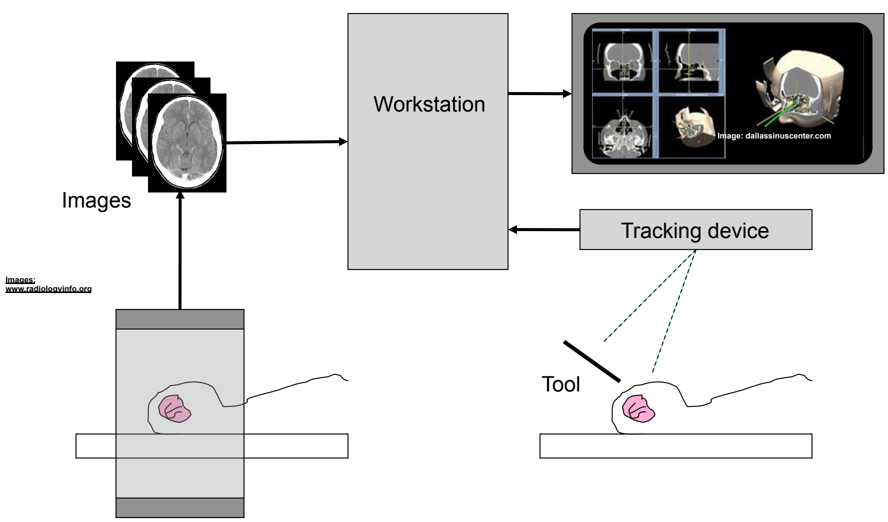
3D Localizers for Surgical Navigation
600.445

Russell H. Taylor

Surgical Navigation Systems



3D localizers

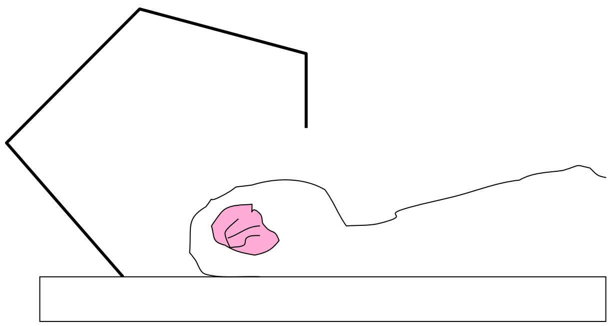
- Determine 3D positions in space relative to some coordinate system
- Also called “3D digitizers”, “3D navigation systems”, “localizers”, etc.
- Many uses
- Many technologies

Localizer technologies

- Instrumented passive manipulator
- Active manipulator
- Ultrasound
- Electromagnetic
- Optical active
- Optical passive
- Miscellaneous – e.g., fiber optic

Passive mechanical linkages

- Encoders & linkage



136   Interactive Image-Guided Neurosurgery

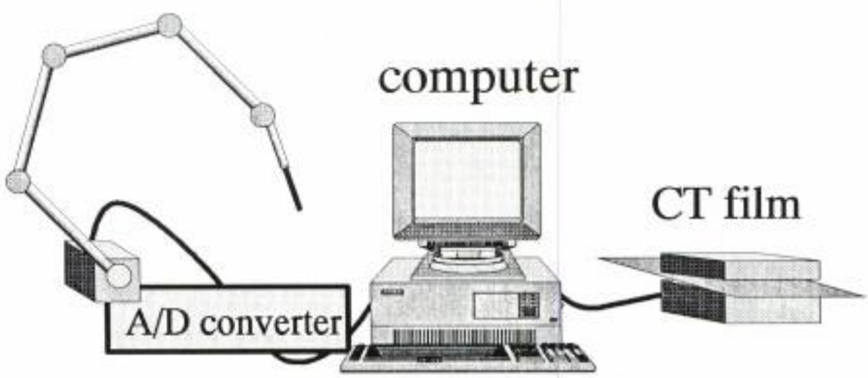


Figure 1. A schematic representation of the neuronavigator system. It consists of a microprocessor and a multi-articulated arm structure.

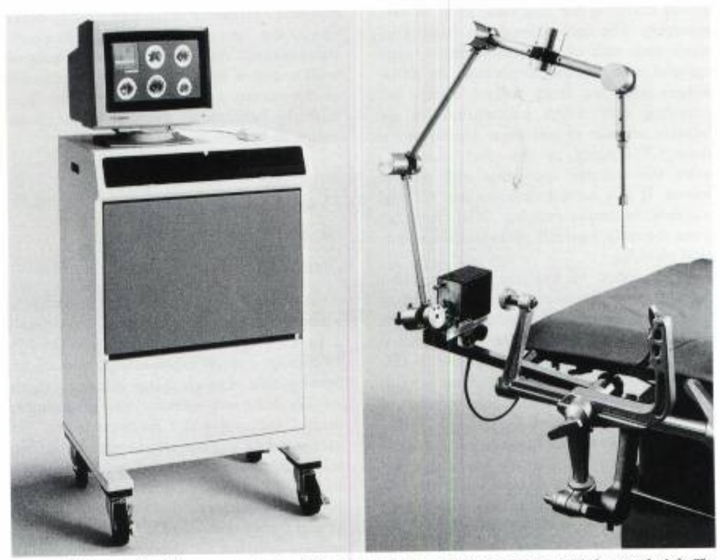


Figure 2. Photograph of the neuronavigator. The computer system is housed in the console box on the left. The sensing arm is secured to the Mayfield skull clamp. Six CT slices are displayed on the computer screen. Two cross markers display the location of the navigator tip.

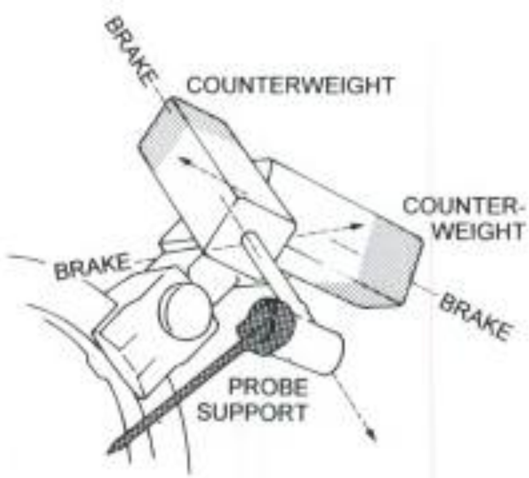


FIGURE 23.3 Mechanical principle of ET-01.

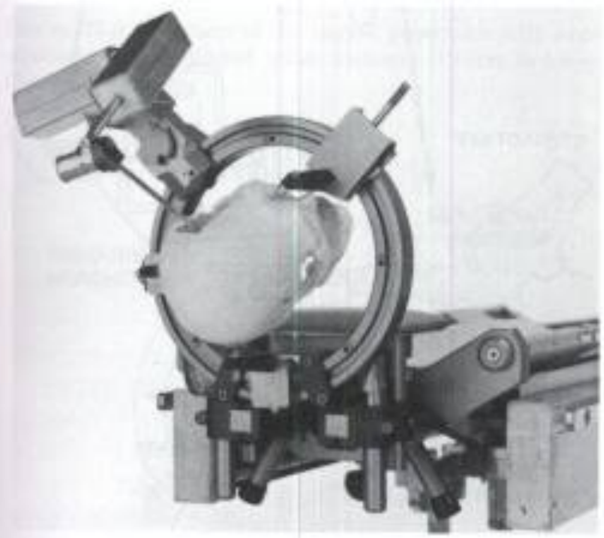


FIGURE 23.4 The ET-01 measuring arm with 4.5 degrees of freedom.

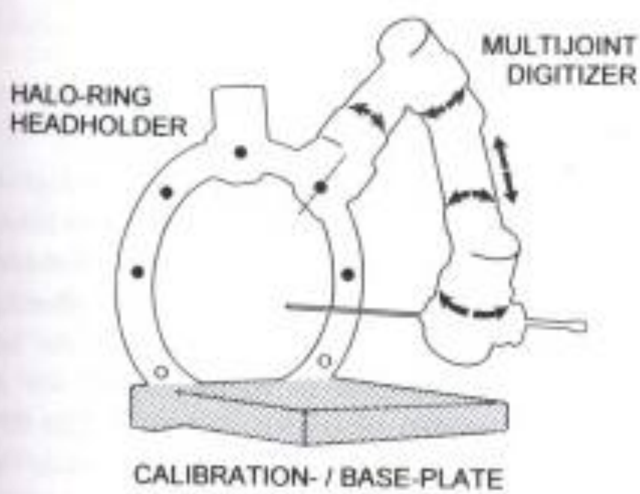


FIGURE 23.7 Four and one-half degrees of freedom in ET-02.

FIGURE 23.6 Digitizer of the second generation with ventriculoscope and docked video camera. (Center bottom) Control console.

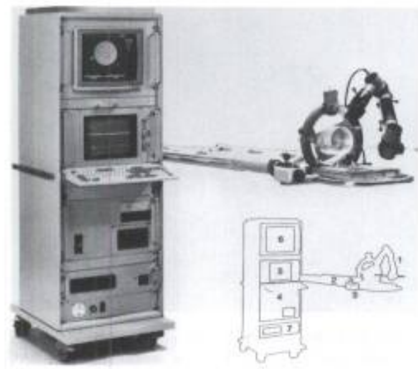


FIGURE 23.8 Overview of the ET-02 system: (1) measuring arm; (2) stretcher; (3) control console; (4) industrial computer; (5) data monitor; (6) graphics monitor; (7) 8-in. floppy drive.

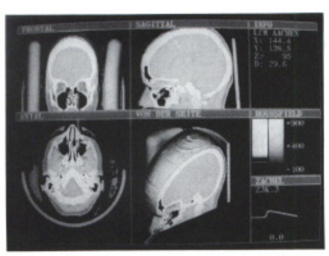
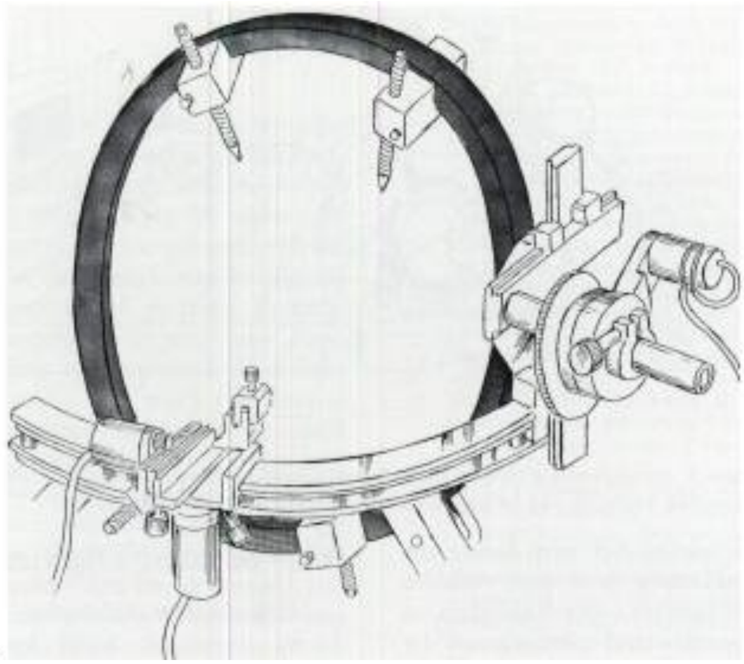


FIGURE 51.1 Image display on the CAS monitor screen.

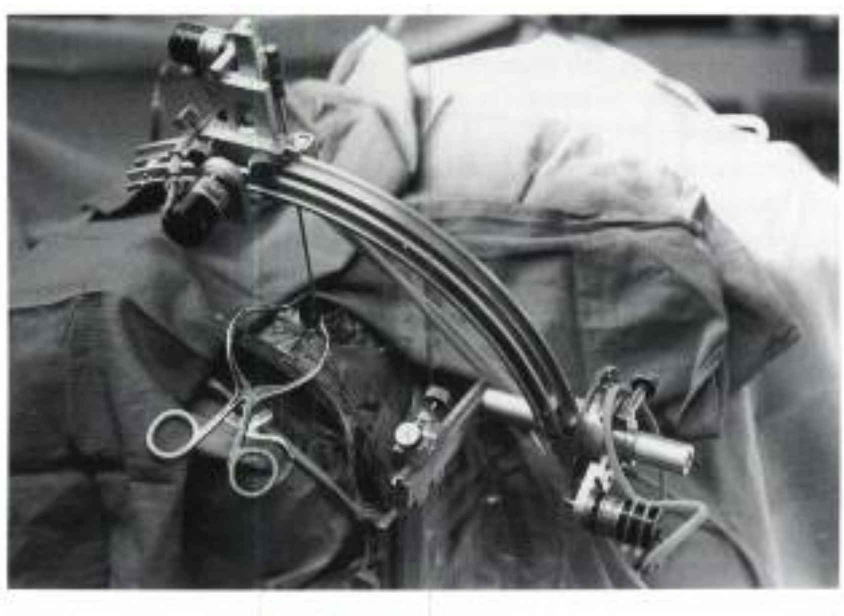
Therefore, we developed an appropriate measuring device which has 6 degrees of freedom [2, 3]. Digital increment encoders have been applied for shaft angle measurement. The pulse signals of the six rotary encoders are evaluated by 16-bit counters. A dedicated 68008 microcomputer calculates the position of the measuring probe from the measured angles and the given arm lengths. The system was developed with 3D imaging (figure 51.1).

A third generation of mechanical systems was developed to achieve better intraoperative handling [4] (figure 51.2). Counterbalanced arm elements allow for easy movements in every position. The 68008 was replaced by a PC-486

FIGURE 51.2 The Aachen device for CAS with electromechanical measuring arm (coordinate digitizer).



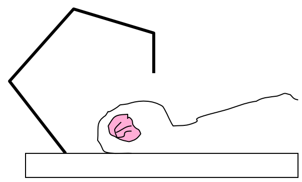
B



A

Passive mechanical linkages

- Encoders & linkage
- Advantages



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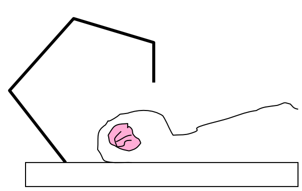
Passive mechanical linkages

- Encoders & linkage
- Advantages:
  - simple
  - no line-of-sight problems



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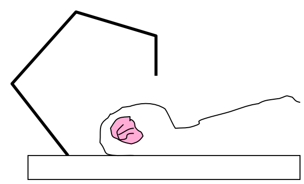
Passive mechanical linkages

- Encoders & linkage
- Advantages:
  – simple
  – no line-of-sight problems
- Drawbacks
  – clumsy
  – single frame
  – reference base



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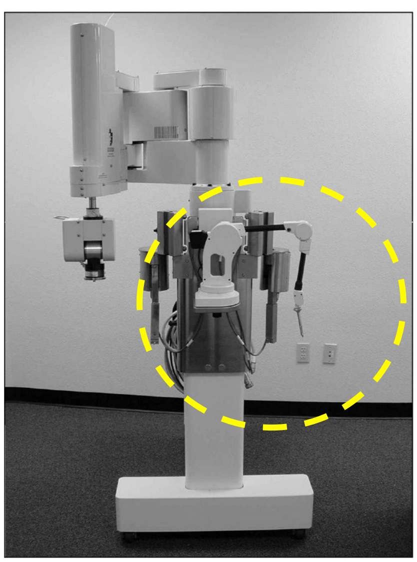
Some commercially used examples



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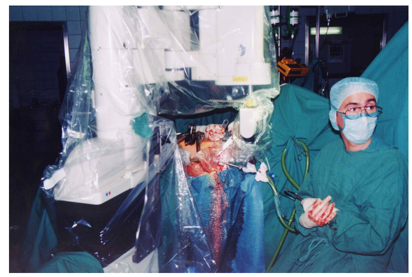
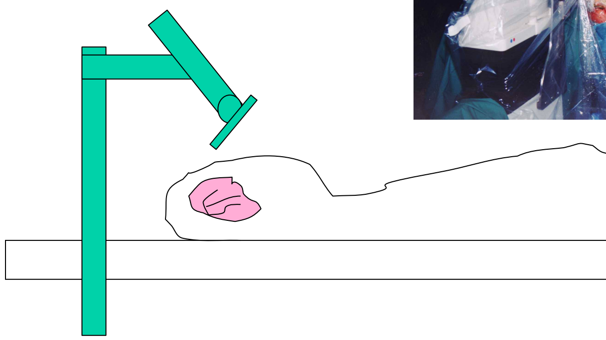
Active mechanical linkages

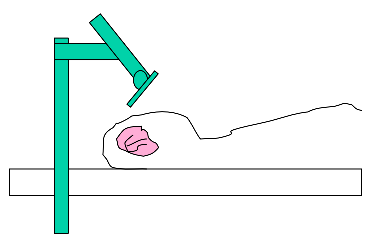
- Robot + hand guiding
- E.g., Robodoc





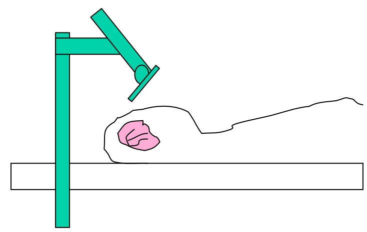
Active mechanical linkages

- Robot + hand guiding
- E.g., Robodoc
- Advantages



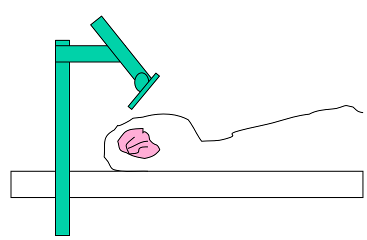
Active mechanical linkages

- Robot + hand guiding
- E.g., Robodoc
- Advantages
  - accurate
  - registered to robot
  - can combine with search, actions
- Drawbacks



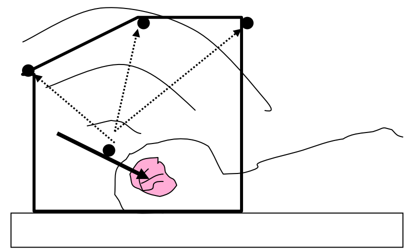
Active mechanical linkages

- Robot + hand guiding
- E.g., Robodoc
- Advantages
  - accurate
  - registered to robot
  - can combine with search, actions
- Drawbacks
  - clumsy
  - expensive
  - single tool, referencing



Ultrasound

- “Clickers”+microphones
- time delays give distances
- multiple distances give pos.



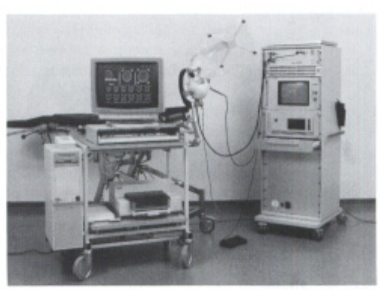


FIGURE 23.9 First sonic digitizer: system overview. Graphic computer (left), head-holder, sonic system (middle), SAC device, measuring computer (right).

intraoperative application. While we were evaluating the Science Accessories Corporation's (SAC) sonic system, we read about a first application of this device by Roberts [14] for the spatial, image-assisted localization of an operating microscope.

SONIC MICROSTEREOMETRY: ET-03

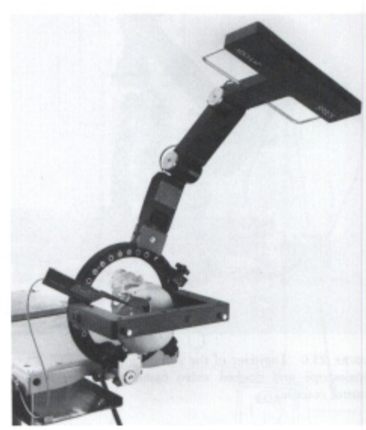


FIGURE 23.10 SPOCS with emitter panel (top), head-holder with detachable calibration frame, and supported targeting instrument (below left).

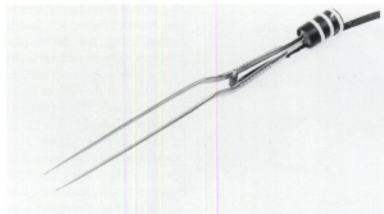


Figure 8. Sonic forceps, with wires directly attached to the emitters since the voltages involved precluded the use of a miniaturized connector.

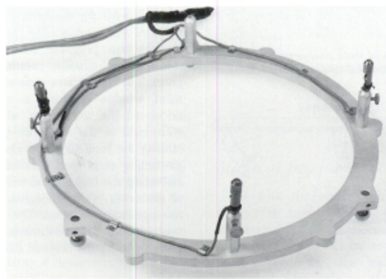


Figure 9. Sonic emitter ring, which attaches to the BRW head ring by the standard BRW ball/cam lock system; emitters can be placed at four points around the ring, allowing its use for posterior-based craniotomies.

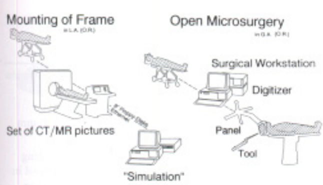


FIGURE 23.11 Sonic microstereometry. Data acquisition and operating procedure.

three microphones was docked with the ring at the same time, immediately after image data acquisition, or in a separate second procedure (see figure 23.11). The system was calibrated with a calibration panel containing three emitters, which were screwed temporarily to the ring. On the basis of the CT or MRI calibration marks, the software determines the exact position of each individual image relative to the calibration panel or base ring (first matrix operation) and then calculates the spatial relationship with the microphone panel (second matrix operation). The position of the targeting tool (one to four emitters) relative to the panel is determined finally in a third matrix operation.

The effect of interfering thermal factors could be largely eliminated by means of a measuring distance between the foot of the panel close to the head-retaining ring and the panel. Before each measuring cycle, a reference signal was emitted by the reference emitter and reached the panel microphones approximately 60 cm away in a known time of travel. Deviations (e.g., owing to temperature shifts) were taken into account auto-

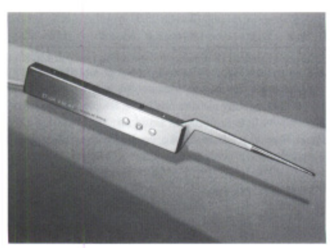


FIGURE 23.12 Bayonet-shaped standard measuring tool.

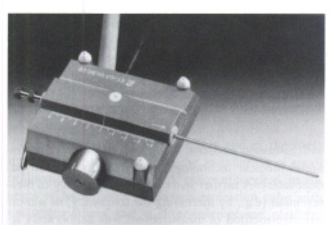
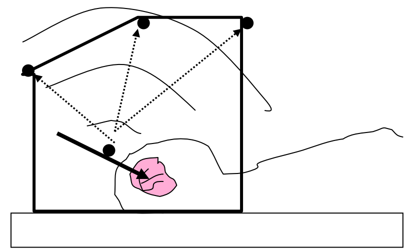


FIGURE 23.13 Measurement platform with four emitters for stereotaxy.

Ultrasound

- "Clickers"+microphones
- time delays give distances
- multiple distances give pos.

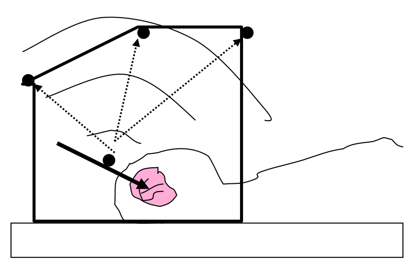
- Advantages



Ultrasound

- "Clickers"+microphones
- time delays give distances
- multiple distances give pos.

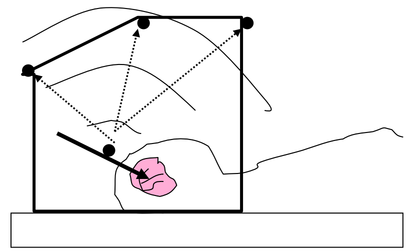
- Advantages
  - Cheap, unobtrusive
  - multiple rigid bodies



Ultrasound

- "Clickers"+microphones
- time delays give distances
- multiple distances give pos.

- Advantages
  - Cheap, unobtrusive
  - multiple rigid bodies
- Drawbacks
  - Accuracy drifts (e.g., temperature)
  - Lack of self-evident warning

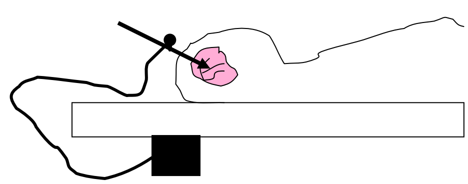


Electromagnetic

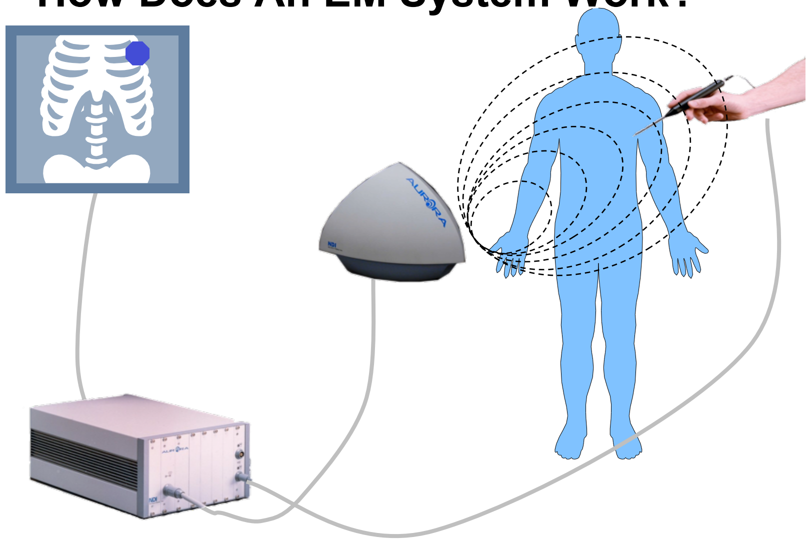
- Originally developed for fighter pilot head tracking
- Reasonably accurate 6 dof
- E.g., Polhemus, Ascension, NDI Aurora

- Advantages

- Drawbacks



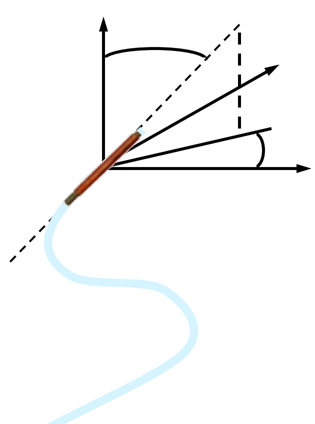
How Does An EM System Work?



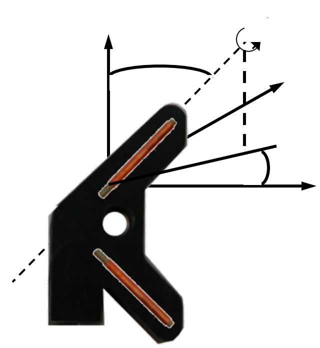
Credit: Paul McDonald, NDI

How a Magnetic System Works

5D Sensor



6D Reference



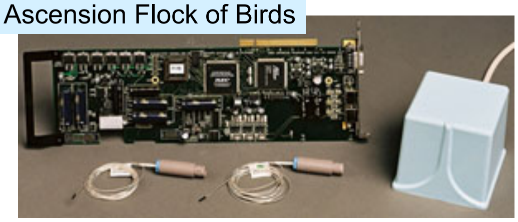
Credit: Paul McDonald, NDI

Current Electromagnetic Products

NDI Aurora

SNT Axiem

Ascension Flock of Birds



Polhemus Patriot

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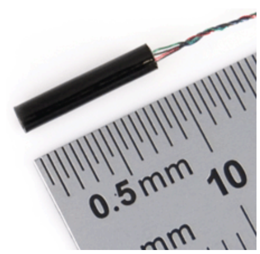
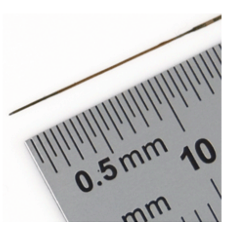
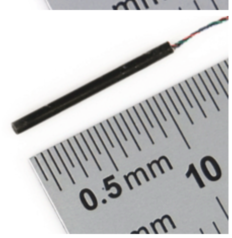
Example: NDI Aurora™

Transmitter | **5 DOF Sensors** | **6 DOF Sensors**







http://www.ndigital.com/medical/aurora-techspecs.php

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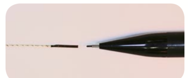
Example: ATI medSAFE™ (Sensors)

Sensor options:

Model 90 6DOF Sensor		**Model 90 6DOF Sensor** • Sensor OD = 0.9 mm • Sensor Length = 7.25 mm • Cable OD = 0.6 mm • Cable length = 6.6 ft. (2.0 m)
Model 130 6DOF Sensor		**Model 130 6DOF Sensor** • Sensor OD = 1.5 mm • Sensor Length = 7.6 mm • Cable OD = 1.2 mm • Cable length = 6.6 ft. (2.0 m)
Model 180 6DOF Sensor		**Model 180 6DOF Sensor** • Sensor OD = 2 mm • Sensor Length = 9.9 mm • Cable OD = 1.2 mm • Cable length = 6.6 ft. (2.0 m)
Model 800 6DOF Sensor		**Model 800 6DOF Sensor** • Sensor OD = 7.9 mm • Sensor Length = 19.8 mm • Cable OD = 3.8 mm • Cable length = 6.6 ft. (2.0 m)

http://www.ascension-tech.com/medical/medSAFE.php

Example: ATI medSAFE™ (Transmitters)

Transmitter options:

Short-Range Transmitter		**Set-Up & Use:** 6.3 cm (2.5 inches) x 4.6 cm (1.8 inches) x 5.2 cm (2.1 inches). Transmitter weighs just 290 grams. It generates pulsed DC magnetic fields for high accuracy tracking in short-range applications. **Ranges:** • 46 cm for Model 800 Sensor; contact Ascension for performance of smaller sensors with this transmitter.
Mid-Range Transmitter		**Set-Up & Use:** 9.6 cm (3.8 inches) cube that generates pulsed DC magnetic fields for high accuracy tracking over medium ranges. **Ranges:** • 36 cm for Model 90 Sensor • 46 cm for Model 130 Sensor • 58 cm for Model 180 Sensor • 78 cm for Model 800 Sensor
Flat Transmitter		**Set-Up & Use:** 56 cm (22 inches) x 56 cm (22 inches) x 2.54 cm (1 inch). Flat transmitter is for unobtrusive placement beneath a patient. It generates a field above planar surface while negating any possible distortion of measurements by ferrous metal in an OR procedural table. **Ranges:** • 40 cm for Model 90 Sensor • 46 cm for Model 130 Sensor • 46 cm for Model 180 Sensor • 46 cm for Model 800 Sensor

http://www.ascension-tech.com/medical/medSAFE.php

Electromagnetic

Pros

- No line of sight required
- Tools can be populated with small sensors
- Generally less expensive than optical

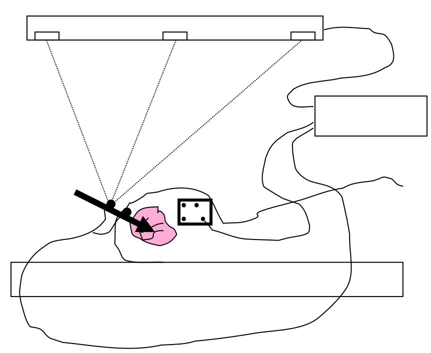
Cons

- Metal Interference
- Less stable than optical
- Smaller measurement volume
- Incapable of tracking more than 4 6DOF tools

Credit: Paul McDonald, NDI

Optical active

- Track LED markers
- Triangulate to locate 3D
- E.g.: Optotrak, Pixsys
- Current “gold standard”
- Advantages
- Disadvantages



A Comparison of Sonic Digitizers Versus Light-Emitting Diode-Based Localization 191

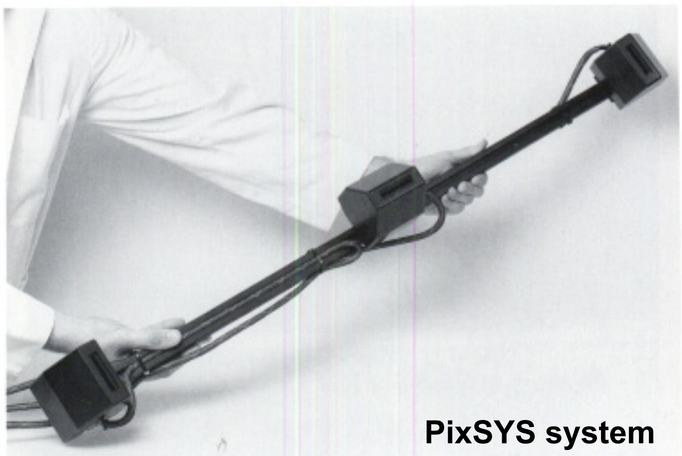
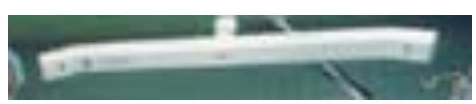


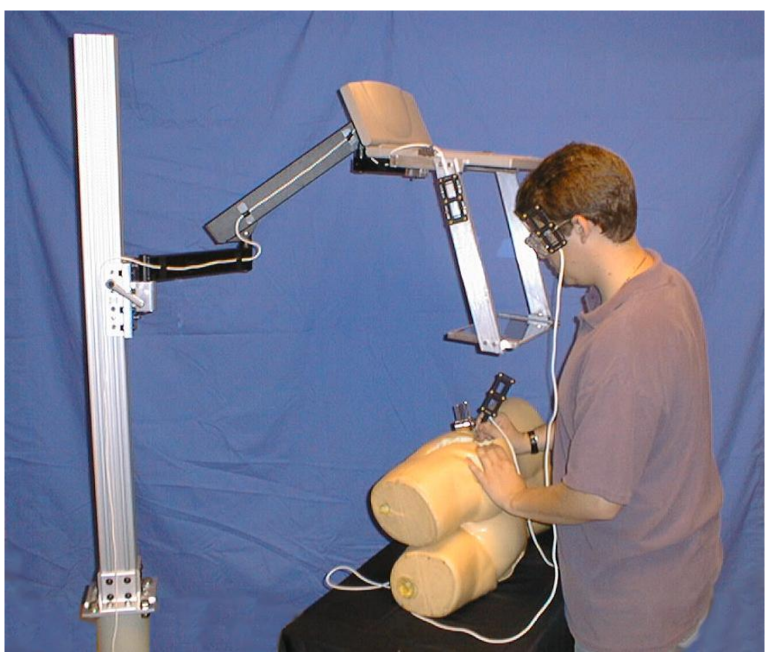
Figure 12. The optical camera system as implemented in the authors' system mounted on an aluminum extrusion.

Optical Active



Flashpoint

FIGURE 51.3 Optical position measurement for CAS.



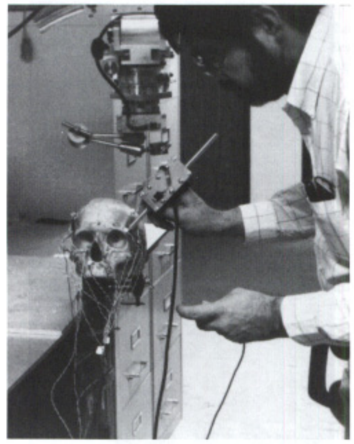
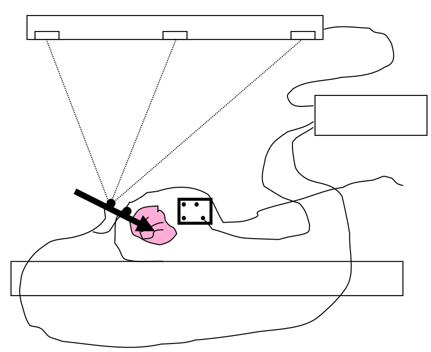


FIGURE 52.8 Locating landmarks on the skull. The position of the tip of the digitizer wand relative to the beacons on the wand has previously been calibrated. The positions of the beacons mounted to the skull are continuously monitored to provide a base coordinate system for the landmark location. Once the skull has been located, the positions of the beacons relative to the preoperative skull coordinate system may be computed.

Optical active

- Track LED markers
- Triangulate to locate 3D
- E.g.: Optotrak, Pixsys
- Current "gold standard"

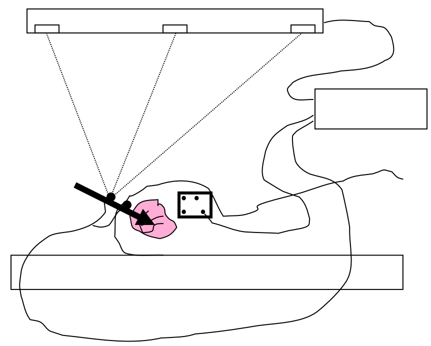
- Advantages



Optical active

- Track LED markers
- Triangulate to locate 3D
- E.g.: Optotrak, Pixsys
- Current “gold standard”

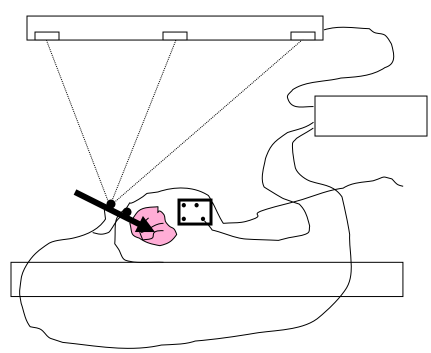
- Advantages
  - very accurate
  - multiple rigid bodies
  - versatile
  - reasonably fail-safe
- Disadvantages



Optical active

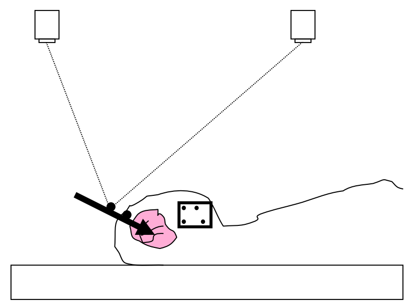
- Track LED markers
- Triangulate to locate 3D
- E.g.: Optotrak, Pixsys
- Current “gold standard”

- Advantages
  - very accurate
  - multiple rigid bodies
  - versatile
  - reasonably fail-safe
- Disadvantages
  - line-of-sight restrictions
  - large, expensive



Optical passive

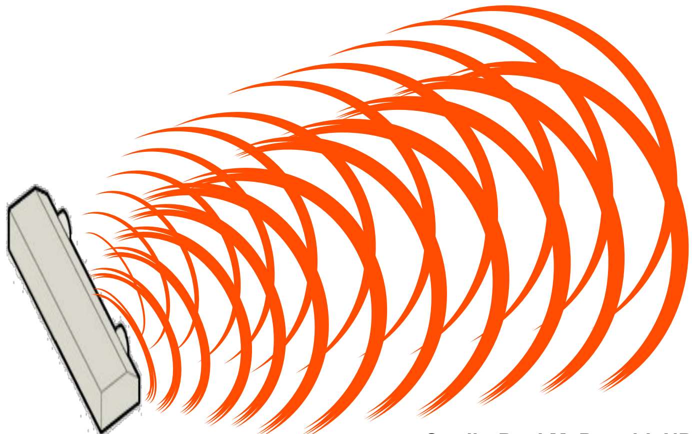
- Triangulate markers in standard video images or specialized IR cameras
- E.g.,
  - Heilbrun, Colchester, Mathelin, …
  - Polaris, Claron



Commercial Example (Reflective Markers): NDI Polaris

How does the Polaris system work?

The illuminators flood the area with infrared light



Credit: Paul McDonald, NDI

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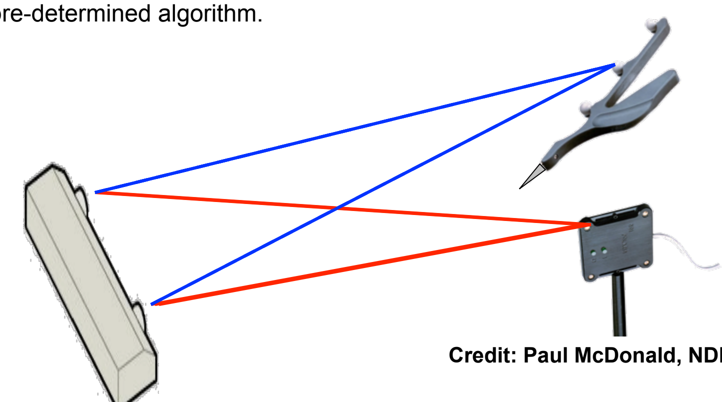
How does the Polaris system work?

The infrared light is reflected back to the Position Sensor by the passive markers, while active markers emit infrared light.

By calculating the position of each individual marker on a tool, the System is able to determine the exact location of the tip of the tool using a pre-determined algorithm.



Credit: Paul McDonald, NDI

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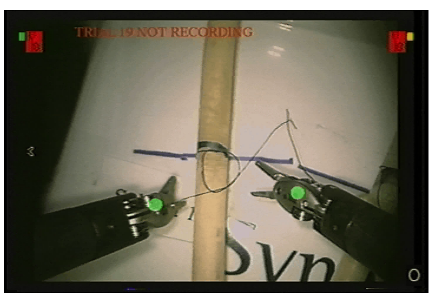
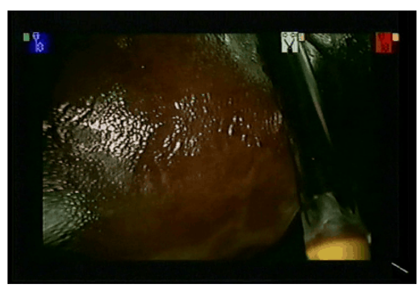
Commercial Example (Ordinary Video): Claron Technology

http://www.clarontech.com

JHU research examples: tool tracking

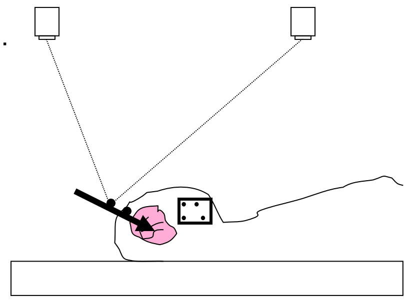




Track video of tools in mono or stereo images

Optical passive

- Triangulate markers in standard video images or specialized IR cameras
- E.g.,
  - Heilbrun, Colchester, Mathelin, …
  - Polaris, Claron
- Advantages
  - Inherent alignment for overlay
  - Same method thru microscope
  - Standard components
  - Fairly fail-safe
- Drawbacks
  - Lots more computing needed (but special hardware possible)
  - Line-of-sight
  - Video resolution



Optical Summary

Pros

- Industry Standard
- Well known and defined performance characteristics
- Ability to track large multiple of tools simultaneously
- Accuracy typically below 0.35 mm RMS
- Large measurement volume
- Variety of targets can be affixed to the tool (IRED,sphere)
- Video self alignment [rht]

Cons

- Line-of-sight required
- Extraneous IR (sunlight)
- Rigid body tracking is most accurate, unable to track flexible devices
- Historically more costly when compared to other technologies
- Larger tools

Credit: Paul McDonald, NDI