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Augmented reality endoscopic system (ARES): preliminary results*

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SUMMARY

Objectives: *During endoscopic surgery, it is difficult to ascertain the anatomical landmarks once the anatomy is fiddled with or if the operating area is filled with blood. An augmented reality system will enhance the endoscopic view and further enable surgeons to view hidden critical structures or the results of preoperative planning.*

Method: *The skull and endoscope are fixed with optical markers that are used as dynamic reference bases for tracking. A small optical tracking device, the easyTrack 200, which is connected to a computer, calculates the positions of the markers. The endoscope is calibrated and registered for augmenting its video with a 3D model. Images of a black and white checkerboard pattern, with 2.5 mm sized squares, are used for calibration with a Matlab based calibration toolbox. Standard modalities of overlay have been developed, including a CT viewer displaying it as an overlay in the endoscopic video stream, and a 3D viewer to render 3D models of preoperatively segmented structures. The accuracy of the augmented reality system was assessed on a plastic skull.*

Results: *The accuracy is calculated by looking at the difference in pixels of several contours in both a real and an overlay image, obtaining a mean of 3-4 pixels that correspond to sub-millimeter accuracy (pixel to mm ratio calculated previously). Mean error was consistently 1-2 [+/- 0.3] mm.*

Conclusions: *A novel augmented reality system for endoscopic surgery is presented. Highlighting hidden structures or CT overlays in the endoscope will give more information in difficult situations and enhance the operation quality.*

Key words: surgery, endoscope, augmented reality

INTRODUCTION

Endoscopic imaging systems are used in many complex procedures in the area of rhinology. During these surgeries it is often difficult to ascertain the anatomical landmarks once the anatomy is fiddled with or if the operating area is filled with blood. Image-guided, computer-assisted surgery has proved to improve localization and targeting, to provide a better anatomical definition of the surgical field, and to decrease invasiveness (1). Augmented reality (AR) allows the user to see the real world, with virtual objects superimposed on it. Therefore an AR system will enhance the endoscopic view and further enable surgeons to view hidden critical structures such as pathologies (e.g. tumors), risk regions or sensitive structures (e.g. arteries or nerves), or the results of a preoperative planning, such as pathways, trajectories or distances. These data will be shown as if they were beneath the surface of the surgical scene and hence in a more intuitive way. Kawamata et al. (2) report an AR system for endoscopic pituitary tumors but fail to describe the process of calibration and registration of endoscope which are critical steps and require expertise in computer vision techniques.

In this paper we present an AR system for endoscopic sinus/skull-base surgeries where the endoscope video stream is augmented with synthetic data for helping the surgeon to get proper anatomical orientation in altered/occluded operating area.

MATERIALS AND METHODS

The AR system consists of an endoscope device from Storz™ (Telecam, Tuttlingen, Germany). In order to correctly augment the endoscope video with synthetic images, the systems needs to know the relative position of the endoscope and the patient. Therefore we use as detecting system the small optoelectronic camera easyTrack 200 [Atracsys™, Bottens, Switzerland]. Both patient's head and endoscope are fixed with

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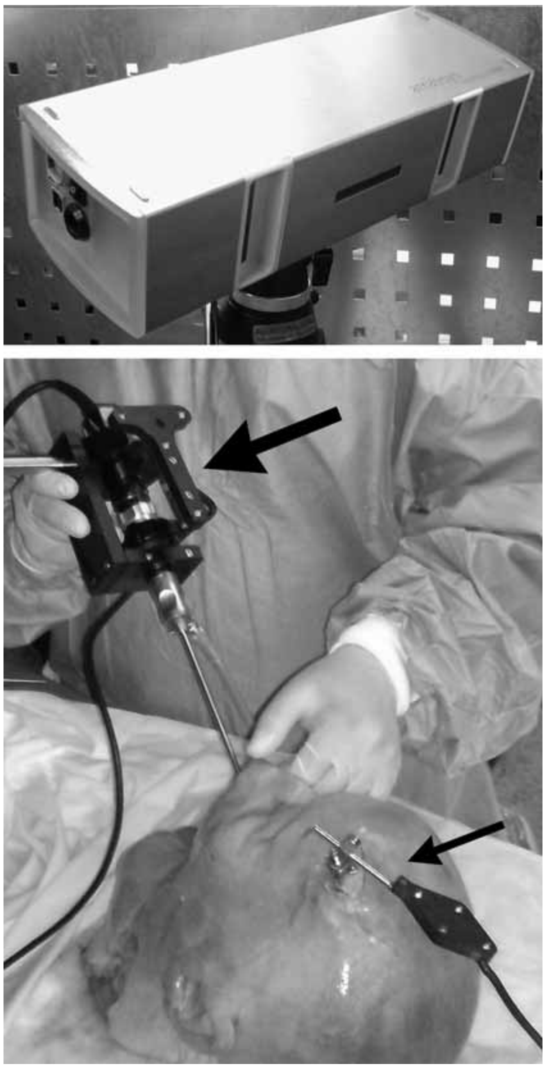

Figure 1. Laboratory setup for augmented reality in the endoscope. Visible are the camera (on top), the tracked endoscope with light emissions diodes (thick arrow) as well the dynamic reference base on the head (thin arrow).

optical markers that are used as dynamic reference bases [DRB] (Figure 1). Using optical markers on both endoscope and patient's head requires first calibration of the optics and its registration to the marker and secondly the registration of the patient to his attached marker. The calibration of the endoscope is made using images of a black and white checkerboard pattern and applying a method based on Heikkila's algorithm [3]. The reprojection error obtained is 0.5 - 1 pixel, which is considered fairly adequate for the purpose. Such method calculates the projection matrix, and the radial and tangential distortion factors that model the optics of the endoscope. The optical coordinate system of the endoscope is registered with the DRB attached to it as described by Thoranaghatte et al. [4]. The combination of calibration and registration provides the projection matrix needed to transform an arbitrary position in the space to a 2D position in the endoscope image.

The synthetic images shown in the augmented reality system

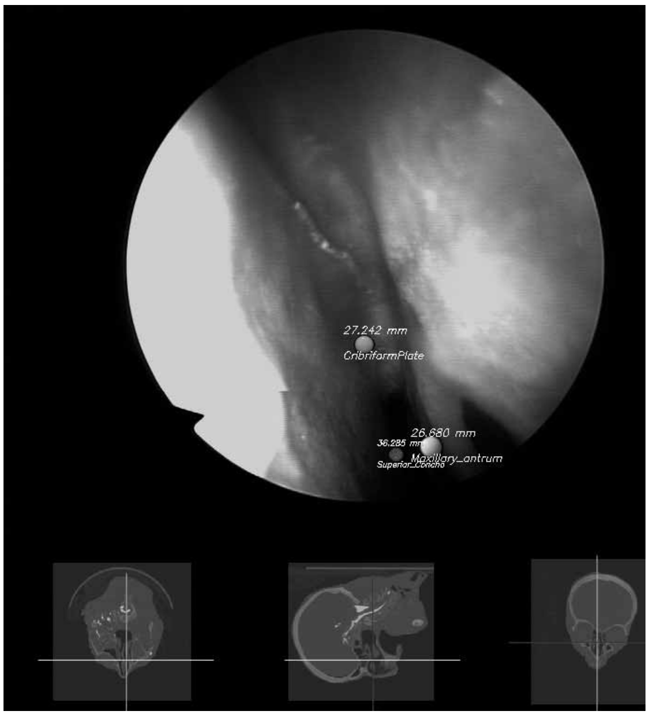

Figure 2. Distances from the endoscope tip to different anatomical landmarks with the corresponding endoscope position as crosshair on the CT are demonstrated.

are normally made from preoperative images of the patient, such as CT or MRI. In order to be able to navigate through these images, the preoperative data has to be registered to the patient's coordinate system, which is provided by the DRB attached to it. Two registration methods have been implemented in our system. Pair-point matching is based on identifying corresponding landmarks from preoperative images in the patient. Surface matching can be used after a pair-point registration in order to increase the accuracy of the calculated transformation. Such methods provide sub-millimeter accuracy.

Different modalities of synthetic image viewer have been developed. First, a CT viewer provides the surgeon with CT images overlapped to the endoscope video. The surgeon can choose a plane from the CT volume by using a tracked pointer and navigating through the patient. Second, a 3D viewer is able to render 3D models of preoperatively segmented structures, such as tumors or risk regions. Finally, a landmark-based guidance viewer has been developed. A CT-based planner allows the surgeon to select important anatomical landmarks, as well as targets and risky structures. Such landmarks are superimposed to the endoscope images during the operation together with distance measurements (Figure 2). In case the surgeon gets lost or there is too much blood in the scene, such landmarks provide him with the necessary information to reach the target and not to damage any important structure.

RESULTS

Accuracy is calculated by assessing the difference between selected contours in both real and overlay image. Mean error was consistently 1-2 [+/-0.3] mm between these contours. Initially, a test on cadaver was performed in order to validate calibration and registration procedures, as well as to measure the accuracy and guidance. The anatomical landmarks selected by the surgeon were overlaid on to the endoscope image, and they proved to be accurate enough to guide the surgeon through the surgical procedure (Figure 2).

DISCUSSION

In endoscopic paranasal and nose surgery dexterity of the surgeon is challenged since space is limited, the operating instruments are long and the operating area is viewed as a two dimensional domain. Currently used opto-electronic or magnetic navigation systems display just the tip of the endoscope on the screen. Having an AR system in such surgeries could make the operations safer and could help the surgeon to acquire these skills faster. We have developed an augmented reality endoscope system with easy to implement calibration and registration procedures. In comparison to contemporary endoscope-navigation system our system provides the surgeon with accurate augmented reality images (1-2 mm) of important surgical landmarks. The tracking holder of the endoscope will be in the future replaced by a smaller and smarter one.

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