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Patient set-up verification by infrared optical localization and body surface sensing in breast radiation therapy

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Abstract

Background and purpose: **The aim of the study was to investigate the clinical application of a technique for patient set-up verification in breast cancer radiotherapy, based on the 3D localization of a hybrid configuration of surface control points.**

Materials and methods: **An infrared optical tracker provided the 3D position of two passive markers and 10 laser spots placed around and within the irradiation field on nine patients. A fast iterative constrained minimization procedure was applied to detect and compensate patient set-up errors, through the control points registration with reference data coming from treatment plan (markers reference position, CT-based surface model).**

Results: **The application of the corrective spatial transformation estimated by the registration procedure led to significant improvement of patient set-up. Median value of 3D errors affecting three additional verification markers within the irradiation field decreased from 5.7 to 3.5 mm. Errors variability (25–75%) decreased from 3.2 to 2.1 mm. Laser spots registration on the reference surface model was documented to contribute substantially to set-up errors compensation.**

Conclusions: **Patient set-up verification through a hybrid set of control points and constrained surface minimization algorithm was confirmed to be feasible in clinical practice and to provide valuable information for the improvement of the quality of patient set-up, with minimal requirement of operator-dependant procedures. The technique combines conveniently the advantages of passive markers based methods and surface registration techniques, by featuring immediate and robust estimation of the set-up accuracy from a redundant dataset.**

Keywords: Radiotherapy; Breast cancer; Surface registration; Quality assurance; Infrared localization

Infrared localization is a rapidly growing technique for patient positioning and immobility verification in external radiotherapy. The method is based on optical tracking devices and consists of the real-time detection and 3D reconstruction of set of surface landmarks highlighted by infrared light-reflecting passive markers. The quantification of control points displacements, with respect to a corresponding reference configuration, provides the immediate description of the quality of patient alignment. Detected set-up errors are minimized by means of fast optimization numerical procedures, which estimate the parameters of spatial transformation for the correction of patient position. With respect to conventional methods, main advantages are related to the quantitative real-time check of the quality of the irradiation set-up and to the potential automatic compensation of patient inter-fractional and intra-fractional set-up errors by means of the servo-controlled movements of the treatment table.

Pre-clinical studies focused on the technological and methodological feasibility of infrared tracking devices in radiotherapy clinical practice [1,15], also in combination with stereoscopic X-ray and ultrasound imaging [17,10]. The clinical application of commercially available optical tracking systems for patient positioning and immobility verification was described in breast [2] prostate [16] and gynaecologic [18] cancer irradiation.

Optical body surface detection and registration with respect to a reference model is emerging as an alternative approach for patient localization in extra-cranial radiotherapy [9,11]. In this case, the real-time localization of passive infrared light reflecting surface control points is replaced by the 3D detection of the entire anatomical

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surface, which is matched with the reference surface model eventually coming from the CT used for treatment planning. This technique allows one to overcome the problem related to the accurate replacement of passive markers on patient's skin landmarks and to count on a complete description of the surface anatomical area involved in the irradiation. The clinical application of body surface sensing in radiotherapy was proposed by Moore et al. [12] who described a method based on interferometer fringe projection. Further methodological investigations were focused on the evaluation of video systems for the instantaneous 3D-surface image capturing through phantom studies [6,8].

As a trade-off between the passive markers based approach and the body surface sensing and registration method, the use of a hybrid configuration of control points including a minimum number of passive markers and a configuration of laser spots was proposed [3]. The rationale was to combine the advantages of the use of passive markers (fast real-time 3D localization and tracking of reliable control points solid to the patient) and of body surface sensing (redundancy of information accounting for inter-session deformations). In addition, the proposed technique was conceived in order to minimize potential drawbacks associated to the use of only passive markers (manual markers replacement on selected skin landmarks; extreme under-sampling of the controlled body area) and of surface sensing methods (computational bulkiness, limiting real-time immobility verification; relatively low robustness of surface registration algorithms, in case of low spatial frequency of the controlled anatomical surface) [3]. This was obtained by using an optical tracker capable of detecting in real-time at 100 Hz the 3D position of passive infra-red light reflecting markers and of red-light laser spots and by taking advantage of an algorithm for constrained surface registration. Although different combinations of passive fiducials and laser spots are feasible [14], simulations and experimental repositioning procedures on a phantom and two volunteering subjects were performed with an hybrid configuration of two passive markers and nine laser spots, in the frame of a simulated breast irradiation clinical scenario [3].

In this paper, we report the outcomes of the clinical application in breast cancer radiotherapy of this technique with a two fiducials and nine laser spots hybrid control points configuration. The obtained performance in detecting and compensating patient set-up errors turned out to be comparable with previous studies based on uniform configurations of up to six passive markers [4]. Advantages in this case are related to the increase in the number of control points and the minimization of operator-dependant procedures for patient remarking [13], thus combining higher swiftness of irradiation set-up and greater reliability in patient set-up verification.

Methods

Inter-fractional patient set-up errors were quantified on a total of 124 irradiations coming from a group of nine patients undergoing breast cancer radiotherapy after conservative surgery (quadrantectomy). Patients were informed on means and purposes of the study and gave their consent for being involved in the trial.

Irradiation technique

The radiation treatment was performed with opposed tangential 6 MV photon beams. The prescriptions at the isocenter was 50 Gy (delivered in 25 fractions) followed by 10 Gy to the tumor bed. Patients were treated in supine position in a vacuum-formed cushion, being this latter supported by means of an inclined plane equipped with arms holder. For each patient, a CT-based 3D treatment plan (Cadplan™, Varian Medical Systems, Palo Alto, CA) was performed, built on about 50 CT slices acquired contiguously with 0.5 cm spacing and 0.5 cm thickness. Safety margins were added around the clinical target volume (CTV) in order to account for breathing movements, set-up errors and beam penumbra. Criteria for field margin definition were focused on the adequate CTV coverage, central lung distance not exceeding 2.5 cm and avoidance of controlateral breast irradiation. Conventional patient centering was performed by aligning two permanent mediosternal tattoos with the orthogonal system of laser lines in both the CT-simulation and therapy rooms at the prescribed skin–source distance; an additional latero-lateral shift was established in treatment planning to reach the treatment position.

Acquisition of reference patient position

Data describing the patient's reference position were obtained from the CT slices used for treatment planning in the nominal clinical procedure. CT acquisition duration was approximately 40–50 s. No specific respiratory gated-4D CT acquisition technique was used before CT scan acquisition. Patients were fitted with two passive markers (M1 and M2-∅ 10 mm) (Fig. 1, left panel) in correspondence of selected natural skin landmarks, close to the mediosternal tattoos used for patient manual alignment. According to Baroni et al. [3], these markers were used as fiducials for the automatic constrained surface registration procedure. Three additional markers (UP, MED and DOWN) (Fig. 1, left panel) were placed in correspondence of natural skin landmarks located on the pathological breast. They were used as verification points for the evaluation of the performance of the registration procedure in detecting and correcting inter-fractional set-up error.

The reference 3D model of patient body surface and the positions of the passive markers were obtained from the CT slices and expressed in the isocentric reference frame (reference dataset). Body contours were extracted by means of image segmentation based on morphological filters (Fig. 1, right panel). Adaptive filtering and Delaunay triangle-based linear interpolation were applied to obtain the 3D reference surface model, which was based on a spatially uniform matrix of 40,000 points. The localization of passive markers was performed by means of 2D cross-correlation technique based on markers shape, providing the 3D coordinates of markers centroids. The uncertainties due to partial volume effects were quantified by comparing the surface of a female phantom obtained by CT scans with the corresponding laser scanned surface. Mismatches between the two point-based models resulted to be lower