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Fuzzy Logic in Control Design Anti-Lock Brake System

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Abstract: In recent years fuzzy logic control techniques have been applied to a wide range of systems. Many electronic control systems in the automotive industry such as automatic transmissions, engine control and Anti-lock Brake Systems (ABS) realize superior characteristics through the use of fuzzy logic based control rather than traditional control algorithms. ABS is implemented in automobiles to ensure optimal vehicle control and minimal stopping distances during hard or emergency braking. ABS is now accepted as an essential contribution to vehicle safety. Intel Corporation is the leading supplier of microcontrollers for ABS and enjoys a technology agreement with Inform Software Corporation the leading supplier of Fuzzy Logic tools and systems. The increasing automotive customer awareness of ABS has greatly increased the demand for this technology. Improving ABS capability is a mutual goal of automotive manufacturers and Intel Corporation. The growing interest in the automotive community to implement fuzzy logic control in automotive systems has produced several major automotive product introductions. The use of fuzzy-logic in conjunction with microcontrollers is a fairly new development in automotive applications. In future it is expected that ABS will be implemented all over the world.

Key Words: Fuzzy logic, ABS, COG, ECU.

I. INTRODUCTION

Formal control logic is based in the teachings of Aristotle, where an element either is or is not a member of a particular set. Since many of the objects encountered in the real world do not fall into precisely defined membership criteria, some experimentation was inevitable. L. A. Zadeh was one of those who investigated alternative forms of data classification. The result of this investigation was the introduction of fuzzy sets and fuzzy theory at the University of California Berkeley in 1965. Fuzzy logic, a more generalized data set, allows for a "class" with continuous membership gradations. This form of classification with degrees of membership offers a much wider scope of applicability, especially in control applications. Although fuzzy logic is rigorously structured in mathematics, one advantage is the ability to describe systems linguistically through rule statements. One such control rule statement for an air conditioning unit might be:

"If temperature is Hot and Time of Day is Noon then air conditioning equals very high." Several rules, similar to the example, could be used to describe a system and controlled response. The parameters of Hot, Time and Very High are defined by membership functions. As linguistic descriptions of a system are much easier to produce than complex mathematical models, fuzzy logic has great appeal for controlling complex systems as changes in the system have little if any effect upon the algorithm. Fuzzy ABS would require more complex control constructs than simple "if - then" rules. In this type of control system, input variables map directly to output variables. This simple mapping does not provide enough flexibility to encode a complex system such as an ABS system. However, more complex techniques are available which can be applied to fuzzy logic systems. For example, it is possible to build a control with intermediate fuzzy variables, or systems which have memory. With these constructs, it is possible to build rules such as...

"If the rear wheels are turning slowly and a short time ago the vehicle speed was high, then reduce rear brake pressure". Such rules lend themselves to development of an ABS braking system based on fuzzy logic. The output of a fuzzy logic system is determined in one of several ways. The Center Of Gravity (COG) technique will be discussed in this paragraph. Once all rules are evaluated, their outputs are combined in order to provide a single value that will be defuzzified. This output calculation is performed as follows. The control rule output value is multiplied by its position along the X-axis, yielding position times weight for the rule. This calculation is repeated for all control rules. These position/weight products are combined to form the sum of products. This sum of the products is divided by the sum of

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output values to determine the COG output along the X-axis. COG is the final system output in a control algorithm.

II. FUZZY EQUIPPED ABS

ABS systems were introduced to the commercial vehicle market in the early 1970's to improve vehicle braking irrespective of road and weather conditions. However, due to the technical difficulties and high cost of early systems, ABS was not recognized by automakers as an advantage until the mid-1980. The ABS market has rapidly grown and is forecast to be $5 billion yearly by 1995 and $10 billion or more by the year 2000. Experts predict that 35% to 50% of all cars built worldwide in five years will have ABS as standard equipment. Electronic control units (ECUs), wheel speed sensors, and brake modulators are major components of an ABS module. Wheel speed sensors transmit pulses to the ECU with a frequency proportional to wheel speed. The ECU then processes this information and regulates the brake accordingly. The ECU and control algorithm are partially responsible for how well the ABS system performs. This paper will focus on using the Intel 8XC196Kx product family, as the ECU, to implement a fuzzy logic control algorithm for use in an ABS system. Since ABS systems are nonlinear and dynamic in nature they are a prime candidate for fuzzy logic control. For most driving surfaces, as vehicle braking force is applied to the wheel system, the longitudinal relationship of friction between vehicle and driving surface rapidly increases. Wheel slip under these conditions is largely considered to be the difference between vehicle velocity and a reduction of wheel velocity during the application of braking force. Brakes work because friction acts against slip. The more slip given enough friction, the more braking force is brought to bear on the vehicles momentum. Unfortunately, slip can and will work against itself during cornering or on wet or icy surfaces where the coefficient of surface friction varies. If braking force continues to be applied beyond the driving surface' useful coefficient of friction, the brake effectively begins to operate in a non-friction environment. Increasing brake force in a decreasing frictional environment often results in full wheel lockup. It has been both mathematically and empirically proven a sliding wheel produces less friction a moving wheel. Inputs to the Intel Fuzzy ABS are derived from wheel speed. Acceleration and slip for each wheel may be calculated by combining the signals from each wheel. These signals are then processed in the Intel Fuzzy ABS system to achieve the desired control. Unlike earlier 8-bit microcontroller architectures with limited math capability, the Intel Fuzzy ABS example utilizes a high performance, low cost, 16-bit 8XC196Kx architecture to take advantage of improved math execution timing.

III. FUZZY BUILDER

Unlike a conventional ABS system, performance of the Intel Fuzzy ABS system can be optimized with less detailed knowledge of the internal system dynamics. This is due to the process used to refine the rule base and in the initial development of the system using Inform Software Corporation fuzzyTECH(R) 3.0 MCU-96 software tuned for the Intel Architecture with optimized code output and the associated Real Time Cross Debugger. The software tool set combined with a linguistic approach to control implemented in the Intel Fuzzy ABS solution allows for rapid development. A cornerstone of this rapid development is the Intel fuzzy logic modeling software kit called fuzzy BUILDER. The development system, called fuzzyTECH(R) MCU-96, is specifically optimized for the MCS(R) 96 architecture. It contains:

→A fully graphical CASE tool that supports all design steps for fuzzy system engineering.

→A simulation and optimization tool for fuzzy systems. This tool displays system performance and can be interfaced to conventional simulators to obtain performance data.

→A code generator which generates complete C-Code for the fuzzy system. The C-Code calls optimized assembly routines on the target controller for fast performance.

The following table shows the performance of several test systems on a 20MHz 8XC196Kx device. All times shown are worst-case execution results. Note FAM rules are individually weighted as opposed to a system in which all rules have identical weight:

Table1: Test System Performance

7 Rules	***20 Rules***	***20 FAM rules***	***80 FAM rules***
2 in/ 1 out	2 in/1 out	2 in/1 out	3 in/1 out
0.22ms	0.33ms	0.34ms	0.50ms

Conventional ABS control algorithms must account for non-linearity in brake torque due to temperature variation and dynamics of brake fluid viscosity. Also, external disturbances such as changes in frictional coefficient and road surface must be accounted for, not to mention the influences of tire wear and system components aging. These influential factors increase system complexity, in turn effecting mathematical models used to describe systems. As the model becomes increasingly complex equations required to control ABS also become increasingly complicated. Due to the highly dynamic nature of ABS many assumptions and initial conditions are used to make control achievable. Once control is achieved the system is implemented in-vehicle and tested. The system is then modified to attain the desired control status. However, due to the nature of fuzzy logic, influential dynamic factors are accounted for in a rule-based description of ABS. This type of "intelligent" control allows for faster development of system code. A recent article entitled "Fuzzy Logic Anti-Lock Brake System for a Limited Range Coefficient of Friction Surface," 1993 IEEE, addresses some of the issues associated with initial development of fuzzy ABS from the perspective of a system manufacturer.

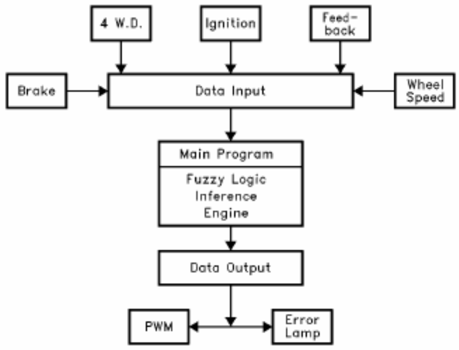

Figure1-ABS Block Diagram

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Inputs:
The Inputs to the Intel Fuzzy ABS are:

1. The Brake: This block represents the brake pedal deflection/assertion. This information is acquired in a digital or analog format.
2. The 4 W.D: This indicates if the vehicle is in the 4-wheel-drive mode.
3. The Ignition: This input registers if the ignition key is in place, and if the engine is running or not.
4. Feed-back: This block represents the set of inputs concerning the state of the ABS system.
5. Wheel speed: In a typical application this will represent a set of 4 input signals that conveys the information concerning the speed of each wheel. This information is used to derive all necessary information for the control algorithm.

The proposed system shown in figure 2 has two types of outputs. The PWM signals to control ABS braking, and an Error lamp signal to indicate a malfunction if one exists.

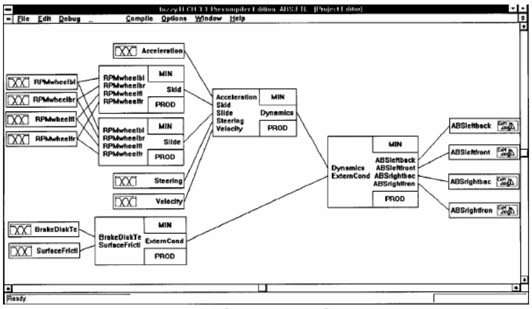

Figure 2-the proposed system.

IV. INTEL FUZZY ABS FEATURES

In the Intel Fuzzy ABS an embedded 87C196JT microcontroller (a member of the 8XC196Kx family) is used in conjunction with Inform Software Corporation fuzzyTECH(R) software. Rules constitute the base of the algorithm and are evaluated in sequence, one after the other. Upon completion of all rules processing the final system output is calculated as previously described. In contrast, if a custom dedicated fuzzy parallel processor were to be used, rules could be evaluated in parallel. The parallel processing method suggests a fast processing cycle. However, in this case data acquisition and data output continues using conventional peripherals. The time gained in parallel rule processing can be lost in acquiring and manipulating data via external peripherals. The best solution continues to use a software fuzzy algorithm on a microcontroller with fast internal peripherals. In this case, sequential rule processing is transparent to the system and the process appears to have been done in parallel. The MCS(R) 96 families of microcontrollers is equipped with high performance internal peripherals that make data acquisition and data conditioning of outputs fast and easy to handle. This and the wide range of addressing modes, broad availability of interrupts and a powerful set of instructions make Intel microcontrollers immanently suitable for fuzzy logic applications.

V. 8XC196KxĐA PERFECT MATCH

For an ABS implementation, the MCS(R) 96 family is also a perfect match. The High Speed Input Output unit can be used to effectively handle I/O without impacting precious on-chip timer resources. Most microcontrollers in the Intel 16-bit family have also incorporated on-chip Analog-to-Digital converters with 1024 discrete codes (10-bit resolution). The use of on-chip A/D reduces chip count. The A/D can be used to sense braking action taken by the driver. In addition, there is a large set of both direct and indirect interrupts to deal with real-time events and exceptions. The priority scheme of the interrupts can be modified dynamically in software. For outputs the on-chip Pulse Width Modulator (PWM) unit is available for use in providing variable output signals to the individual wheels. Changing the frequency and/or the duty cycle of the PWM can be done simply with a very fast register write operation. In addition to the peripherals, microcontrollers in the Intel 16-bit MCS(R) 96 family have internal RAM and ROM. Program instructions and data can be stored on-chip for optimized execution. No long external bus cycles are required to read data due to the large register based architecture. This feature is extremely beneficial to fuzzy logic. The knowledge base, i.e., the rules and the membership functions can be stored on-chip. Thus, rules can be evaluated in a very short amount of time.

VI. CONCLUSION

The use of fuzzy-logic in conjunction with microcontrollers is a fairly new development in automotive applications. Intel is not currently aware of any projects in production for ABS applications, but there have been numerous papers presented on using fuzzy logic and or neural networks to control such automotive applications as ABS, automatic braking for collision avoidance, adaptive cruise control and chassis control. Fuzzy Sets and Systems is an excellent journal devoted to fuzzy logic and control systems based on fuzzy logic.

VII. FUTURE WORKS:

In Future it is expected that this technology of FUZZY ABS must be implemented in every part of the world. The usage of fuzzy ABS is almost implemented in countries like US, etc. But many companies are still expected to take part in implementation of Microprocessors/Microcontrollers like Intel for ABS to expand its usage. Implementation of Microprocessors that reduce the price but not mechanism is also expected in this procedure. Many scientists & Engineers are experimenting on above topics. However it is sure that we see no cars without Fuzzy Anti-lock Brake control in near future.

VIII. REFERENCES

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