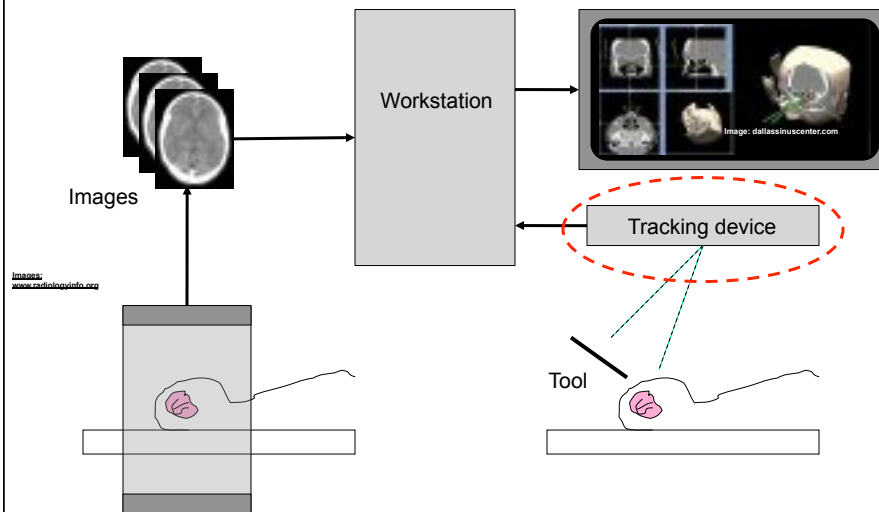


3D Localizers for Surgical Navigation 600.445

Russell H. Taylor



Surgical Navigation Systems



www.medicalimaging.org



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

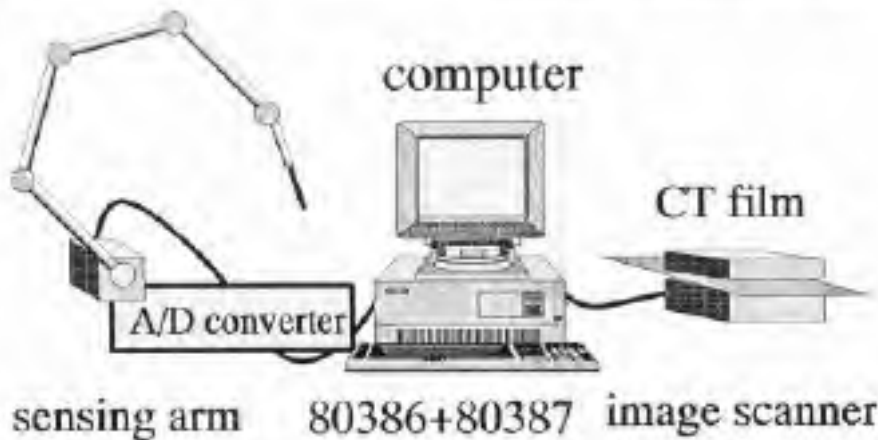
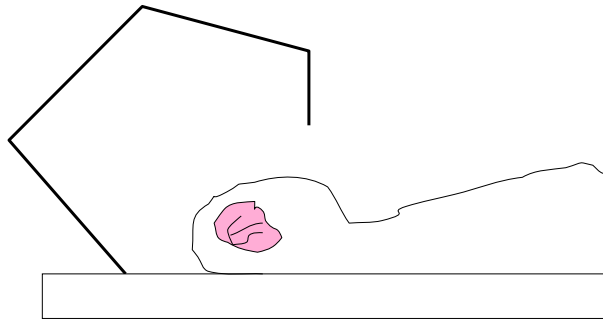


Figure 1. A schematic representation of the neurosurgical system. It consists of a microprocessor and a multi-articulated arm structure.





Figure 2. Photograph of the neuronavigator. The computer station is located in the console area on the left. The viewing arm is secured to the Mayfield skull clamp. Six CT slices are displayed on the computer screen. The cross markers display the location of the navigators tip.

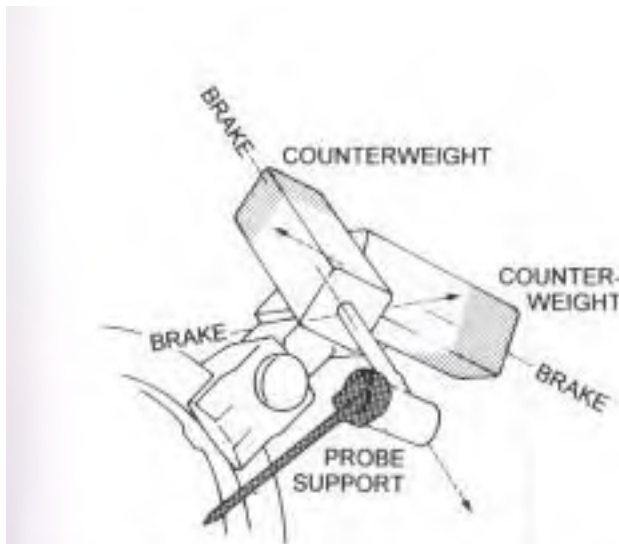


FIGURE 23.3 Mechanical principle of ET-01.





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

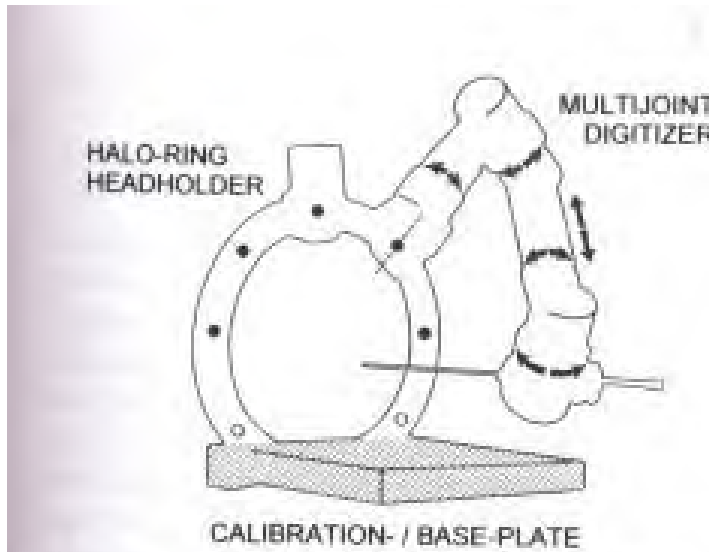


FIGURE 23.7 Four and one-half degrees of freedom in ET-02.





Figure 23.6: Digitizer of the second generation with video microscope and docked video camera. (Center bottom) Control console.

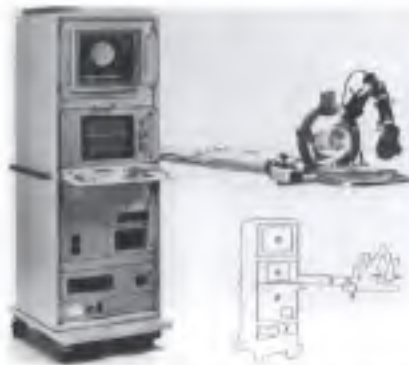


Figure 23.8: Overview of the ET-02 system: (1) mounting arm; (2) joystick; (3) control console; (4) industrial computer; (5) data monitor; (6) graphics monitor; (7) floppy drive.

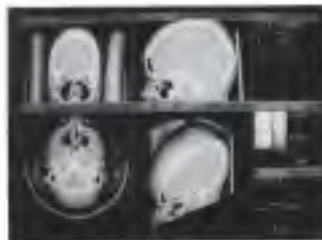


Figure 31.1: Image display on the CAS monitor screen.

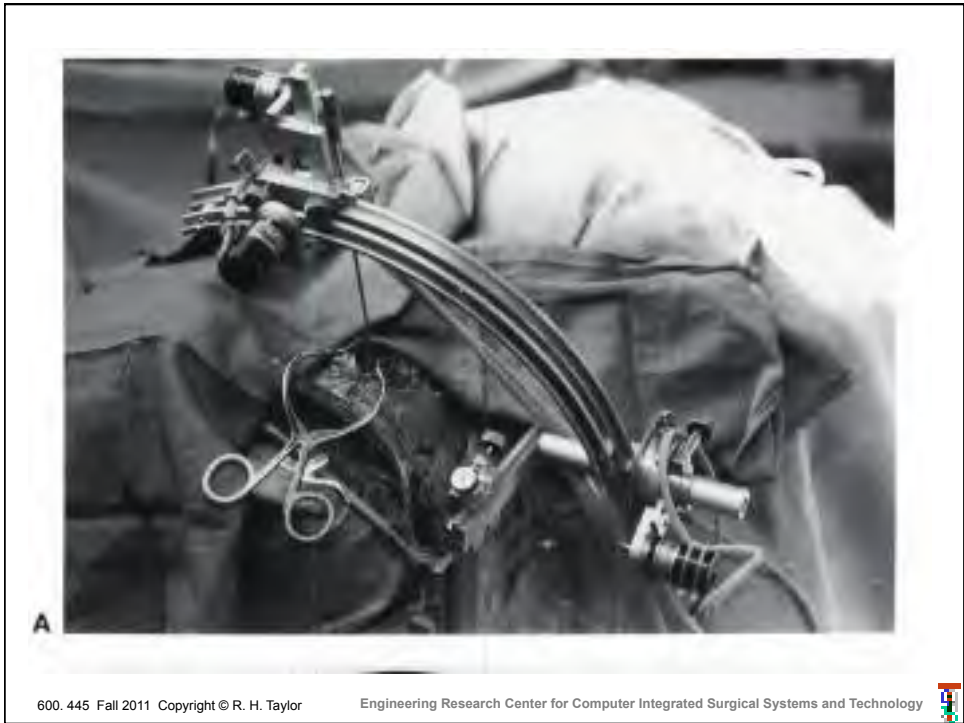
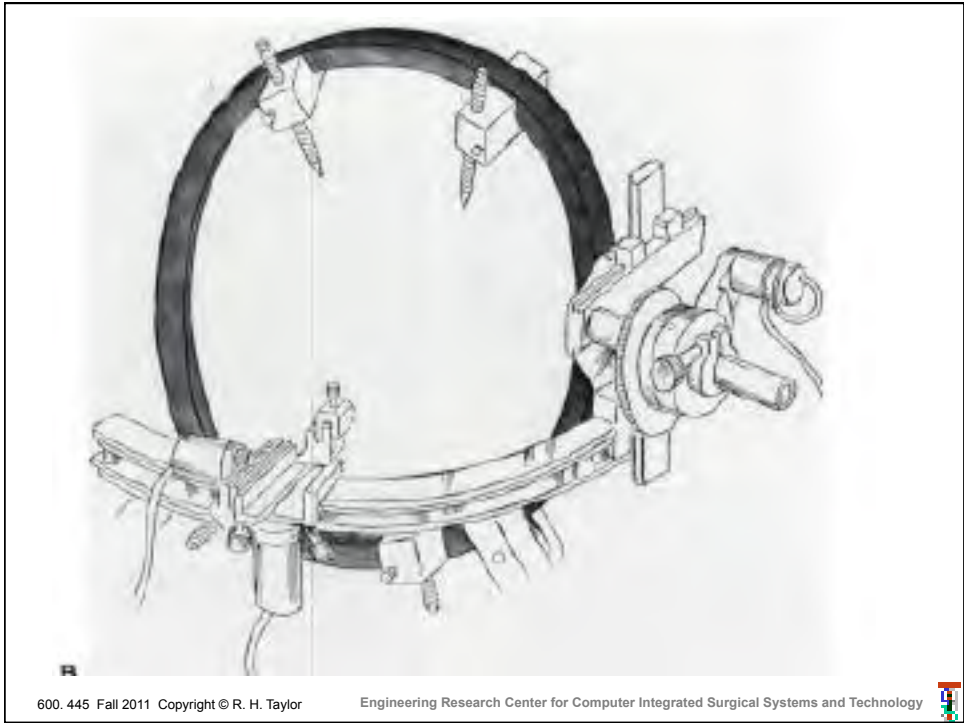
Therefore, we developed an appropriate mounting device which has 6 degrees of freedom [2, 3]. Digital instrument encoder have been applied for each angle measurement. The probe signals of the six rotary encoders are evaluated by 6-to-10 converter. A dedicated IBM PC microcomputer calculates the position of the measuring probe from the measured angles and the given arm lengths. The system was developed with 3D imaging (figure 31.1).

A third generation of mechanical system was designed to achieve better performance handling [4] (figure 31.2). Unbalanced arm elements allow for easy movements in every position. The IBM PC was connected to the PC-AT.



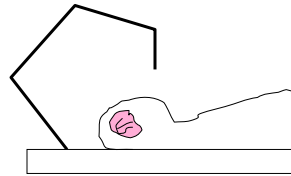
Figure 31.2: The hardware device for CAS with three-dimensional mounting arm coordinate digitizer.





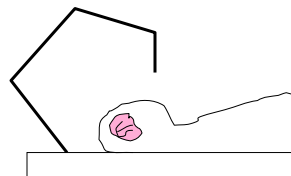
Passive mechanical linkages

- Encoders & linkage
- Advantages



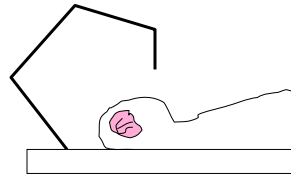
Passive mechanical linkages

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

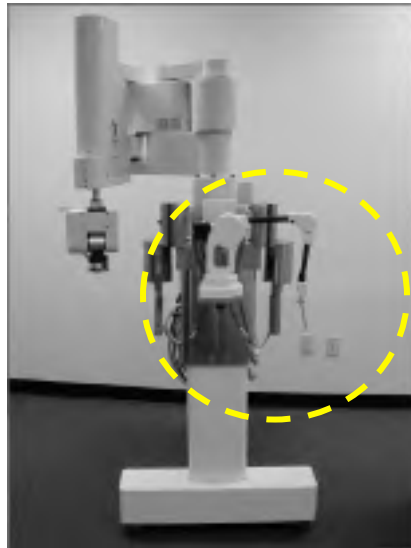


Passive mechanical linkages

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

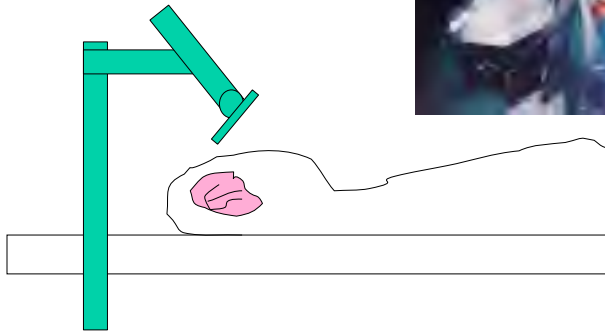


Some commercially used examples



Active mechanical linkages

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



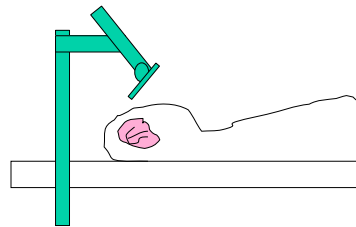
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Active mechanical linkages

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



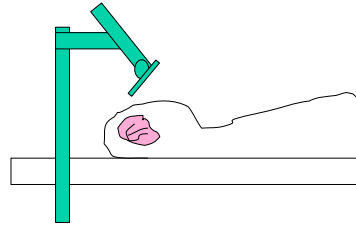
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Active mechanical linkages

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



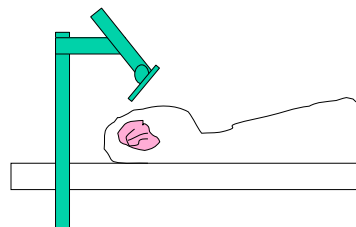
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Active mechanical linkages

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



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Ultrasound

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

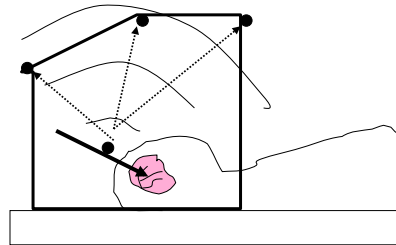


FIGURE 21.3 First sonic digital system overview. Graphic computer (left), hand-holder, sonic system (middle), SAC device, measuring computer (right).

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 system number: ET-05



FIGURE 21.4 SPKS with writer panel (top), hand-holder with detachable calibration frame, and supported targeting instrument (below left).





Figure 4. Sonic forceps, with wires directly attached to the handles since the designs involved precluded the use of a conventional connector.



Figure 5. Sonic emitter ring, which attaches to the DMT head ring by the standard DMT head/scan disk system; connectors can be placed on four points around the ring, allowing its use for posterior-based craniotomies.

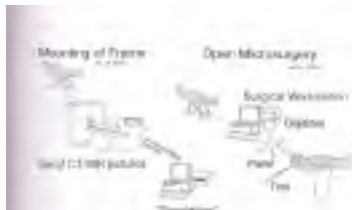


Figure 23.11. Sonic microscopery. Data acquisition and operating procedure.

Three microphones was drilled with the ring on the same line, immediately after image data acquisition, or in a separate second procedure (see figure 23.11). The system was initialized with a calibration panel containing microscopery, which were inserted sequentially in 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 on base ring (two matrix operation) and then calculates the spatial relationship with the microscopery panel (second matrix operation). The position of the targeting tool (see in line systems) relative to the panel is determined solely in a third matrix operation.

The effect of interfering external 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 recording cycle, a reference signal was emitted by the reference emitter and received the panel microphones approximately 60 cm away from known time interval. Deviations (e.g., owing to temperature shifts) were taken into account auto-



Figure 23.12. Reformed shaped standard mounting tool.

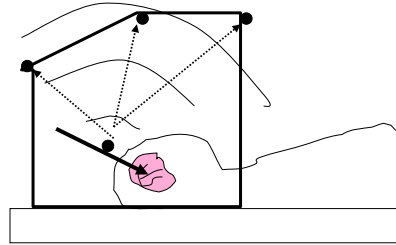


Figure 23.13. Measurement platform with four microphones.



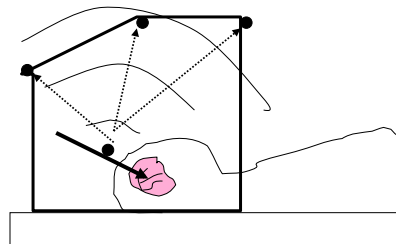
Ultrasound

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



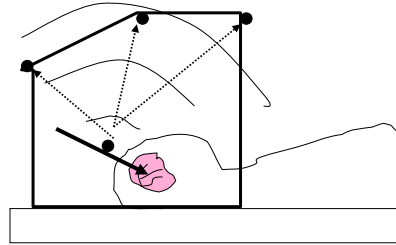
Ultrasound

- “Clickers”+microphones
- time delays give distances
- multiple distances give pos.
- Advantages
 - Cheap, unobtrusive
 - multiple rigid bodies



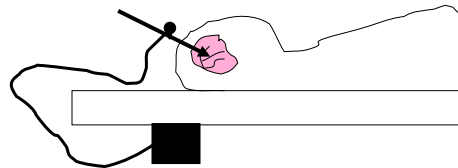
Ultrasound

- “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

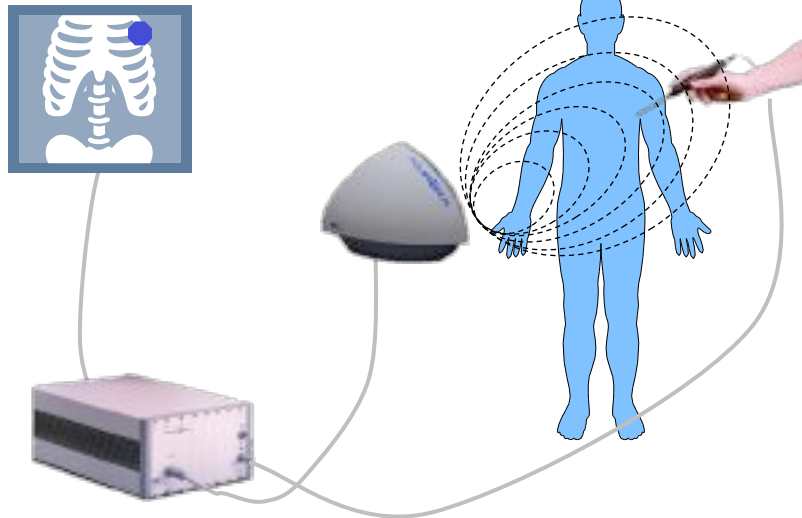


Electromagnetic

- 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

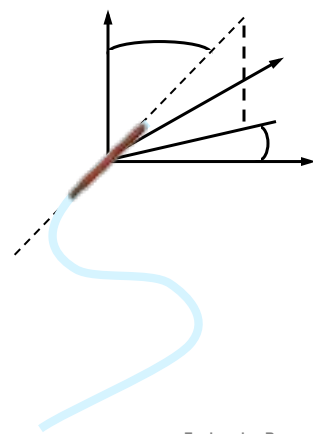
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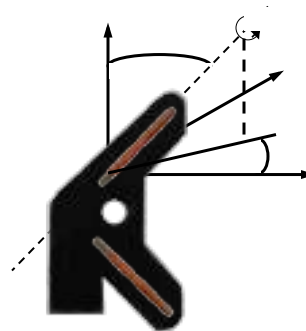


How a Magnetic System Works

5D Sensor



6D Reference



Credit: Paul McDonald, NDI

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Current Electromagnetic Products

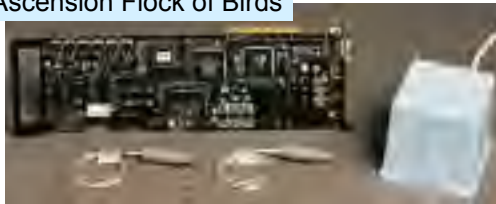


NDI Aurora



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		<p>Model 90 6DOF Sensor</p> <ul style="list-style-type: none"> • Sensor OD = 5.8 mm • Sensor Length = 7.25 mm • Cable OD = 8.6 mm • Cable length = 4.4 ft. (1.3 m)
Model 130 6DOF Sensor		<p>Model 130 6DOF Sensor</p> <ul style="list-style-type: none"> • Sensor OD = 1.5 mm • Sensor Length = 7.5 mm • Cable OD = 1.2 mm • Cable length = 4.6 ft. (1.4 m)
Model 180 6DOF Sensor		<p>Model 180 6DOF Sensor</p> <ul style="list-style-type: none"> • Sensor OD = 2 mm • Sensor Length = 9.9 mm • Cable OD = 1.2 mm • Cable length = 3.5 ft. (1.1 m)
Model 800 6DOF Sensor		<p>Model 800 6DOF Sensor</p> <ul style="list-style-type: none"> • Sensor OD = 7.8 mm • Sensor Length = 19.8 mm • Cable OD = 3.8 mm • Cable length = 3.5 ft. (1.1 m)

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

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Example: ATI medSAFE™ (Transmitters)

Transmitter options:

Short-Range Transmitter		<p>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 293 grams. It generates pulsed DC magnetic fields for high accuracy tracking in short-range applications.</p> <p>Ranges:</p> <ul style="list-style-type: none"> • 46 cm for Model 800 Sensor; contact Ascension for performance of smaller sensors with this transmitter.
Mid-Range Transmitter		<p>Set-Up & Use: 9.8 cm (3.8 inches) diameter; generates pulsed DC magnetic fields for high accuracy tracking over medium ranges.</p> <p>Ranges:</p> <ul style="list-style-type: none"> • 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		<p>Set-Up & Use: 56 cm (22 inches) x 56 cm (22 inches) x 2.54 cm (1 inch). Flat transmitter is for unobstructive placement beneath a patient. It generates a field above planar surfaces while negating any possible distortion of measurements by ferrous metal in an OR procedural table.</p> <p>Ranges:</p> <ul style="list-style-type: none"> • 40 cm for Model 90 Sensor • 56 cm for Model 130 Sensor • 66 cm for Model 180 Sensor • 86 cm for Model 800 Sensor

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

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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

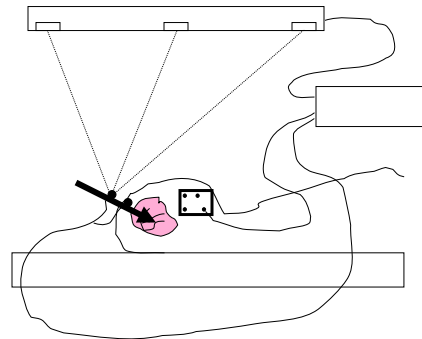
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Optical active

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



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



Optical Active





FIGURE 51.3 Optical position measurement for CAS.

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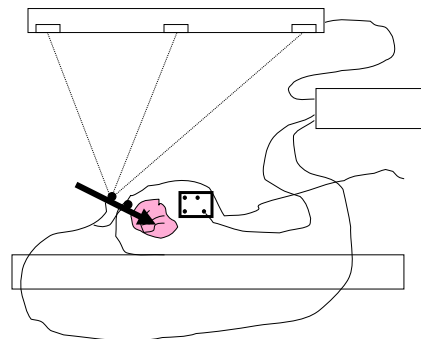


FIGURE 10.11 Tracking headsets on the skull. The position of the tip of the distal end of the handpiece on the skull has previously been calibrated. The positions of the beacons mounted in the skull are rigorously maintained to provide a base coordinate system for the handpiece location. Once the skull has been located, the position of the beacons relative to the preoperative skull coordinate system may be compared.



Optical active

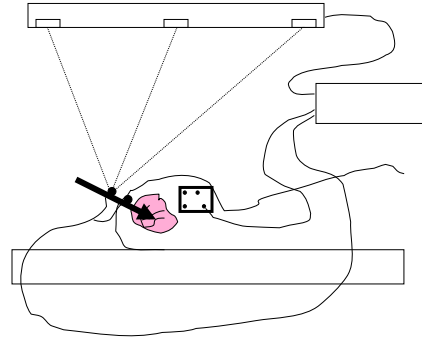
- Track LED markers
- Triangulate to locate 3D
- E.g.: Optotrak, Pixsys
- Current “gold standard”
- Advantages



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



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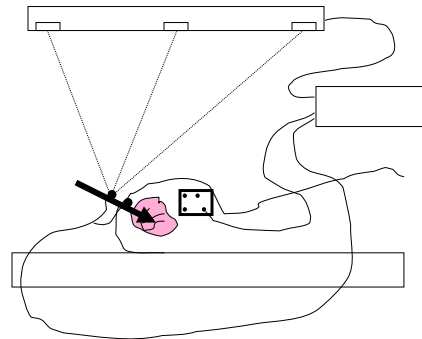
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Optical active

- 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



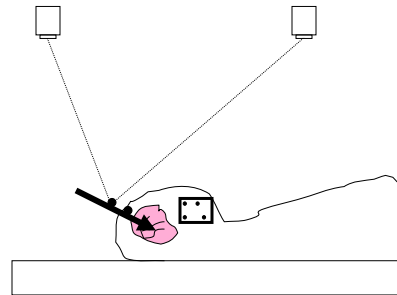
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Optical passive

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



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Commercial Example (Reflective Markers): NDI Polaris



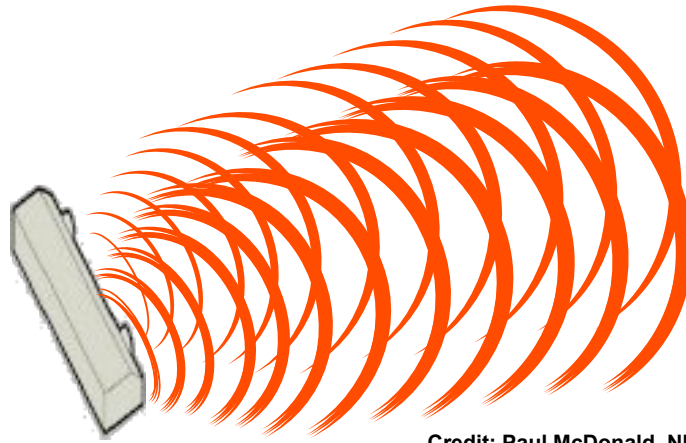
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How does the Polaris system work?

The illuminators flood the area with infrared light



Credit: Paul McDonald, NDI

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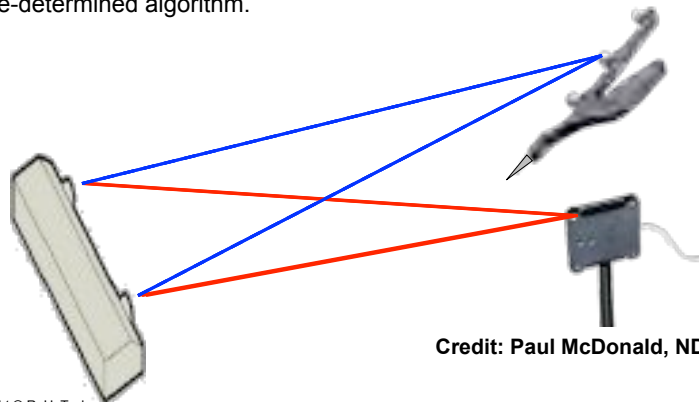
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How does the Polaris system work?

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>

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JHU research examples: tool tracking



Track video of tools in
mono or stereo images



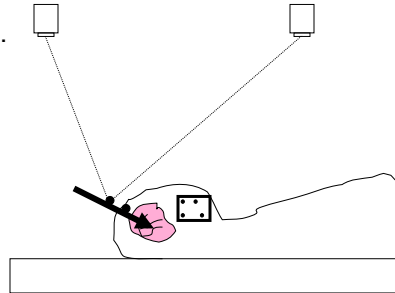
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Optical passive

- 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

