Computer Aided Surgery & Augmented Reality – An Overview

Michael Figl, Wolfgang Birkfellner
Center for Biomedical Engineering and Physics
Medical University Vienna

Computer Aided Surgery (CAS)

Intraoperative Guidance using Visualization

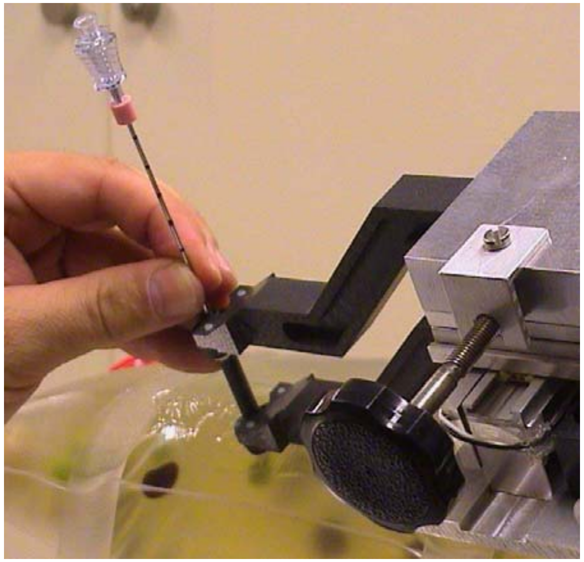
Planning preoperative imaging, eg CT, MRI, US

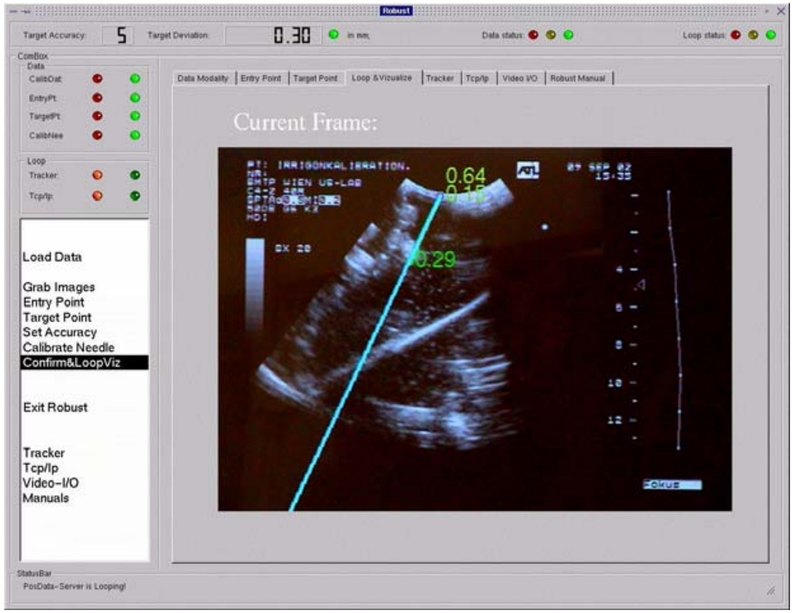
Guidance intraoperative imaging using computer aided visualization, position systems, robots, ...

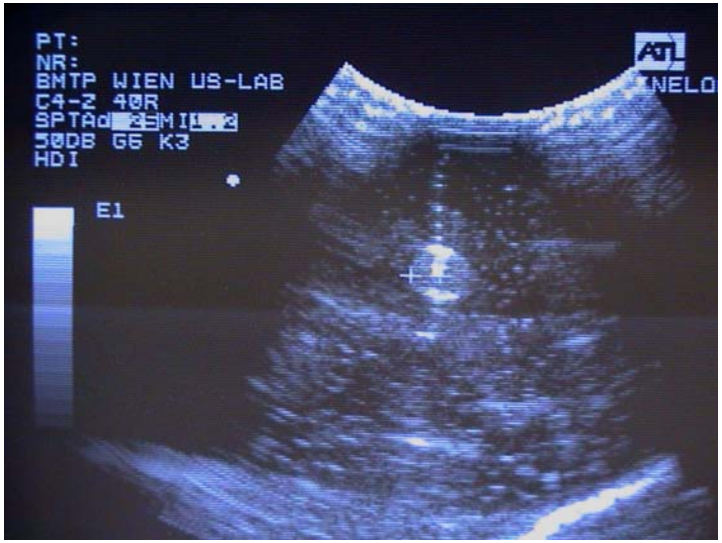
Registration the preoperative planning has to be transformed to the intraoperative situation

B-Rob I

- peas in gelatine (~5.5mm)
- 20 biopsies
- accuracy 1.9 mm

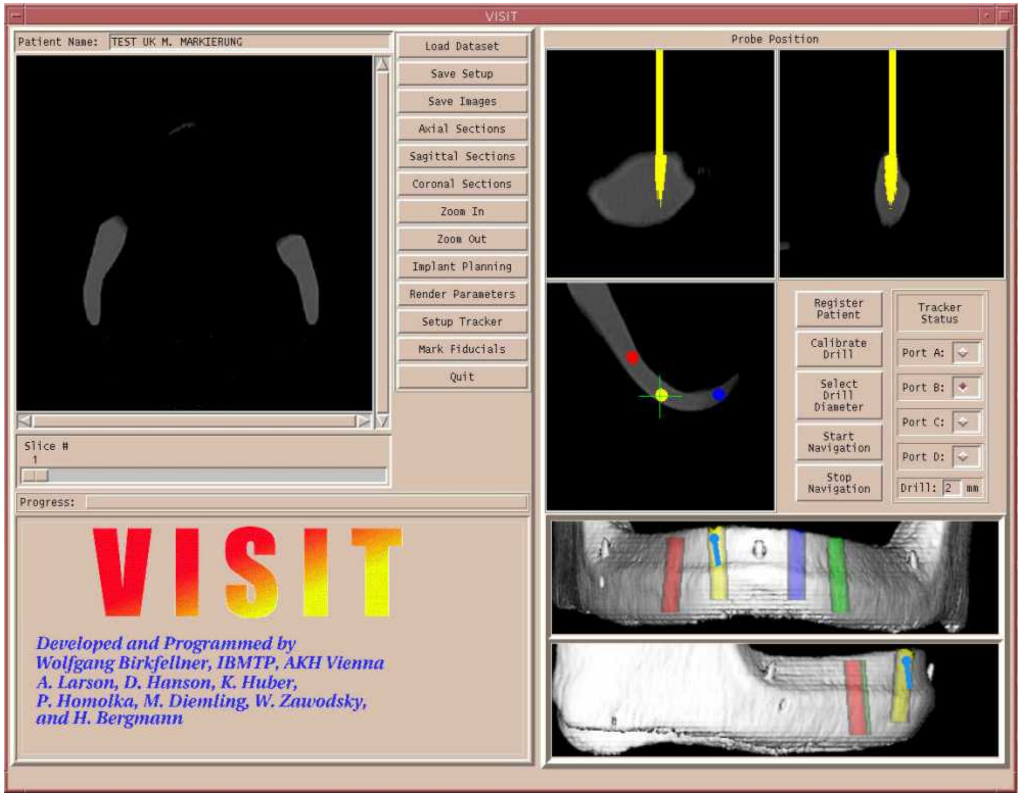






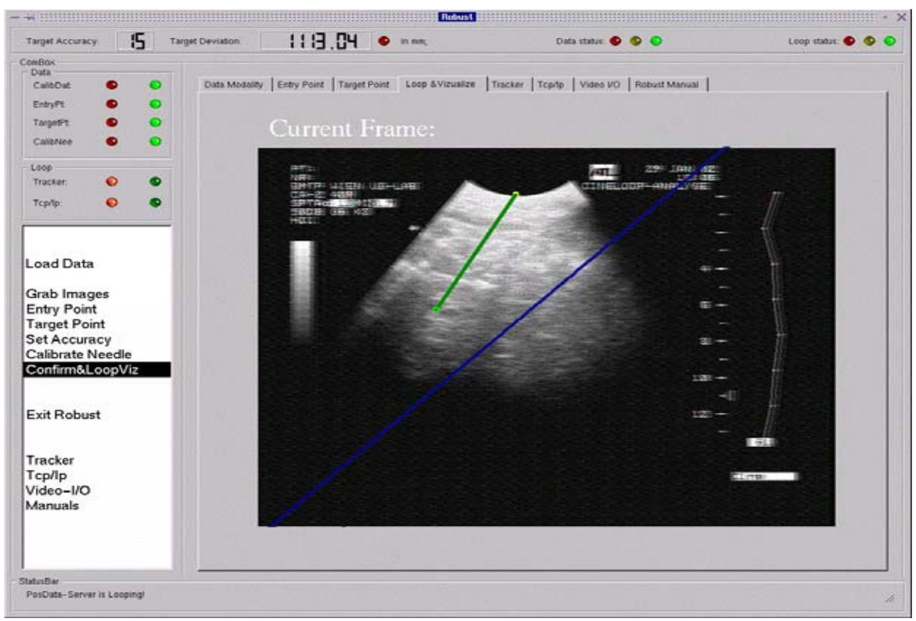
VISIT

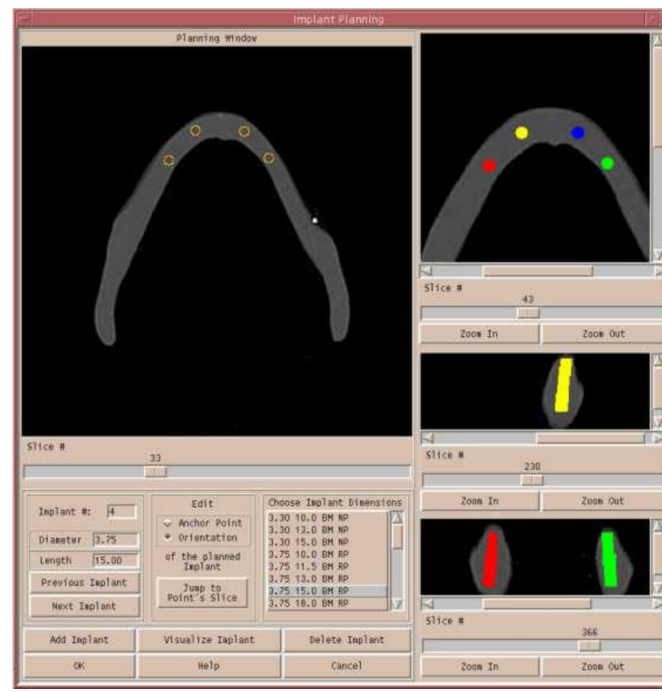
- dental implantology
- optical tracking
- AVW graphics library
- Tcl/Tk, ANSI C
- for SGI, SUN, Linux



Planning

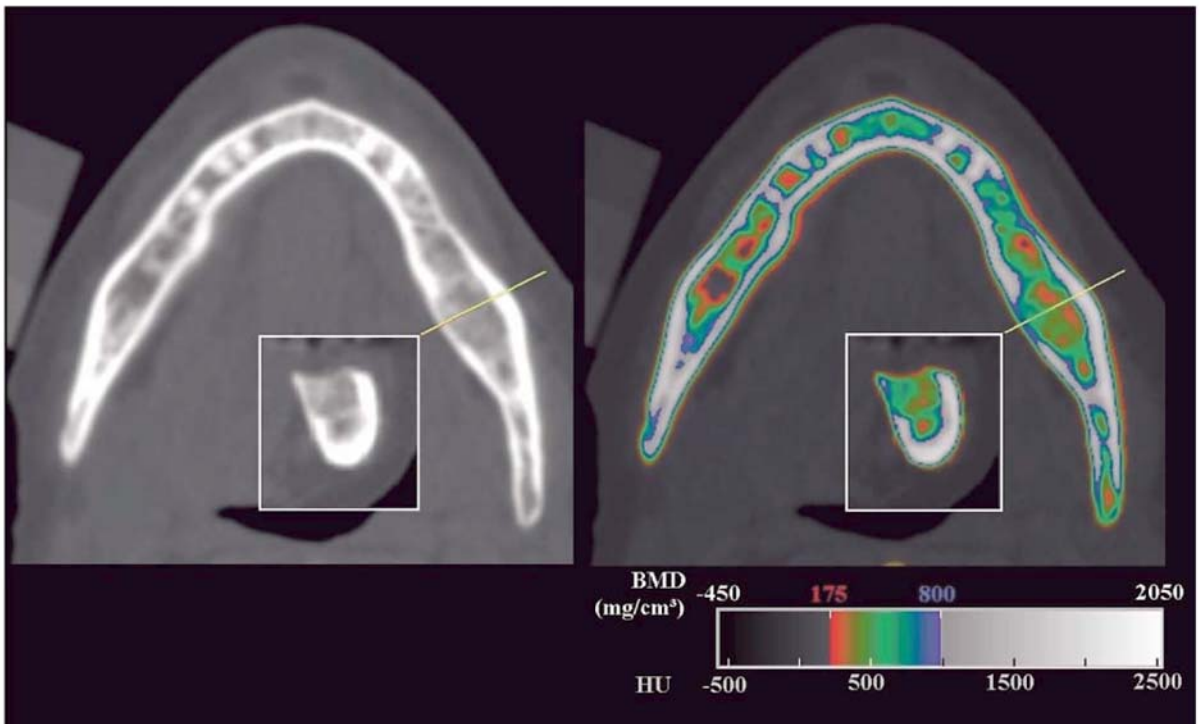
planning in preoperative images
has to be registered to the intraoperative situation





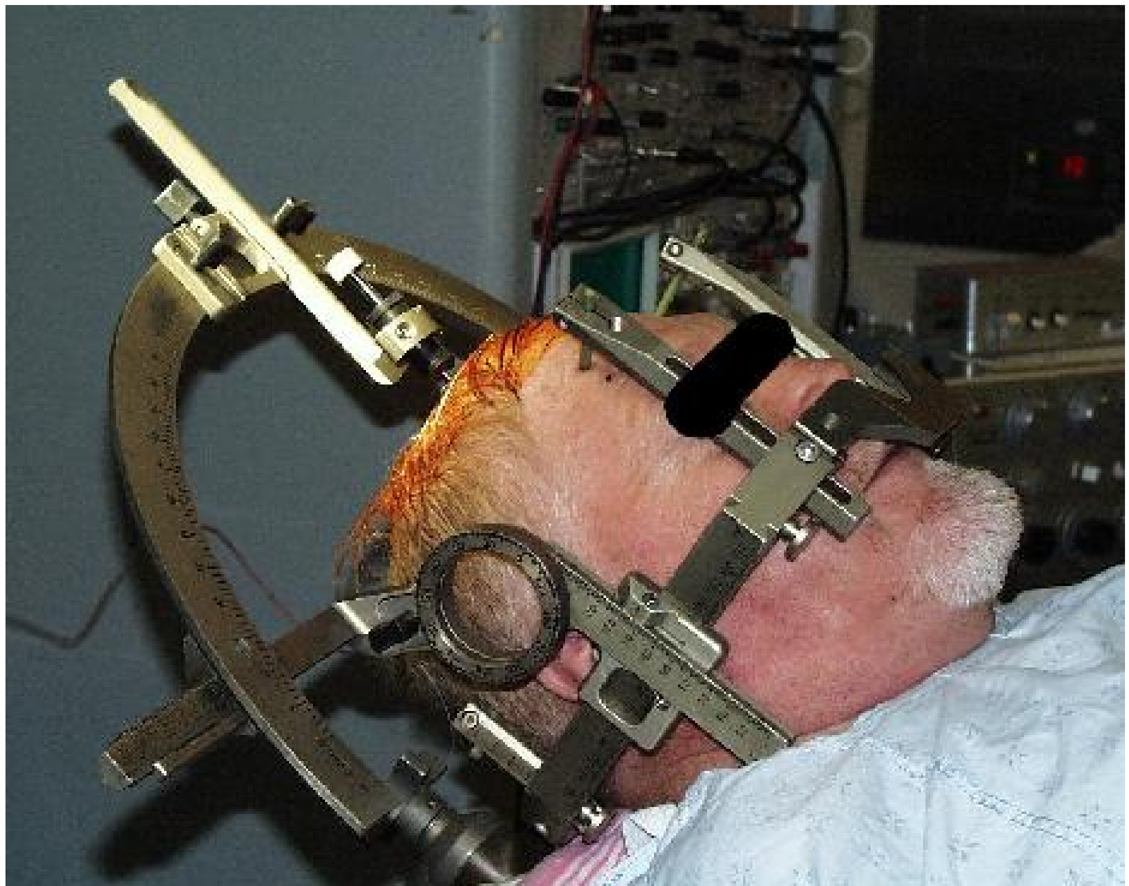
Augmented Planning

visualization of bone mineral content from quantitative CT



Literature: *Homolka P, Beer A, Birkfellner W et al.: Bone mineral density measurement with dental quantitative CT prior to dental implant placement in cadaver mandibles: pilot study. Radiology. 2002 Jul;224(1):247-52.*

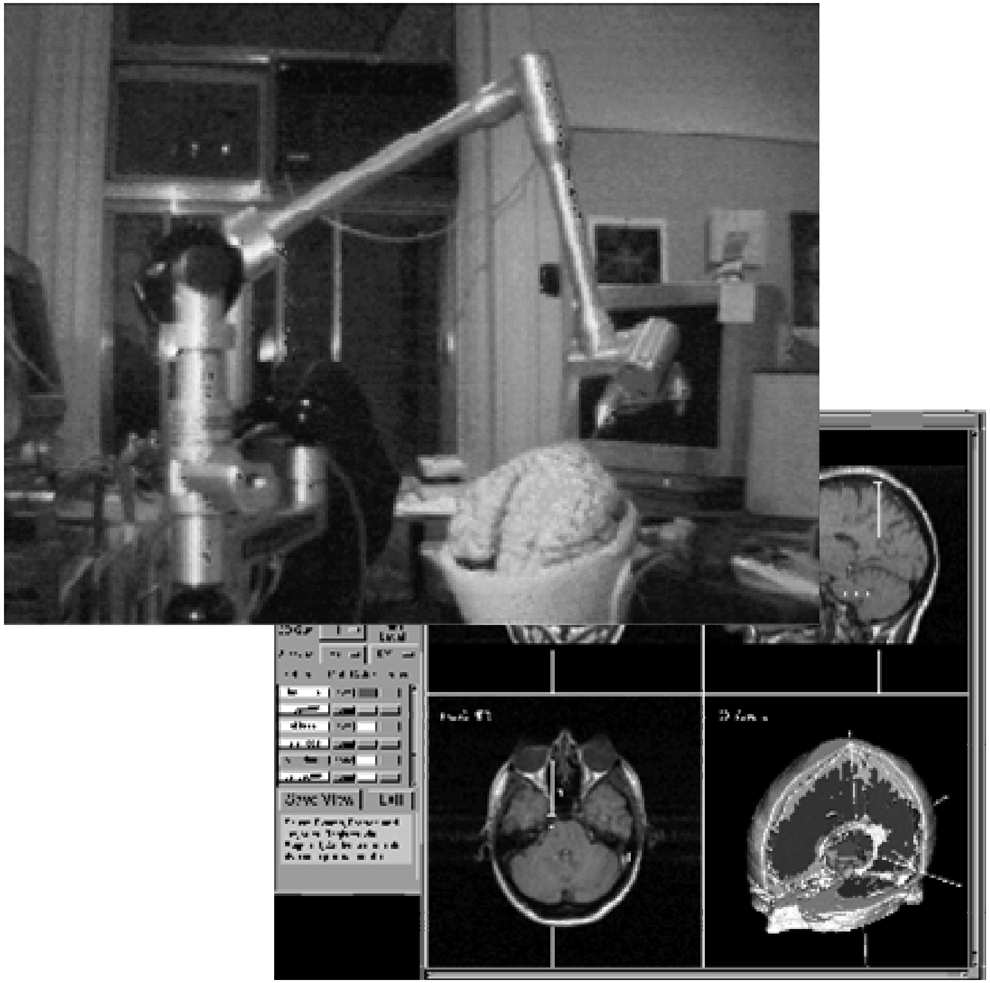
Positioning



Frameless stereotaxy

first systems introduced by Watanabe et al around 1987

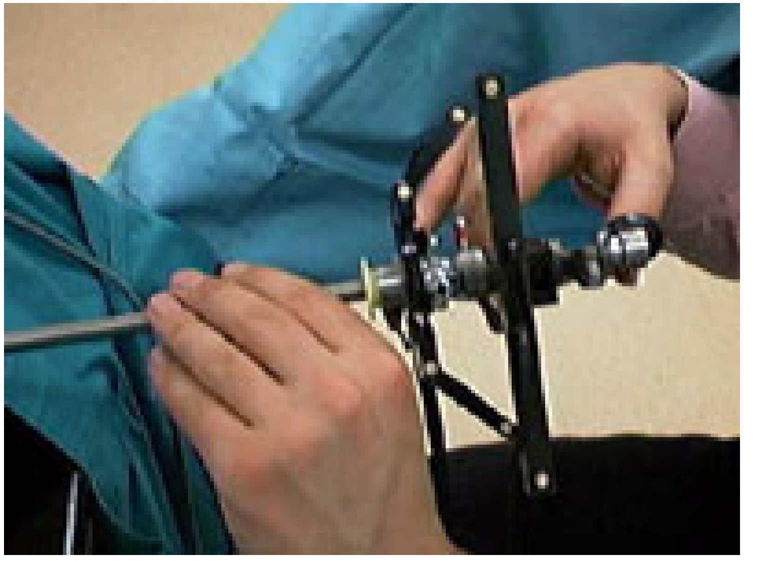
Usually mechanically tracked instruments, the patient is fixated by means of a Mayfield clamp



Mechanical Systems

- mainly of historic interest
- passive arm, encoders give positions of joints
- only one arm feasible, sterilization problems

Trackers - optical



• cameras localize optical beacons

• by knowledge of the geometry of the beacons, the position and orientation can be derived by triangulation

• commercial systems include

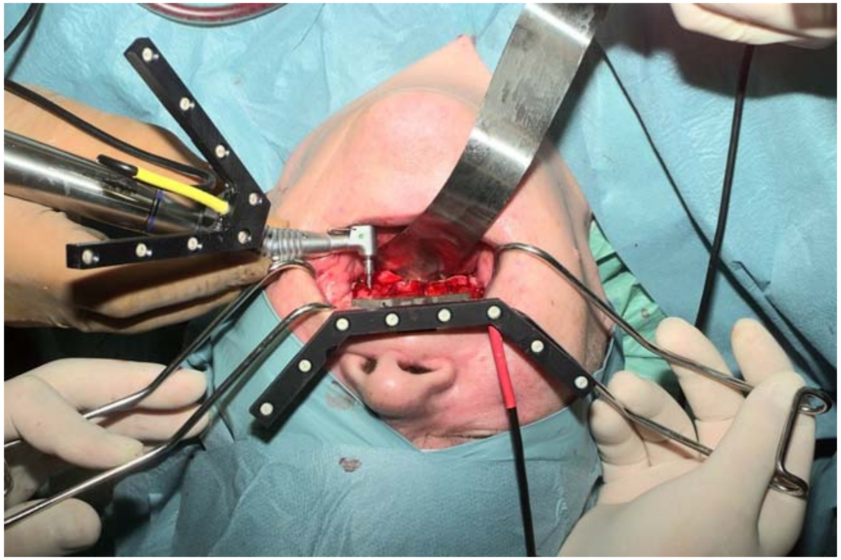
- systems with three linear CCDs, slit-apertures and consecutively fired active LEDs

- systems with two planar CCDs and active or passive markers

Probes for optical trackers

Active probes –
infrared emitters are localized

Passive Probes – reflective markers are used; the field of view of the tracker is flushed with infrared light



All optical trackers suffer from line-of-sight problems

Optical Systems

- Flashpoint 5000 – Stryker/Leibinger (www.boulderinnovatorsgroup.com)

  - 3 linear CCD system, consecutively fired markers, wireless active system, serial connection; approx. 15 Hz

- NDI Optotrak – Northern Digital (www.ndigital.com)

  - 3 linear CCD system, cylindrical optics instead of slit apertures, wired system, SCSI connection; update rate up to 900 Hz

- ART/Qualisys – ART (www.ar-tracking.de)

  - 2 passive planar CCD cameras, 3M coated spheres, TCP/IP connection; update rate: 50 Hz

- Ascension Laser Bird (www.ascension-tech.com)

  - Inside-out Laser fanbeam tracker, instead of beacons, sensors are used. Not too many data yet.

Electromagnetic Systems

- AC-based systems: search coils localize themselves in AC-pulsed electromagnetic fields (www.polhemus.com)

- DC-based systems: Fluxgate-sensors determine position by measuring electromagnetic induction generated by quasistaic currents (www.ascension-tech.com)

- Problem: Systematic errors in the presence of metals

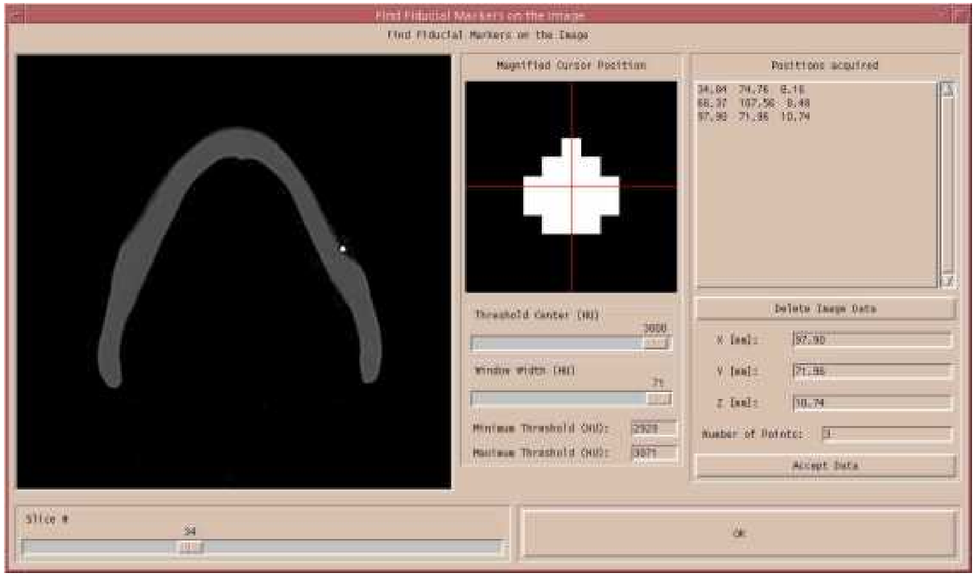
Registration

Find a transformation that maps the coordinate system of the patient (given by a tracker probe or the imaging modality) to an image – either a pre- or intaroperatively acquired volume image, or a planar image such as C-arm or US-image.

Types of transforms:

- Rigid body transformations (6 dof)
- Registrations including additional dof
  - Image deformations (tissue)
  - Image distortions

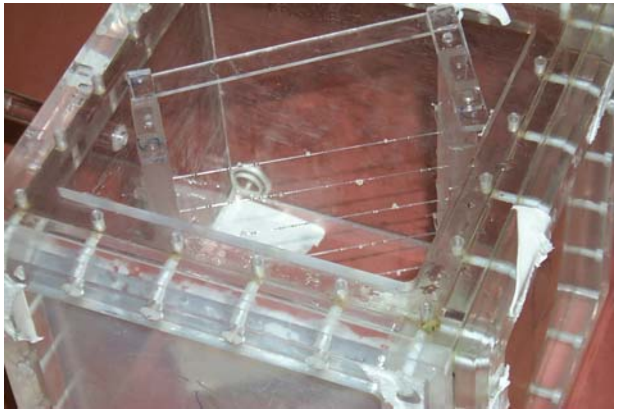
Patient to Image Registration



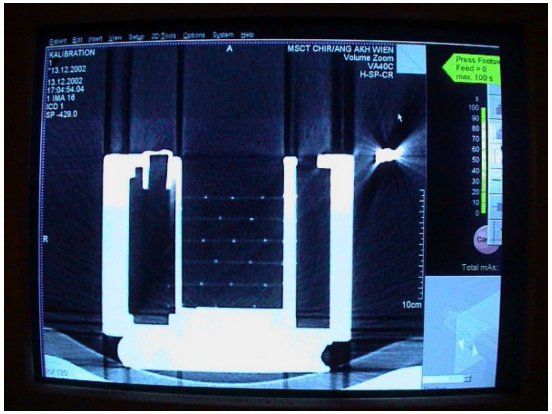
Point to point registration (Horn) using at least three markers and a point probe error 0.7 +/- 0.15 mm

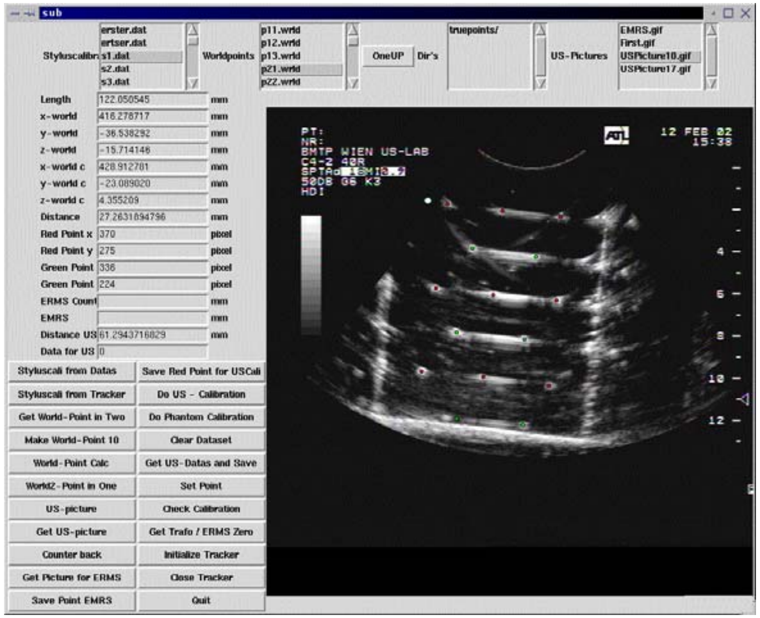
US Scanhead Calibration

demanded: transformation from US image to tracker probe mounted on the scanhead

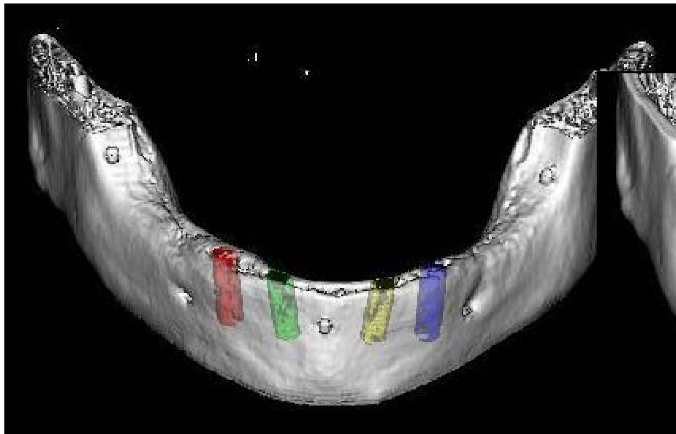


similar method for CT





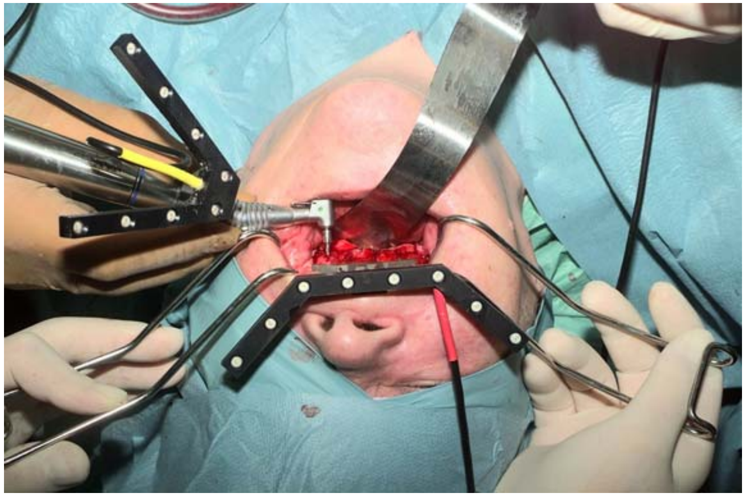
Cadaver Study using VISIT

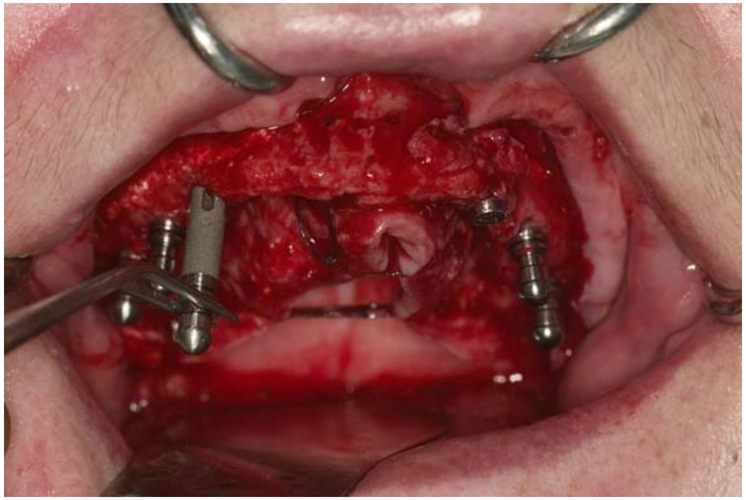


- HR-CT 1x0.3x0.3 mm^3 Voxel
- Blind insertion of four dental implants (cadaver mandibles covered with plaster)
- 1.0 +/- 0.7 mm accuracy
- Main problem: mechanical instability of the drill

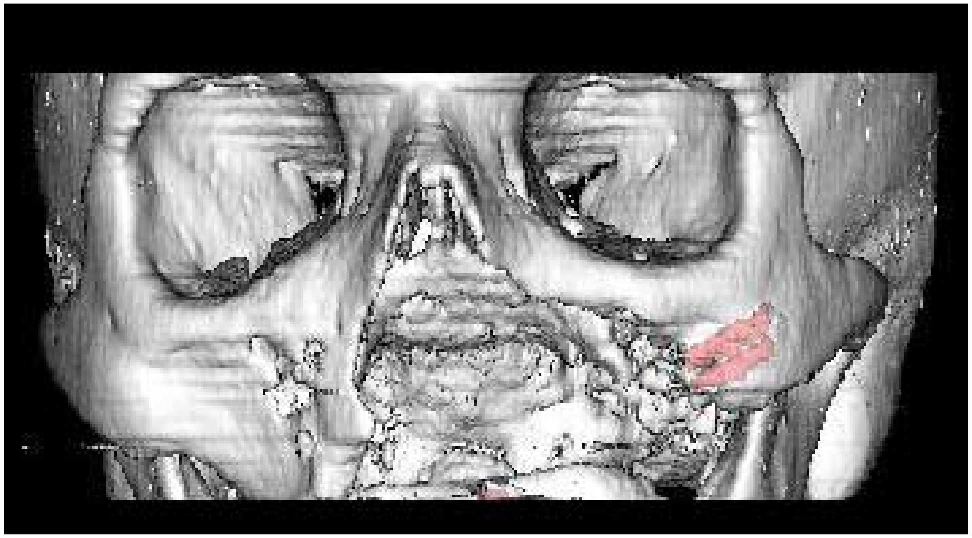
Patient Study using VISIT

- 32 implants, 5 patients after tumor resection and primary reconstruction
- accuracy
  top 1 +/- 0.5 mm
  bottom 1.3 +/- 0.9 mm





Implant Insertion after Hemimaxillectomy



- Sealing of the nasopharynx after radical resection of squamous cell carcinoma
- Minimal invasive approach not feasible without CAS

A Century of AR

The Skiascope, a head-mounted fluorescent screen (from R. F. Mould, „A Century of X-Rays and Radiation in Medicine“)

A military AR system, from the Microvision website (http://www.mvis.com)

Introductory website:
http://www.se.rit.edu/~jrv/research/ar

Characteristics of AR Systems

Aim:

- Overlay of artificial „target information“ over real-world view
- Virtual scenery adopts itself to the position of the viewer

Technology:

- Visualization devices such as head-mounted displays (HMD)
- Position tracking or pose estimation
- Interfacing to 3D-visualization systems

Challenges

Optics

- Focal problems, display quality, parallax error, calibration

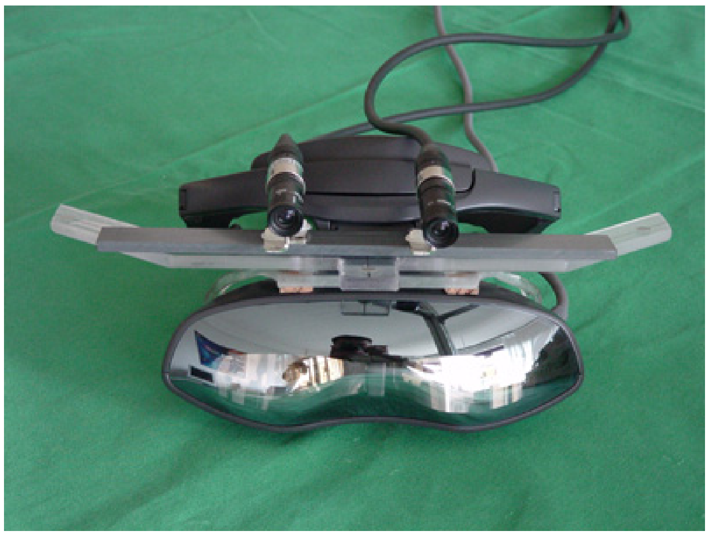
Technology

- Appropriate visualization, tracking, latency, weight

Acceptance

- Appropriateness for given applications, acceptance of end users

Approaches: See-through HMDs



The Glasstron, a see-through HMD by Sony Corp. Photograph courtesy of Tobias Salb, University of Karlsruhe, Germany

The Nomad, a retinal display system by Microvision, Bothell/WA – http://www.mvis.com/

Advantages:

- Widely available
- Lightweight

Disadvantages:

- No fixed calibration
- No fixed focus

Approaches: Video-See through HMDs

Advantages

- Common focal plane
- Arbitrary mixing of real and virtual image
- Fixed calibration

Disadvantages:

- Poor image quality
- High image processing requirements
- Weight & Cost

A head-mounted video see-through display. Photograph courtesy of Dr. Frank Sauer, Siemens Corporate Research, Princeton/NJ.

Approaches: Semi-transparent panels

A semitransparent panel from the MRCAS-group, Pittsburgh/PN. (http://www.mrcas.ri.cmu.edu)

Advantages:

- Focal problem solved
- (Non-HMD) See-through system

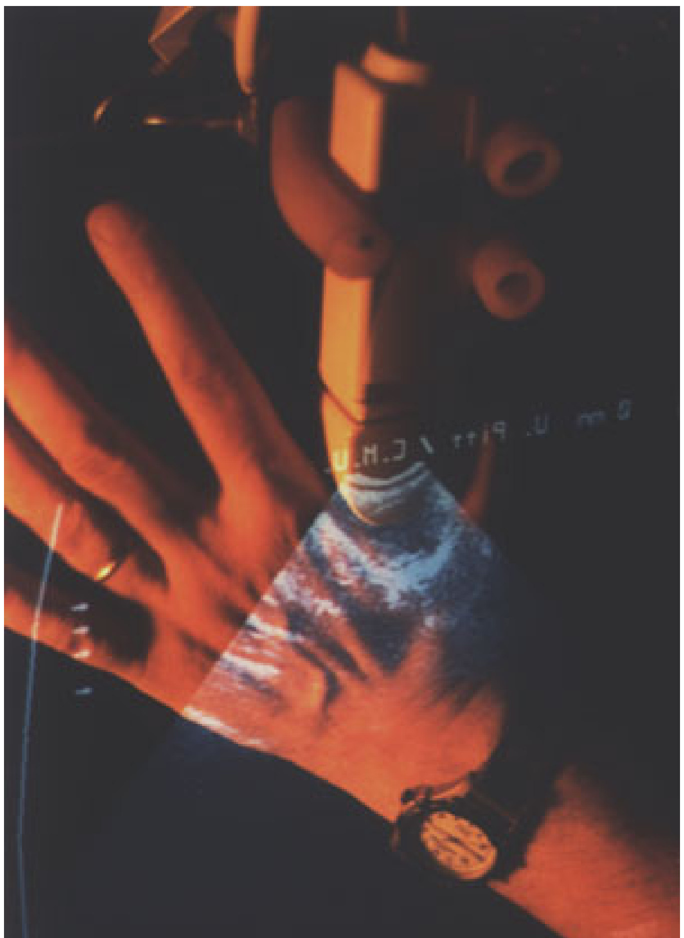
Disadvantages:

- Sterility
- Considerable parallax problems - possible solution provided by integral photography methods (Dohi Labs)

Left Front Right

Illustration of an integral photography approach. Images courtesy of Dr. Nakajima, University of Tokyo

Approaches: Integration into Imaging Modalities



Advantages

- Possibility to exploit specific features of the chosen modality

Disadvantages:

- High specialization

The sonic flashlight – a panel type display attached to a B-mode ultrasound device. Image courtesy of Dr. G. Stetten, Carnegie Mellon University, Pittsburg/PA – http://www.stetten.com

Approaches: Medical Optical Instruments

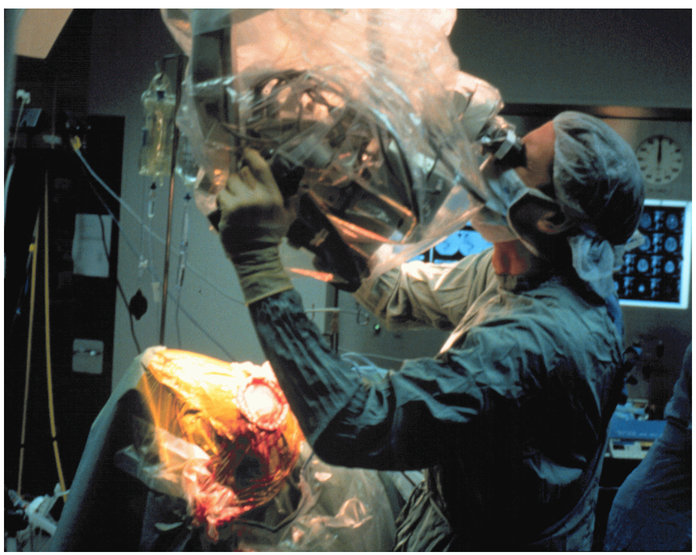
Operating Microscopes or operating binoculars can be adopted to AR-visualization.

Advantages:

- Optical system. Focal and parallax problems can be solved.
- Acceptance – the physician is already familiar with the device itself.

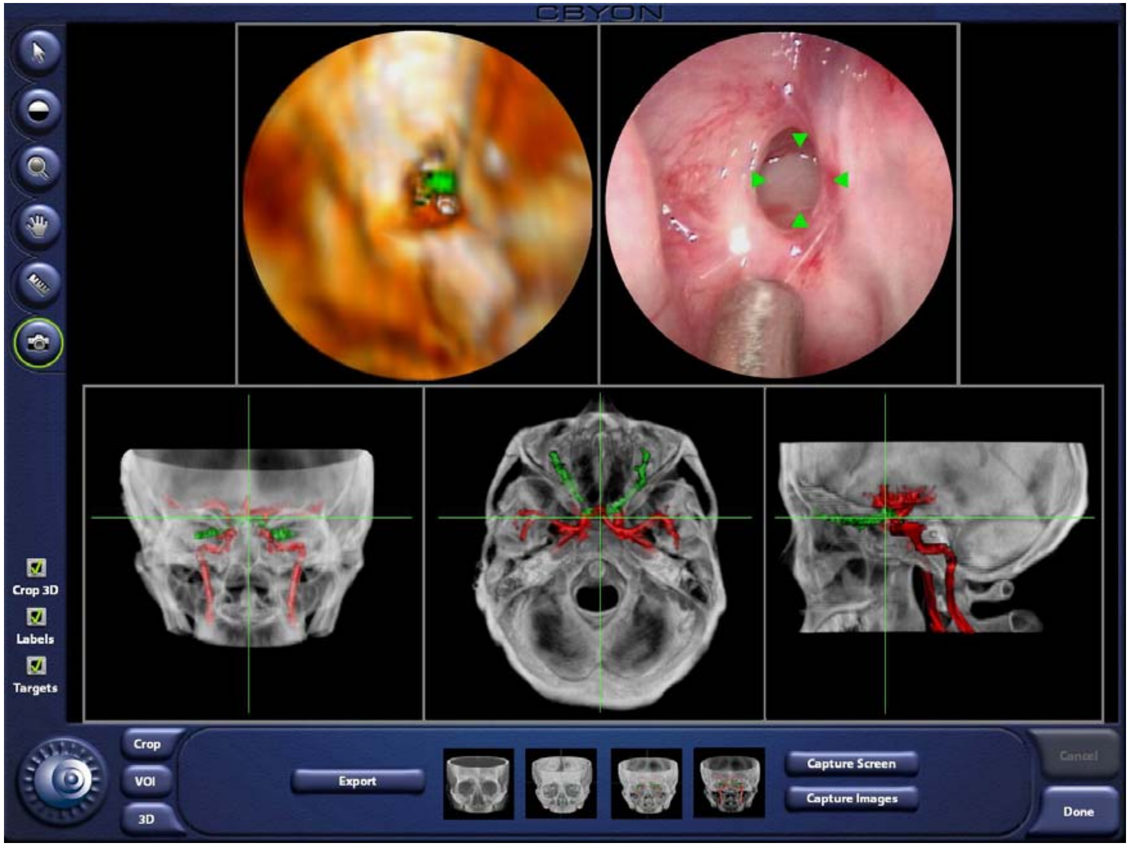
Disadvantage:

- Specialization



The MAGI system – an AR-operating microscope. Photograph courtesy of Dr. D. Hawkes, Guy‘s Hospital, London/UK. http://www-ipg.umds.ac.uk/magi/

Approaches: Medical Video Instruments



Advantages:

- No see-through system necessary

Disadvantage:

- Specialization

A screenshot of the CBYON system. Image courtesy of Dr. Ramin Shahidi, IGL Labs, Stanford/CA, and CBYON Inc., Palo Alto/CA

http://neurosurgery.stanford.edu/igl

Introducing the Varioscope

- Head-mounted
- Cost effective
- Approx. 300 grams
- Wide range of clinical applications
- Introduced in the surgical field by **Life Optics** Vienna

(http://www.lifeoptics.com)

Varioscope AR

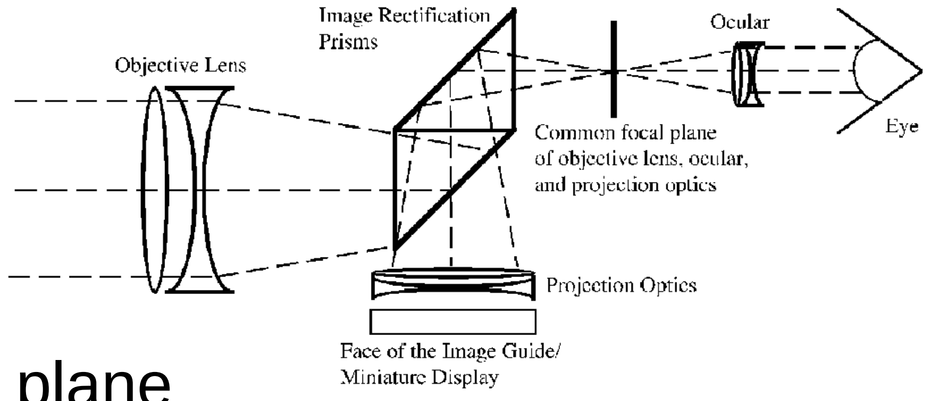
Development of an enhanced version of the Varioscope capable of stereoscopic fusion of optical images and computer-generated graphics -
the Varioscope AR

Development of an interface between the navigation system and the control unit for the Varioscope AR

Technical data

VGA displays, 1700 cd/m^2 (Planar,Beaverton/OR)

- Semi-transparent beamsplitters in the image rectification prisms

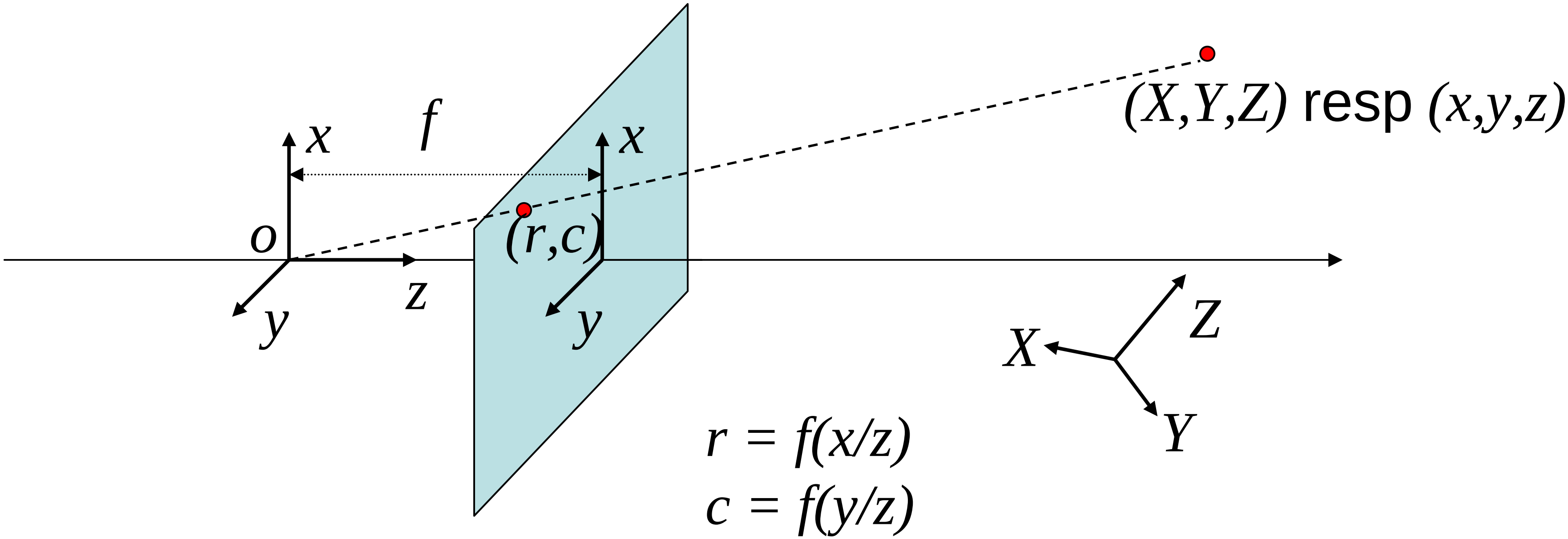


- Fusion in the focal plane of the main lens and the ocular

Camera Calibration

seven parameters:

- 3 rot and 3 translation *(X,Y,Z)* to *(x,y,z)*
- effective focal length *(x,y,z)* to *(r,c)*



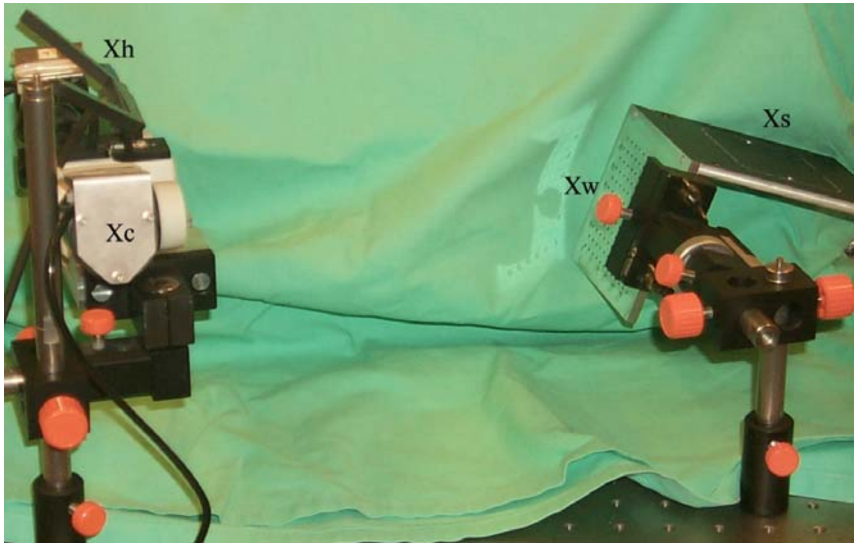
http://www-2.cs.cmu.edu/afs/cs.cmu.edu/user/rgw/www/TsaiCode.html

Calibration of the Varioscope AR

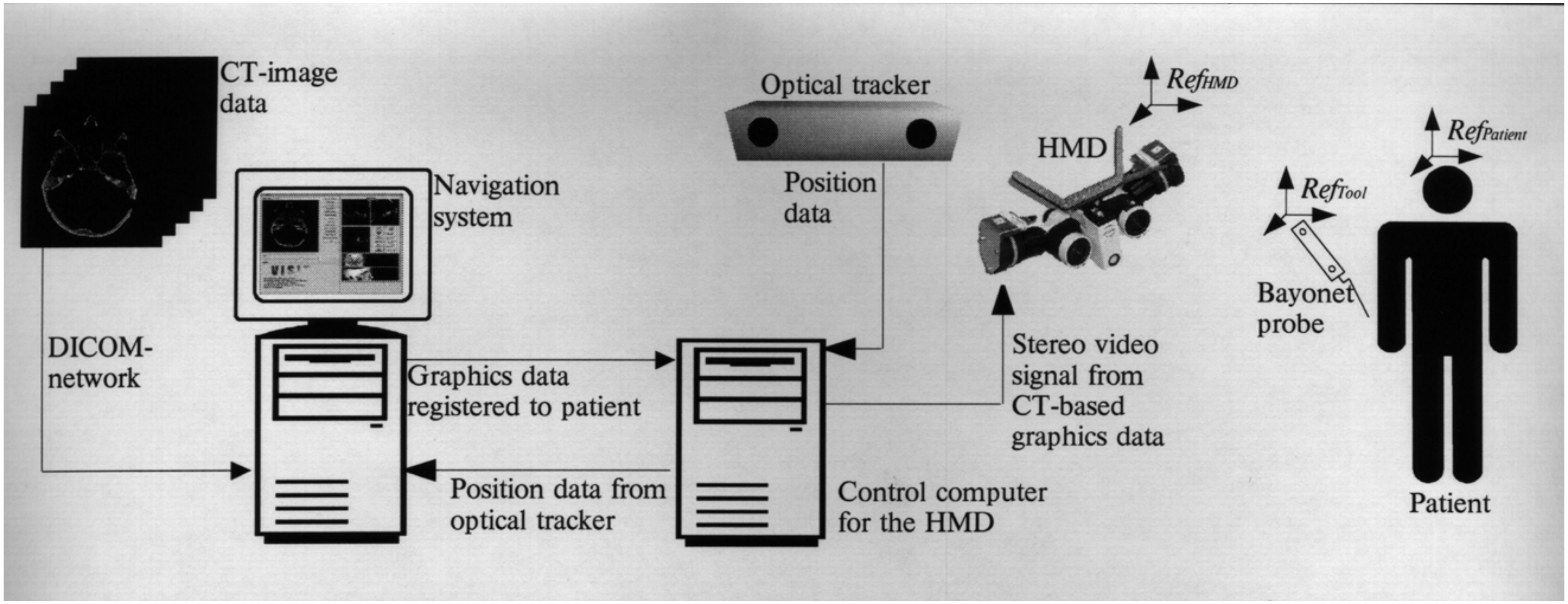
Transformation from
X_h to X_c

- camera calibration: T_{wc}: X_w to X_c
- tracker T_{hs}: X_h to X_s
- point to point T_{sw}: X_s to X_w

$$T_{hc}=T_{wc}\,T_{sw}\,T_{hs}$$

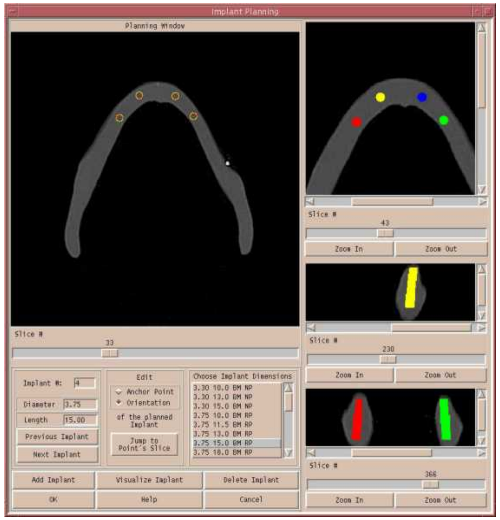


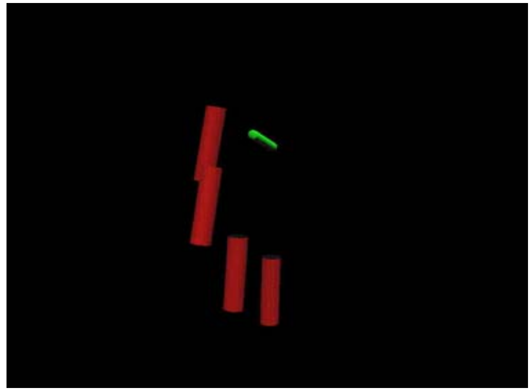
Data Flow

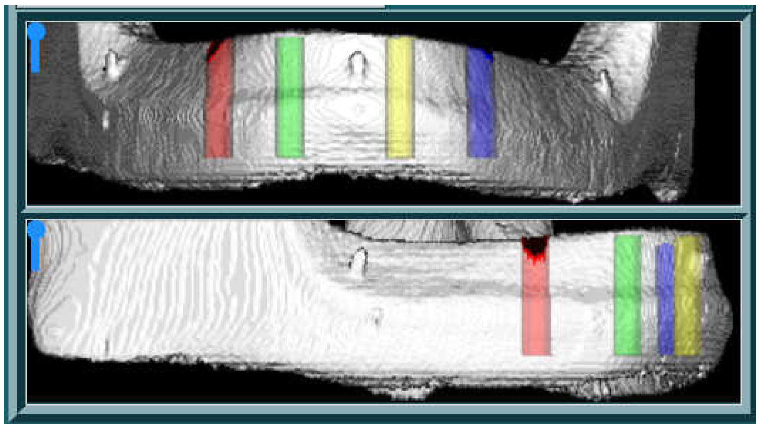


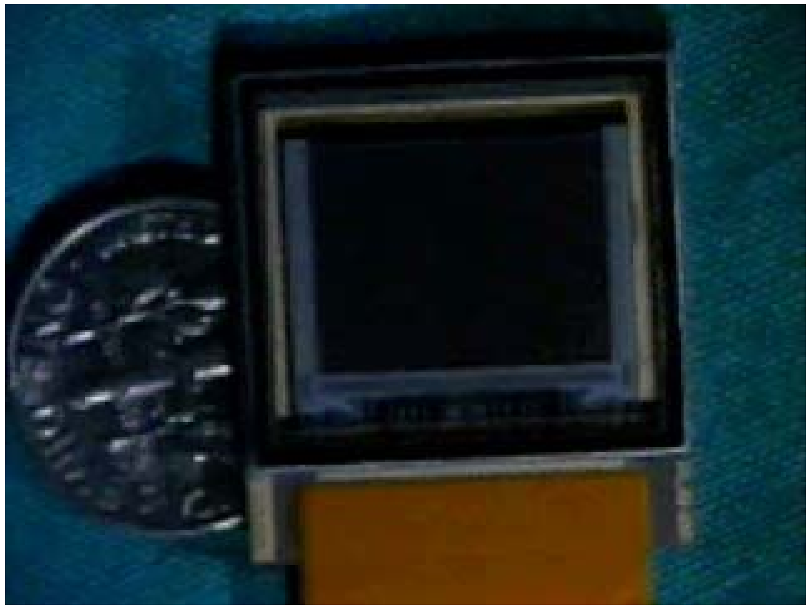
CT-image data
Optical tracker
Ref HMD
HMD
Ref Patient
Navigation system
Position data
Ref Tool
Bayonet probe
DICOM-network
Graphics data registered to patient
Stereo video signal from CT-based graphics data
Position data from optical tracker
Control computer for the HMD
Patient

What can be seen?
From Navigation to OpenGL

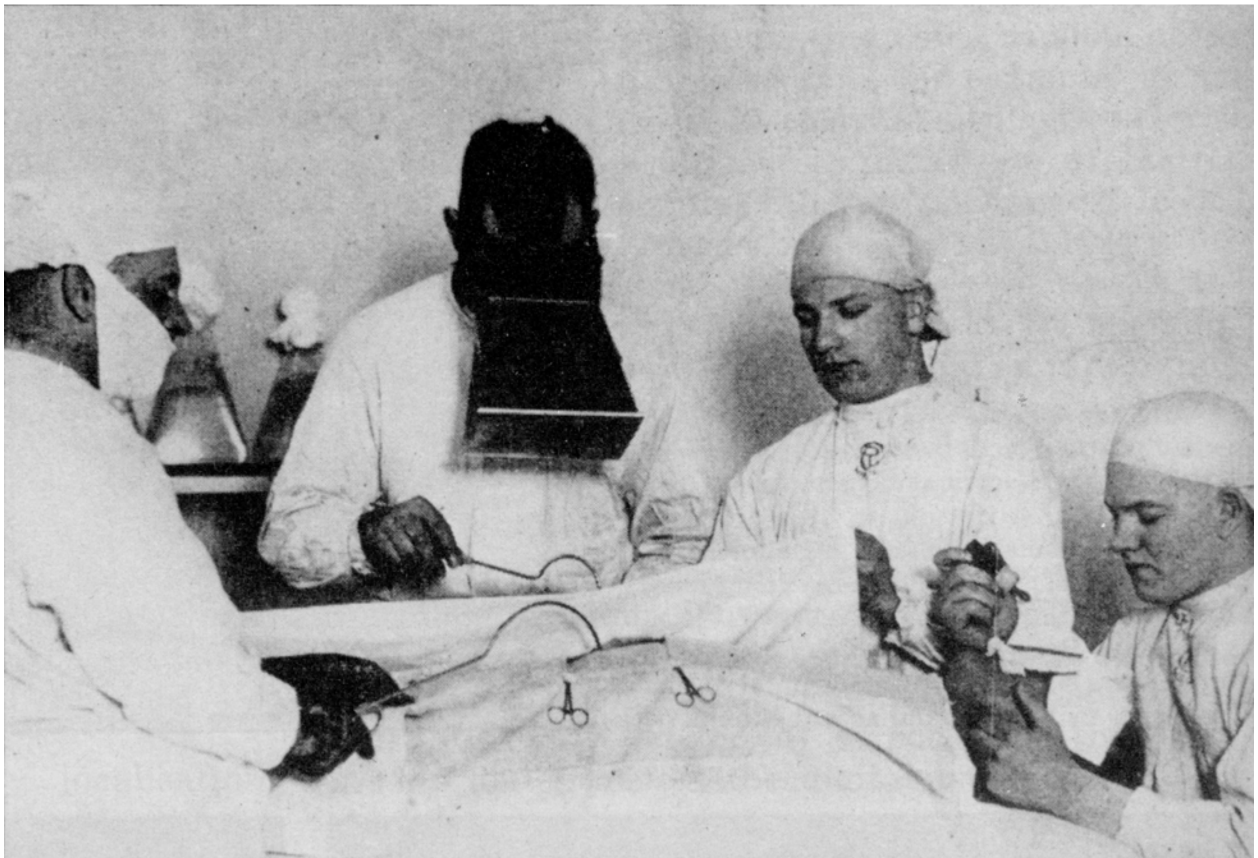








Intraoperative Application



Cadaver Study

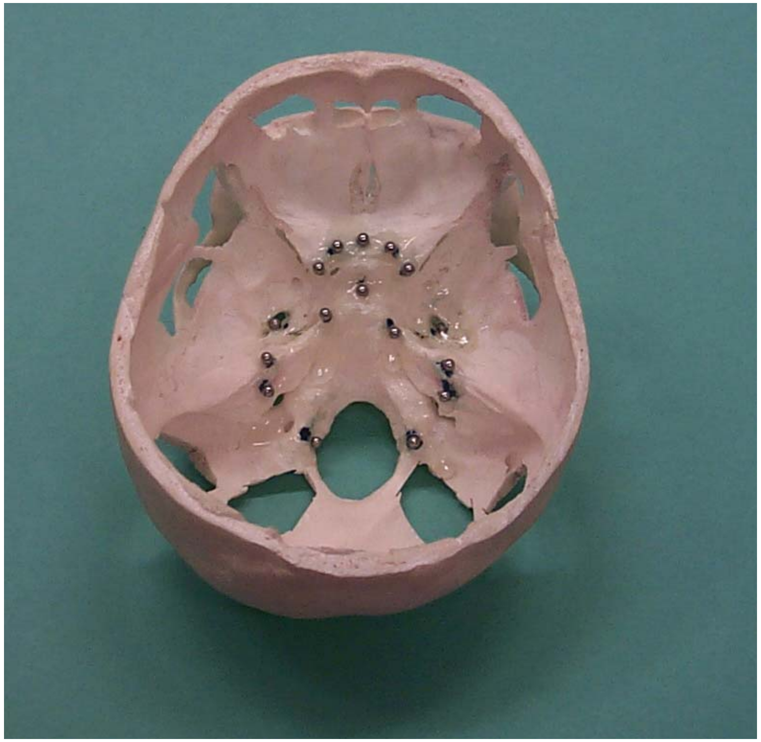
- three jaws, five implants each planned using VISIT
- stereoscopic display with 33 Hz

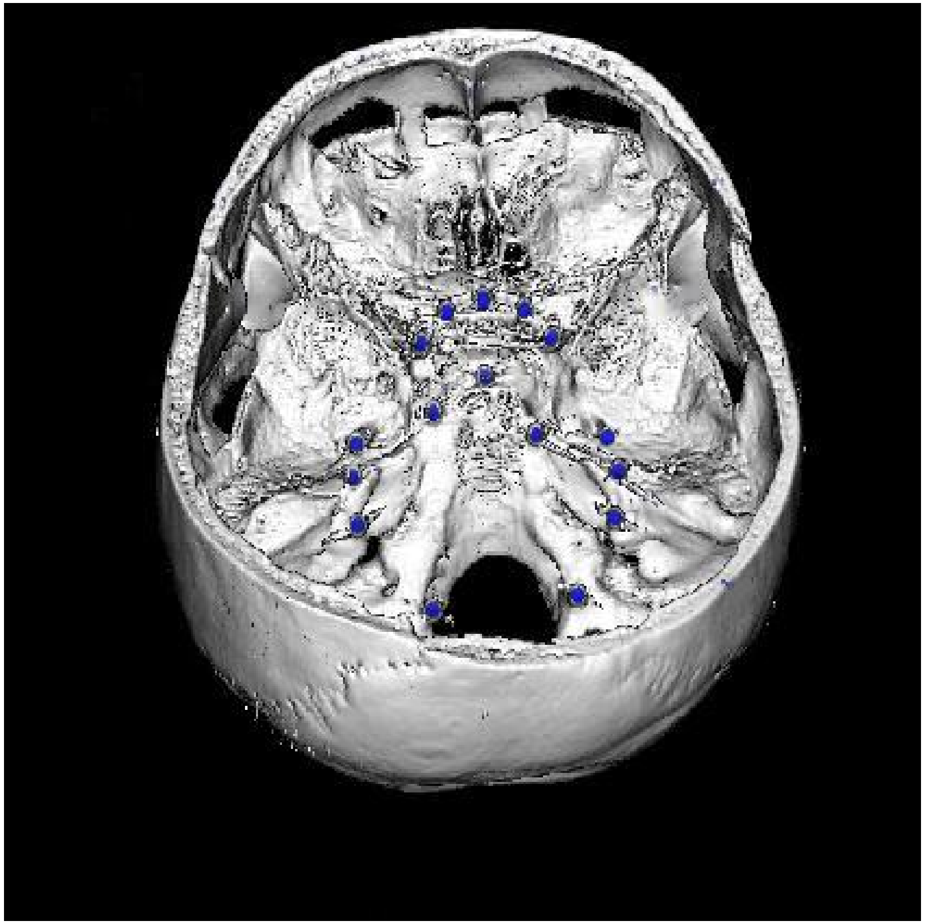
accuracy

top 0.57 +/- 0.49

bottom 0.77 +/- 0.63

Stereoscopy Phantom





improvement in hitting
monoscopic vs stereoscopic:
50% vs 81 %

[redacted]

Thank you!

michael.figl@univie.ac.at