✂ Schnittkante ✂

Graph theoretical approaches to image-based surgical navigation

R. Borndörfer, S. Zachow, N.N.

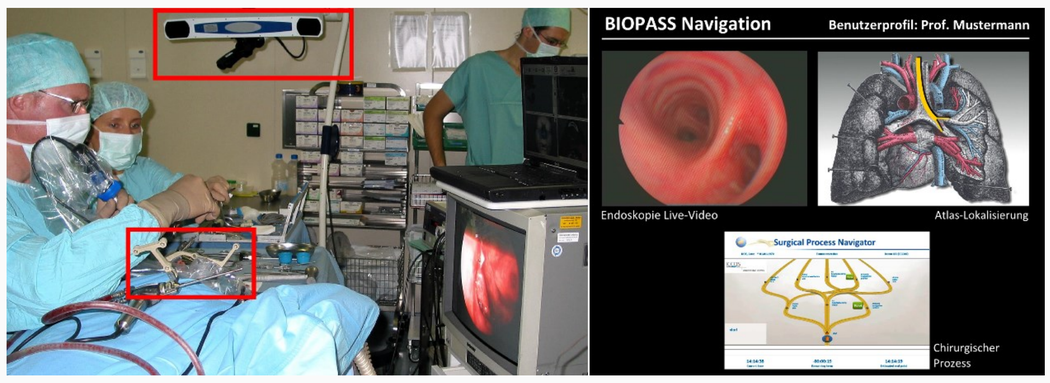
Cooperation: Mathematical Optimization and Visual Data Analysis
Funding: ZIB

Navigation for minimally invasive endoscopic surgery

In minimally invasive surgery, medics using flexible endoscopes are facing a complex navigation problem due to a limited indirect view, rotating images, disturbed hand-eye-coordination, etc.

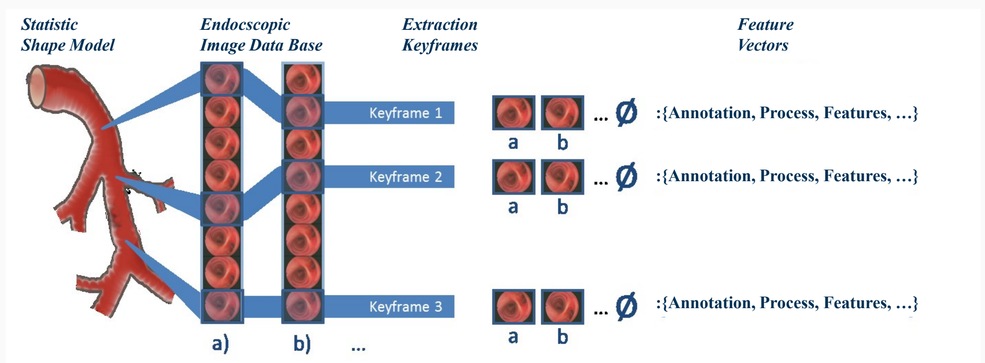
Experienced endoscopic surgeons are able to mentally assign an anatomical position to the endoscopic image while simultaneously looking at video images being acquired from the tip of the instrument, and directing the instrument through lumina of the human body.

Instead of using electromagnetic, mechanical, or optical devices to precisely locate the tip of the instrument, an image-based approach is to be developed that reduces the technical complexity in the operating room.



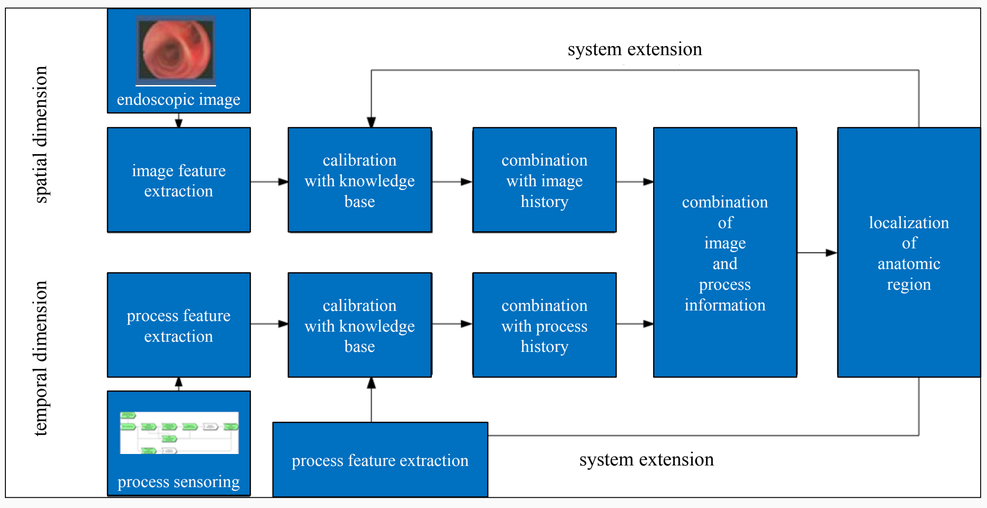
Complex surgical environment for transluminal endoscopy

Image-based navigation approach



Identify the position of a flexible endoscope within lumina of the human body by matching live endoscopic images in situ with previously learnt image sequences to assist surgeons in transluminal endoscopic navigation:

- select a limited set of representative images from endoscopic image sequences
- define image features by ontology framework
- convert the set of endoscopic image sequences into sequences of feature vectors
- set up atlas of different anatomical lumina as a graph
- analyze endoscopic images and match with learnt sequences to estimate the endoscope positions, considering a probability based on adjacent images along the path
- communicate and visualize the actual position of the endoscopic tip with respect to the anatomical reference



Graph theoretical approach

Compute most likely position of endoscope tip by identifying best match between path in anatomical atlas and complete sequence of feature vectors:

- **compute likelihood of path match as a sum of logarithms**

$$\max \prod p_v \Leftrightarrow \max \sum \log p_v \Leftrightarrow \min \sum |\log p_v|$$

- **compute best matching path as a shortest path**
- **compute best matching alternatives as 2-shortest,…,k-shortest paths**
- **use fast k-shortest path algorithm by Eppstein**
- **recompute k-shortest paths in real time when new information becomes available**
- **calibrate algorithm with surgery, surgeon, etc. profiles**

Mathematical Challenges

- finding a path with certain features is hard (graph isomorphism problem)
- reoptimization version of Eppstein's algorithm with fast update of data structures must be developed
- extend to ensure combinatorial diversity of k-shortest paths
- extend to take backtracks into account

Work Plan

- **WP 1** Construct a library of landmark reference graphs together with members of the BiOPAss project.
- **WP 2** Develop and implement reoptimization variant of Eppstein's k-shortest path algorithm.
- **WP 3** Evaluate path matching approach in minimal invasive surgery.

Collaboration

BIOPASS · Gefördert vom Bundesministerium für Bildung und Forschung · Projektträger VDI|VDE|IT · iccas · Universitätsklinikum Leipzig · HNO Leipzig · imise · TUM · MITI · DORNHEIM MEDICAL IMAGES · LOCALITE · ZIB

7/1/2015