. By using NeuFuz4, an accurate, reliable, high-performance solution control program was generated for the COP8 in a much shorter time than would be required for a manually written program. NeuFuz4 is extremely flexible, training data may be either precise values for high performance solutions to well known problems or rough fuzzy-logic type approximations if not precise training data is available.

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