Advanced Visual Medicine: Techniques for Visual Exploration & Analysis

Image-guided Surgery and Medical Mixed Reality

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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-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-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

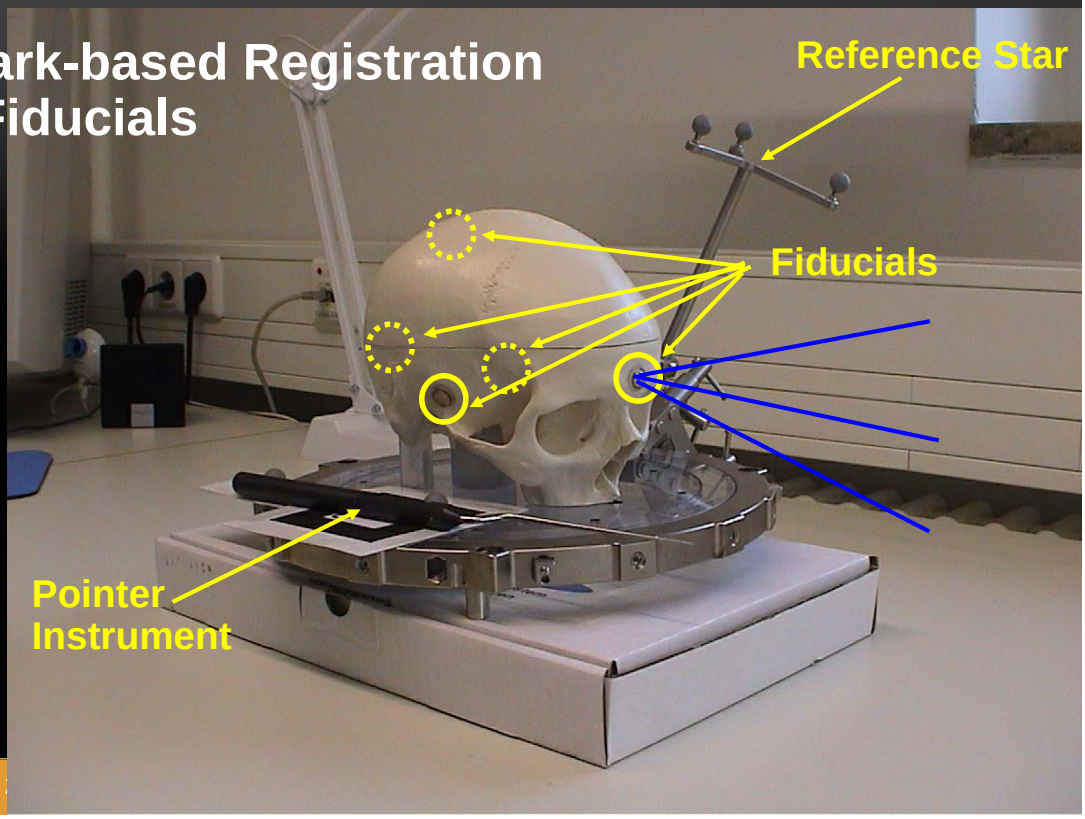
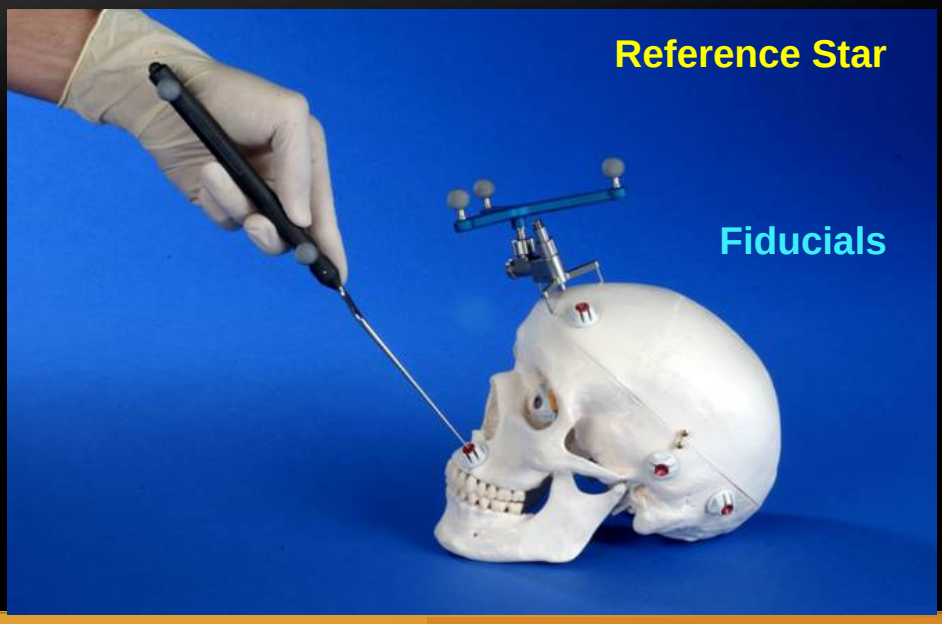


Image-guided Surgery (5)

Landmark-based Registration with Fiducials



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (6)

Typical Image-based Navigation/Surgery (IGS)

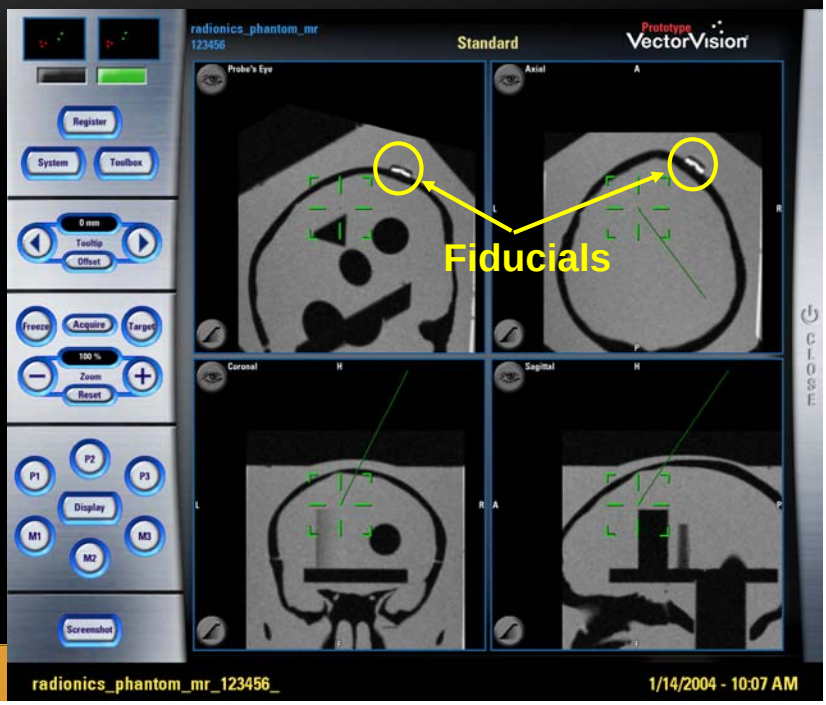
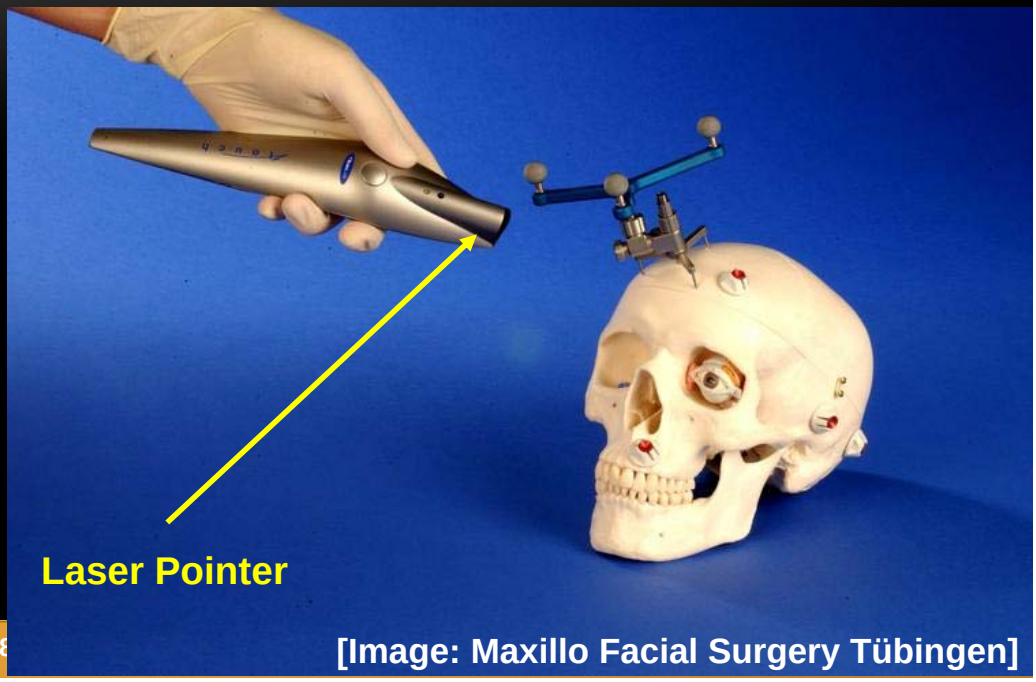


Image-guided Surgery (7)

Pointset-based Registration with Laser Pointer



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (8)

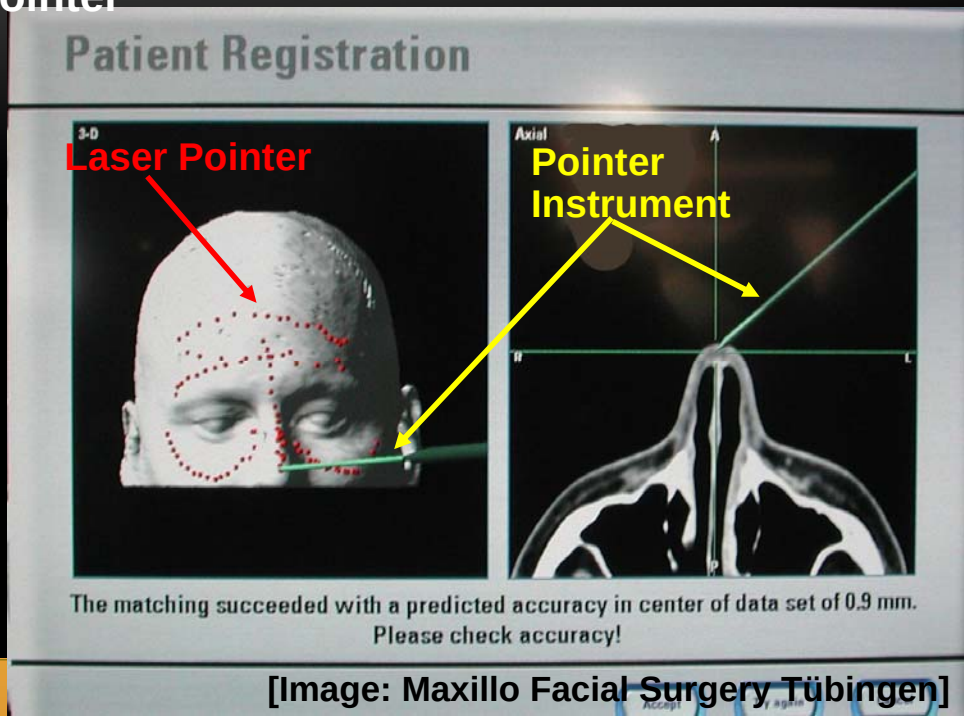
Pointset-based Registration with Laser Pointer

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

[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (9)

Pointset-based Registration with Laser Pointer



[Image: Maxillo Facial Surgery Tübingen]

Image-guided Surgery (10)

Optical (infrared) Tracking

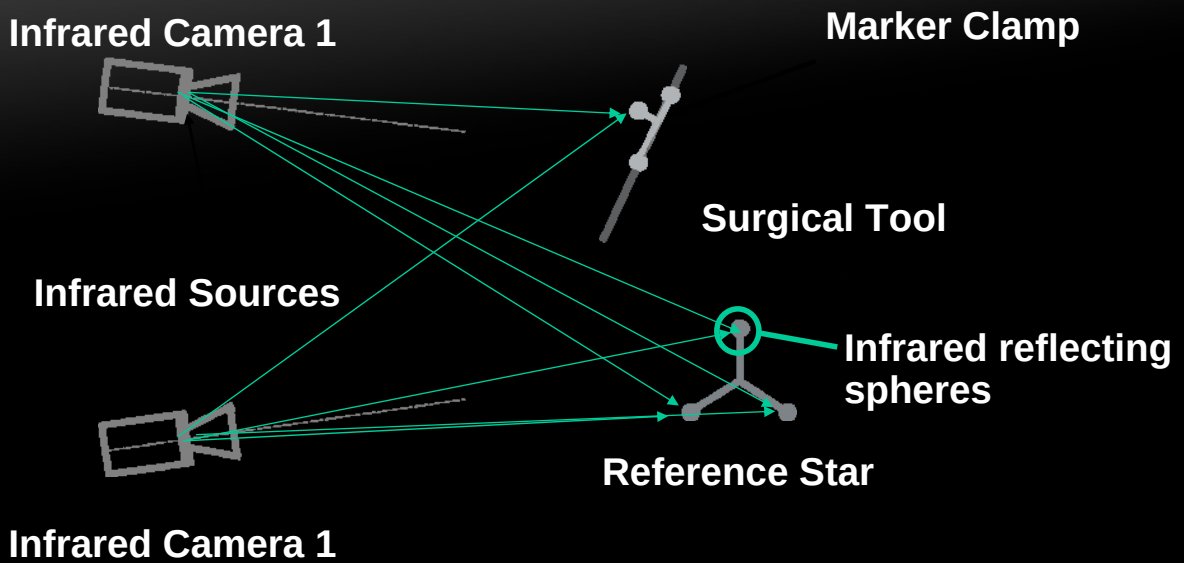
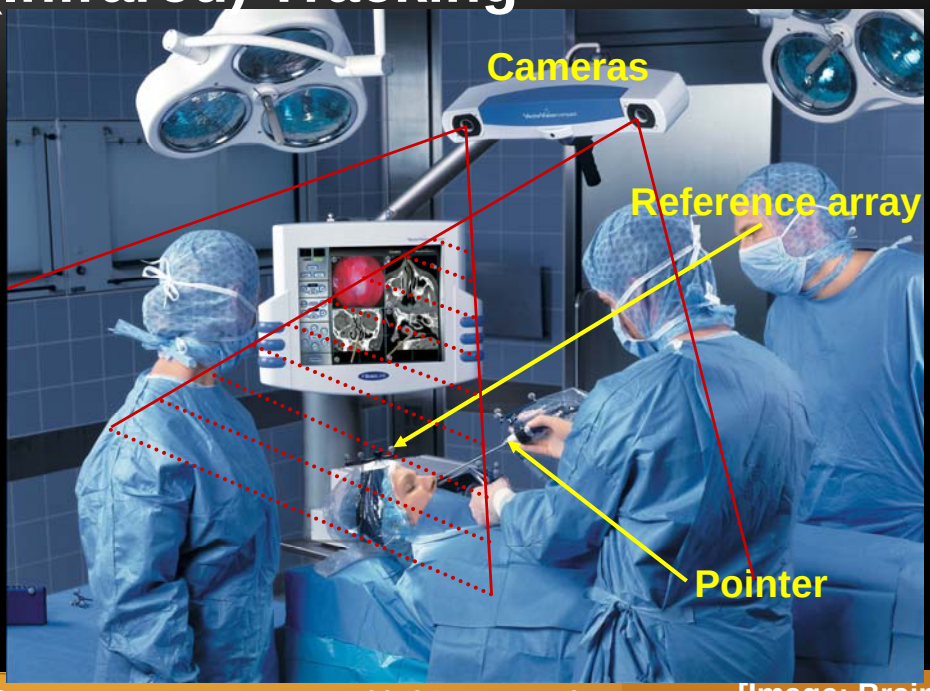


Image-guided Surgery (11)

Optical (Infrared) Tracking



[Image: BrainLAB]

Image-guided Surgery (12)

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 (13)

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 (14)

Example for Brainshift

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

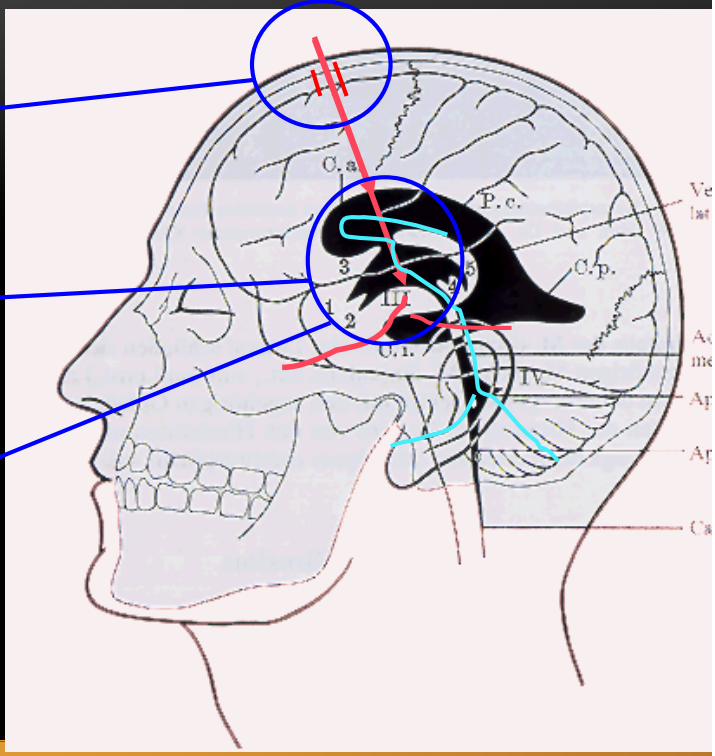


Image-guided Surgery (15)

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]

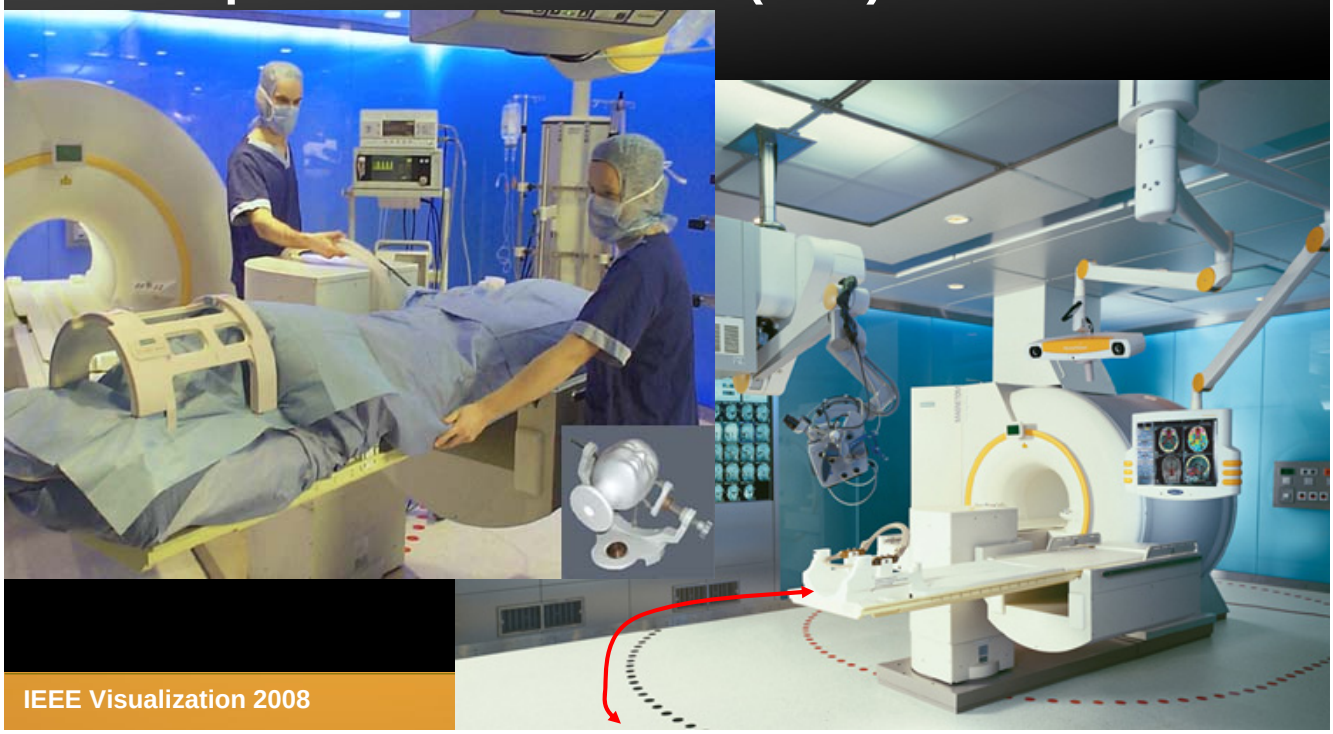
Intra-operative Imaging (3)

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)



Intra-operative Imaging (5)

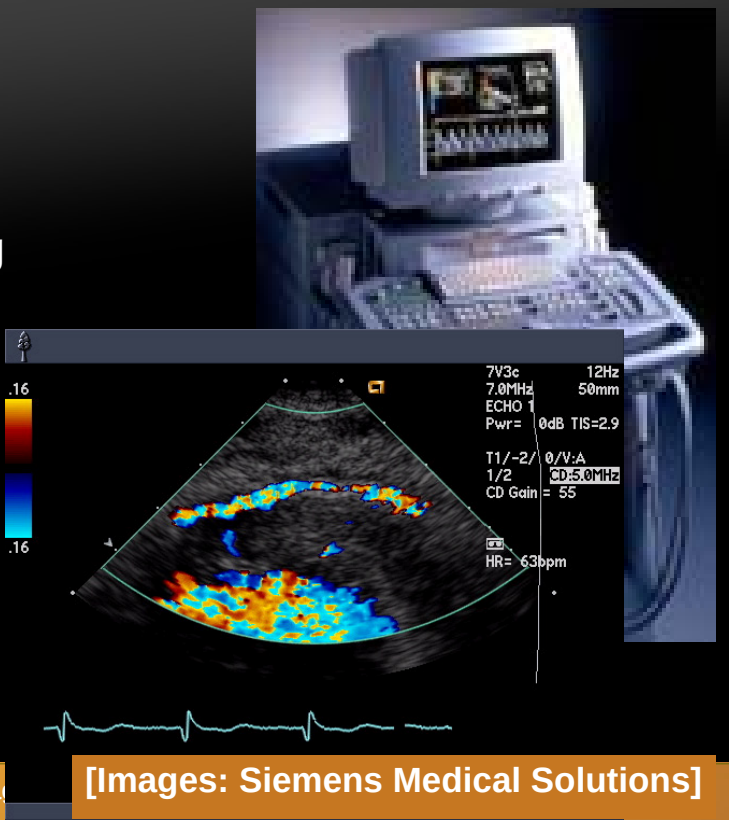
C-Arm / intra-operative CT

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

Intra-operative Imaging (2)

Ultrasound

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

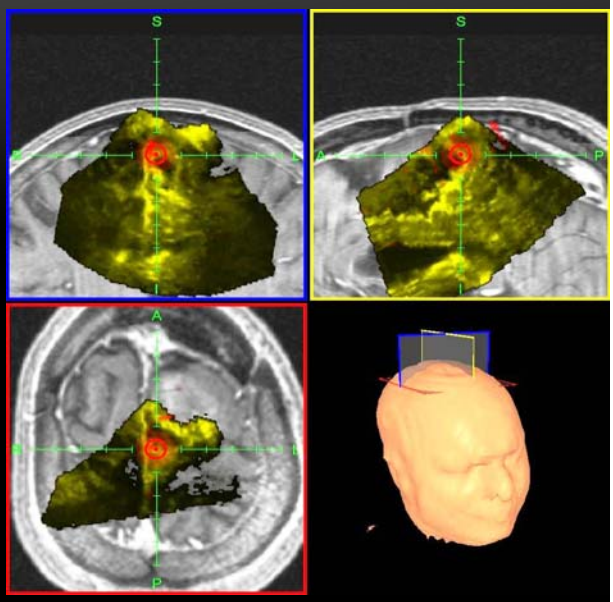


[Images: Siemens Medical Solutions]

Intra-operative Imaging (3)

Ultrasound

- Used to adapt to **brainshift** or other **tissue deformations** (resection control)
- Lacks good **spatial orientation**
- What **additional instrument** is used?



Tumor remnant at red area

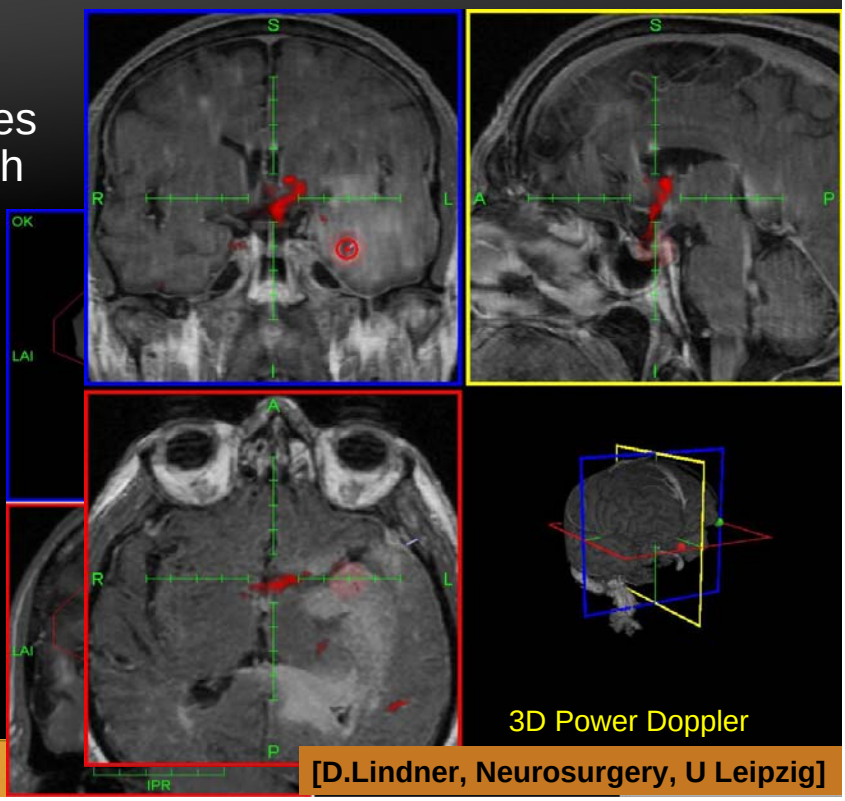
- **5% difference** between 3D US and post MRI

[D.Lindner, Neurosurgery, U Leipzig]

Intra-operative Imaging (4)

Ultrasound

- Use typically requires the **registration** with **pre-operative** datasets (neurosurgery: often MRI)
- Addional US functionality: **Doppler** for blood flow



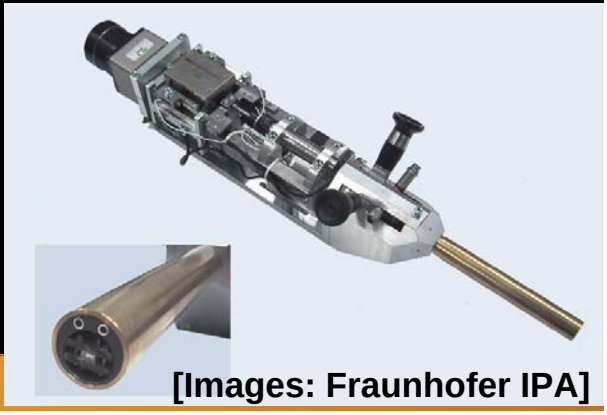
3D Power Doppler

[D.Lindner, Neurosurgery, U Leipzig]

Intra-operative Imaging (5)

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



[Images: Fraunhofer IPA]

Medical Mixed Reality (1)

- 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 (2)

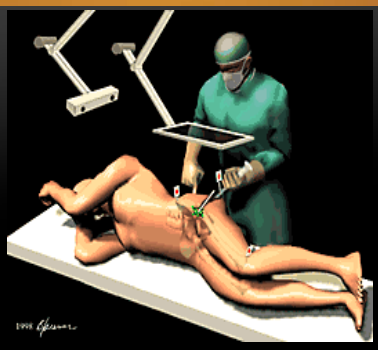
Combines virtual and real world in a mixed reality (augmented reality)

- 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 (3)

Video/Semi-See Through

- Registered TFT for virtuality
- See-through for reality
- But, reduced visual quality

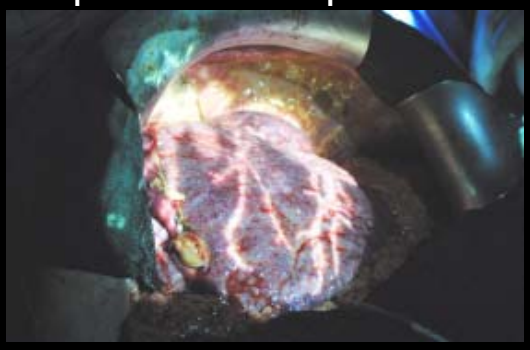


[Schwaldt, 2002]

Medical Mixed Reality (4)

Projection

- Poor quality without good projection screen
- **Occlusion by objects** between projector and screen
- Requires more space



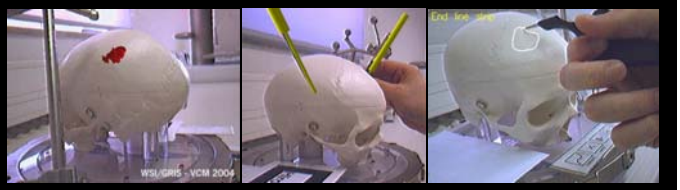
[Ritter et al., 2006]

Medical Mixed Reality (6)

Standard display and Camera

- Post processing ➔ **good quality**
- Navigated display or navigated camera

[Weber, 2003]



[Images: VCM L/TÜ]

Medical Mixed Reality (7)

Various Medical Mixed Reality Projects

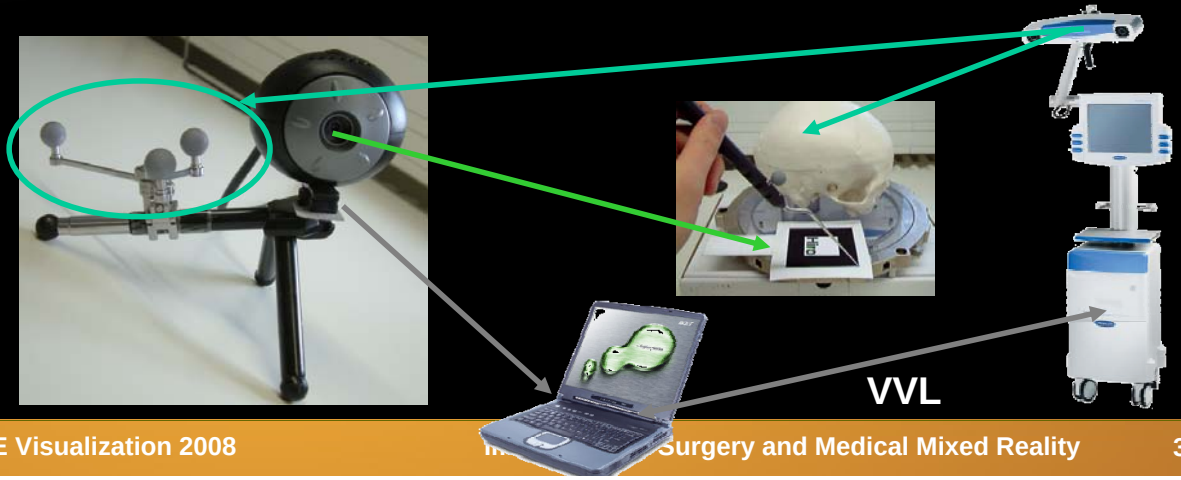
- **Mixed Endoscopic Reality** [Dey et al., MICCAI 2000]
- **Ultrasound and HMDs** [Sauer et al., ISAR 2001]
- **Minimally-invasive liver surgery** [Scheuering et al., Medical Imaging 2001]
- **MEDARPA** [Schwald et al., ISMAR 2002]
- **ARSys-Tricorder** [Goebbels, CURAC 2003]

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

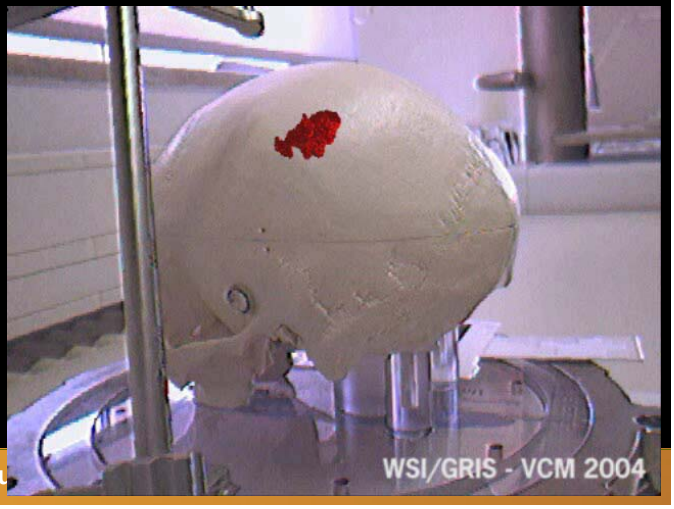
Medical Augmented Reality based on Image Guided Surgery

Overlay of manually placed tumor model

Medical Mixed Reality (11)

Issue

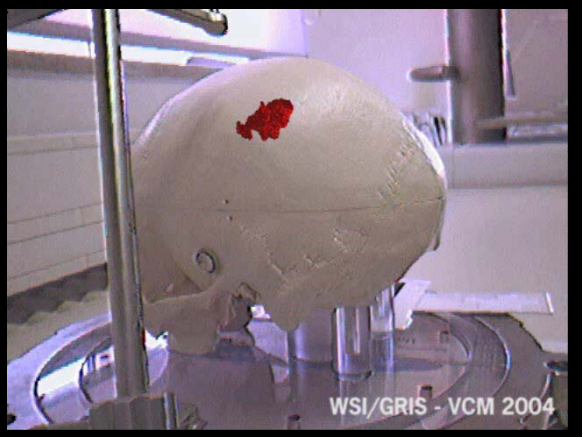
- High position accuracy, but **lower orientation accuracy**
  - → visual vibrations due to small errors in orientation
- Occlusion



Medical Mixed Reality (12)

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 (13)

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 (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

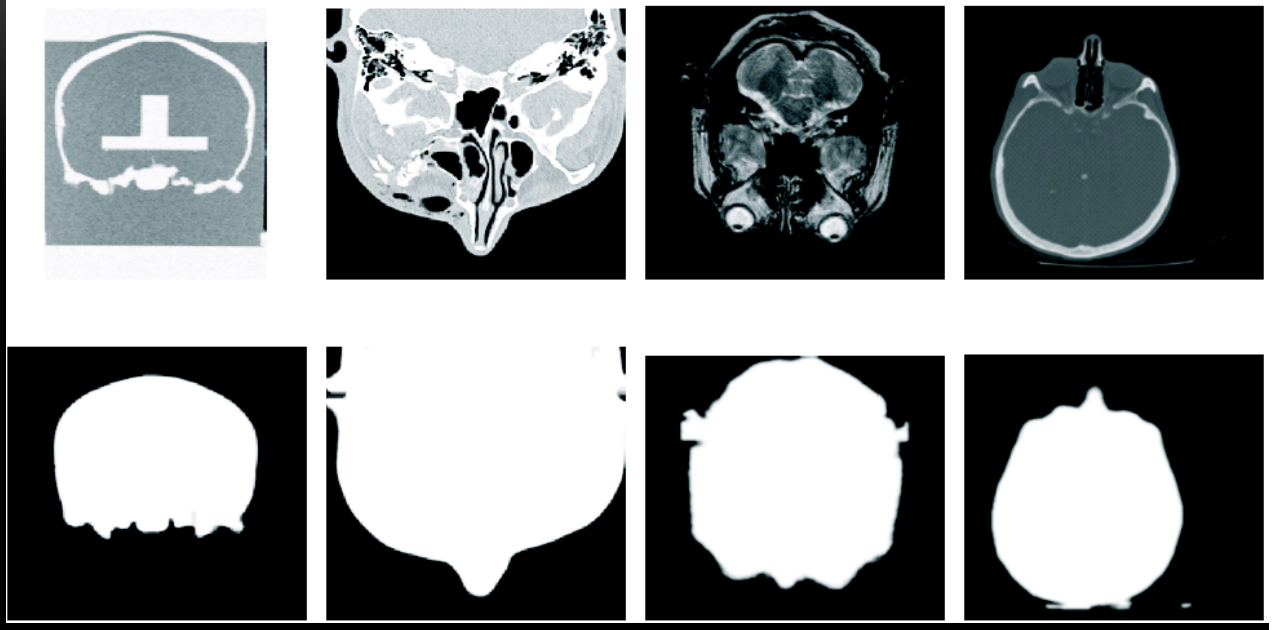
Medical Mixed Reality (15)

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)

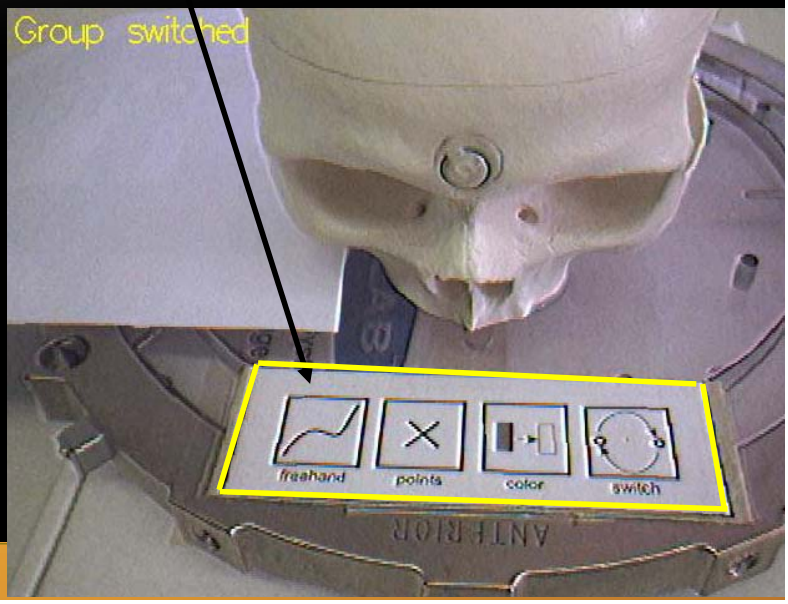
Interaction in the OR

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

Medical Mixed Reality (20)

Interaction in the OR

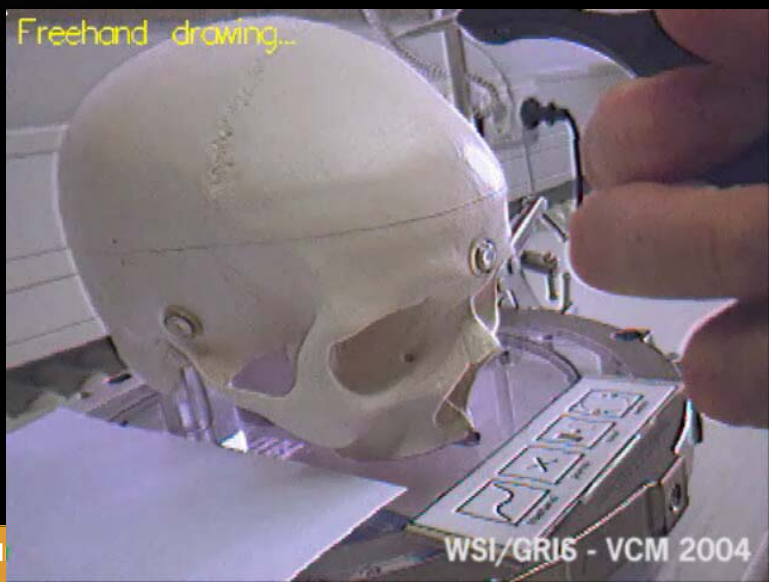
- **Calibrated**, sterilizable stickers
- Once calibrated, interaction **can be measured** by tracking system
- **Flexible functionality** (ie., screen shots, mapping of volume, etc.)



Medical Mixed Reality (21)

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.)

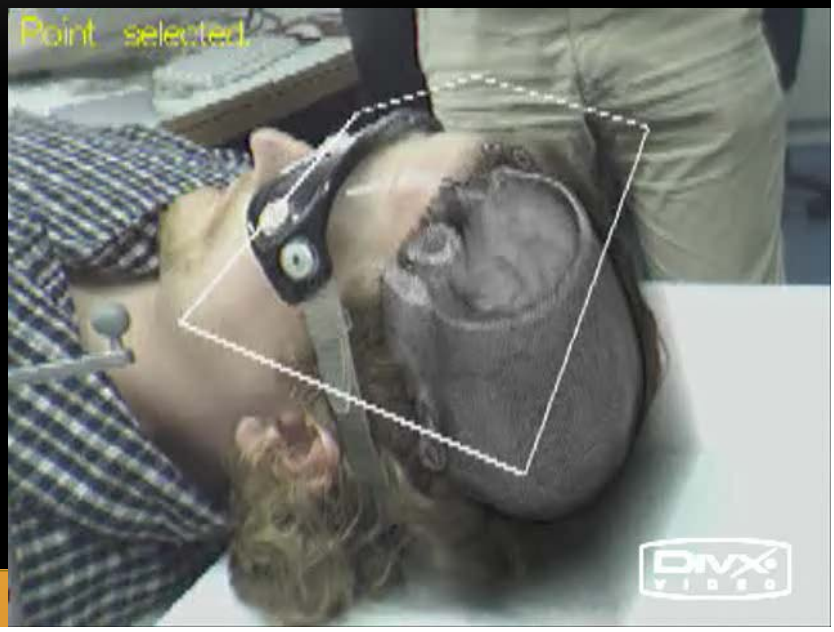


IEEE Visualization 2008

Medical Mixed Reality (22)

Interaction in the OR

- Specification of target points



Medical Mixed Reality (23)

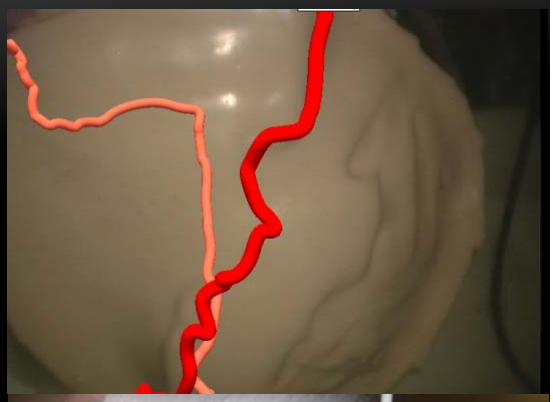
Application in Heart Surgery

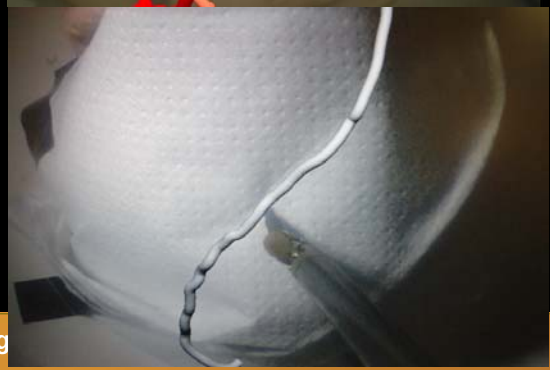
- 3D printing phantom
- Risk structures on basis of optical/electrical conductor

Medical Mixed Reality (23)

Application in Heart Surgery

- 3D printing phantom
- Risk structures on basis of optical/electrical conductor

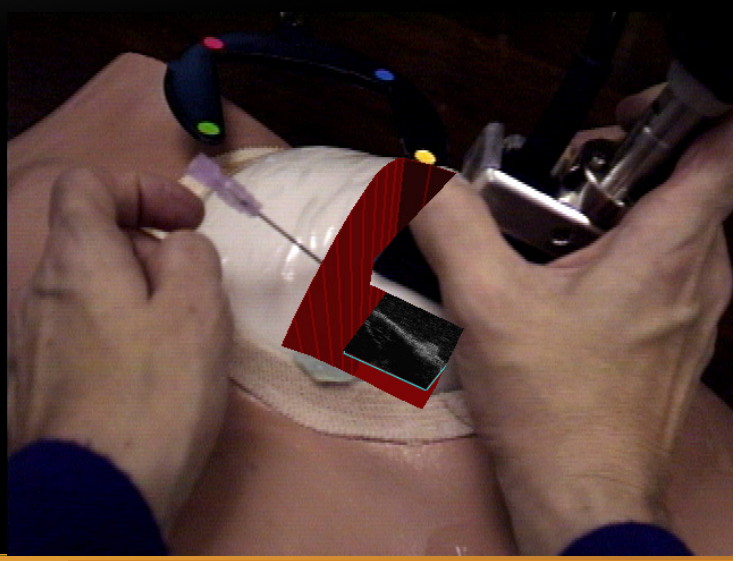




Medical Mixed Reality (24)

Various Medical Mixed Reality Projects

- **Needle biopsies with Ultrasound and HMD**
- Supporting visualization of organs, risk structures etc.

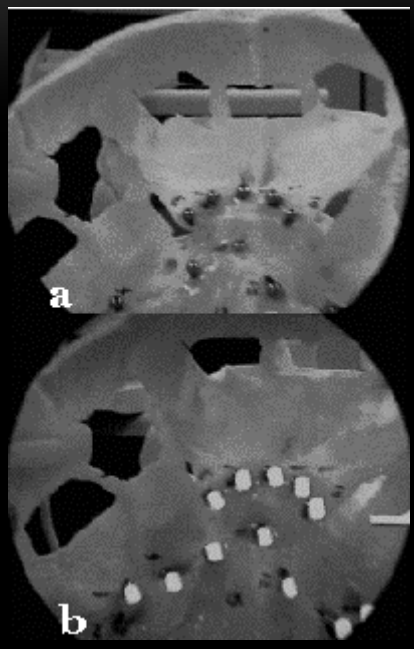


[Image: Bajura et al., SIGGRAPH 1992]

Medical Mixed Reality (25)

Various Medical Mixed Reality Projects

- **VarioscopeAR – Augmented Microscope**

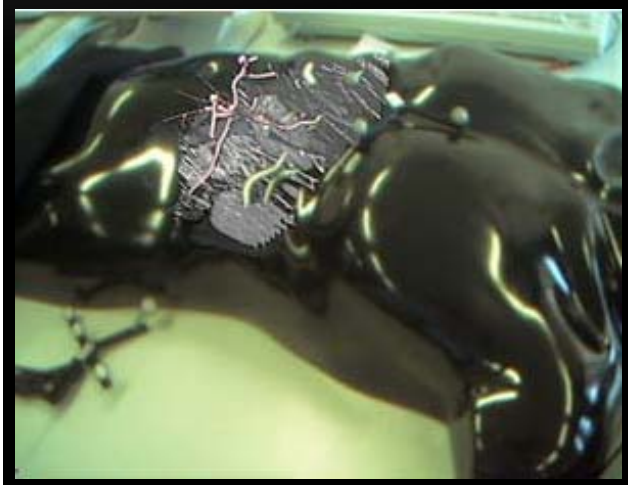


[Birkfellner et al., ISAR 2001]

Medical Mixed Reality (26)

Various Medical Mixed Reality Projects

- **Liver Surgery**: Supporting visualization of organs, risk structures etc.



[Bornik et al. BVM 2003]

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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BrainLAB

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