Imaging and Sensors for Computer Assisted Surgery

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Position and Surface Sensors

- Position/Orientation Sensors
  - Mechanical
  - Optical (Active, Passive)
  - Magnetic
  - Acoustic
- Surface Sensors
  - Optical (Passive, Active)
  - 2.5D Ultrasound
  - X-Ray
  - Real-time MRI

in (

- Localize surgical instruments
- Localize exposed rigid surfaces (eg. scalp, bone) and measure deforming surfaces (eg. skin, heart)
- Localize scanners and other equipment (eg. X-Ray or Ultrasound Scanners)

Navigational guidance, Registration, Tracking

- Accuracy and Resolution
- Speed:
  - Bandwidth
  - Latency
- Robustness
- Multiple objects
- Volnerability to interference, line of sight requirement, unobtrusiveness

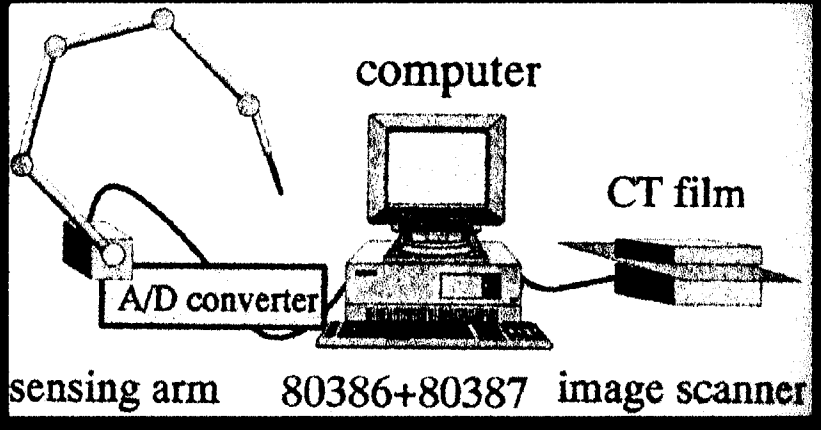
Mec[illegible]

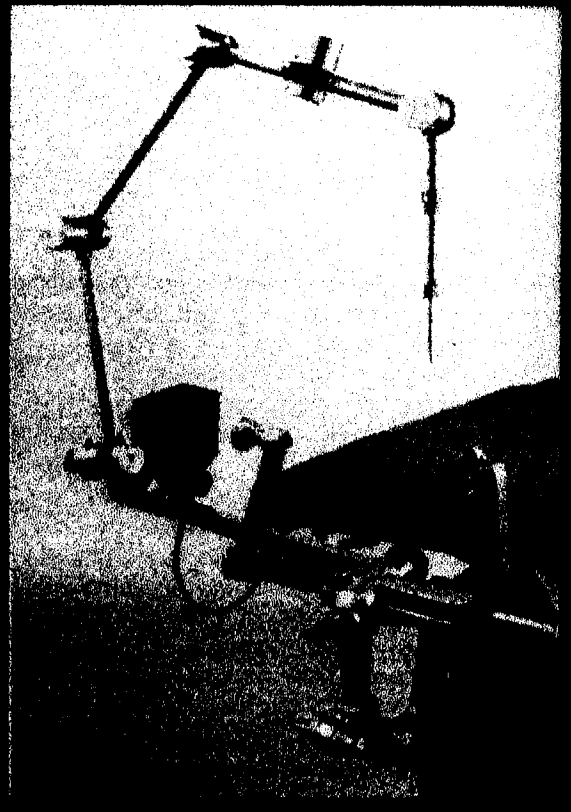
- Passive mechanical pointers with links and joints (> 6 DOF)
- Encoding : potentiometers or optical encoder
- Encoded angles and links kinematics -> locate tip

Accuracy	0.1 mm - 2.5 mm
Robustness	Very Good
Impediment	Yes
Multiple Objects	No
Some Examples	NeuroNav, Mark I , Mark II

Neuronavigator

- Multi-joint Arm
- PC and Image Scanner

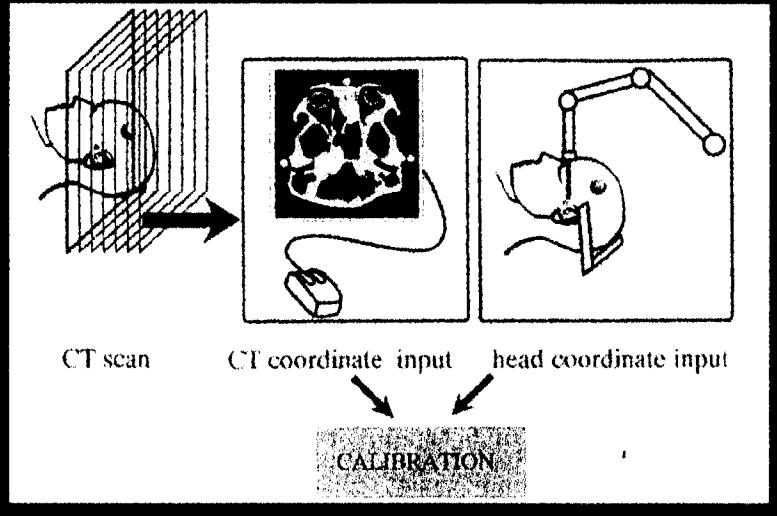


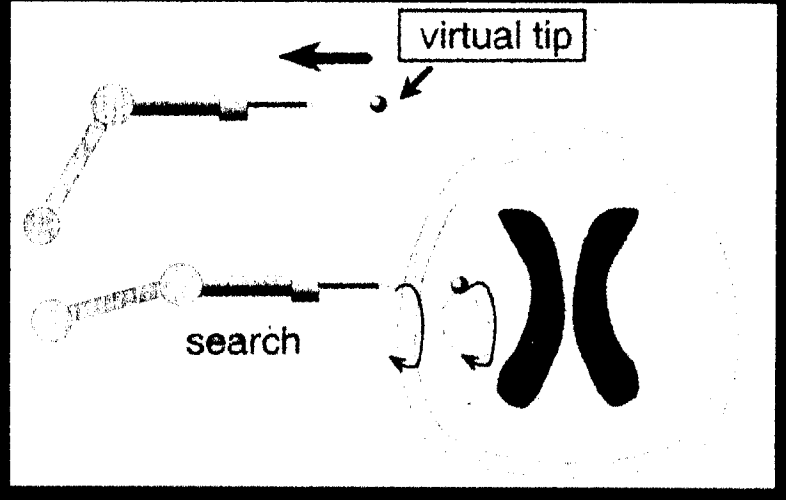


E. Watanabe, Tokyo Metropolitan Police Hospital, Tokyo, Japan

Neurosurgical Navigation

- Registration with Pre-operative CT of Brain
- Report and Visualize tip location in CT data
- Navigational Feedback using "Virtual-tip"





Optical Position Sensors

- Vision Systems with Active Markers
  - Active Markers (infra-red LEDs) placed on target objects
  - Tracking by multiple cameras (2D array, cylindrical lens with linear CCD arrays, or PSD sensor)

Accuracy	**0.2- 0.3 mm in OR range**
Resolution	**best about 0.01 mm**
Response Times	**2500 - 200 Hz**
Watch out for	**heat sources; Occlusion**
Impediment	**No**
Multiple Objects	**Yes**
Some Examples	**Optotrak, Pixsys/Flashpoint**

Magnetic Sensors

- Emitter coils are fed with alternating or direct current - create a magnetic field
- Receiver coils produce current when moved in magnetic field of emitter
- Receivers have 3 perpendicular coils
- Commercial systems - Bird, Polhemus (3Space Isotrak)

Accuracy	**about +/- 3 mm**
Update rates	**Polhemous 20 Hz, Bird 100 Hz**
Watch for	**Metallic objects (eddy currents)**
Multiple Objects	**No**
Impediment	**Yes**

Example [illegible]

A. Kato et al, Depts. of Neurosurgery and Radiology and Surgical Center, Osaka University Medical School, Japan

- Register CT/MR with Magnetic emitter ref. frame in OR
  - Four markers are placed on patient's head before CT/MRI
  - In OR, markers are read by placing probe with magnetic receiver mounted on it
- Use CT/MR for navigation . Update probe position every 30 sec

Acoustic [illegible]

- Ultrasound emitters (spark emitters or piezo-electric crystals) attached to object
- Receivers (microphones or piezo-electric) placed in OR

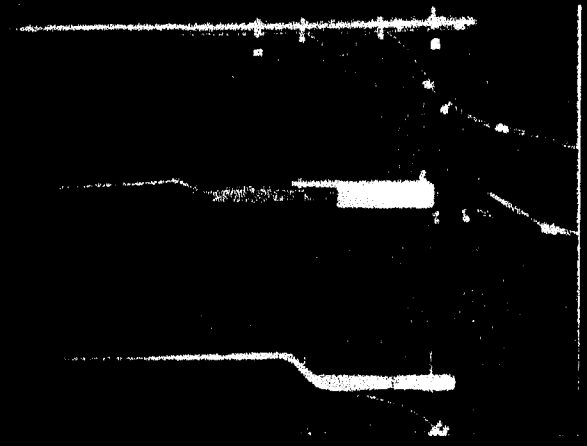
Accuracy	about 1 mm
Resolution	about 0.1 mm
Response Times	Orders of msec in OR range
Robustness	Temperature, humidity, Occlusion
Multiple Objects	Yes
Impediment	No

Example Use of [illegible] Wand

Frameless Stereotaxy

G. H. Barnett, et. al, Cleveland Clinic Hospital, Cleveland, Ohio

Detectors mounted on OR Table



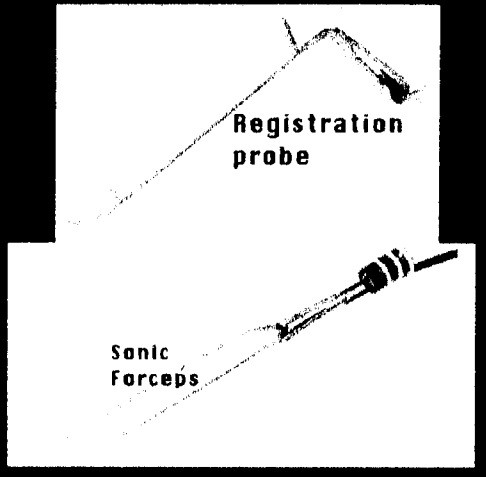
Emitters on tools

Reproducibility	0.6-1mm (at < 1 m range)
Accuracy	1.5 mm +/- 0.7 mm (rough)
Example Use	Frameless Stereotaxy

Some Figures

R. Bucholz, et. al, St. Louis University Health Sciences Center, St. Louis, MO

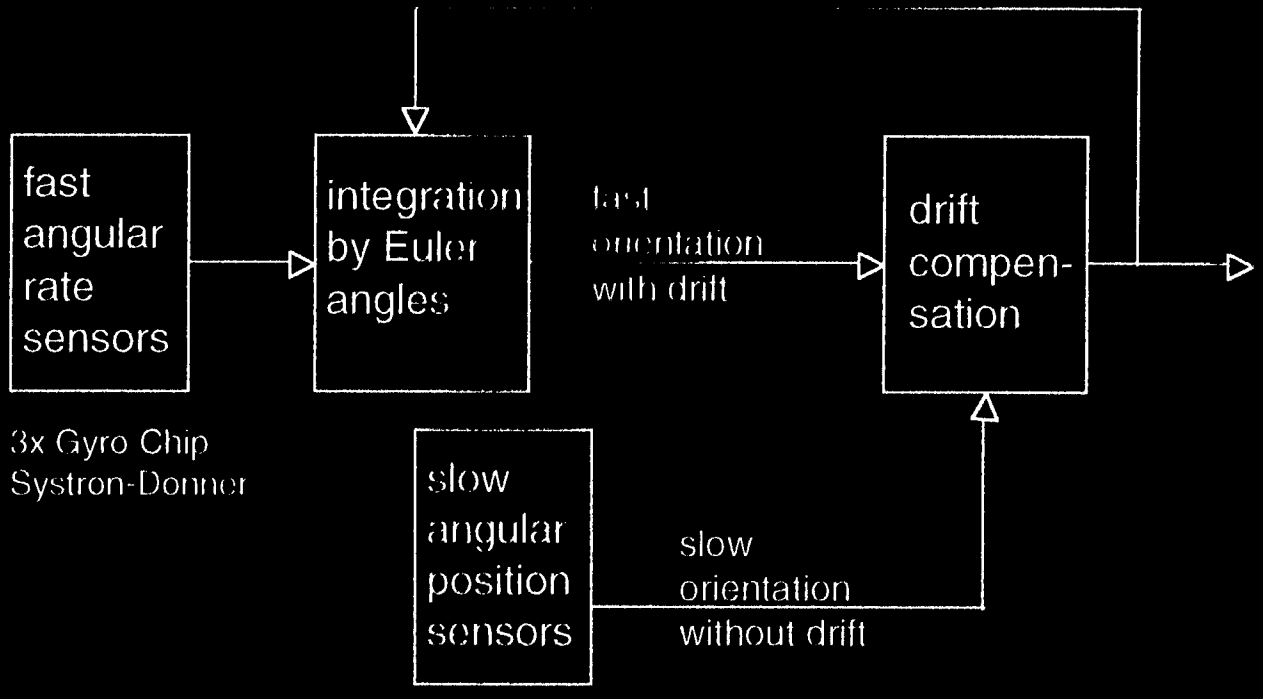
Microphone Arrays on adjustable slides



Emitters on tools

Accuracy	about 2.5 mm
Example Use	Frameless Stereotaxy

INS Head Tracker



- Foxlin and Durlach, Research Lab of Electronics, MIT 1994

INS Tracker Performance

Specification	Achieved
Angular Range	yaw: +/- 180° pitch: +/- 90° roll: +/- 90°
Positional Range	unlimited
Angular Velocity	+/- 1000°/s
Angular Accelaration	> 6000°/s²
Angular Accuracy	pitch & roll: 1° yaw: ~ 3°/min drift
Angular Resolution	0.0082° RMS
Bandwidth	tested to 15 Hz probably flat to 70Hz
Latency	0.1 ms

Surface Sensors

- Optical Surface sensors
  - Passive stereo vision
  - Active range imagers: structured light, laser scanner (Ladar)
- 2.5D Ultrasound
  - Can be used to localize patient's unexposed organs (ex. bone) in conjuction with a position tracker
- X-Ray
  - Can be used to localize patient's unexposed organs (ex. bone) in conjuction with a position tracker

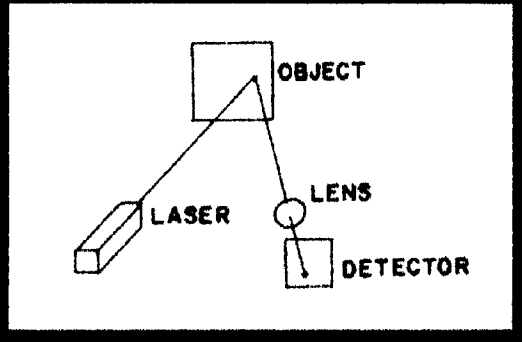
Passive Stereo Vision

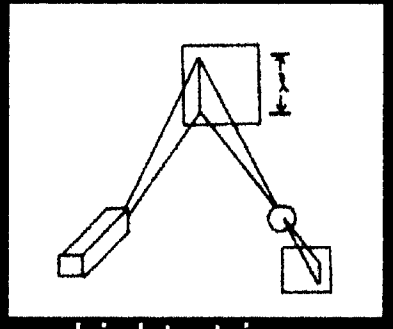
- At least 2 cameras look on the scene with object
- Disparity of the corresponding points in two images are used to find 3-d location of the points
- When object is featureless or textureless, passive markers are placed (or pattern can be projected) on them as features to be identified in images

Accuracy	1 mm in OR range
Response Times	1000pt/sec to video rate
Resolution	best about 0.01 mm
Robustness	Affected by ambient light metal-reflectors; Occlusion
Impediment	No
Multiple Objects	Yes

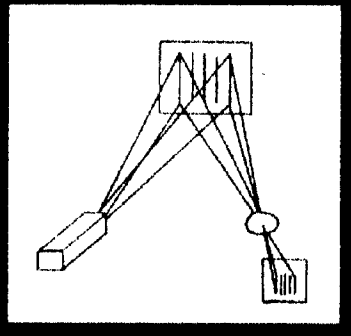
Active Range Imagers

- Time of flight laser scanning range imager
  - ERIM, Perceptron, K2T - Long range
- Active illumination (structured light) range imager





Light stripe

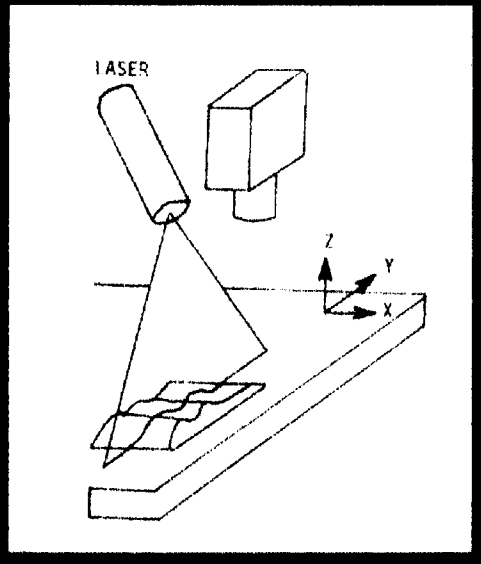


- Active Range from Defocus Sensor

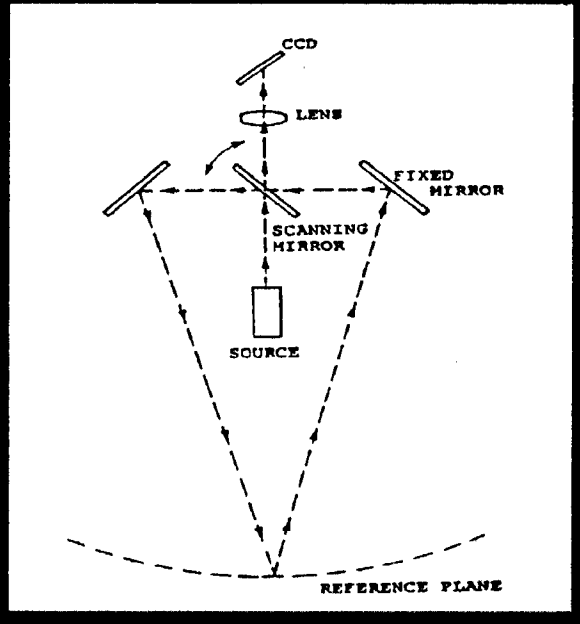
...ht Stripe Ra... finders

- A laser light stripe is projected onto object
- An imaging sensor (CCD video camera) views intersection of object with plane of light
- Faster ones project a pattern of light
- Ultrafast ones view all "profiles" in parallel

Accuracy	0.5-1 mm in OR range
Response time	tens of secs - millisec (ultrafast)
Robustness	Reliable; Occlusion prone
Impediment	No
Multiple Objects	Yes



Basic light stripe sensor



Synchronous Scanning

Grey-code K2T range sensor

X-ray

- A position tracker is attached to the X-ray device
  - The X ray projected images needs to be calibrated wrt to this position tracker
  - External calibration of device tracker wrt OR F-of-Ref

Accuracy	about 0.5 mm
Response time	Requires segmentation
Robustness	Very Reliable
Impediment	No; But harmful
Multiple Objects	Yes

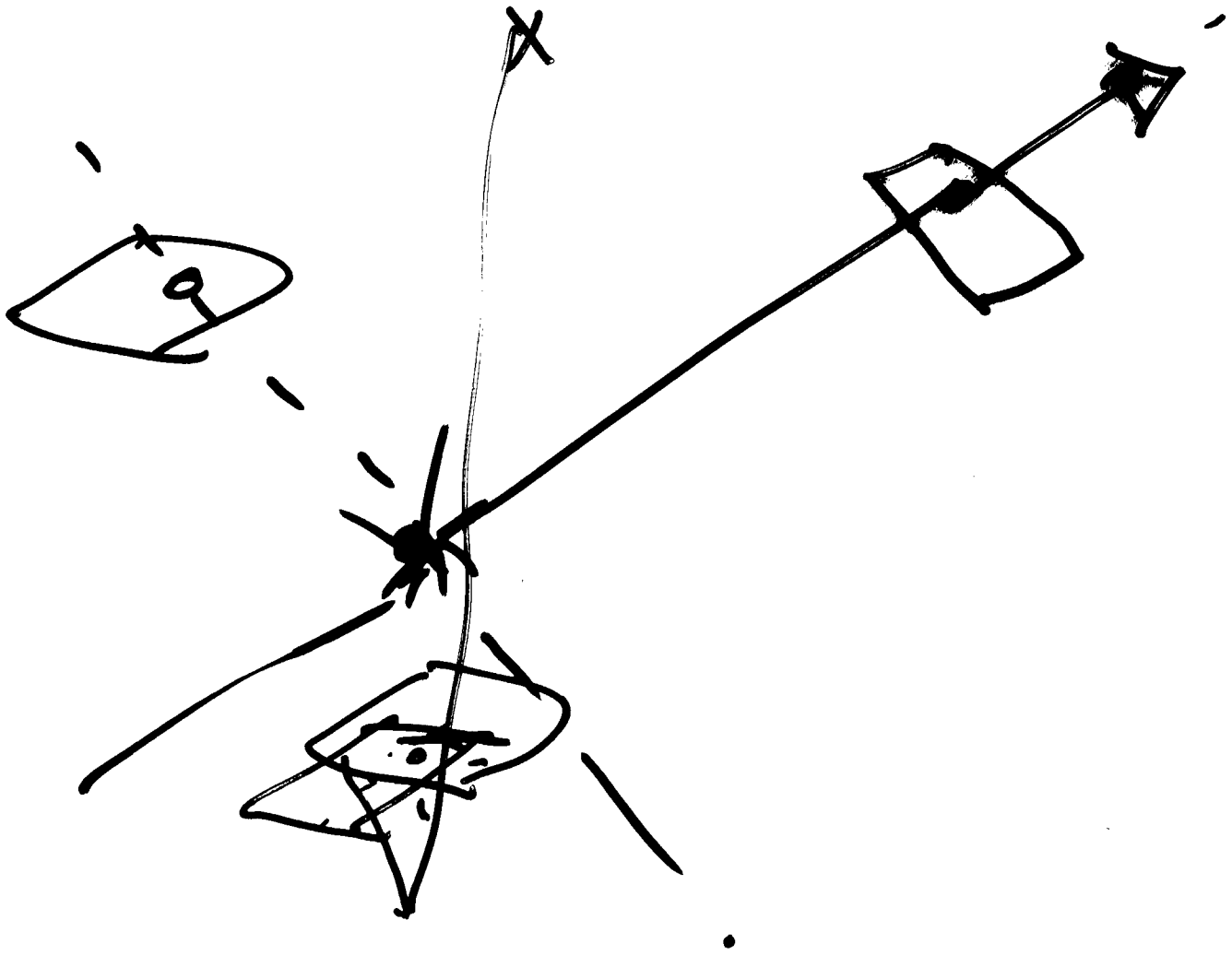
2. [illegible]

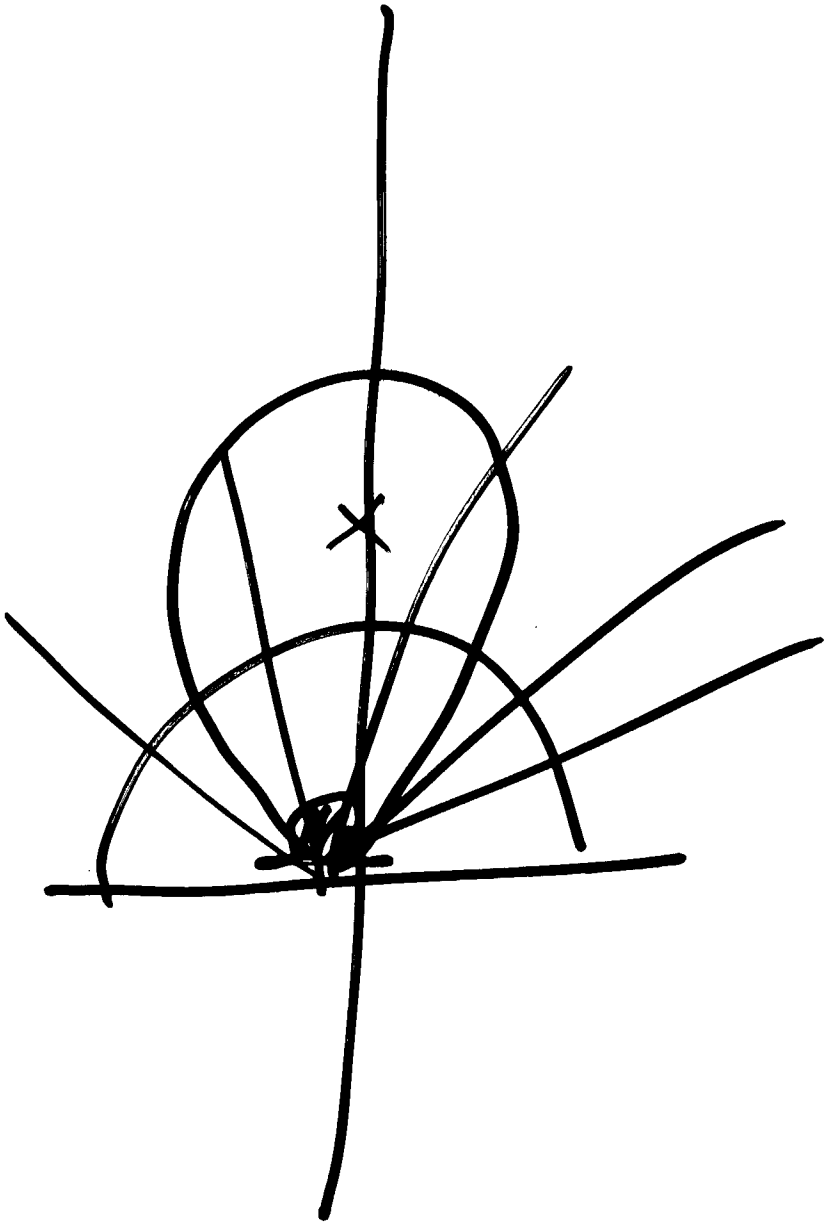
- Phased Array Ultrasound scanners
  - Linear arrays or Annular arrays
  - Frequency of operation 3.5 - 5 MHz
- US-Scanners as localizers
  - Reference frame (eg. Optotrak LEDs) attached to them
  - Calibration of US image wrt the co-ord frame of
  - Calibrate and Track FOR on scanner with OR Ref. Frame

Accuracy	**about 1 mm**
Resolution	**Typical 1 mm;** improves with freq
Response time	**Imaging 2-4 s;** segmentation

Open Configuration Split-Magnet Prototype

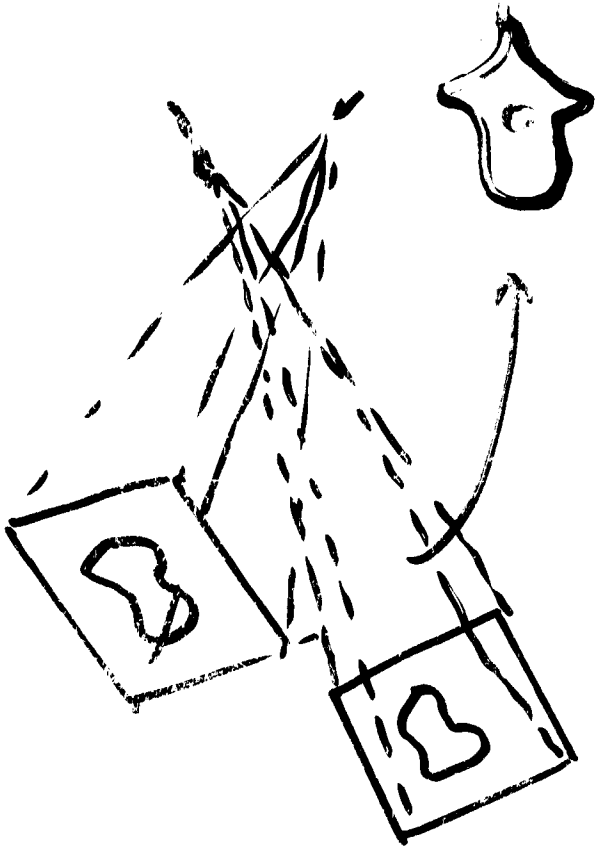
- Open-configuration allows physicians access to patient.
- Guiding, monitoring, controlling therapeutic interventions or minimally invasive surgical procedures.
- Diagnostic capabilities of MRI can be used for direct control of surgical medical lasers.
- Non-incisional, non-invasive method of MR guided focused ultrasound to treat breast tumors.





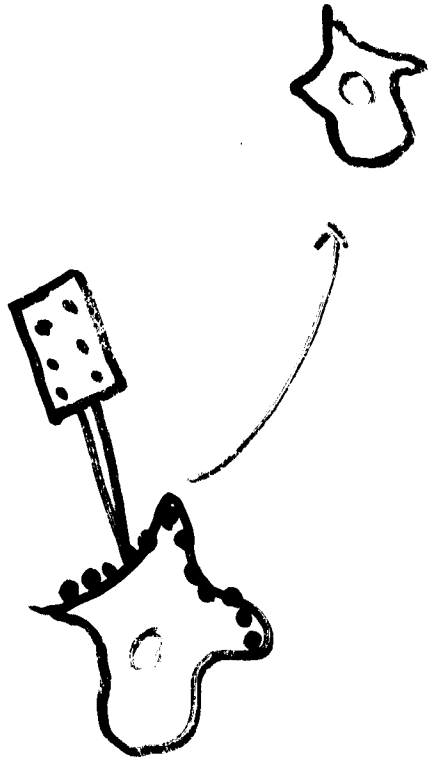
3D/2D

X ray



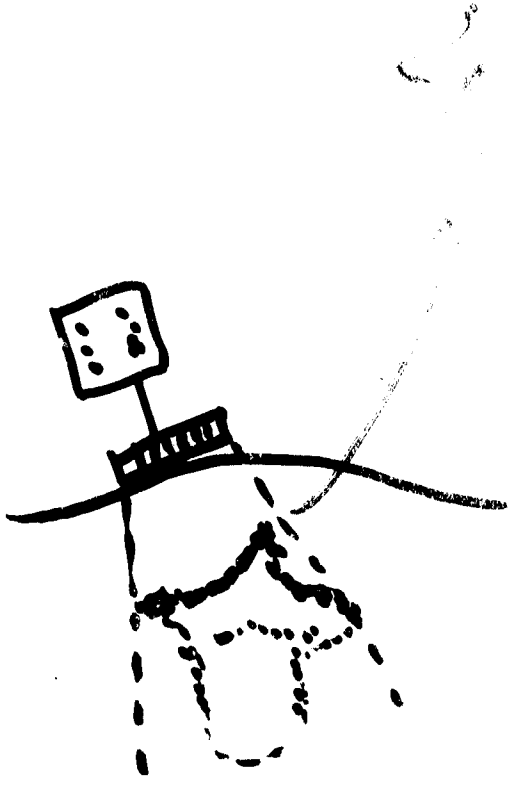
3D/3D

Pointer



3D/2.5D

Ultra Sound



MULTI-SENSOR FUSION

REAL-TIME INTRA-OPERATIVE FEEDBACK

REAL TIME MRI

INTEGRATED APPROACH

DIAGNOSIS, PLANNING, EXECUTION, EVALU-ATION

PRESION- REGISTRATION & MECHANISM

SAFETY & VERIFICATION

Cost & Benefit

Medical Applications of Robotics Technology

From

Diagnosis and Visualisation
Planning and Simulation
Telemedicine and Mobile Computing

To

Inter-Operative Use

- **Image Overlay**
- **Registration**
- **Image-Guided Navigation**
- **Tele-Surgery**