Endoscopic Navigation System for Minimally Invasive Skull Base Surgery

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The skull base stands out as one of the most intricate anatomical regions in the human body. It comprises numerous blood vessels, optic nerves, and vital tissue structures. Consequently, the minimally invasive skull base surgery is a challenging operation with high risk. Currently, endoscopic guided surgery is extensively employed for skull base tumor surgery. However, the 2D endoscopic image has a limited field of view and lacks spatial information. Surgeons can solely identify critical subcutaneous tissues based on their clinical experience. Augmented reality (AR)-based endoscopic surgical navigation enables surgeons to observe subcutaneous tissues by superimposing virtual objects on endoscopic images. This technology effectively expands the surgical field of vision, enhances the depth information of the structure space, thereby improving the accuracy and safety of the surgical procedure. The core of this technique lies in the coordinate matching of surgical instruments, tissue structures, endoscopic images, and preoperative medical images. Real-time virtual-real fusion is achieved by integrating virtual objects into endoscopic images. This study firstly presents the development of a virtual reality preoperative planning system aimed at providing an optimal path for surgical instruments. Subsequently, endoscopic image processing methods are introduced for color restoration, depth estimation, feature matching, pose estimation, and 3D reconstruction. Regarding the intraoperative navigation, the transformation relationship between the CT image and patient spaces was established by extracting and matching the patient's facial points. The positioning of surgical instruments and the virtual-real fusion of multimodal images were subsequently achieved through endoscopy calibration, projection transformation, and rotation correction. Based on experimental results, the positioning accuracy of the developed endoscopic navigation system was determined to be within the range of 1-2 mm. This precision is regarded as acceptable ranges in cranial based domain. The key technologies of the endoscopic navigation system are also applied in the Ultrasound-guided percutaneous puncture navigation robot and X-ray-guided orthopedic navigation robot.