Analysis of Cone-Beam CT using prior information

Matt Moores[1], Cathy Hargrave[1,2], Fiona Harden[1], Kerrie Mengersen[1]

[1]Queensland University of Technology
[2]Radiation Oncology Mater Centre

Contact : m.moores@student.qut.edu.au

Image-Guided Radiotherapy

In radiotherapy it is important to deliver the prescribed dose to the tumour, while minimising exposure to any sensitive organs and other tissues that are nearby. The radiation beam can be controlled very precisely, but the size, shape and position of organs within the body can vary between one treatment and the next. This places limitations on the accuracy of the treatment and can lead to side-effects.

Many newer models of linear accelerators feature on-board medical imaging devices. These enable the radiotherapist to obtain an X-ray computed tomography (CT) scan *in situ*, once the patient has been carefully positioned for treatment. Using this 3D image, the radiotherapist can assess whether the degree of change exceeds tolerance. However, it can be very difficult to identify some of the critical organs in the CT scan, due to image blurring and artefacts. For this reason, the analysis is based on bony anatomy and implanted fiducial markers, rather than soft tissue.

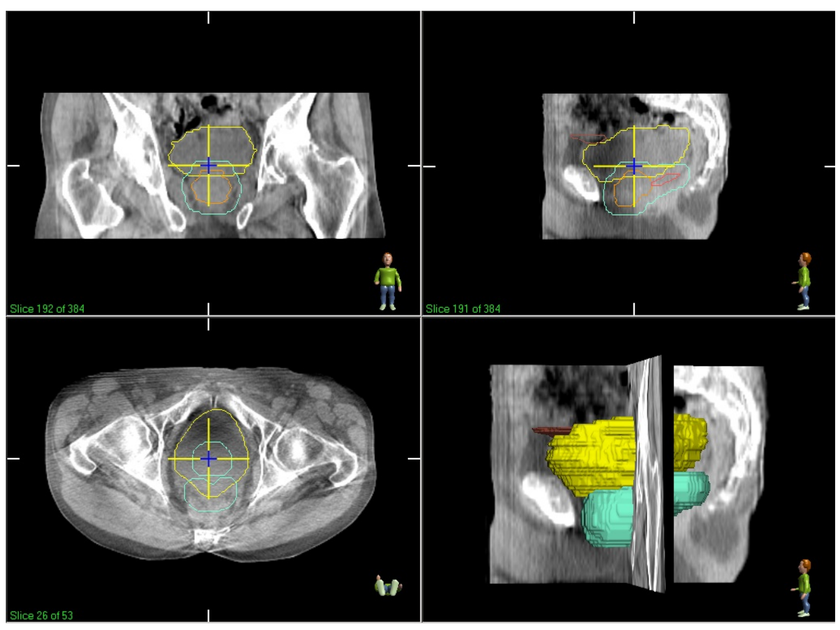


Figure 1: A Cone-Beam CT scan with contoured regions of interest: bladder (yellow); prostate (orange); seminal vesicles (red); and treatment planning volume (aqua).

The goal of this research is to incorporate prior information to aid the radiotherapist in analysing the on-board imaging. Sources of information include: the treatment plan; published literature on physiological variability; and the properties of the Cone-Beam CT scans. This information will be used to annotate the medical image, with the aim of providing a clinical decision support tool for radiotherapy.

Treatment Plan

The treatment plan for an individual patient is based on a high-resolution, fan beam CT scan. The radiation oncologist annotates this image with the contours of the tumour and nearby organs. The radiation dose field from the linear accelerator is targeted according to this information.

The planning CT and its associated contours can be viewed as a snapshot of the patient at a point in time. Model parameters that can be estimated from this data include between-pixel correlation, object geometry, and relationships between objects. However, in order to estimate the uncertainty associated with these parameter values, additional information is needed.

Physiological Variability

One source of uncertainty is the variation in size, shape and position of the organs in the body. The degree of variability is specific to the organ in question. For example, in pelvic CT scans for prostate cancer there can be a large variation in the size of the bladder and rectum, which can also displace other nearby organs. Frank et al. [1] demonstrate that the position of the prostate and seminal vesicles is correlated with the volume of the bladder and rectum. Their findings are summarized in Table 1:

Organ	Ant-Post	Sup-Inf	Left-Right
prostate	$\overline{x} = 0.1$, *sd* $= 4.1$ mm	$\overline{x} = -0.5$, *sd* $= 2.9$ mm	$\overline{x} = 0.2$, *sd* $= 0.9$ mm
seminal vesicles	$\overline{x} = 1.2$, *sd* $= 7.3$ mm	$\overline{x} = -0.7$, *sd* $= 4.5$ mm	$\overline{x} = -0.9$, *sd* $= 1.9$ mm

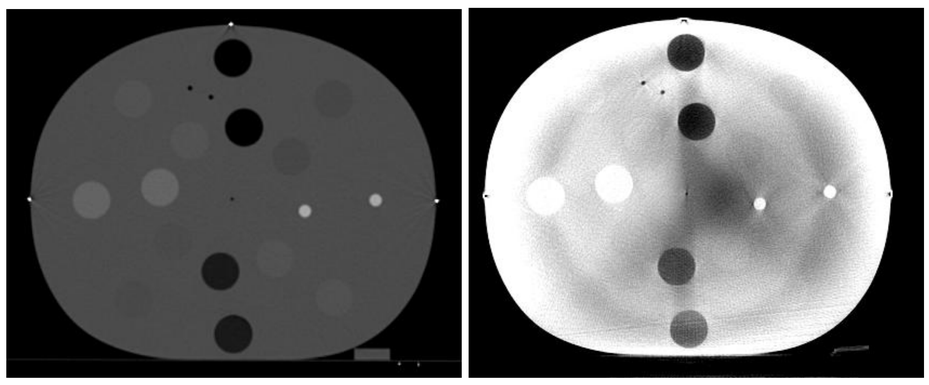
Table 1: Mean $\overline{x}$ and standard deviation *sd* of observed [1] variability in position, along 3 axes: anteropostreior (Ant-Post); superoinferior (Sup-Inf); and lateral (Left-Right).

They report that the mean rectal volume varied between 35 and 140cm^3, while the mean bladder volume varied between 120 and 381cm^3. There have been several other studies quantifying the translation, rotation and volume variation of organs over time. These could be combined using a Bayesian meta-analysis [2] to provide a more robust estimate of the variability.

Cone-Beam CT

In addition to the biological variation, there are technical sources of variability that must be taken into account. The main one of these is the difference in imaging modality between the planning CT and the treatment CT. The on-board imaging available from the linear accelerator is obtained by projecting a cone shaped X-ray beam onto a flat detector panel. Since the equipment required is less bulky, the patient can be scanned *in situ*, which is an advantage over alternatives such as CT-on-rails.

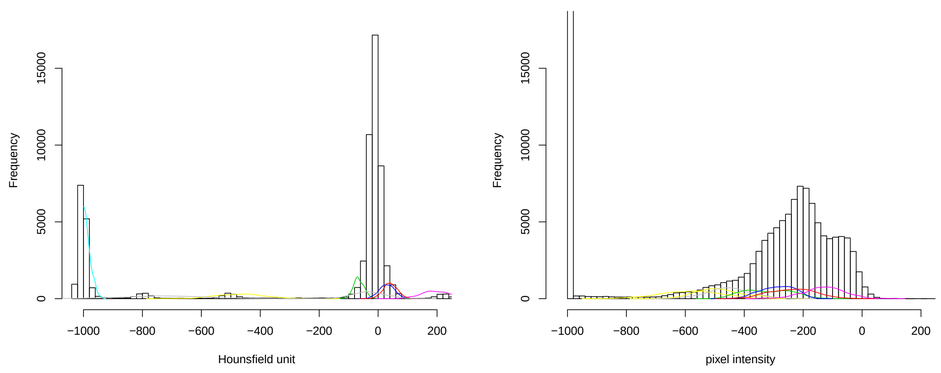
At the voxel level, there will be differences in image resolution due to changes in the field of view. However, this can be adjusted for by resampling and cropping. Of greater concern is the amount of noise and artefacts present in the Cone-Beam CT scans. A noise reduction step may be required, before segmentation.



(a) Fan Beam CT (b) Cone Beam CT

Figure 2: A single slice of a CT phantom.

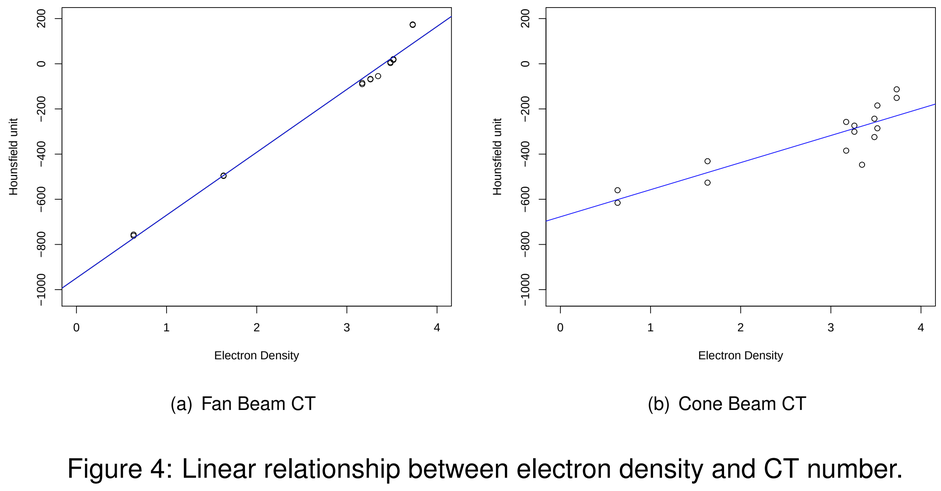
Figure 2 shows a single slice of a fan beam CT and Cone-Beam CT side-by-side, demonstrating the difference in image fidelity between the two modalities. The object in these scans is a CT phantom, which is manufactured from epoxy to mimic the X-ray attenuation of biological tissue.



(a) Fan Beam CT (b) Cone Beam CT

Figure 3: Distribution of pixel intensity values.

The pixel values in a fan beam CT scan are measured in Hounsfield units, where air is -1000 and water is 0. Figure 3 demonstrates that this relationship does not hold for Cone-Beam CT. The variation in pixel intensity within homogeneous regions of the CT phantom is much greater.



(a) Fan Beam CT (b) Cone Beam CT

Figure 4: Linear relationship between electron density and CT number.

References

[1] Frank, Steven J. and Dong, Lei and Kudchadker, Rajat J. and De Crevoisier, Renaud and Lee, Andrew K. and Cheung, Rex and Choi, Seungtaek and O'Daniel, Jennifer and Tucker, Susan L. and Wang, He and Kuban, Deborah A. (2008) Quantification of Prostate and Seminal Vesicle Interfraction Variation During IMRT, *International Journal of Radiation Oncology*Biology*Physics* **71**(3): 813-820.

[2] Stojanovski, Elizabeth and Mengersen, Kerrie (2010) Bayesian Methods in Meta-Analysis. In *Encyclopedia of Biopharmaceutical Statistics*, ed. S. C. Chow, 116-120: Taylor & Francis.