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3-D Reconstruction of the Sphenoid Sinus from Monocular Endoscopic Views: First results

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ABSTRACT:

For intervention at the pituitary gland, the shortest and most subtle method is an operation through the paranasal sinuses and especially through the sphenoid sinus. To avoid dangerous interference with adjacent nerves and organs, the physician has to orient himself in the very small sphenoid cavity and navigate across the hollow to breakthrough the sellar floor to the pituitary gland above.
Especially in re-operations and anatomical variants such as so-called *kissing carotids,* transsphenoidal surgery is a challenge even in experienced hands. To support such a surgery, image systems can be applied, such as preoperative CT or intra-operative endoscopy. While preoperative CT-data is used for operation planning and navigation support, endoscopy is currently used only for examination of the surfaces inside the sphenoid sinus. In this work, we present a 3-D reconstruction of the sphenoid sinus for navigation support, based on a monocular endoscopic sequence of images, yielding a grid describing the walls of the sphenoid sinus.

INTRODUCTION:

For intervention at the pituitary gland, e.g. for the removal of pituitary adenomas, currently the shortest, most subtle, as well as the most difficult method is transsphenoidal surgery. This means, that the pituitary gland at the base of the brain is approached through the patients nose along the nasal septum and through the sphenoid sinus, a small cavity of the skull behind the eyes. Breaking through the *sellar-floor,* the pituitary gland can be reached, and the tumor can be removed through the patient's nose, s. Fig. 1. To avoid dangerous interferences and contact with adjacent nerves and organs, such as the internal carotid arteries, supplying the brain hemispheres, the physician has to orient himself in the very small sphenoid sinus and navigate across the cavity to breakthrough to the sellar floor to reach the pituitary gland behind [1]. Due to the high potential risks related to such a surgical procedure, this type of minimal invasive operation is currently only performed by skilled and experienced surgeons. To support the specialist, imaging systems are applied, such as preoperative CT and MRI scans as well as intra-operative endoscopic and microscopic imaging. CT and MRI volume image data can be used beforehand to make the surgeon acquainted with the patients individual anatomy for operation and navigation planning. Intra-operatively acquired image data such as microscopic or endoscopic images are currently used for the examination of surfaces in the nasal cavities and the sphenoid sinus only.
To obtain higher-level information from a sequence of endoscopically acquired 2-D images, a 3-D reconstruction of the sphenoid sinus from monocular endoscopic images is proposed. Such a reconstruction yields a triangulated mesh describing the walls of the sphenoid sinus. First results of such a reconstruction will be described based on image data obtained from a scull.

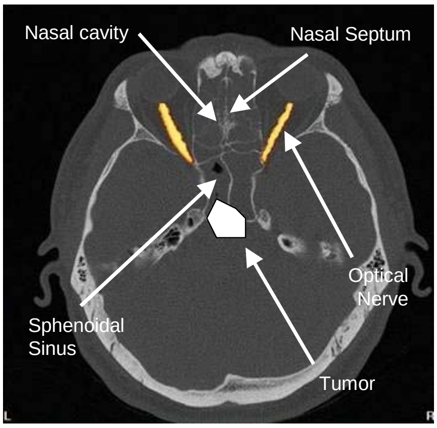

Image 1: *Transnasal approach to the tumor in the pituitary gland, depicted in an axial CT slice of a head..*

METHODS:

In this work, the 3-D reconstruction of the sphenoid sinus is based on a marker-less approach referred to as *structure from motion* [2]. The first step is to detect robust point features in the first image of the endoscopic image sequence, to track these points through all further images and replacing lost features in each frame. The detection and tracking algorithm is based on the Kanade-Tomasi tracker [3] with the extension of Shi and Tomasi [4]. Additionally, the tracker contains a number of improve-

ments such as illumination compensation, outlier detection and feature drift prevention for long image sequences [5].
Based on a set of detected and tracked features, the camera's extrinsic parameters (pose and translation) as well as 3-D positions of these features can be calculated by factorization the projection equation. The resulting 3-D positions of the features can be refined using a non-linear optimization based on the corresponding error of back-projection. Since optics of endoscopes show stronger degrading effects (e.g. distortion, noise) than common video systems, features detected in such images tend to be instable or get lost over long period of time. Therefore, an initial 3-D reconstruction is calculated based on a short subsequence. Based on this initial approximation, the features' information of the remaining images is added piecewise to the 3-D representation using an iterative procedure. Thus, the reconstruction is extended image by image to the complete image sequence.
Once, a 3-D point cloud has been obtained from the triangulation of the tracked feature points, in a final step a mesh is triangulated using the *tight cocone* approach, as suggested in [6]. Since this triangulation approach is watertight and closes the opening, a final manual interaction is needed to open the reconstructed sphenoid sinus.

Image 2: *Overview of laboratory scanning setup including the scull, the robot and the rigid endoscope*

RESULTS:

Several monocular image sequences of the sphenoid sinus of a skull phantom were obtained by using a surgical robot (Mitsubishi) holding a rigid, 0^o-endoscope (s. Figure 2). All single images were captured by slowly moving the tip of the endoscope backwards from the sphenoid sinus through the nasal cavity, resulting in sets of 300-500 single images. Additionally, corresponding recordings of a calibration target were captured and used to calculate the distortion of the optical system as well as to obtain the intrinsic parameters of the imaging system. Figure 3 shows the triangulated mesh of a 3-D reconstruction from the sphenoid sinus in the skull phantom depicted in Fig. 2.

Image 3: *Reconstructed triangulated 3-D view of the sphenoid sinus from skull phantom.*

DISCUSSION:

By reconstructing the sphenoid sinus from intraoperatively obtained endoscopic images, the already applied endoscopic image modality gains value within pituitary surgery, since higher-level information can be obtained from 2-D images. Such 3-D reconstructions can be used for enhanced navigation during surgery as well as for training purposes.

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