Feasibility of differential geometry-based features in detection of anatomical feature points on patient surfaces in range image-guided radiation therapy

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論 文 名: Feasibility of differential geometry-based features in detection of anatomical feature points on patient surfaces in range image-guided radiation therapy
(画像誘導放射線治療における距離センサーを用いた微分幾何学に基づく患者体表面特徴点検出法の開発)

区　　分：甲

論　文　内　容　の　要　旨

In image-guided radiation therapy (IGRT), anatomical feature points on patient surfaces are used in the estimation of intra-fractional positioning errors. Positioning errors might deviate the dose distribution towards the neighboring normal tissues, thereby raising the probability of complications in the normal tissues and reducing the dose directed at the target tumour. Positioning errors are typically estimated based on the registration of range images of a region-of-interest (ROI) on the patient surface. Currently, the ROI is selected manually and subjectively, and it is required to include stable anatomical regions, for example, the nose region for monitoring the positioning of patients with intra-cranial tumors. However, it was found that the manual method could be irreproducible and might affect the registration accuracy.

The goal of this study was to automate the detection of anatomical feature points in range images, which can be used for monitoring of patient positioning errors in radiation therapy. The basic idea was to reconstruct the patient’s surface in the surface image for the computation of the curvature features that characterize the shape of the surface. The range image was pre-processed for extracting the ROI, including the anatomical landmarks, based on a template-matching technique and reducing the noise. Next, a smooth (i.e. continually differentiable) mathematical surface of the patient’s body surface was reconstructed by using a non-uniform rational B-spline (NURBS) modelling technique. Curvature features, i.e. shape index and curvedness were computed, where the shape index characterizes the local shape type and the curvedness characterizes the degree of curvature. Finally, a rule-based function was used for localizing the feature points on the surface based on the curvature features. The framework was tested on range images acquired by a time-of-flight (TOF) camera and a Kinect sensor for two surface (texture) types of head phantoms A and B that had different anatomical geometries. The detection accuracy was evaluated by measuring the residual error, i.e., the mean of minimum Euclidean distances (MMED) between reference (ground truth) and detected feature points on convex and concave regions. Translational and rotational positioning errors were simulated for evaluating the MMED under positioning error conditions. In addition, the variability in the estimated curvature features at the edge points was computed. The variability at a point was quantified by calculating the difference between the feature value at the point and the average of the feature values of the points on the same edge type (i.e., convex or concave).

The MMEDs obtained using convex feature points for range images of the translated and rotated phantom A were 1.79±0.53 mm and 1.97±0.21 mm, respectively, using the TOF camera. For the phantom B, the MMEDs of the convex and concave feature points were 0.26 ±0.09 mm and 0.52±0.12 mm, respectively, using the Kinect sensor. There was a statistically significant difference in the decreased MMED for convex feature points compared with concave feature points ($P<0.001$). As for the variability in curvature features, the standard deviation (SD) of the variability has decreased at the points on convex edges from 0.25 mm^{-1} (without NURBS reconstruction) to 0.18 mm-1 (with NURBS reconstruction). For the concave regions, the SD has decreased from 0.10 mm^{-1} to 0.04 mm^{-1}. For the shape index feature, the SD has slightly increased after the NURBS surface reconstruction for both concave and convex features. In summary, the decrease in the variability of curvedness feature indicates the improvement of the proposed framework in detection of the feature points.

In conclusion, the proposed framework has demonstrated the feasibility of differential geometry features for detection of anatomical feature points on a patient surface in range image-guided radiation therapy.