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An Enumeration of Radiotherapy Terminologies, Planning and its Optimization

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Abstract

The process of radiotherapy involves irradiating radiation in the tumours to destroy cancer cells shielding healthy tissues and vital organs from the effect of radiation. Therefore the objective of this paper is an effort for understanding the Intensity Modulation Radiation Therapy (IMRT) machine along with its treatment planning. The radiotherapy terminologies that enumerates details about Dose Volume Histogram (DVH), bixels, voxels and the standard for sharing medical images compatible with various devices known as Digital Imaging Communications in Medicine (DICOM). Finally the optimization techniques involved in cancer treatment using Intensity Modulation Radiation Therapy (IMRT) is formulated. The linprog tool in MATLAB is used to solve the formulated Linear Programming Problem (LLP) to illustrate the application of operation research in radiotherapy.

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Keywords: Digital Imaging Communications in Medicine (DICOM); Intensity Modulation Radiation Therapy (IMRT); Linear Programming Problem (LPP); Dose Volume Histrogram (DVH).

1. Introduction

Generally for external-beam beam radiation therapy high energy X-rays, gamma rays and charged particles are used to shrink tumours and cancer cells by damaging their DNA[1].The standard radiotherapy machine called a linear accelerator (LINAC) performs a type of conformal radiotherapy known as intensity modulated radiotherapy (IMRT). The IMRT shapes the radiation beams to closely fit the area of the cancer, shields healthy tissues and vital organs from the effect of radiation to avoid the side effects in cancer treatment [2]. The rest of the paper is organized

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as follows. Section 2 briefs about the literature survey, section 3 deals with the explanation of IMRT equipment, planning, and radiotherapy terminologies. Section 4 describes about dose volume histogram (DVH) and Digital Imaging Communications in Medicine (DICOM). In section 5 Linear Programming formulation (LLP) for IMRT optimization is framed and solved to show the application of Operation Research in cancer treatment and finally section 6 deals with conclusion and future scope of the paper.

2. Literature Survey

[3] proposed a stochastic frame work to design individualized treatment strategies that dynamically adapt to tumour-response, to deliver the right dose to the right location at the right time. [4] has framed the models radiation dose distribution is described by design dose matrix and thereby dividing the matrix into different kinds of shape matrixes to solve them through optimization programming. For Fluence-map optimization Primal-dual interior-point method is proposed by [5]

3. External Beam Radiotherapy

3.1 IMRT Equipment and Treatment Planning

Intensity Modulated Radiotherapy (IMRT) facilitate a shaped array of 3mm beamlets using a Multi-Leaf Collimator (MLC), which is a specialized, computer-controlled device with many tungsten fingers, or leaves, inside the linear accelerator[6]. Multi-Leaf Collimator (MLC) creating a time-varying opening allows a finer shaped distribution of the dose to avoid unsustainable damage to the surrounding structures (OARs) [7]

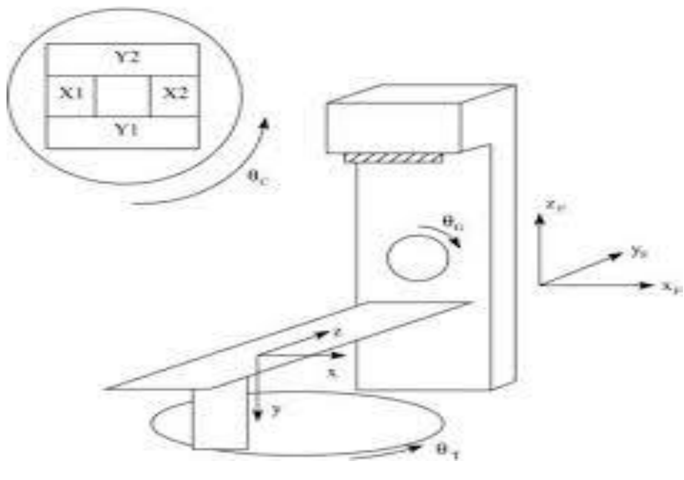

Fig. 1. IMRT Machine

Based on sequential method the solution approach to IMRT treatment planning is as shown in Fig. 2. In IMRT there in an intensity map for each angle. A collection of shape matrices are created to satisfy each intensity map as shown in Fig. 3. [8]

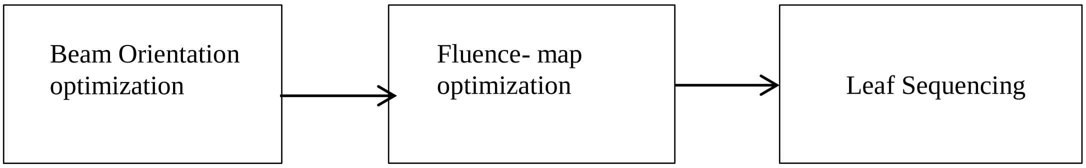

Fig. 2. IMRT Treatment Planning

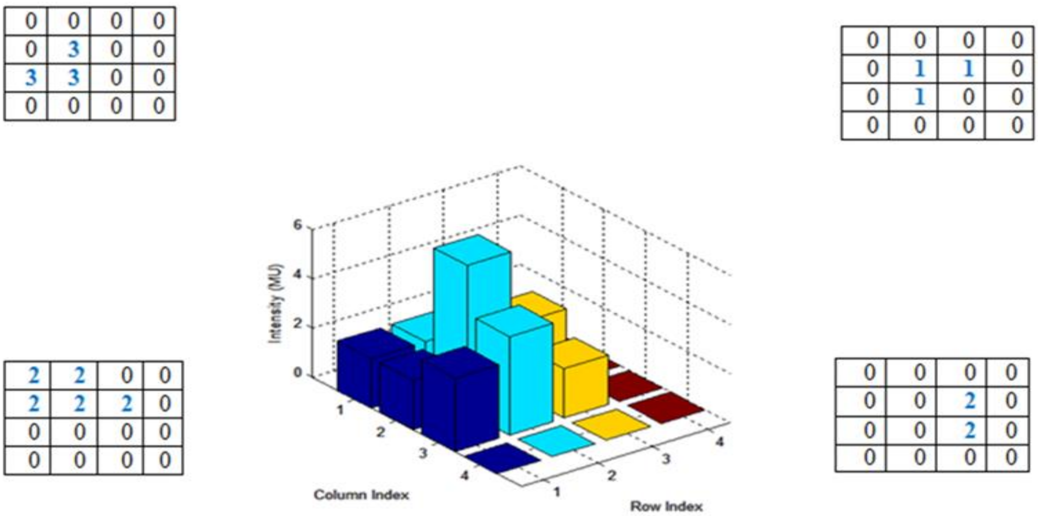

Fig. 3. Creating a Fluence-map using MLC

4. DICOM images and DVH

4.1 DICOM images

The National Electrical Manufactures Association (NEMA) created a standard to aid distribution and viewing of medical images known as DICOM. This standard is compatible with all modern imaging equipment's, accessories, networking servers, workstations, printers and picture archiving and communication systems (PACS) which are installed by multiple manufactures.

MatLab supports DICOM files and is vital tool in processing of DICOM images. The figure below shows a snap shot of reading metadata and image data of DICOM file using MatLab.

```
>> info = dicominfo('brain_001.dcm')

info =

                          Filename: [1x78 char]
                       FileModDate: '12-Feb-2014 14:26:52'
                          FileSize: 132914
                            Format: 'DICOM'
                     FormatVersion: 3
                             Width: 256
                            Height: 256
                          BitDepth: 16
                         ColorType: 'grayscale'
    FileMetaInformationGroupLength: 180
        FileMetaInformationVersion: [2x1 uint8]
           MediaStorageSOPClassUID: '1.2.840.10008.5.1.4.1.1.4'
        MediaStorageSOPInstanceUID: '0.0.0.0.1.8811.2.1.20010413115754.12432'
                 TransferSyntaxUID: '1.2.840.10008.1.2.1'
            ImplementationClassUID: '0.0.0.0'
         ImplementationVersionName: 'NOTSPECIFIED'
      SourceApplicationEntityTitle: 'NOTSPECIFIED'
                         ImageType: 'ORIGINAL\PRIMARY\MPR'
                       SOPClassUID: '1.2.840.10008.5.1.4.1.1.4'
                    SOPInstanceUID: '0.0.0.0.1.8811.2.1.20010413115754.12432'
```

Fig. 4. Metadata and image data of DICOM file

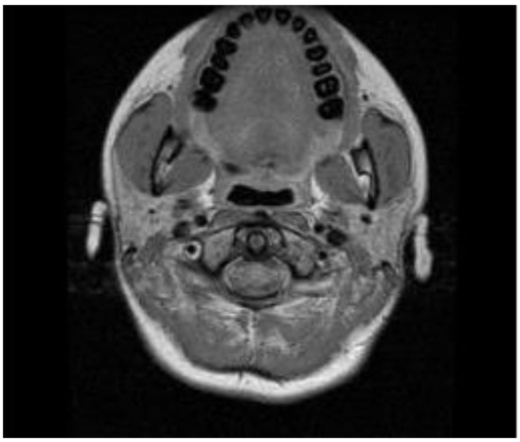

Fig. 5. MRI of the brain read from DICOM file

4.2 Dose-Volume Histogram

Dose-Volume histogram is mathematical tool to assess whether a radiation therapy plan meets desired constraints for a volume of interest, within certain limitations. The relation between differential dose-volume histogram or dDVH and more familiar cumulative dose-volume histogram is

$$cDVH(D) = \sum_{x=D}^{D\max} dDVH(x) \qquad (1)$$

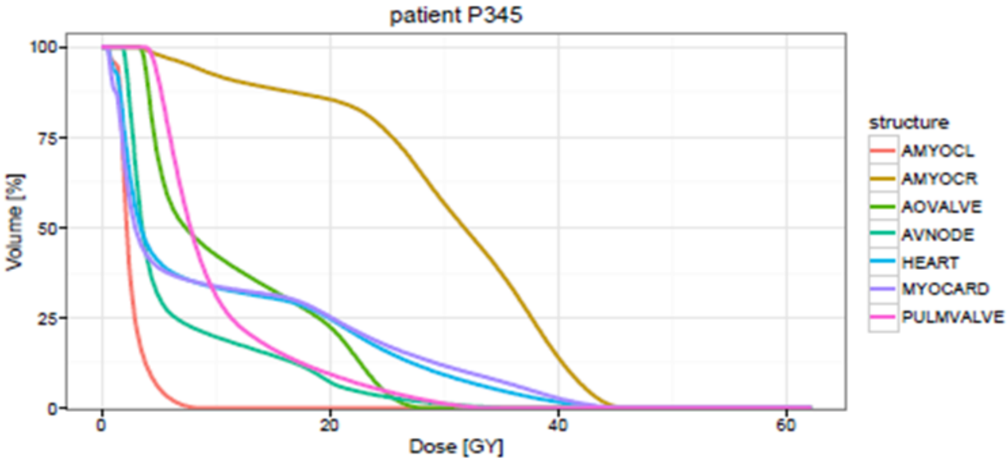

Fig. 6. Dose Volume Histogram

5. Linear Programming Formulation for IMRT

5.1 Problem Statement

The target is divided into nine voxels, voxel 1 to 9. For simplicity we have considered the two-dimensional approach for the problem. Each beam is divided into three beamlets that make total six beamlets.

Also, it is given that 7Gray of radiation is at least required to damage the tumour cells. Also, the spinal tissue cannot tolerate the radiation of more than 5Gray level.

The region which is subjected to radiation therapy is divided into 9 voxels where voxel1, voxel3, voxel6 and voxel9 are other healthy tissues, voxel2, voxel4, voxel7 and voxel8 are tumour tissues and voxel5 in the spinal tissue. So, we need to minimize the damage to vowels 1,3,5,6 and 9.

5.2 Structured Input

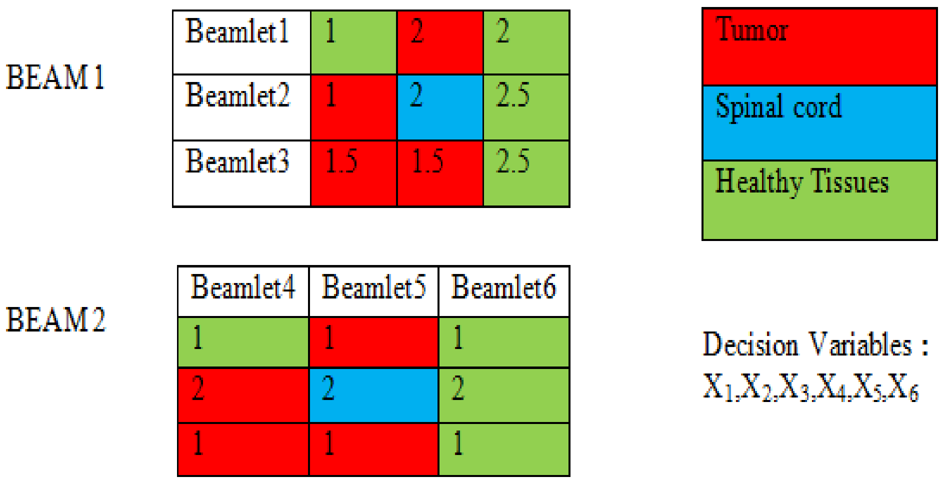

Fig. 7. Beamlet irradiation on voxels in 2D

The target area is discretized into equal size cells known as Voxels. The two beams are split into number of beamlets known as Bixels to incident on voxels. The Multi –Leaf Collimator (MLC) of IMRT machine minimizes the intensity of X-rays on healthy tissues and critical organs and maximizes the intensity to kill the tissues in tumor region.

5.3 Problem Formulation

Minimize total healthy tissue dose:

$$Z = (1+2)X1 + (2+2.5)X2 + 2.5X3 + X4 + 2X5 + (1+2+1)X6 \qquad (2)$$

Subject to Constraints:

$$2X1 + X5 >= 7$$
$$X2 + 2X4 >= 7$$
$$1.5X3 + X4 >= 7$$
$$1.5X3 + X5 >= 7$$
$$2X2 + 2X5 <= 5$$
$$X1, X2, X3, X4, X5, X6 >= 0$$

Where , Z is the objective function
X1, X2, X3, X4, X5, X6 are decision variables

Intensities of Beamlets

Beamlet	Intensity
1	2.25
2	0
3	3
4	3.5
5	2.5
6	0

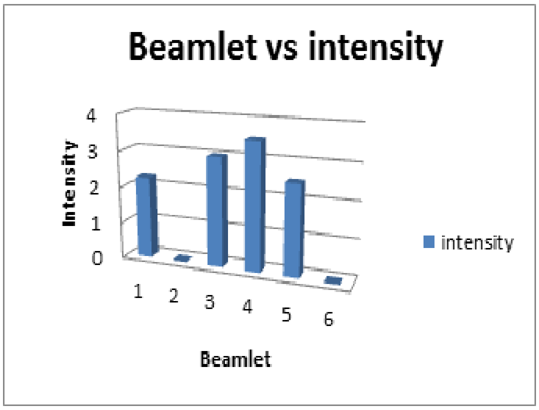

Fig. 8 Beamlet Intensity for irradiation in tumors region sparing organ at risk

Objective: Minimize total healthy tissue dose (voxels 1, 3, 5, 6 and 9),
Z = 22.75 Gy

6. Conclusion

The IMRT machine and its treatment planning are discussed. Then the need for DICOM standard along with DVH generated using 3D image data sets created from various treatment modalities are explained. Finally the LLP formulation for IMRT optimization are formed and solved by Linprog MatLab tool to illustrate the application of Operations Research for cancer treatment. The future scope of the paper is to analyze the possibility of graph theory, multiobjective optimization and Markov models for treatment planning optimization.

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