Teleassisted stereotactic endoscopic surgery

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Summary

The ARTMA Virtual Patient® System introduced augmented reality for visualization of virtual anatomical structures in endoscopic surgery (Lit. 1). Computer generated structures are fused with the endoscopic video images in real time. Interventional Video Tomography (IVT) allows 3D reconstruction from any kind of medical planar imaging data like endoscopic video, fluoroscopic imaging and ultrasound and their correlation with computer tomography (CT) and magnetic resonance imaging (MRI).

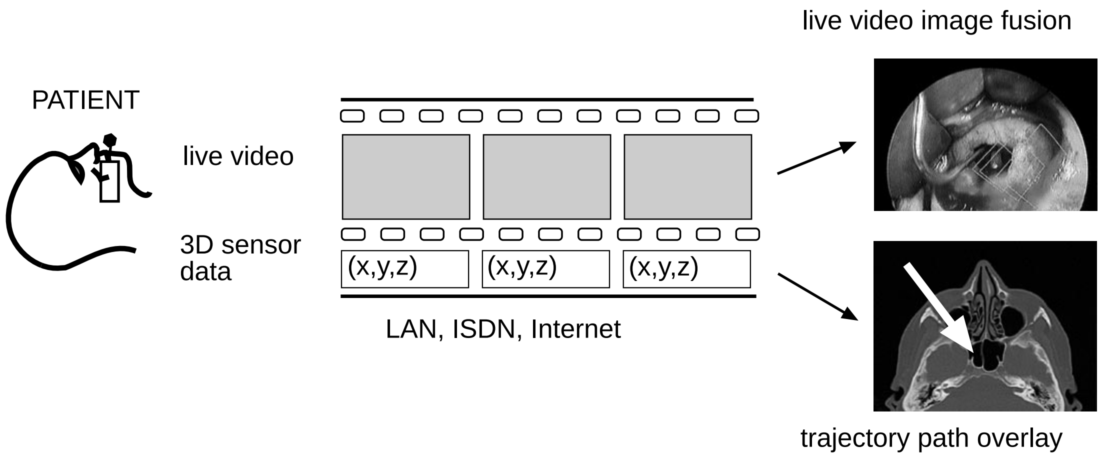
This technology makes it feasible to distribute intraoperative imaging over a network and visualize in the operating room stereotactic surgical simulations created by experts in remote locations. Although we show the communication between different countries it will have the biggest impact for workflow and communication within departments with networked computers.

1. Material and Method

We have extended our previous work (Lit. 2) to telementor assisted ear-nose-throat (ENT) surgery by broadcasting the IVT data set over a network in real time, introducing major technology advances.

1.a Remote definition of patient image coordinate transformation

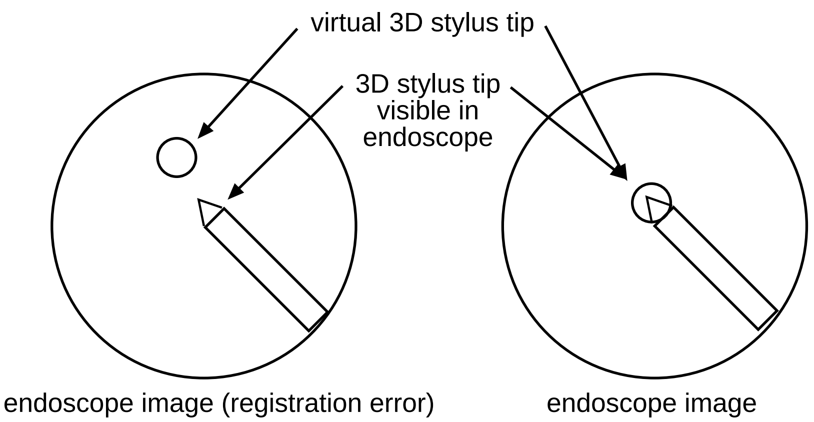
The patient image coordinate transformation is based on the IVT data set (Lit. 3) without use of a 3D digitizing probe to identify fiducial markers. The virtual representation of any surgical instrument tracked with 3D sensors is defined in the video overlay and independent of the physical sensor attachment. The only input needed for the system to be calibrated for stereotactic navigation is live video data with synchronously



recorded 3D sensor data. This IVT data set is simultaneously also transmitted over the network. Therefore the calibration procedure itself can be performed on any remote computer that accesses the IVT data over a network.

1.b Real time system accuracy control

The static accuracy of a typical 3D digitizer based on magnetic field technology is 0.03'' RMS for x,y,z position and 0.15° RMS for receiver orientation. Large metallic objects within the operating space might influence the accuracy of the digitizing system. Therefor the performance of the navigation system is continuously monitored by process-



ing redundant information, comparing visually 3D transducer data with stereophotometric image reconstruction data. In a simple implementation the tip of an instrument visible in a live endoscope video image is checked for a possible overlay matching error with the virtual computer generated instrument tip.

2. Remote simulation

The telementor surgeon at the remote network location defines a surgical access path to a region of interest in 3D relative to the patient's CT data set. A major disadvantage is that the anatomical situation as rendered in the CT might not correlate anymore with the intraoperative status quo. Although this is a known limitation of current stereotactic navigation systems it is especially problematic in teleassisted surgery. The telementor does not have the option of a check of accuracy, e.g. by comparing anatomical and fiducial markers on the patient with their position in the imaging data.

2.a Preoperative imaging

Immediately prior to the actual surgical procedure the surgeon navigates the endoscope under visual control along a trajectory that in ENT surgery would follow the natural cavity of the nose. This intervention is recorded as IVT data set and then transmitted to the remote telementor location. It is a visual representation of the anatomical situation close to the region of interest.

Characteristic anatomical structures visible in the IVT data set are marked in the CT. The patient image coordinate transformation defines the back projection of these computer generated structures to the IVT data set. Either a calibration error or a preoperative change of the anatomical topography become immediately apparent as matching error in the overlay of the computer generated structures on the IVT image. The surgical simulation is now based on the CT and the IVT data set of the surface topography close to the region of interest. This gives the telementor the capability of a plausibility check of his simulation.

3. Intraoperative image fusion

To guide the surgeon during the surgical procedure this graphic overlay is now visualized in the operating room. The back projection parameters for the virtual data structures at the remote site are identical to the parameters at the operating room. Therefore it is only necessary to transmit few drawing instructions over the network, the actual computation of the computer graphics and the video image fusion is performed at the local computer in the operating room. On the computer monitor or in a head-up display the surgeon has now superimposed onto the live video of the endoscope stereotactic computer generated graphic structures. This structures were completely created at the telementor site without any action necessary on part of the surgeon at the operating room.

The video component of the IVT data set is broadcasted over the network. On any remote computer the remote software application developed by ARTMA computes the projection parameters for the visualization of stereotactic navigation data by video image fusion.

4. Real time intraoperative imaging

Although with imaging data from the endoscope only the surface topography is detected we evaluate the clinical potential of documentation and visualization of a soft tissue shift over the time period of the surgical intervention. The monoscopic endoscope image makes it difficult to determine the depth of the virtual data structures relative to the topography visible in one single endoscope image.

4.a Depth perception of virtual structures in monoscopic endoscope video images

The vertical position of virtual structures within the visual field of endoscope images is easier to identify than the depth position. We use motion parallax and size as visual cues. By alternating the direction of the endoscope view at least 30 degrees during the observation we use the parallax to identify the depth. With this method we track a three dimensional shift of soft tissue structures during the time span of the surgical intervention. This is made possible by acquiring short IVT data sequences during critical phases of the surgical procedure.

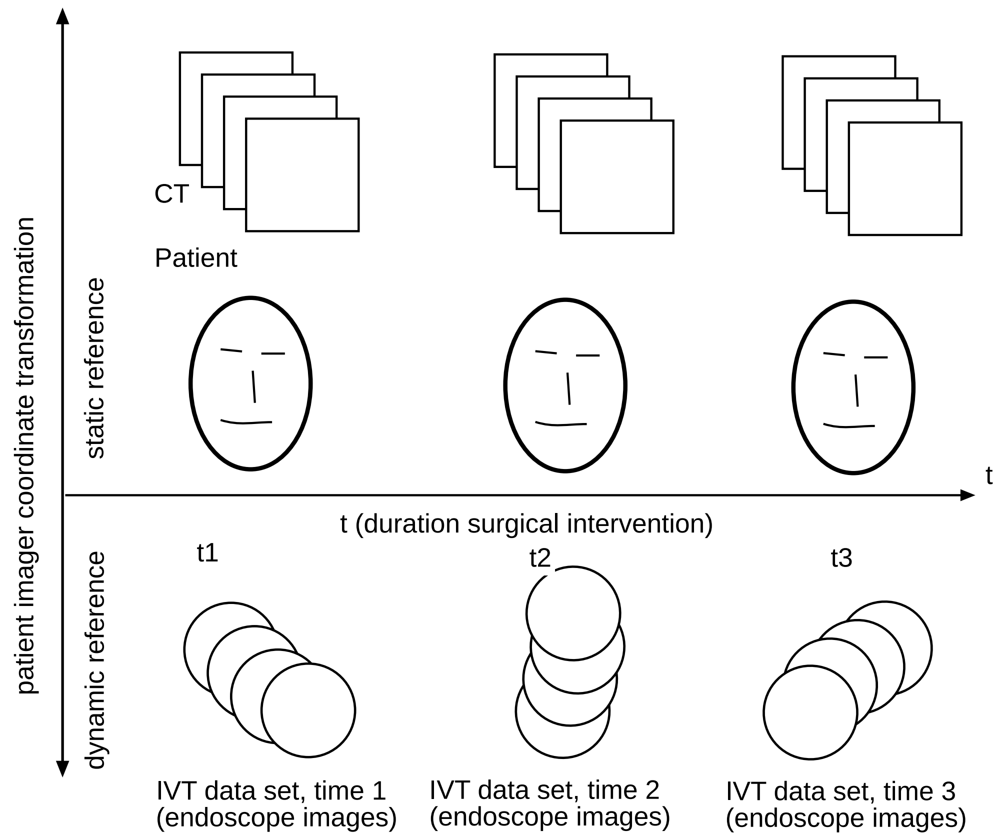
4.b Projection of a trajectory path on static images

Simultaneously the stereotactic position of the endoscope and any instrument is visualized as projection of a virtual instrument onto planar images like x-ray or volume imaging data like CT and MRI.

5. Documentation of intraoperative soft tissue shift

Similar to a flight data recorder the IVT data set can be continuously recorded to document critical phases in a surgical procedure. Instruments are tracked by 3D sensors, their position and orientation relative to the patient's anatomy is known.

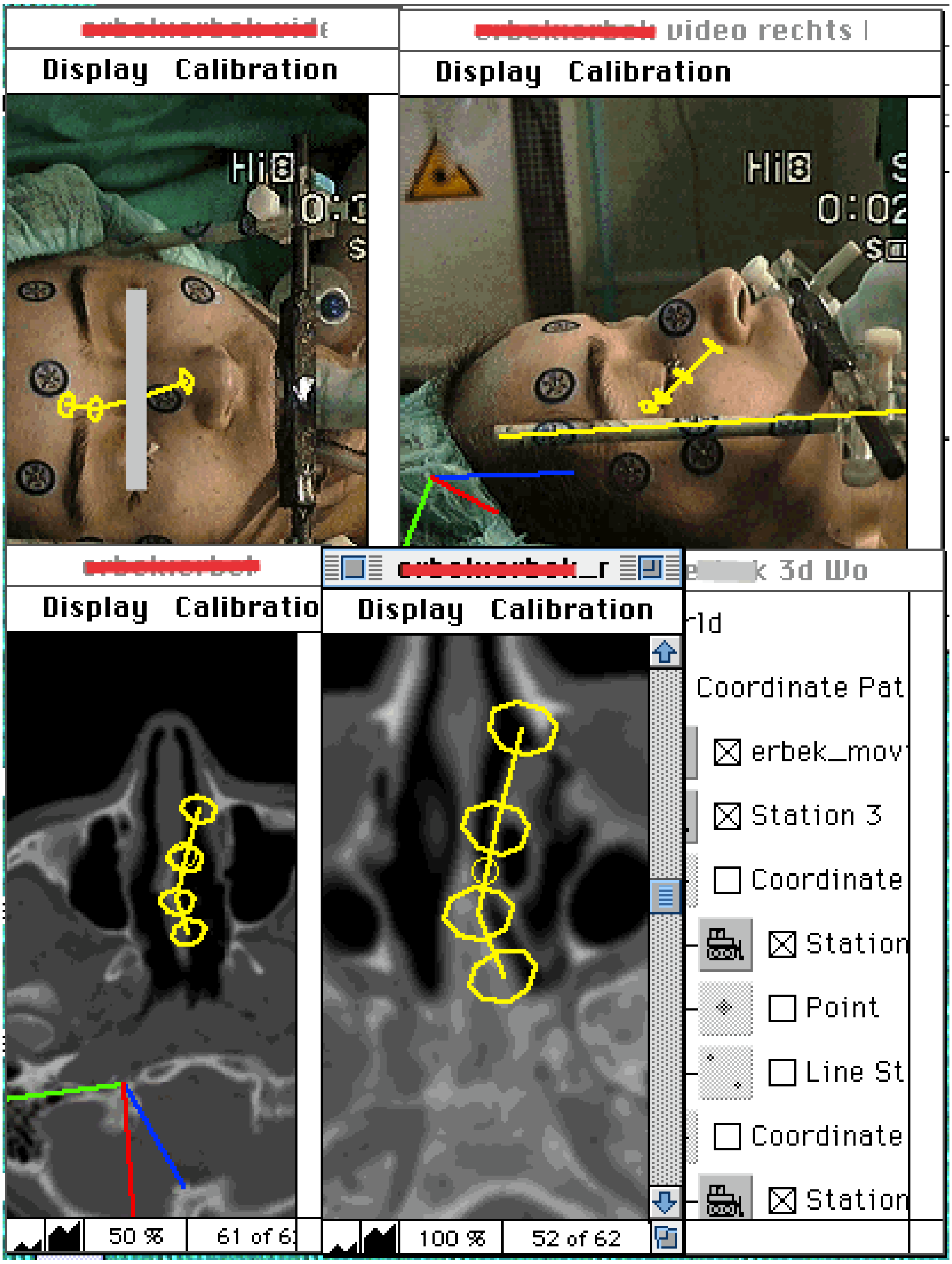
5.a Dynamic patient image coordinate transformation



At the beginning of the surgical procedure (time t1) the patient image coordinate transformation is defined for CT and IVT data set identically. During the surgical procedure part of the patient's anatomy shifts relative to the location at the time of the CT acquisition. The IVT data set at time t2 was recorded after such a soft tissue shift. The original computer graphics overlay on the IVT data set t1 does not match the anatomical situation at t2. A match can be achieved by defining a new reference to the IVT data set at t2. For this we need currently structures that can be identified unambiguously in different images. The use of ultrasound stereotaxic endoscopy resolves some of these limitations (Lit. 4). The integration of ultrasound images in the IVT data set will be presented in a future paper.

6. Discussion

The ARTMA Virtual Patient® System introduced augmented reality for visualization of virtual anatomical structures. The stereotactic navigation is verified by intraoperative imaging. This imaging data (IVT data set) can now be also distributed over a network. Independent of the physical location the expert can observe the surgical procedure and visualize for the surgeon the advice as graphic overlay intraoperatively



on the live endoscope images.

We will connect a telesurgery system at the CAR96 congress in Paris with an ARTMA Virtual Patient® system in the operating room of the University of Innsbruck, Dept. ENT. A live video and stereotactic navigation data transmission of a surgical procedure will be presented to demonstrate the state of development.

7. References

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