Photon Absorption Implementation for Cancer Therapy by Monte Carlo Method

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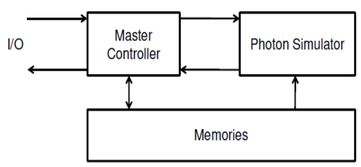
Introduction

Photo Dynamic Therapy is the most optimistic emerging treatment which can be efficiently used in treating cancer at different stages. The challenge is identifying the cancerous cells and treating them without affecting the healthy cells.

The cancer cells usually absorb more light fluence than the healthy cells. So the cancer cells can be identified using this method. The major challenge in adapting this methodology for treatment of cancer cells is estimating the light dose for the treatment.

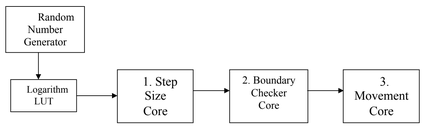
The Monte Carlo algorithm is adapted to estimate the light dose at different stages of the treatment. Monte Carlo algorithm is a versatile method of obtaining approximate solutions to very highly complicated analytical problems. This implementation in particular needs numerous pseudo random numbers for accurate results [2]. So an MCML model with assistance of a photon simulator will help in estimating the light dose distribution. The pseudo random number assist in analyzing the photon packet's distribution as a random variable.



Methodology

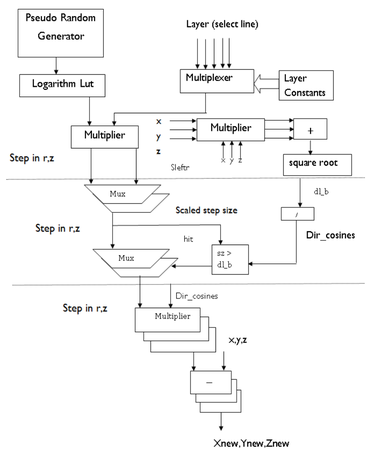
Position Update Engine

The position update engine determines the next interaction coordinates of the photon packet. The next interaction site coordinates are calculated using step size which is determined by sampling a probability function which is based on the mean free path of the photon packet.



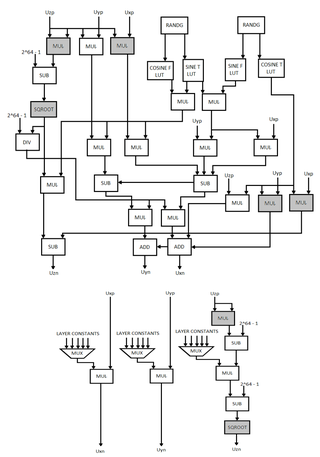
The random number generator uses the Mersenner Twister algorithm and generates a random variable with range 0 to 1. The step size core calculates the step size of the photon packet traversing through the layers. The skin layers in this project are limited to 5 layers [1][3].

Methodology



Direction Update Engine

A photon can have three different interactions in this stage; 1. Traversing a tissue layer without meeting other photons 2. Encountering a boundary, 3. The photon interacts with another photon. The rotation core and reflect transmit core architectures are shown below respectively.

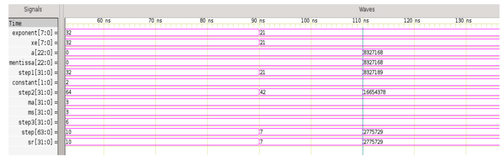


Design Improvements

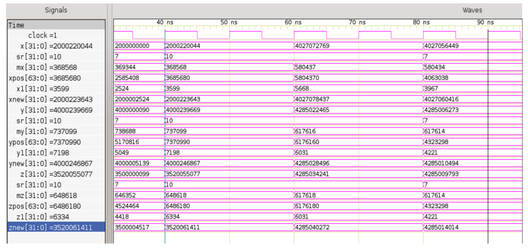
- All the direction cosines are values in between 0 and 1; they are represented as fixed-point data after the decimal point.
- To conform to the standard 32-bit format, the lower bits removed from the decimal value (which requires division by a power of 10).
- Division is an extremely resource intensive so, it was eliminated by a simple approximation, 10^9 ~ 2^30 which is a binary shift operation of 30 bits.

Results

The 32-bit binary input is converted in to exponent and mantissa format . The logarithm value is calculated using this format.



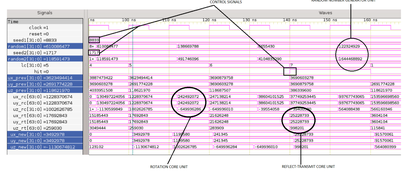
The exponent 'xe' is calculated by finding the Most significant 1-bit using a mask algorithm. The mantissa is also calculated in the same way. The priority encoder is implemented in the logarithm LUT for simplicity.



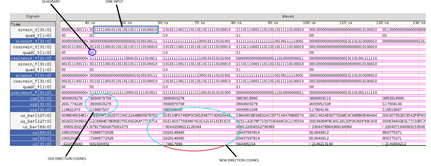
The step size 'sr' is multiplied with mx. This gives a result which is added to the previous coordinate to get the final coordinates in x,y,z directions

Direction Update Results

This top unit consists of an embedded control unit for generating signals that modify the behavior of its cores. The updated direction cosines output are refreshed every cycle.



If hit = 0 then this output will be the result obtained from the rotation core and if hit = 1, the output will be from the reflect transmit core. The variables 'ux', 'uy' and 'uz' are the bit restricted values of 'ux_bar','uy_bar and 'uz_bar'.



Summary

This implementation was focused more on the front-end design and we used LUTs to achieve the required speed. The existing model in hardware, which was built on Altera STRATIX III FPGA, consumed 40W. Our direction update engine consumed around 8.1W, which is quite reasonable as this, is the most critical core in the design. Our implementation is the first step in the practical application of photodynamic therapy for treatment of cancer. We have built an over view of the real design which includes all the blocks that are essential for the final product.

Key References

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[2] "Hardware Implementation of Pseudo Random Number Generator by Mersenne Twister (MT) Algorithm" by Sricharan Narayan, December 2011.

[3] L. Wang, S. Jacques, and L. Zheng, "MCML-Monte Carlo modeling of light transport in multi-layered tissues," Computer Methods and Programs in Biomedicine, vol. 47, no. 2, pp. 131–146, 1995.

[4] T. Dougherty, "Photodynamic Therapy," Photochemistry and Photobiology, vol. 58, no. 6, pp. 895–900, 1993.

[5] V. Tuchin, "Light scattering study of tissues," Physics-Uspekhi, vol. 40, no. 5, pp. 495–515, 1997

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