Project Report on

Monte Carlo Simulation of Linear Accelerator for Dosimetric Analysis

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Abstract: Radiation therapy is a type of cancer treatment that uses beams of intense energy to kill cancer cells. The equipment most often used for the procedure is the Linear Accelerator (LINAC), which produces beams of X-rays. It is required to evaluate the dose distribution of the LINAC machine before applying radiation therapy to the human body. This project is aimed at achieving the same. The algorithms to evaluate dose distribution for radiotherapy planning will be based on Monte Carlo methods. In terms of accuracy and providing realistic results, Monte Carlo methods have proven to be promising. The project is in collaboration with MVR Cancer Center at Calicut and aim to simulate an Elekta 6MeV LINAC for its dose evaluation.

1 Introduction

Cancer is one of the deadliest diseases in the world today. Cancerous cells are formed when cells in the body fail to die and instead have an abnormal and uncontrollable growth. With over 100 types of cancer reported to date, this disease can affect any part of the body. One of the major techniques for cancer treatment is radiotherapy.

Radiotherapy uses waves of energy, such as light or heat, to treat cancers and other tumours and conditions. The most commonly used machine in radiotherapy is the Linear Accelerator (Linac). A LINAC produces X-rays in the range of 5-30 MeV.

The head of a LINAC consists of a target, primary collimator, flattening filter, ionisation chamber, mirror and secondary collimator (MLC- Multi Leaf Collimator in Figure 1). It produces beams of radiation to the affected area of the patient body to kill the cancer cells. Once the cancer is diagnosed, the dose of the radiation will be determined from the CT(Computed Tomography) images taken from the patient as part of the treatment.

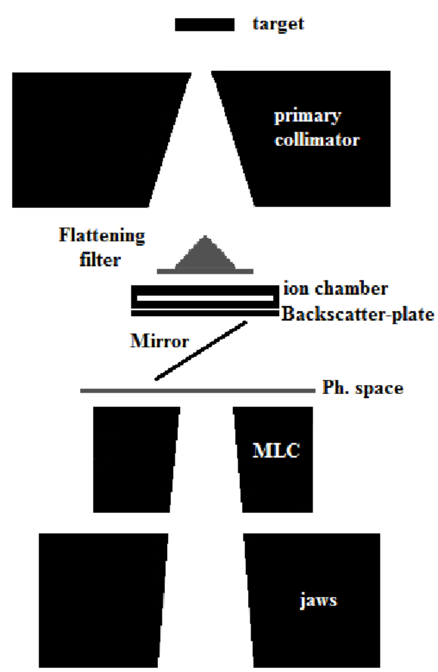

Fig 1:Geometry of the Elekta linac gantry.

In this project, we initially try to simulate the LINAC head for beam production. For this, the phase space is generated. The phase space contains information such as energy, position, direction, etc. of millions of particles (photons, electrons, positrons). In the next stage, the particles which constitute the phase space are transported in the patient or phantom and the dose distribution is calculated.

To ensure the precision of the dose, we deploy the Monte Carlo (MC) simulation method. This method relies on repeated random sampling to obtain numerical results and can help us to acquire accurate results.

The accuracy depends on the number of histories, and consequently, the simulation time. To reduce the simulation time, parallel computing will have to be used, which can be implemented in Geant4 using suitable libraries.

2 Motivation

With the deadly disease of cancer affecting a significant population all over the world, any step that contributes towards its treatment is of much help. Radiotherapy, being one of the primary treatment techniques for cancer, requires a proper analysis of the dose of radiation to be transferred to the patient. For this dosimetric analysis, the LINAC shoots radiation beams on a physical phantom which acts as the patient body. These physical phantoms are quite expensive. Moreover, only proprietary software is available for phantom simulation.

By using the open-source simulation toolkit Geant4, our project aims to simulate the LINAC and the phantom for the analysis, thus avoiding the cost of the physical phantom as well as the proprietary software. This, in turn, is hoped to provide easier availability of the treatment at a lower cost for the patients.

3 Problem statement

Monte Carlo simulation of a linear accelerator for treatment planning of cancer:

1. Simulation of radiation beam production in LINAC.
2. Simulation of beam transport from LINAC head to phantom.
3. Dosimetric analysis of radiation.

4 Literature Review

4.1 Background

The LINAC uses microwave technology to accelerate electrons in a 'waveguide. The electron gun attached to the waveguide acts as the electron source. The electrons are accelerated down the structure by pulses of microwave from a magnetron (Figure 2). The electron beams, on leaving the accelerator tube, are bent by magnetic fields. Once the electron beam hits the target, X-ray beams are produced.

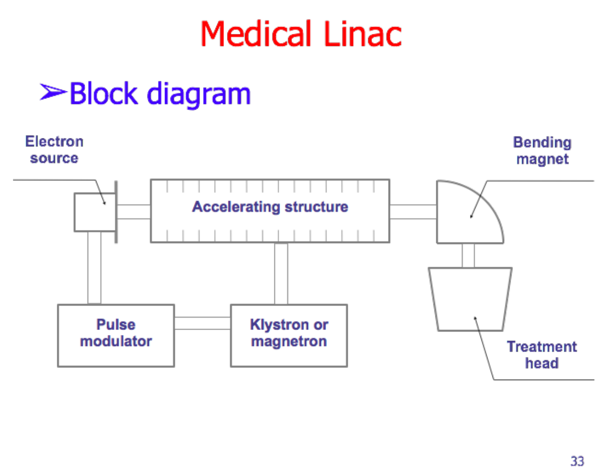

Fig 2: Block Diagram of Medical LINAC electron acceleration structure.

Primary collimators, which are situated right below the target, direct the beam in the direction of the treatment and reduce leakage. At the lower end of the primary collimator is the flattening filter, which reduces the beam intensity in the centre to provide uniform radiation intensity distribution. The beam then enters the ionization chamber, from which measurements of the amount of radiation are taken and uniformity of the beam is controlled.

The backscatter plate (In Elekta Synergy Platform LINAC) avoids backscattered radiation from secondary collimators. The mirror placed on beam central axis shows the position of the radiation beam and enables patient set-up.

The next focus is to target the radiation dose to cancer cells as precisely as possible to minimize side effects and avoid damaging normal cells. Imaging tests are used to contour the shape and location of one's tumour and define its boundaries.

The customized beam is usually shaped by a multileaf collimator (MLC) that is incorporated into the head of the machine. The patient lies on a moveable treatment couch and lasers are used to make sure the patient is in the proper position. The treatment couch can move in many directions including up, down, right, left, in and out. The beam comes out of a part of the accelerator called a gantry, which can be rotated around the patient. Radiation can be delivered to the tumour from many angles by rotating the gantry and moving the treatment couch.

4.2 Related Works

Several works have been done in the field for the simulation of Linear Accelerators, some of which are briefed below.

In a work done by Kagri Yazgan and Yigit Cecen [1], Monte Carlo N-particle (MCNP) code was used to simulate a medical electron linear accelerator gantry. Flux, dose, and spectrum analyses were performed for filtered and FFF (Flattening Filter-Free) systems separately. Per cent depth dose and dose profile measurements were calculated with Monte Carlo simulations and compared with experimental and theoretical values for quality assurance of the model. The following were the results of the experiment:

- The average photon energy was 3.54 times higher in the filtered system than in the FFF system.
- The average photon dose was 3.18 times higher for the FFF system than for filtered system.
- The errors in the comparison of simulation-experimental values were only 0.22%.

Mohammad Taghi Bahreyni Toossi et al. [2] on the other hand used the MCNP-4C to simulate electron beams from Neptun 10 PC medical linear accelerator. They measured and calculated, output factors for 6, 8 and 10 MeV electrons applied to eleven different conventional fields. The measurements were accomplished by Wellhofler-Scanditronix dose scanning system. Their findings revealed that output factors, acquired by MCNP-4C simulation and the corresponding values obtained by direct measurements were in a very good agreement.

In a work done by B. Serrano et al. [3], an MC code MCNPX (Monte Carlo N-Particle eXtended) was used to model a 25 MV photon beam from a PRIMUS(KD2-Siemens) medical linac. The mean electron beam energy produced by the linac was stated to be 19 MeV.The entire geometry including the accelerator head and the water phantom was simulated to calculate the relative depth-dose distribution and the dose profile. The measurements were done using an ionisation chamber in water for different square field ranges. Results showed that the mean electron beam energy is 15 MeV and not 19 MeV as mentioned by Siemens. In the near future, these results will help us to validate the dose deposition on IMRT (Intensity-Modulated Radiation Therapy) treatment, especially for the head and neck regions.

Yahya Tayalatia et. al [4] developed a computational model for 6MV Elekta Synergy Platform LINAC using GATE Monte Carlo software. The simulation was carried out using v6.2 of GATE, built on top of GEANT4 simulation toolkit. There were only a few primary event interactions in the penumbra tail of radiation field, because of which points lower than 10% of the maximum dose area were not considered. The simulated depth dose profiles were in good agreement with the measured ones, with uncertainty less than 1.6%. The simulation of lateral dose profiles also fit accurately with the measurements with less than 1.8% of error uncertainties.

M Attarian Shandiz et al. [8] formulated a computer algorithm for detailed Monte Carlo simulation of the transport of electrons with kinetic energies in the range of 0.1 and 500 keV in bulk materials and in thin foils. The differential cross-section(DCS)s for elastic scattering were calculated using a relativistic partial-wave code ELSEPA, which allows considering different scattering potentials. For inelastic collisions, the DCS was found to be completely determined by the optical oscillator strength (OOS). This can be constructed by combining atomic photoabsorption cross-sections with low-energy OOSs obtained either from density functional theory calculations or from experimental optical data. Upon comparison of simulation results with several experimental computations, they showed that this MC code provided a realistic description of the penetration and energy loss of electrons in bulk materials, within the considered energy range.

Alex C. H. Oliveira et al. [9] worked on the evaluation of dose distributions in radiotherapy planning. They aimed at creating a computational model of the head of a 6 MeV Linac using the MC code Geant4 for the generation of phase spaces. For assessing the beam quality (photon and electron spectra along with two-dimensional distribution of energy) and analyzing the physical processes which take place in producing the beam, information was taken from the phase space. The MC simulations were divided into two parts. In the first part, the simulation of the production of the radiation beam was performed and then the phase space was generated. In the second part, the simulation of transport of the sampled phase space in certain configurations of the irradiation field was performed to assess the dose distribution in the patient (or phantom).

5 Work Plan

5.1 Work done so far

1. Literature Survey: Understood the working and components of a LINAC head.

2. Visited the MVR Cancer Centre: Attended a talk on LINAC and its internals.

5.2 Work plan for the semester

1. Understand the working of Geant4 code for Monte Carlo based particle simulation.

2. Simulation of radiation beam production by the LINAC machine.

6 Conclusion

Cancer has grown to become the second leading cause of death. Because of the same, radiotherapy's prominence has increased, and with it, the need for proper dosimetric analysis. Since the overdose of radiation can even lead to the patient's death, it is of utmost importance to ensure the correct dose for treatment. Using Monte Carlo simulation, dosimetric evaluation can be done with high accuracy. For the process, the simulation of beam production in LINAC and beam transport to the simulated phantom are also to be done. Through this project, we hope to simulate an Elekta LINAC at MVR Cancer Centre.

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