Automatic Fiducial Detection in T2 Weighted MRI in a Manifold Learning and Gaussian Mixture Modeling Framework

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Introduction: The current state of the art workflow for radiation therapy planning for prostate cancer (PCa) involves acquiring an MR scan for the prostate as the high quality soft tissue contrast enables accurate manual delineation of the prostate capsule. The generation of a patient's radiation treatment dose plan however requires a tissue specific electron density value that can be directly obtained from CT images. Gold seeds or fiducials implanted in the prostate prior to treatment are frequently used to enable the rigid registration of the two modalities required for the transfer of the prostate contours from MRI to CT. For future MR-alone planning the automatic detection of these fiducials is also necessary to provide information for mapping synthetic-CT based digitally reconstructed radiographs to portal imaging immediately prior to the delivery of each treatment fraction. To automate either pipeline, an efficient detection method for the fiducials from MRI is necessary. On MRI the fiducial intensities are similar to calcifications and depending on the MRI sequence signal heterogeneities and partial volume effect may be observed. This work proposes an template matching framework for automatic fiducial detection. Manifold learning for template selection from training image is followed by Gaussian mixture modeling (GMM) for probable candidate selection from a test image. All probable candidates are compared to selected templates and ranked according to a similarity score for fiducial detection. The proposed approach detects fiducials with an accuracy of 95% when compared to the manual detection.

Method: Clinical MR and CT scans of 15 localised PCa patients aged between 61-78 years, acquired prior to intensity modulated radiation therapy (IMRT), were chosen to validate the proposed method. For each patient, a small field of view pelvis T2-weighted (T2w) MRI and a T1-weighted (T1w) sequence were available for gold seed detection. The T1w and T2w sequences were acquired sequentially in the same plane (TR=690 ms, TE=7 ms, flip=80˚). These parameters provided a homogeneous signal void for the gold seed fiducials. The fiducials are cylindrical in shape with dimension of 0.6×0.6×2 mm. The proposed approach (Fig. 1) may be broadly divided into three stages: (a) template selection from manifold learning (spectral clustering) , (b) possible fiducial candidate selection with GMM and, (c) fiducial detection with template matching. Manual contours of the fiducials were made by an experienced radiation therapist and used for training.

The orientation of a fiducial was determined from the major axis orientation of its 3D reconstruction in the axial plane (Fig. 2). The appearance of a fiducial (Fig. 2, 3D reconstruction of manual segmentations) is dependent on the orientation of its major axis with respect to the axial plane. Interpretation of the orientation variability is difficult, therefore we have assumed that the fiducials lie on an embedded non-linear manifold in a higher dimensional space. Hence a non-linear dimensionality reduction with spectral clustering was performed to group fiducials with similar orientations. Spectral clustering ensured that minimum intra-class distance and maximum inter-class distance of higher dimensions (0˚-360˚) were preserved in lower dimensions. The fiducials with minimum L1-distance to cluster centroids were selected. Manifold learning and spectral clustering ensures that the most representative templates are selected for the template matching framework.

During validation the prostate was segmented[1] from the T2w MRI to determine the volume of interest (VOI). The T1w intensities within the VOI were modelled in a GMM and Markov random field (iterated conditional mode) framework. The fiducials with signal void were then clustered in one of the Gaussians along with other false positives (calcifications). The volume distribution of the fiducials was considered to be normal $\mathcal{N}(\mu;\pm 3\sigma)$ as learnt from the training manually labelled components. Therefore, all fiducial candidates with volume outside this normal distribution were discarded. The remaining fiducial candidates were each converted to a mesh and rigidly registered (iterative closest point (ICP)) to the templates created during training, in order to normalize the orientation of the detected component with respect to the template. The Dice similarity coefficient (DSC) was then computed between all detected fiducials and the templates. The highest DSC value for each fiducial was considered and only first 4 ranked fiducials were selected with the prior knowledge that 3 fiducials were implanted inside prostate. The 4th fiducial was selected for quality control to remove ambiguity between a fiducial and calcification. The fourth candidate was discarded if the difference between the 3rd and the 4th was more than 10% (empirically selected in a small cohort of 5 patients). Further manual inspection was requested if the difference was less than 10%.

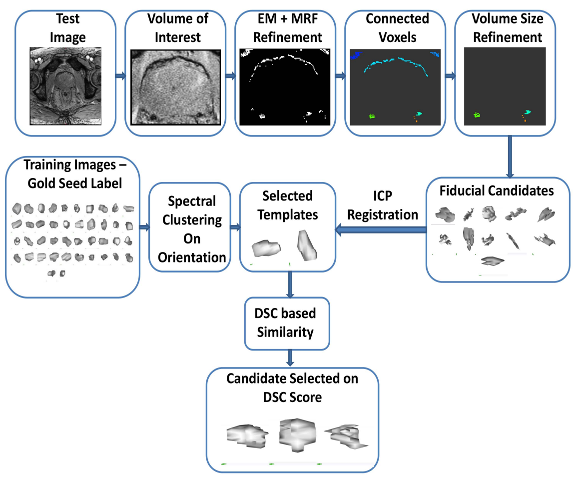

Fig. 1. Proposed automated gold seed fiducial detection pipeline.

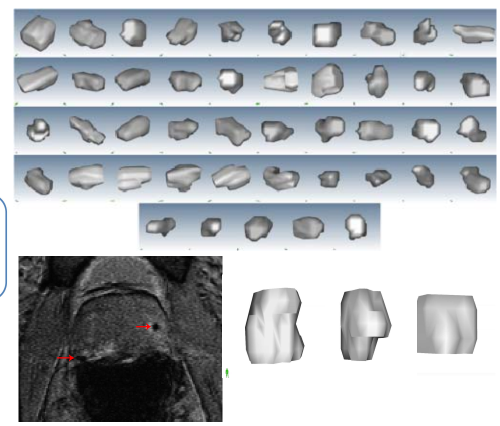

Fig. 2. The appearance of the fiducials are different depending on their orientation in the axial plane resulting in different manual segmentation and hence 3D reconstruction.

Results: The validation of fiducial detection was performed in a leave-one-patient-out framework. Manual detection of fiducials is challenging in MRI, and often the radiation (RT) therapist contouring the gold seeds needs to verify the location with the patient's corresponding CT, as the fiducials in CT have very high intensity values (higher than any tissue) and are characterised by a metallic streak. The accuracy of the proposed approach was compared with manual detection when the RT was not allowed to verify using the CT (Table 1). Two separate RTs contoured the fiducials to determine the inter-observer difference. The contour from the more experienced observer was considered as the ground truth to compute the inter-observer difference in determining the centre of gravity (COG) of the gold seeds. The same ground truth was used to determine COG differences between the method and the observer. Compared to the manual detection accuracy of 93%, our method achieved an accuracy of 88%, i.e. a difference of 5%.

Table 1. Quantitative comparison with manual detection of fiducials.

	Manual	Automatic
Sensitivity	91%	84%
Specificity	100%	100%
Accuracy	93%	88%
COG (in mm)	0.62±0.64	0.53±0.48

Conclusion: A completely automatic method to detect intra-prostatic gold seed fiducials from MRI has been demonstrated. This method should improve radiation therapist efficiency, has applications in the automatic registration of MR and CT images for radiation treatment planning, and provides an important bridge for online patient positioning prior to treatment delivery in MR-alone radiation therapy. The detection method achieved 95% (0.88/0.93=0.95) detection accuracy when compared to manual experts and the inter-observer difference of COG for the method is less than the difference achieved with manual contouring.

References: 1. Chandra, S.S., Dowling, J.A., Shen, K-K., Raniga, P., Pluim, J.P.W., Greer, P.B., Salvado, O., Fripp, J. (2012). Patient Specific Prostate Segmentation in 3-D Magnetic Resonance Images. *IEEE TMI.*, 31(10): 1955-1964.