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Design of Temperature Control Simulation System with FPGA

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Abstract — This paper describes FPGA implementation of a Fuzzy Logic Controller (FLC) using VHDL for temperature control (FTC). This paper describes the implementation for a basic fuzzy logic controller in Very High speed integrated-circuit Hardware-Description Language (VHDL). It is not intended as an introduction to fuzzy logic control methodology; instead, we try to demonstrate the implementation of a fuzzy logic Programmable Gate Array (FPGA). The main advantages of using the HDL approach are rapid prototyping, and allowing usage of powerful synthesis controller through the use of the VHDL code. Use of the hardware description language (HDL) in the application is suitable for being implemented into an Application Specific Integrated Circuit (ASIC) and Field tools such as Xilinx ISE,The system is built up with major modules namely fuzzification, inference, implication and defuzzification. The VHDL code is downloaded into FPGA board of SPARTAN

IndexTerms FLC, FTC, Fuzzification implication, defuzzification controller, Fuzzy, Synthesis, FPGA

1. INTRODUCTION

An effective and efficient controller for the surrounding environment is crucial in many technical processes. Ranging from IC fabrication to the production of chemical solutions, any changes in the ambient parameters can have a drastic effect in the outcome of a process, at the very least lowering the yield or quality of the product. Among the crucial parameters that merits close supervision is the temperature of the environment. As such, temperature controller is critical to the quality, appearance and consumer acceptance of a manufacturer's products.

The processes that requires temperature controller has various unfavorable characteristics including non-linearity, dead zone time, external disturbances and so on. Conventional approximations do not produce satisfactory temperature controls for controlling complex processes, which is usually the case in the industry because they suffer from various drawbacks such as slow stabilization, overshooting and overall slow responseand reduces the steady-state error
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The Fuzzy Logic Controller (FLC) is also able to bring the A fuzzy system improves the relative performance of a temperature control process with respect to the conventional scheme. It compensates non-linear errors, accelerates temperature constant at the desired value regardless of changes in the load or environment. This project attempts to enable a fuzzy-based control of the temperature employing VHDL as a mean of improving upon conventional methods.

Several works had been done in this area. Zhiqiang et al. [9] had developed a closed loop control system incorporating fuzzy logic for a class of industrial temperature control problems employing a unique FLC structure with an efficient realization and a small rule. Their works demonstrated in both software simulation and hardware test in an industrial setting that the fuzzy logic control is much more capable than the current temperature controllers. This includes compensating for thermo mass changes in the system, dealing with unknown and variable delays and operating at very different temperature set points without retuning. Thyagarajan *et al.* in [3] presented four control schemes designed using advanced techniques for regulating the temperature of the Air Heat Plant. The four control schemes are namely, PID, fuzzy logic control, FLC using genetic algorithms (FLC-GA) and Neuro-Fuzzy control (NFC). All these schemes are evaluated with respect to set-point tracking using performance indices. Their works to design a fuzzy logic temperature controller with FPGA. The FLTC is able to bring the temperature constant at the desired value regardless of changes in the load or environment.

Highlighted superiority of FLC over PID, FLC-GA FLC and NFC schemes. Some more works utilizing fuzzy logic to control temperature for specific applications is discussed here [4]-[5].

2. DEVELOPMENT OF DEVICE MODELS

A. Methods for model development

A fuzzy proportional integral derivative (PID) controller, which is fabricated on a field programmable gate array (FPGA). is proposed to control an industrial process. The fuzzy logic is provided to tune the PID parameters by using a gain scheduling method. The tuning scheme is represented by a fuzzy system, which consists of fuzzification rule inference and defuzzification. The fabricated FPGA chip, XC2S50-5tq-144, is embedded with the fuzzy system, which the chip is called fuzzy-PID controller. The fuzzy-PID controller is contained several circuits, such as multiplier, adder, subtraction and some of the other logic gate. The controller system uses two converter cards: TDA8763AM/3 (10 bits, high speed) to convert from analog to digital signal. DAC08 (8 bits) to convert from digital to analog. The maximum speed of the controller about 2,1 µsec per action at 40.550 MHz. is calculated from timing summary. The fuzzy-PID controller based on FPGA is verified by using to control model of level and temperature process. From the experimental results of the level and temperature control, the fuzzy-PID controller has achieved and shown the better performance than standard PID controller E50AK. which is automatic tunable parameter system.

A large number of fuzzy control applications with the physical systems require a real-time operation to interface high speed constraints; higher density logic devices such as FPGA can be used to integrate large amounts of fuzzy logic in a single IC. Fuzzy logic controller provides an alternative to PID controller since it is a good tool for the control of systems that are difficult in modeling. The control action fuzzy logic controllers can be expressed with simple "if-then" rule, there are many ways to implement a fuzzy logic controller; one of them is using FPGA. Fuzzy controllers are more sufficient than PID controllers because they can cover a much wider range of operating conditions than PID can, they also can operate with noise and disturbances of different nature.

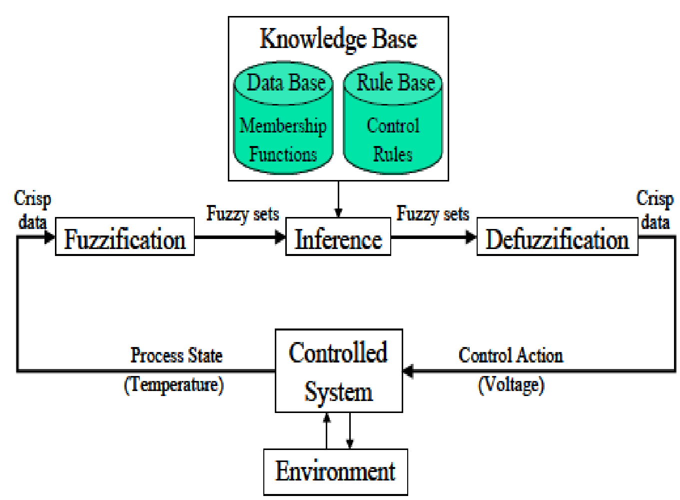
A fuzzy logic was used to perform the temperature control. The idea behind the use of the fuzzy logic was from the fact that temperature is not explicitly defined. For example, Considering of "it is warm", is this true, given that a measured temperature is 70 oF? One would hesitate to answer "true" or "false"; rather prefer to say "sort of". This is not a question of uncertainty about the external world, because we are sure of the degree of temperature. Rather, it is a case of vagueness or uncertainty about the meaning of the linguistic term "warm". Fuzzy logic treats the true value of warmness is a number between 0 and 1, rather than being just "true" or "false". Thus, a fuzzy set ***F*** in a universe of discourse ***X*** is characterized by a membership function ***F*** that takes values within [0, 1] as follows: : $X \rightarrow [0,1]$ F

3. CHOICE OF THE MODEL

To design a fuzzy logic temperature controller with FPGA. The FLTC is able to bring the temperature constant at the desired value regardless of changes in the load or Environment.

A block diagram for a fuzzy control system is given in Figure 1. The fuzzy controller consists of the following four components:

1. Rule base: set of fuzzy rules of the type "if-then" which use fuzzy logic to quantify the expert's linguistic descriptions regarding how to control the plant.
2. Inference mechanism: emulates the expert's decision-making process by interpreting and applying existing knowledge to determine the best control to apply in a given Situation.
3. Fuzzification interface: converts the controller inputs into fuzzy information that the inference process can easily use to activate and trigger the corresponding rules.
4. Defuzzification interface: converts the inference mechanism's conclusions into exact inputs for the system to be controlled.



4. DEVICE MODELING USING VHDL

The FTC model has been converted into behavioral level using VHDL. The generated VHDL four hardware components are interconnected in a similar manner. Synthesis is the process of transforming one representation in the design abstraction hierarchy to another representation. Synthesis process has performed using simplify tools [8] for synthesizing the compiled VHDL design codes into gate level schematics. The synthesis tool is also used to optimize the gate level design for area by applying specified options. It initially processes the VHDL building blocks such as multiplier, registers, gates and flip-flops etc, for which it can determine whether logic blocks can be shared between the building blocks function for efficiency performance. While synthesizing the design with the synthesis tool, HDL library browser was used to synthesize the design in a hierarchical manner. The synthesized schematic is also simulated to ensure the synthesized design functions the same way as the validated VHDL model for VLSI implementation.

1 Fuzzification module

This module is divided into two similar parts; both serving the same function. The module accepts two crisp (i.e. real world) signals (“Error” and “CError”) and produces 4 fuzzified values (2 fuzzy values for each input) forward to Implication module. In this model, each input signal discourse upon 5 triangular membership functions using Equation (1).

$$Y = mX + c, \qquad (1)$$

2 Inference module

In this module, appropriate rules are selected to be fired based on the fuzzy variables that are chosen according the regions that the variables fall in. Only two fuzzy variables are activated at any given time. As a result, each fuzzy variable results in firing two rules. As a consequence, a total of 5 rules are fired. This process is achieved by dividing the universe of Discourse into 3 regions where each region containing only two fuzzy variables. The “Output” value is represented using fuzzy singleton sets in place of membership functions like those of the two inputs. The use of singleton values allows faster inferencing as well speeding up the defuzzification process. The downside of singleton values is that a certain
Amount of accuracy is sacrificed as each output values now represents a range of input values.

rule[0]
rule[1]
rule[3]
rule[2]
rule[4]
Error
CError
Region Selector (Error)
Region Selector (CError)

This module receives the 5 fuzzy variables from the Fuzzification Module and performs the Mamdani Min implication operation on the combination of these five variables. Continuing the previous examples, composition functions.The five resulting output of the implication operation will then be fed into the Defuzzification module.

3 Defuzzification module

This module accepts fifteen inputs each from the Implication module (i.e. f_min[0-4]) and the Inference module (i.e. rule[0-2]) and produces the defuzzified/crisp output signal for the control system.

5. Functional and Timing Simulations

Upon successful completion of the VHDL coding functional simulation is performed to verify the correct functionality and to determine the deviation or tolerance parameters of the FTC using generated test bench. A set of stimuli as inputs (functional vectors that changes with at fixed time duration) is fed into the test bench. The waveform in the values of the inputs and the corresponding output in hex form at the various instances determined by the stimuli in the test bench.

6. FPGA Implementation

The generated synthesized net list of the FTC chip has been downloaded into FPGA (FLEX10K EPF10K70) board from Altera for verification the correctness of the algorithm functionality. Note that the FPGA board contain a built-in 8-bit DIP switch, a dual-digit 7 Segment display, and three expansion slots, each with 42 I/O pins and 7 global pins as shown in Fig . Demonstration of FPGA enabled fuzzy algorithm To make compatible the fuzzy based FTC chip inputs with I/O pins in FPGA board, the 8-bit DIP switches as manual inputs and 8-bit of two 7-segment LEDs as outputs are chosen for verifying correct functionality of the FTC chip for VLSI implementation. We have seen that the maximum propagation delays of any paths between the input and output nodes are around 200ns at the most. Hence, an approximate maximum operating frequency of the FTC chip can be inferred at around 5.00MHz. Furthermore, a similar inference can be made for the critical path. Based on the longest maximum propagation delay, it can be said that the critical path is from the Error7 to Output7, taking a duration of 199.3ns.

7. APPLICATION

Temperature control is widely used in various processes. These processes, no matter it is a process of large industrial plant, or a process in home appliance, share several unfavorable features such as non-linearness, interference, dead time, and external disturbance, etc. Conventional control approaches usually cannot achieve satisfactory results for this kind of processes. Besides this all other processes that requiring temperature control has various unfavorable characteristics including non-linearity, dead zone time, external disturbances and so on. Currently used conventional approximations do not produce satisfactory temperature controls for controlling complex processes, which is usually the case in the industry because they suffer from various drawbacks such as slow stabilization, overshooting and overall slow response. This fuzzy system based temperature controller can be applied in any kind of environment by which we can get an improvement of relative performance with respect to the conventional scheme. It compensates non-linear errors, accelerates the response and reduces the steady-state error.

The FLC is also able to bring keep the temperature constant at the desired value regardless of changes in the load or environment. Thus we can experience a great solve of the overshooting problem. It also can able to improve the slow stabilization problem. Thus it application can be implemented on almost all scale industry

8. CONCLUSION

A fuzzy logic temperature controller has been designed with an industrial application in mind. The system has been coded, compiled and simulated in VHDL. The hardware implementation demonstrated complete, correct functionality and met all the initial system requirements. Maximum operating frequency is 5MHz with a critical path of 199.3ns. This could take advantage of the high speeds achievable using hardware, and as a result would be a beneficial and economic investment for designs requiring fuzzy logic.

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