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Development Of Temperature Tracker For Neonatal Intensive Care Unit

Neha Joshi[1], Rajanish Kamat[2], Pawan Gaikwad[3]

[1]VLSI Research Laboratory, Department of Electronics, Willingdon College, Sangli, Maharashtra,India

[2,3]Embedded System and VLSI Research Laboratory, Department of Electronics, Shivaji University, Kolhapur, Maharashtra, India

Abstract

In this research work an embedded system is developed to control the physical parameter; necessary for the Neonatal Intensive Care Unit (NICU). In a special case, the newborn babies are kept under the supervision of Neonatologists as well as the technologically advanced control unit, NICU. The prototype developed in this research work focuses on monitoring the skin-temperature of a newborn baby using measuring-probe with the temperature sensor AD590. The amount of current engendering from the sensor was converted into its voltage equivalent with the help of a current to voltage converter. A serial Analogue to Digital Converter (ADC) module was deployed to sample the analogue voltages, and produce corresponding digital equivalents. The Field Programmable Gate Array (FPGA) from Xilinx Inc. was set to be the target device to implement a soft Intellectual Property (IP) core; necessary to control the skin-temperature of newborn baby kept inside the Incubator. The system developed in this research work compares a pre-decided skin-temperature with the existing skin-temperature of a newborn baby and make a decision to turn on either the heating or cooling system to retain the temperature.

Keywords: *Skin-temperature, AD590, LT1311, Serial ADC, FPGA*

1. Introduction

An Incubator is basically an isolator for a premature/weak newborn baby, which provides environmental condition as its mother's belly. It is a careful controller where the ambient temperature, humidity, skin temperature of baby and light intensity of the Neonatal Intensive Care Unit (NICU) can be maintained. It also helps to protect preterm infant from light, germs and noise that may cause infections, sickness or other types of diseases [1]. The infants have to be kept in the intensive care units when the baby is suffering from the problems as given in [2].

Nowadays, there is a demand by Neonatologists or Pediatricians for easy systems which can monitor and control the various parameters of baby incubator/radiant warmer and transmit the same information at the receiving end. From existing systems point of view, the NICUs are facilitated with incubator along with the Radiant Warmer. The Radiant Warmer is a body warming device maintaining the body temperature of the baby and limits the metabolism rate. Heat has a tendency to flow in the heat gradient direction, which is from high temperature to low temperature. The heat loss in some newborn babies is rapid; hence body warmers provide an artificial support to keep the body temperature constant. In certain areas with very cold climate, babies are kept on Radiant Warmer for couple of hours; immediately after birth to ensure the baby is stabilized [3]. In addition, a system acquiring data at desired sampling rate and monitoring fault with alarm system are available [4]. In the context of aforesaid requirements and existing NICU systems, the present research work is to improve the scenario and develop an embedded system for NICU technology that use sensors to obtain physical parameters of incubator.

The main focus in this research work was given on controlling the skin temperature of baby kept inside incubator using a temperature sensor AD590 and the data acquisition system developed around reconfigurable device: Field Programmable Gate Array (FPGA). The AD590 sensor transfigures the physical parameter, temperature into the form of current in microampere. So it was necessary to convert the current into its voltage equivalent and then give it to the data acquisition system (DAS). The DAS module was developed deploying serial Analogue to Digital Converter (ADC) and a soft Intellectual Property (IP) core developed in a Hardware Description Language (HDL). The prototype is applicable to measure skin-temperature by deploying special probes to keep baby's skin-temperature at 36.5˚C inside the incubator of NICU. The control system designed in this work deals with controlling the skin-temperature; in addition to simply monitoring it. The expected skin-temperature was sensed using the temperature sensor and converted into its digital equivalent. The moment, when the temperature value deviates from its anticipated one, the FPGA based embedded system permit the heating or cooling system to obtain the desired skin-temperature of the infant.

2. Block Diagram of the Incubator Parameter Controller

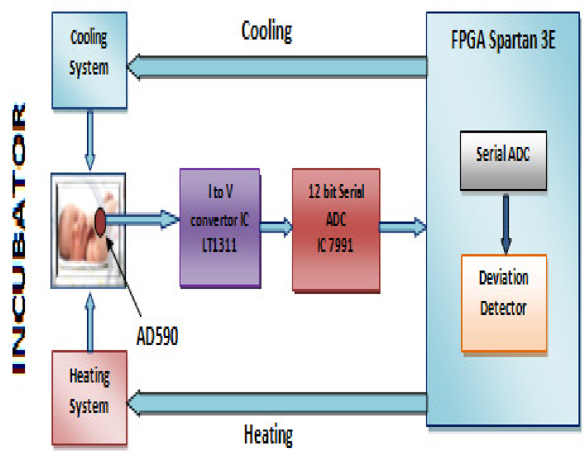

Fig. 1 Block Diagram of the FPGA based Skin-Temperature Controller for the Incubator

The Fig.1 portrays the prototype developed for neonatal care unit to monitor the baby's skin-temperature and control it to the pre-set value using a closed loop system. It gives an idea about that, the skin-temperature of newborn baby being measured by using the temperature probe with AD590. The Linear Current Output of the device is 1 microampere per degree Kelvin [5]. The serial ADC unit 'PmodAD2', developed by Digilent Inc. was installed to convert analogue input into its digital equivalent. To interface AD590 with the ADC, the current to voltage converter IC from linear technology was deployed. The LT1311 is a quad current-to-voltage converter. The Accurate Gain of the device is 20mV per microampere [8].

The voltage generated from LT1311 was further given to analogue input at the serial ADC. The ADC generates 12 bit serial output in relation with the analogue voltages it samples. The AD7991 device operates on Inter IC communication protocol. For that, a soft IP module provided in [6] was implemented in the Xilinx FPGA Saprtan-3E. The VHDL process was developed to compare the digital signal; associated preferred temperature. The top level VHDL core was developed to instantiate the serial ADC driving module. As shown in Fig. 1, the process entitled as, 'Deviation Detector' checks for digital equivalent signal; related with the skin-temperature. In this prototype, when the skin-temperature sensed by AD590 inside the incubator exceeds the magnitude 36.5˚C, the cooling system had to get activated. On the contrary, when the skin-temperature drops down than the expected one, the radiant warmer control signal was activated to increase and maintain the newborn baby's skin-temperature.

3. Soft IP Core Implementation in FPGA for NICU.

The Soft IP Core given in [6] drives the serial ADC module 'PmodAD2'. It was instantiated in the top level VHDL design. In addition to that, a process was developed in this research work to compare preset 12 bit magnitude, stored in the serial ADC driving module. The following VHDL code shows the process performing test for a pre-decided value at a 16 bit signal 'DCH0_ADC'; which is associated with the set temperature.

```
Deviation_Detector: PROCESS (RESET_INC, CLK_INC,
DCH0_ADC)
BEGIN
IF RESET_INC ='1' THEN
WARMER_COOLER<= (others=>'0');
        elsif rising_edge(CLK_INC) then
                if DCH0_ADC > X"0008" then
                        WARMER_COOLER<= "01";
                elsif  DCH0_ADC < X"0008" then
                        WARMER_COOLER<= "10";
                end if;
        END IF;
END PROCESS;
```

The VHDL lines in the process shows that, there are three signals in its sensitivity list; that means, the moment when any event occurs on either of these signals, the process get executed. The global reset named as 'RESET_INC' resets the two bit vector signal: 'WARMER_COOLER'. On rising edge of the system clock 'CLK_INC' the comparison of the pre-set digital value is performed, and the necessary value ride on the signal 'WARMER_COOLER' as shown in the VHDL code lines of the process named as 'Deviation_Detector' .

4. Simulation Results of Incubator Soft IP Core.

To perform simulation on the soft IP core designed in this research work, stimuli were applied on the input and internal signals as shown below in Fig.2. It illustrate that, when the reset signal 'reset_inc' is asserted high, the signal 'warmer_cooler' was reset to "00"; indicating neither of the temperature control system-related signals enabled. On the contrary, when the 'reset_inc' signal was pulled down to low, according to the status available at the 16 bit internal signal (dch0_adc[15:0]), one of the slice bit from the 2 bit signal ('warmer_cooler') was asserted to high. This concludes that, when the pre-decided value of signal 'dch0_adc[15:0]' gets deviated, then the cooling or heating related bit from 'warmer_cooler' gets asserted high.

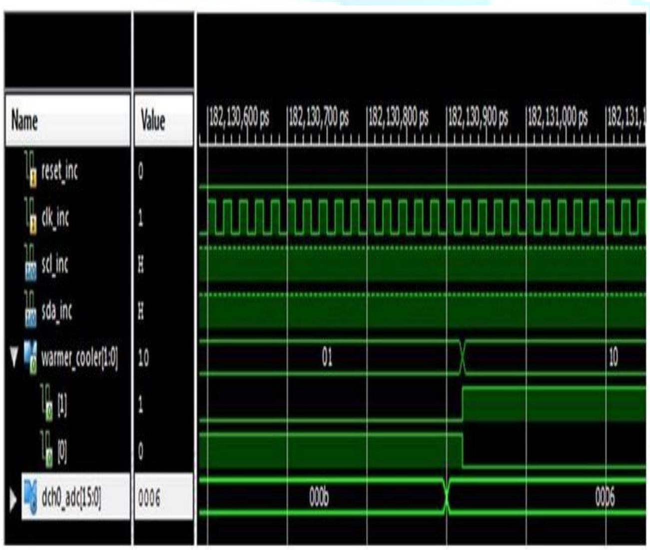

Figure 2: Waveforms showing the Simulation Results for the Incubator System obtained using Xilinx ISim Simulator

To compare the simulation results with the actual readings obtained at the hardware end, the resolution of serial ADC and its 12 bit magnitude has to be taken into account. As given in [5], the AD590 produces 1 microampere current for a degree Kelvin temperature. In this research work, the focus has been given on maintaining the new-born baby's skin-temperature around 36.5 ˚C (i.e.309.65 ˚K). Thus, the temperature sensor produces 309.65 microampere current for this controllable parameter. The serial ADC requires the input in the form of voltage; therefore, the current to voltage converter IC was deployed in the signal conditioning system. The IC LT1311 has its gain factor of the order of 20 mV per microampere. As a result of temperature 36.5 ˚C (sensed by AD590), the analogue voltage produced at the linear technology device was of the order of 6.193mV. The LSB size for the AD7991 is V_{REF}/4096. The FPGA Nexys2 Digilent board has onboard 3.3V power out lines, which was given as V_{REF} to the ADC module. Thus, its LSB size becomes 0.805 mV. The theoretical analogue input for the ADC can be calculated by multiplying LSB size with the Decimal Equivalent of its Digital Output. In other words, when the serial ADC produces 0008H, it reveals that, its analogue input is approximately 6 mV. Thus, for the temperature value about 36.5 ˚C, the serial ADC produces the 16 bit value 0008H (or 0008). When the serial ADC produces digital signal of the magnitude greater than 0008, it means that, the temperature value exceeds the control parameter. This makes essential to turn on the cooling system by sending necessary activation signal from the FPGA. On the counter part of this, as the temperature reduces less than 36.5 ˚C, the heating system gets triggered from the FPGA core.

The simulation results shown in Fig.2 illustrates that, when the signal 'dch0_adc[15:0]' exceeds the value 0008 (becomes 000B), then the signal 'warmer_cooler[1:0]' produces "01". It indicates that, the cooler system get triggered from the FPGA. On the other side, when the 16 bit signal 'dch0_adc[15:0]' becomes less than that of 0008 (i.e. 0006), the 'warmer_cooler' signal generates "10", so as to turn on the heating system and maintain the skin-temperature of newborn baby to 36.5 ˚C.

5. Synthesis Results and FPGA Implementation of the Soft IP Core

The Fig.3 explores the Register Transfer Level (RTL) synthesis of the entire soft IP core implemented in the Xilinx FPGA Spartan3E device: xc3s500e-4fg320. The user constraint format (.ucf) file was developed to interconnect the I/O pads of Xilinx Spartan3E FPGA device; embedded on the Digilent Nexys2 board. The reference manual of this board is given in [7] and the same was referred to interconnect clock signal provided from the board to FPGA device. The different hardware resources available on the Nexys2 board were connected to the FPGA I/O pads using this constraint format file as shown below.

```
# UCF FOR SPARTEN3E DEVICE: XC3S500E-4FG320
    NET "RESET_INC" LOC = B18; # BTN0 (Button Switch)
    NET "CLK_INC" LOC = B8;       # Onboard clock
    NET "SCL_INC" LOC = L17;      #JA3
    NET "SDA_INC" LOC = M15;      #JA4
    NET "WARMER_COOLER[0]" LOC = J14;  #LED0
    NET "WARMER_COOLER[1]" LOC = J15;  #LED1
```

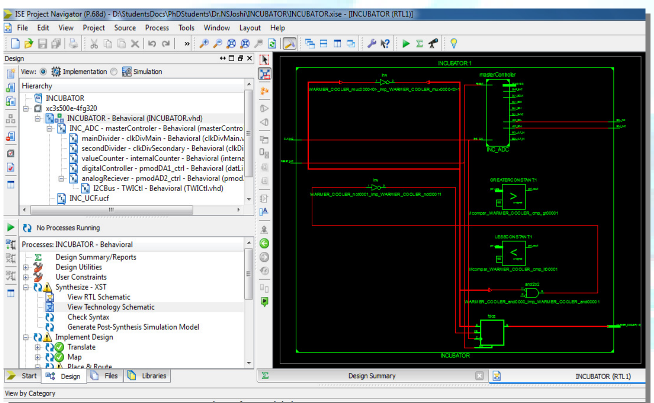

Figure 3: RTL Synthesis of the Soft IP Core for Skin-Temperature of the Newborn Baby Kept Inside the Incubator of NICU

6. Conclusion

The research work is a prototype development to control the skin-temperature of a newborn baby kept inside the incubator of NICU at the value of 36.5˚C. The potential of HDL, that is, executing more than one module concurrently has been utilized in this research work. By means of executing data acquisition process in a VHDL component and comparing the magnitude of the temperature in another VHDL module, gives the evidence of HDLs having the concurrency in behavior. As a result of this, the prototype developed in the research work for neonatal care unit takes an immediate action and generate necessary signals to turn on either the heating or the cooling system of the incubator. The data acquisition system was developed installing temperature sensor AD590, serial ADC and FPGA from Xilinx Inc.

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