# Applications of Cone Beam Computed Tomography in Radiotherapy Treatment Planning

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# List of Abbreviations

ACA: Adaptive Convolution Algorithm

ART: Adaptive Radiotherapy

CBCT: Cone Beam Computed Tomography

CNR: Contrast-to-Noise Ratio

COR: Centre of Rotation

CPU: Central Processing Unit

3D-CRT: Three- dimensional Conformal Radiotherapy

CT: Computed Tomography

CTV: Clinical Target Volume

DDR: Distance Dependent Resolution

DICOM: Digital Imaging and Communications in Medicine

DMPO: Direct Machine Parameter Optimisation

DVH: Dose Volume Histogram

DQE: Detective Quantum Efficiency

2D: Two-dimensional

3D: Three-dimensional

FBP: Filtered Back Projection

FDK: Feldkamp Davis Kress

FOV: Field of View

FPI: Flat-Panel Imager

fps: frames per second

FWHM: Full-Width at Half Maximum

GPU: Graphical Processing Unit

H&N: Head and Neck

HU: Hounsfield Unit

IGRT: Image-Guided Radiotherapy

IMRT: Intensity Modulated Radiotherapy

IQ: Image Quality

kVp: Peak kilovoltage

lp/cm: line pair /centimetre

mAs: milli-ampere second

MEX: Matlab Executable

MLC: Multi leaf Collimator

MLEM: Maximum-Likelihood Expectation-Maximisation

MRI: Magnetic Resonance Imaging

MTF: Modulation Transfer Function

MU: Monitor Unit

OAR: Organs at Risk

OBI: On-Board Imager

OSEM: Ordered Subset Expectation Maximisation

PCT: Planning Computed Tomography

PET: Positron Emission Tomography

PTV: Planning Target Volume

QA: Quality Assurance

ROI: Region of Interest

SAD: Source-to-Axis Distance

SBRT: Stereotactic Body Radiotherapy

SD: Standard Deviation

SDD: Source-to-Detector Distance

SNR: Signal-to-Noise Ratio

SPECT: Single Photon Emission Computed Tomography

SSD: Source-to-Surface Distance

TFT: Thin-Film Transistor

TPS: Treatment Planning Systems

# I. Abstract

In recent years Image-Guided Radiotherapy (IGRT) has experienced many technical advances. One of the most significant has been the widespread implementation of kilovoltage imagers attached to the gantry of linear accelerators (LINACs); these units are capable of 2D planar imaging, fluoroscopy and 3D Cone Beam Computed Tomography (CBCT) imaging. With CBCT imaging, the treatment plan can be modified based on patient's anatomy just before the treatment session. This method of Adaptive Radiotherapy (ART) helps in managing a patient's treatment by compensating for the effect of daily setup variation and changes to the tumour during the course of radiotherapy. Currently the image quality of CBCT is sufficient for patient set-up verification; however the use of CBCT for dose calculations requires reproducible CT numbers in order to be used effectively during ART. The aim of this project was to investigate methods to improve the image quality of CBCT datasets in order to facilitate their use in dosimetric calculations.

The project was divided into two major parts. In the first part, the conventional Feldkamp-Davis-Kress (FDK) cone-beam reconstruction algorithm was implemented in Matlab. The algorithm was then modified using weighting factors for data redundancy and for non-equal cone angles. A 2D adaptive filter was used to remove noise and to compensate for the loss of resolution. A modified in-house reconstruction algorithm was developed and the image quality obtained was comparable to reconstructed images obtained using the Varian OBI system software. The images are free of crescent artifacts and showed a maximum spatial resolution of 7 line pairs/cm. The effect of different reconstruction filters on CBCT image quality was also studied and guidelines were produced for different anatomical sites to assist in choosing appropriate filters to achieve optimal reconstructed image quality.

In the next part of the research, a comparative study between Varian and in-house reconstructed images was performed using Planning CT (PCT) images as a reference dataset. The feasibility of using the Varian and in-house reconstructed images for treatment planning was investigated by acquiring CBCT images of the Rando anthropomorphic phantom. An Intensity-Modulated Radiotherapy (IMRT) treatment plan was generated using both sets of reconstructed images using the Pinnacle$^3$ treatment planning system.

Planar dose distributions were extracted from both the datasets in order to evaluate dose distributions quantitatively based on 3%/3mm Gamma analysis criteria. These distributions were then compared against the reference PCT image and it was found that in-house reconstructed images showed good agreement with the PCT images with a gamma passing rate of 99.8%. Although several pre-processing steps performed on the Varian images were not included during in-house reconstruction, the results demonstrated the potential for use of in-house reconstructed CBCT image for treatment planning.

As an alternative to FDK reconstruction, iterative reconstruction using Maximum Likelihood solutions was also investigated. Since the Ordered Subsets Expectation Maximisation (OSEM) package used in this study is intended for fan-beam geometry, only the slices from the central plane of cone-beam were chosen. The projections were corrected for distance-dependent resolution and centre of rotation offset. When the number of iterations was increased to 16, the algorithm converges well and showed more uniform images. However, the images were not comparable to FDK-based images due to the intrinsic difference in data handling. The OSEM program was developed initially for emission-based measurements and did not model the scatter component effectively for transmission-based measurements. Including the scatter component more effectively may make it more realistic for CBCT geometry.

# II. Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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My final thanks, as always, go to my family, whose love and support are so important to me.

# IV. Publications

**Journal Papers**

1. Srinivasan, K, Mohammadi, M, Shepherd, J 2014, 'Applications of linac-mounted kilovoltage cone-beam computed tomography in modern radiation therapy: A review', *Polish Journal of Radiology*, vol. 79, pp. 181-193.

2. Srinivasan, K, Mohammadi, M, Shepherd, J 2014, 'Cone Beam Computed Tomography for adaptive radiotherapy treatment planning', *Journal of Medical and Biological Engineering*, vol. 34(4), pp. 377-385.

3. Srinivasan, K, Mohammadi, M, Shepherd, J 2014, 'Investigation of effect of reconstruction filters on cone-beam computed tomography image quality', *Australasian Physical & Engineering Sciences in Medicine*, vol. 37, pp. 607-614.

**Conference Presentations**

1. Use of Cone Beam Computed Tomography for Radiotherapy Treatment Planning, EPSM 2011, held in Darwin.

2. Varian CBCT for Adaptive Radiotherapy Tasks, EPI2k12, held in Sydney, March 2012.

3. Investigation of effect of reconstruction filters on image noise and resolution in Varian Cone-beam Computed Tomography, EPSM 2012, held in Gold coast, 2012.