Visual Medicine: Image-guided Surgery and Medical Mixed Reality

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Outline

Advanced Topics in Visual Medicine

- Visual Analysis of Perfusion Data
- **Image-guided Surgery and Medical Mixed Reality**
- Diffusion Tensor Imaging and Visualization
- Model-based Vessel Visualization
- Fast Tagged Multi-Res Volume Rendering
- CT Reconstruction and Functional Imaging
- Soft-Tissue Simulation

Discussion

Image-guided Surgery (1)

- **Image-guided Surgery (IGS)**
- **Tracks instruments** during intervention
- **Representation** of instruments in patient dataset
- Requires tracking technique
  - Magnetic tracking
    - **Interference** with metallic objects
    - Small magnetic field
    - Complex setup
    + Does **not require** line-of-sight
    + Can track (invisible) **tip of instrument**

[Image: NDI Aurora]

Image-guided Surgery (1)

- **Tracks instruments** during intervention
- **Representation** of instruments in patient dataset
- Requires tracking technique
  - Magnetic tracking
  - Optical (infrared) tracking
    - Tracks only **end of instrument**
    - Requires **line-of-sight**
    + High accuracy
    + No (little) interference

[Image: NDI Polaris]

Image-guided Surgery (1)

- **Tracks instruments** during intervention
- **Representation** of instruments in patient dataset
- Requires tracking technique
  - Magnetic tracking
  - Optical (infrared) tracking
  - Video tracking
    - \- Low accuracy
    - \- Requires line-of-sight
    - \+ Simple setup

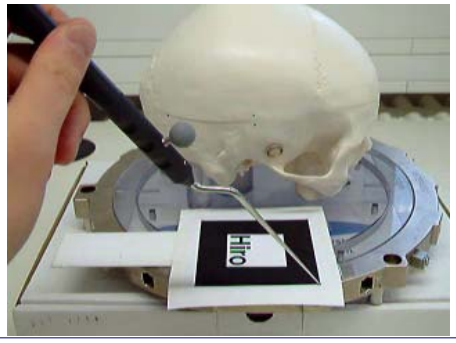


Image-guided Surgery (1)

- **Tracks instruments** during intervention
- **Representation** of instruments in patient dataset
- Requires tracking technique
  - Magnetic tracking
  - **Optical (infrared) tracking**
  - **Video-tracking**
- Requires **registration** of patient to dataset

Image-guided Surgery (2)

Registration:

- Computes **relationship** between patient (**OR coordinate system**) and image **dataset**
- Usually rigid transformation: Rotation, Translation
- Landmark-based (fiducial markers)
- Pointset-based (laser pointer, ICP)

Image-guided Surgery (3)

Landmark-based Registration with Fiducials

In maxillo-facial surgery, 2.4 screws, placed in asymmetrical positions, are used as fiducials

[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (4)

Landmark-based Registration with Fiducials

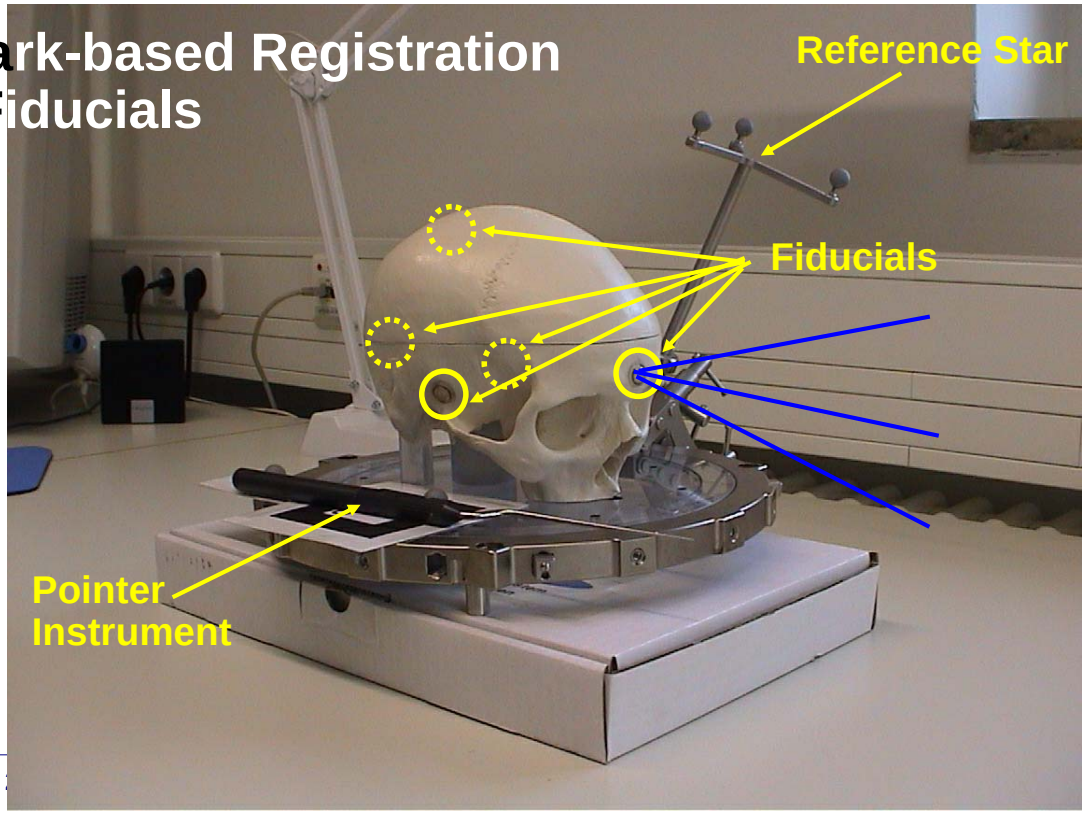
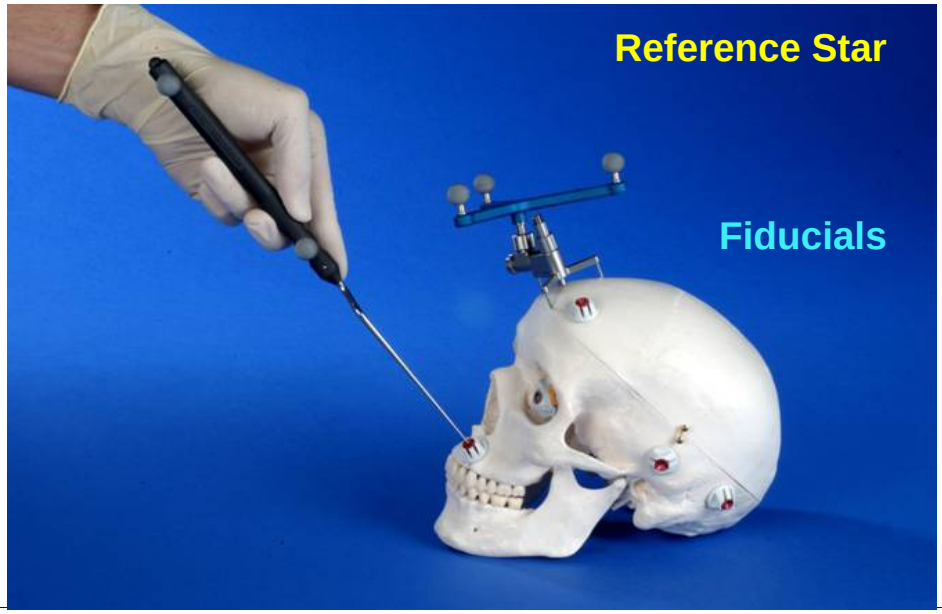


Image-guided Surgery (5)

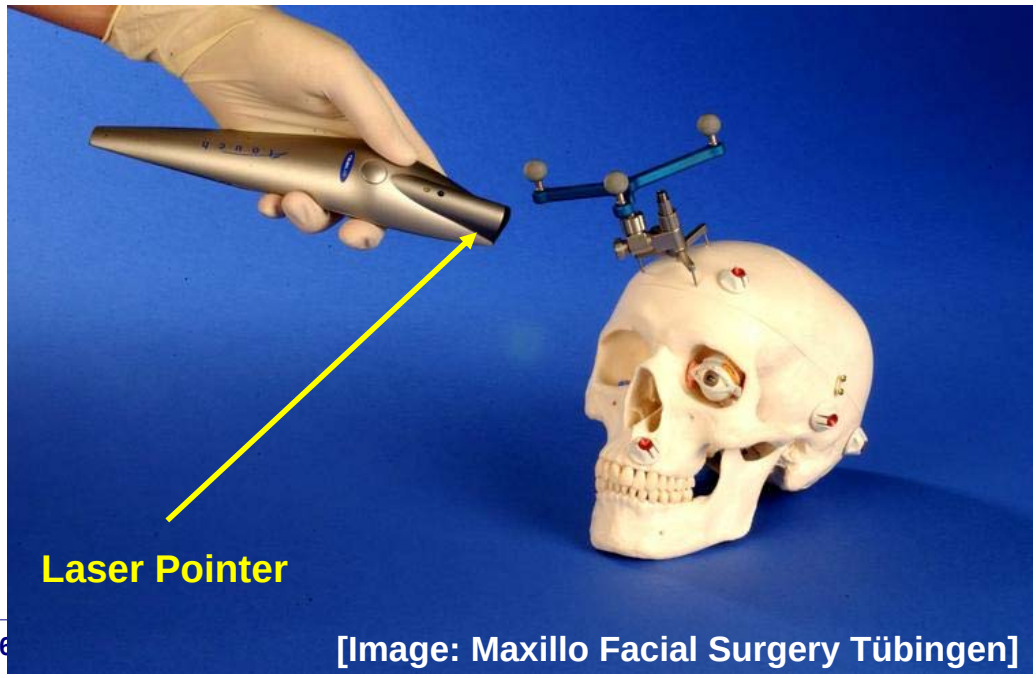
Landmark-based Registration with Fiducials



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (6)

Pointset-based Registration with Laser Pointer



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (7)

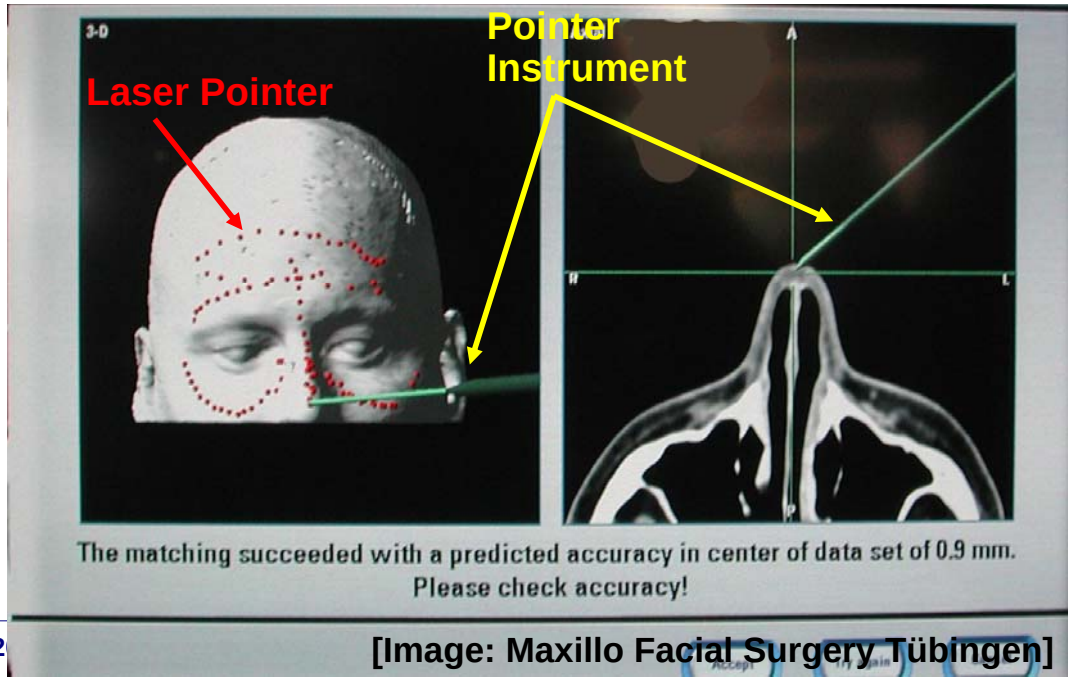
Pointset-based Registration with Laser Pointer

- Laser point is seen by infrared cameras
- Pointsets are measured
- Registration by ICP

 [Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (8)

Pointset-based Registration with Laser Pointer



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (9)

Optical (infrared) Tracking

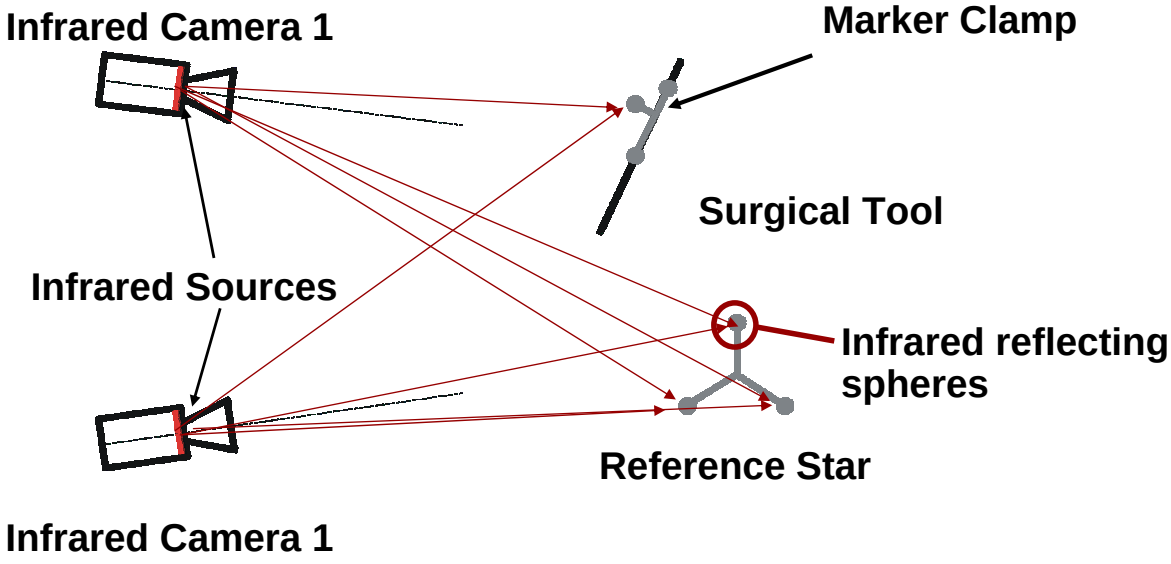


Image-guided Surgery (10)

Typical Image-based Navigation/Surgery (IGS)

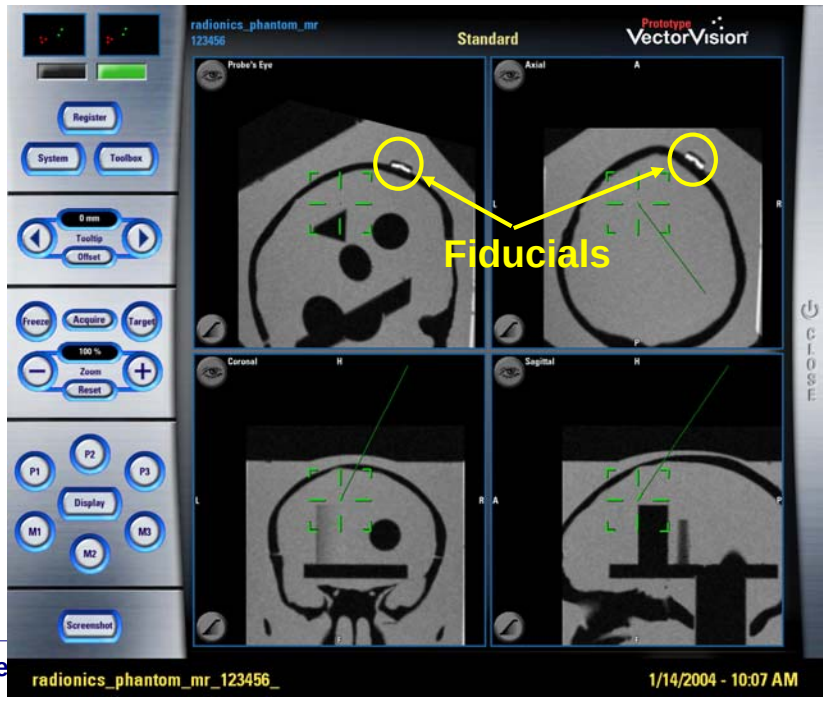


Image-guided Surgery (11)

Issues

- **Accuracy**: The better the registration, the better the accuracy is
- **Occlusion of markers**: tracking not possible
- **Visibility**: Only visible end of instruments is tracked (ie., minimally-invasive surgery)
- **Adaptiveness**: Marker clamp needs to be fixed to instrument

Image-guided Surgery (12)

Issues, cont'd

- **Tissue deformation**
  - IGS typically depends on preoperative data acquisition
  - Depending on target area, **significant deformations** may take place (ie., Brainshift)
  - Deformations occur **not uniformly** (may be small in target area)
  - Data is **not up-to-date**, or **intra-operative imaging** is required

Image-guided Surgery (13)

Example for Brainshift

- **Drilled hole** in skull: significant deformations
- **Ventricular system**: negligible deformations
- After **ventriculostomy**: (still minor) deformations

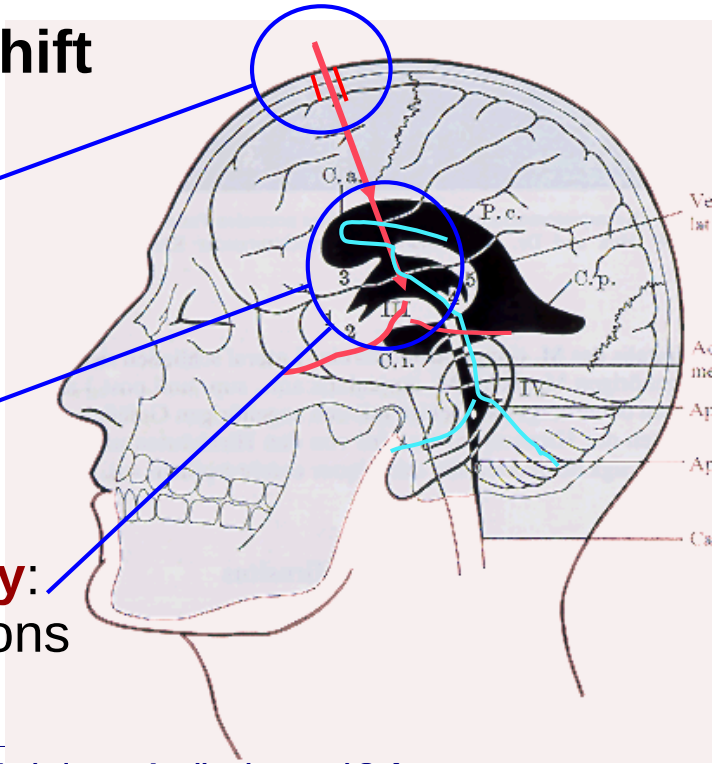


Image-guided Surgery (14)

Tissue Deformation

- Head: Can be **potentially controlled** (setup)
- Abdomen: **Very difficult** to control (permanent non-uniform deformations)
- Heart/Lungs: **Might be** controllable by heart/breathing **monitor** (periodic movement)

Intra-operative Imaging (1)

Possible with

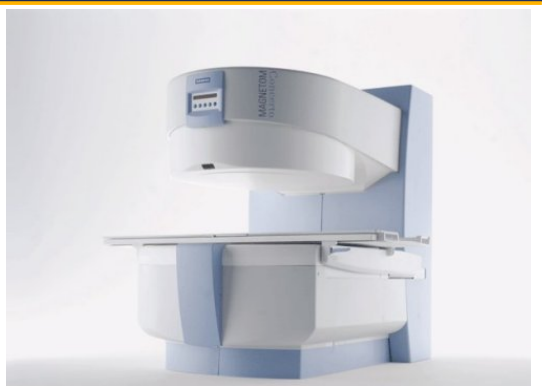
- MRI (OpenMR, intra-operative fullfield MR)
- X-rays (C-arm, intra-operative CT)
- Ultrasound
- Endoscopic scanners

Images need to be **registered** with patient and pre-operative acquired dataset
(ie., marker clamp is **fixed to ultrasound probe**)

Intra-operative Imaging (2)

OpenMR

- Allows direct, but limited access to patient
- Low field scanner (ie.,0.2T-0.5T): limited image quality
- Requires MR-suitable instruments and OR



[Image: Siemens Medical Solutions]

[Image: Brigham & Womens Hospital]

Intra-operative Imaging (3)

Intra-operative full-field MR (1.5T)

- Patient is moved on OR-table in and out of MR scanner
- Requires MR-suitable instruments and OR
- Expensive and complex system (requires shielded cabin)

Intra-operative Imaging (4)

Intra-operative full-field MR (1.5T)

[Images: BrainLAB]

Intra-operative Imaging (5)

C-Arm / intra-operative CT

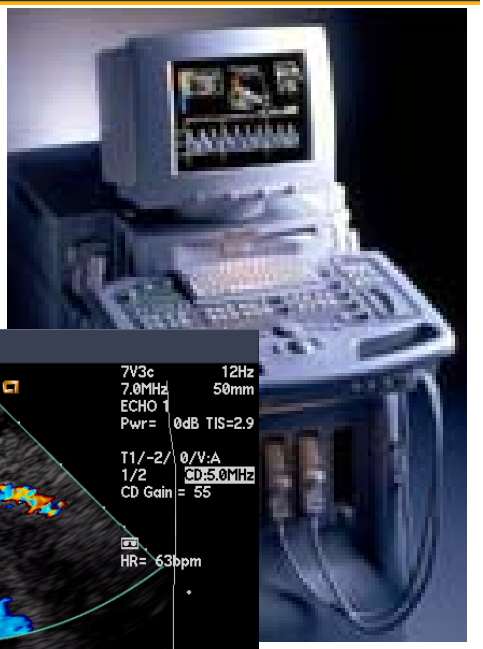
- X-ray images
- 2D (C-Arm)
- Lower quality as extra-operative scanning
- Radiation

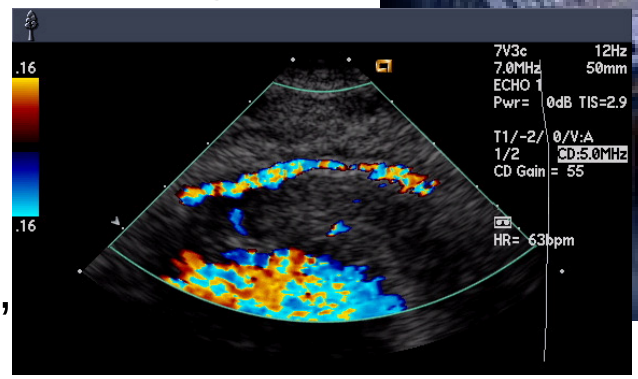
[Image: Philips Medical Systems]

Intra-operative Imaging (6)

Ultrasound

- Emits soundwaves and records echo
- Truly interactive scanning
- Very noisy
- Various modes
- Often used for abdomen, brain, heart





[Images: Siemens Medical Solutions]

Coronary Artery Bypass Graft

Intra-operative Imaging (7)

Endoscopic Scanners

- Introduced through endoscope to target area
- Laser scanner for geometric measurements
- Holographic scanners for volumetric measurements (depends on optical properties though)
- No (little) available devices, mostly research

Medical Mixed Reality (1)

Combines virtual and real world in a mixed reality (augmented reality)

- Tracking method
- Display method
  - Head-Mounted-Displays (HMDs):
    - Too cumbersome/bulky for surgery
    - Too limited perception and motion
  - Video see-through devices
  - Standard display (monitor) plus video camera

Medical Mixed Reality (2)

Combines virtual and real world in a mixed reality (augmented reality)

- Tracking method
- Display method
  - Head-Mounted-Displays
  - **Video see-through devices**
  - Standard display (monitor) plus video camera

[Image: MEDARPA]

Medical Mixed Reality (3)

- Real world viewing device needs to be tracked
- Fusion of real and virtual videostreams
- How to handle virtual objects behind the real objects (occlusion handling)

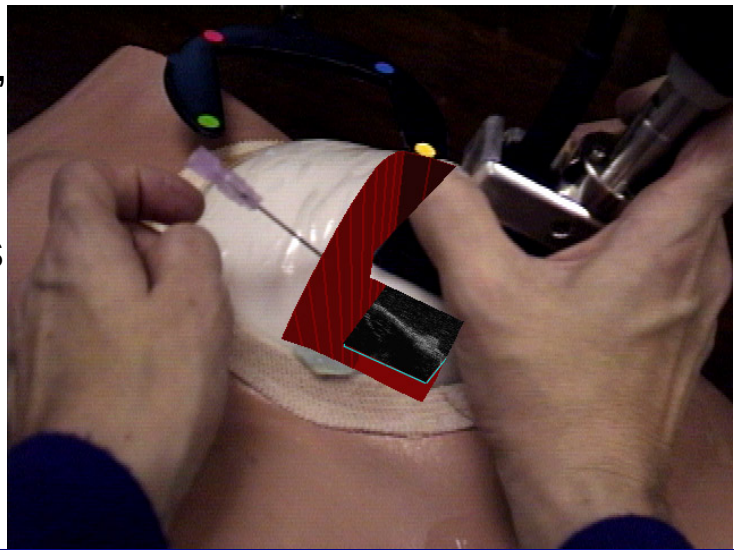
Medical Mixed Reality (4)

Various Medical Mixed Reality Projects

- **Needle biopsies with Ultrasound and HMD**

[Bajura et al., State et al., SIGGRAPH 1992/1996]

- Supporting visualization of organs, risk structures etc.

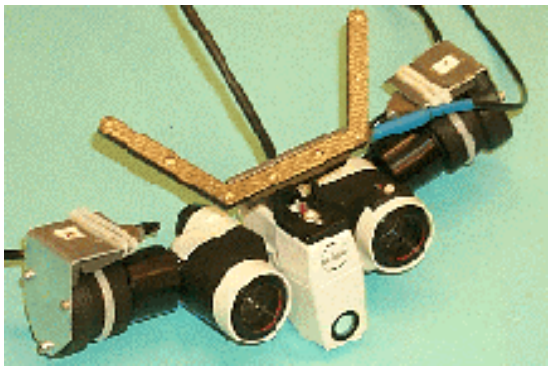


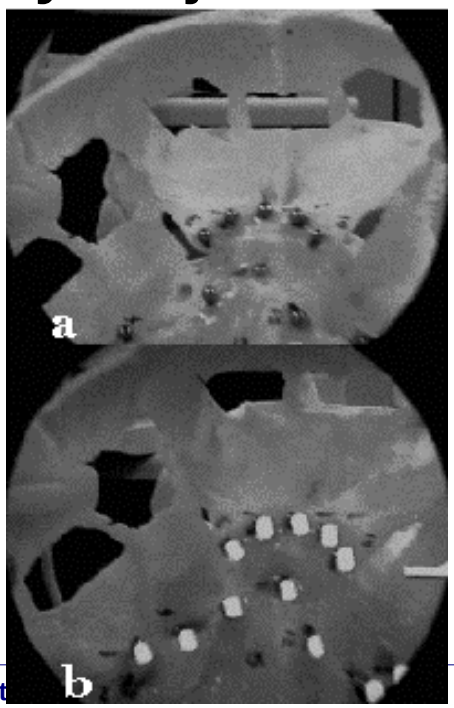
Medical Mixed Reality (5)

Various Medical Mixed Reality Projects

- **VarioscopeAR – Augmented Microscope**

[Birkfellner et al., ISAR 2001]

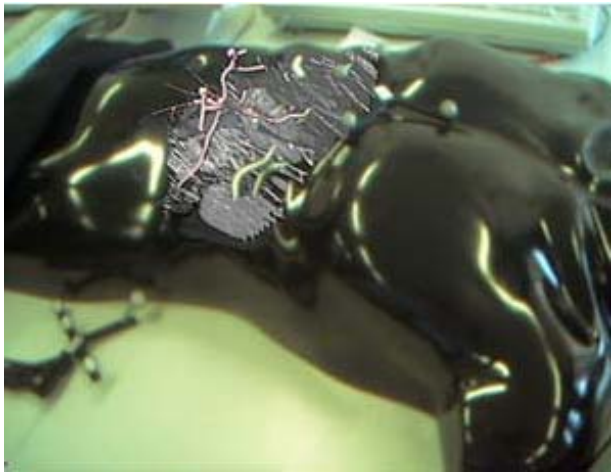


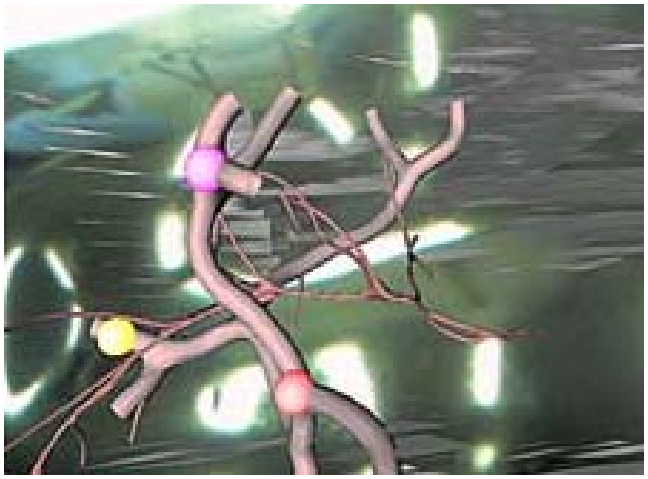


Medical Mixed Reality (6)

Various Medical Mixed Reality Projects

- **Liver Surgery** [Bornik et al. BVM 2003]:
  Supporting visualization of organs, risk structures etc.





Medical Mixed Reality (7)

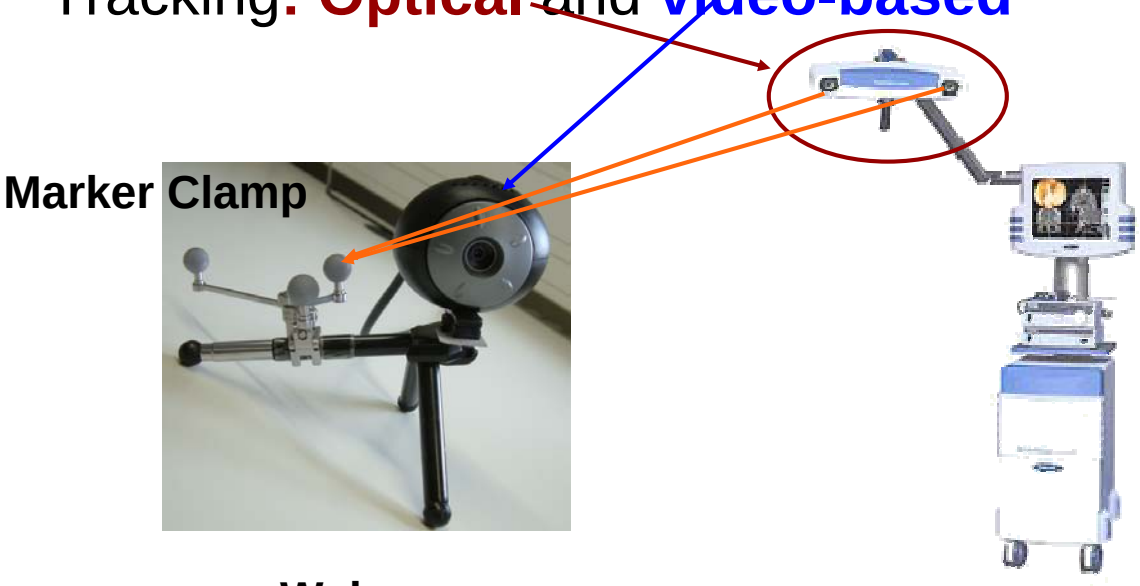
Various Medical Mixed Reality Projects

- **Mixed Endoscopic Reality** [Dey et al., MICCAI 2000]
- **Ultrasound and HMDs** [Sauer et al., ISAR 2001]
- **Minimally-invasive liver surgery** [Scheuering et al., Medical Imaging 2001]
- **MEDARPA** [Schwald et al., ISMAR 2002]
- **ARSys-Tricorder** [Goebbels, CURAC 2003]

[Image: MEDARPA]

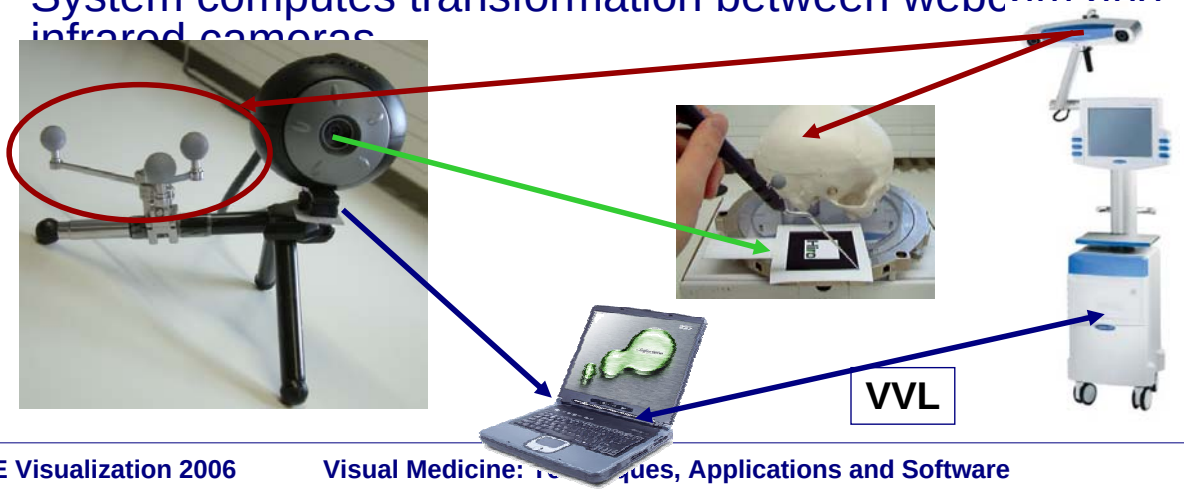
Medical Mixed Reality (8)

Tracking: **Optical** and **video-based**



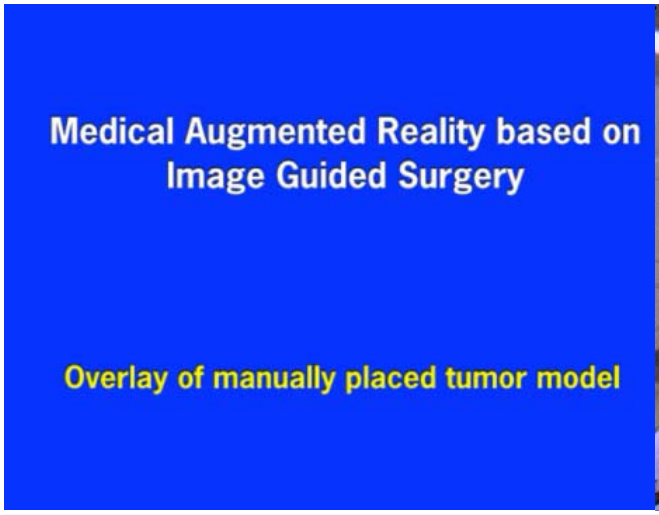
Medical Mixed Reality (9)

- Infrared cameras see patient (skull) and video marker
- Infrared cameras see marker clamp on webcam
- Webcam sees video marker (ARToolkit)
- System computes transformation between webcam and infrared cameras

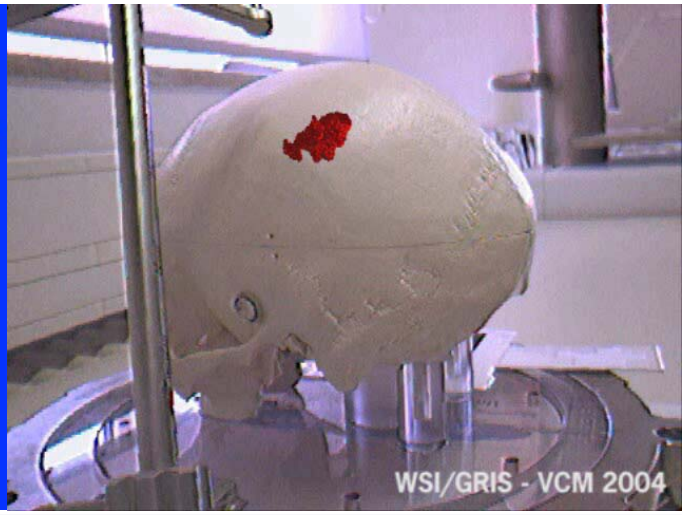


Medical Mixed Reality (10)

Camera is moving



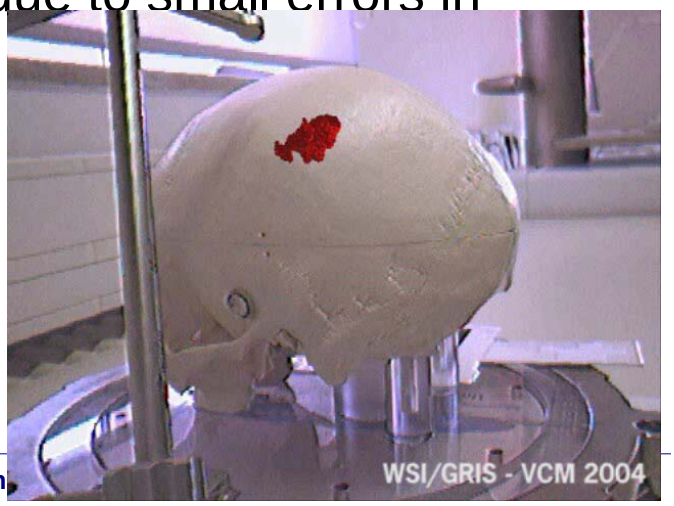
Object is moving



Medical Mixed Reality (11)

Issue

- High position accuracy,
  but **lower orientation accuracy**
  → visual vibrations due to small errors in orientation
- Occlusion



Medical Mixed Reality (12)

Occlusion Issue

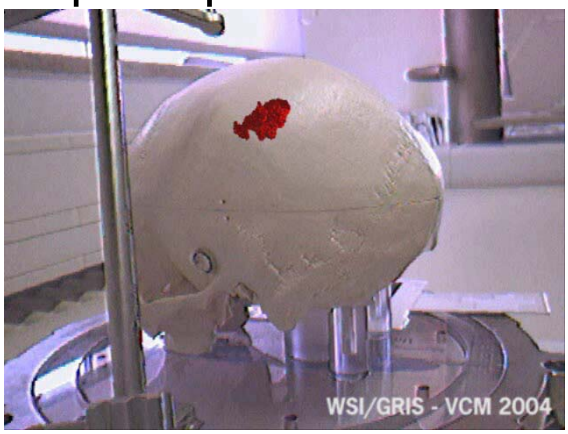
- Video stream **is 2D**, hence it does not contain depth information
- Virtual objects **are 3D** and maintain depth information
- Medical mixed **reality requires correct depth sorting** for depth perception

  → We need to recover depth information

Medical Mixed Reality (13)

Standard MMR

- Virtual objects are **painted over** video stream
- **Does not allow** correct depth perception
- Objects behind should be
  - **not painted** at all
  - **painted differently** (semi-transparent, etc.)



Medical Mixed Reality (14)

Recovery of 3D Depth Information

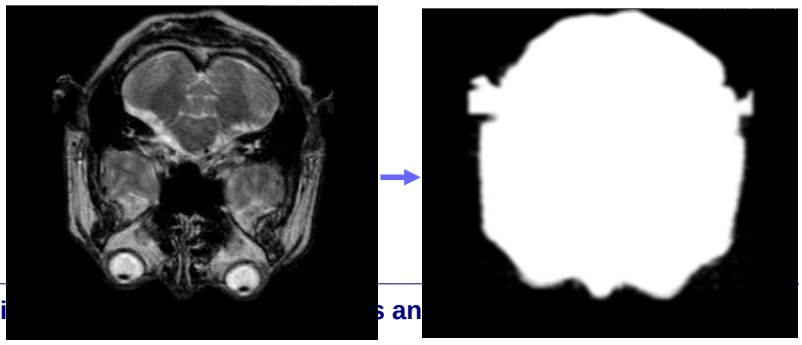
- Have **preoperative acquired** patient dataset
- **Extract phantom** geometry of patient
- **Render** phantom **into depth buffer** for depth sorting only
- But: Phantom is usually too complex for mandatory interactivity

  → **Simplify** phantom

Medical Mixed Reality (15)

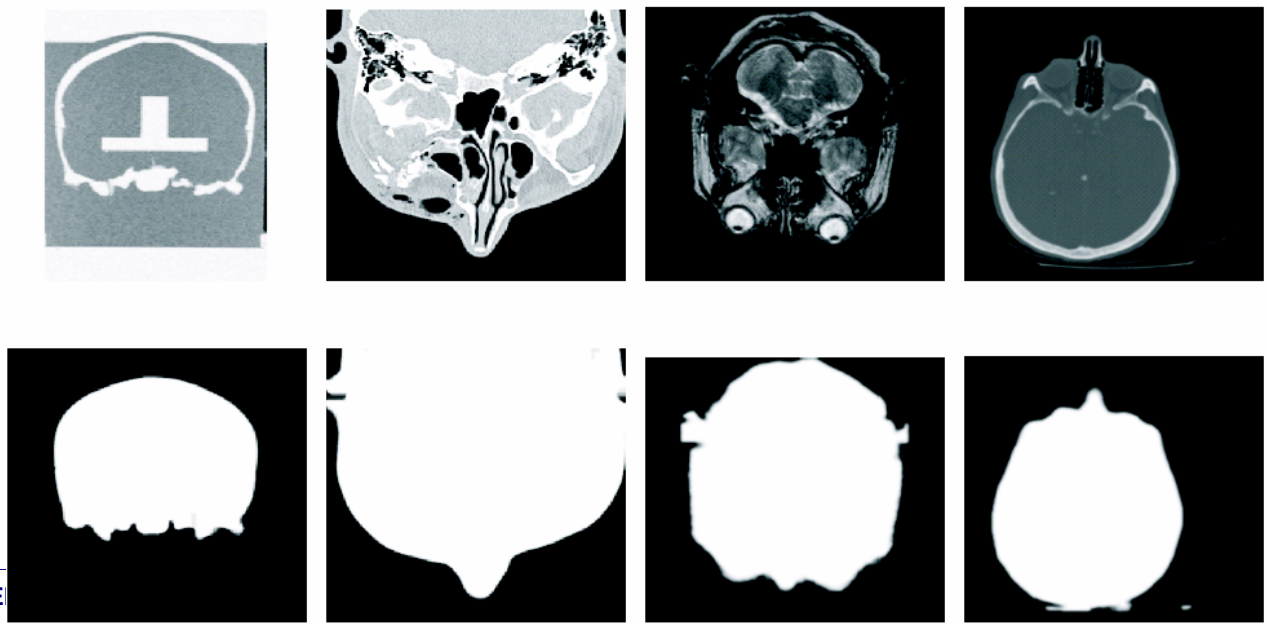
Simplify Phantom

- **Clean** dataset (Gauss, opening/closing)
- Compute **visual hull** (cull interior details): First-hit ray casting
- **Smooth** result (Median, Gauss)
- **Extract** isosurface



Medical Mixed Reality (16)

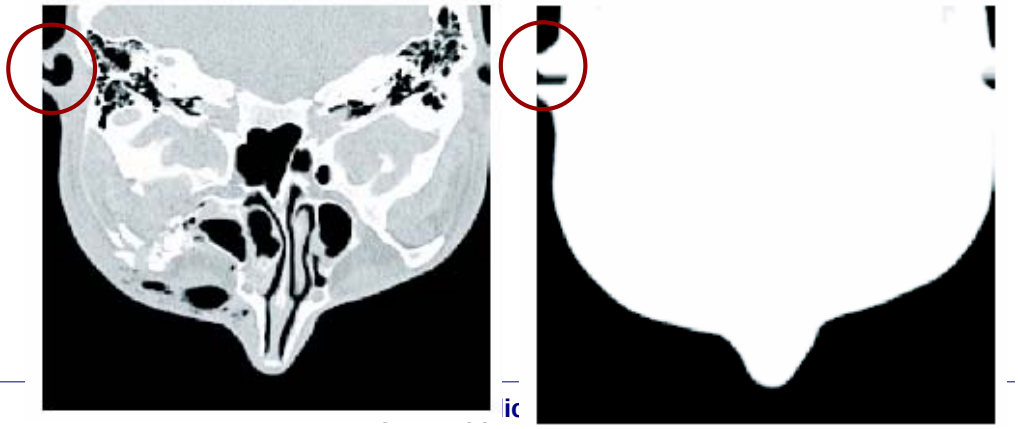
Examples



Medical Mixed Reality (17)

Small Imperfections

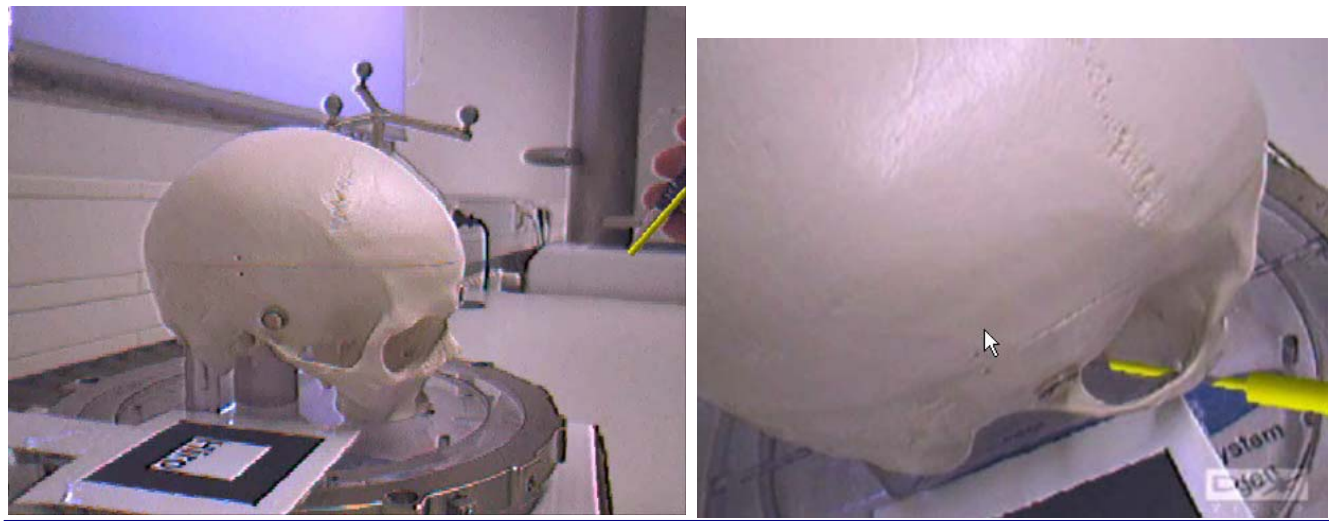
- Ray-casting does not catch all details, in particular details in non-convex areas
- But accuracy sufficient for virtually all cases



Medical Mixed Reality (18)

Correct Occlusion Handling

- Details at cheek bone are also handled correctly



Medical Mixed Reality (19)

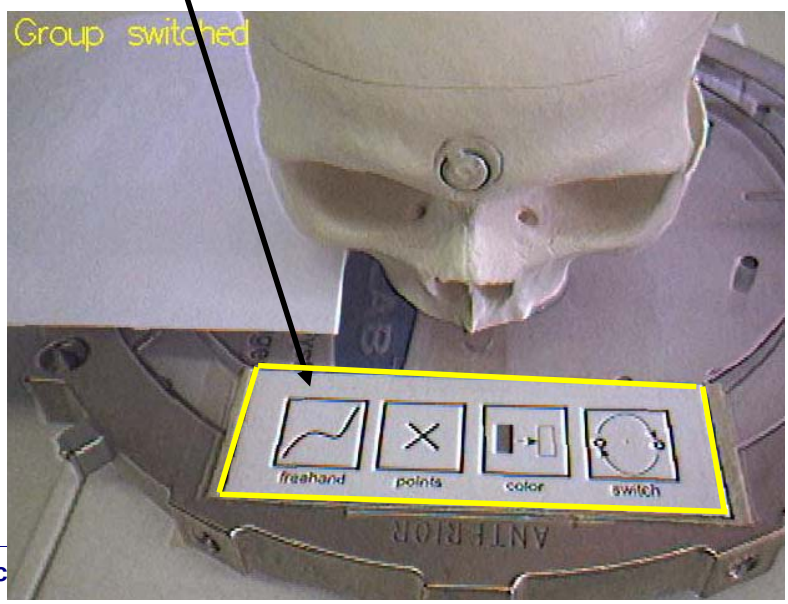
Interaction in the OR

- Assisting personnel
- Pedal-button (hard to find the right one)
- Tracked instruments

Medical Mixed Reality (20)

Interaction in the OR

- **Calibrated**, sterilizable stickers
- Once calibrated, interaction **can be measured** by tracking system
- **Flexible functionality** (ie., screen shots, mapping of volume, etc.)



Medical Mixed Reality (21)

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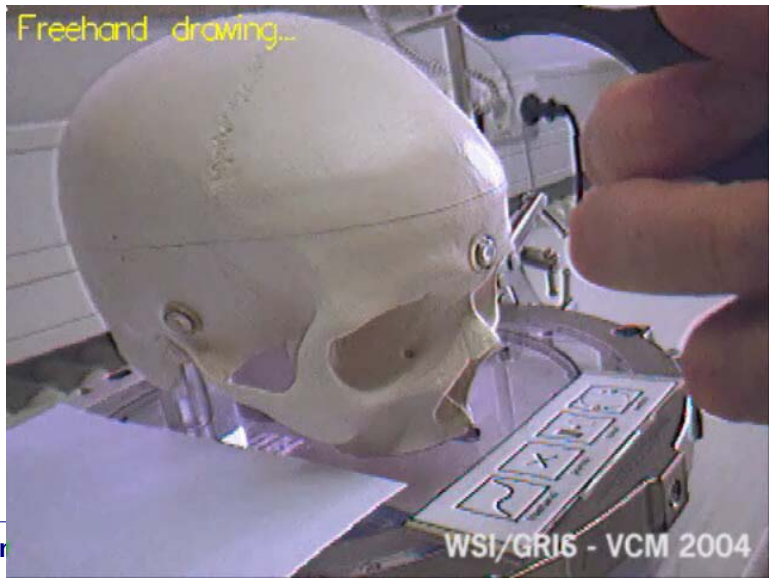
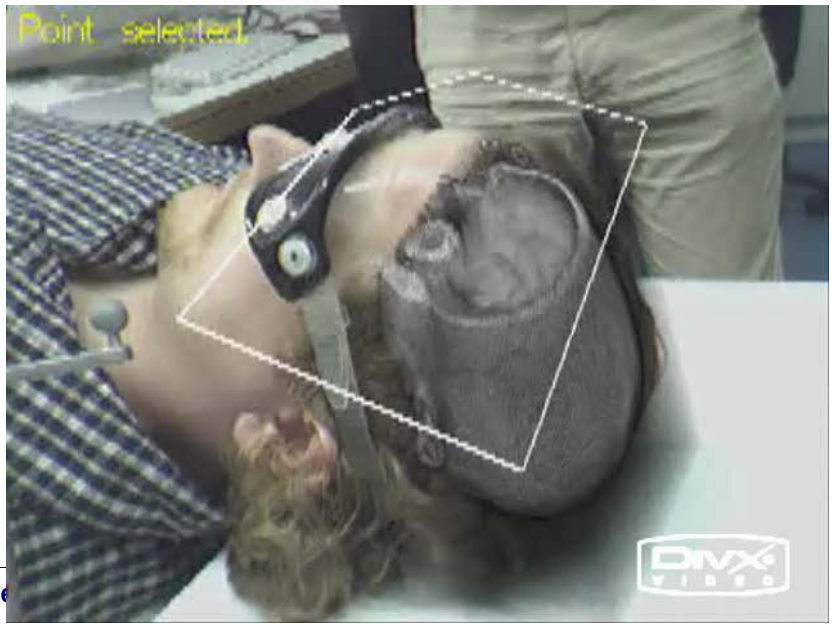


Medical Mixed Reality (22)

Interaction in the OR

- Spezification of target points



Summary

- Image-guided surgery uses **tracking** and **registration** to match **patient dataset** to **patient** on OR table
- Occlusion issue needs to be solved
- **Tissue deformation** may be a **significant problem** for image-guided surgery
- May require **intra-operative imaging**
- Simulation of tissue deformation is still **too far off**

Acknowledgements

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