FORCE FEEDBACK IN ROBOTIC NEUROSURGERY

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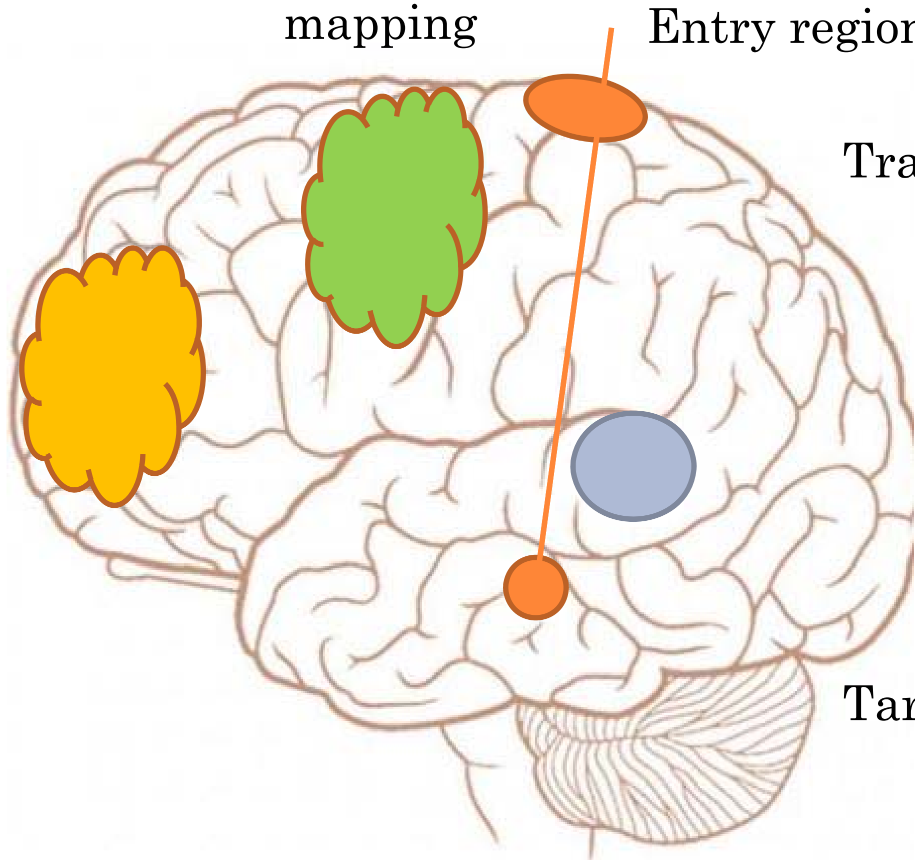
Brain and computer assisted robotic surgery



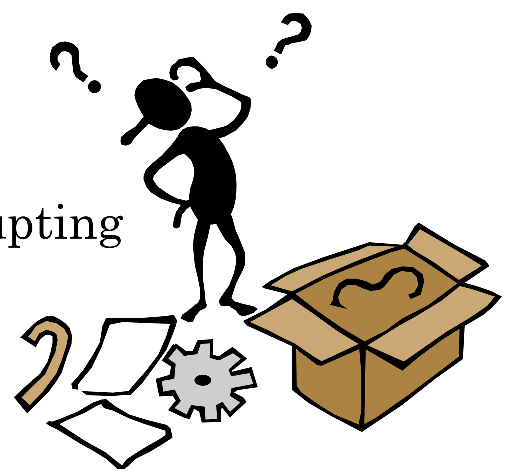
Brain Pathologies

- Stroke
  - blockage or rupturing of blood vessels in the brain
- Neurodegenerative diseases (Alzheimer's disease, **Parkinson's disease**, motor neuron disease, and Huntington's disease)
  - gradual death of individual neurons, leading to diminution in movement control, memory, and cognition
- **Epilepsy**
  - chronic neurological disorders characterized by seizures
- **Brain tumors**

The interconnectivity of the brain requires that neurosurgeons operate with precise localization to protect the brain's functionality.

Computer assisted neurosurgery/ robotic neurosurgery

- **Tools for surgical planning**
- Surgical simulators for training and planning (patient specific)
- Intra-operative Images/ models update
- Precise targeting
- Tremor filtering, motion/force scaling to improve accuracy
- Regions constraints definition (safety enhancement)
- Ergonomic and comfortable position for the surgeon
- Access to sophisticated imaging data without interrupting the surgical procedure

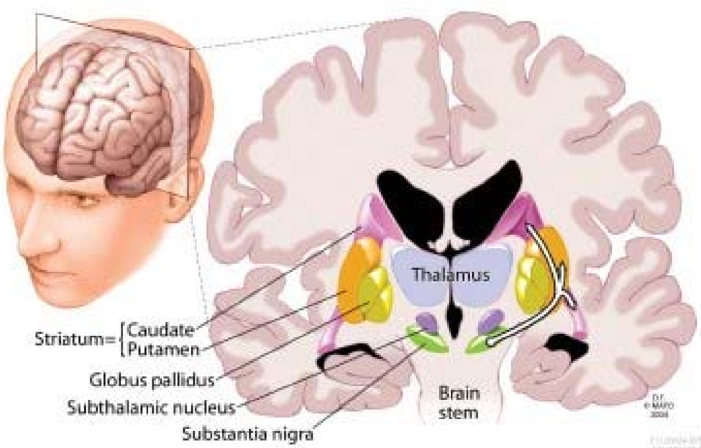


PARKINSON'S DESEASE

- Degenerative disorder
  - Death of the dopamine-generating cells in the substantia nigra in the mid brain
  - Motor-related symptoms (shaking, rigidity, difficulty in walking and gait)

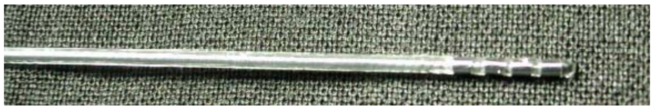
- Treatments using levodopa and dopamine agonist

- Treatment stimulating the thalamus, the globus pallidus, or the subthalamic nucleus



PARKINSON'S DESEASE

- **Target** subthalamic nucleus, globus pallidus internus, caudal part of the ventro-lateral nuclei of the thalamus



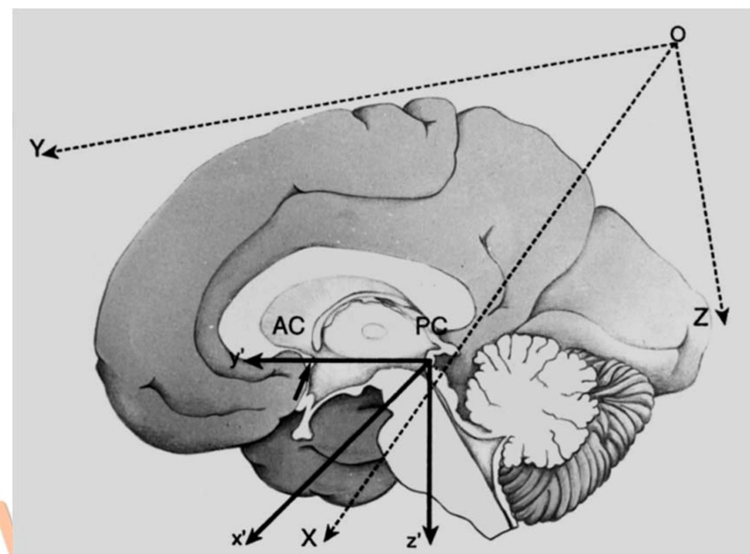
Platinum iridium electrodes

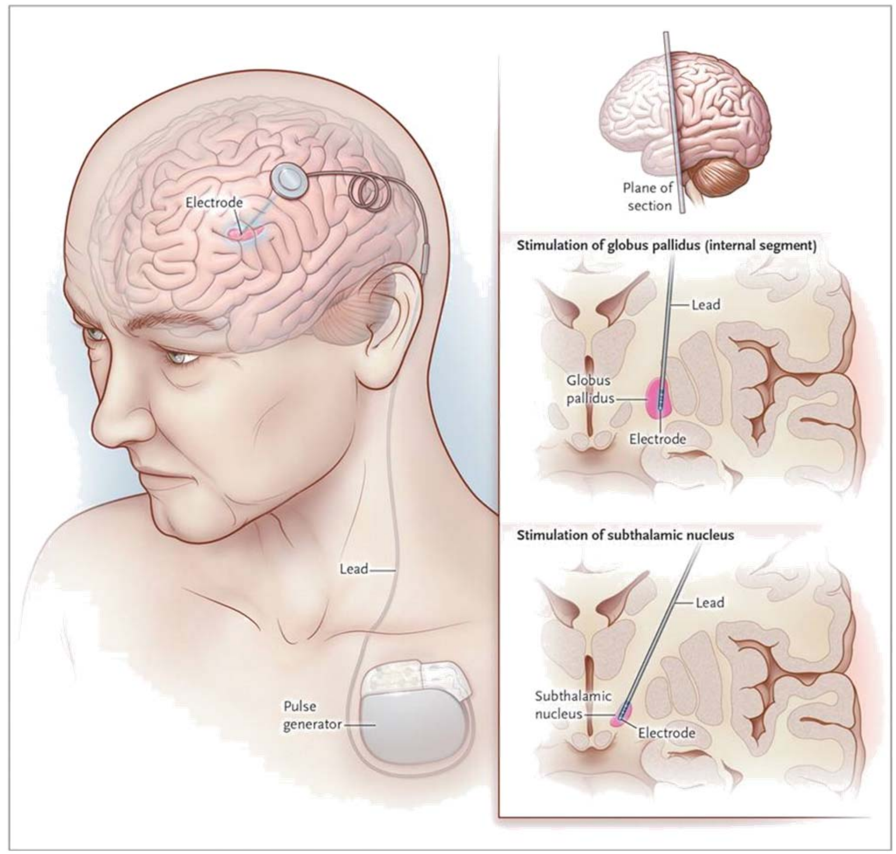
Cylindric electrode contacts

1.27 mm diameter and 1.5 mm length

1-3.5 V 60-210 μsec PW 1 mA

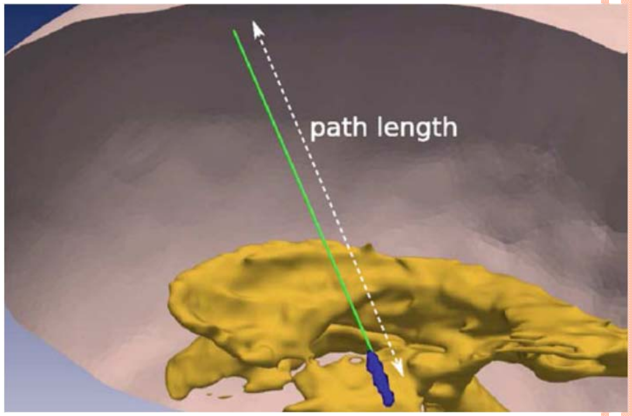
2-185 Hz

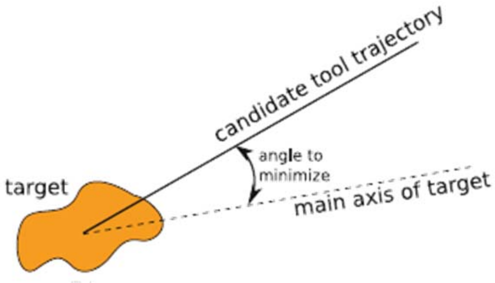




Deep Brain Stimulation

- Planning rules
  - Place the electrode into the target
  - Position of the insertion point
  - Path length restriction (<90 mm)
  - Avoid risky structures (ventricles/ vessels)
  - Minimize the path lenght
  - Maximize the distance between the electrode and risky structures
  - Optimize the orientation of the electrode depending on target shape
  - Placing the tip as close as possible to the center of the target





Vaillant (1997), Brunemberg (2007),
Shamir (2010), Essert (2011), Beriault (2011)

EPILEPSY

Epilepsy is a neurological disorder associate with seizures (abnormal electrical activity) that affects **1%** of the world population

30% of patients remain refractory to medications, for them surgery is an effective treatment

Normally brain electrical activity is non-synchronous. In epileptic seizures, due to structural or functional problems within the brain, a group of neurons begin firing in an abnormal, excessive, and **synchronized manner** (paroxysmal depolarizing shift).

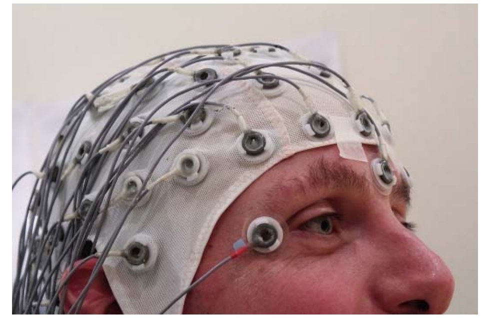
The specific area from which seizures may develop is known as a "**seizure focus (EZ)**".

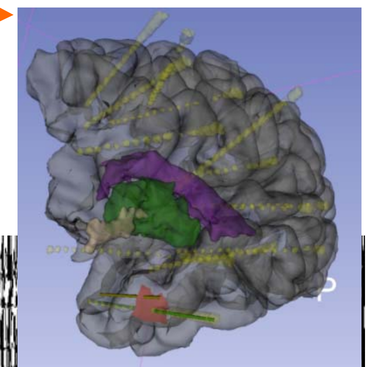
Focal seizures begin in one hemisphere of the brain while generalized seizures begin in both hemispheres.

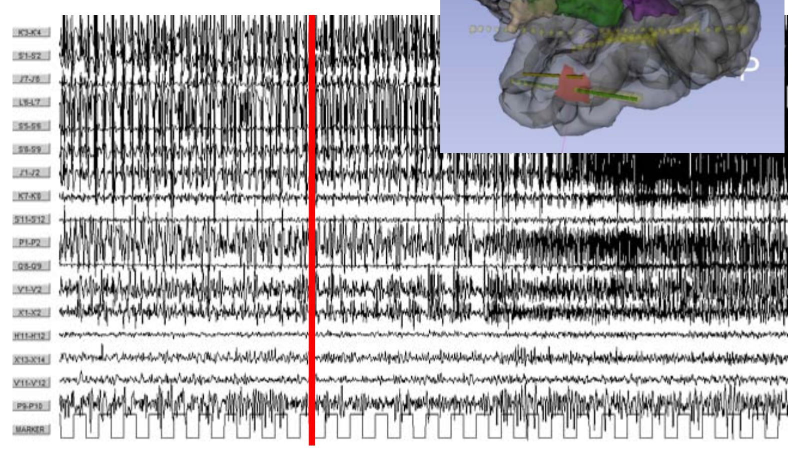
Epileptogenic Zone (EZ): cortical area where ictal discharges originate and which must be surgically resected to achieve seizure freedom

Identification of the EZ

- Identification of the target (EZ):
  - Long term video-EEG
  - Neuropsychological evaluation
  - MRI
  - SPECT
  - Stereoelectroencephalography (SEEG)
  - Cortical grids





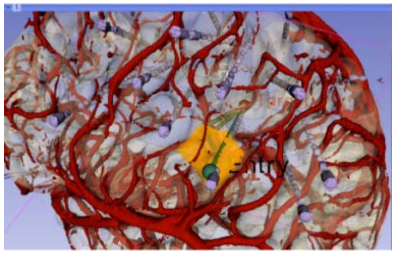


- Surgery
  - Anterior temporal lobectomy
  - Callosotomy
  - Multiple subpial transection

AUTOMATIC TRAJECTORY PLANNER FOR SEEG

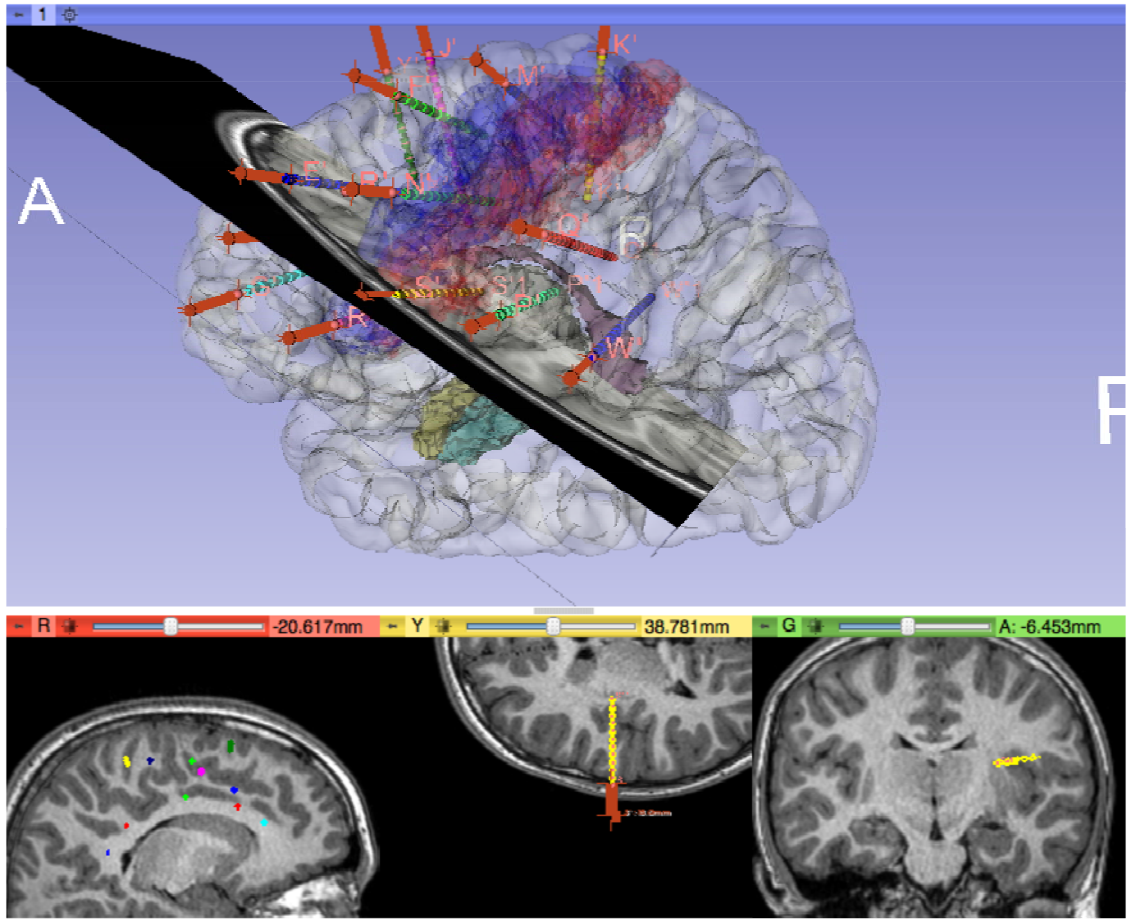
Rules:

- Maximize electrodes distance from vessels



- Maximize perpendicularity to the skull

- Avoid important structures (e.g ventricles)

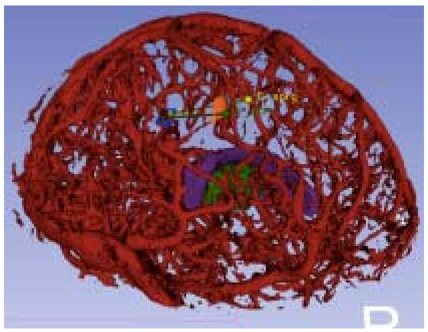


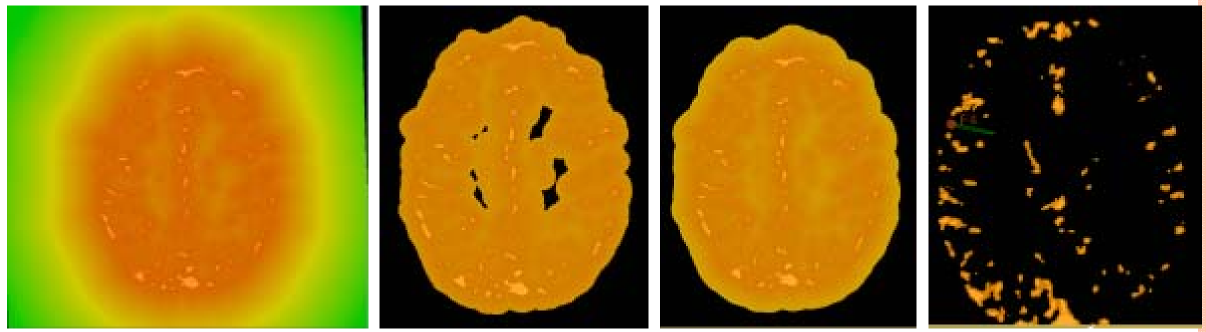
De Momi E, et al. Multi-trajectories automatic planner for StereoElectroEncephaloGraphy (SEEG).. 2014
De Momi E, et al Automatic trajectory planner for StereoElectroEncephaloGraphy procedures: a retrospective study.

Automatic Trajectory Planner for SEEG

How to translate the rule into maths:

- *Maximize electrodes distance from vessels*





Danielsson, 1980

- Enhance vessel from images dataset
- Compute a distance map, each voxel value is the distance to the nearest vessel
- Assign a cost value to trajectories

AUTOMATIC TRAJECTORY PLANNER FOR SEEG

How to translate the rule into maths:

- *Maximize electrodes distance from vessels*

Voxel-line intersection: 2D ray tracing

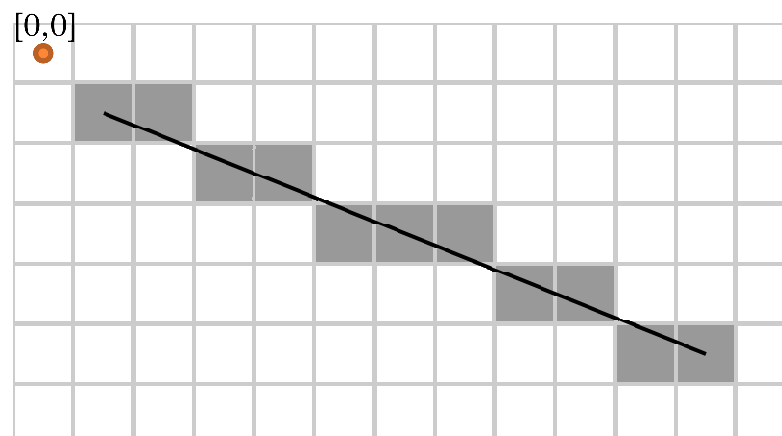
Case 1: $x_0 \leq x_1$ $y_0 \leq y_1$ the line has a negative slope whose absolute value is less than 1

Bresenham's algorithm chooses the integer y corresponding to the pixel center that is closest to the ideal (fractional) y for the same x; on successive columns y can remain the same or increase by 1. The general equation of the line through the endpoints is given by:

$$\frac{y-y_0}{y_1-y_0} = \frac{x-x_0}{x_1-x_0}$$

Since we know the column, x, the pixel's row, y, is given by rounding this quantity to the nearest integer:

$$y = \frac{y-y_0}{x_1-x_0}(x-x_0)+y_0$$



The slope $y-y_0/x_1-x_0$ depends on the endpoint coordinates only and can be precomputed, and the ideal y for successive integer values of x can be computed starting from and repeatedly adding the slope.
In practice, the algorithm can track, instead of possibly large y values, a small *error value* between −0.5 and 0.5: the vertical distance between the rounded and the exact y values for the current x. Each time x is increased, the error is increased by the slope; if it exceeds 0.5, the rasterization y is increased by 1 (the line continues on the next lower row of the raster) and the error is decremented by 1.0.

Bresenham, IBM Journal of Research and Development, 1965

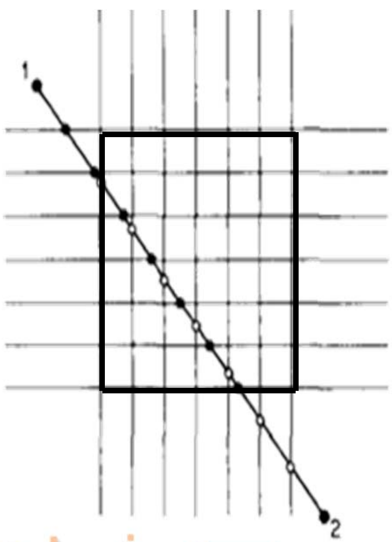
AUTOMATIC TRAJECTORY PLANNER FOR SEEG

How to translate the rule into maths:

- *Maximize electrodes distance from vessels*

Voxel-line intersection: 3D ray tracing (non isotropic voxels)

- Decompose the volume in an intersection of 3 sets of planes, each one orthogonal to a main axis.
- Compute the first intersection between the line and a set of planes: then, since planes are equally spaced, iteratively add the projection of the plane spacing on the line axis to obtain the others.
- New intersection marks new crossed voxel: finally, purge duplicate voxel crossings



$$\begin{cases} \mathbf{l}_0 + (\mathbf{l}_b - \mathbf{l}_a)t, t \in \Re \\ (\mathbf{p} - \mathbf{p}_0) \cdot \mathbf{n} = 0 \end{cases}$$ Solve for $\boldsymbol{t}$

$\mathbf{l}_a$ and $\mathbf{l}_b$ are start and end point of line tracing

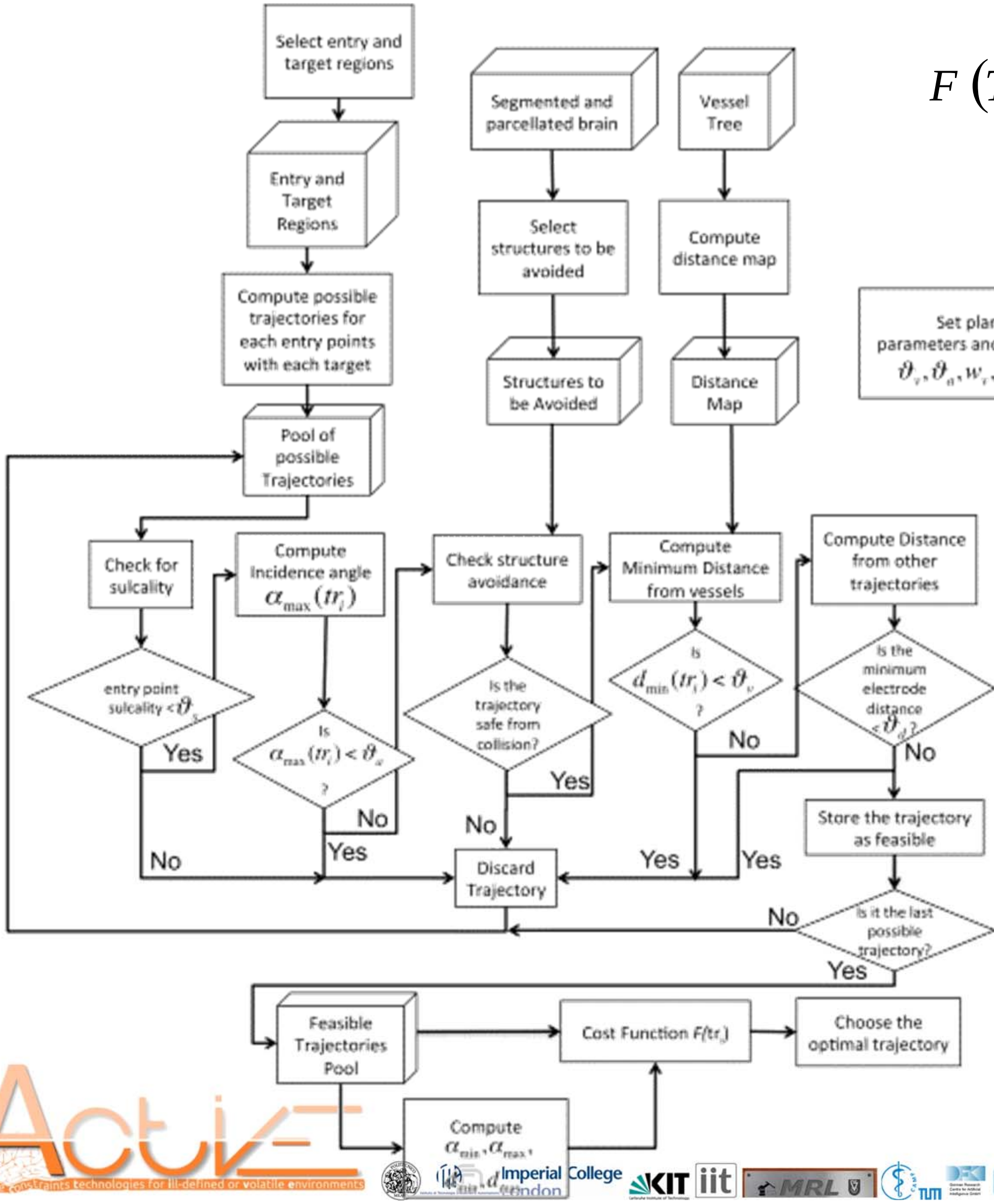
$\mathbf{p}$ is the generic point of the plane

$\mathbf{p}_0$ is a point on the plane

$\mathbf{n}$ is the plane normal

Siddon, Medical Physics, 1985

Automatic Trajectory Planner for SEEG

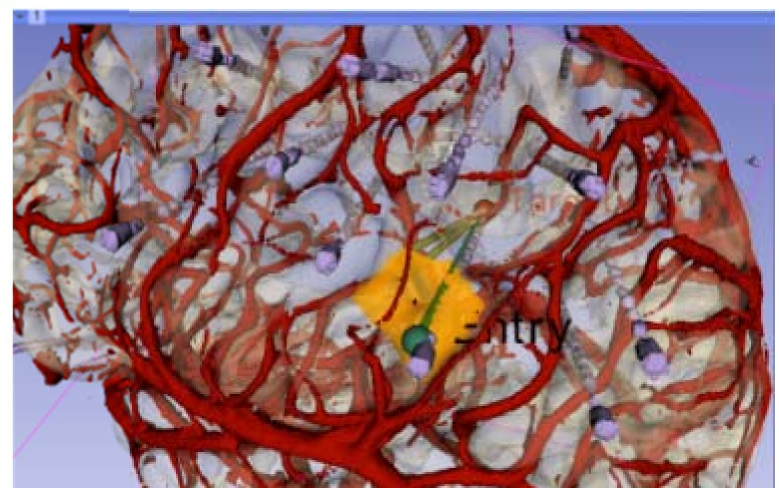


Set planning parameters and thresholds: $\vartheta_v, \vartheta_a, w_v, w_a, \vartheta_d, \vartheta_s$

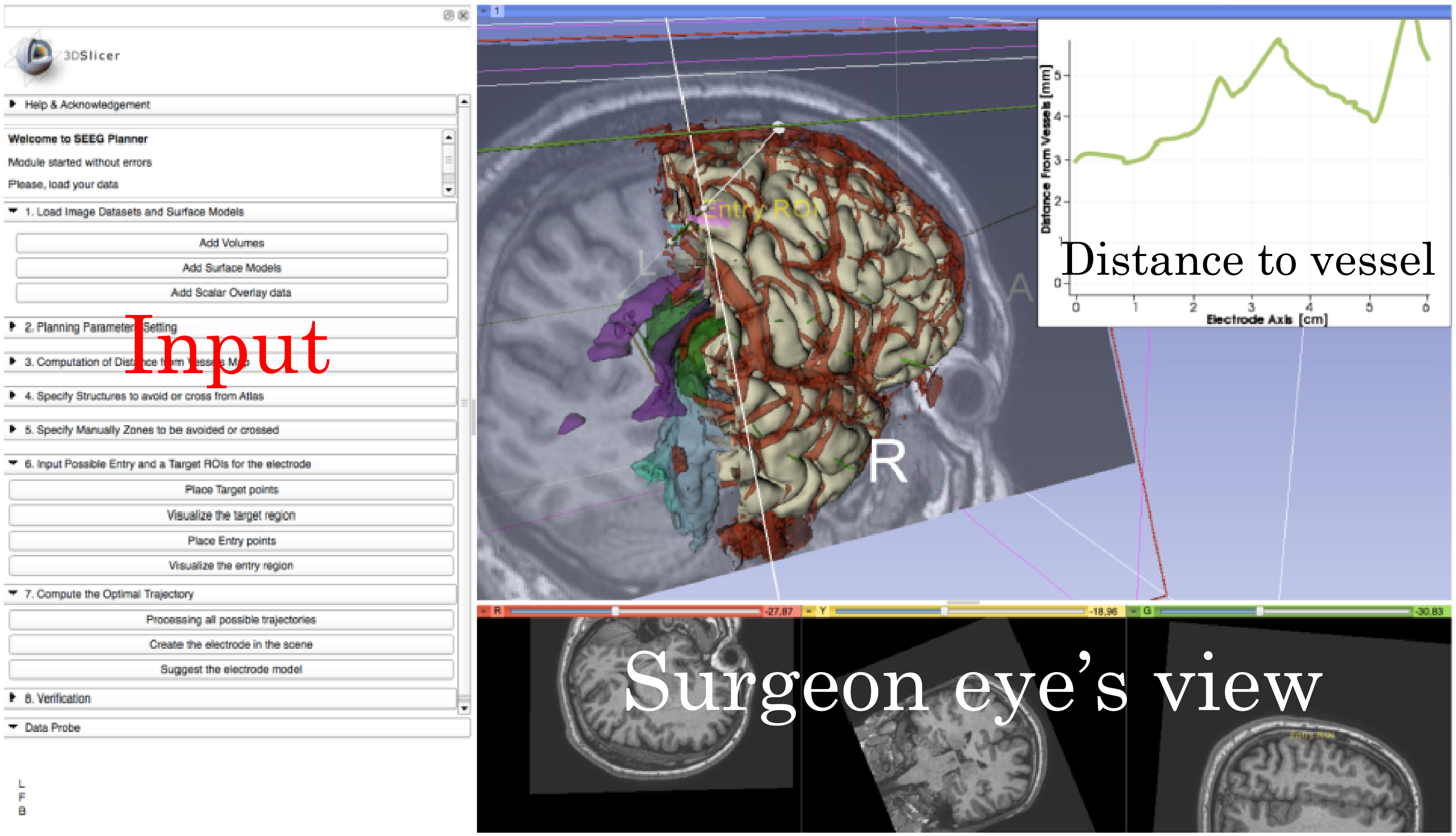
$$F(TR_h) = \overset{0.8}{w_v} \cdot f_v(TR_h) + \overset{0.2}{w_a} \cdot f_a(TR_h)$$

$$f_v(tr_i) = \begin{cases} \dfrac{d_{\min}(tr_i) - d_{\min}}{d_{\max} - d_{\min}} & d_{\min}(tr_i) > \vartheta_v \\ \text{Discarded} & d_{\min}(tr_i) \le \vartheta_v \end{cases}$$

$$\begin{cases} d_{\max} = \max_i d_{\max}(tr_i) \\ d_{\min} = \min_i d_{\min}(tr_i) \end{cases}$$



AUTOMATIC TRAJECTORY PLANNER FOR SEEG



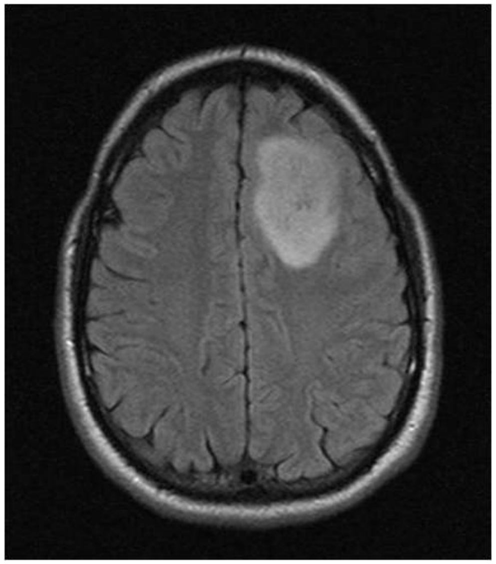
Brain tumours

The most common primary brain tumors are:

Gliomas	(50.3%)
Meningiomas	(20.9%)
Pituitary adenomas	(15%)
Nerve sheath tumors	(8%)

13,000 deaths per year in the United States alone as a result of brain tumors

- <u>Treatment</u>: tissue removal (remove all the tumoral tissue without damaging funtional brain areas)



Brain tumours Treatments and drugs

Surgery

In some cases, tumors are small and easy to separate from surrounding brain tissue, which makes complete surgical removal possible. In other cases, tumors can't be separated from surrounding tissue or they're located near sensitive areas in brain, making surgery risky.. For instance, surgery on a tumor near nerves that connect to eyes may carry a risk of vision loss.

Radiation therapy

Radiation therapy uses **high-energy beams, such as X-rays or pro**tons, to kill tumor cells. Radiation therapy can come from a machine outside the body (external beam radiation), or, in very rare cases, radiation can be placed inside your body close to your brain tumor (brachytherapy).

Radiosurgery

Radiosurgery uses multiple beams of radiation to give **a highly focused form of radiation treatment to kill the tumor cells in a very small area**. Each beam of radiation isn't particularly powerful, but the point where all the beams meet — at the brain tumor — receives a very large dose of radiation to kill the tumor cells.

Chemotherapy

Chemotherapy drugs can be taken orally in pill form or injected into a vein (intravenously). The chemotherapy drug used most often to treat brain tumors is temozolomide (Temodar), which is taken as a pill. Many other chemotherapy drugs are available and may be used depending on the type of cancer. Another type of chemotherapy can be placed during surgery. When removing all or part of the brain tumor, the surgeon may place one or more disk-shaped wafers in the space left by the tumor. These wafers slowly release a chemotherapy drug over the next several days.

Targeted drug therapy

Targeted drug treatments focus on specific abnormalities present within cancer cells. By blocking these abnormalities, targeted drug treatments can cause cancer cells to die.

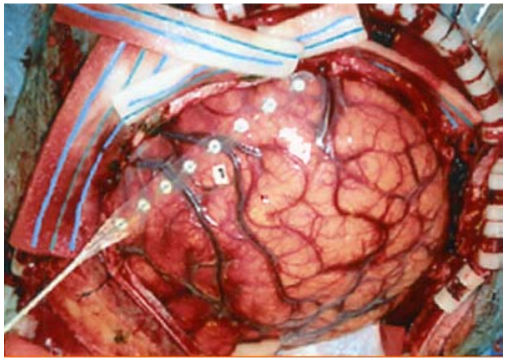
Brain Mapping and Awake Neurosurgery

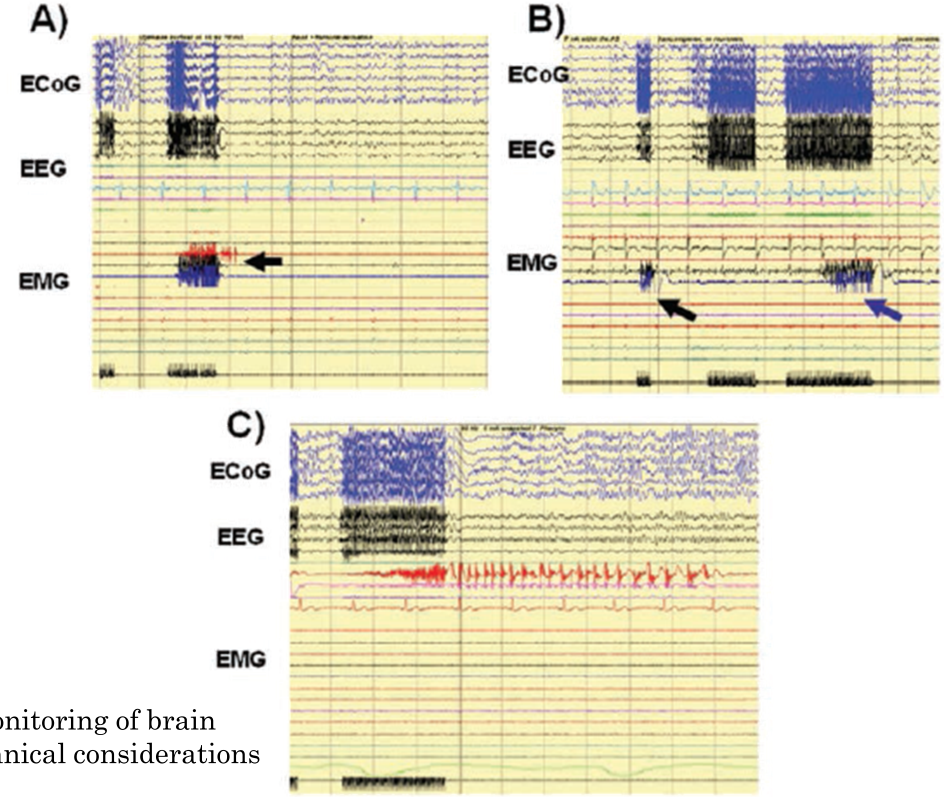
In Low-grade gliomas surgery is performed according to functional and anatomical boundaries to achieve the **maximal resection** with **maximal functional preservation**

The purpose of **brain mapping procedure** is to reliably identify cortical areas and subcortical pathways involved in motor, sensory, language, and cognitive function.

Application of short pulse trains with frequencies of 25–60 Hz 2-4ms

Seizures as side-effect

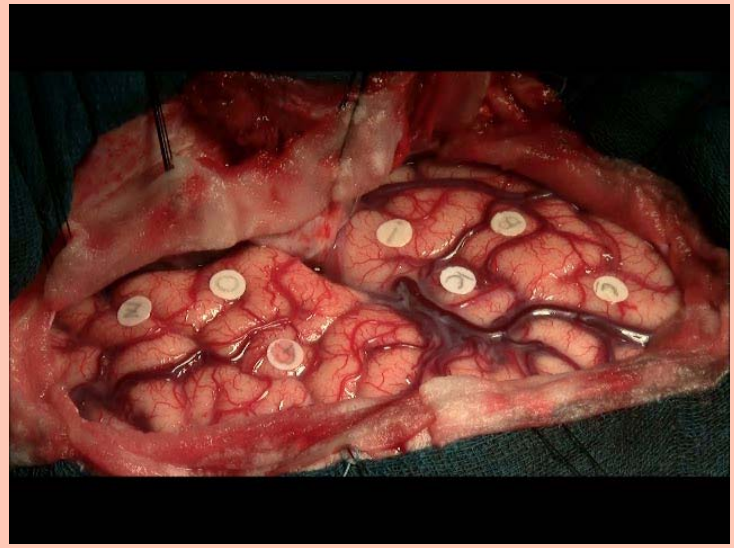




Bertani et al. (2009) Intraoperative mapping and monitoring of brain functions for the resection of low-grade gliomas: technical considerations

The Brain and Skull motion during surgery

Accidental movements/ seizures
Surgeon actions
Patient voluntary movement
Stimulation induced movements



Blood pulsation
Breathing
Brain shift

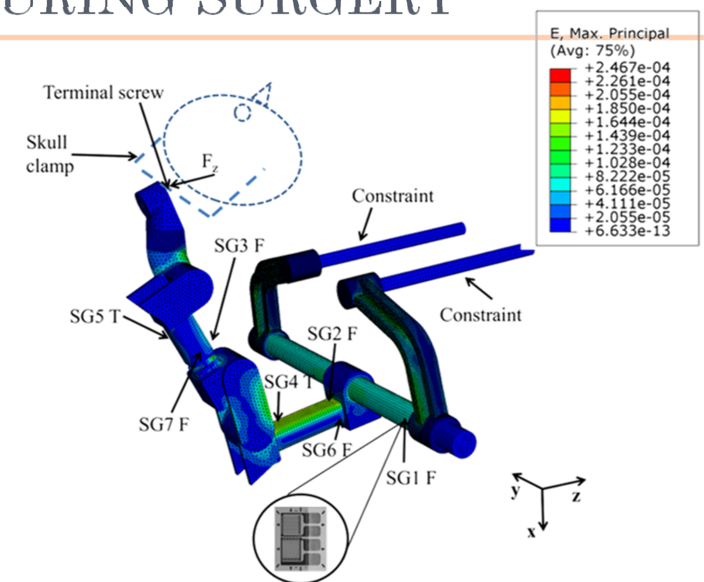
Frequency content, frequency occurrence; target displacement, velocity, acceleration

The Brain and Skull motion during surgery

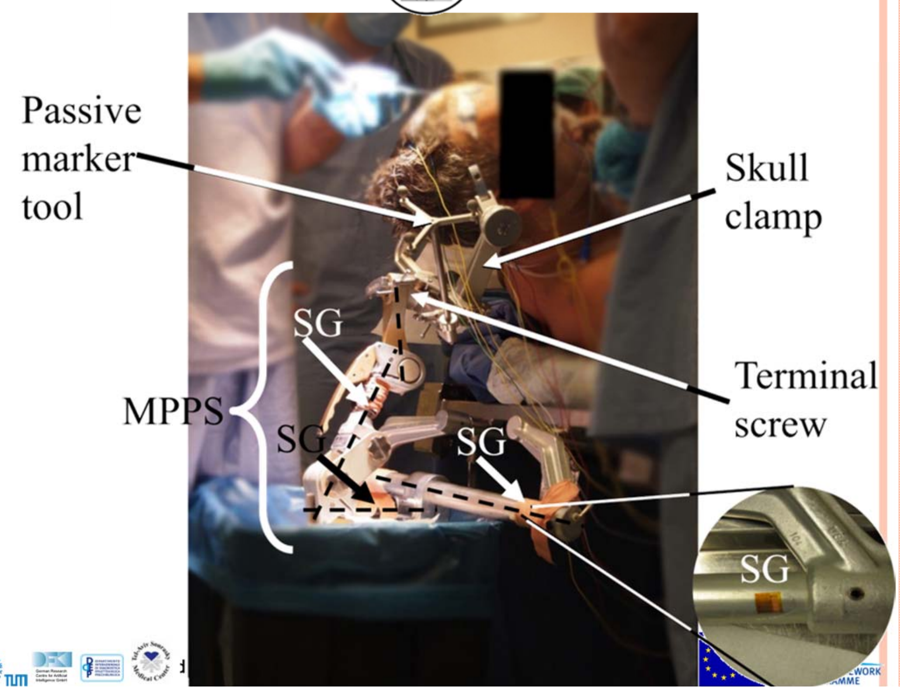
$$\begin{bmatrix} s_1 \\ \vdots \\ s_N \end{bmatrix} = \begin{bmatrix} c_{11} & \cdots & c_{1N} \\ \vdots & \ddots & \vdots \\ c_{N1} & \cdots & c_{N6} \end{bmatrix} \cdot \begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \mathbf{C} \cdot \mathbf{w}$$

Strain signals

Force/moments



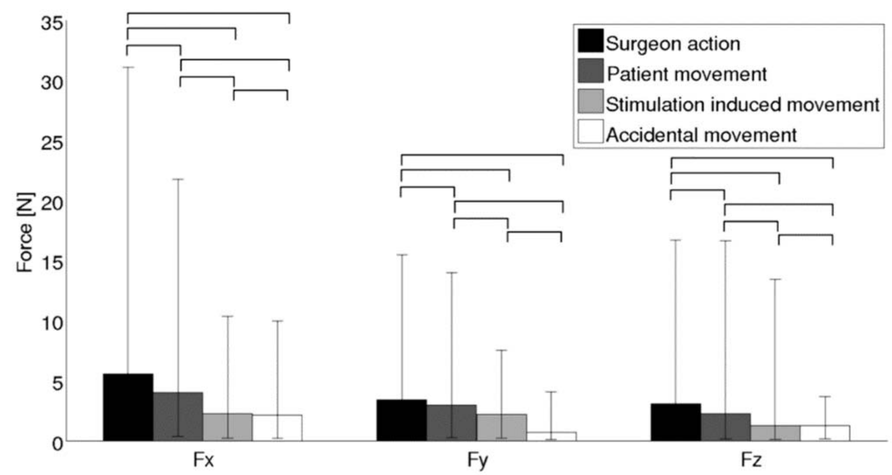
Mayfield model (ABAQUS) → Forces acting on the terminal screw → Constraints → Choice of SG locations



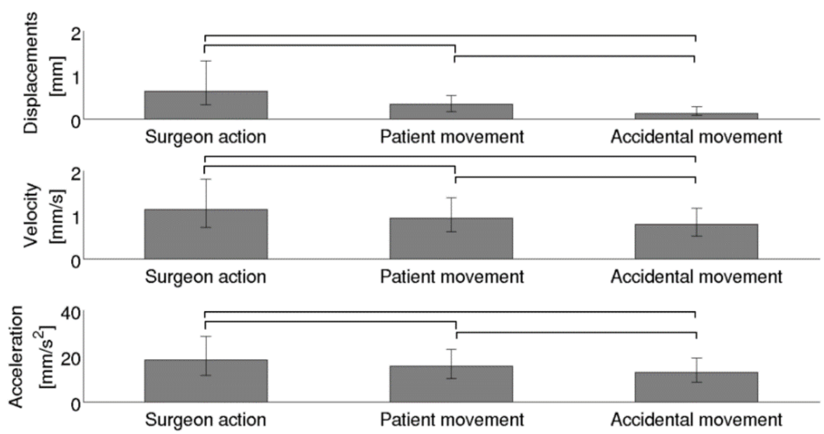
THE BRAIN AND SKULL MOTION DURING SURGERY

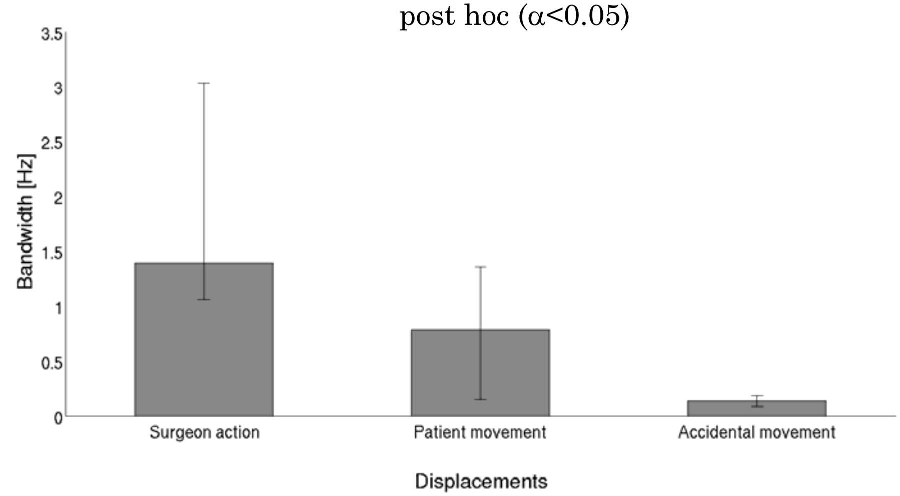
X is vertical direction

Maximum values correspond to skull opening using a drill



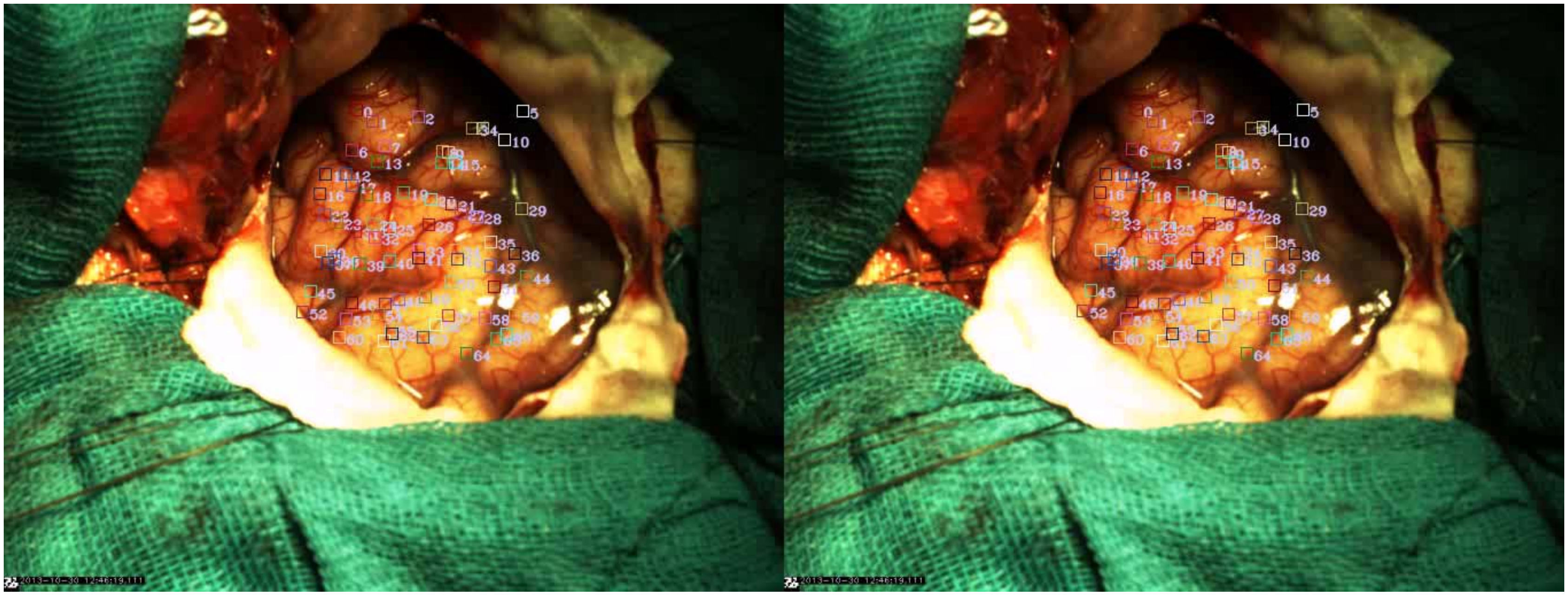
Kruskal-Wallis test, with Dunn-Sidák post hoc (α<0.05)

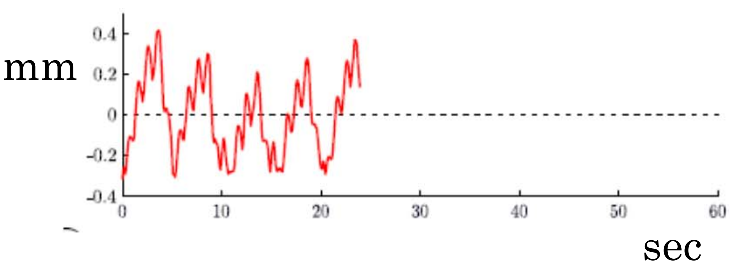


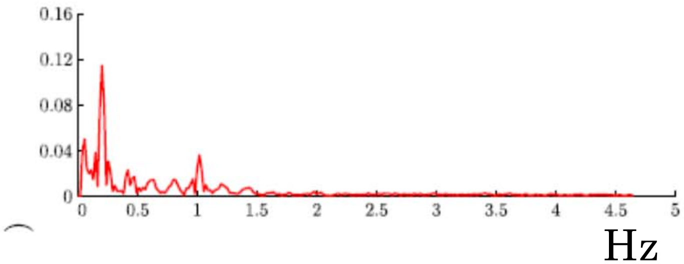


De Lorenzo, et al. Intra-operative forces and moments analysis on patient head clamp during awake brain surgery

The Brain and Skull motion during surgery







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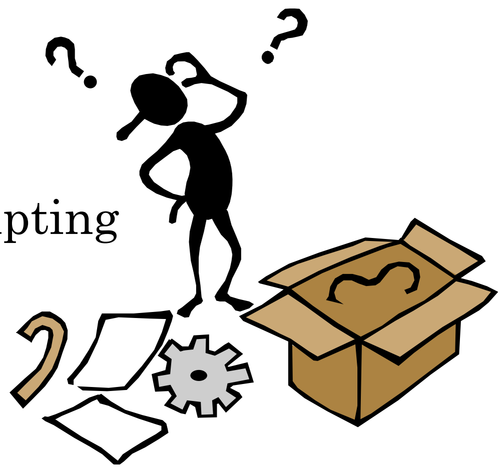
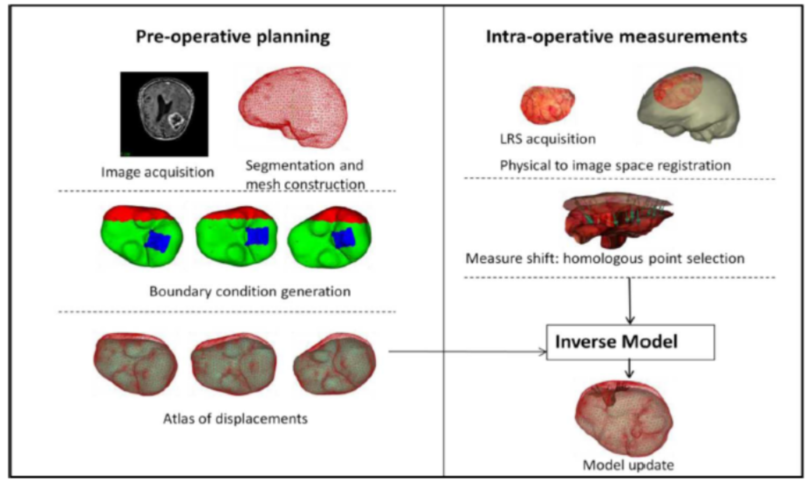


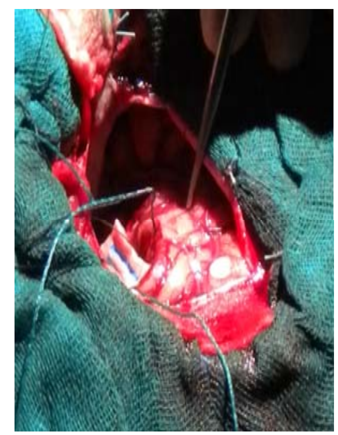
BRAIN MODELS

- Surgical planning (and intra-operative update)
- Surgical simulators
- Robot control



BRAIN SHIFT

-<u>CSF leak </u>(Mean cortical shifts of 5-6 mm have been reported, with maximum shift of over 20 mm, and mean tumor shifts of 3-7 mm, with a maximum of 15 mm)
-<u>tissue removal, retraction</u>



Active constraints technologies for ill-defined or volatile environments

Brain Models

Constitutive model of brain tissue (**hyperelastic, linear viscoelastic medium**)

Polinomial strain energy function W

$$W = \int_0^t \left\{ \sum_{i+j=1}^{N} \left[C_{ij0} \left(1 - \sum_{k=1}^{n} g_k \left(1 - e^{-(t-\tau)\tau_k} \right) \right) \right] \times \frac{d}{d\tau} \left[(J_1 - 3)^i (J_2 - 3)^j \right] \right\} d\tau$$

τ_k are characteristic times
g_k are relaxation coefficients
N is the order of polynomial in strain invariants (as a result of the assumption of the brain tissue initial isotropy the energy depends on the histories of strain invariants only) used for strain energy function description

$J_1 = Trace[\mathbf{B}]$ $\quad J_2 = \dfrac{J_1^2 - Trace[\mathbf{B}^2]}{2J_3}$ $\quad J_3 = \sqrt{det\mathbf{B}} = 1$ strain invariants

(tissue incompressibility)

B left Cauchy Green tensor
C_{ij0} describe the instantaneous elasticity of the tissue

Miller, 1998

FRICTIONAL FORCES IN BRAIN TISSUE

Measurement of the **forces required to penetrate brain tissue** are necessary to:

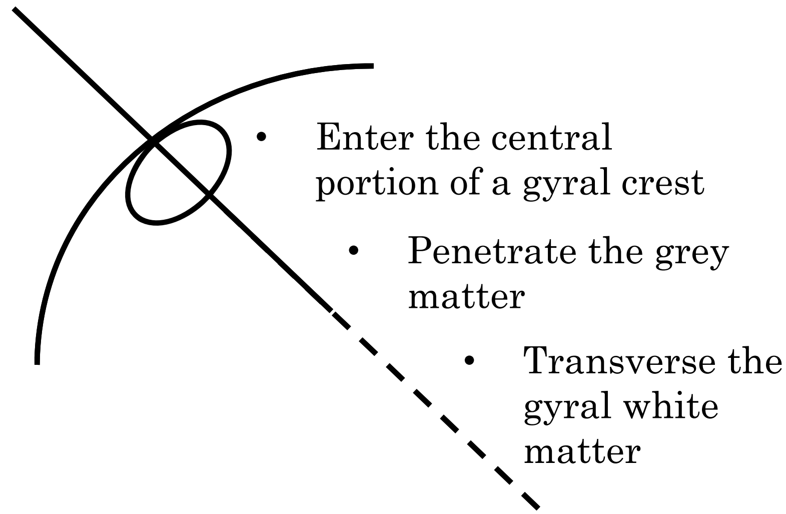
- Determine the minimum dynamic range needed by probe's actuators
- Increase the safety of the robotic system
- Understand the specifications for the sensor system to be used for haptics

PROBES USED

- 2.5mm stainless-steel sphere attached to a thin stiff wire for the measurement of the penetration forces
- Standard 3.0mm ventricular catheter, for the measurement of penetration and drag forces

SENSOR

- Chatillon DGGS-R-250g force gage fixed to a mechanical advancer driven by electric motor

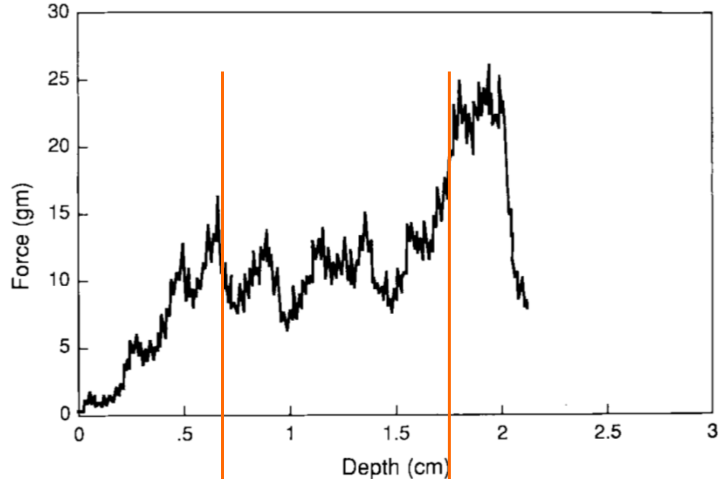


Advancing rate 0.33mm/s
4 Hz

Howard et al. (1999) Measurement of the force required to move a neurosurgical probe through in vivo human brain tissue. IEEE Trans Biom Eng. 46 (7) 891-894

FRICTIONAL FORCES IN BRAIN TISSUE

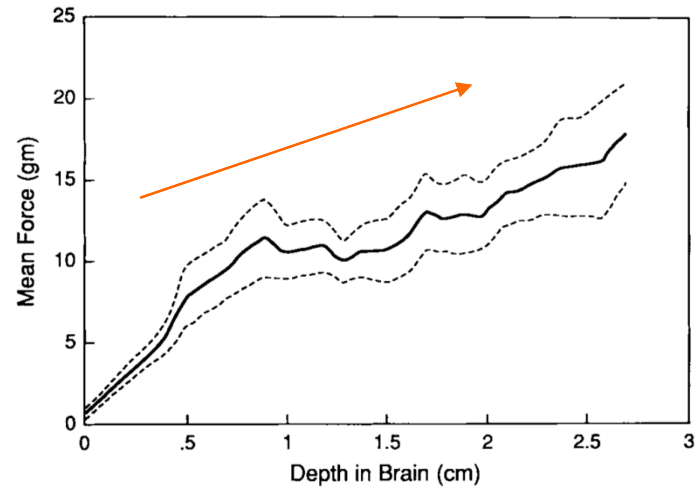
2.5mm stainless-steel sphere



Sphere in contact with the cortical surface and brain tissue displacement

Contact with subsurface structures

Standard 3.0mm ventricular catheter



Penetration and drag resistance

Steadily increasing drag forces as more of the probe become embedded in the brain tissue:

- Tissue friction coefficient 2.8 ±0.3 grams/ cm

A penetration of 6 cm would require force of approximately 23 g (0.23 N) during the final stage of insertion

Howard et al. (1999) Measurement of the force required to move a neurosurgical probe through in vivo human brain tissue. IEEE Trans Biom Eng. 46 (7) 891-894

Force feedback enhancement

Determine the optimal **force ranges** during robot-assisted neurosurgical procedure:

- Providing quantitative FB to trainees
- Set force limits to improve surgical safety

		Median (interquartile range)		
		Stab Incision	Carrying Incision	Retraction
Cerebrum (n = 24)	Gyrus rectus (n = 8)	<0.01 (0.00 – 0.03)	0.02 (0.01 – 0.03)	0.03 (0.03 – 0.05)
	Inferior temporal gyrus (n = 8)	<0.01 (0.00 – 0.01)	0.02 (0.00 – 0.03)	0.07 (0.06 – 0.09)
	Middle frontal gyrus (n = 8)	<0.01 (0.00 – 0.01)	0.15 (0.12 – 0.18)	0.08 (0.06 – 0.10)
Cerebellum (n = 12)	Cerebellar hemisphere (n = 8)	0.01 (0.00 – 0.01)	0.03 (0.02 – 0.04)	0.08 (0.02 – 0.13)
	Cerebellar vermis (n = 4)	0.02 (0.01 – 0.02)	0.12 (0.12 – 0.12)	N.A.
Brainstem (n = 22)	Midbrain (n = 6)	0.01 (0.00 – 0.01)	0.11 (0.04 – 0.26)	0.15 (0.13 – 0.20)
	Pons (n = 8)	<0.01 (0.00 – 0.01)	0.05 (0.04 – 0.06)	0.18 (0.12 – 0.21)
	Medulla (n = 8)	0.01 (0.01 – 0.03)	0.09 (0.06 – 0.16)	0.09 (0.06 – 0.11)
Other (n = 8)	Corpus callosum (n = 4)	0.01 (0.00 – 0.03)	0.23 (0.09 – 0.43)	N.A.
	Perforating floor of third ventricle (n = 4)	<0.01 (0.00 – 0.01)	N.A.	N.A.

N.A. = Not applicable.

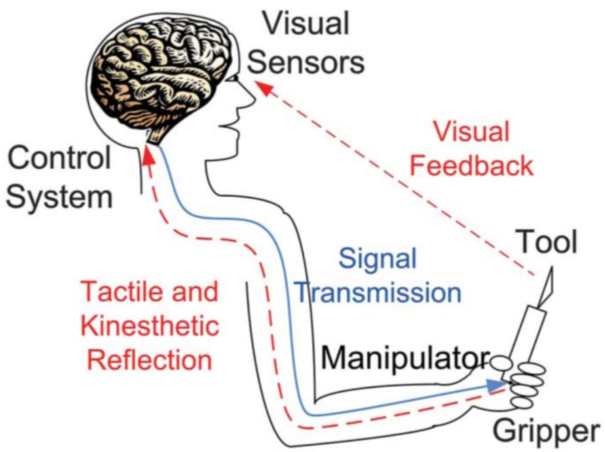
[N]

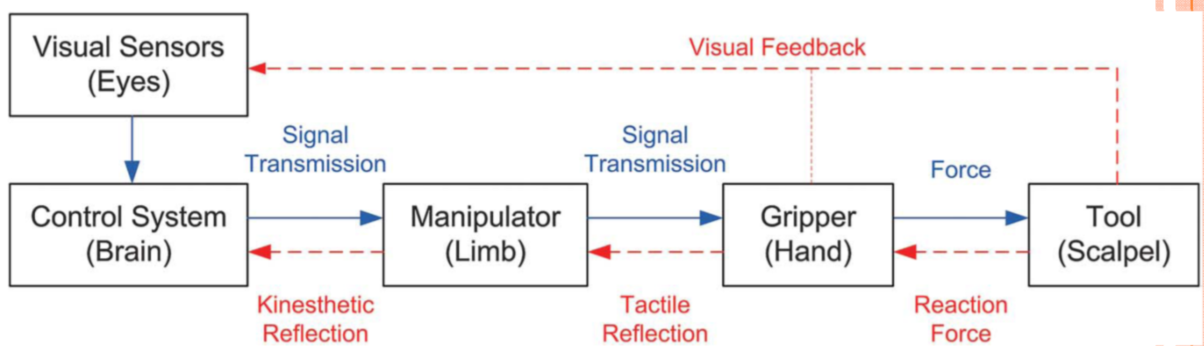
Marcus et al. 2014 Forces exerted during microneurosurgery: a cadaver study

FORCE FEEDBACK ENHANCEMENT

Haptics (sense of touch) gives information on the material properties of an object (stiffness, texture, weight, size, orientation and curvature)

Haptic stimulation: **tactile** (cutaneous feedbak through mechanoreceptors - passive pressure) and **kinesthetic** (force feedback revolving around muscle stimulation – active touch).





L'Orsa, 2013

1 kHz update

The computational task in **haptic rendering** is to generate signals that are relevant to particular applications. Whether this signals should refer to forces, displacements or a combination of these and their derivatives is still the object of debate.

FORCE FEEDBACK ENHANCEMENT

Tactile sensitivity depends on size, density, frequency range, nerve fiber branching and type of stimulation (skin motion or sustained pressure).

A haptic display for simulating tactile sensations must:

- Mantain active pressure for the user to feel a **hard surface** after initial contact;
- Mantain a slight positive reaction against the skin after initial contact **for soft surfaces** (without active pressure or relative motion);
- Provide some relative motion between the haptic surface and the skin to accurately display **texture**.

The force excerted must be greater than 0.06 to 2 Newtons per cm^2

Hale, 2004

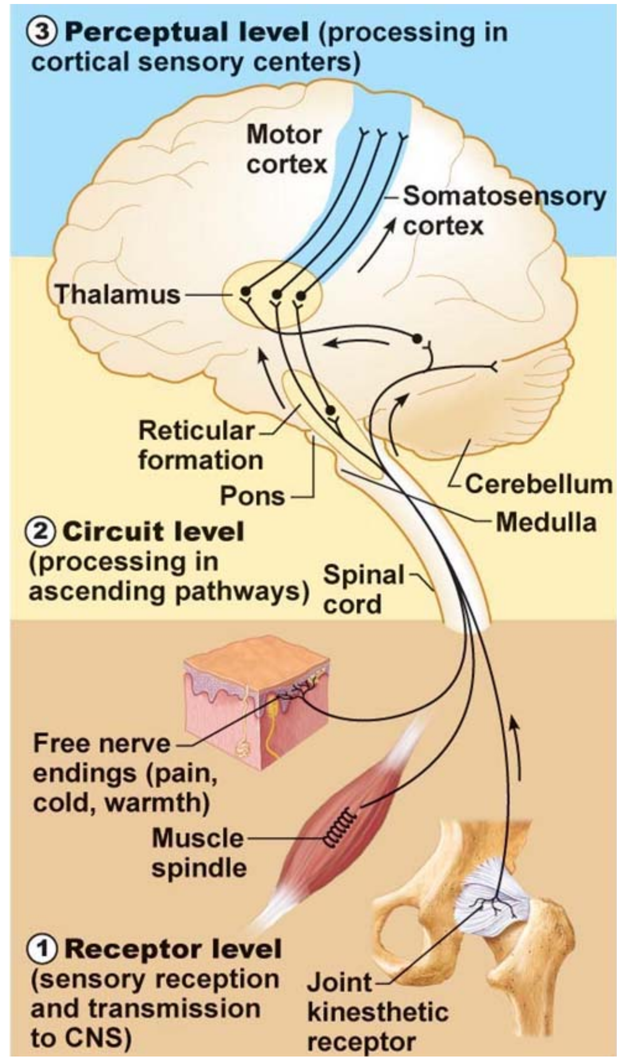
FORCE FEEDBACK ENHANCEMENT

Kinesthesia: perception of limb movement and position + perception of force.
This sensory perception originates primarily from mechanoreceptors in muscles.

The differential threshold for force averages 7-10% over a force range of 0.5-200 N.

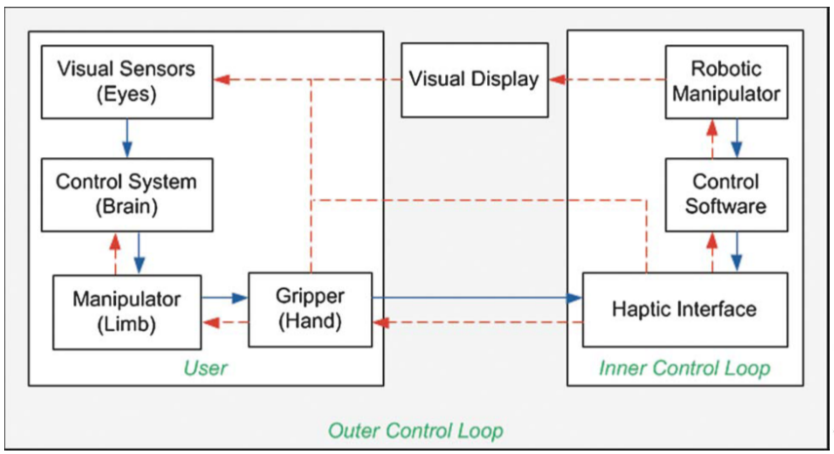
Discrimination deteriorates for forces smaller than 0.5 N, with the threshold increasing to 15-27%.

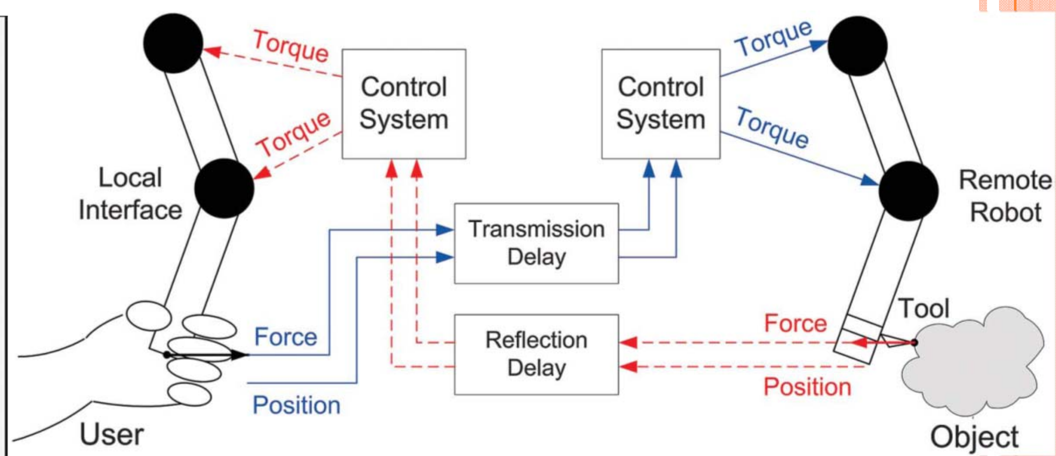
Forces as small as 0.14 – 0.2 N can still be distinguished.



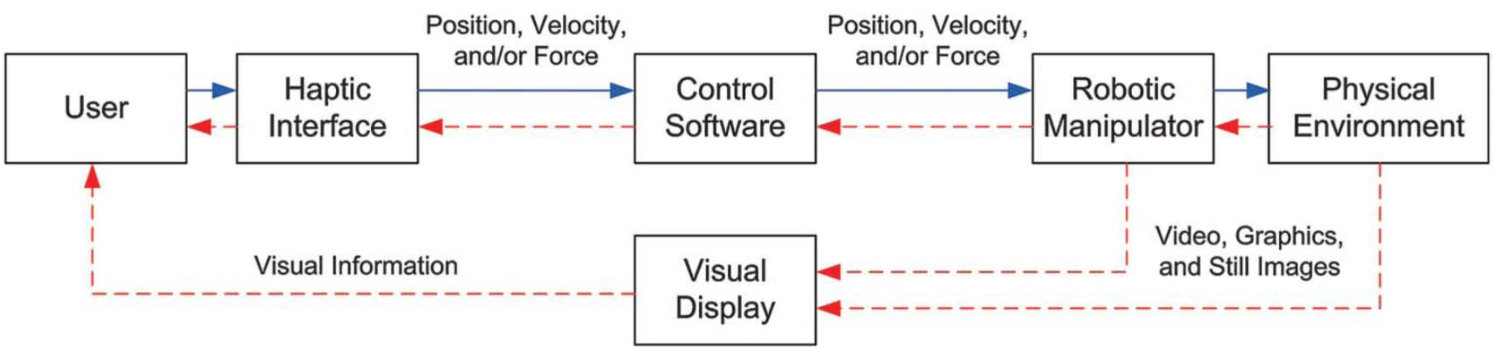
Jones L., Human and Machine Haptics, 2000

Force feedback enhancement

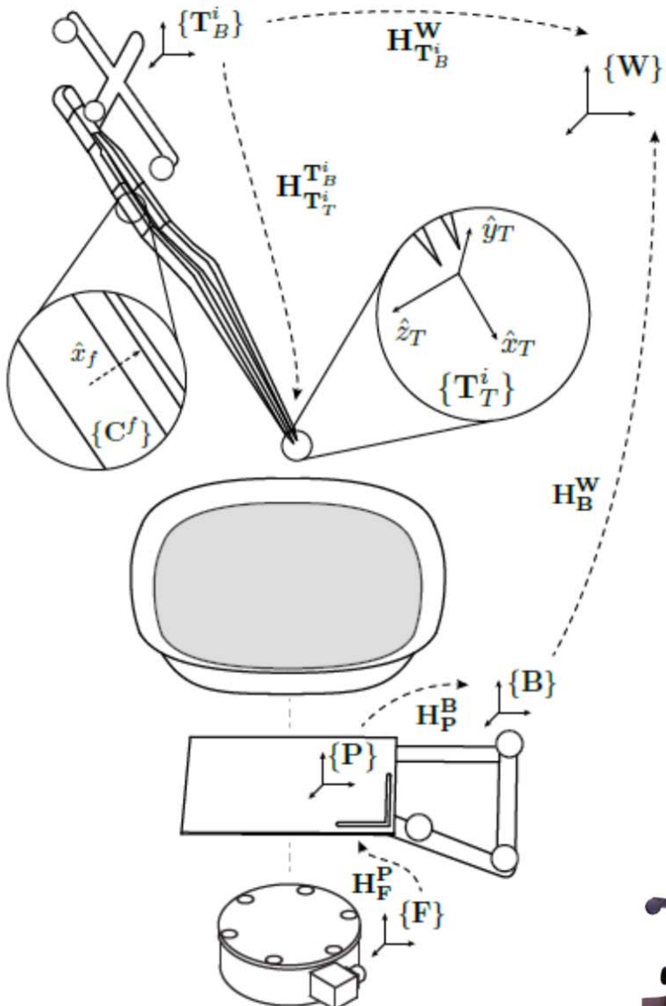




ACTUATORS



FORCE FEEDBACK ENHANCEMENT

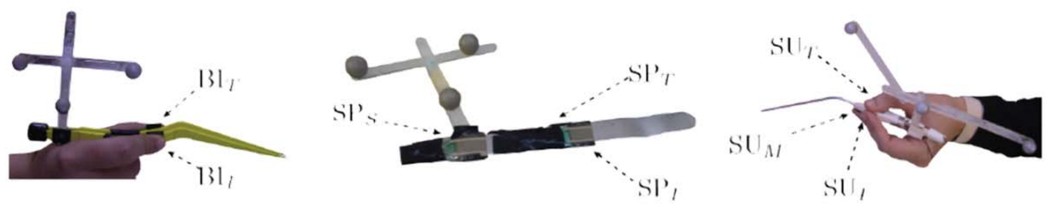


- Three neurosurgeons
- Force sensors:
  - Load cell (Gamma F/T sensor, 1 kHz)
  - Tactile sensors (FSR 408 series sensors, 1 kHz)
- Surgical tools:

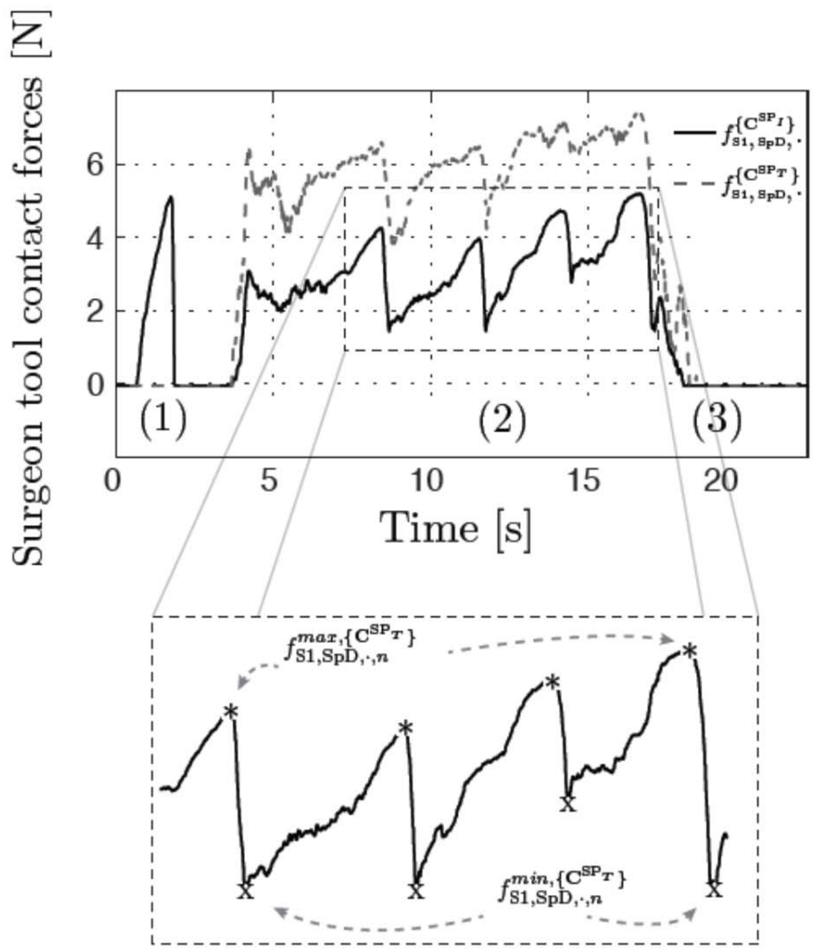
Bipolar forces/ spatula/ suction tool

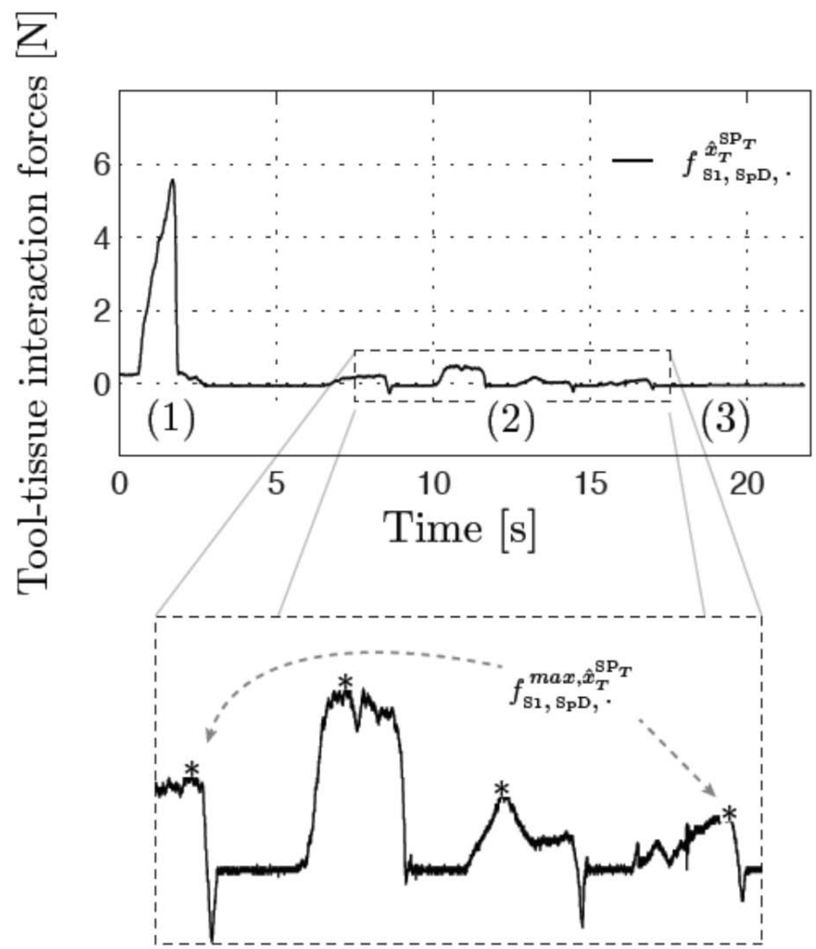
- Surgical actions: indentation/ gripping/ cutting

(a) (b)



FORCE FEEDBACK ENHANCEMENT





2.3 N/ cm^2

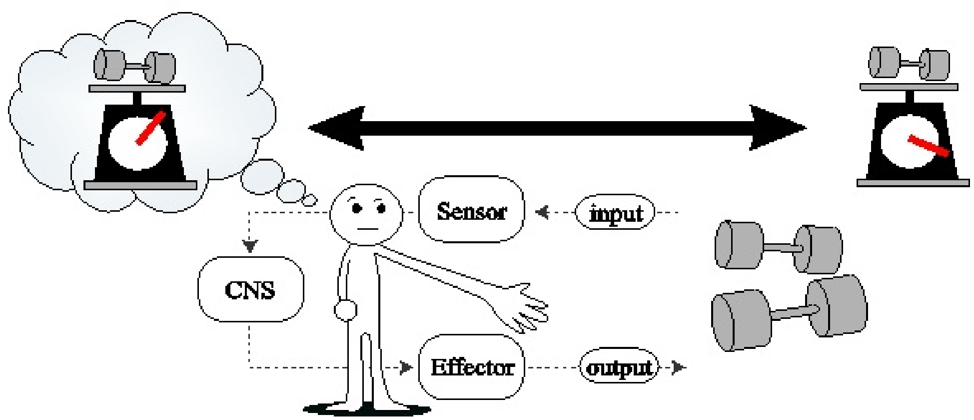
0.5 N

FORCE FEEDBACK ENHANCEMENT

Haptic interface

- Stylus-type interfaces – the surgeon grips a scalpel-like protrusion
- Wearable glove-type interfaces

WORKSPACE: range of motion that is mechanically allowable by its structural design
SIZE
ENCODER RESOLUTION
PRODUCED FORCE



NEUROSURGICAL SIMULATORS

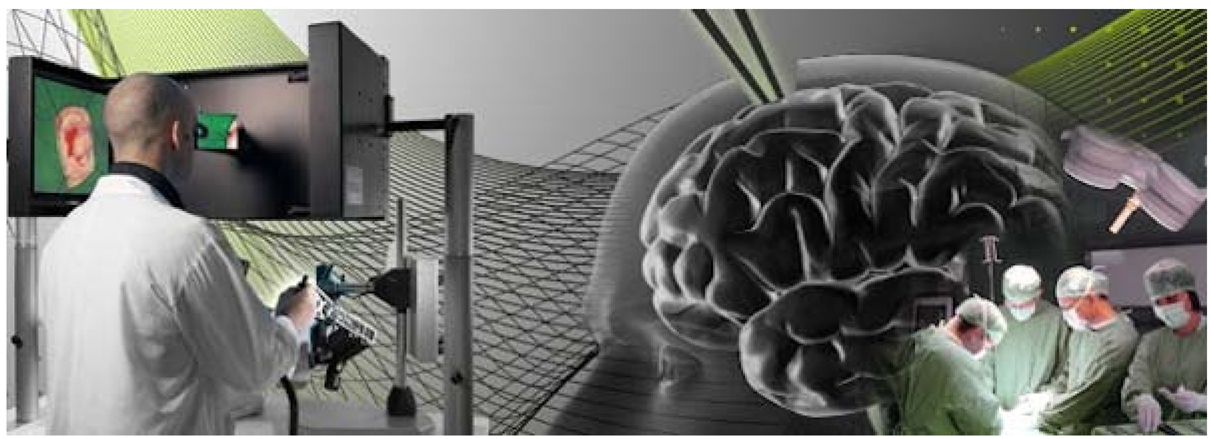
- Teach both **behavioral and procedural aspects of medicine and surgery** (Procedural simulators stress the cognitive reasoning that goes into successful completion of a surgical intervention, often incorporating physiological response and anatomic findings that can influence a surgeon's intraoperative decisions)
- Improve the fidelity of behavioral simulations of **tasks and emergencies**
- Provide an objective assessment of **trainee performance** (Selden et al., 2013)

Neurosurgical Simulators: NeuroTouch

Top gun pilots train on virtual reality (VR) simulators.

VR simulation technology brings training of future neurosurgeons to a whole new dimension. It can also help medical practitioners prepare for complex surgical interventions using innovative surgical techniques.

NeuroTouch integrates an array of tailored training scenarios based on real medical cases by incorporating patient-specific images and tissue data.



Neurosurgical Simulators: NeuroTouch

The NeuroTouch system (Delorme et al., 2012) allows performing soft-tissue manipulation such as **tumor debulking and electrocautery**.

The interface mimics the binocular microscope and provides haptic feedback. **Bleeding** and even brain **pulsation** are simulated, (Chan et al., 2013).

Azarnoush et al. (2014) presented a pilot study with innovative metrics to assess neurosurgeons performances using the NeuroTouch platform with simulated brain tumors.

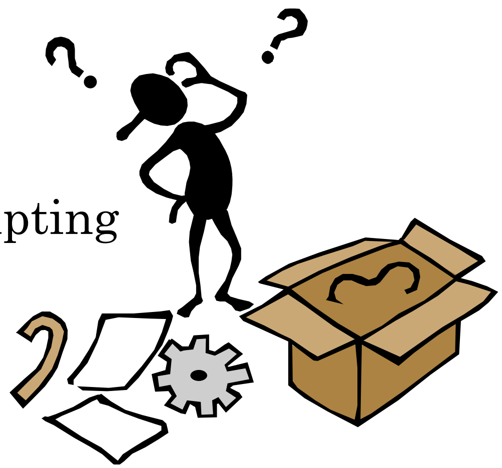
Neurosurgical Simulators: Immersive touch

- Improved pre-operative surgery planning can increase better utilization of OR's from better prediction of surgery times and increase surgeons' OR productivity

- The **3D patient-specific anatomy model** can facilitate surgeon/patient communication and lead to improved patient consent process

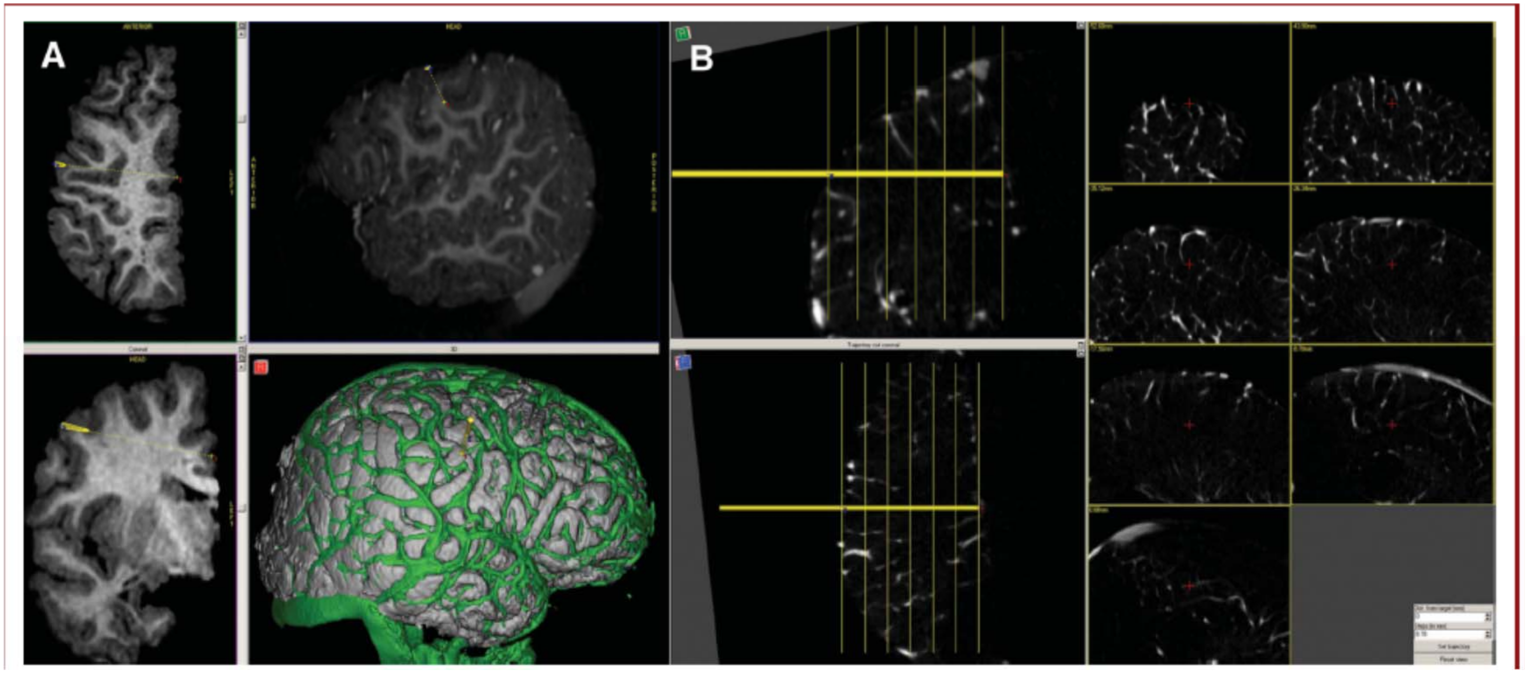
COMPUTER ASSISTED NEUROSURGERY/ ROBOTIC NEUROSURGERY

- Tools for surgical planning
- Surgical simulators for training and planning (patient specific)
- Intra-operative Images/ models update
- **Precise targeting**
- Tremor filtering, motion/force scaling to improve accuracy
- Regions constraints definition (safety enhancement)
- Ergonomic and comfortable position for the surgeon
- Access to sophisticated imaging data without interrupting the surgical procedure



Systems available applications and limitations

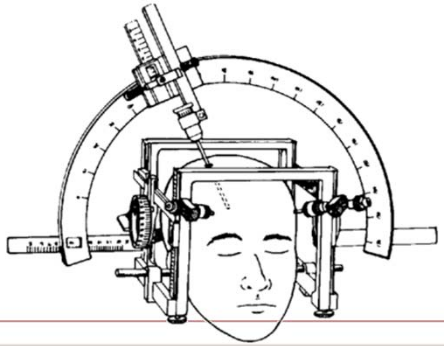
- Renishaw Mayfield Neuromate
  - Application: SEEG, endoscopy
  - Control modality: Autonomous

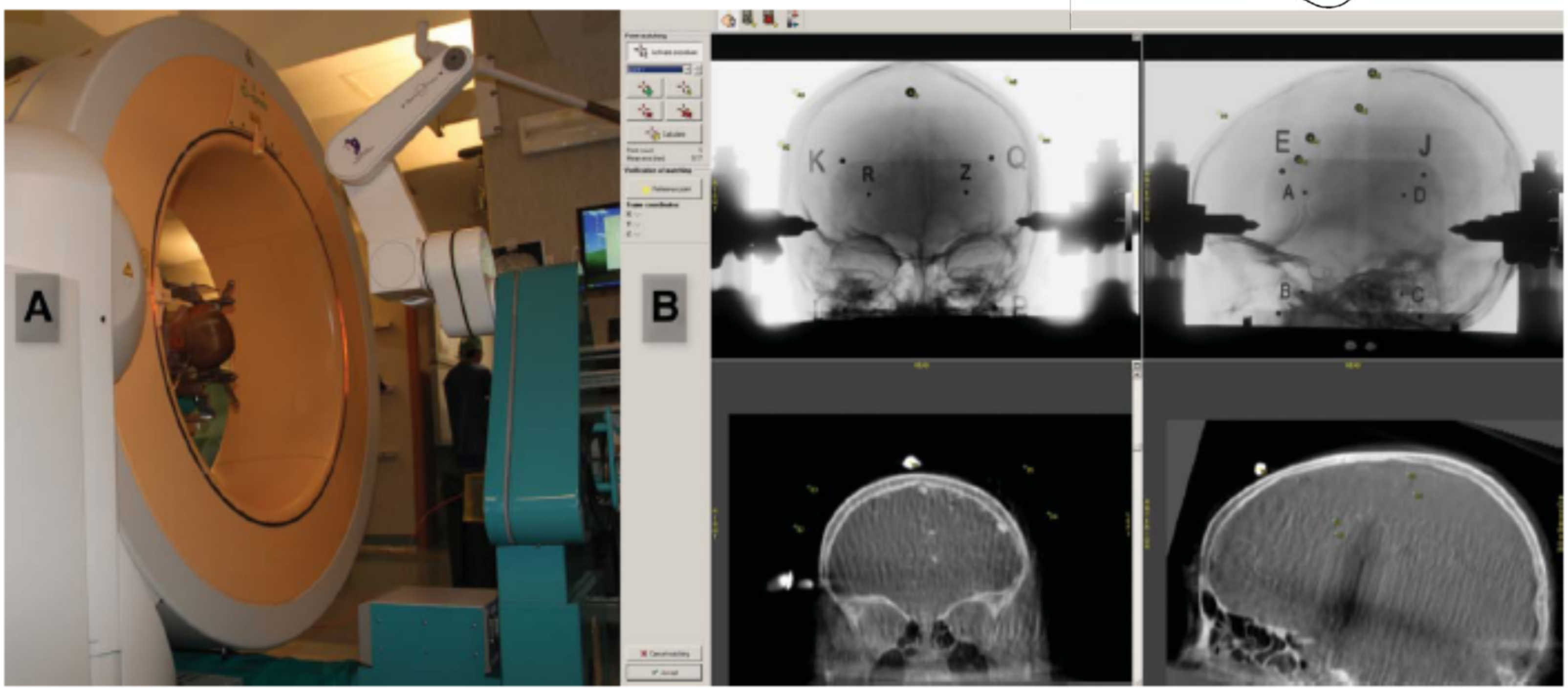


Cardinale et al. 2013

Systems available applications and limitations

- Renishaw Mayfield Neuromate
  - Patient-robot registration: O-arm imaging



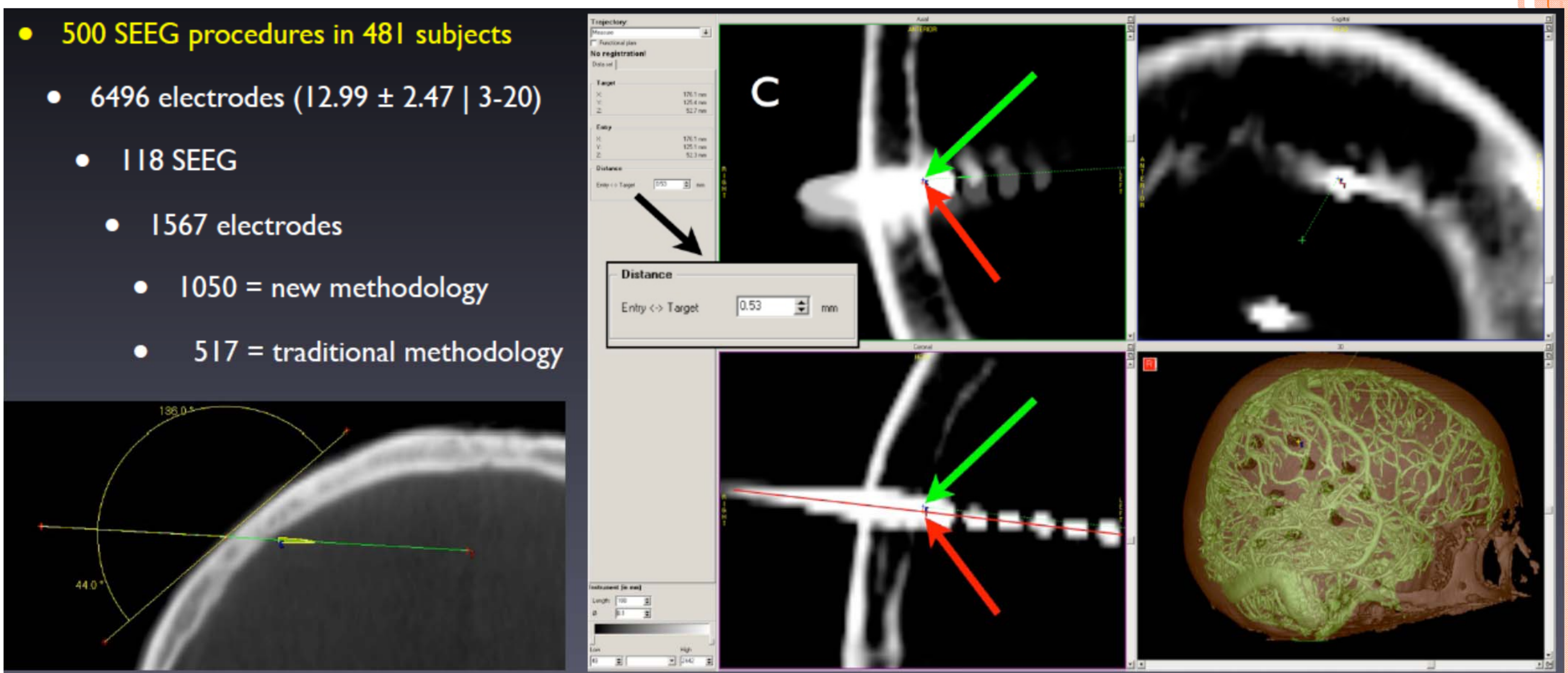


Cardinale et al. 2013

SYSTEMS AVAILABLE APPLICATIONS AND LIMITATIONS

- Renishaw Mayfield
  - Increased accuracy

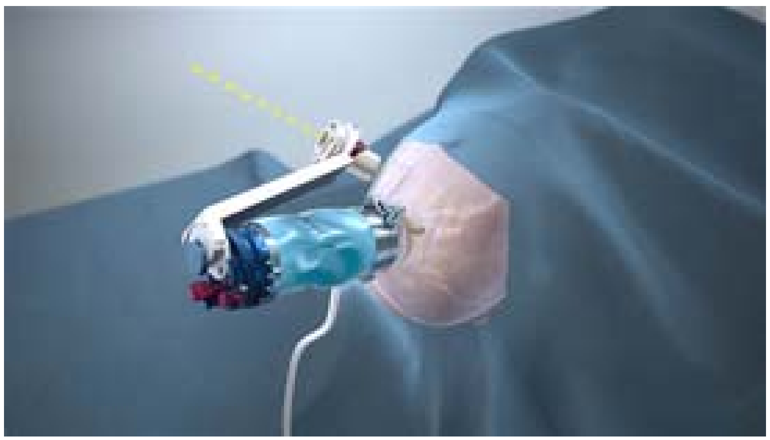
New methodology: 0.78 mm (IQrange: 0.49 - 1.08) Traditional methodology: 1.43 mm (IQ range: 0.91 - 2.21)



Cardinale et al. 2013

Systems available applications and limitations

- MAZOR, Renaissance
  - Application: DBS
  - Control modality: Autonomous



The Renaissance system is FDA-cleared for both spine and brain surgery

Systems available applications and limitations

- Medtech, Rosa
  - Application: SEEG, endoscopy
  - Control modality: Autonomous and hands-on

COMPUTER ASSISTED NEUROSURGERY/ ROBOTIC NEUROSURGERY

- Tools for surgical planning
- Surgical simulators for training and planning (patient specific)
- Intra-operative Images/ models update
- Precise targeting
- **Tremor filtering, motion/force scaling to improve accuracy**

  (Surgeons may have hand tremor on the order of 50-100 microns, 8-12 Hz)
- Regions constraints definition (safety enhancement)
- Ergonomic and comfortable position for the surgeon
- Access to sophisticated imaging data without interrupting the surgical procedure

Systems available applications and limitations

- Imris, Neuroarm
  - Application: brain tumor
  - Control modality: Tele-operated

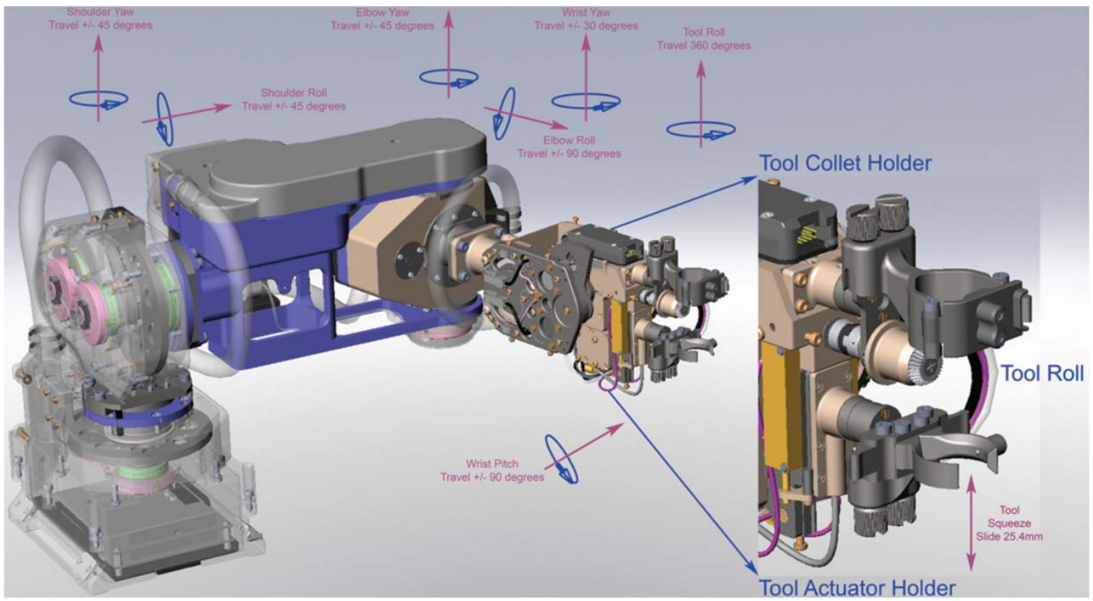
- Robotic arm draped
- Surgical tools: bipolar forceps, needle driver, tissue dissectors, suction, microscissors
- Modified surgical microscope
- Communication headsets
- Plugging manipulators (10 minutes)

- Uninteded motion (2.4 cm)

- Slow down the robot's movement
- Foot-operated emergency stop

SYSTEMS AVAILABLE APPLICATIONS AND LIMITATIONS

- Imris, Neuroarm
  - Application: brain tumor
  - Control modality: Tele-operated



- Access to sophisticated imaging data without interrupting surgical procedure

- 2 MR-compatible robotic arms, 7 DoFs (3T)
- 6 DoFs position control, 3 force FB
- Each joint has 2 absolute encoders (titanium joints)
- Workstation with access to MR images and real-time high-def 3D images
- Haptic interfaces (Phantom premium, Sensable)
- Modified and traditional instrumentation

- Open loop configuration with piezoelectric motors - 1m/s -> 200 mm/sec
- 750 g normal payload
- The surgeon commands postions (dangerous)
- Force sensors (ATI nano17)

Systems available applications and limitations

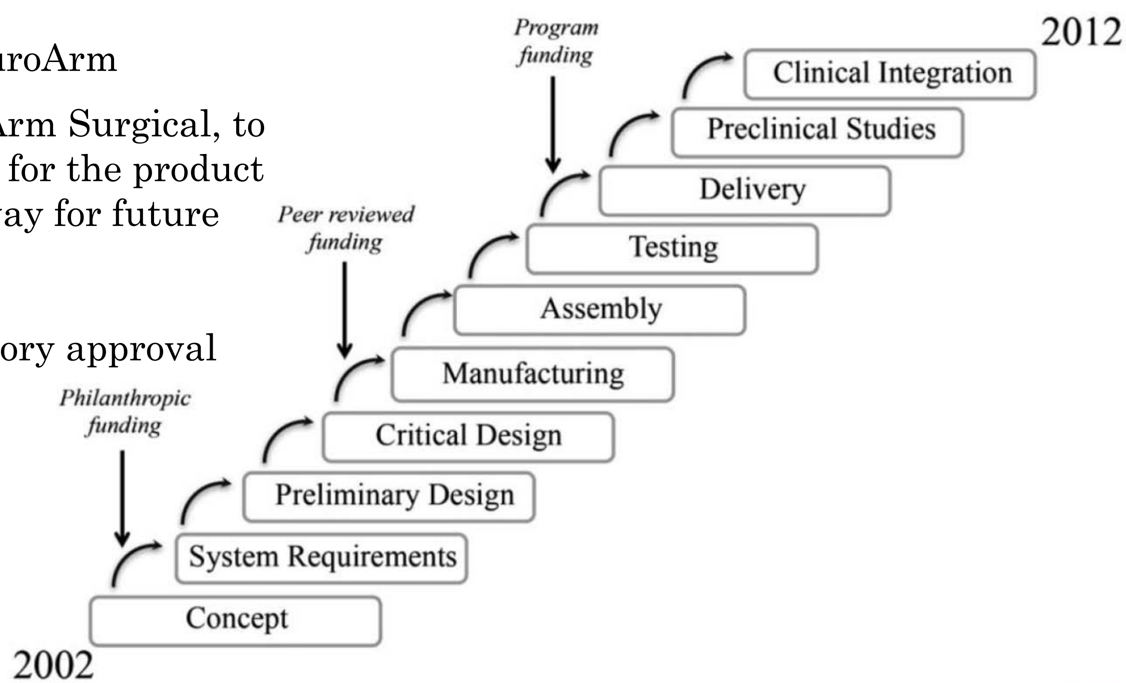
2001 University of Calgary and MacDonald, Dettwiler and Associates Ltd

- project requirements
- overall feasibility of the project: preliminary design review determined that microsurgery would need to be decoupled from the magnet because vision technology was not yet advanced enough and components were too large to achieve microsurgery within the bore of the magnet
- critical design review determined the feasibility of constructing the robot according to regulatory requirements
- Manufacture and testing of neuroArm

A company was established, neuroArm Surgical, to hold the neuroArm IP (create value for the product through IP protection, paving the way for future commercialization)

- institutional ethical and regulatory approval

35 cases (2013)



The ACTIVE Robotic Scenarios

Resection/ disconnection

Tele-operated

- Motion compensation (skull and brain)
- Dynamic active constraints

Stereoelectroencephalography electrodes implantation

Hands-on

- The surgeon is master
- Dynamic active constraints

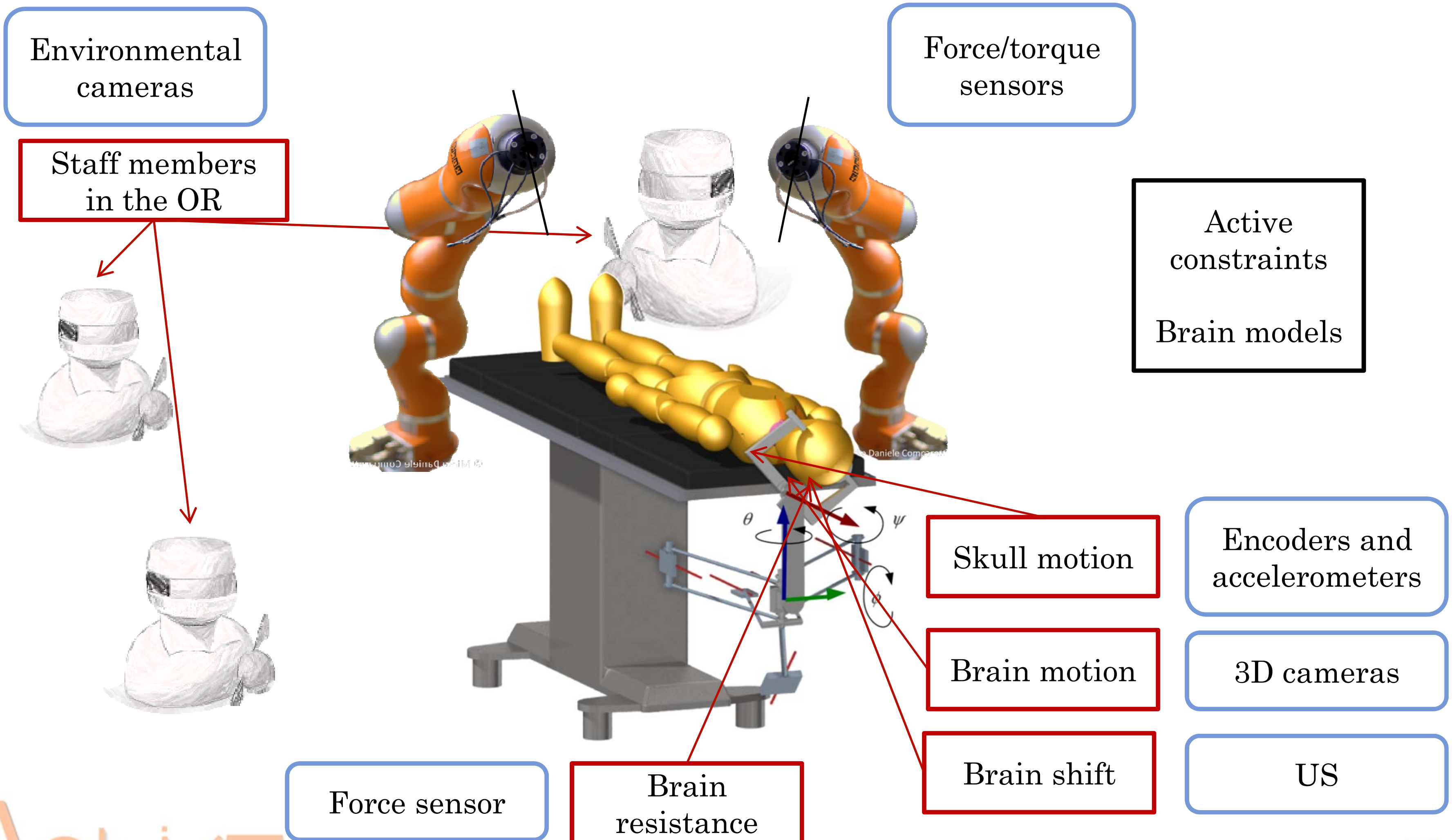
Autonomous

- Robots Approaching

Stimulation

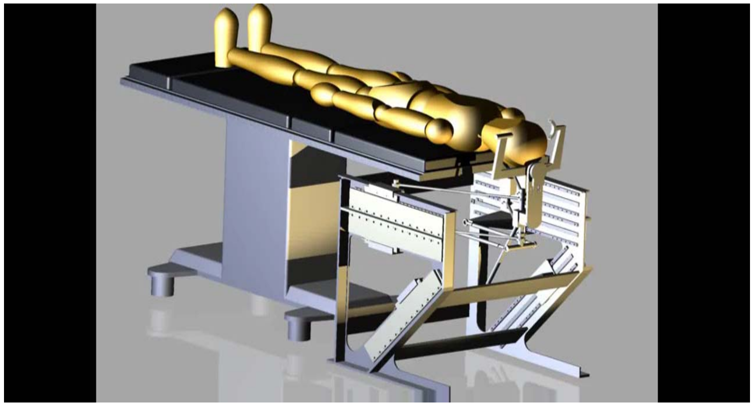
THE ACTIVE PROJECT SENSORS/ACTUATORS

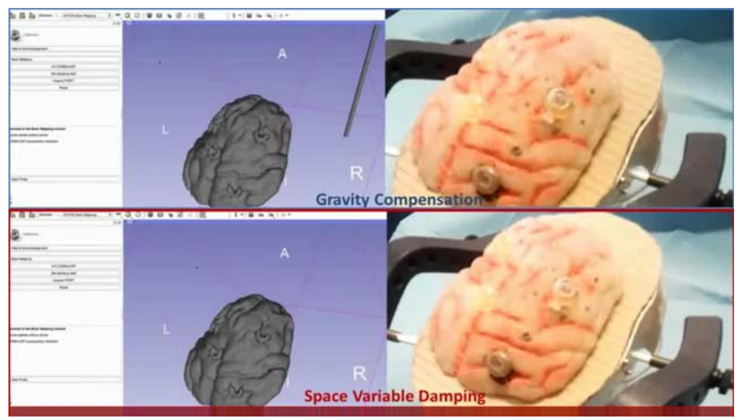
http://www.active-fp7.eu/index.php/video




JOHNS HOPKINS
UNIVERSITY
TUM

Some of the joint achievements





CONCLUSIONS

- Commercially available navigation systems are routinely used in neurosurgery (e.g. Medtronic, Brainlab, …)
- Intra-operative images update is needed (iMR, iUS)
- Positioning tools are needed (they replace the stereotactic frame)
- Surgeons not using robots/ simulators are refractory to their introduction in the clinical routine
- Surgeons using simulators and robots love them!

This is a push for research and development…

IF YOU WANT TO JOIN….

http://www.nearlab.polimi.it/