2D-3D & 3D-3D Fusion Imaging (US & CT/MR): Interventional US Applied to Prostate Brachytherapy

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Ultrasound imaging offers a fast, inexpensive, radiation-free and portable image processing method. In the field of prostate cancer treatment, ultrasound imaging can be used for diagnosis and therapy guidance.

1 Stepper guided 3D ultrasound

In the field of prostate treatment typically a transrectal ultrasound probe is used. Based on the human anatomy this limits the probe movement to the direction along the rectum and the rotation around the longitudinal axis of the probe. To prevent any additional movement the transrectal probe is mounted on a stepper device holding also the template used for the catheter positioning. To be able to track the probe movement we mount an encoder to the stepper device, which allow a detection of the probe movement based on a reference position. To acquire images the physician can select the slide-to-slide distance. While moving the probe with the stepper device the system automatically grab the corresponding US image via a standard frame grabber.

2 Improved contouring methods

The functionality of the "three slice contouring" is stretching already existing base contour on transversal slices and scaling it in the X und Y directions according to user defined envelope contours on the orthogonal slices. To keep this feature as intuitive as possible the three orthogonal contours needs to be kept synchronous. Therefore during the contour definition we distinguish between fixed contour points given by the intersection of the current slice with already defined contours and moveable contour points (see figure 1). this semi-automatic contouring method is not restricted to in transversal base contour.

"Path contouring" is designed mainly for more or less "cylindrical" objects like the urethra or catheters. We define first the basic shape (e.g. circle or ellipse) of the object on the transversal slices and then the path describing the course of the object can de described by a 3D line consisting of multiple segments (see figure 2). The system automatically calculates the 3D object representation by using a copy of the base contour on the additional transversal slices repositioned by the defined path. In case of multiple base contours, the interpolated temporary contours between two defined ones are used to calculate the result.

3 Multi-Modality Registration and Fusion

In some cases the target area in ultrasound images is not as visible as it should be to ensure a qualitatively high treatment, whereby other modalities like MRI provides better images. The images of both modalities can be registered in a unique dataset, i.e. gathering pre-operatively an MRI volume and use it in combination with the intra-operative ultrasound guided life procedure (fusion, see figure 3). We implemented a method is based on Mutual Information, which works completely automatically. The method operates entirely in 3D space and does not require similar images resolution and/or slice thickness or acquisition along the same direction on both modalities. The algorithm moves and rotates one volume against the other using a simulated annealing scheme, while the best registration is ascertained by comparing the results of the Mutual Information approach.

4 Dose Calculation & Optimization

Based on a long experience and expertise in algorithmic development of dose calculation engines for Brachytherapy, a very fast algorithm has been developed and implemented, enabling almost real time optimization of the 3D dose distribution. The realized implementation offers an independency on future recommendations on dosimetry protocols in the Brachytherapy. A new generation of algorithms for anatomy based optimization of 3D dose distributions in Brachytherapy (DVHO and SVBO engines) has been development and implemented. These are dose-volume-histogram (DVH) based, and realize a 3D optimization including target volumes (see figure 4) and 3 organs at risk (OAR) in a few seconds (0.1 – 2 s usually). Figure 5 demonstrates the results when using the DVHO optimization tool. Currently a worldwide unique engine for a real inverse planning has been introduced and released, the HIPO. HIPO states for Hybrid Inverse Planning and Optimization and is able to offer an adequate needle configuration that fulfills the dosimetric objectives and constraints of planner within 1-3 minutes depending on the anatomy of the specific patient (see figure 7). HIPO is an interactive tool and enables for a first time in prostate Brachytherapy to achieve a treatment planning user-independent.

5 Results

The described technology has been implemented in the commercially available system SWIFT™, distributed by Nucletron B.V., The Netherlands. The implementation of such kind of tools resulted in a reduction of the total treatment time (treatment means here the total clinical procedure) from previously of 264 minutes (mean value for CT based procedures) to a mean value of 79 minutes, that means a reduction of treatment duration by a factor of 3.3. At the same time an analysis of the quality of realized implants and plans could be improved. Using SWIFT 100% of plans could fulfill all dosimetric constraints versus 94% when only manual planning was used. SWIFT has been installed in over 50 centers world-wide and several thousands patents have been already treated. In Offebach we treated since 2002 ca. 700 patients successfully.

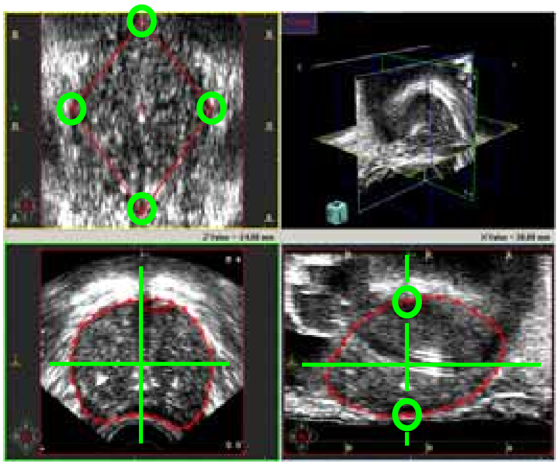

Fig 1: Three slice contouring with highlighted fixed contour points

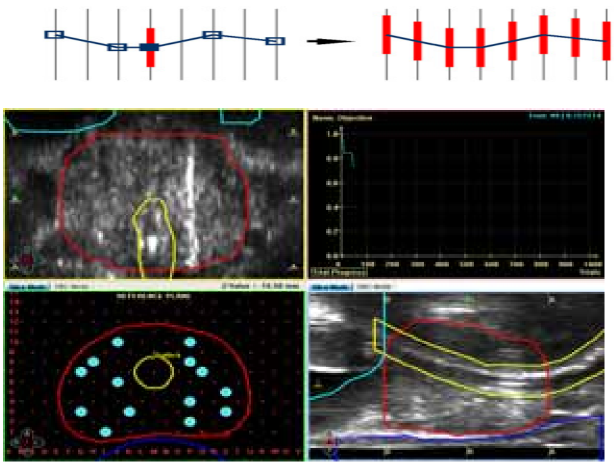

Fig 2: Path contouring & HIPO screen running for a prostate implant

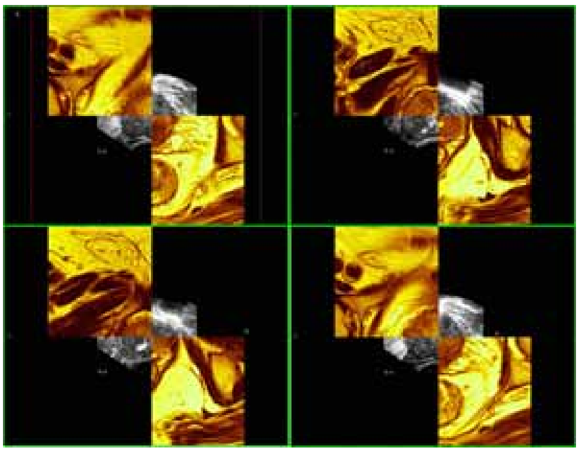

Fig 3: Automatic U/S & MRI registration

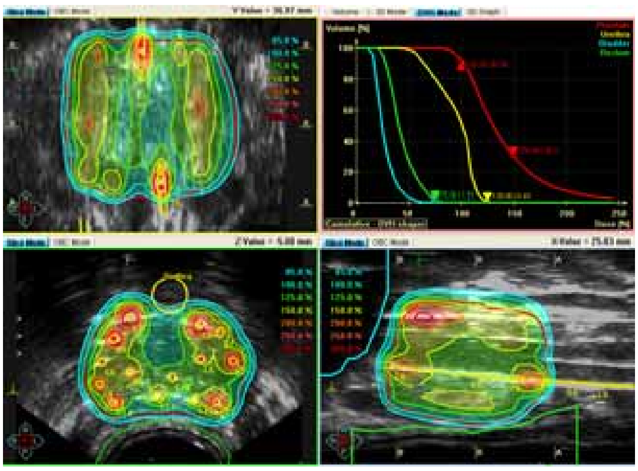

Fig 4: Results using the DVHO optimization engine with super-imposed dose distributions