ME 328: Medical Robotics
Winter 2019

Lecture 7: Tracking for surgical navigation

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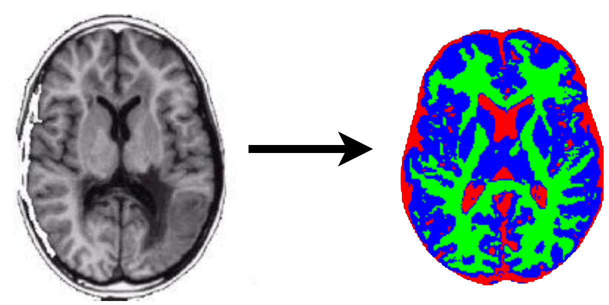
key technologies associated with image-guided procedures

medical imaging and image processing

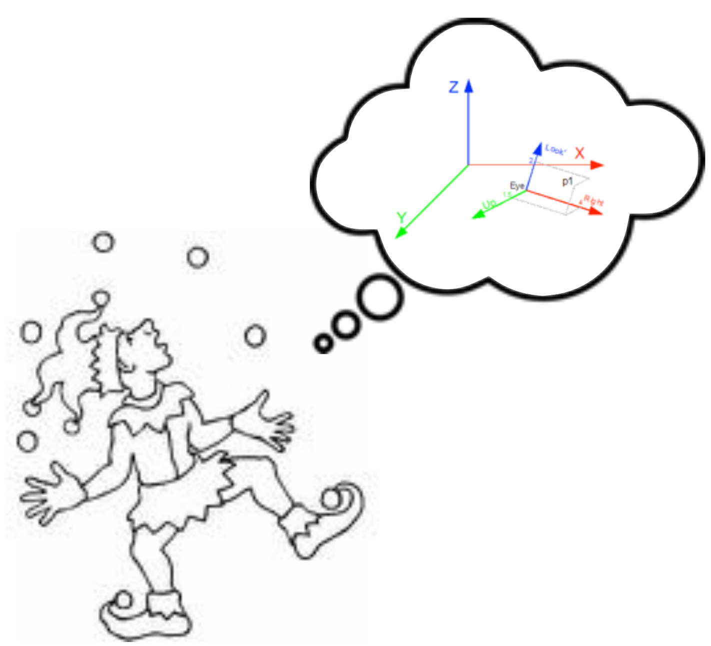
replaces vision

data visualization and image segmentation



replaces visual reasoning

registration, tracking systems, and human-computer interaction



replaces hand-eye coordination

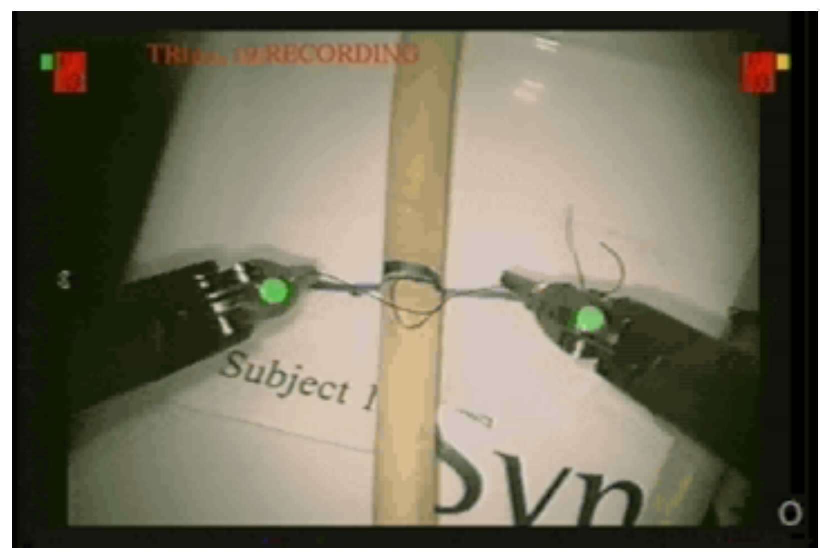
tracking and surgical navigation

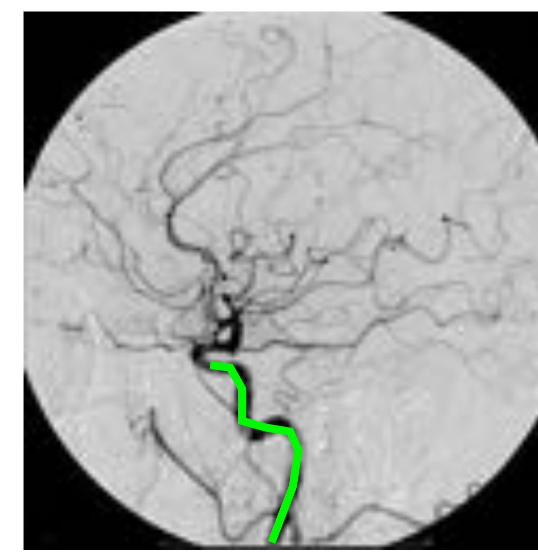
tracking

goal: to determine the position and orientation of tools and anatomical structures in image-guided procedures

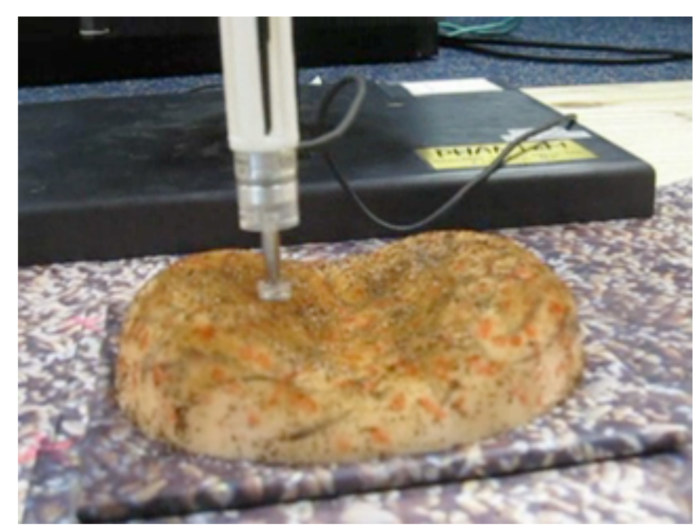
typical purposes:

1. display a dynamic virtual representation on screen relative to real images (i.e., augmented reality)



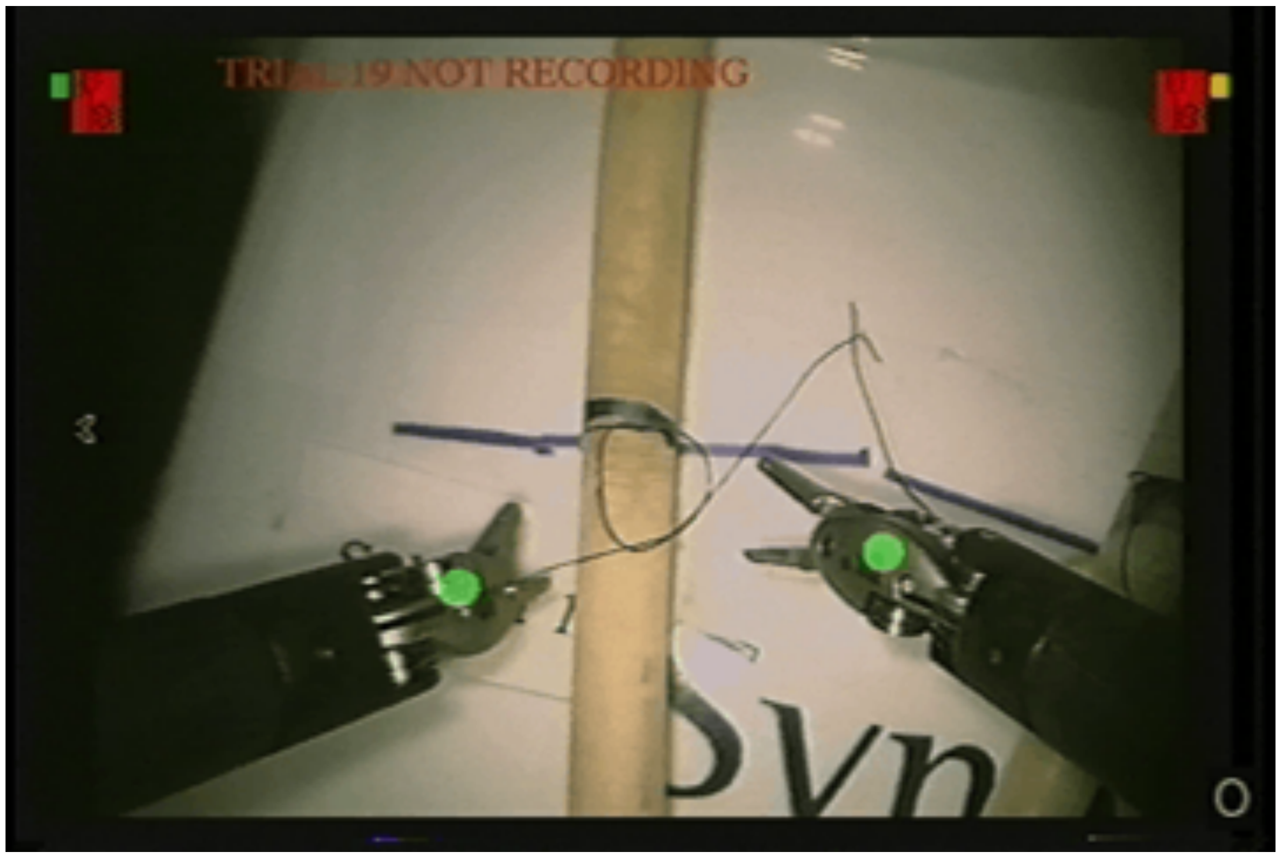


2. control a robot based on pose changes of tools and anatomical structures

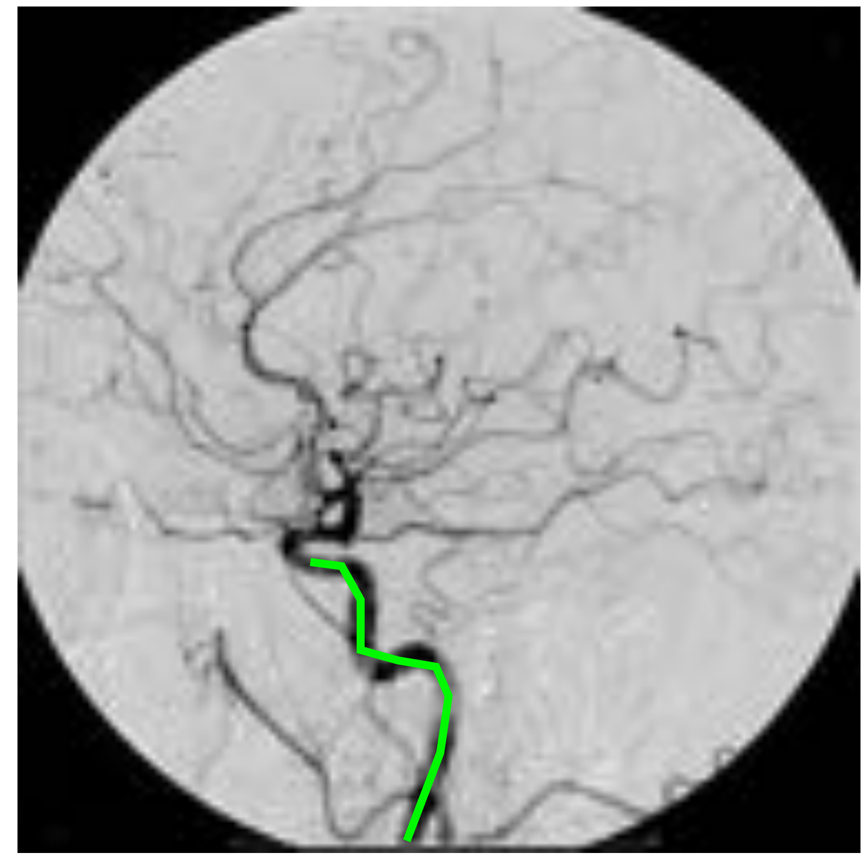


goal1: information display

display a dynamic virtual representation on screen relative to real images (e.g., augmented reality)



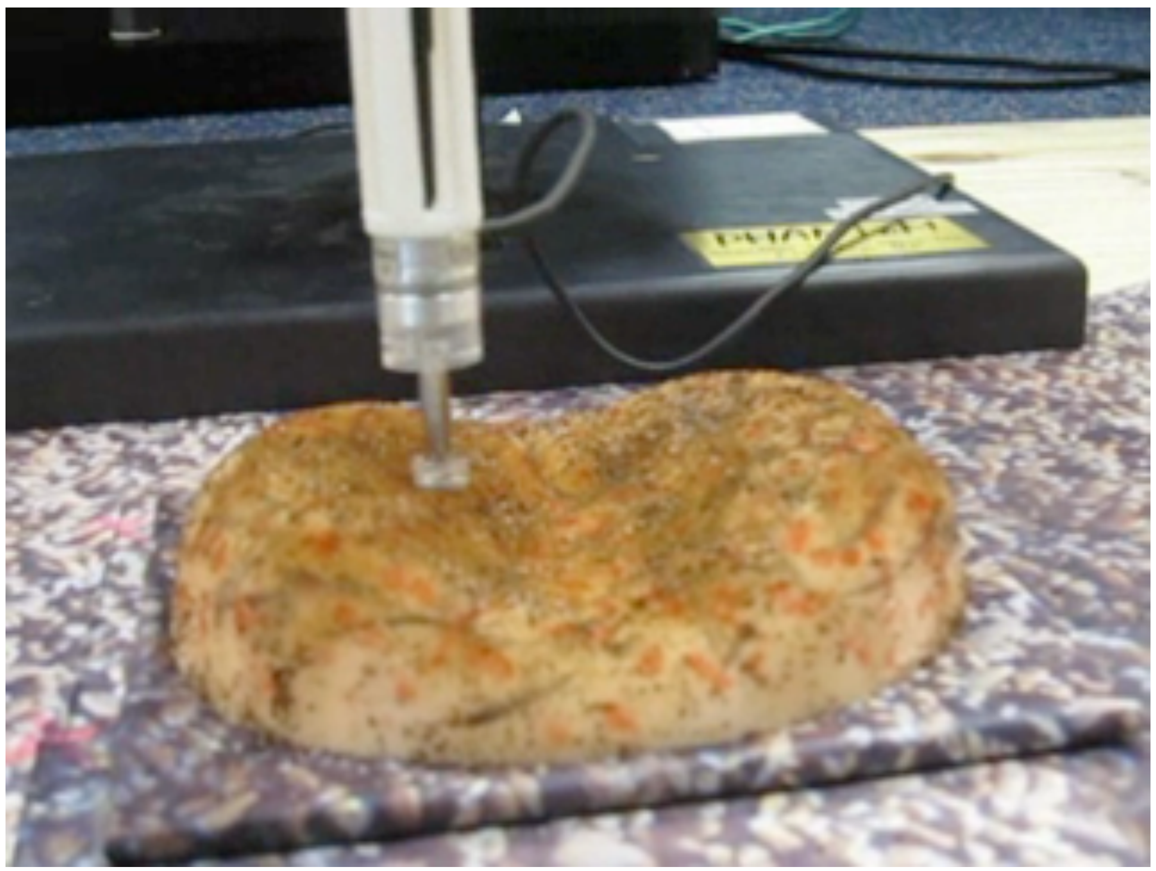
here, instruments are tracked so that "force dots" can be placed on them to prevent occlusion of the workspace

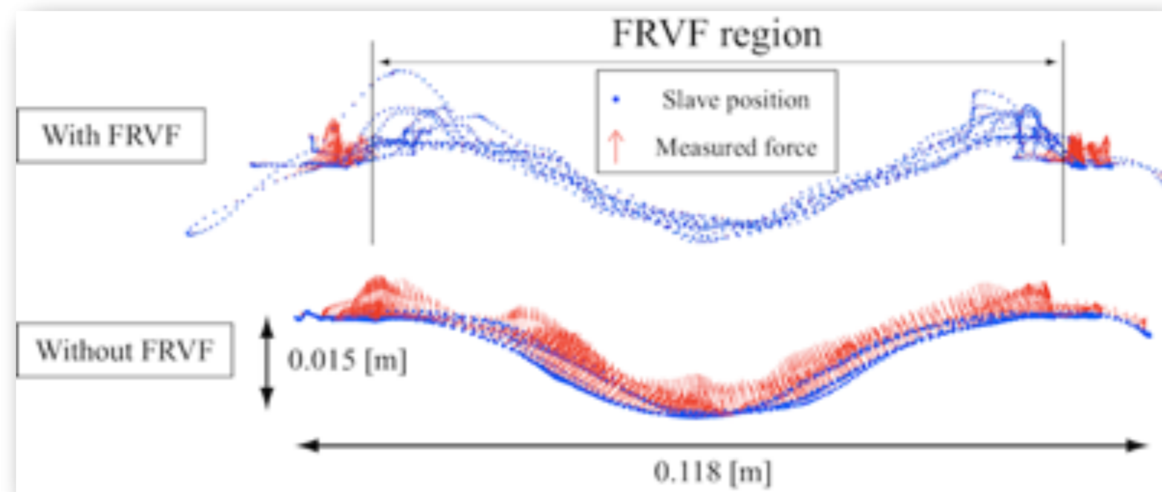


here, a dynamic graphical image of a catheter is overlaid on a static DSA image

goal 2: robot control

control a robot based on pose changes of tools and anatomical structures





in this example, virtual fixtures are created to keep the instrument away from the tissue surface

Yamamoto et al. (2011)

tracking requirements

1. Refresh rate: refresh rate of ~100Hz with a latency of less than 1ms, regardless of the number of tracked objects.
2. Concurrency: tracks up to *n* sensors concurrently.
3. Working volume: meets the needs of the procedure
4. Obtrusiveness: sensors are wireless and can function for several hours, all hardware components can be positioned so that they do not restrict the physical access to the patient, and the system does not have any effect on other devices used during the procedure
5. Completeness: sensors are small enough to embed in any tool and provide all 6DOF
6. Accuracy: resolution less than 0.1mm and 0.1°
7. Robustness: not affected by the environment (light, sound, ferromagnetic materials, etc.)
8. Cheap: costs less than ~$5000

G. Welch and E. Foxlin. Motion Tracking: No Silver Bullet, but a Respectable Arsenal. IEEE Computer Graphics and Applications, 22(6):24-38, 2002.

slide from Ziv Yaniv, Sheikh Zayed Institute for Pediatric Surgical Innovation Children's National Medical Center

mechanical tracking

method: robot kinematics combined with joint sensing is used to compute an end-effector position (this comes for free with a robot!)

caution:

- accuracy depends on correct kinematics
- limited workspace, obtrusive

stereotactic frame

coordinate measuring machine (e.g. Faro Arm)

robot (e.g., Mako)

optical tracking

method: use camera rigs to track fiducial markers that are attached to the instrument or anatomical structure of interest

passive markers: spherical markers reflect infrared light, emitted by illuminators on the position sensor

active markers: infrared-emitting markers are activated by an electrical signal (example: Polaris, NDI)

what are the advantages and disadvantages over mechanical trackers?

what about “traditional” computer vision?

electromagnetic tracking

method: a transmitter (magnetic field generator) is used to induce a current in sensor coils that can be embedded into the tracked objects

Aurora, NDI

transmitter

sensor coils

TrakStar, Ascension

what are the advantages and disadvantages over optical trackers?

SurgTrak: Affordable Motion Tracking and Video Capture for The da Vinci Surgical Robot

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OBJECTIVE

Robotic surgery provides high resolution video and instrument movement data useful in assessing surgical skill. This data could enable the development of training algorithms to accelerate learning curves. However, only a few research centers have access to the instrument data housed within the da Vinci robot's Application Programming Interface (API). Here we present a hardware and software solution that obviates the need for da Vinci API access during dry, cadaver, and animal lab training: SurgTrak. Our method achieves comparable data (all degrees of freedom of the tool and wrist and camera) to the da Vinci API at a far lower cost and without the intellectual property agreements needed to license API access from Intuitive Surgical. Our hardware and software is highly configurable and does not put the robot at risk of damage or malfunction. Further, it is deployable to any unmodified da Vinci robot.

FIGURE 1 Our modified tool next to a standard da Vinci Si instrument. Both motion tracking and grasper tracking are achieved within the tool body and outside the surgical field.

FIGURE 2 The da Vinci grasper is driven by four spindles in the tool body. By measuring the angle of these spindles we know the pose of the tool.

FIGURE 3 LEFT Internal components of SurgTrak including potentiometers to measure spindle angle, and electrical connection to tool-tip for contact sensing. CENTER Spacer featuring tracker receptacle positioned to optimize signal quality and strain relieved signal wiring receptacle. RIGHT Internal view of modified tool showing final product.

DESCRIPTION

Our system consists of synchronized video and surgical tool motion recording unified by custom software. Video is recorded at up to 30Hz from the da Vinci master console using an Epiphan DVI2USB device, Epiphan Systems Incorporated, Ottawa, Ontario, Canada. Tool position and orientation are captured with a 3D Guidance trakSTAR magnetic tracking system, Ascension Technology Corporation, Burlington, VT, USA. Grasper and wrist position is recorded by measuring the angular position of the four spindles driving the four tool degrees of freedom (See figures 2 and 3). Custom USB-enabled hardware based on PhidgetInterfaceKit 8/8/8 (Phidgets Incorporated, Alberta, Calgary, Canada) was developed, including a set of inexpensive potentiometers that extract absolute spindle angle and additional environmental signals. Data streams from the video recording, position recording and wrist signal recording are united by purpose-built Visual C++ software running on a Windows 7 based laptop computer utilizing the windows multimedia timer.

RESULTS

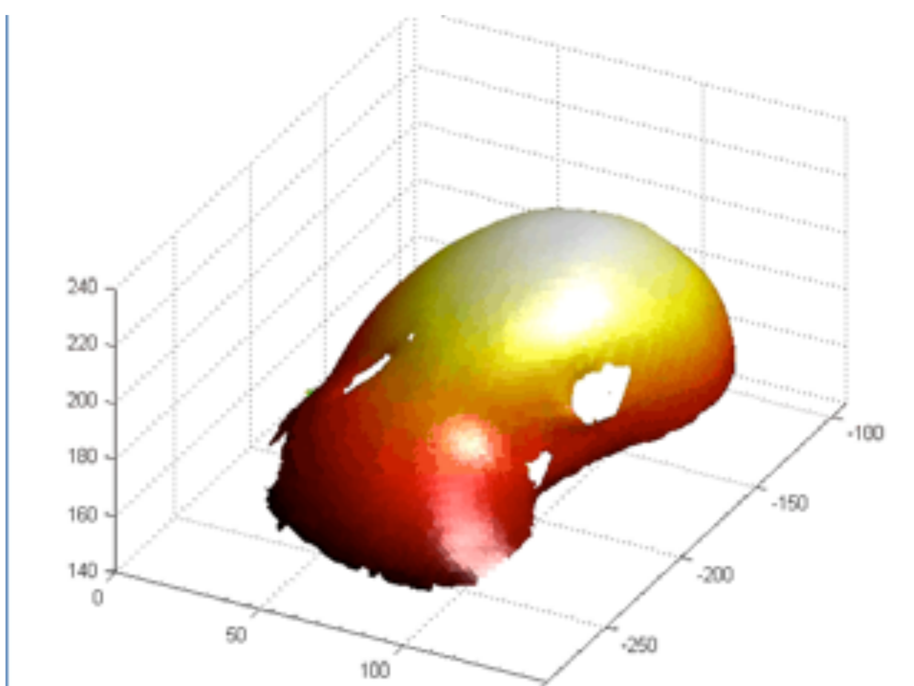
SurgTrak requires no modification of the da Vinci surgical robot and no access to its inner workings. It can be adapted to da Vinci standard, da Vinci S and da Vinci Si surgical robots.
The addition of SurgTrak recording equipment is transparent to the surgeon. It requires only one wired connection to each tool and camera. Data is recorded to compact, manageable files for later analysis. Video data can be analyzed manually via an Objective Structured Assessment of Technical Skills protocol or via automated methods. SurgTrak is currently in use in a multicenter study to validate robotic surgical education curricula. Two complete systems have been constructed and deployed: one to the University of Washington Institute for Simulation and Interprofessional Studies (ISIS) and the second to Madigan Army Medical Center. To date, over 750 iterations of surgery-like tasks have been logged. These include tasks such as FLS Block Transfer and a new, more challenging rocking peg-board task. Figure 4 depicts the system and typical results.

FIGURE 4 As surgeons perform tasks the video stream they view and motions they produce are recorded at 30 Hz and stored to a hard drive. All tracking occurs outside the surgical field, with the [illegible] position sensors and instrumentation located at the back of the tool body (seen also in Figure 1).
Data collected includes spindle angle (tool-tip pose), tool position and orientation in space, tool contact with tasks, and video of the entire task or procedure.

surface imaging
(computer vision, depth sensing)

Bumblebee Firewire Stereo Vision Camera

Microsoft Kinect

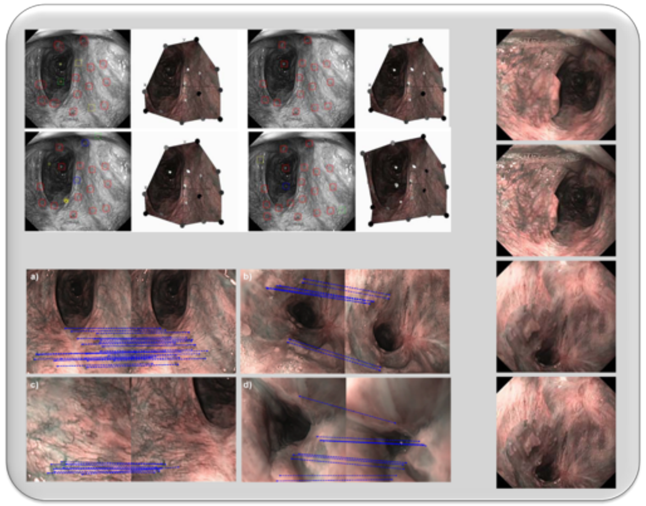


Optimet Conoprobe surface scanning (Vanderbilt)

Sick Laser Measurement Sensor

image: Microsoft

other trackers



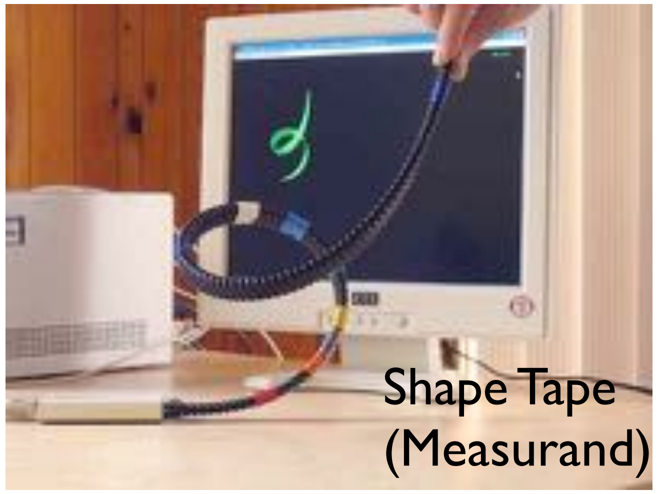
optical ego-motion (self-motion) computes camera motion; appropriate for endoscopes

Technische Universität München

ultrasonic systems: sound point sources are attached to the objects; time of flight between the source and a number of detectors is used to estimate the location of the source

inertial measurement units use accelerometers and gyroscopes to detect acceleration and orientation

Shape Tape uses fiber optics to estimate the location and orientation along its length



Shape Tape (Measurand)

Virginia Tech Shape Tape example: http://www.youtube.com/watch?v=ZMZr1jNDVGY