Automatic Speed Control of DC Motor using FPGA

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ABSTRACT

The DC motor is most important equipment in many industrial applications which requires efficient controllability over variable speed-load characteristics. The efficient speed control of DC motor is of very crucial importance in all the applications. The emergence of fuzzy logic and FPGAs (Field Programmable Gate Array) has made the controllability highly efficient with greater efficiency over other conventional speed control techniques like PID etc. This paper presents a Fuzzy logic controller (FLC) design methodology to construct fuzzy controller on FPGA for DC motor speed control. The PWM (Pulse Width Modulation) technique is used to drive the motor with correct control signals. The proposed system allows the motor to run at desired speed even when the load on the motor varies. The hardware description language (HDL), Verilog HDL is used to design the fuzzy controller on FPGA Spartan 3 hardware using Xilinx ISE 14.4 software tool.

Keywords— FPGA, PWM, Fuzzy Logic Controller, Fuzzification, Verilog HDL

1. INTRODUCTION

High performance DC motors are extensively used in industrial applications. The DC motor drive is a highly controllable electrical motor drive. The DC motors form the backbone of electric drive machines. Disk drives, cooling fans, cranes, elevators, drills, robotic manipulators, guided vehicles, electric traction are some of applications where DC motors are employed. With such a wide variety of applications, the speed control of motor is of very crucial importance. Thus the control system has increased demand because of the rapidly growing industry. Thus, more accurate and faster control systems are needed and better performance is expected. There are many speed control methods available but often a speed control method with a high degree of efficiency and accuracy is required.

A field programmable Gate Array (FPGA) is a large Programmable logic device that can be used to implement combinational and sequential logic circuits. Thus, an FPGA can also be used to implement the control-logic design. FPGAs provide all the features required to implement any complex designs. The FPGAs have many advantages over the microprocessors. The FPGAs have improved performance, reduced cost, more reliability and are very fast. The design, synthesis, testing and verification of the digital system is done using hardware description languages. There are two types in HDLs namely Verilog HDL and VHDL.

From the past several years it is found that the growth of fuzzy logic is rapid with large variety of applications. Unlike other conventional controllers fuzzy logic controller is not dependent on mathematical models of the system. The FLC make use of desire behavior of object under control. The FLCs are fast with higher accuracy when compared to other speed control methods. The pulse width modulation (PWM) is used along with FLC for optimized performance. In analog domain, current is controlled by the use of analog components like potentiometers which basically are resistors. However, in digital logic no analog components are permitted and hence a different method to control voltage/current is required. This is where the pulse width modulation comes in picture. PWM is a technique that changes the overall/average voltage across the load consequently changing the current flowing through too.

The FPGAs provide an efficient way for hardware implementation of fuzzy logic controller. The simple block diagram of the proposed system is given in Figure 1. The hardware implementation of fuzzy logic controller is done using FPGA. After powering the system, the motor is allowed to run at desired speed. However, when a load applied on the DC motor is varied, speed changes. The IR sensor is used to sense the speed of the motor. The sensed speed is compared with desired speed by the fuzzy controller and sends the necessary control signals to motor driver through PWM.

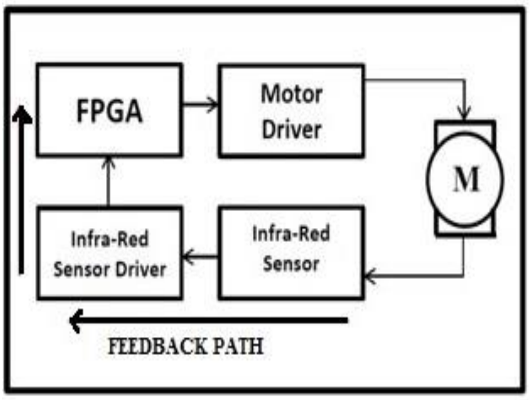

Fig-1: Simple block diagram

2. FUZZY LOGIC CONTROLLER

Fuzzy logic concept is similar to the human mind. Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control strategy. The associated membership functions are used to produce the output in a fuzzy logic controller by fuzzification of inputs and defuzzification of outputs. The different members of the associated membership functions are defined based on the values of crisp inputs. From this point of view, the memberships of different membership function are considered as range of inputs. These membership functions decide the output of a fuzzy logic controller.

The implementation of fuzzy logic technique to an application involves the following three steps [1]:

1. Fuzzification – converts crisp sets or crisp data into fuzzy sets or Membership Functions
2. Fuzzy Inference Process – combines membership functions with the control rules to obtain the fuzzy output
3. Defuzzification – different methods are available to calculate each associated output and prepare the lookup table. It selects the output from the lookup table based on the current input during an application.

Fuzzification is the first step in fuzzy control system. Most of the variables are crisp variables. In a fuzzy system, these variables are needed to be converted into fuzzy variables and this data is processed in fuzzy inference process to obtain the desired output. This can be achieved in two steps, firstly derive the membership functions and represent them using linguistic variables. For DC motor, we may partition the input variable as VL (very low speed), L (low speed), M (medium speed), H (high speed), VH (very high speed). The membership functions of input variable are shown in Figure 2.

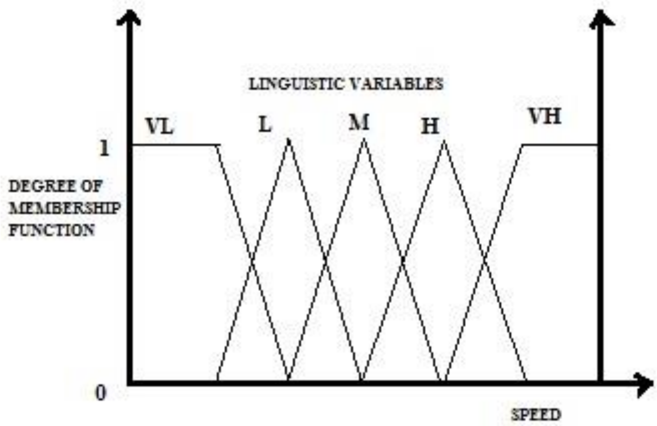

Fig-2: Membership functions

The fuzzy inference process determines the control rules known as fuzzy rules. In the field of artificial intelligence (machine intelligence) there are various ways to represent knowledge. Perhaps the most common way to represent human knowledge is to form it into natural language expressions of the type;

IF premise (antecedent), THEN conclusion (consequent);[2]

The form in Expression is commonly referred to as the IF–THEN rule based form. It typically expresses an inference such that if we know a fact (premise, hypothesis, antecedent), then we can infer, or derive, another fact called a conclusion (consequent) [2]. The rule base table for DC motor speed control with above said linguistic variables can be given in Table 1. Here, NC (No change), DDC (Decrease duty cycle), IDC (Increase duty cycle) are the conclusions. Then TAR and CUR represent target functions which are required to be achieved at output and current functions respectively.

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearity's existing to the systems. To achieve the result, develop the control curve of the system representing the I/O relation of the systems and based on the information; define the output degree of the membership function with the aim to minimize the effect of the non-linearity [5].

TAR / CUR	**VL**	**L**	**M**	**H**	**VH**
VL	NC	IDC	IDC	IDC	IDC
L	DDC	NC	IDC	IDC	IDC
M	DDC	DDC	NC	IDC	IDC
H	DDC	DDC	DDC	NC	IDC
VH	DDC	DDC	DDC	DDC	NC

Table-1: Rule base table

3. PULSE WIDTH MODULATION

One essential aspect of controlling motors is the ability to change the speed of rotation and the amount of torque produced. PWM is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only, when switched on. PWM is a comparatively recent technique, made practical by modern electronic power switches [6]. One simple but usually impractical means of achieving this is to adjust the supply voltage up and down as required. However, it is more effective and common to use the PWM concept. By adjusting the duty cycle of the signal (modulating the width of the pulse, hence the "PWM") i.e, the time fraction it is "on", the average power can be varied, and hence the motor speed. [3]

Mathematically , Let Vsource be the input voltage, Vout be the output voltage across motor terminals, D be the duty cycle, T_{on} and T_{off} are the time periods for which the voltage signal remains ON and OFF respectively.

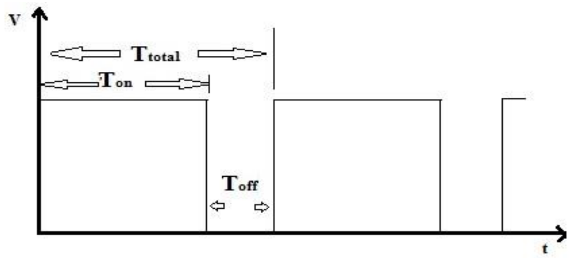

Fig-3: PWM representation

The output voltage at the terminals of the load can be expressed as,

$$V_{out} = D \times V_{source} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$V_{out} = (T_{on} / T_{total}) \times V_{source} \ldots\ldots\ldots\ldots (2)$$

From above equations, it is clear that the output voltage of DC motor depends on "Ton" as "Ttotal" and "Vsource" remain constant. The PWM not only gives us a way to vary the output at the load's terminals, it also consumes less power with its analog counterparts.

4. IR SENSORS

An infrared sensor is an electronic instrument which by emission and detection of infrared radiation senses the required characteristics of an object under consideration. Infrared sensors can also be used to measure the heat being emitted by an object and detecting the motion. Infrared waves are not visible to the human eye. In the electromagnetic spectrum, the infrared radiation is located between the visible and microwave regions. The infrared waves typically have wavelengths between 0.7μm and 1mm. The Infrared technology has applications in many everyday products. Televisions use an infrared detector to interpret the signals sent from a remote control. The low power requirements, simple circuitry with portable feature have made the infrared sensor to be advantageous over other sensors. [4]

5. CLOSED LOOP OPERATION

As shown in the figure 1, the block diagram represents a closed loop control system. Initially, the motor which is driven by the motor driver is powered to rotate at a desired speed which is set by programming the FPGA. Then if there is any load variations, speed also changes. If load increases, speed decreases and if load decreases, speed increases.

The IR sensor emits radiation signals on to the shapt of the motor. The reflected radiation from the white mark on dark background is converted into a pulse and is sent to FPGA which represent one RPM count. The FLC implemented in the FPGA compares the measured speed with the desired speed and makes necessary control decisions. The output of the FLC is given to PWM. Then PWM takes the necessary command signals from FLC and sends the necessary control signals to the motor driver circuitry which then drives the motor at desired speed. This process keeps repeating all the time in order to run the motor at desired speed irrespective of the load variations.

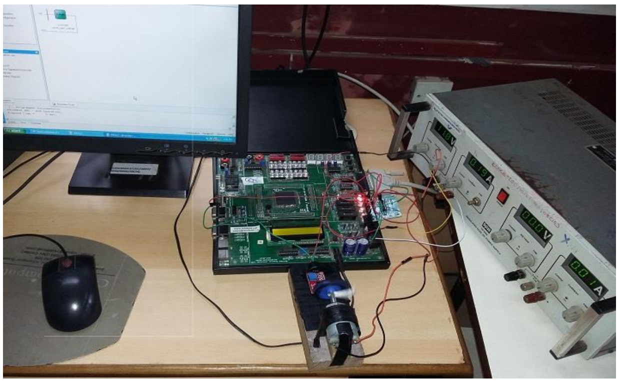

Fig-4: Experimental setup

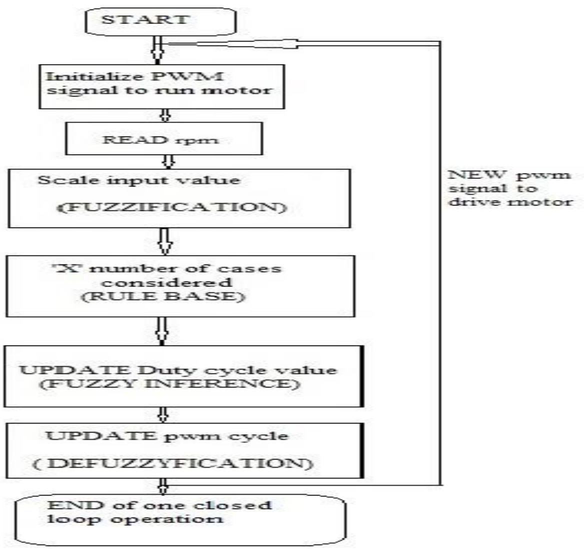

Fig-5: State flow diagram for FLC

6. CONCLUSION

The Fuzzy logic controller which is fast and efficient controller with improved accuracy is designed. The FLC is implemented in FPGA using verilog HDL. The proposed system is used successfully to control the speed of DC motor under variable load conditions. The FLC offers high flexibility with simpler design compared to other conventional speed control methods like PID etc. The future scope may include implementation of FLC on SOCs (system on chip).

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