FUZZY LOGIC BASED HARDWARE: SOME EXPERIENCES

A. B. Patki

Abstract

Three decades of fuzzy logic systems had led to development of first generation fuzzy logic based hardware which provided faster fuzzy control solutions incorporating inference engines. The emergence of corporate computing is likely to place heavy demand on soft computing which has fuzzy logic as its core. In order to meet the challenges of the second generation fuzzy logic based hardware, issues like Standardization, role of computer architecture from VLSI/WSI viewpoint and associated research and development efforts are required to be sorted out. The need for specialized manpower develpment has been brought.

Key Words: Fuzzy Logic Hardware, VLSI/WSI, VHDL, Product CAD, Standardization, Corporate Computing

1. Introduction

The three decades of fuzzy logic oriented activities had revealed that fuzzy logic based systems have potential for applications in various areas leading to industrial investment in using fuzzy logic based products. Till recently, these have been implemented mostly as software modules working on conventional microprocessor, personnel computer and workstation type of computing platforms. However, while applying fuzzy logic techniques for real time complex applications, a need for more effective and high speed approach was felt. This has given an opportunity to look into fuzzy logic implementations using hardware. Thus, the origin of fuzzy logic based hardware was an outcome of substitution approach for software implementation for control applications. At present the activity in fuzzy hardware area has merely emerged in the form of implementing software algorithms in Integrated Circuits (IC) chips for rule based fuzzy controllers incorporating fuzzy inference. Typically, the present applications of fuzzy logic systems are more towards consumer products. This has created an impression that the household appliances and consumer products are the likely segments for application of fuzzy logic hardware. The other important fuzzy logic applications area which focuses on information processing products for engineering applications, simulation and modelling, data base retrieval and other similar systems lead to fuzzy microprocessor development [7] with support software and peripheral chips. Even these isolated efforts have not been coordinated to maximize the benefits due to inadequate level of industrial participation. The likely segment of industry that is expected to come up with interest in fuzzy logic systems is the Information Technology industry.

The changing world of corporate computing has not yet been benefited from the potentials of fuzzy logic systems. This sector as a thrust area for fuzzy logic application is very challenging because it is felt that in the near future it will be hard to distinguish and separate out the goals of the computer based information processing systems from the goals of the corporations since these would be intimately connected leading to deployment of soft computing methodologies for information systems in corporate computing. The fuzzy logic forms the core for soft computing technology and hence the developments in fuzzy logic hardware field are of direct relevance to corporate computing [15],[19]. In order to realise the full potential of fuzzy logic, there is a need to consider the fuzzy logic based hardware development activity from a different perspective viz.,the role of microelectronics in fuzzy logic hardware development. Thus, a new discipline in microelectronics catering to the special requirements of fuzzy logic hardware is likely to emerge which will have its impact on fuzzy logic systems as was observed in the past with regard to digital electronics [11],[12],[13].

2. Existing Scenario In Fuzzy Logic Based Hardware

The early attempts of studying fuzzy logic switching systems [9],[16] and their electronic implementations have resulted in fuzzy flip flop development [6]. This was followed up with varieties of fuzzy inference processing hardware implementations [3],[5],[8],[18] which demonstrated control type of applications with different levels of fuzzy rule antecedent representations and inference processing speed capabilities viz. Fuzzy Logic Inferences Per Seconds (FLIPS). Thus, FLIPS started appearing as an index for assessing the raw power of Fuzzy Inference Hardware Performance which was analogous to MIPS rating of yesteryear CPUs. Similarly, the issues of membership function representation and associated trade off between memory oriented approach (representing the complete membership function information regarding X-axis and Y-axis values in Random Access Memory) and computation oriented approach (adopting triangular and trapezoidal membership function key points and calculating other points by interpolation) for membership function representation were considered as a significant parameter for fuzzy hardware controllers.

Most of the fuzzy logic based hardware literature deals with solutions treated as mapping from fuzzy sets into fuzzy sets with fuzzifier, inference engine and defuzzifier as hardware modules integrated into Application Specific Integrated Circuit (ASIC) form. Due to the limitations of ASIC based approach, hardware solutions for fuzzy control

Author is with Department of Electronics, Government of India, Electronics Niketan, 6, CGO Complex, Lodi Road, New Delhi-110003, India
EMail: patki@xm.doe.ernet.in

are now viewed as architectural approaches. Thus three segments viz. a) Dedicated fuzzy coprocessors b) Fuzzy Inference ASICs and c) Generic Chip Set Approach have emerged.

The generic chip set approach [1], [11] serves the purpose of bridging the gap between dedicated fuzzy coprocessors and fuzzy ASICs for embedded applications. Depending on the application, a combination of chips from the fuzzy generic chip set along with other digital ICs can be used to build embedded systems. An opinion that in fuzzy control applications the software is more important than the fuzzy chip hardware is fast changing although in the current practices the fuzzy hardware is seen only as an aid to enhance the inherent processing power of general purpose information processing unit for fuzzy inference. Fuzzy chips for inference processing have been designed with this emphasis and are utilized to offer fuzzy logic solutions finding acceptable marketing time to introduce new fuzzy logic based products/solutions. Software implementations of fuzzy control algorithms on standard micro-controllers (i8051, ST9, MC68HC11 etc.) are widely used. Several hardware and support software development products have emerged from Motorola, Aptronix, Togai Infra Logic, OMRON etc. to provide 'sort-of' general purpose solutions for fuzzy controller implementations. Analog design approaches have been also used in hardware implementations but are on a very limited scale as compared to digital design approaches. Certain products around fuzzy inference processor have been configured in the form of printed circuit boards as OEM components using ASIC techniques.

3. Need For Standards In Fuzzy Logic Based Electronic Hardware

The VLSI CAD technology has been used for development of fuzzy logic based electronic hardware. The digital hardware development approach deploys the state of the art VHDL based design methodologies for developing fuzzy logic integrated circuits. The suitability of VHDL has been viewed as a common hardware description language for specifications, simulation and synthesis of complex VLSI designs. VHDL has helped in exploring various alternatives for fuzzy logic hardware chip design [1],[3]. Design experiences in VLSI design activity has brought out several significant observations that are needed for introducing standardization culture in fuzzy logic electronic hardware development. Presently, every designer follows his or her own methods in the absence of any standards and no effort towards standardization has come forward. The major cause for this state of affairs can be attributed to the very small number of researchers actively engaged in fuzzy logic based hardware development and inadequate industry orientation. However, if full potential of fuzzy logic is to be effectively deployed, the standardization process needs to be looked into. Some of the considerations for formulating standards are as follows:

i) The design experience of developing fuzzy logic generic chip set has revealed that user programmability for membership function representation (X-axis) is an important feature for generic chip set to effectively serve to bridge the gap in existing fuzzy hardware approaches using dedicated fuzzy co-processor and fuzzy ASICs.

ii) The issues of precision requirement in membership function representation (Y-axis) in providing generic chip set solution has indicated that the existing standard cell libraries commercially available from various VLSI CAD vendors (Compass VTI, Mentor Graphics, Synopsys, Viewlogic etc.) do not include any generic standard cell for fuzzy hardware module. Thus, there is an immediate requirement for developing standard cells library to support fuzzy logic devices to give boost to VLSI designers engaged in fuzzy logic hardware development. The standard cell library could include min-max circuits, precision convertor blocks for internal representations useful for hedge generators, weightage blocks , etc.

iii) The VHDL based design approach coupled with the Field Programmable Gate Array (FPGA) technology has simplified the in- circuit chip performance evaluation. This has resulted into faster product demonstration turn around time and has reduced silicon foundry dependence for prototype development. After the early field trial performance evaluation and subsequent modification loop is carried out, the product designer can consider the silicon foundry fabrication for mass scale production of chips. The real benefit of FPGA will be more visible in fuzzy logic based hardware development only if FPGA modules can directly support primitive fuzzy operations. Currently no such primitive blocks are supported and if standardization process also concentrates on this aspect, the Fuzzy FPGA (FFPGA) technology will boost up the fuzzy logic based hardware development and faster product prototyping.

iv)The typical bit oriented approach in digital hardware design maps as a digit oriented philosophy for fuzzy hardware development. Experimental work carried out indicate that similar to the VHDL supported bit vector representation, the digit representation including addition of related support features will improve the acceptability of VHDL for fuzzy hardware development. VHDL standards IEEE STD-1076-1987 released in 1987 and subsequently revised as IEEE STD-1076-1993 had catered to incorporate number of new features. Syntax for certain constructs had been made more consistent and many ambiguities in the earlier version have been resolved. However, from fuzzy logic hardware development angle, the 1993 VHDL standard revision did not include specific features.

It is felt that in future, vendors should share interfaces for independent products serving the role as a cooperative community of standards users instead of adopting narrow interest attempts to control many design, development and marketing decisions associated with their own products, which may or may not alter the direction of technological change. The trends in market events are indicating that the strategy of designing one's own components to develop a superior integrated design are not likely to yield expected results. In order to boost fuzzy logic based hardware activity, it is necessary to concentrate on issues brought out above and a dedicated working group be created at the level of international forum with representation from academic, professional bodies and industrial organizations leading to formulation of Standards.

4. Role Of Microelectronics In Fuzzy Logic Electronic Hardware

The present models of fuzzy logic hardware which are primarily implemented as ASICs, work as special coprocessors completely based on state of the art digital binary logic device approach and the task of the chip designer is to implement these using VLSI CAD. The first generation fuzzy logic electronic hardware which was a response to substitute software solutions for fuzzy logic had concentrated itself from this view point only. In the next generation of fuzzy logic hardware, a new model which integrates the following issues will emerge as an active research area.

4.1 Mixed Mode — Analog and Digital Technologies

Many of the practical advantages that are being claimed for fuzzy logic can only be realized if fuzzy logic hardware is implemented as high performance systems. Unlike digital circuits which have the advantage of standard technologies for highest density in devices available, analog circuits can take advantage of the modest precision that is required in fuzzy logic models, resulting in small and fast devices.

4.2 Issues of VLSI Architectures

The transition to second generation fuzzy logic hardware is to have its focus on VLSI architecture as the key. The von Neumann model which is universal in general purpose computing suffers from the problem of information (instructions and data) flowing back and forth to the processor and memory through a single channel of finite bandwidth. Very fast memory devices (DRAM), wide data transfer buses, interleaved memory blocks etc. have provided ways and means of overcoming von Neumann performance bottlenecks to some extent in general purpose computing but is not likely to give the performance boost in fuzzy logic applications for corporate computing requirements.

Specifications of the architecture involves the definition of the instruction set and behavior of components (register files, functional units, memory) visible to the user of processor. The architecture is largely implementation independent though it may strongly favour one technology over another. With introduction of VLSI, the architecture is viewed as program host i.e. performance of implementation of that architecture for programs of interest and architecture as implementation requirements i.e. communication is more expensive than computation. Thus architectures that require significant amounts of global interaction will suffer in implementation. The central concern in the architectural design for fuzzy logic hardware is the choice of operations to be supported in hardware. The nature of computations and the frequency of operations is examined by profiling the execution of sample programs. Unlike numeric computation, the fuzzy logic computations are characterized by use of linked data structures as objects in additions to arrays [14] more frequent use of pointers and less frequent use of array indexing, more irregular looping (more while and less do loops).

4.2.1 Object Oriented Architecture

Object oriented architectures or simple architectures with more resources (registers, Content Address Memory, on-chip associated cache, etc.,) are the transition phase technological issues for fuzzy logic hardware for second generation. Object oriented architectures evolve around the concept of object as the primary unit for addressing, access control and instruction manipulation. The intel iAPX 432 microprocessor which is really a two chip system (fetch and execute parts are in separate chips) adopts this type of architecture that permits users to define their own object types. Intel 432 was the first microprocessor to define and implement floating point operation on-chip as opposed to using a coprocessor. In the context of object oriented architecture for fuzzy logic hardware, the on-chip floating point operations get replaced by fuzzy logic operations unit.

4.2.2 Vector Architecture

In vector architectures, the vector elements are stored in main memory in an ordered manner so as to have fixed increment between successive elements called strides. A vector processor is a collection of hardware resources that includes vector registers, functional pipelines, processing elements and the register counters for performing vector operations. A fuzzy membership function is a vector that is a set of scalar data items, all of the same type, stored in memory. Vector processing happens when arithmetic and logical operations are performed on vectors. Some of the commonly used vector instructions are as follows:

a) Vector-Vector instructions : one or two vector operands are fetched from the respective vector registers, enter a functional pipeline(FUZOP , Hedge Generator) and produce results for another vector register [1], [2].
b) Vector-Memory Instruction: Vector load/store - The elements of a vector are loaded/stored element by element from/ to memory to/from vector register.

In general, vector operations are faster than scalar operations which is due to matching the vector element access time with the execution times in each stage of a pipelined functional unit. Fast performance is due to very high clock frequency.

4.2.3 Parallel Processing Architecture

Parallel computing is becoming increasingly cost effective and affordable means for providing enormous computing power. Amdahl's Law describes the fundamental limitation that commonly specifies the maximum speed up that can be achieved for a problem. The law states that the performance improvement that can be gained by a parallel implementation is limited by the fraction of time the parallel mode can be used in an application. It results into the fact that theoretically, to extract large speed-ups for a fixed number of processors, we have to increase problem size. Practically, the problem size that we can run for a particular problem is limited by the memory of the parallel computer. Hence, indirectly the speed-up of a parallel implementation is dictated by the number of processors and the amount of memory available on the parallel machine [17]. The issues of parallel processing are of paramount importance while the concepts like fuzzy normalization, convexity, fuzzy measure and fuzzy integral etc., are to be supported at the hardware level, All these issues have not been examined so far from fuzzy logic based hardware angle.

Vector processor provides a high throughput for even non vector code; thus vector architecture can provide very high performance for other applications. It is not clear that all fuzzy logic corporate computing problems can be effectively parallelised to provide the speed of a single vector processor.

4.3 Use of Advances in VLSI/WSI Technologies

Wafer Scale Integration (WSI) technology provides a path for very high density integrated vector and parallel architecture implementations. A typical wafer ranges in size from 2 to 8 inches in diameter, contains the equivalent of 25 to 100 microprocessors of intel 8086 size [10]. WSI eliminates interchip connections and improves reliability reducing noise and delays. Most of the architectures use some form of parallelism and thus the amount of functions to be placed on chips are continuing to grow.

5. Product Development Using Fuzzy Logic Hardware-Integrated Approach For Prototyping CAD tools

Product development around fuzzy hardware involves the typical design, development and prototype product demonstration cycle which at present is in the form of an asynchronous step process. Here the experiences of other design engineers who are using virtual instrumentation for design, development and testing of prototype needs to be utilized for fuzzy prototype product development which will result in much faster time to introduce new products into the market. The virtual instrumentation mechanism deployed the idea of the software usage as the instrument. Similarly, new product design tools are needed to express the connection between concept, code, chips to bridge the gap between fuzzy research and related product design and development in general and particularly for hand-held portable fuzzy logic based products integrating algorithm development, simulation, software code generation and translation of VHDL VLSI integrated circuits chips using standard icons into block diagrams to rapidly create and simulate sophisticated fuzzy logic designs to visualize the products. This helps in streamlining prototyping and simplifying implementation as an electronics workbench. Object Linking and Embedding (OLE) concepts are very useful for integrated rapid prototyping CAD environment. Research efforts like RECIPE [4] allow user participation at the early stages of product development. The object oriented modeling approach supports the simulation of product behavior at functional level. Direct user interaction to assess product capabilities starts in a virtual reality sense since the product is functioning and gets used in a simulation mode and user is using the keyboard as input device. Thus, rapid prototyping CAD environment provides an integrated approach to implement product concepts and ideas through product software simulation including VLSI integrated circuit chips and associated interface electronic circuitry.

6. Manpower Training Aspects to face Challenges of Fuzzy Logic Hardware Development

The experience in undertaking research in fuzzy logic based hardware has highlighted the issue of non-availability of technical manpower with the knowledge of interdisciplinary areas covering fuzzy logic, VLSI CAD design, Computer architecture, hardware algorithms and product design and prototyping technology. In order to give boost to fuzzy logic hardware oriented research and development activity, it is felt that there is an immediate need to develop specialized courseware and introduce migration courses for the professionals from other engineering disciplines. Professional bodies in association with industries should encourage special events in the form of tutorials and capsule courses to prepare the existing industrial work force to participate effectively. In order to overcome manpower shortage problems, globally research groups can be identified in various IEEE regions, developing nations, international bodies etc., to undertake cooperative joint research and development programme.

7. Conclusions

The fuzzy logic hardware development has typically seen its emergence as speedy accelerated solutions for substitute software on the conventional general purpose hardware. The limitations of ASICs are leading to approaches of generic chip set development and the impact of corporate computing is likely to boost fuzzy logic hardware development as an emerging area with significant role of the microelectronics.

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