Spatial Measurements for Medical Augmented Reality

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Abstract

This paper presents a set of Augmented Reality (AR) based interaction techniques for spatial analysis of medical datasets. Computer-aided medical planning tools such as our Virtual Liver Surgery Planning System require precise and intuitive interaction for the quantitative inspection of anatomical and pathological structures. We argue that AR is a superior tool compared to desktop 2D or 3D visualization for performing such analysis, because it allows true direct manipulation of 3D virtual objects in space, while rendering the medical data in the familiar context of the user's own body.

1. Introduction

In computer-aided medical treatment planning it is not sufficient to just perform qualitative inspection of the data, but also to carry out quantitative analysis, i. e. measurements of distances, volumes or angles. Therefore, we developed a spatial measurement toolkit which allows different measurement possibilities for the Virtual Liver Surgery Planning system [1]. This system aims at assisting teams of surgeons and radiologists in making informed decisions regarding the surgical treatment of liver cancer, in particular different kinds of liver tumor resections. Currently, physicians often have to build their own mental 3D model of complex anatomical structures based on the information extracted from 2D computed-tomography images, with the aid of 2D measurement tools. However, high model complexity creates a trend towards using 3D visualization and 3D interaction in computer-aided medicine.

In contrast to existing measurement tools [2, 3] which rely on keyboard and mouse for interaction, the proposed spatial measurement methods are based on *direct manipulation* with 6 degrees of freedom. Various studies show an improved spatial perception through stereoscopy and 3D interaction [6, 5]. This fact leads us to believe that 3D measurements can be better carried out in an AR environment than with desktop-based 2D or 3D applications. In the following we introduce a set of various measurement tools using 3D interaction for quantitative assessment of important medical structures.

2. Distance Measurements

Free-handed *point-to-point* distance measurements are important to verify required safety distances around tumors when planning to remove them. The simplest option for measuring distances allows a user to drag a three-dimensional "rubberbanding" line by pressing and holding the button on the pen. The line is shown as a thin tube with conical arrowheads (see Figure 1(a)). Real-time display of the current length allows interactive probing of distances from a common start point. In some cases, the user is more interested in precise inter-structure distances. Therefore, the distance measurement tools include an automatic *snapping* to the nearest object surface after pressing the action button.

A *ruler* is a very common facility for measuring distances in real life. Therefore, a tracked physical ruler of about 40cm length (see Figure 1(c)) is introduced as an interaction prop for fast determination of distances. It can be operated with one or two hands, and affords virtual scales (overlaid on the ruler, or digital numbers floating over the ruler in space). An additional important feature of the ruler is the capability of measuring minimal distances semi-manually. For that aim, the ruler controls a straight line used to intersect objects. The distance between the nearest intersections on both sides of the ruler is interactively reported.

3. Volume Measurements

Volume Measurement is extremely important to assess the status of the tumor, and the remaining liver tissue. In this mode, the pen must be moved inside the desired volume, which is highlighted for feedback, and triggers a fast volume calculation algorithm [4]. The numeric information that has been obtained is temporarily attached to the pen's tip and can be positioned in space. Color coding allows to identify which measured value belongs to which volume (see Figure 1(b)).

The direct volume measurement method allows the calculation of individual objects. However, for treatment planning, a volume calculator is required to measure the aggregated volume of multiple objects (e.g., the volume of two or

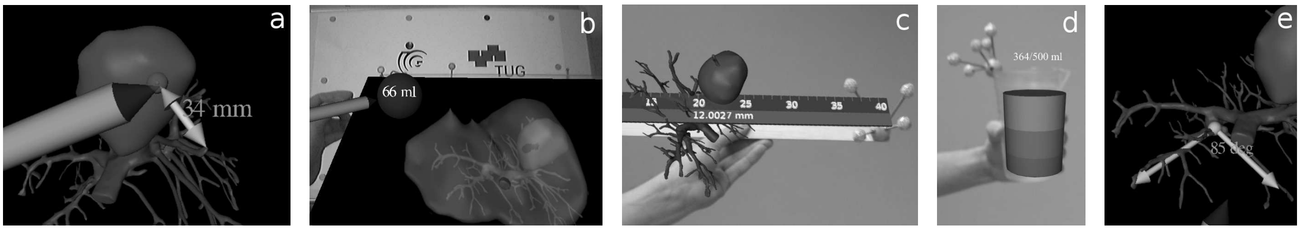

Figure 1. The measurement tools are used for spatial analysis of medical datasets.

more resected tumors). For this purpose, we added a tracked prop, the *measurement jug*. Virtual objects can be deposited in the jug using simple drag and drop with the pen. Each object is represented by a color coded virtual slice in the jug, with the height of the slice corresponding to the object's volume. The overall volume is displayed numerically on top of the jug (see Figure 1(d)). To improve the overview in case of a cluttered display with many different volume objects, the ones deposited in the jug can be rendered invisible until the jug is emptied by a turnover gesture.

4. Angular Measurements

Angular measurements can be necessary for analyzing the vascular structure. Angles between branches are often important for planning access to the tumor during intervention. The geometry of the angular measurement tool is similar to the distance measurement tool. Two cylinder-shaped lines span an angle in 3D, the lines are delimited by two conic endpoints, while the apex corner is visualized by a sphere (see Figure 1(e)). By placing the pen and pressing the button, the user specifies the apex and the two endpoints.

5. Automated Measurements

In addition to manual measurements, which give full control to the user, automated measurement of distances and volumes are provided for cases when overall assessment of objects is of interest. *Minimal distance* calculation can be applied for two disjoint objects (e.g. two tumors). For treatment planning it is sufficiently accurate to calculate the minimal distance on the basis of surface vertices. The minimal distance measurement is triggered by selecting two disjunct objects with the pencil. After the calculation, a distance line is drawn indicating the length and position of the distance. For measuring the minimal distance between non-disjoint objects (e.g. one major branch of a vessel structure and a tumor), automated algorithms cannot be applied without manually altering the object topology. However, the interactive ruler can still be used for this task.

Another automated calculation is the *maximal object extension* which is necessary for diagnosis especially for deciding the operability of a patient. The user simply selects the desired object with the pen, and the maximal extension is computed. The calculation is done through principal component analysis, and the result is drawn inside the transparently rendered target object as three orthogonal cylindric lines indicating the principal components.

6. Conclusion

This paper presents a set of AR-based measurement tools for medical applications. The main benefit compared to conventional 2D or 3D visualization workstations is the true direct interaction possibility using 6 DOF input devices, and an enhanced visual feedback through a stereoscopic visualization. A first informal evaluation with physicians was encouraging for further developments of these tools.

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