Research Paper Engineering

Design of HDL Model Integrating Biosensors, Disease Analyzer, Expert system and Pump controller for medical application

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ABSTRACT

The research work proposes an automated disease detection and drug delivery unit that can be used for detection and monitoring of cancer. The delivery unit was designed, modeled and implemented in this work. A software reference model for the complete unit as a system is developed and analyzed for its functionality, for the first time. It is found that with the growth in population and due to changes in environmental conditions, human race is prone to various diseases. With shortage of medical practitioners and doctors, there is an immediate need for alternate solutions to cater to the needs of the common man. HDL model is designed by the integration of Biosensors, Disease analyzer, Expert system and Pump controller. The HDL model is synthesized using Xilinx ISE and the synthesis results obtained shows that the design occupies only 148 slices operating at a maximum frequency of 293 MHz. It is thus suitable for real time implementation. The PID controller is modeled using HDL and is synthesized targeting Virtex II pro FPGA device. The results show that the PID controller can operate at a maximum frequency of 1045 MHz.

Keywords : Biosensor, Nano Sensors, DNA, FPGA

1. Introduction

The Indian healthcare industry is growing at at such a rapid pace that it is expected to become a $280 billion industry by 2020. One million Indians are reported to be dying due to inadequate healthcare facilities and that over 700 million people are reported to be having no access to specialist care as 80% of specialists live in urban areas. It is also noted with concern that 40% of the primary health centers in India are understaffed. Diseases in Indians are increasing at an alarming rate of 6% and the estimated doctor's availability in India are 2.1% and medical practitioners are 6%. There is a huge demand for medications and doctors for after treatment monitoring. Nano-bio sensor based automated disease detection and drug delivery unit thus can overcome the shortcomings spelt out above and is discussed.

2. Background Theory on Biosensor

Human genomes have billions of DNA base spheres to sense the DNA sequence. Arrays of sensors are used for genome sensing. Nanobio sensor consists of X-Y array of elements. These elements further consist of pixels called as electronic components [1]. The function of nanobio sensor is to detect the amount of current change and the corresponding concentration of unknown DNA sequence in a given electrolyte is detected.

Based on the equation of $N(t)$, mathematical models for nanowire sensor is developed [1].

$$N(t) = \rho_2\, t\left[\frac{A}{C_t} + \frac{1}{k_F N_0}\right]^{-1} \quad (1)$$

Choosing appropriate values for C_t, the geometries of the sensor, three different sensors can be modelled[3].

The expert system processes the data and detects the presence of cancer and classifies the various diseases. Based on the classification process, the expert system also generates control signals to the control unit to diffuse corresponding drug stored. The feedback system in the control unit constantly monitors the diffusion process. The expert system and control unit have been integrated and implemented on FPGA to understand the hardware implementation performances of the system.

The automated disease detection unit consists of the following blocks:

- ✓ Biosensors
  - ➢ Disease sensing units with current/voltage output
- ✓ Disease analyzer
  - ➢ Data base consisting of details of diseases and remedies
- ✓ Expert system
  - ➢ Disease analyzer and control unit to diffuse the drug as per the disease
- ✓ Pump controller
  - ➢ Controls the drug diffusion based on the inputs provided by master controller

3. PID Controller Design and Modelling

This block implements a 32-bit digital PID controller with automatic correction [2]. The inputs are a reference input (ref) and a feedback input (fdb) and the output (out) is the saturated PID output. Figure 1 shows a PID controller. A feedback loop is used to monitor the drug diffusion. Based on the feedback signal, the control unit monitors the drug diffusion process. The differential equation describing the PID controller before saturation which is implemented in this block is given by equation (2)

$$u_{presat}(t) = u_p(t) + u_i(t) + u_d(t) \quad (2)$$

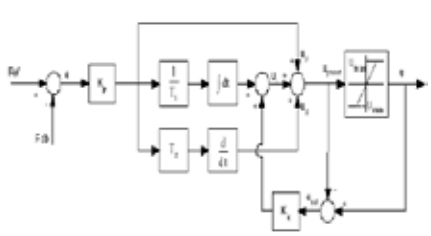


Figure 1 Simulink Model of PID Controller [4]

The proportional term is $u_p(t) = K_p e(t)$, where K_p represents the proportional gain of the PID controller and $e(t)$ is the error between the reference and feedback inputs.

4. FPGA Implementation of Expert System and PID Controller

For real time implementation of expert system and PID controller logic, it is necessary to verify the hardware performances of the complex system. The complexity of expert system is large as it consists of 5 neurons. Each neuron receives 100 input samples. Thus the total number of multipliers that are required together in the hidden and output layer is 21605; number of adders required is 2 for sigmoid transfer function. Similarly the PID controller requires 4 multipliers, 4 adder/ subtractor unit, two accumulators and one transfer function. The fundamental building blocks of expert system and PID controller are adders, multipliers, memory elements and control logic.

5. Design and Implementation of Adders and Multipliers

Multiplier logic presented in previous section is modeled using Verilog HDL and verified using ModelSim. In order to estimate the performances of various multipliers, FPGA implementation is carried out for various multipliers and is presented in this section.

5.1 Implementation of Multiplier

FPGA implementation involving translation mapping, place & routing as well as device configuration is important. In design process, the implementation of design deals with all the constraints like area, timing and power. For comparing the performances of the multipliers, the designs are implemented using Spartan-3 family FPGA.

5.2. Synthesis Report of Multipliers

From the synthesis report obtained, BCSD multiplier utilizes memory of 180 MB and the maximum clock frequency is up to 84.946 MHz. 11.772 ns is the time to estimate approximately and in most cases it is the maximum time that would be more accurate than the actual timing of the design. The results obtained from map report estimate 8.147 ns as the minimum period without considering wiring delays of the circuit. Actual timing after routing will be in between the two values of time. Further

Table 1 Synthesis Report of Multipliers

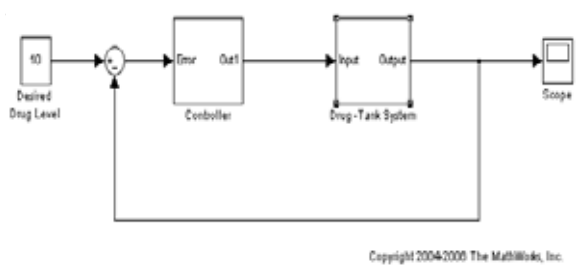
there would be no combinational delay for a sequential circuit. On careful observation after the pin assignment, the floor plan will be shifted near to the I/O blocks thereby reducing the delays. Table 1 shows the synthesis reports of multipliers in terms of number of slices, 4 input LUTs, usage memory, combinational delay and minimum pin delay [5].

Parameter	BCSD Multiplier	ARRAY Multiplier	MODIFIED BOOTH Multipler	BAUGH WOOLEY Multiplier
Device utilization summary				
No. of slices	158/1920	158/1920	197/1920	158/1920
No. of 4 input LUTs	275/3840	275/3840	345/3840	275/3840
No. of IOs	48	48	48	48
No. of bonded IOBs	48 /173	48 /173	48 /173	48/173
Total usage memory – KB	179976	179976		179528
Max.Combinational path delay – ns	37.526	37.526	39.577	37.486
Place & Route report Device utilization summary				
No. of external IOBs	48/173	48/173	48/173	48/173
No. of LOCed IOBs	0/48	0/48	48/48	0/48
No. of slices	143/1920	143/1920	186/1920	144/1920
No. of SLICEMs	0/960	0/960	0/960	0/960
The Average Connection Delay (ACD) - ns	1.149	1.149	0.884	1.132
The maximum pin delay – ns	3.381	3.381	4.203	3.399
The ACD on the 10 worst nets is - ns		2.961	3.022	2.796

Table 1 shows the performance measures of multipliers constraints, delay and number of gates of multipliers. From the reports obtained it is concluded that, better optimization is obtained for memory of 29MB and 2 ns of timing. With the help of high radix algorithm, the clock frequency is increased and number of additions/ subtractions is more in comparison with BCSD.

6. Drug Diffusion Controller System Model and Analysis

Simulink model for the proposed architecture is developed and simulated. The Simulink model is shown in Figure 6. The model consists of a drug decision unit that selects the corresponding drug and the amount of drug to be diffused. The selected quantity is taken as reference and based on this information the controller drives the drug diffusion unit. The results are monitored on scope. The results obtained are presented.



- ✓ The Drug storage-tank system
- ✓ A Controller subsystem to control the level of drug in the tank by varying the voltage applied to the pump
- ✓ A reference signal that sets the desired drug level
- ✓ A Scope block that displays the height of water as a function of time

The controller block contains a simple proportional-integral-derivative controller. Once the classification algorithm detects the cancer cells based on the processing carried out in the expert system, a suitable drug is selected after considering the patients history and other parameters such as height, weight and age. A suitable number corresponding to the parameters is used to set the desired drug level. The controller unit is triggered by the expert system and the PID controller diffuses the drug. The transient response of the simulink model is captured and is shown in Figure 6.

Figure 6 Simulink Model of Drug Diffusion Unit

To measure the performance characteristic of sensor models, matlab based simulink model has been developed and sensors have been characterized for disease detection [3].

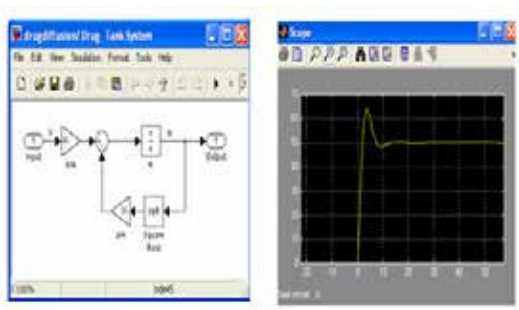


Figure 7 Simulation Results of Drug Diffusion Model

The control unit has a transient response and overshoots the normal value by 10%. It settles to the nominal value in less than 10ms. This is achieved by the use of PID controller. Overshoot and settling time of the proposed unit is better in performance. Use of only proportional or PI or PD controller may not be able to get the required results. Thus the developed system is suitable for drug diffusion unit.

7. FPGA Implementation Results and Discussion

Disease detection and drug delivery unit model is synthesized targeting Virtex 4 FPGA with 35 million gate complexity. Table 2 presents the hardware utilization result of the implemented design.

Table 2 Synthesis Results of Drug Diffusion Unit

Resource utilization	This work	Previous work (approximated estimation)
Number of LUTs	148	372
Operating frequency	292.757 MHz	134 MHz
Power consumption	33mW	41mW

The design utilizes multipliers, adder/subtractor, comparators and registers. From the synthesis results, it is found that the design operates at a maximum frequency of 292 MHz, and occupies 148 slices. Thus the design is optimized for area and speed.

8. Conclusion

In order to analyze the performances of hardware implementation of the proposed system, HDL model is developed for expert system consisting of neural network. The HDL model is synthesized using Xilinx ISE. The synthesis results obtained shows that the design occupies only 148 slices whilst operating at a maximum frequency of 293 MHz. It is therefore suitable for real time implementation. The PID controller is modeled using HDL and is synthesized targeting Virtex II pro FPGA device. The results show that the PID controller can operate at maximum frequency of 1045 MHz. From the results obtained, it is concluded that demand exists for automation in the field of medical electronics for detection of diseases and automatically deliver suitable drug from the storage unit.

REFERENCES

[1] Jolliffe I.T. Principal Component Analysis, Series: Springer Series in Statistics, 2nd ed., Springer, NY, 2002, XXIX, 487 p. 28 illus. ISBN 978-0-387-95442-4 | [2] Ang, K.H., Chong, G.C.Y., and Li, Y. (2005). PID control system analysis, design, and technology, IEEE Trans Control Systems Tech, 13(4), pp.559-576. http://eprints. gla.ac.uk/3817/ | [3] S.M.Ushaa, Dr.Madhavilatha, Prof. Madhusudhana Rao Ganji -"Design and Analysis of Nanowire Sensor Array for Prostate Cancer Detection" (Submission code: IJNBM-20274) for the (IJNBM). Int. J. Nano | [4] Ang, K.H., Chong, G.C.Y., and Li, Y. (2005). PID control system analysis, design, and technology, IEEE Trans Control Systems Tech, 13(4), pp.559-576. http://eprints. gla.ac.uk/3817/ | [5] Shanthala. S, and Dr. S. Y. Kulkarni "VLSI design and implementation of Low Power MAC unit with Block Enabling technique" published in the Journal "European Journal of Scientific Research" Vol. 30, No. 4, (2009) , pp. 620-630, during April 2009. |