BrachyShade: Real-time Quality Assurance for High Dose Rate Brachytherapy

by

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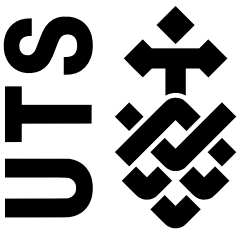
Master of Engineering by Research



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Dedication

To My Father

Abstract

High dose rate (HDR) brachytherapy is a popular form of radiotherapy in which radiation is delivered to the tumour via a small sealed radioactive source, which is moved through a sequence of positions in an array of catheters pre-implanted in the target area. Brachytherapy offers a key advantage over external beam radiotherapy, since the radiation dose is delivered directly to the diseased tissue while minimising the dose applied to healthy tissue in proximity to the target volume.

The accuracy of source placement is critical to the success of HDR brachytherapy. Deviations between the planned source position and the actual position achieved during treatment, due to anatomical changes (e.g. due to swelling or post-imaging tumour growth) or imperfect catheter placement, can harm healthy tissue or under-irradiate diseased tissue. Therefore, a reliable, accurate, real-time 3D source tracking system would be extremely valuable for treatment quality assurance and would allow a treatment plan to be modified in real time if positioning errors are detected.

HDR BrachyView is an in-body source tracking system designed to monitor the location of a HDR prostate brachytherapy source developed at the Centre of Medical Radiation Physics at the University of Wollongong, based on a tungsten pinhole camera with a silicon pixellated photon detector. Source position is estimated by back-projecting images of the source projected through the pinholes onto the imaging plane. Although HDR BrachyView has been shown to perform very well, it is challenging to manufacture, and suffers from a small systemic error in position estimation.

BrachyShade proposes to replace the tungsten collimator with a series of small spherical or spheroidal tungsten occluders embedded in a plastic shell, suspended over

the same pixellated detector (TimePix) used in the original HDR BrachyView. Instead of tracking bright projections of the source, the shadow of the source will be tracked, and by parametrically fitting an analytic model of the shadow map (where the model parameters are source position and intensity), the source position will be estimated. The proposed design significantly simplifies the manufacturing process, lowering the costs of manufacturing; it will also allow many more photons to arrive at the detector, enabling faster acquisition of a high quality position estimate. The achievable accuracy is comparable to HDR BrachyView, with a wider field of view achievable, depending on the specific configuration of tungsten occluders.

This Thesis presents a set of Monte Carlo simulations of the system, performed in Geant4. A sophisticated analytic model of the shadow map has been derived, and an algorithm developed which estimates the source position by minimising the error between the output of the analytic model and the detected photon map. A post-processing stage eliminates the effects of Compton scatter, which are otherwise mathematically challenging to include in the analytic model. Exhaustive test results proving the accuracy of the algorithm are presented. A second analytic method for estimating source position via a hierarchical pattern-matching strategy is also described, and preliminary results presented.

Keywords: Cancer, HDR Brachytherapy, Quality Assurance

Abbreviations

AAPM	American Association of Physicists in Medicine
ABS	American Brachytheapy Society
ACIM	Australian Cancer Incidence and Mortality workbooks
AIHW	Australian Institute of health and Welfare
AJCC	American Joint Committee on Cancer
BSDF	Backscatter dose fraction
BT	Brachytherapy
CCD	Charge-coupled device
CIRS	Computerized Imaging Reference Systems
CMRP	Centre for Medical Radiation Physics
CoG	Geometrical centre
CoMi	Ideal centre of mass
CRT	Conformal radiation therapy
CTV	Clinical Target Volume
DHT	Dihydrotestosterone
DRE	Digital rectal examination
DSP	Direct source projection
DVH	Dose Volume Histogram
D90	The Dose Delivered to at least 90% of The Target Volume
D80	The Dose Delivered to at least 80% of The Target Volume
EBRT	External Beam Radiotherapy
ESP	Extensive source projection

ESTRO	The European Society for Radiotherapy and Oncology
FOV	Field of View
HDR	High Dose Rate
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IGRT	Image-guided radiation therapy
IMRT	Intensity modulated radiation therapy
ISUP	International Society of Urological Pathology
LDR	Low Dose Rate
LET	Linear energy transfer
MOSFET	Metal Oxide Semiconductor Field Effect
PBT	Prostate Brachytherapy
PCB	Printed Circuit Board
PDR	pulsed Dose Rate
PSD	Plastic Scintillation Detector
PTV	Planning Target Volume
OARs	Organs at Risks
QA	Quality Assurance
SD	Standard deviation
SBR	Signal to background ratio
SDD	Source to detector distance
SEM	Error of the sample mean
SNR	Signal to Noise Ratio
SSIM	Structural Similarity Index
SVD	Singular Value Decomposition
TLD	Thermoluminescent Dosimeters
ToA	Time of arrival mode
ToT	Time over threshold mode
TPS	Treatment Planning System
TRUS	Transrectal Ultrasound
V100	The Percentage of the Prostate Receiving %100 of the prescriped Dose
WED	Water-equivalent depth

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