Method for Projecting Functional 3D Information onto Anatomic Surfaces

Accuracy Improvement for Navigated 3D Beta-Probes

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Abstract. Today the main challenge in cancer surgery is increasing the accuracy in tumor resections. Malignant cells must be completely removed, while harm to the surrounding healthy tissue must be minimized. An interesting idea to solve this problem is the use of nuclear-labeled cancer tracers and intraoperative navigated nuclear probes for residual control after minimal tumor resection. The idea is to produce an activity encoded surface, which localizes the radioactively marked residual malignant cells. The thus created surface map is consequently used to direct the surgeon during resection by means of augmented reality or by simulating a count-rate at the tip of a surgeon's instrument improving the accuracy. However, there is a certain distance between the surface and the probe's tip during the scan procedure. Moreover, the nuclear probe is not always positioned perpendicular to the surface. The main contribution of this work is to develop a data post-processing procedure that takes into account these factors, aiming to increase the accuracy of the nuclear probe navigation system and thus contribute to a more accurate tumor resection procedure.

1 Introduction

The main trend in today's surgery is toward a minimally invasive treatment. In cancer resection, this means that malignant cells must be completely removed with minimal invasion to normal tissue. Beta-probes have been developed to aid the surgeon in this process by detecting residual cancer on the resection borders. This can be achieved by marking cancer with beta-emitting tracers. Since beta-particles are emitted almost exclusively from malignant cells and do not penetrate far into tissue, such a device allows accurate detection of residuals [1, 2].

Navigated 3D beta-probe imaging increases the accuracy of cancer resection by detecting and applying therapy simultaneously. In that case, the nuclear probe is tracked and based on its synchronized position and reading, a 3D activity

surface map is generated. This can be used to direct the surgeon by augmented reality or by simulating the count-rate at the tip of surgeon's instrument [3]. However, in order to have high accuracy in navigated 3D beta-probe imaging, it is important to visualize the readings as accurate as possible on the activity encoded surface. Therefore a crucial aspect of the navigated 3D beta-probe is data post-processing.

The current work on navigated 3D beta-probe imaging has been limited to generation of activity maps based on the synchronized position and reading of the probe [3]. Since the probe is not necessarily directly touching the surface nor perpendicular to it, the there introduced visualization could be improved in terms of accuracy. No methods for the projection of the data onto preoperative anatomic images have been considered in the past.

A similar problem arises in functional brain imaging where the functional information is acquired in 3D. Here, the information has to be projected onto the anatomy of the brain to analyze the cortical structure that is active. The state of art for that projection restricts to the use of interpolation for the activity of each surface element based on the closest volume element or the closest one in direction of the normal of the surface element [4, 5]. The inverted approach, i.e. the projection of the data onto the surface, is not known to us.

2 Methods

We have two sets of input data: a 3D CT scan and a 7D set of navigated beta-probe data (position of the tip of the probe, position of the tail of the probe and beta-radiation intensity). As an output we need a surface with activity levels at its points– activity encoded surface (4D set of data). In order to get the desirable result we need

- to create a vector image of the surface on the basis of its image (segmentation);
- to transform the acquired vector image of the surface into the coordinate system of the beta-probe data (registration);
- to project the beta-probe data to the surface for data representation (visualization).

The latter was done for a phantom data-set shown in figure 1.

2.1 Segmentation

In the first step we extracted the surface of the phantom from the CT scan of dimension $512 \times 512 \times 159$ $[voxels]$ and resolution $0.98 \times 0.98 \times 1$ $[mm^3]$.

For the extraction of phantom's volume we used a graph cut algorithm as proposed in [6]. Two thresholds were used to segment only the phantom volume. Furthermore a seed point was chosen manually inside the phantom.

In order to acquire the surface of the phantom we used the matching cube algorithm. The result was saved in an Open Inventor (.iv) file and used for visualization with surface rendering techniques.

Fig. 1. The phantom with the CT spots

2.2 Registration

To do a proper projection, it is necessary to have both data-sets in the same coordinate system (here the phantom coordinate system in the tracking space). In order to correspond the coordinate system of the CT scan and the coordinate system of the phantom in the tracking space four fiducial points (CT spots) were attached to the phantom before the examination. For the acquisition of the coordinates of the spots in the CT scan we used a threshold algorithm, since they have unique and high Hounsfield units in the CT data. The correspondence of points between the fiducial points in the phantom coordinate system "P" and the CT coordinate system "CT" was established fully automatically [7]. Based in the point correspondences the transformation matrix $T_{CT \to P}$ was calculated according to [8]. After the estimation or the registration matrix the entire surface of the phantom in CT coordinates was transformed into the phantom coordinate system: $p_P = T_{CT \to P}\ p_{CT}$.

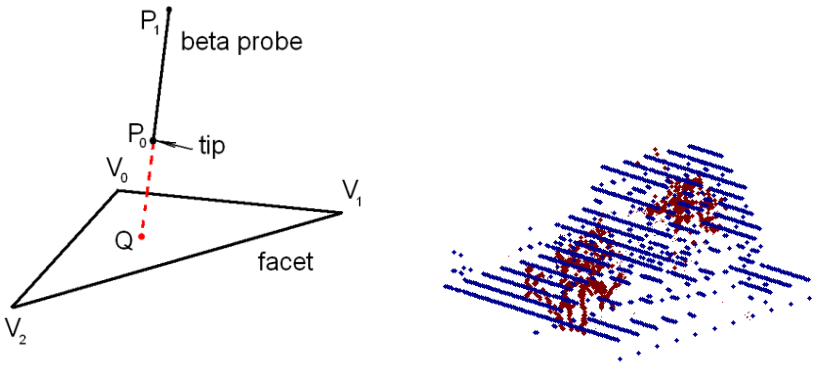
2.3 Projection and visualization

The final step and major contribution of this work is the projection of the data onto the previous extracted anatomic surface. The standard approach is to find the closest point on the surface to each of the beta-probe data-points and to attach the beta-probe activity level to the found point. A considerable disadvantage of this approach is that an activity level acquired at a certain distance from the surfaces is attached to a point determined by the distribution of the vertices in the surface rendering procedure rather than to a point of the surface which affected the beta-radiation level at beta-probe's tip.

In this work the orientation of the beta-probe was taken into account. The activity level at the beta-probe's tip was attached to the point of intersection of the beta-probe axis with the closest facet to the tip.

According to the .iv file data the points on the surface form facets in triplets. To determine the projection the axis of the probe was extended and intersected with the surface. The closest facet to the tip was chosen as facet where the

Fig. 2. (a) The activity level at the tip of the probe P_0 is attached to the point Q of intersection of the axis of the probe and the facet. (b) The activity encoded surface, blue (dark) points determine the surface, red (light) points show high activity zones and thus localize the malignant cells



(a) Projection (b) Results

activity was originated. As final output of our implementation a matrix with the correspondence between points in the beta-probe data-set and facets on the surface was created. As a result the set of original points of the surface is extended by the points with activity levels. This result is visualized in a 3D plot with a color encoded surface (fig. 2a).

3 Results

The described procedures in the previous section were performed for a phantom data-set. The activity encoded surface was visualized by Matlab graphs and is shown in figure 2b. Each original surface point was shown in blue color (dark points), each point with activity level was shown in red color (light points) in size according to its activity level (higher activity level means bigger point).

4 Discussion

In the present work a first step toward an improved accuracy by means of post-processing for a navigated beta-probe imaging system was made. The algorithms proposed showed to work well on the available data-set. The chosen segmentation and registration steps managed to generate a proper 3D dimensional surface to project the data onto. The projection algorithms here introduced were also applicable to the problem and allowed a qualitatively adequate solution for the task set in the introduction. However, there are still steps ahead.

In particular the first problem to be addressed is efficiency. The current projection algorithm is rather time-consuming. Using our Matlab implementation,

it took approximately 30 hours to correspond a beta-probe data-set of approximately 2000 points with a surface data-set of approximately 7500 points in a Pentium 4 1.6[GHz] PC. However, this can be easily improved by an implementation based on efficient algorithms and data structures and implementations in C++. This is however not an issue and out of scope for a first prove of concept for the system.

To complete this work a thorough comparison of the original system and the said with the proposed algorithms is needed. In order to do so, we already scheduled a row of ex-vivo experiments for the evaluation of the overall system performance in minimal tumor resection.

We strongly believe that this extension will allow a better visualization and a better user-interface and a more precise detection of residual malignancy. As a consequence we hope to contribute with another 'grain' toward a less-invasive and yet higher-efficacy therapy for cancer.

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