Accepted for presentation at ASTRO 2004

Automatic Male Pelvis Segmentation from CT Images via Statistically Trained Multi-Object Deformable M-rep Models

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Purpose/Objective: The purpose of this study was to evaluate m-rep deformable models for automatic segmentation of multi-object soft-tissue complexes in low contrast images with application to bladder, rectum and prostate in planning and treatment CT images. M-rep deformation is guided by knowledge of object and inter-object geometry and image intensity patterns gained through a statistical training procedure. The method is broadly applicable but is tested here for adaptive radiotherapy for prostate cancer, where the segmentation is applied to CT images acquired in the treatment room over the course of radiotherapy.

Materials/Methods: M-reps* are deformable models that describe anatomical objects in terms of a mean shape and local broadening & elongation, twisting & bending, and displacement of volume elements of the object(s) forming the mean. M-reps also model non-rigid between-object and within-object geometry such as the relationship between adjacent non-interpenetrating structures. Principal modes of shape variation computed in non-Euclidean space provide statistics of variability of the object(s) within a training population. Separately, image intensity statistics are generated in m-rep object-relative coordinates from the same training images.

The mean model is deformed in a target image by successive optimization to yield the most probable segmentation given the image data. The objective function reflects both the shape statistics and the intensity statistics produced at training. The deformation proceeds from the multi-object complex as a whole, to single objects starting from inter-object predictions, to intra-object volume sections. For the male pelvis the supra-pubic bones are segmented first, followed by the bladder/rectum/prostate complex, and finally the individual soft tissue structures.

In this study of the applicability of m-reps for adaptive therapy, the same-patient mean model and image intensity training were derived from the planning image. Also the shape statistics in this study describe the transformation between the planning image model and the treatment images.

Results: M-rep segmentations obtained in this study were compared to expert human segmentations by statistical analysis of metrics including volume overlap, mean surface separation, maximum surface separation, and separation-distance histogram quartiles. Clinically acceptable, non-interpenetrating segmentations of the prostate and other soft tissues were obtained.

Conclusions: Automatic m-rep segmentation works well for adaptive radiotherapy for prostate cancer. The effectiveness of m-reps is attributed to several important

properties: 1) the ability to represent solid volume geometry; 2) geometric modeling that reflects both local shape and local inter-regional relations; 3) the inclusion of statistics describing geometric properties of individual objects and object groups and of inter-relationships between these objects; 4) the inclusion of statistical aspects of intensity patterns in object-relative geometry; and 5) the multiscale nature both of training and of segmentation of target images. The next step is generalization to the multi-patient situation. This will involve more stages of statistical training, more stages in the model deformation process, and greater attention to the variability of relationships between the various structures comprising the multi-object m-rep model.

Acknowledgements: J. Bechtel, MD and J. Rosenman, MD for image contouring, and Y-Y. Chi, BS and K. Muller, PhD for statistical analysis of data.

Research supported by NIH P01 EB002779

*S Pizer et al, Deformable M-Reps for 3D Medical Image Segmentation, Int J Comp Vision, 55: 85-106 (2003)