[POSTER] Endoscopic Image Augmentation Reflecting Shape Changes in Cutting Procedures

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ABSTRACT

This paper introduces a concept of endoscopic image augmentation that overlays shape changes to support cutting procedures. This framework handles the history of measured drill tip’s location as a volume label, and visualizes the remains to be cut overlaid on the endoscopic image in real-time. We performed a cutting experiment, and the efficacy of the cutting aid was evaluated among shape similarity, total moved distance of a cutting tool, and the required cutting time. The results of the experiments showed that cutting performance was significantly improved by the proposed framework.

Keywords: Endoscopic image augmentation, volumetric cutting model, computer assisted surgery

1 INTRODUCTION

Augmented reality (AR) techniques have gained attention as an intraoperative aid in a variety of fields of surgery [1, 2]. In bone cutting procedures, for example, the volumetrically rendered (VR) images generated from the patient’s CT/MRI images are used for preoperative planning and for clinical training [3, 4]. Specifically, in microendoscopic discectomy for spinal disorders, all procedures are performed in tight spaces while observing the small portion of the target structures with poor depth information. If the scheduled cutting area is overlaid on the endoscopic images, it becomes easy to understand the corresponding relation to the planned target shapes. In order to realize such AR navigation, however, accurate estimations of the current shape are essential as the surgery progresses, because of shape changes that occur when the target is cut. Also, the support information should be carefully visualized because conventional semi-transparent representation may make visual confirmation of the target area more difficult.

In this paper, we propose a concept of endoscopic image augmentation that reflects shape changes in bone cutting procedures for spinal surgery navigation. Our framework generates an augmented endoscopic (AE) image that overlays the remains to be cut based on the history of the drill tip’s location. The AE image enables precise cutting by visualizing a differential map between the current state and the target 3D shape spatially registered to the endoscopic image. We have conducted a human experiment that compares the proposed AE image and the VR image of the target shape. The efficacy of the cutting aid was evaluated among shape similarity, total moved distance of a cutting tool, and the required cutting time.

2 AUGMENTED IMAGE GENERATION FOR CUTTING PROCEDURES

The processing flow used to generate the proposed AE image is shown in Figure. 1. Preoperative planning is first performed to define the 3D region scheduled to be cut $L_p$ on the spine. Interactive virtual cutting [4] is also available for scheduling the cutting area using 2D slice images or volume rendered image of the patient’s CT images $I$. We assume an optical tracking system such as Polaris (Northern Digital Inc.) is used to measure the orientation $e$ and location $p_0$ of the endoscopic camera and the tip of the surgical tool $p_1$ during surgery.

We model 3D regions that have already been cut using a volume label $L_c$ that has the same size as $I$. The value $l = 0$ is first set as the noncutting voxel in $L_c$. The tool tip is described by a sphere with a radius $R$ to model the tip of a surgical drill. We assume that the voxels where the surgical tool tip has passed within the scheduled region $L_p$ represent the cut out region. The voxel value $l$ in $L_c$ is then updated from the relation between the central location of the arbitrary voxel and the tip position. The remains to be cut is defined using another volume label $L_r$ and updated in real time during surgery. The relationship of these volume labels is simply defined by volume subtraction $L_r = L_p - L_c$.

Next, the differential map $D(x) (x \in \mathbb{R}^3)$ is generated from the cutting label $L_c$, the camera’s location and orientation to represent the difference between the target shape and the current shape. $D(x)$

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is a 2D projected image that visualizes the remains to be cut in the depth direction registered to the camera image \( C(x) \), and generated by volume rendering of \( I_v \). The AE image \( C_{AR}(x) \) is finally generated using \( D(x) \) by shifting the pixel value of \( C(x) \) locally. \( C_{AR}(x) \) is the augmented reality image that designates the remains to be cut as a time-varying color map that is updated as cutting progresses.

### Experiments and Results

We have designed an experimental system to confirm the proposed AE image and to evaluate its performance as a cutting aid. In the system, the measurement of the router is performed by mounting a PHANToM Omni stylus pen on the electric router (Proxxon Inc.). Images of the object to be cut were captured using a generic video camera (Sony HDR-CX720Vz) as a substitute for an endoscopic camera. Only a part of the object to be cut can be viewed using an endoscopic camera during actual microendoscopic surgery. To replicate the visual cues and the space conditions, we constructed an experimental workspace covered by a metal frame with a vinyl sheet, wherein the object to be cut is not directly visible from the outside.

First, we confirmed time-varying appearance of the differential map \( D(x) \) during the cutting operation. The results obtained are shown in Figure 2(a). A cutting operation was performed using an electric router on a 50mm cuboid-shaped wooden block via an acquired enlarged image at the default stage and up to 15\%, 30\%, 45\%, 60\%, and 75\% for the target shape. A color map on the right side was used to render \( D(x) \) by shifting hue values of \( C(x) \). Next, Figure 2(b) shows the AE images of a 3D printer model created from preoperative CT data with spinal structures. The orientation of the camera was changed from 0\(^\circ\) to 90\(^\circ\). These figures demonstrate that the AE images successfully visualize the direction and depth that should be cut, which allows better understanding on what areas need to be cut, in which direction, and to what degree.

The cutting experiment was conducted with seven participants, and the efficacy of the AE image and the VR image of the target shape as a cutting-aid was compared. We have prepared four different types of cutting tasks for the wooden blocks, and evaluated cutting performance using the three indicators: the required cutting time \( E_1 \), the moving distance of the electric router tip \( E_2 \), and the shape similarity \( E_3 = 2 | I_{R} \land I_{E} | / (| I_{R} | + | I_{E} |) \) between the region that was already cut and the region scheduled to be cut. TABLE 1 shows median values and standard deviation of the data measured from one cutting task. Significant difference was found in \( E_2 \) and favorable results were obtained based on the median values with regard to all of the indices.

![Figure 2. (a) AE images of a wooden cube as the cutting operation progresses, (b) AE images of a 3D printer model made from CT images with different camera orientations. The direction and depth that should be cut on the spinal structure are visualized using the color map.](image)

### Conclusion

This paper introduced the concept of endoscopic image augmentation that overlays shape changes to support cutting procedures. The AE images could visualize direction and depth that should be cut in real time, and results of the human experiments showed that cutting performance was improved by the developed framework.

### References


