3D Localizers for Surgical Navigation
600.445

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Traditional Stereotactic Systems

Cosman-Roberts-Wells (CRW) head frame
CT Image
Brown-Roberts-Wells (BRW) head frame
### Surgical Navigation Systems

![Diagram of 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
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 head clamp, i.e., CT slices are displayed on the computer screen. Two crosshair markers display the location of the navigational 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 vertical microscope and clocked video camera. (Cursor portion) Central console.

Figure 23.8 Overview of the ET-02 system: (1) measuring arm; (2) mirror; (3) control console; (4) industrial computer; (5) data monitor; (6) graphics monitor; (7) 8-in. floppy drive.
Therefore, we developed an appropriate measuring device which has 6 degrees of freedom [2, 1]. Digital incremental encoders have been applied for shaft angle measurement. The pulse signals of the six rotary encoders are evaluated by 16-bit counters. A dedicated 8086 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 5). A third generation of mechanical systems was developed to achieve better intraoperative handling [3] (figure 52). Counterbalanced arm elements allow for easy movements in every position. The 8086 was replaced by a P5706.
Passive mechanical linkages

- Encoders & linkage
- Advantages
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, REMS
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 MICROSTEREOSCOPY:** ET-03

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

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Figure 6. sonic fuses, with easy density adapted to the emitters since the echoes involved precluded the use of a mistuneded connector.

Figure 9. sonic emitter ring, which connects to the IBW head ring by the standard IBW ballCam lock system. emitters can be placed at four points around the ring, allowing for four-center point source.

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Engineering Research Center for Computer Integrated Surgical Systems and Technology
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

- 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
Example: NDI Aurora™

Transmitter

5 DOF Sensors

6 DOF Sensors


Example: ATI medSAFE™ (Sensors)

Sensor options:

Model 90 6DOF Sensor
- Sensor OD = 0.7 mm
- Sensor Length = 7.25 mm
- Cable OD = 5.6 mm
- Cable length = 6.6 ft. (2.0 m)

Model 130 6DOF Sensor
- Sensor OD = 1.5 mm
- Sensor Length = 7.5 mm
- Cable OD = 1.2 mm
- Cable length = 6.6 ft. (2.0 m)

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
- Sensor OD = 7.9 mm
- Sensor Length = 19.8 mm
- Cable OD = 3.0 mm
- Cable length = 6.6 ft. (2.0 m)

http://www.ascension-tech.com/medical/medSAFE.php
Example: ATI medSAFE™ (Transmitters)

**Transmitter options:**

<table>
<thead>
<tr>
<th>Transmitter Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-Range Transmitter</td>
<td>Set-Up &amp; Use: 6.3 cm (2.5 inches) x 4.4 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: 66 cm for Model 800 Sensor; contact Ascension for performance of smaller sensors with this transmitter.</td>
</tr>
<tr>
<td>Mid-Range Transmitter</td>
<td>Set-Up &amp; Use: 9.6 cm (3.8 inches) cube that generates pulsed DC magnetic fields for high accuracy tracking over medium ranges. Ranges: 58 cm for Model 180 Sensor.</td>
</tr>
<tr>
<td>Flat Transmitter</td>
<td>Set-Up &amp; Use: 56 cm (22 inches) x 56 cm (22 inches) x 2.54 cm (1 inch). Flat transmitter is for isoburusive 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: 46 cm for Model 800 Sensor.</td>
</tr>
</tbody>
</table>

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 a few 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

PixSYS system

Figure 12: The optical camera system as implemented in the authors' system mounted on an aluminum extrusion.
Optical Active
Figure 5.28: Locating landmarks on the skull. The position of the tip of the digitizer wand relative to the bony landmarks on the skull has previously been calibrated. The positions of the landmarks relative to the skull are continuously monitored to provide a base coordinate system for the bony landmark location. Once the skull has been located, the positions of the landmarks 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

- 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
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

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