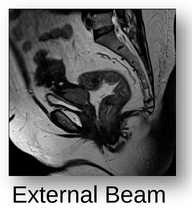
Unified Registration Framework for Cumulative Dose Assessment in Cervical Cancer across External Beam Radiotherapy and Brachytherapy

Sharmili Roy[1], John J. Totman[1] and Bok Ai Choo[2]

[1] A*STAR-NUS Clinical Imaging Research Centre, Singapore, [2]National University Health System, Singapore

Introduction

- Chemotherapy and external beam radiotherapy boosted with high-dose-rate brachytherapy is the standard of care for local advanced cervical cancer.
- Treatment outcome is greatly influenced by organ doses over all sessions.
- Typically, each session is optimized individually which results in multiple dose distributions with their corresponding anatomical images.
- Registration of the anatomical images is crucial to assess cumulative dose.
- The brachytherapy applicator makes the underlying registration very complex.
- This paper proposes a unified framework to register individual therapy sessions into one coordinate frame for a cumulative dose assessment.

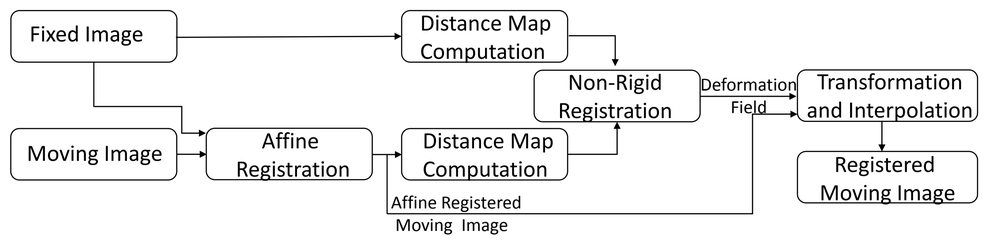


External Beam Radiotherapy Image

Brachytherapy Anatomical Image

Brachytherapy Applicators

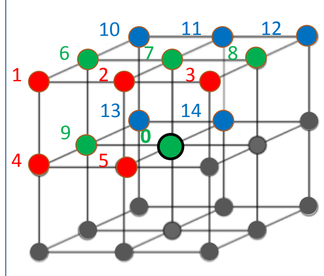
Methods

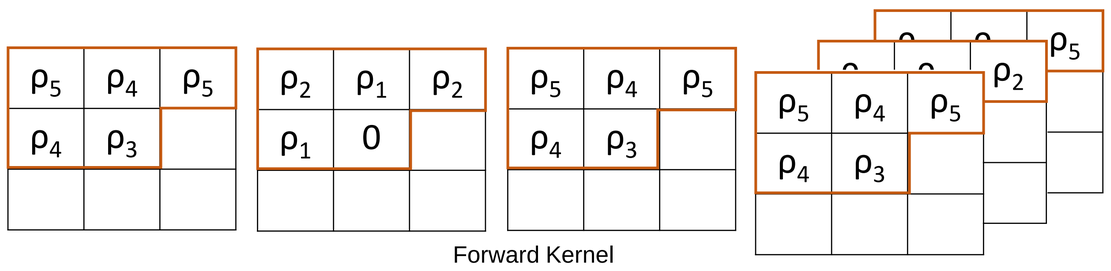


Overview of the registration pipeline

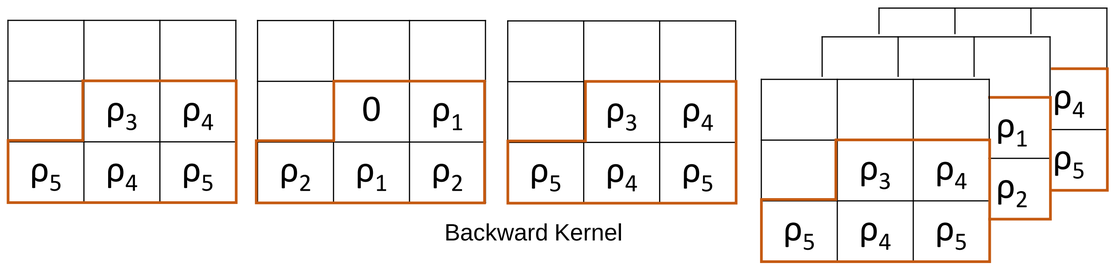
- To overcome structural dissimilarities between external beam radiotherapy and brachytherapy images, these anatomical images are transformed into their distance maps from the uterus.
- The distance maps are registered using Bspline-based non-linear registration.
- The resulting dense deformation is used to transform the original anatomical image.

Methods – Geodesic Distance Map





Forward Kernel



Backward Kernel

- We propose the use of 3D geodesic distance map.
- Given a 3D image I, an anatomical region Ω, and a binary mask M, the unsigned geodesic distance of voxel $\boldsymbol{x}$ from Ω is:

$$D(x; M, \nabla I) = \min_{\{x' | M(x')=0\}} d(x, x')$$

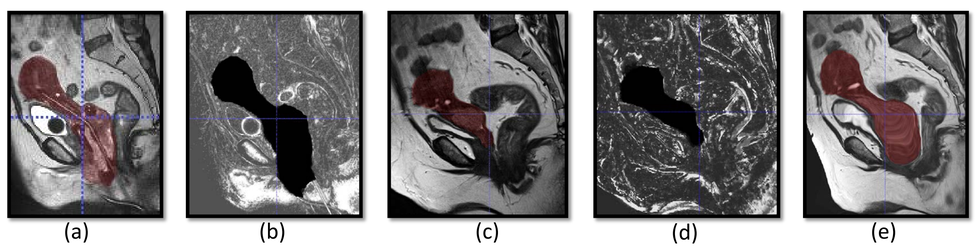
$$d(a,b) = \min_{\{\Gamma \in P_{a,b}\}} \int_0^1 \sqrt{\| \Gamma'(s) \|^2 + \gamma^2 (\nabla I \cdot u)} ds$$

- $P_{\boldsymbol{a,b}}$ is the set of all paths between points $\boldsymbol{a}$ and $\boldsymbol{b}$. $\Gamma(s)$ is one such path parameterized by its arclength $s \in [0,1]$.
- The unit vector $\boldsymbol{u}$ is tangent to the direction of the path and γ weighs the contribution of the image gradient.
- To compute the distance D, the forward kernel scans the mask M from top-left-front-corner to the bottom-right-back corner and generates an intermediate function $C(\boldsymbol{x})$.

$$C(x,y,z) = \min_{1 \le i \le 14} (C_i + \sqrt{FwdKern_i + \gamma \nabla I_{i,0}(x,y,z)^2}, \nu M(x,y,z))$$

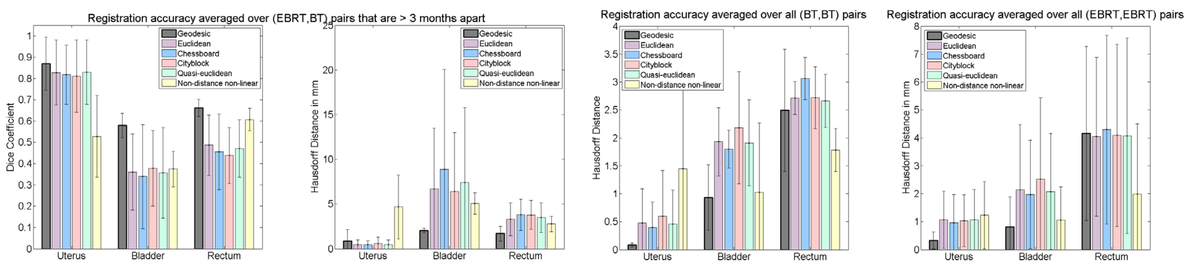
- The backward kernel scans $C(\boldsymbol{x})$ to generate the distance D.

Results



(a) (b) (c) (d) (e)

This figure illustrates registration between an external beam radiotherapy (EBRT) image and a brachytherapy (BT) image. (a) BT image overlaid with uterus segmentation, (b) uterus-based geodesic distance map of BT image, (c,d) EBRT image and its uterus-based geodesic map, (e) registered EBRT image based on registration between (b) and (d)



Quantitative comparison of registration accuracy of geodesic distance with other distance metrics and conventional free-form registration. Image pairs consisted of various combinations of BT and EBRT images.

Conclusion

- This paper proposes a unified method to register external beam radiotherapy and brachytherapy images of the pelvis for cumulative dose quantification.
- By converting images to their distance maps, this framework can also register two brachytherapy images or two external beam radiotherapy images.
- This enables assessment of 3D cumulative dose across multiple sessions of radiotherapy throughout the course of a patient's treatment.

References

1. Christensen, G. E., Carlson, B., Chao, K. C., et al., "Image-based dose planning of intracavitary brachytherapy: registration of serial-imaging studies using deformable anatomic templates," International Journal of Radiation Oncology* Biology* Physics 51(1), 227-243 (2001).
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