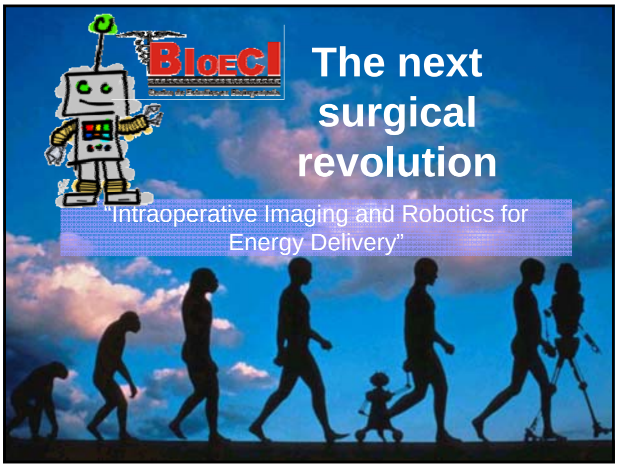
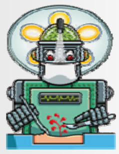
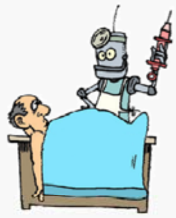


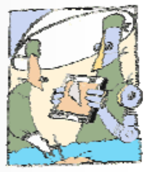
¿de qué estamos hablando?

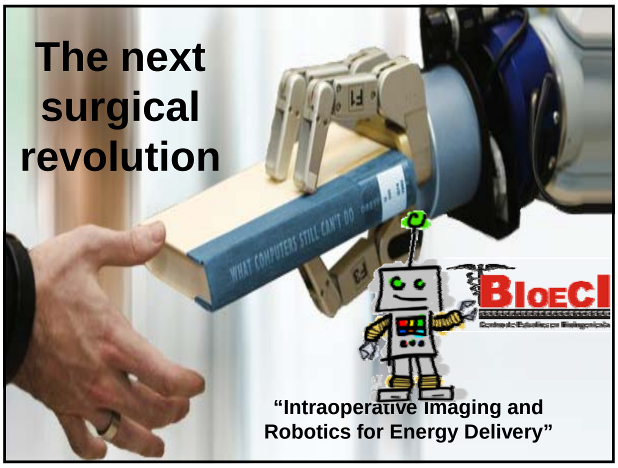
¿hablamos de un *"Intelligent Robotic Sugeon"*? …





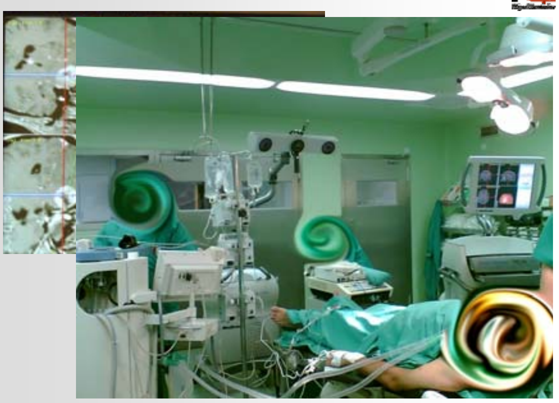
O … más bien de *"Advanced Robotic Tools"*?



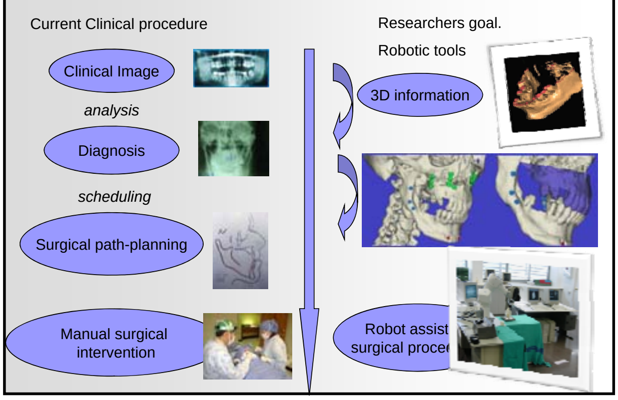


PASADO: cortar, y luego mirar

PRESENTE: mirar, planificar y luego cortar



FUTURO CERCANO: mirar, planificar, fusionar inf., re-planificar, mínimo daño a tejidos sanos



outline of the presentation

- Goals in Robotic Energy Delivery Systems
- Robotic Energy delivery systems
- Intraoperative imaging for positioning
- Surgical robots for positioning

concept

Goals in Robotic Energy Delivery System

- is the use of high energy to treat disease.
- Since the discovery of x-rays over one hundred years ago, radiation has been used more and more in medicine, both to help with diagnosis (by taking pictures with x-rays), and as a treatment (radiotherapy).
- This can be given either as <u>external source</u> from outside the body using x-rays or from within the body as <u>internal source</u>.

ROBOTICS + IMAGING = FINE POSITIONING

what we pretend?

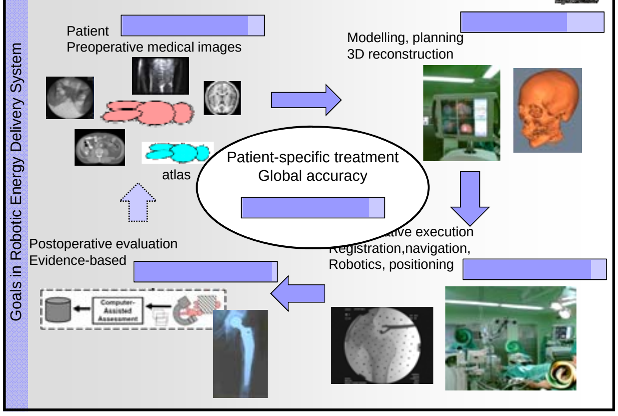
Goals in Robotic Energy Delivery System

- *" to develop a partnership between man (the surgeon) and machine (the new robotic tools) that seeks to exploit the capabilities of both to do a task better than either can do alone"* R. Taylor
- *"Treating the body without surgery and without damaging healthy tissues will define the surgery of the future"*

"we can position ourselves very precisely but in the precisely wrong place" L. Joskowicz

the big picture: present CAS

Goals in Robotic Energy Delivery System



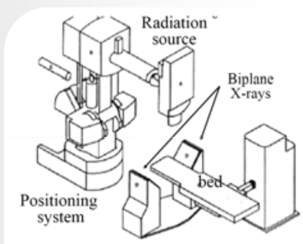
outline of the presentation

- Goals in Robotic Energy Delivery Systems
- Robotic Energy delivery systems
- Intraoperative imaging for positioning
- Surgical robots for positioning

present technologies

Robotic Energy Delivery System

CYBERKNIFE: A robotic radiosurgery system

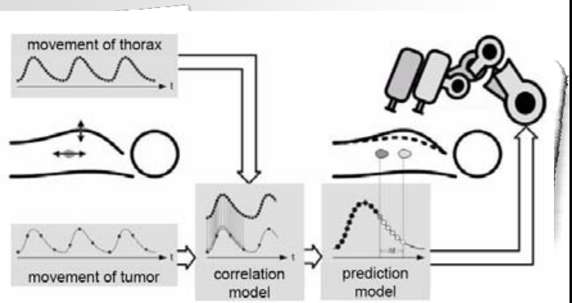


<u>External source</u>

present technologies

Robotic Energy Delivery System

CYBERKNIFE: A robotic radiosurgery system



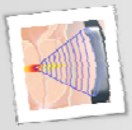
clinicians to significantly reduce margins while eliminating the need for gating or breath-holding techniques.

unprecedented range of positions–allowing access to virtually any tumor from any direction

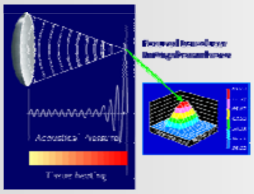
present technologies

Robotic Energy Delivery System

HIFU: High Intensity Focused Ultrasound



HIFU technology uses a high-intensity convergent ultrasound beam generated by high power transducers to produce heat. HIFU is intended to allow the surgeon to necrose prostatic tissue without damaging intervening and surrounding tissue, thus eliminating the need for incisions, transfusions, general anesthesia and their resulting complications.



Ultrasound wave emission is based on transducer vibration. This results in dilatation and contraction modification of acoustical pressure. The acoustical pressure creates tissue movement (dilatation and contraction) which amplitude is directly related to the pressure level. As the tissue response is not perfectly elastic, energy is lost and converted into heat.

Internal source

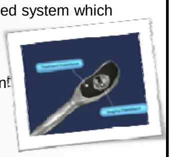
present technologies

Robotic Energy Delivery System

HIFU: High Intensity Focused Ultrasound

The Ablatherm HIFU device is made up of 2 modules: the treatment module on which the patient is positioned and the control module which enables the surgeon to plan and check the treatment via a computerized system which guides the robotic endorectal probe.

The probe is installed on a mobile support. The ultrasound generator and the integrated ultrasound scanning equipment (or transducers) are located on the end of the probe.

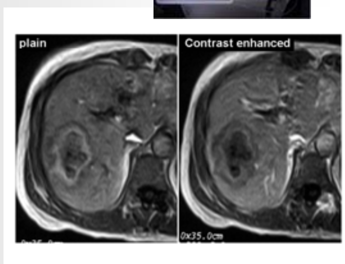


present technologies

Robotic Energy Delivery System

LASER ABLATION SYSTEMS:

A large-scale, 12-year study has found that laser ablation with magnetic resonance (MR) guidance is as effective as traditional surgery in the treatment of liver tumors in some patients. *Annual Meeting of the Radiological Society of North America (RSNA).*

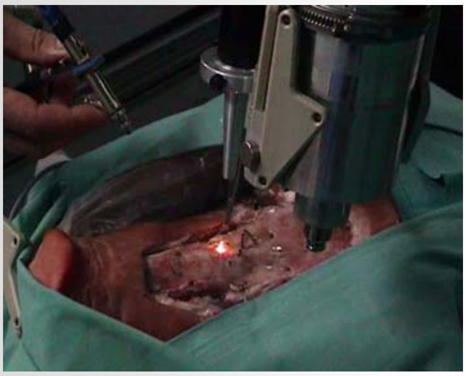


Liver metastases 24 hours after LITT (left image non contrast enhanced, right image after administration of a contrast agent.

present technologies

Robotic Energy Delivery System

LASER ABLATION SYSTEMS:



clinical specialities

Goals in Robotic Energy Delivery System

- Neurosurgery: biopsies, tumor removal, parkinson, epilepsy treatments,…
- Orthopaedics: hip and knee implants, fractures, ACL ligaments,…
- Laparoscopy, ENT: camera support, simulations, virtual colonoscopy,…
- Craneo and maxilofacial: preoperative planning of fragments, precise placement,…
- Radiation therapy: tumor ablation, radiation,..
- …

where we go?

Goals in Robotic Energy Delivery System

"The main challenge is how can we get high-quality medical care onto the battlefield as close to the action and as close to the soldiers as possible,"
John Bashkin, head of business development at SRI International

outline of the presentation

- Goals in Robotic Energy Delivery Systems
- Robotic Energy delivery systems
- Intraoperative imaging for positioning
- Surgical robots for positioning

intraoperative imaging for positioning

- Medical & surgical imaging
  - Tecnologías pre e intra operatorias
  - Precisión en imágenes intraoperatorias
  - Registro entre imágenes intra y pre
- Requisitos para los sistemas “delivery enery”
- Soluciones investigadas y ejemplos de aplicaciones
  - US-guidance
  - Fluoroscopia para clavo distal
  - Magnetico-acustico
  - Ecohaptic

imagen médica

Intraoperative imaging for positioning

- Primera imagen médica
- Los valores de intensidad están relacionados con las características del tejido y con el fenómeno físico utilizado para la adquisición de la imagen.

Roentgen, 1895

- Importante herramienta de diagnóstico

imagen médica

Intraoperative imaging for positioning

Characteristics:

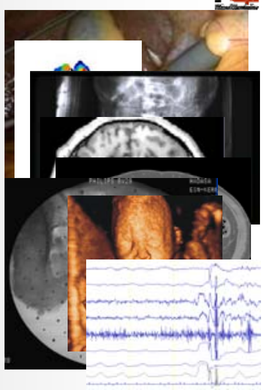
- Preoperative or introperative use
  - Depends on the size and location of imaging machine
- Dimensionality: 2D, 2.5D, 3D, 4D,
- Image quality
  - Pixel intensity, spatial resolution, signal/noise ratio,…
- Field of view
- Radiation to patient and to surgeon
- Functional or anatomical imaging
  - Neurological activity, blood flow, cardiac activity,…
- Suitable for: bones, soft tissues, fetus, surface tumors…
- Clinical use
  - Diagnosis, surgical, navigation

imagen médica

Intraoperative imaging for positioning

Naturaleza física:

- Óptica
- Táctil
- Rayos X
- Resonancia Magnética MRI, fMRI, iMRI, MRA
- Tomografías CT’s
- Fluoroscopia
- Ultrasonidos 2D / 3D /4D
- Electroencefalografias EEG, MEG
- otras



Intraoperative imaging

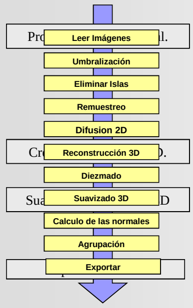
Modality	Intra-operative Availability	Accessability	Data Dimensionality
Computed Tomography (CT)	available (not widespread)	high	3D
Magnetic Resonance Imaging (MRI)	available (not widespread)	high	3D
X-ray	available	high	2D projection
functional Magnetic Resonance Imaging (fMRI)	not available	moderate	3D
Positron Emission Tomography (PET)	not available	moderate	3D
Single Photon Emission Computed Tomography (SPECT)	not available	moderate	3D
X-ray Fluoroscopy	available	high	2D projection
C-arm CT	available	low	3D
Ultrasound (US)	available	high	2D
optical imaging	available	high	2D projection

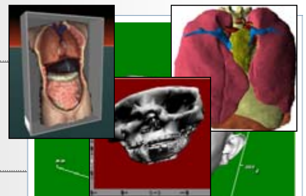
Table 1: Classification of imaging devices according to their availability for intra-operative use, their accessability to physicians around the world, the dimensionality of the data they acquire and the type of information conveyed by the images.

Extracted from:
Image-Guided Procedures: A Review
Ziv Yaniv and Kevin Cleary

generic pipeline

Intraoperative imaging for positioning

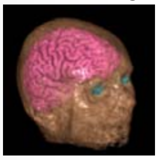


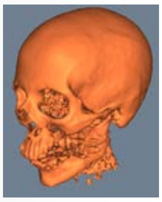


Principales formatos comerciales
- VRML, Ribe…
- PolyData
- Structured grid

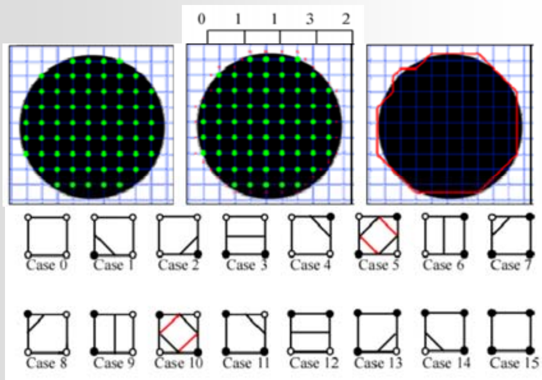
3D reconstruction

- **Volume Rendering**
  - Algoritmos de raycasting (isosurface, MIP, composite,…)
- **Surface Rendering**
  - Realiza la reconstrucción del contorno de un objeto
  - Bajo coste computacional
  - Identificación difícil de los contornos si hay muchas intensidades en la imagen
  - Algoritmo del escultor (triangulación Delaunay)
  - Algoritmo Marching Squares / Cubes

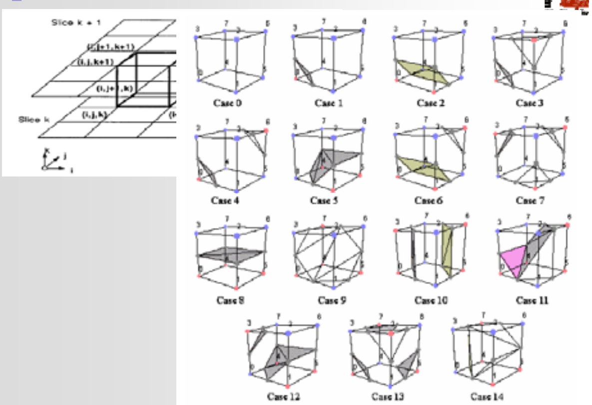




Marching squares



Marching cubes



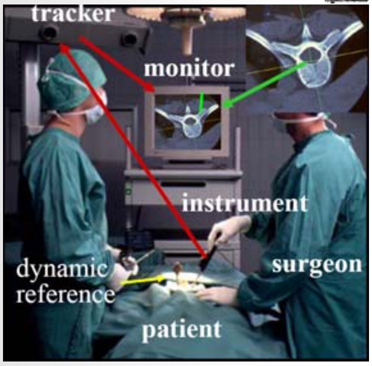
planificación y registro

Intraoperative imaging for positioning

navegación

Intraoperative imaging for positioning

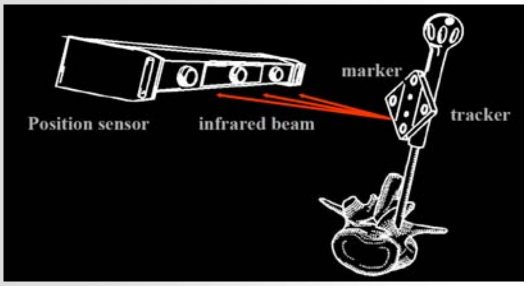
- Optical-based CAS



navegación

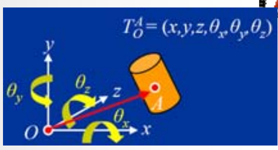
Intraoperative imaging for positioning

- Principio de funcionamiento

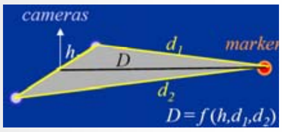


principios de la navegación quirúrgica

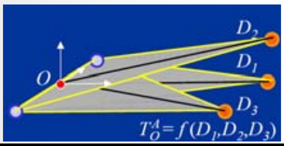
6 parameters(3 translations + 3 rotations) uniquely determine the position and orientation of an object



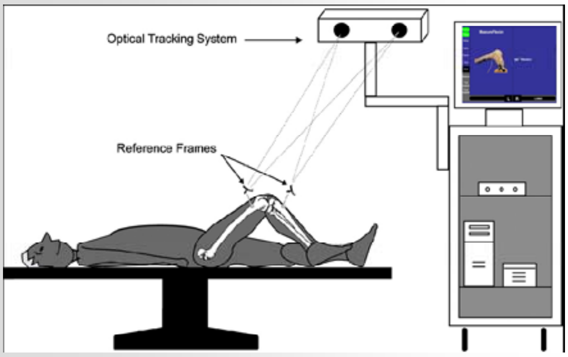
By triangulation with two cameras, the distance of a marker from the origin can be determined



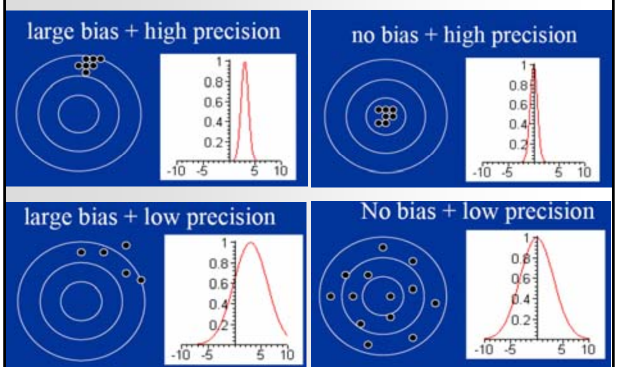
From three marker distances the position and orientation of a rigid tracker is uniquely determined



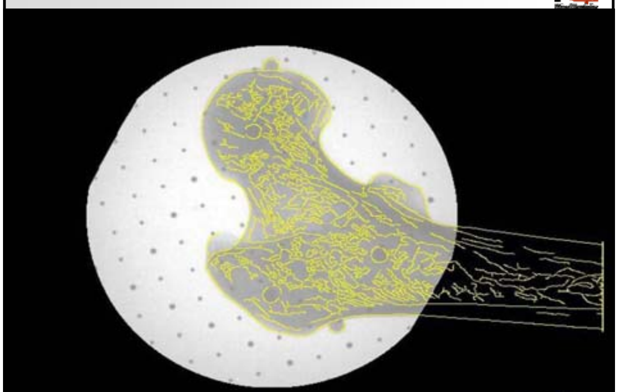
principios de la navegación quirúrgica



Accuracy in navigation

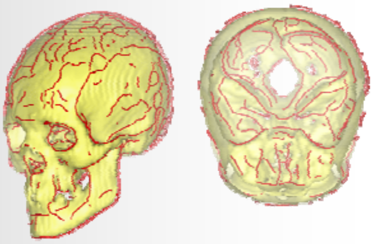


Registro 2D



Registro 3D

Intraoperative imaging for positioning

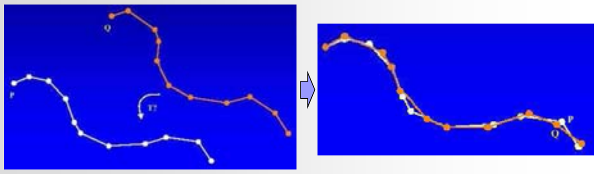


- Marcas invasivas
- Marcas externas
- Registro con datos atlas
- Movimiento de los tejidos

Algoritmo ICP

Intraoperative imaging for positioning

- Búsqueda del punto más próximo: En la primera fase hay que identificar, para cada punto de la superficie P, el punto más cercano de la superficie del modelo Q.
- Calcular transformada: calcular la transformación rígida T que minimiza las sumas de los cuadrados de las distancias entre los pares de puntos próximos (p,q).
- Transformación: Aplicar la transformación rígida T a todos los puntos del conjunto P.
- Iterar: repetir los pasos 1 a 3 hasta converger, aplicando un umbral de tolerancia.



Planificación y registro

Intraoperative imaging for positioning

- Tejidos blandos
- Registro sobre información 3D reconstruída

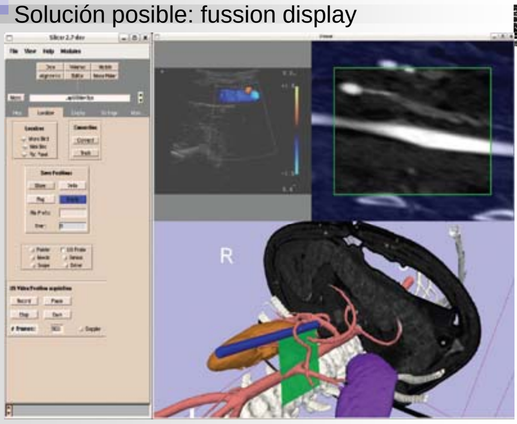
Interventional ultrasound

Intraoperative imaging for positioning

Prostate radiotherapy.
"The dancing prostate". By A. Zitman (MGH)

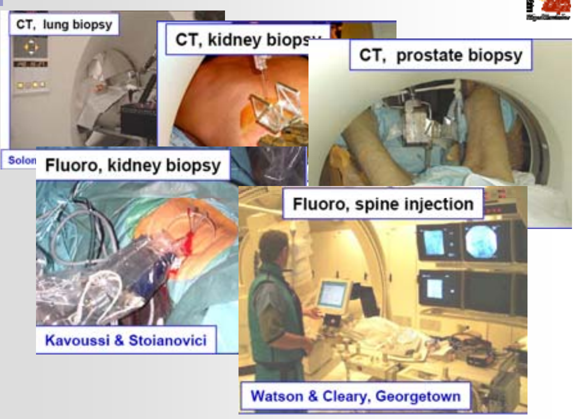
- *operator dependent*
- *invasively deforms tissues*
- *no image outside the body*
- *needs calibration*

Solución posible: fussion display



Ejemplos y aplicaciones de image-guided surgery

Intraoperative imaging for positioning

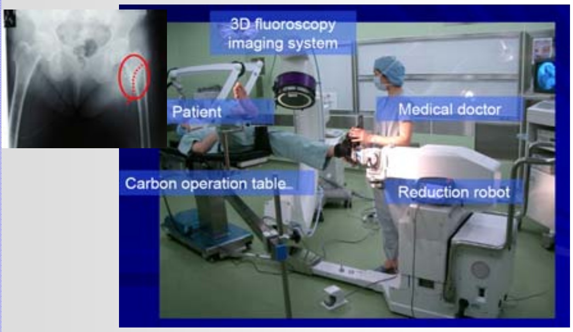


Ejemplos y aplicaciones de image-guided surgery

© M. Mitsuishi

Intraoperative imaging for positioning

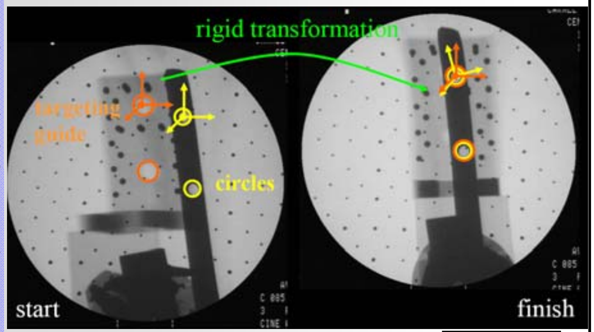
- Reducción de la fractura de la cabeza del fémur



Ejemplos y aplicaciones de image-guided surgery

© L. Joskovicz

Intraoperative imaging for positioning



Inserción clavo distal

Ejemplos y aplicaciones de image-guided surgery

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Intraoperative imaging for positioning

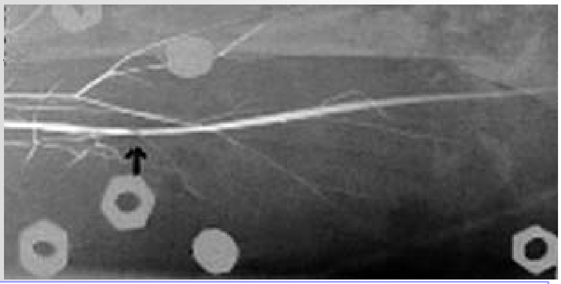
Sharpnel removal

Terror wounds are characterized by explosion injuries and penetration of metal shrapnel

Sharpnel removal: indications

© L. Joskovicz

Intraoperative imaging for positioning



Removal of shrapnels requires utmost accuracy in detection and removal

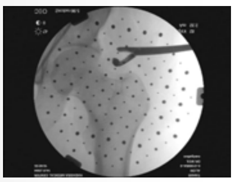
Sharpnel removal: requirements

© L. Joskovicz

Intraoperative imaging for positioning

Accurately removal of shrapnel relies on:

- getting to the target
- efficiently grasping the metal fragment

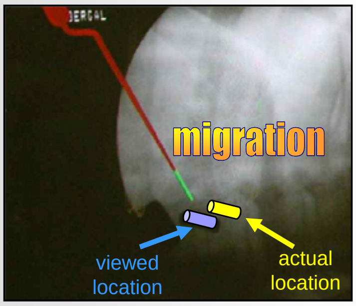


Real-time fluoroscopy is the most commonly used approach

© L. Joskovicz

Intraoperative imaging for positioning

Fragment migration during navigation

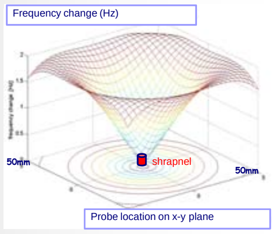


Fragment migration misleads the surgeon

Metal detector probe

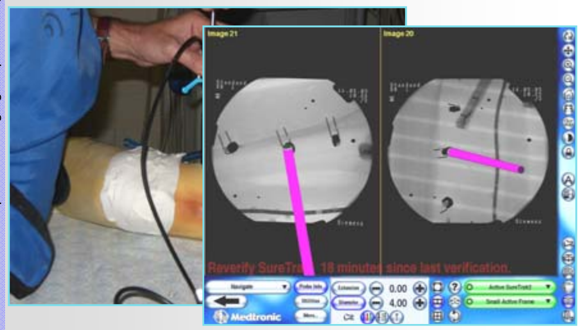
Experimental design

- Sensitivity range: 2-5 cm from fragment location
- Output : audio frequency change.
- Limitations: designed to locate without physical extraction.



Fluoroscopic navigation

Navigation with the metal detector probe



Results

Experiment #1: no fragment migration

no difference

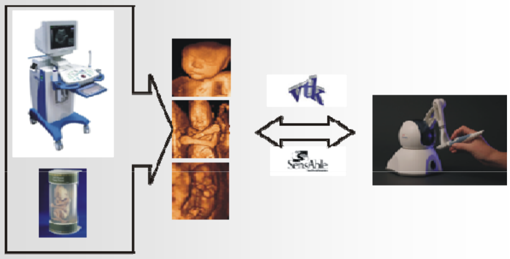
Experiment #2: with fragment migration

great difference!

Fragment number	**Metal detection (secs)**	
	without	**with**
1	**180**	25
2	65	10
3	25	10
4	45	10
5	25	15
6	**180**	5
Average	*86*	*12.5*

More than six times faster!!

Concepto de EcoHaptic



Aplicación inicial: aplicación ginecológica. [ref. Fetouch project]
A partir de la información de ecógrafos 2D/3D ser capaces de "palpar" la imagen ecográfica.

Aplicación futura: aplicación de diagnóstico e intraoperativa.
Analizar y mejorar la información suministrada por US para un análisis volumétrico de la misma.

Experimentación y comparativa

Interacción háptica en EcoHaptic:

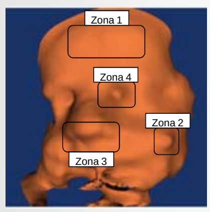
Constante de Elasticidad	**Constante de *Damping***					
	0,0010	**0,0015**	**0,0020**	**0,0025**	**0,0030**	**0,0035**
0,1	Mala	Mala	Mala	Mala	Mala	Inestable
0,2	Buena	Buena	Buena	Buena	Mala	Inestable
0,3	Buena	Buena	Buena	Buena	Mala	Inestable
0,4	Buena	Muy buena	Muy buena	Muy buena	Mala	Inestable
0,5	Buena	Muy buena	Muy buena	Muy buena	Mala	Inestable
0,6	Buena	Muy buena	Muy buena	Muy buena	Mala	Inestable
0,7	Buena	Buena	Buena	Buena	Mala	Inestable
0,8	Buena	Buena	Buena	Buena	Mala	Inestable
0,9	Mala	Mala	Mala	Mala	Inestable	Inestable
1,0	Mala	Mala	Mala	Mala	Inestable	Inestable

- Mejores resultados
  - Valores intermedios de la constante de elasticidad
  - Valores pequeños de la constante de damping

Experimentación y comparativa

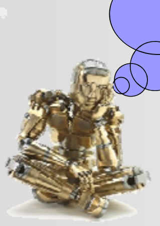
Interacción háptica en EcoHaptic. Zonas geométricas:

Geometría	**Tiempo de ejecución (segundos)**
Convexa ángulos pequeños (Zona 1)	Buena interacción
Convexa ángulos grandes (Zona 2)	Buena interacción
Cóncava ángulos pequeños (Zona 3)	Interacción aceptable
Cóncavas ángulos grandes (Zona 4)	Fallos en la interacción



outline of the presentation

- Goals in Robotic Energy Delivery Systems
- Robotic Energy delivery systems
- Intraoperative imaging for positioning
- Surgical robots for positioning



Surgical robots for positioning

- Requisitos de posicionamiento
- Esquema de posicionamiento
  - Sistema teleoperado
  - Sistema autónomo
- Patient-mounted robots vs table-mounted robots
  - En paciente, en camilla, móvil…
  - Problema de registro y precisión

Surgical robots for positioning

A Safety Point of View

SURGEON

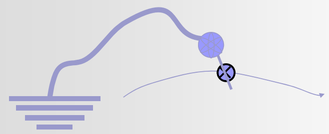
Efficient natural sensors Dexterity Coordination Capacity in reasoning and learning Adapting his skills	Subject to fatigue Stability Precision Unable to see through tissues Subject to radiations	Geometric accuracy Precision in controlling forces Possibility to work in hostile environment Repeatability No fatigue Stationarity Rapidity	Weak capacity in deciding, learning, adapting Incomplete models Reliability

Better accuracy
Safety increased
Trauma decreased
Decreasing number of interventions
Post operative comfort and fast recovering

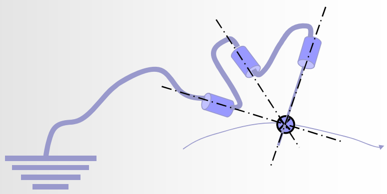
Surgical robots for positioning

Kinematic constraints: Remote Rotation Center

- A classical spherical wrist does not rotate at the “right” point



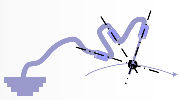
A RRC system does and thus “cancel” the Constraint
3 = (6 + 3) – (6 x 1)



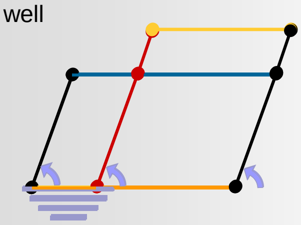
Surgical robots for positioning

RRC or “The Magical Parallelogram”

- RRC with spherical links requires complex parts

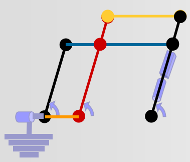


- … while a basic parallelogram may do the job as well

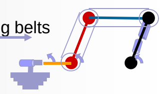


Surgical robots for positioning

Implementation of RRC



From solid links to timing belts



Sistemas teleoperados

Endoassist - intuitive camera control in endoscopic surgery

Sistemas teleoperados

Surgical robots for positioning

Project:	Robotic Teleoperated High Intensity Focused Ultrasound (HIFU) System
Client:	US Army

High Intensity Focused Ultrasound (HIFU) has been investigated since early last decade and has proven to be a valuable non-invasive surgery technique. With currently available technology, HIFU energy can be precisely targeted to cure some cancers, cauterize tumors, and stop bleeding. The concept of non-invasive hemorrhage control is particularly significant in combat scenarios where immediate access to surgery is limited. HIFU has been shown to effectively control bleeding from vessels up to 2mm in diameter and the technology is evolving rapidly. It is expected that in the near future, HIFU will effectively control hemorrhage from vessels 8-10mm diameter.

The Army is interested in HIFU-based hemorrhage control on the battlefield by integrating a robotic teleoperated (where the surgeon is controlling the arm from a remote location) system with the Life Support for Trauma and Transport (LSTAT) system. The LSTAT is an advanced platform that allows monitoring and intervention on severely injured patients during transport.

Energid is developing a robotic HIFU system that a) allows use of the device by remote users, b) integrates with LSTAT, and c) provides the dexterity and workspace necessary to apply HIFU on an extremity injury, femoral bleeding and some intra-abdominal injuries.

http://www.energid.com/energid-projects-robotics-hifu.htm

Sistemas autónomos

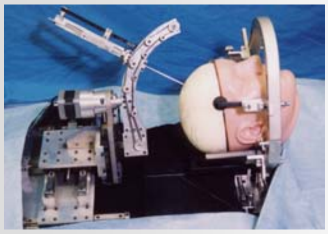
PathFinder - frameless stereotactic precision

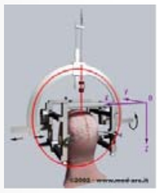
ROBONAV (Robodoc, by Curexo tech. Company)

M-850 hexapod from Fraunhofer-Institut für Produktionstechnik und Automatisierung (IPA)

Table mounted robot

Surgical robots for positioning





Patient mounted robot

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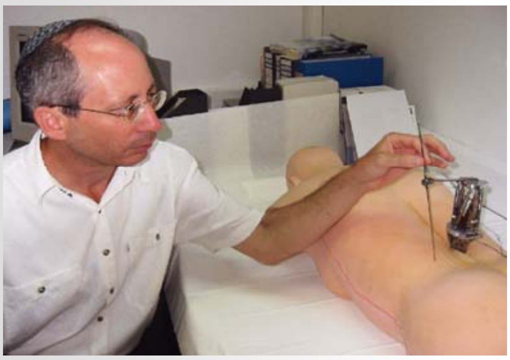
MARS

Surgical robots for positioning



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MARS

Surgical robots for positioning

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SECAO society: Andre Bauer, Jose Mª Fdez. Meroño, Roque Torres
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Thanks

"Nurse, get on the internet, go to SURGERY.COM, scroll down and click on the 'Are you totally lost?' icon."