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Investigation of two respiratory monitoring systems used for 4D CT and respiratory gating

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INVESTIGATION OF TWO RESPIRATORY MONITORING SYSTEMS USED FOR 4D CT AND RESPIRATORY GATING

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CERTIFICATION

I, Joanne L. McNamara, declare that this thesis, submitted in partial fulfilment of the requirements for the award of Master of Science by Research, in the faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Signed.....

Date.....

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ABSTRACT

Respiratory gating enables breathing synchronised activation of CT image acquisition and linear accelerator radiation output. Two commercially available respiratory gating systems used for planning and treatment of thoracic and abdominal cancer are investigated. The strain gauged AZ-733V respiratory gating system (Anzai Medical Systems, Tokyo, Japan) was used concurrently with the infrared Real-time Position Management system (Varian Medical Systems, Palo Alto, CA) to measure the respiratory cycle of 15 volunteers. Correlation between systems was measured in six locations and the optimum position of the external surrogates determined based on signal amplitude, reproducibility of breathing waveforms and the coefficient of determination between Anzai and RPM signals. The mean value of R^2 between the two systems was found to be 0.611, 0.788 and 0.925 when both markers were positioned at the xiphoid, midway between the xiphoid process and umbilicus, and at the umbilicus respectively. When positioned in separate locations results were varied, R^2 values ranging from 0.345-0.965. Results highlighted the importance of external surrogate position to the respiratory signal obtained, and indicated that the external marker position on the chest wall needs to be reproducible between 4D CT scanning and treatment. Recommendations are made that external surrogates must always be positioned at the umbilicus for the most clinically useful scans.

Image distortion and artifacts were studied using the Anzai AZ-733V respiratory gating system in combination with the Siemens Sensation Open CT scanner. A moving respiratory phantom was constructed and the volumetric accuracy of retrospectively reconstructed 4D CT images for three moving test objects, across five frequencies and four amplitudes of movement was compared. Volumetric accuracy was found to be within 10% for retrospectively reconstructed gated objects moving with a period of 4 s, amplitude 1 cm. Large deviations of 19.4-51.6% from the static volume of the objects were observed in gated images for periods of 3 s or less. Significant distortion and under sampling was observed in gated images of the objects moving with a period of 10 s. Artifacts were related to the partial projection effect and data sufficiency conditions outlined in literature (Keall 2004, Pan 2004, Dinkel 2007).

GLOSSARY AND ABBREVIATIONS

3DCRT: Three-dimensional conformal radiation therapy

4D CT: Four-dimensional computed tomography

ABC: Active Breathing Control

ACPSEM: Australasian College of Physical Scientists and Engineers in Medicine

AP: Anterior-Posterior

CCD: Charge coupled device

CTV: Clinical Target Volume

DIBH: Deep Inspiration Breath Hold

DICOM: Digital Imaging and Communications in Medicine.

DRR: Digitally Reconstructed Radiograph

Duty cycle: Ratio of the beam on time to the total treatment time.

EPID: Electronic Portal Imaging Device

EOE: End of Exhale

EOI: End of Inhale

External surrogate: Traceable reference point exterior to the patient

Exhalation: Resting expiratory level (Keall 2006)

Fiducials: Reference points located within the patient

Gating window: Range of the surrogate signal to which image acquisition or treatment is restricted.

GTV: Gross Tumour Volume

Hysteresis: The lagging of an effect behind its cause

ICCC: Illawarra Cancer Care Centre

Interfraction motion: Motion which occurs between fractions

Intrafraction motion: Motion which occurs during a fraction (treatment session).

IGRT: Image-guided radiation therapy

IMRT: Intensity Modulated Radiation Therapy

MLC: Multi-leaf collimator

Phase sorting: The phase angle specifies a percentage of the period of the breathing cycle

Pitch: The ratio of distance that the table moves during one complete rotation of the x-ray tube to slice thickness.

PTV: Planning Target Volume

Prospective 4DCT gating: Data acquisition is triggered by events in the respiratory signal

Range of motion: Displacement between inhalation and exhalation (Keall 2006)

Respiratory gated: The synchronisation of image acquisition and treatment with respiration such that the image is acquired/radiation delivered only during a specified portion of the breathing cycle (Keall 2006).

Retrospective 4DCT gating: CT and respiratory signal are acquired simultaneously. Post scan, CT images are sorted into respiratory phases based on phase or amplitude of the respiratory trace.

RPM system: Real-time Position Management respiratory gating system (Varian Medical Systems, Palo Alto, Ca)

rpm: Respirations per minute

SI: Superior-Inferior

Spirometer: A device measuring the volume of air entering and leaving the lungs.

Tumour residual motion: Tumour motion when the surrogate signal is in the gating window.

PREFACE

This thesis compares the waveforms obtained from two different respiratory gating systems, the Anzai AZ-733V and the Real-time Position Management (RPM) infrared marker system. The primary aim was to determine if the two respiratory gating systems can be used interchangeably for radiotherapy planning and treatment. The design required observation and quantification of variations in signal ascribed to difference in monitoring methods or sensor placement.

The secondary aim of this thesis was to observe and quantify artifacts in 4D CT images and to determine if a relationship exists between severity of artifacts in 4D CT, duration of breathing cycle, and amplitude of tumour movement. The intention was to make recommendations, based on findings and literature, for optimum 4D CT respiratory gating parameters to be adhered to during 4D CT patient scans.

Chapter One contains a literature review. Issues associated with respiratory gating both in 4D CT and dose delivery, and previous work that has been reported which addresses these issues is summarised. The principles of 4D CT and the implications of gated CT acquisition on treatment planning are outlined. Artifacts in 4D CT and their cause are considered. Chapter one also describes the two respiratory gating systems to be used in this work; the Anzai AZ-733V respiratory gating system and the RPM system.

Chapter Two focuses on the measurement of respiration by two commercially available respiratory gating systems utilising external surrogates. Method and experimental set-up for the comparison of respiratory waveforms obtained from the Anzai AZ-733V system, consisting of a belt with a strain gauge, and an infrared camera-based motion-tracking system (RPM), is provided. The respiratory waveforms recorded simultaneously by the RPM and Anzai systems for a cohort of 15 staff volunteers are compared. For each volunteer, six anatomic marker locations are studied. The coefficient of determination between the two systems in each case is determined. Results are both tabulated and presented graphically. The external marker positioning has an impact on the respiratory signal obtained by the external surrogate. The influence of this was made apparent and the implications to radiotherapy planning and treatment are discussed.

In Chapter Three, artifacts are explored in 4D CT images. The Anzai AZ-733V respiratory gating system is coupled with the Siemens Sensation Open CT scanner and the accuracy of reconstructed images of a commercially available moving respiratory phantom (Anzai) assessed. An in-house respiratory phantom capable of variable frequency and amplitude of movement was constructed. Results compare volumetric accuracy of retrospectively reconstructed 4D CT images for three moving test objects, across five frequencies and four amplitudes of movement. Distortions in 4D CT images are related to the partial projection effect and data sufficiency conditions determined by scan parameters. Chapter four provides a conclusion and possibilities for future work in respiratory gating.

This work has been presented in part at the following conferences/ meetings:

McNamara, J., Metcalfe, P., Williams, M. "Comparison of two radiotherapy respiratory gating devices**" Engineering and Physical Sciences in Medicine and The Australian Biomedical Engineering Conference 2007**, Fremantle, Western Australia, 14-18 October 2007 (Abstract) *Aust. Phys. Eng. Sci. Med*. 30 (4) 373

McNamara, J., Metcalfe, P., Williams, M. "Comparison of two radiotherapy respiratory gating devices" Austin Health, Melbourne, 12th October 2007

McNamara, J., Metcalfe, P., Williams, M. "Comparison of two radiotherapy respiratory gating devices" **Vic/Tas branch of the ACPSEM Annual General Meeting**, Peter MacCallum Cancer Centre, Melbourne, 3rd December 2007 *Awarded Best Postgraduate Speaker*

Experiments were performed at the Illawarra Cancer Care Centre and results should be translatable to other centres using the combined system i.e. Anzai AZ-733V respiratory gating system with Siemens 4D CT and Real-time Position Management system coupled with Varian linear accelerators. As such two papers are in preparation for

submission to journals. These include one paper dealing with the comparison of the two gating systems and another paper outlining findings from the artifact study.