KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST

MNL Medical Navigation Lab.

Research Collaboration with NTUU "KPI"

Sep. 26, 2017

Ph.D. Deukhee Lee

Center for Bionics, KIST, Seoul, S. Korea

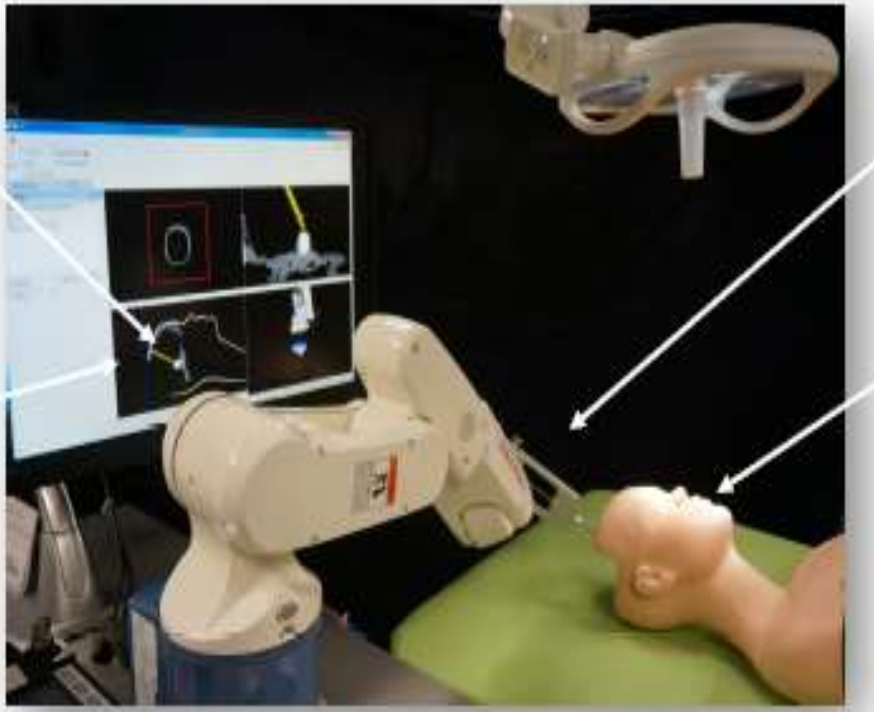
KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST MNL Medical Navigation Lab.

Image-Guided Surgical Systems

3D patient modeling

VR surgical planning



Surgical navigation

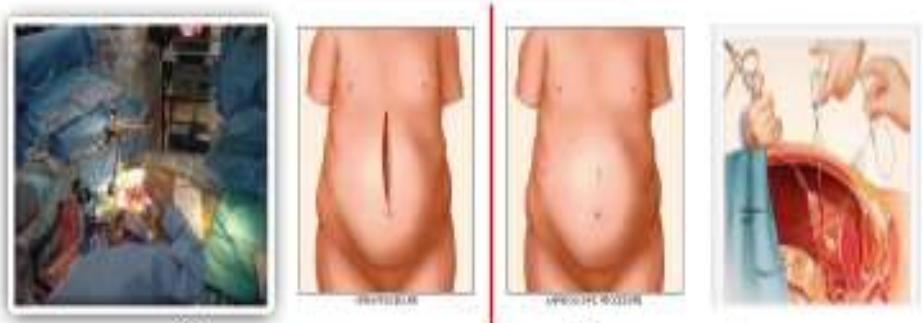
Image-patient registration

Minimally Invasive Surgery

- **The development of science and technology leads to the development of medicine.**
- Modern Surgery
  - Three main developments in early 19th century
    - Bleeding control
      - Cauterization
      - Blood transfusions
    - Pain control
      - Anesthesia
    - Infection control
      - Equipment sterilization
      - Rigorous hand washing
      - Rubber gloves
- Minimally Invasive Surgery
  - Benefits
    - Less pain and scarring
    - Reduced risk of infection
    - Faster recovery

Mini video camera tech. in late 20th century

Minimally Invasive Surgery



Open surgery

Laparoscopic surgery

Minimally Invasive Surgery

- Modern Surgery
  - Three main developments in early 19th century
    - Bleeding control
      - Cauterization
      - Blood transfusions
    - Pain control
      - Anesthesia
    - Infection control
      - Equipment sterilization
      - Rigorous hand washing
      - Rubber gloves
- Minimally Invasive Surgery
  - Benefits
    - Less pain and scarring
    - Reduced risk of infection
    - Faster recovery

Mini video camera tech. in late 20th century

Minimally Invasive Surgery

Open surgery | Laparoscopic surgery

Non-Invasive Surgery

- Medical imaging modalities in late 20th century
  - CT
  - US
  - MRI

- Non-Invasive Surgery
  - Radiation
    - Gamma Knife
    - CyberKnife
    - Linear Accelerator (LINAC)
  - Ultrasound
    - Extracorporeal Shock Wave Lithotripsy (ESWL)
    - High Intensity Focused Ultrasound (HIFU)
  - Magnetic field
    - Extracorporeal Magnetic Innervation (ExMI)
    - Transcranial Magnetic Stimulation (TMS)

Computer Assisted Surgery

- Limits of MIS
  - Less intuitiveness
  - 2D images on screen
  - Pivot motion of tools
  - Poor eye-hand coordination

In early 21th century (the present)
- **Robot Tech.**
- **Information Tech.**

Robot Surgery
Navigation surgery

Laparoscopic surgery

Robotic surgery (DaVinci)

Navigation surgery

Operating Room of the Future

- In the future...
  - Emerging technologies
    - AI, Big data, IoT...
      - IBM Watson health
      - Google Deep Mind health
    - VR, AR
      - Microsoft Hololens

More safety

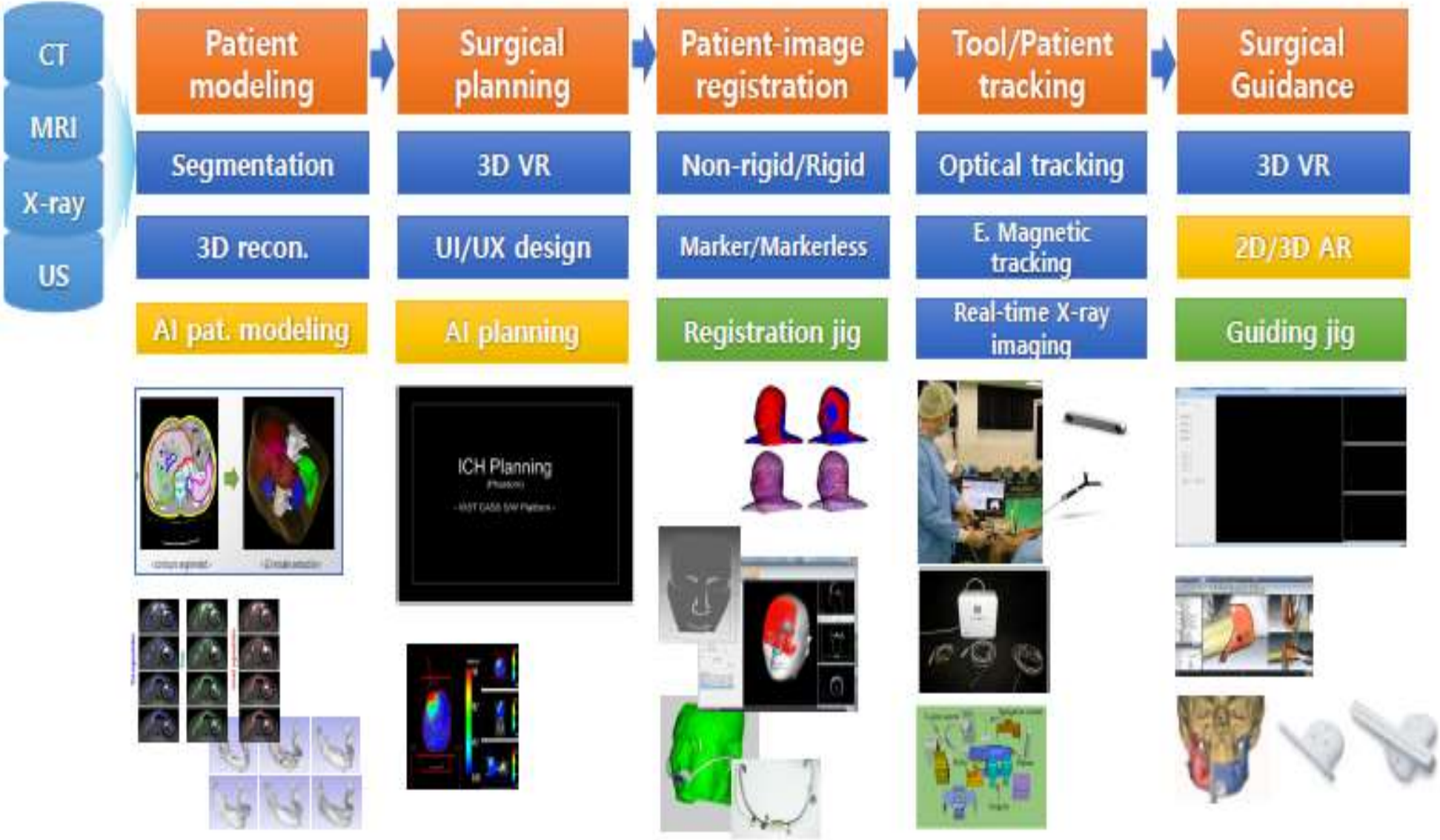
Efficient medical practice

Intuitive inspection

Comfortable environment

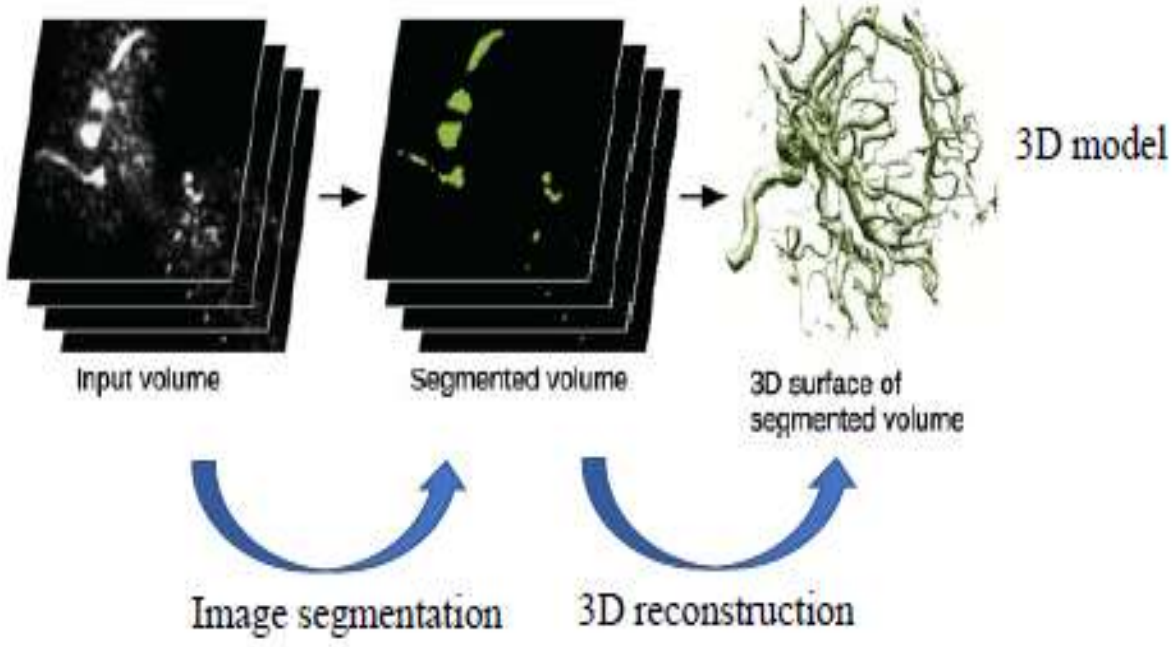
Operating room of the future

Tech. Procedures of IGS (Image-Guided Surgery)



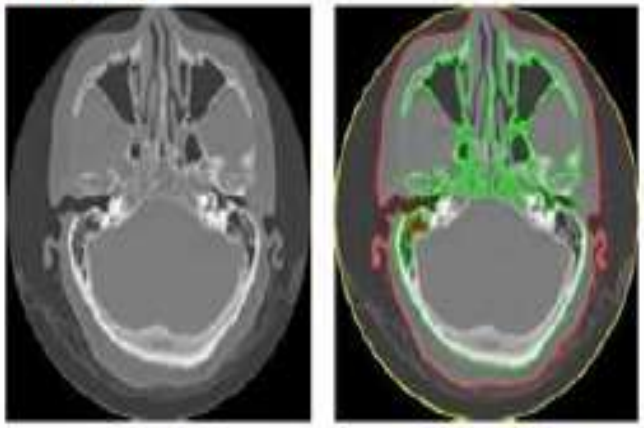
Patient Modeling

Image segmentation and 3D reconstruction

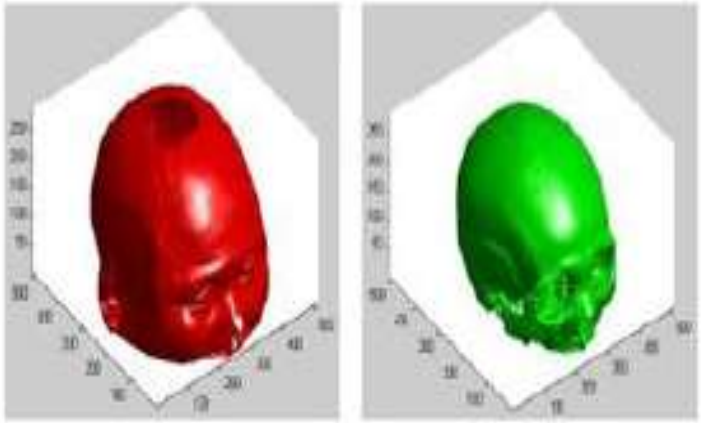


Automatic Segmentation

Brain surgery

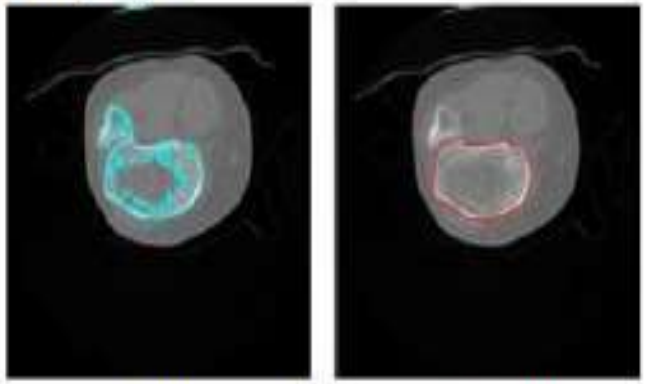


original segmentation

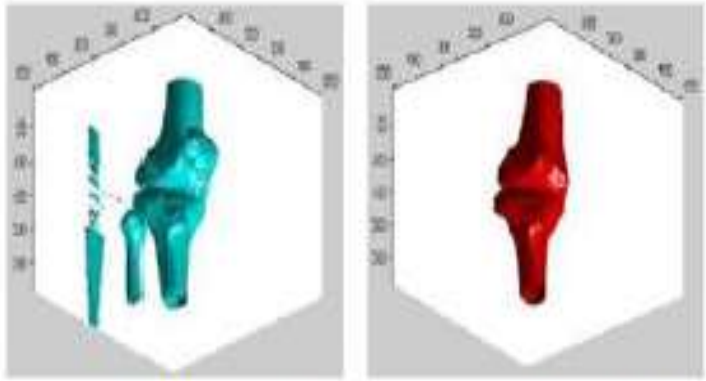


skin skull

Knee surgery

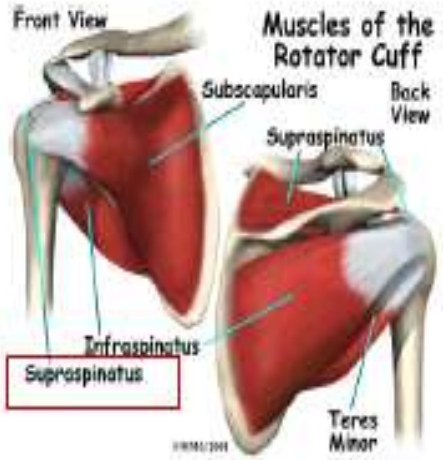


manual iso-value our method

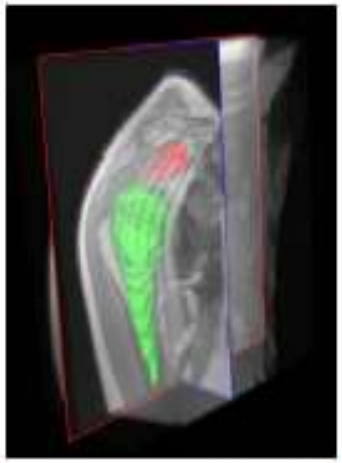


manual iso-value our method

Segmentation for shoulder



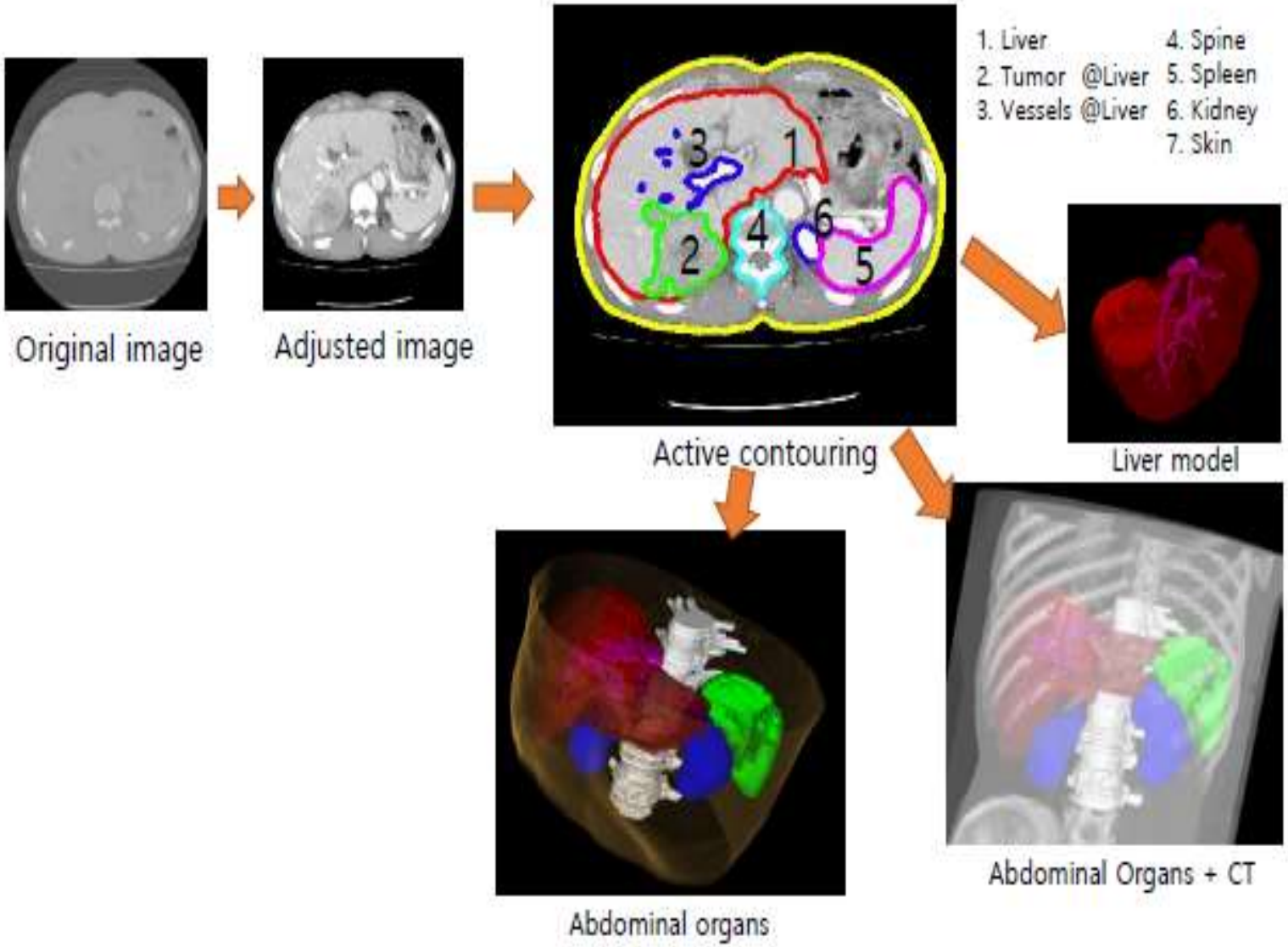
Anatomy of Rotator Cuff



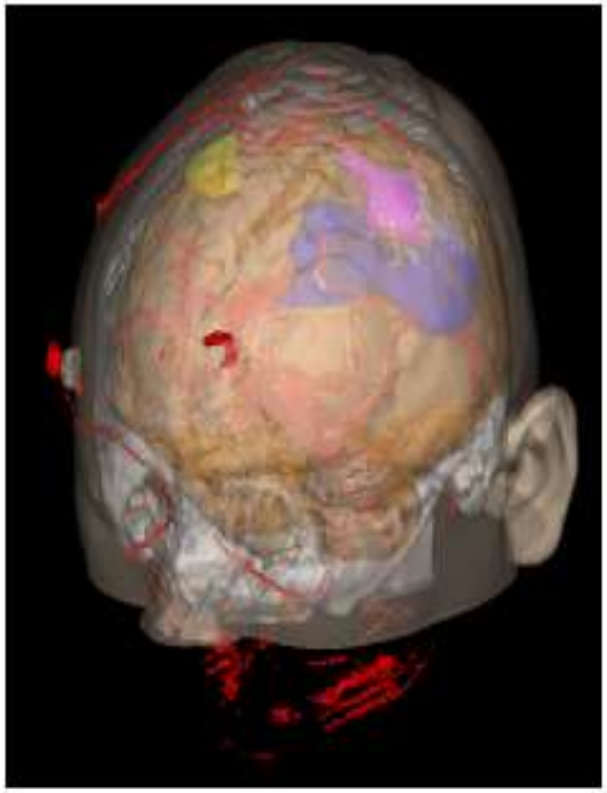
3D models of supraspinatus and humerus

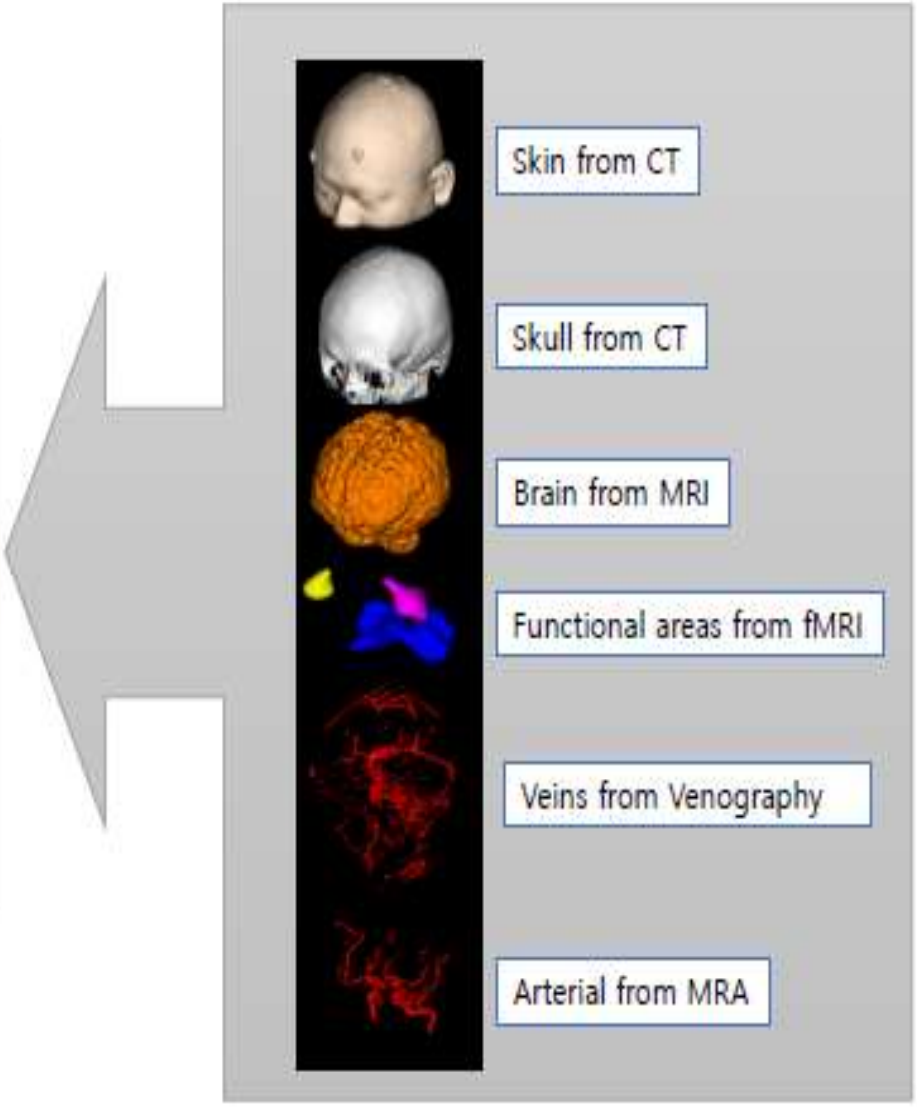
Segmentation for abdominal organs

Automatic segmentation of Liver, Tumor, Vessel, Skin, Spine, Spleen, and Kidney



Brain map using multi-modal images





VR Medical Simulation

3D model + Haptic/tracking device

Sample video (youtube)

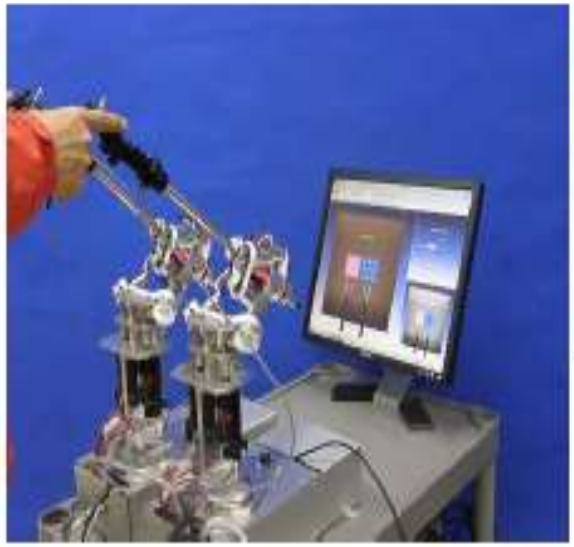
Dental simulation

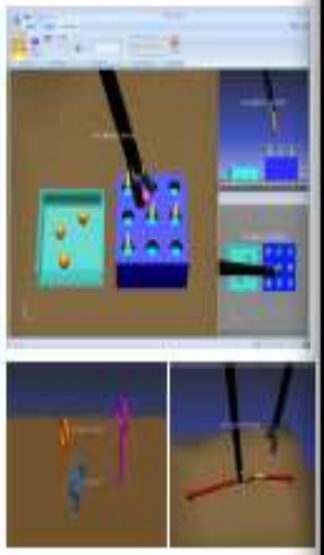
- Carious lesion detection & drilling
- Workbench for eye-hand coordination

Dental simulation, 2004~2005

Laparoscopy surgery simulation

- High-fidelity haptic and visual rendering for laparoscopic surgery
- Human organ modeling & deformable modeling
- Haptic device with laparoscopic instruments

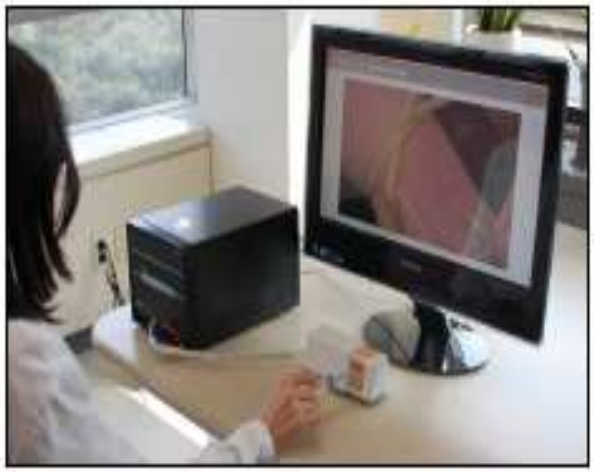


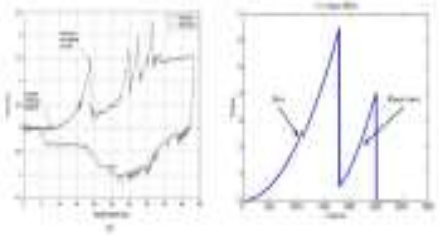


Laparoscopy surgery simulation, 2007~2010

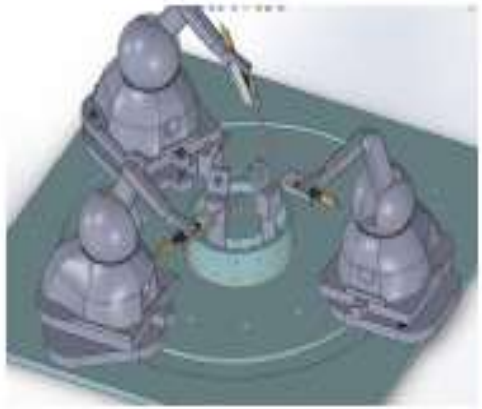
Needle insertion simulation

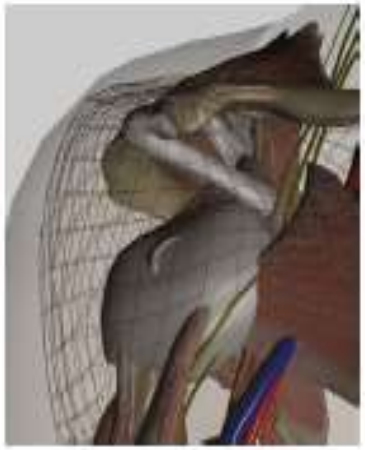
- Intravenous injection simulator with haptic interface
- Simulate delicate force feedback and small difference
- 2 DOF input/ 1DOF output

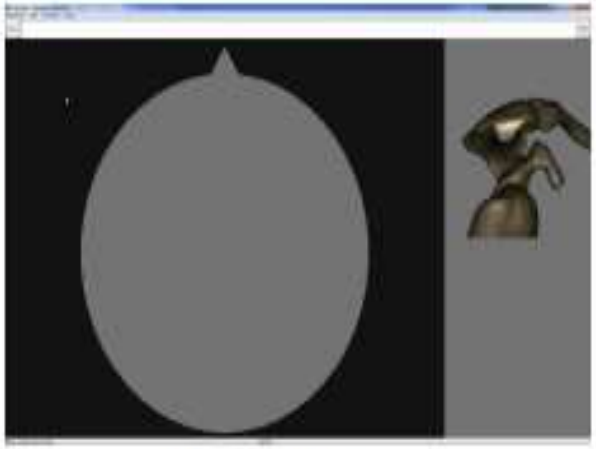




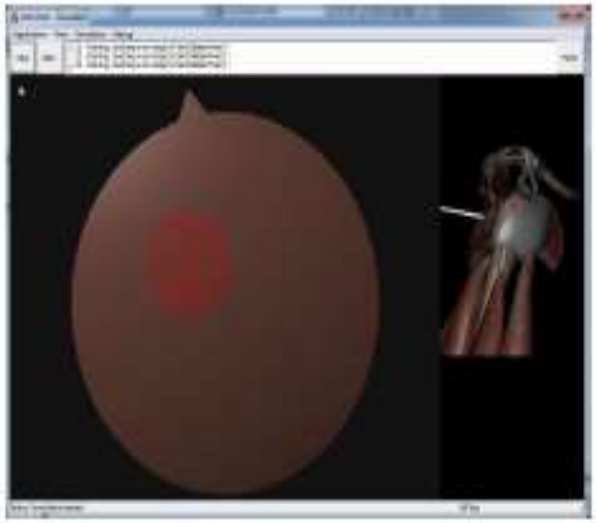
Arthroscopic surgery simulation







Deburring



Anatomy navigation

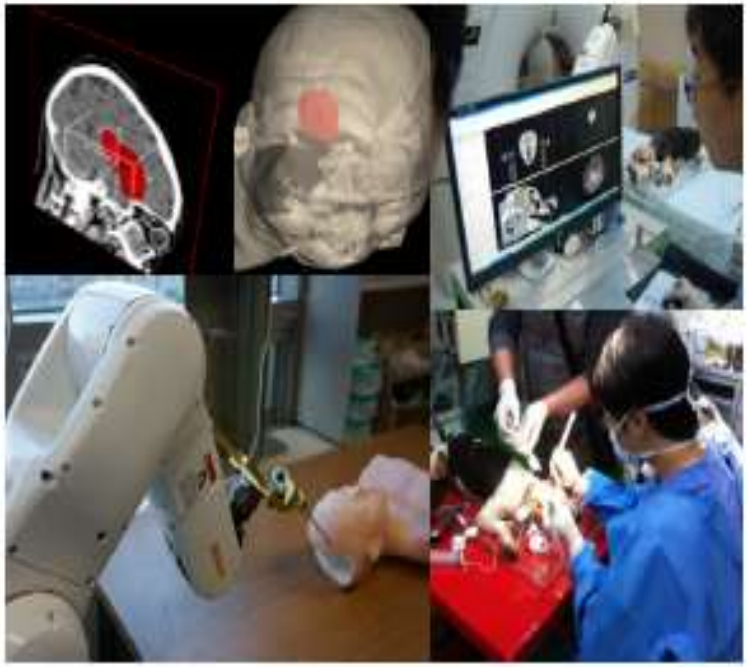
Arthroscopic surgery

KIST 한국과학기술연구원
Korea Institute of Science and Technology

KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST MNL Medical Navigation Lab.

VR Surgical Planning & Navigation



Surgical robotic system for brain surgery

Computer navigation system for knee surgery
(ACL reconstruction)

ACL Reconstruction Surgery

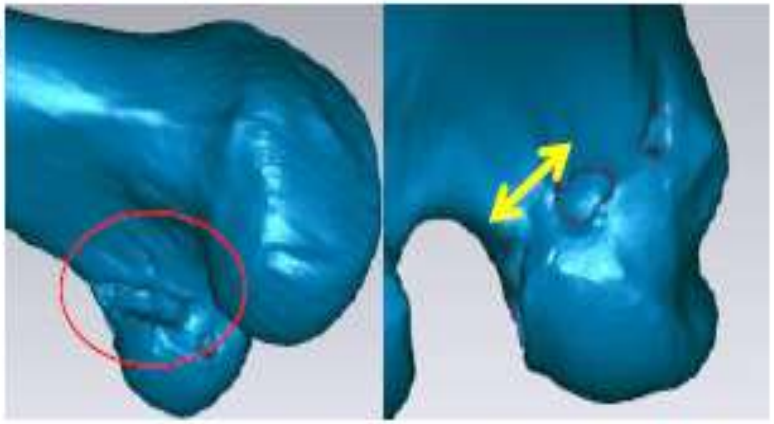
- Anterior Cruciate Ligament Reconstruction

ACL Reconstruction

Extracorporeal View of Arthroscopic Surgery

Arthroscopic surgery

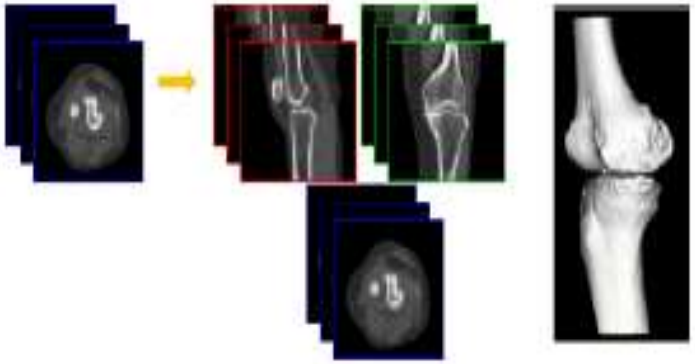
Tunneling failures:



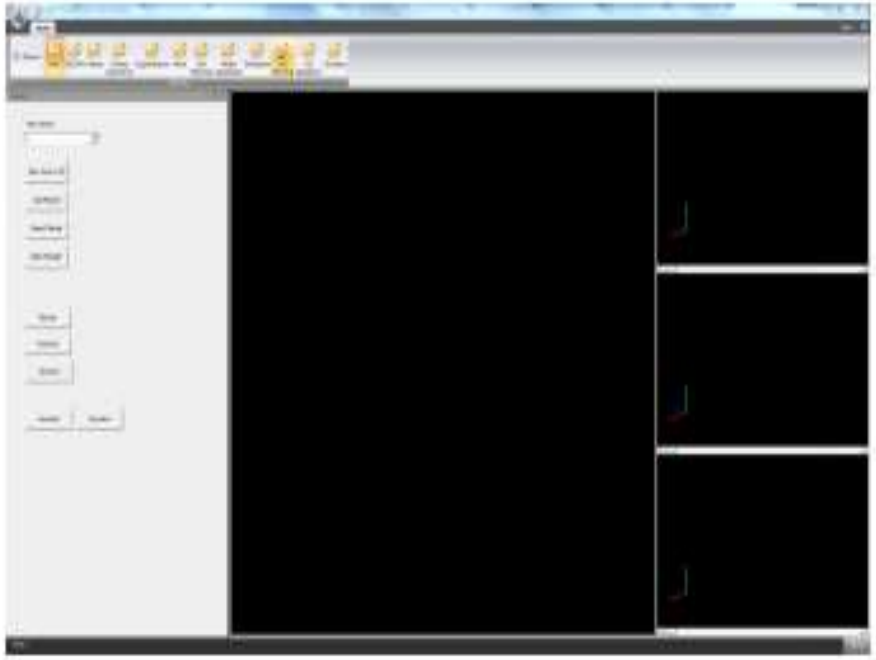
Posterior wall breakage

Short femoral tunnel

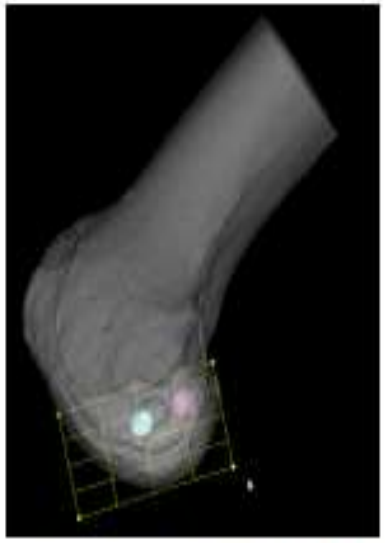
3D VR surgical planning for ACLR



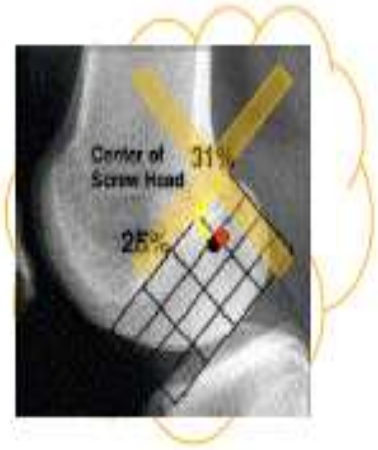
3D reconstruction (patient bone model)



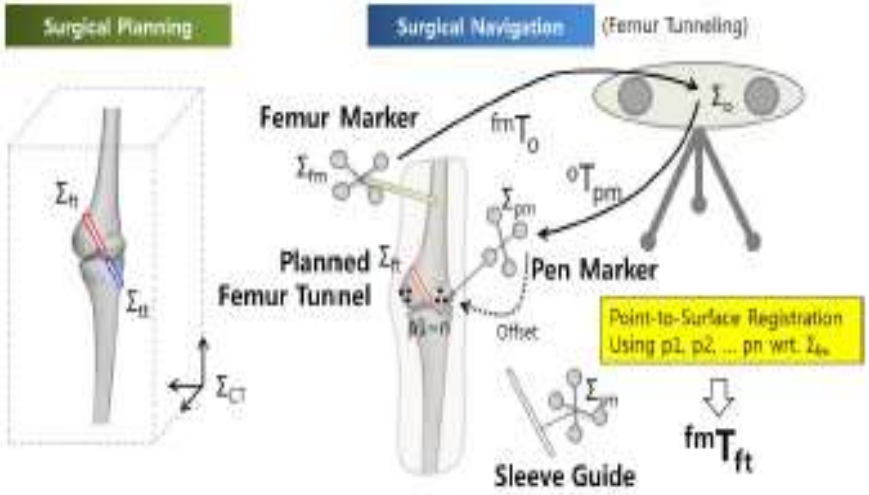
Surgical planning



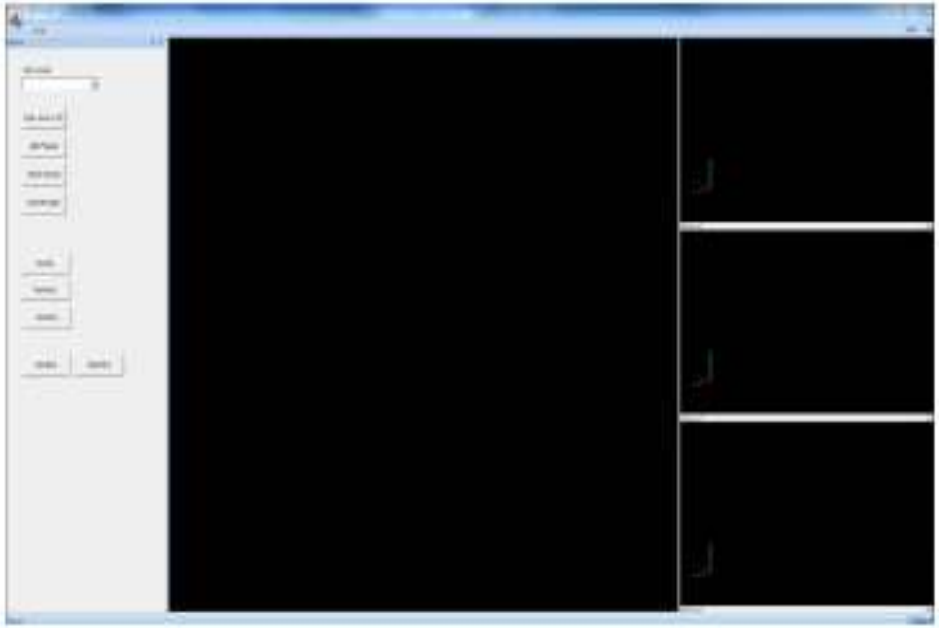
3D Quadrant method

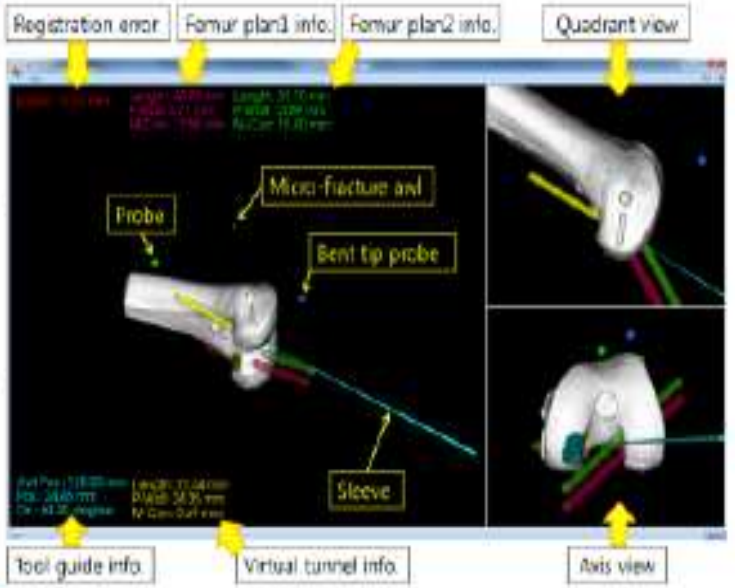


Navigation of ACLR



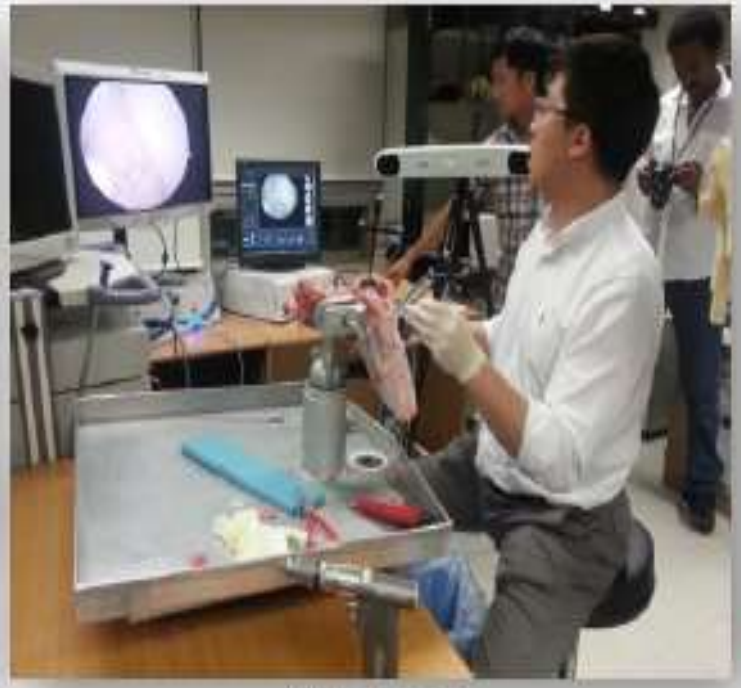
- Registration
  - Pre-op. plan data + intra-op. patient
- Real-time 3D pose tracking
  - Optical tracking system (Polaris Spectra®; NDI)
  - Femur, tibia, tools
- Surgical plan can be changed while checking predicted results in real time.





Phantom / animal / cadaver test of ACLR

Phantom test



Animal test

Cadavar test

† w/t Samsung hospital

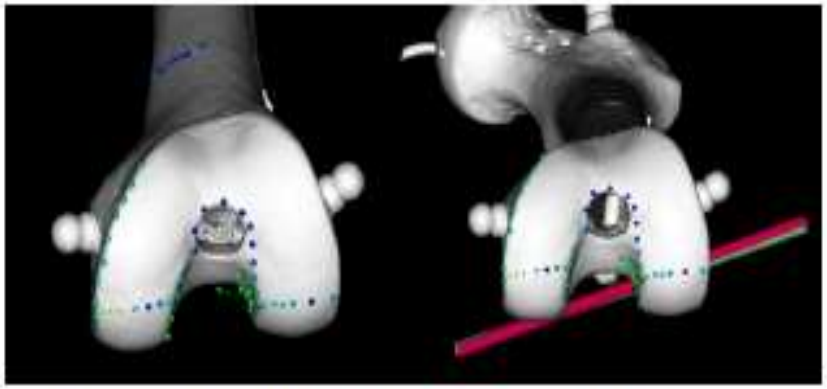
Accuracy results

FRE (mm)	Averag e	SD	Max error
Phantom	0.2804	0.2089	0.8665

TRE (mm)	Entry Point Distance	Angle Difference
Phantom	0.6746 mm	0.6542°

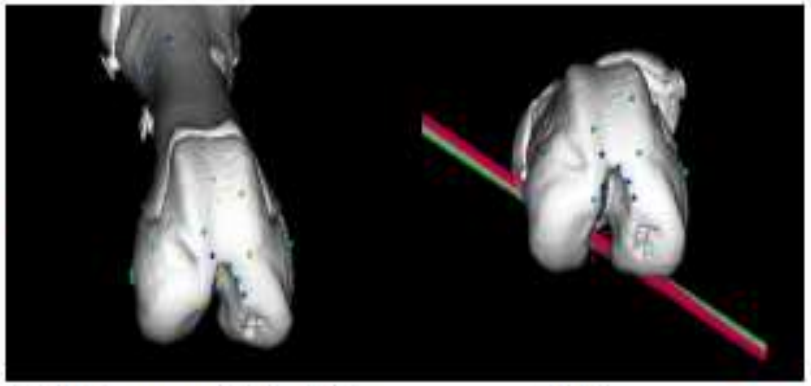
FRE (mm)	Average	SD	Max error
Femur	0.4501	0.4412	2.0977

TRE (mm)	Entry Point Distance	Angle Difference
Femur	0.4814mm	0.8533°



FRE [range: 0.0-1.0]

TRE
green: plan, red: result



FRE [range: 0.0-1.0]

TRE
green: plan, red: result

KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST

MNL Medical Navigation Lab.

Intro. To Research Projects

Sep., 2017

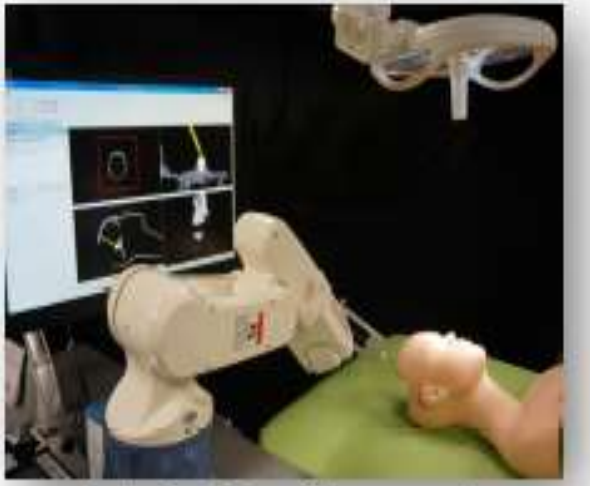
KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST

MNL
Medical Navigation Lab.

Robotic guidance system for ICH (Intracerebral Hemorrhage) removal

Intracerebral hemorrhage



Robotic ICH guidance system

Project Description

- Target surgery: stereotactic aspiration (Surgery for intracerebral hemorrhage)

Diagnosis | **Pre-op. processes** | **Intra-op. processes**

CT scan and diagnosis

Mounting the coordinate frame

CT registration with the frame

Surgical planning with respect to the frame coordinate system

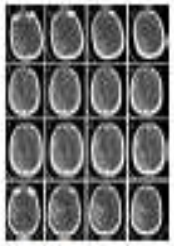
Setting the stereotactic arc on the frame

Insertion of evacuation catheter along the guidance of the head frame

- Research objective:
  - **Frame-less robotic ICH surgery** has been developed in order to reduce processing time considering emergency situation of ICH(Intracerebral Hemorrhage) surgery.
    - It's no need to mount the coordinate frame on the patient's head
    - It doesn't need to re-CT scan in order to register the frame to image
      - radiation exposure reduction

Methods

- 3D VR surgical planning



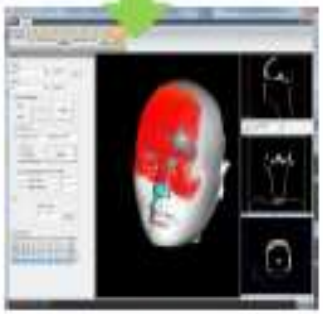
CT volume data

Insertion path of the evacuation catheter with respect to the CT coordinate system

x4

- Face registration

3D face scanning of phantom



Registration of intra-op. face and pre-op. CT face using Weighted-ICP

Insertion path w.r.t. robot coordinate system

- Robotic guidance

Robotic guidance of insertion path

3D face scanner

Weight	Under 1 kg
Measurement precision	Under 100 um
Dimension	130 x 90 x 200 mm^3
Measuring area	300 x 220 mm^2
Measuring distance	720 mm
Brightness	284 lux

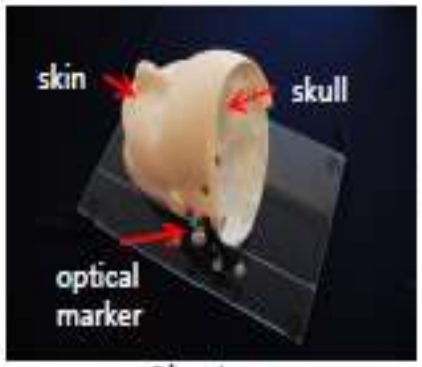
KIST 한국과학기술연구원 Korea Institute of Science and Technology

Bionics @KIST

MNL Medical Navigation Lab.

Results

- Phantom test



Phantom

OTS

Accuracy test using OTS (NDI polaris spectra)

	Target (mm)	Orientation (degree)
Average	1.94	0.65
SD	0.49	0.20
MAX	3.22	0.95
MIN	0.93	0.28

- Animal test

Intra-op.

Post-op.

Animal ICH model

Anesthesia

Skull drilling

Blood injection

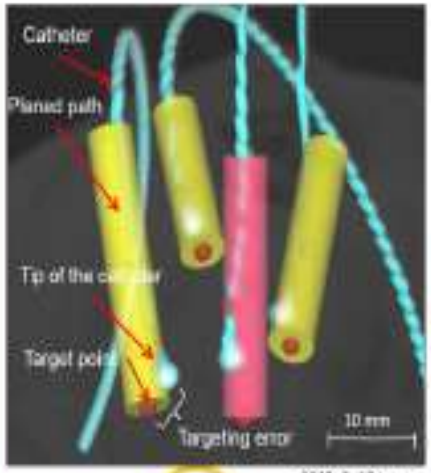
CT scan & planning

3D face scan & registration

Surgeon's insertion of evacuation catheters

CT scan

Segmentation of the catheters and overlay of the planned insertion path



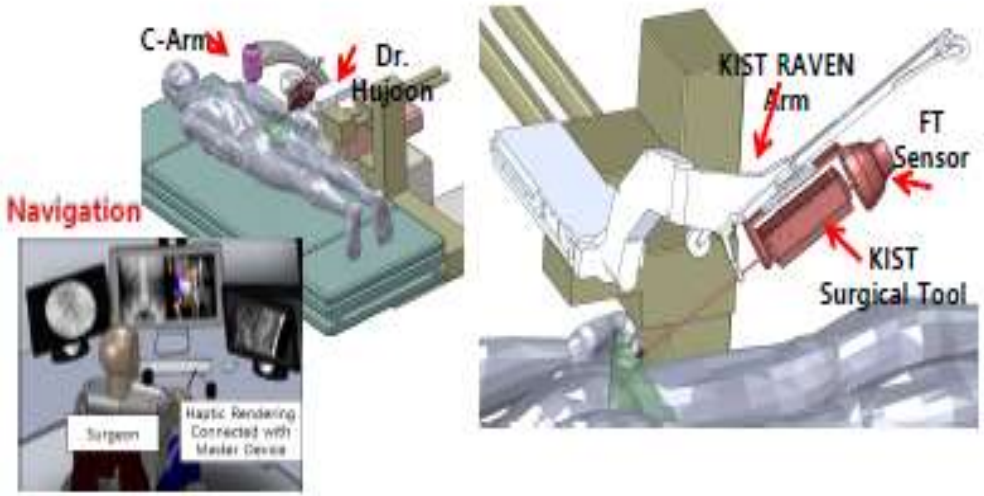
KIST 한국과학기술연구원 Korea Institute of Science and Technology

Bionics @KIST

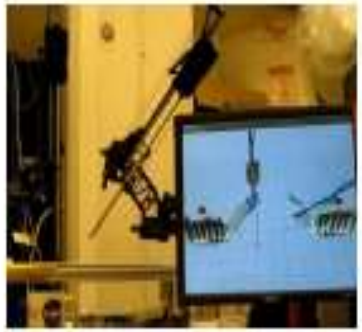
MNL Medical Navigation Lab

Development of next-generation micro-surgical robot based on open platform

Period: Nov. 01, 2013- Oct. 31, 2018 (5 years)
Fund: 1,000K USD/year, MOTIE



Cost-effect, open platform micro-surgical robot

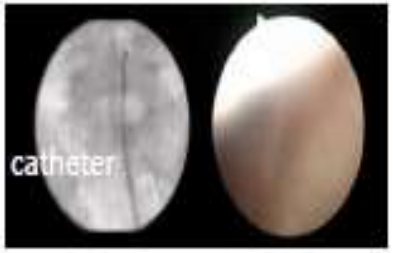


Raven platform developed by U. of Washington

Project Description

- Target surgery
  - SELD(trans Sacral Epiduroscopic Laser Decompression) of Epiduroscopic neuroplasty



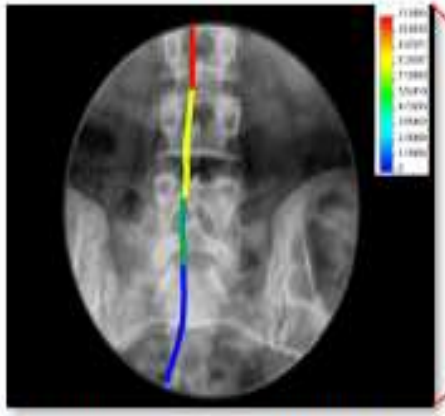


X-ray img. Epiduroscopic img.

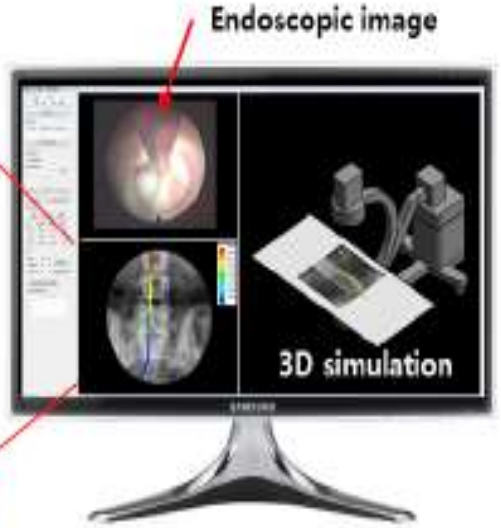
Insertion an EN catheter to a target ruptured lumbar disk through sacral hiatus

- My research objective:
  - 3D catheter shape tracking in order to guide catheter insertion

A-P direction

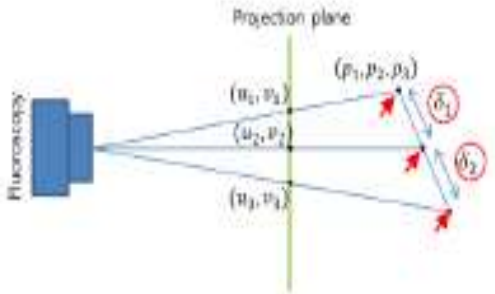


X-ray image + depth information



Methods

- 3D shape estimation using single C-arm x-ray device



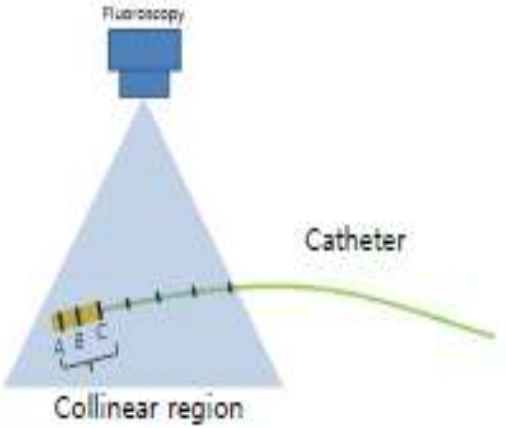
Collinear points with known interpoint distances

$$u_n = f\frac{p_1 + \delta_n b_1}{p_3 + \delta_n b_3}$$

$$v_n = f\frac{p_2 + \delta_n b_2}{p_3 + \delta_n b_3}$$

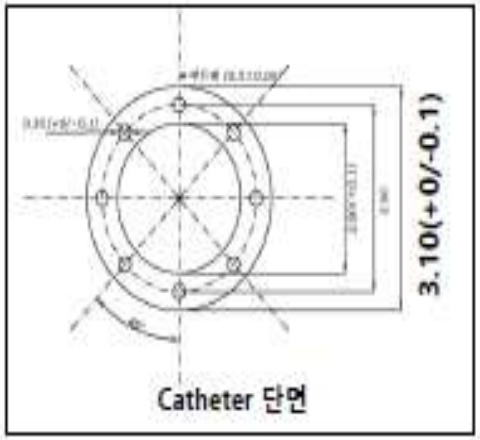
For direction cosine, (b_1, b_2, b_3), each 3D point position is, $p + \delta b$

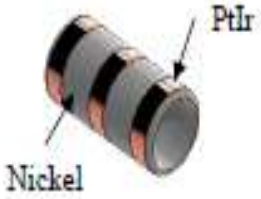
Radio opaque marker bands



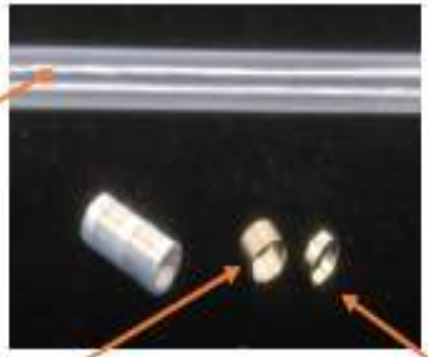
Ref: Haralick, Robert M. "Monocular vision using inverse perspective projection geometry: Analytic relations." *Computer Vision and Pattern Recognition, 1989. Proceedings CVPR'89., IEEE Computer Society Conference on.* IEEE, 1989.

Marker band for 3D pose tracking





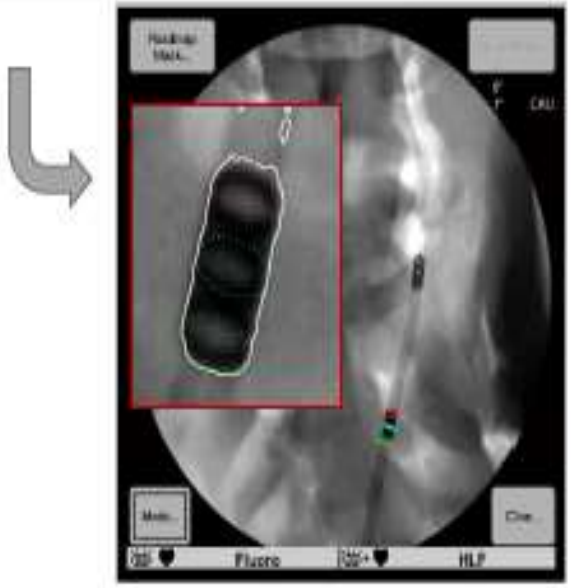
PTFE heat shrink tube
thickness : 0.05mm(±0.02)
ID before shrink : 3.81mm
ID after shrink: 2.26mm
Shrink temp. : 300℃
Heat resistant temp. : 260℃

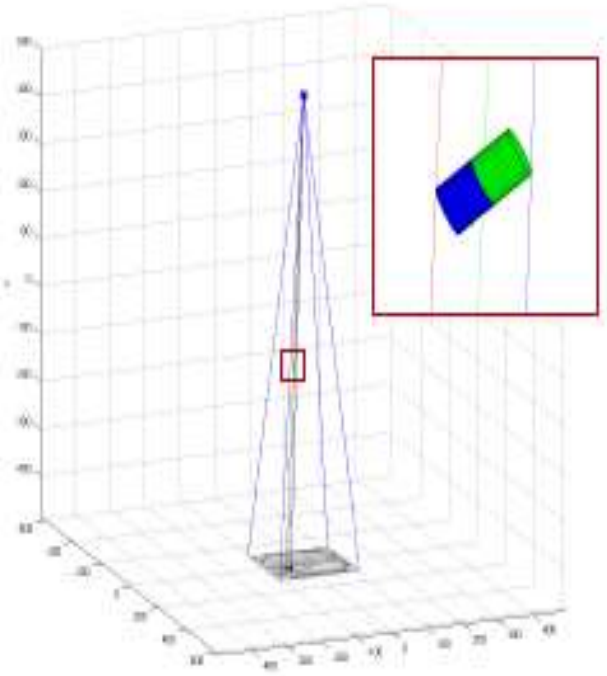


Pure Nickel
Φ3.4X Φ3.12X L2.0

PtIr(Pt90%,Ir10%)
Φ3.4X Φ3.12X L1.0

C-arm X-ray imaging



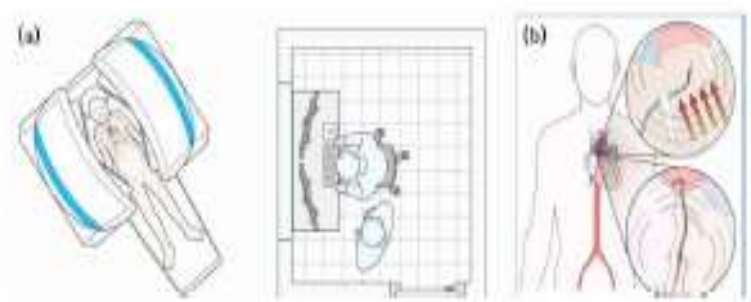


KIST 한국과학기술연구원 Korea Institute of Science and Technology

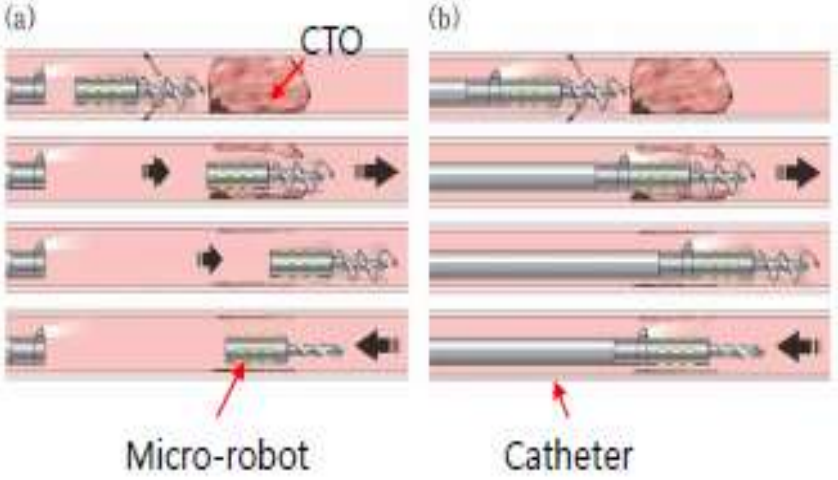
Bionics at KIST MNL Medical Navigation Lab.

Development of microbiorobotic systems for surgical treatment of CTO (Chronic Total Occlusion)

Period: June 01, 2015 – May 31, 2019 (4 years)
Fund: 3,000K USD/year, MOTIE



External magnetic field driven micro-robots for CTO treatment

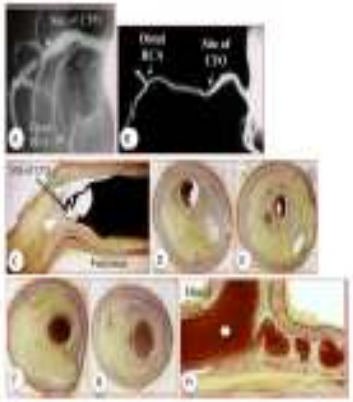


Drexel University · 서강대학교 Sogang University · 가톨릭대학교 서울성모병원 · KIST · KR TECH 주식회사 글로벌테크

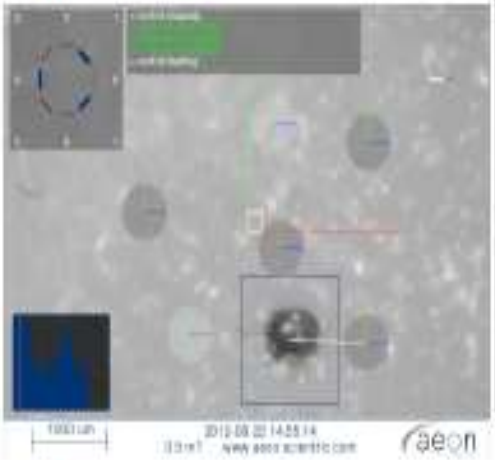
서울대학교 · 서울대학교 SNUH 분당서울대학교병원 · SAMSUNG 삼성서울병원 · DK+

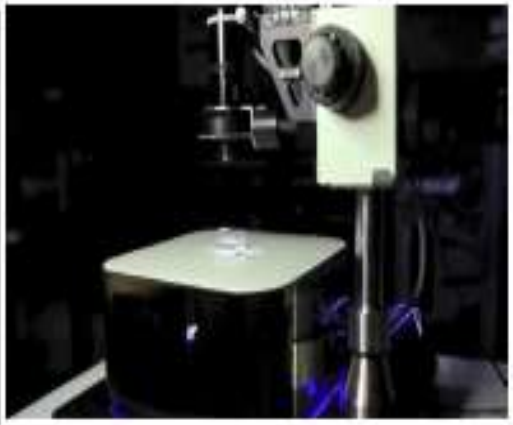
Project Description

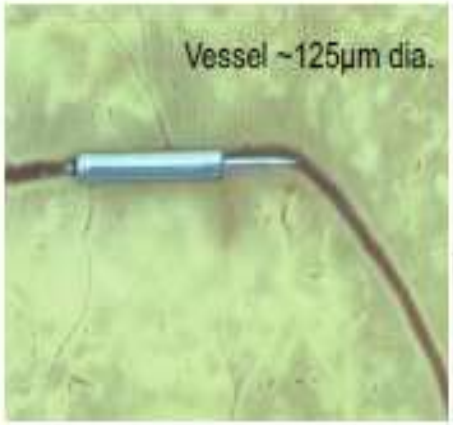
- Target surgery
  - CTO (Chronic Total Occlusion) Percutaneous Coronary Intervention



Micro-robots

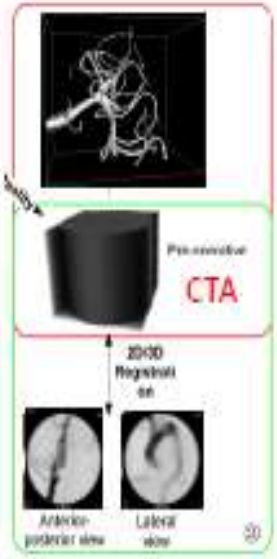






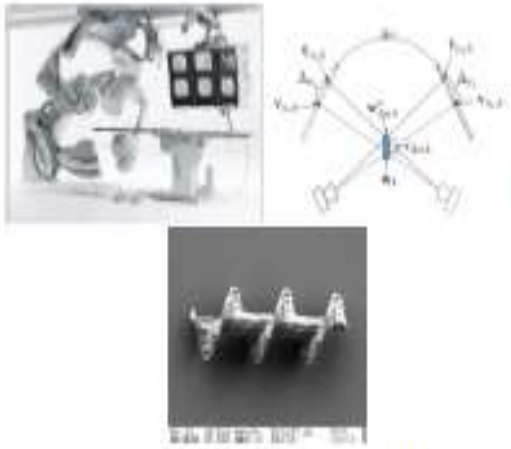
Project Description

- My research objective:
  - 3D VR based micro-robot guidance system



1. 3D cardiovascular modeling

2. Patient registration using bi-plane x-ray

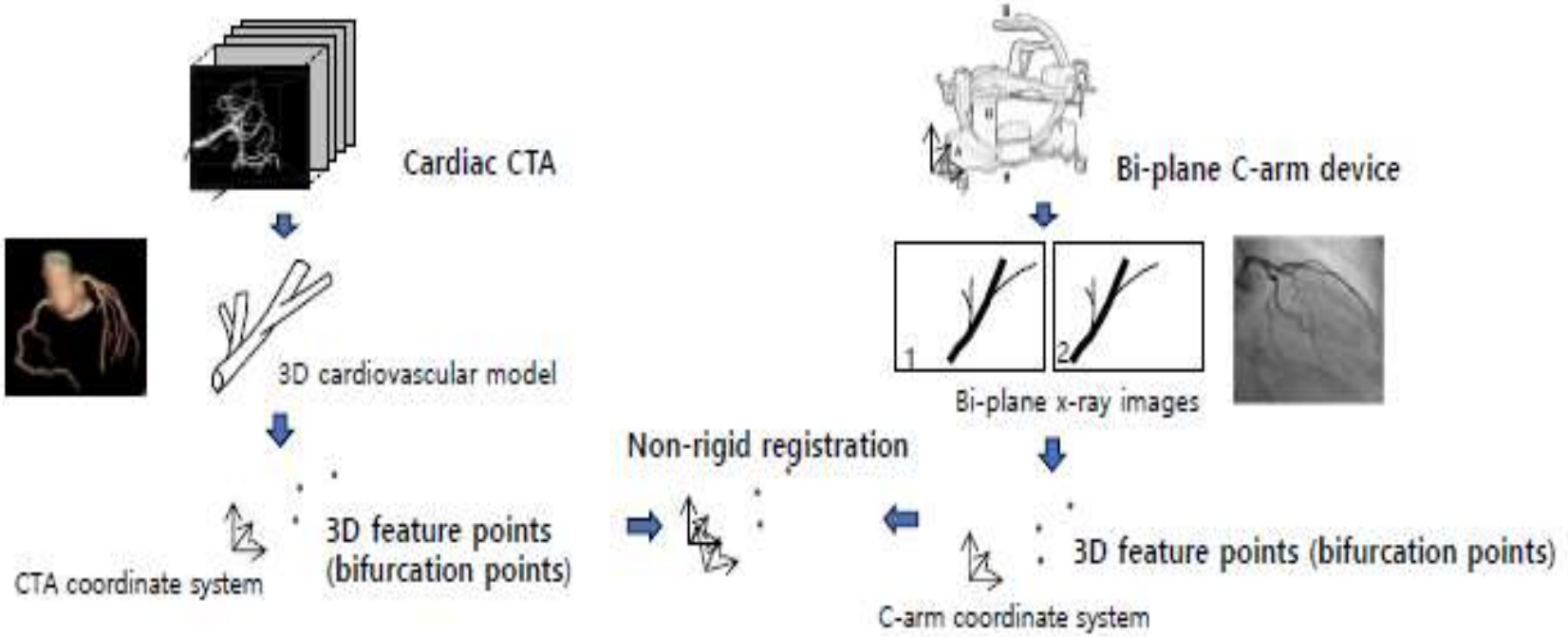


3. micro-robot tracking using bi-plane x-ray

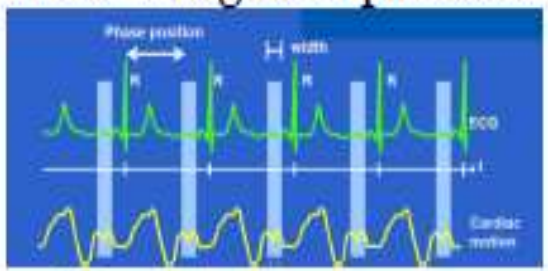
4. Micro-robot guidance in 3D VR environment

Methods

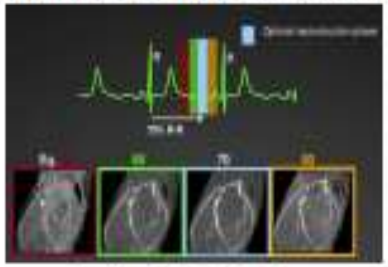
- Real-time non-rigid registration of CTA to bi-plane x-ray images using the bifurcation points of cardiovascular pattern



- Heartbeat compensation using ECG phases on cardiac CTA & coronary angiography



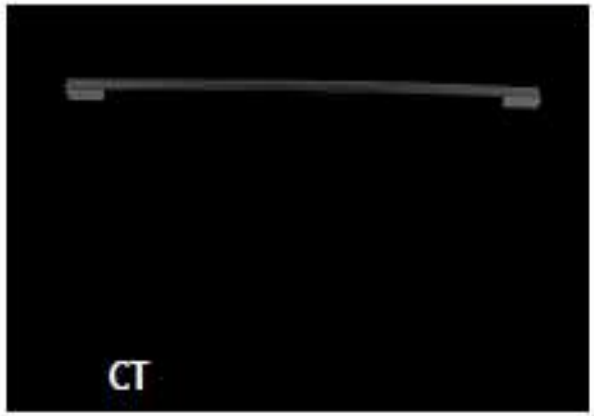
ECG monitoring on scan

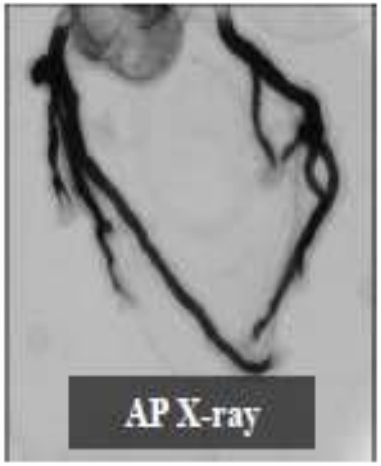


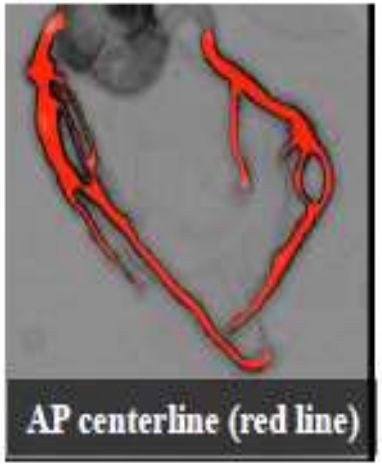
Cardiac CT-ECG phases

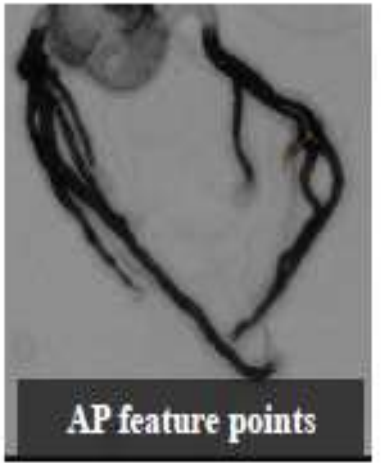
Cardiac Segmentation & Modeling

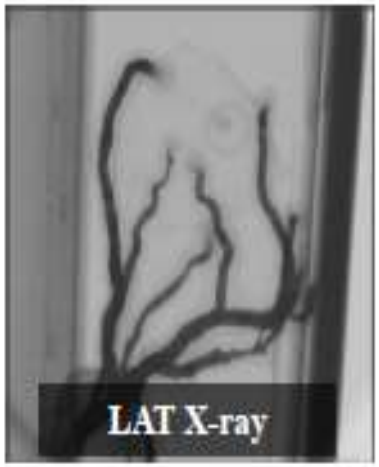
- Coronary artery deforming phantom
- **2D** coronary artery segmentation and bifurcation points detection

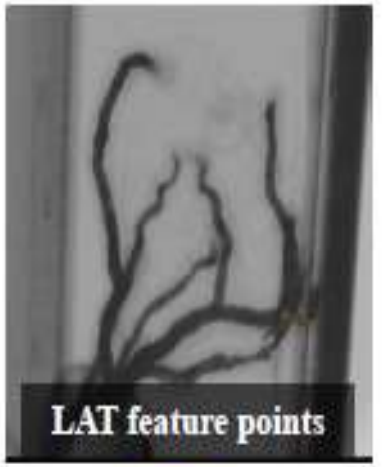






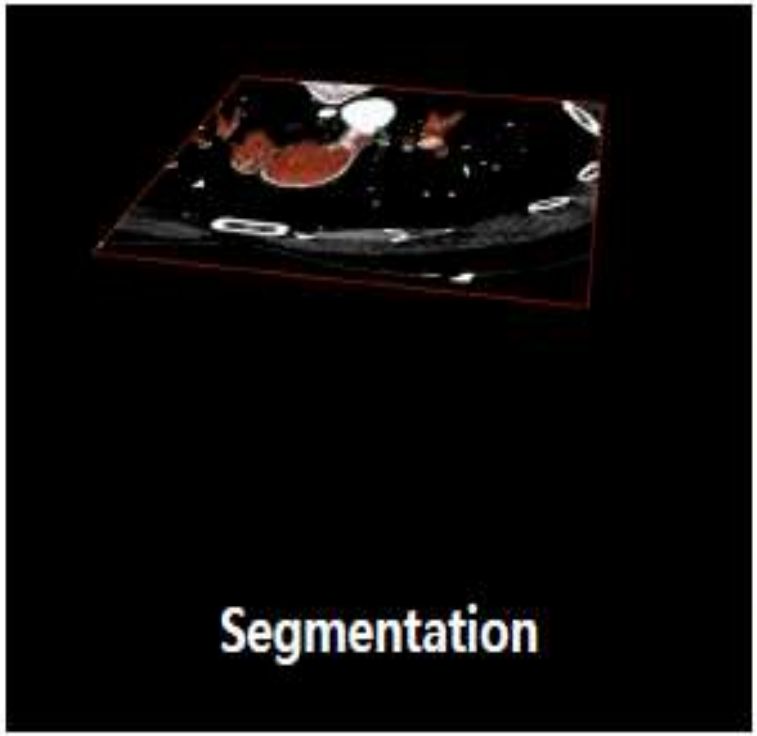


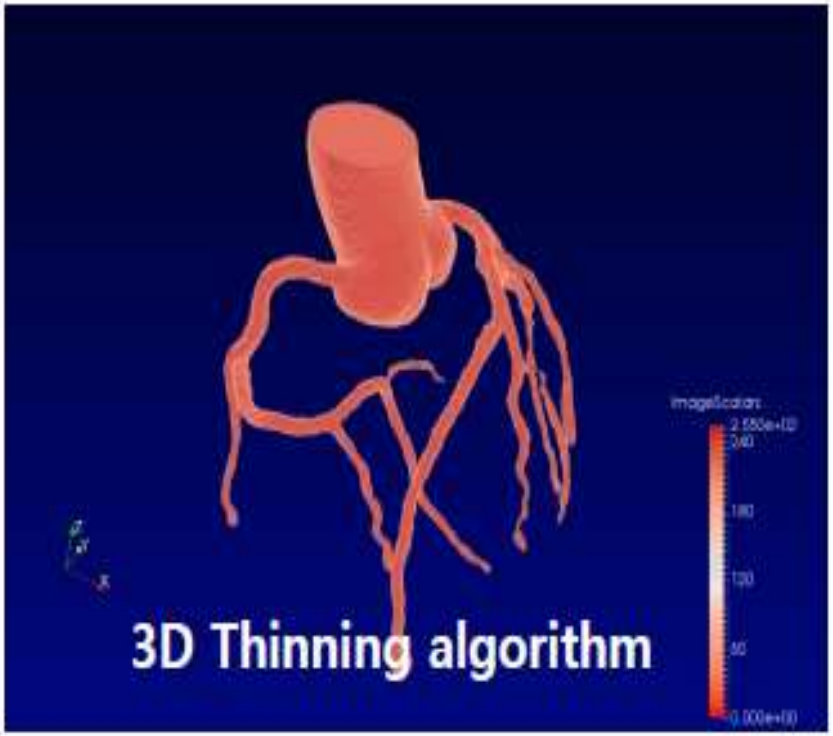




Cardiac Segmentation & Modeling

- 3D coronary artery segmentation and bifurcation points detection





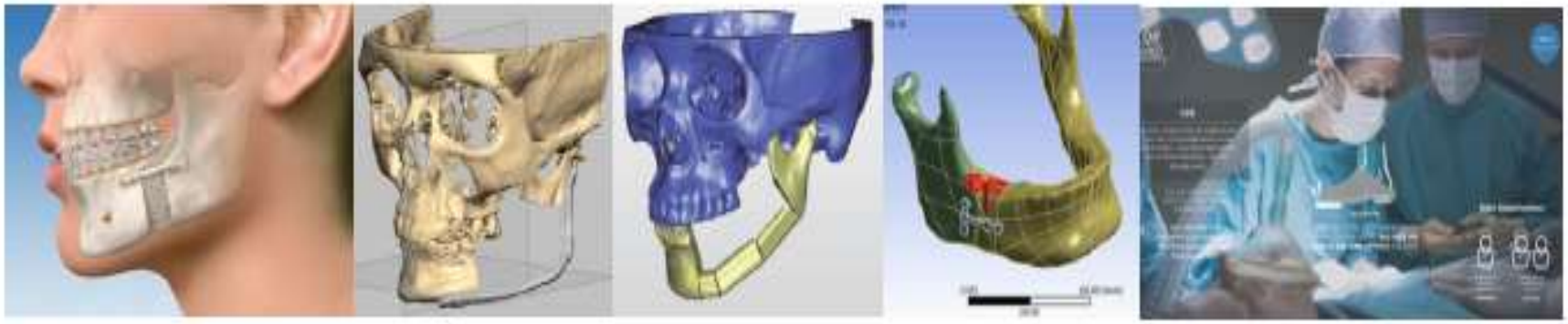
KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST MNL Medical Navigation Lab.

3D Image-Guided Maxillofacial Reconstruction Surgery

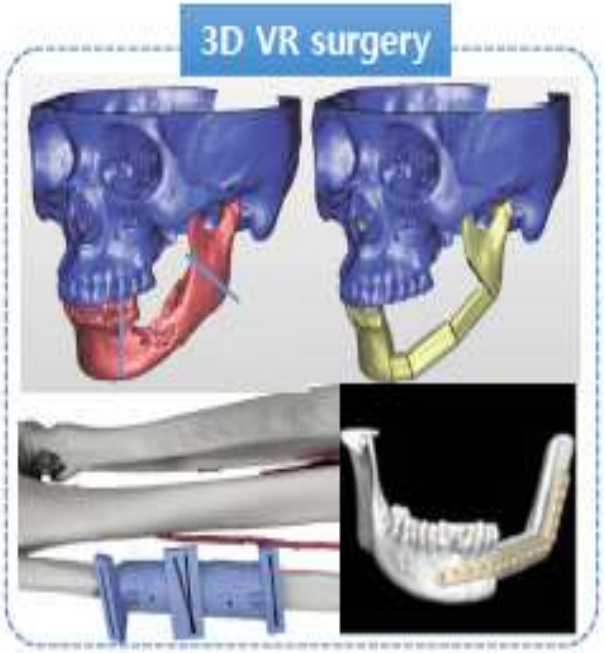
Period: Jan 01, 2015 – Dec. 31, 2017 (3 years)

Fund source: intramural project

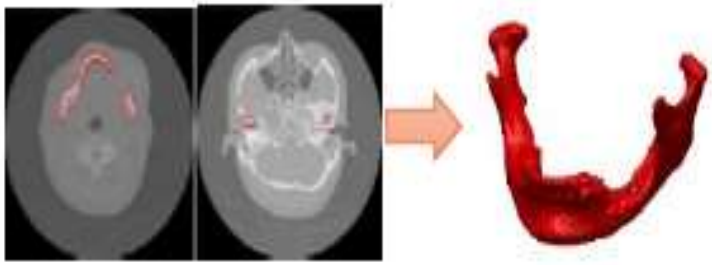


Project Description

- Target surgery
  - Maxillofacial reconstruction surgery

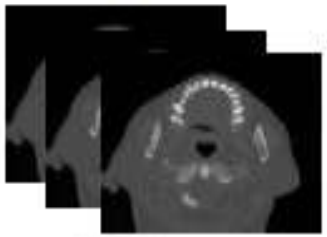


- Research objective:
  - 3D mandibular modeling from CT data
  - Surgical planning time reduction using optimized functions and user interface
  - Operation time reduction and success rate enhancement through surgical guide

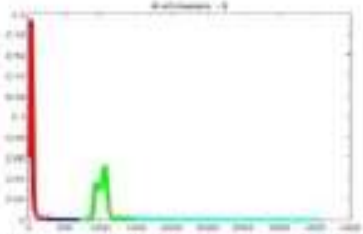


Methods & Results

- **Fully automatic** mandibular segmentation from CT

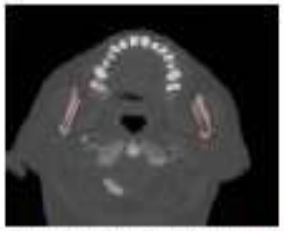


3D CT data



3D data rough labelling using AGMC (Adaptive Global Maximum Clustering) algorithm

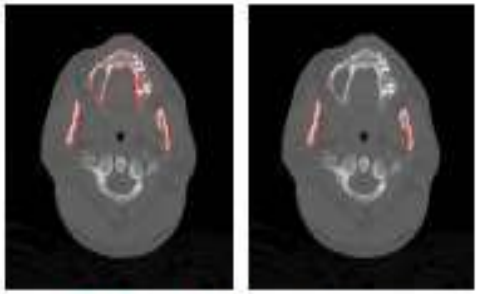
Selection of target mandibular label in the AGMC labeled image.



Fine segmentation of mandibular label using active contour

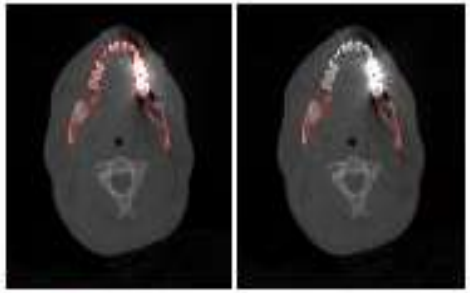
#95 : starting slice

up



#43 : Maxilla region removal

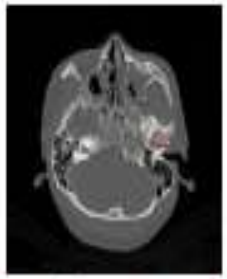
down



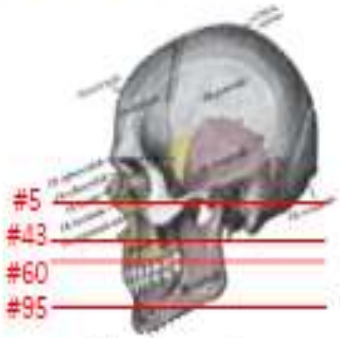
#60 : the upper teeth region removal

- Results

up



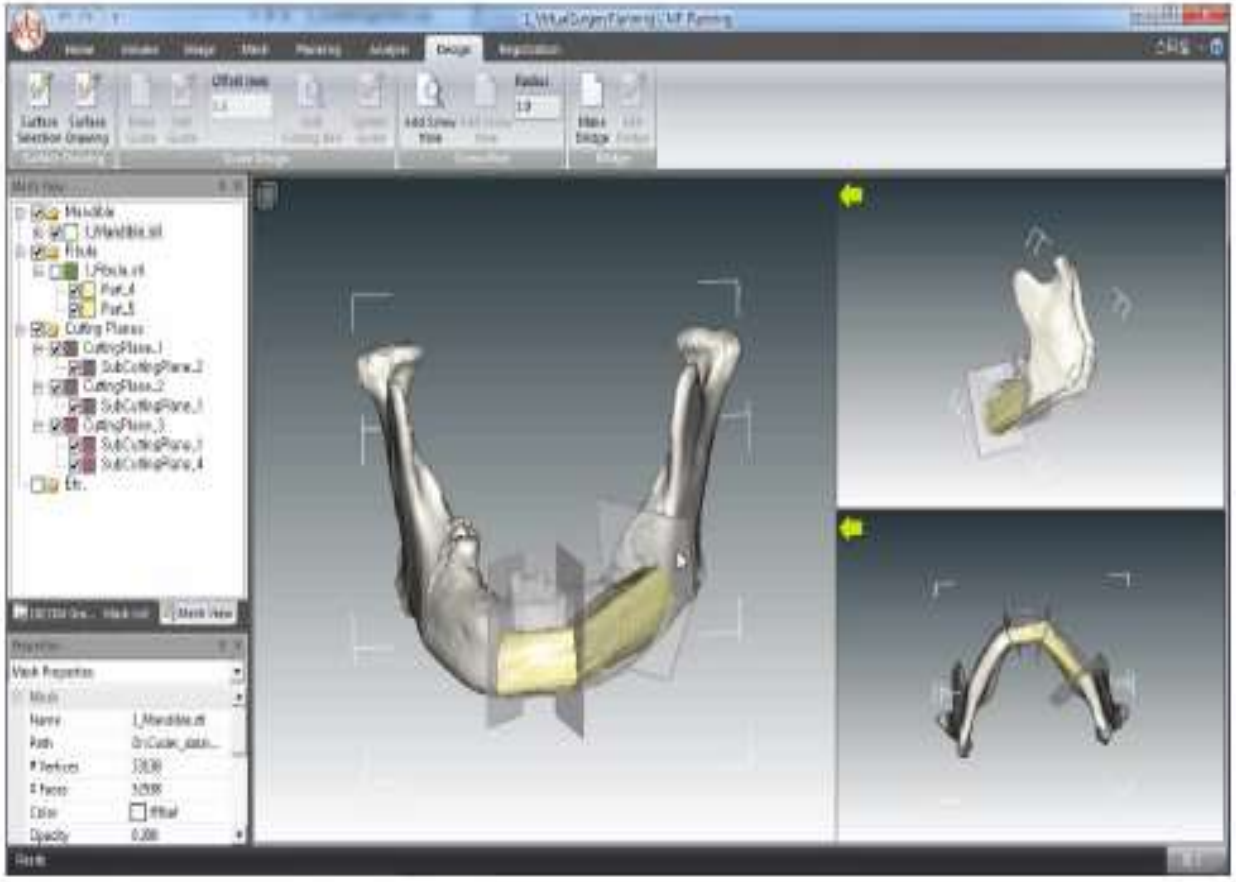
#5 : condyle segmentation



CT slice number

Methods & Results

- Patient Specific Resection Guide design and Guide design specific user interface
  - Positioning panel, resection rail generation, screw hole generation
  - Surface selection, mesh offsetting, Boolean operation



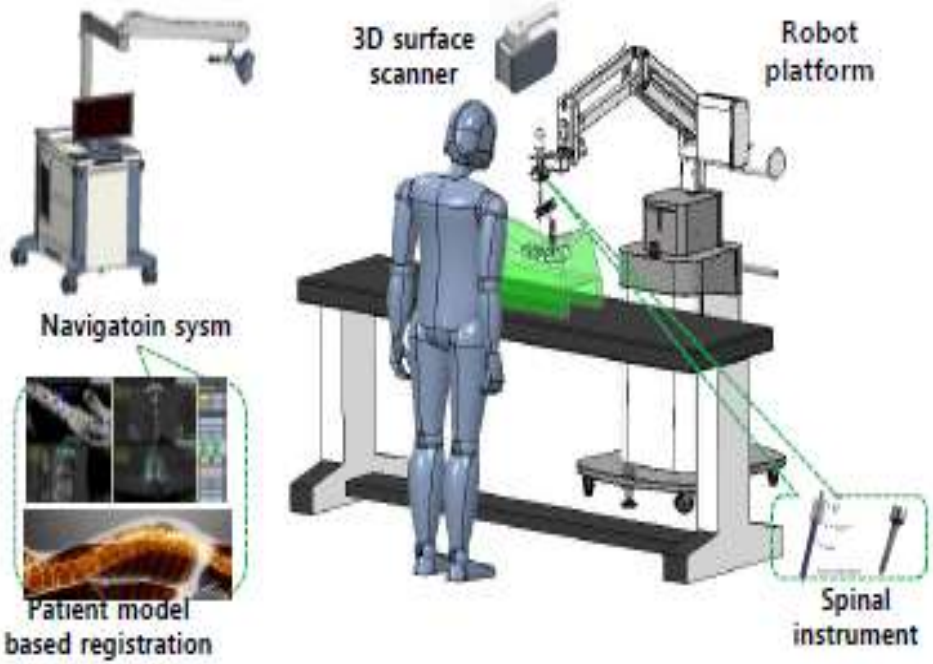
KIST 한국과학기술연구원
Korea Institute of Science and Technology

Bionics at KIST MNL Medical Navigation Lab.

Robotic System for Spinal Surgery

2017 World Class 300 R&D project

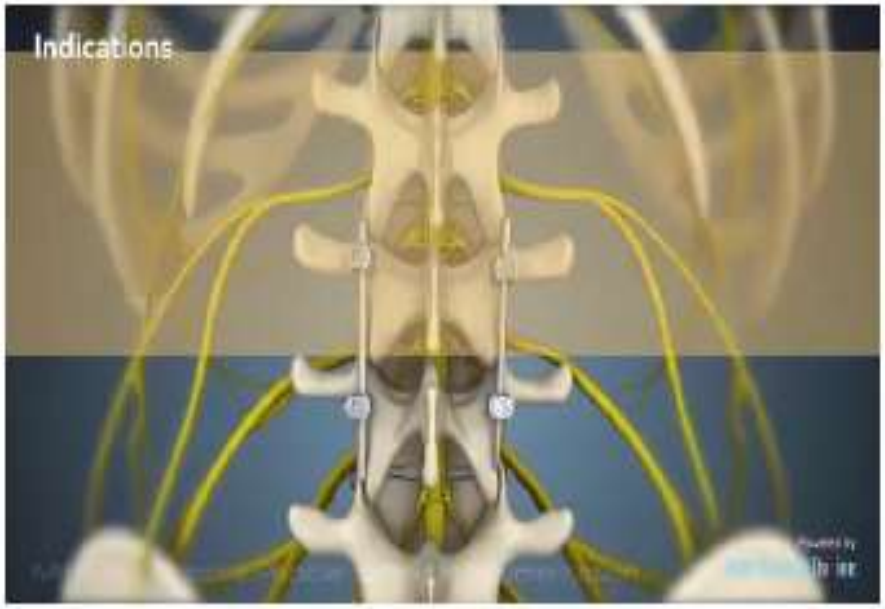
Period: **March 01, 2017** – Dec. 31, 2021 (58 months)
Fund: 1,140K USD/year, Ministry of SMEs and Startups



㈜ 고영테크놀러지 | 한양대 에리카산학협력단 | 한국과학기술연구원 | 연세대학교의료원 산학협력단

Project Description

- Target surgery: minimally invasive pedicle screw instrumentation
- Research objectives:
  - Novel patient-to-image registration for **radiation exposure reduction**
  - **Precise guidance of surgical instrumentation**

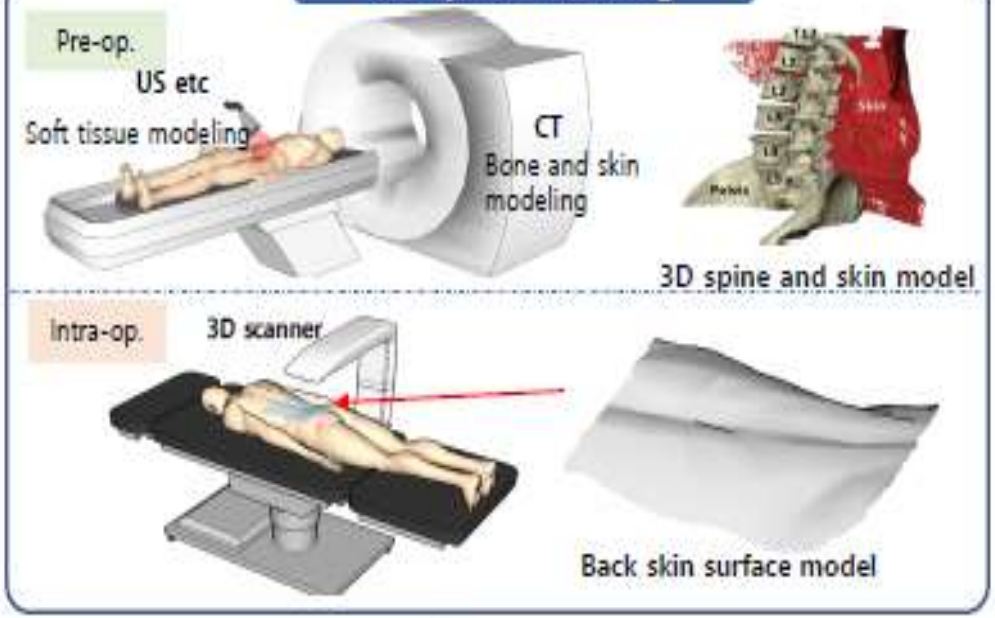


Minimally invasive pedicle screw instrumentation

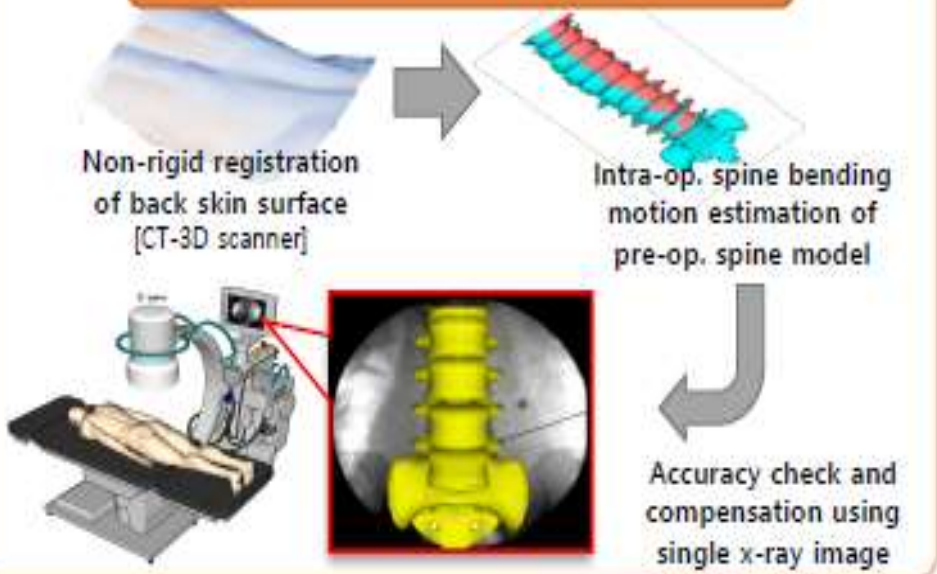
Mazor X (2016, Mazor Robotics, Ltd.)

Processes for Non-Invasive, Radiation-Free Patient-to-Image Spine Reg.

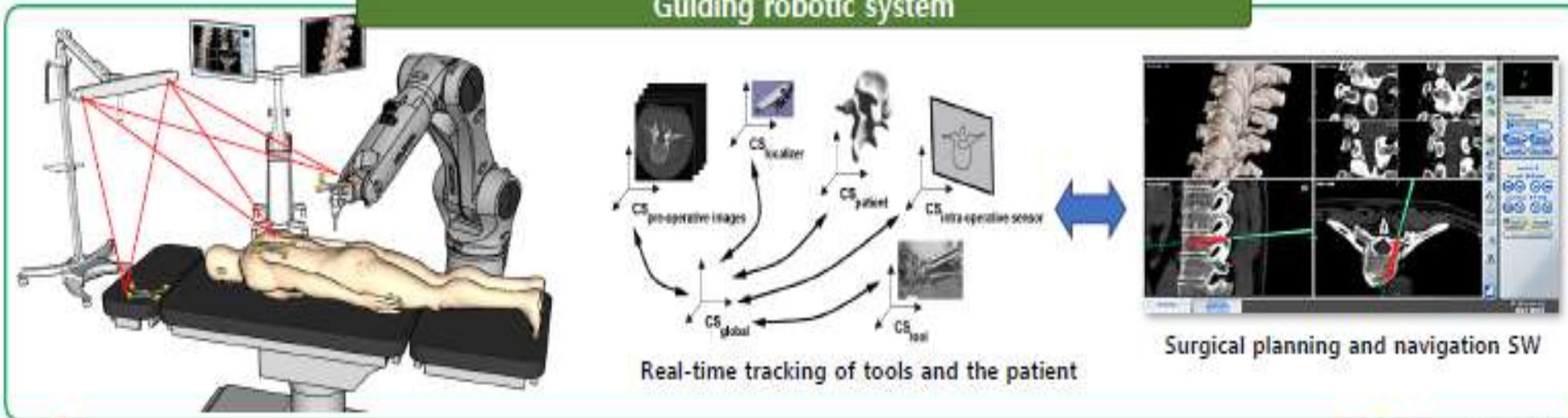
3D spine modeling



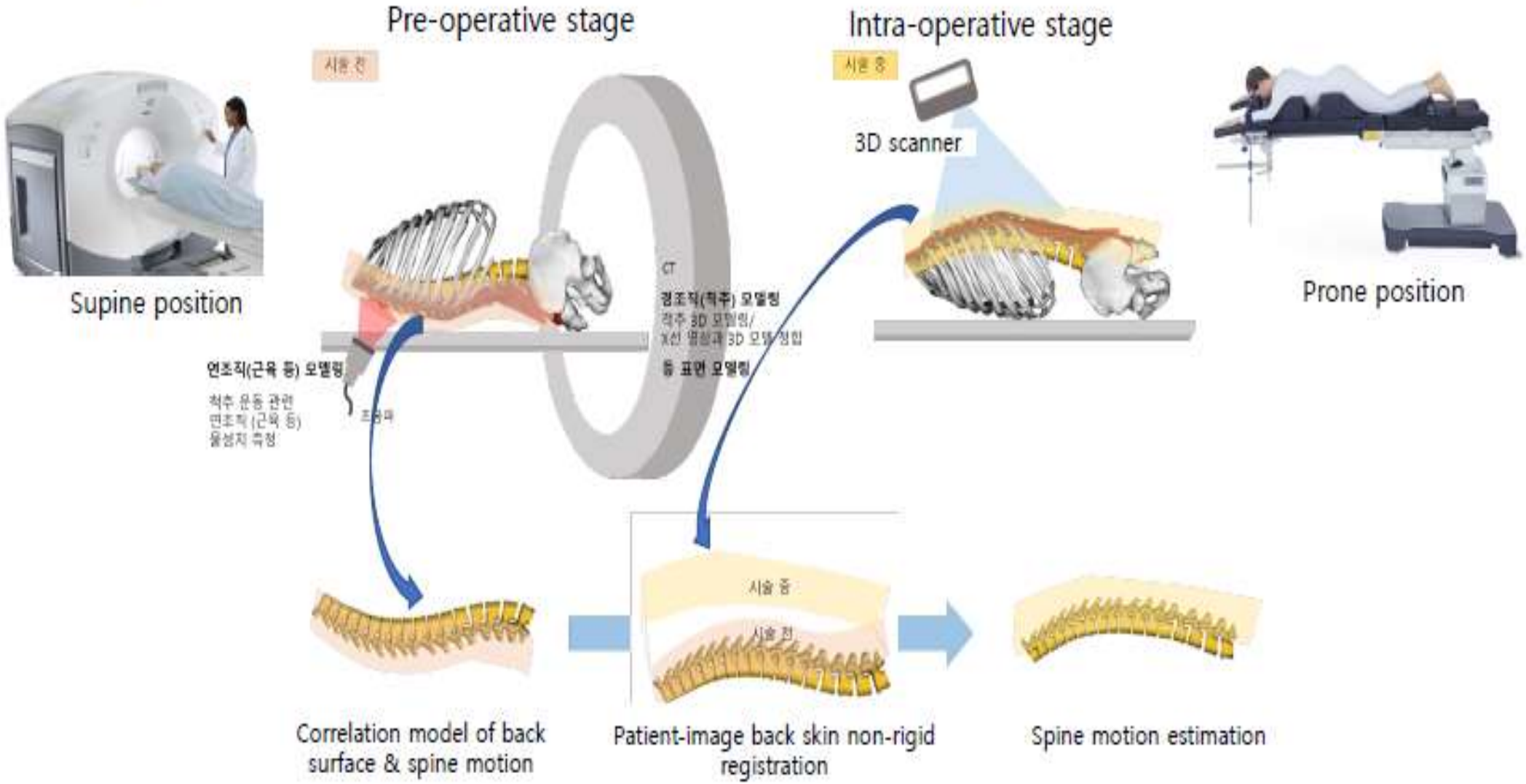
Estimation of spinal deformation due to back surface deformation



Guiding robotic system

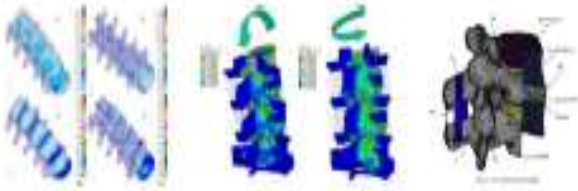


Patient-image registration using the correlation model of **back surface & spine motion**



연구내용

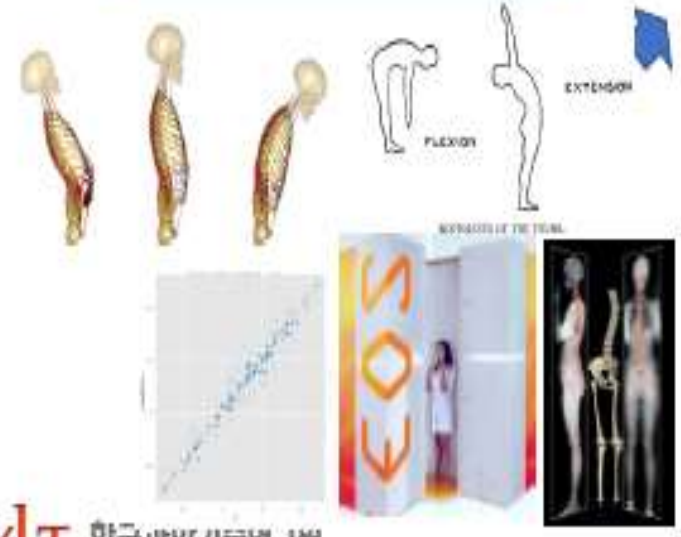
해석기반 동적 모델 최적화



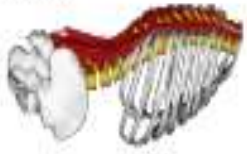
수술계획 & 내비게이션 SW

경조직 환자 모델링

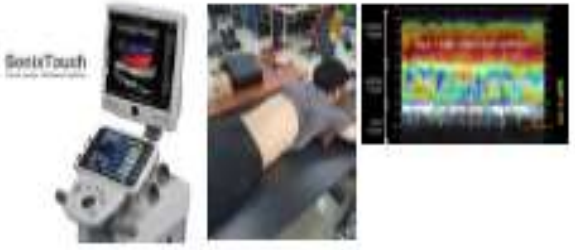
AI 동적 모델링



OpenSim



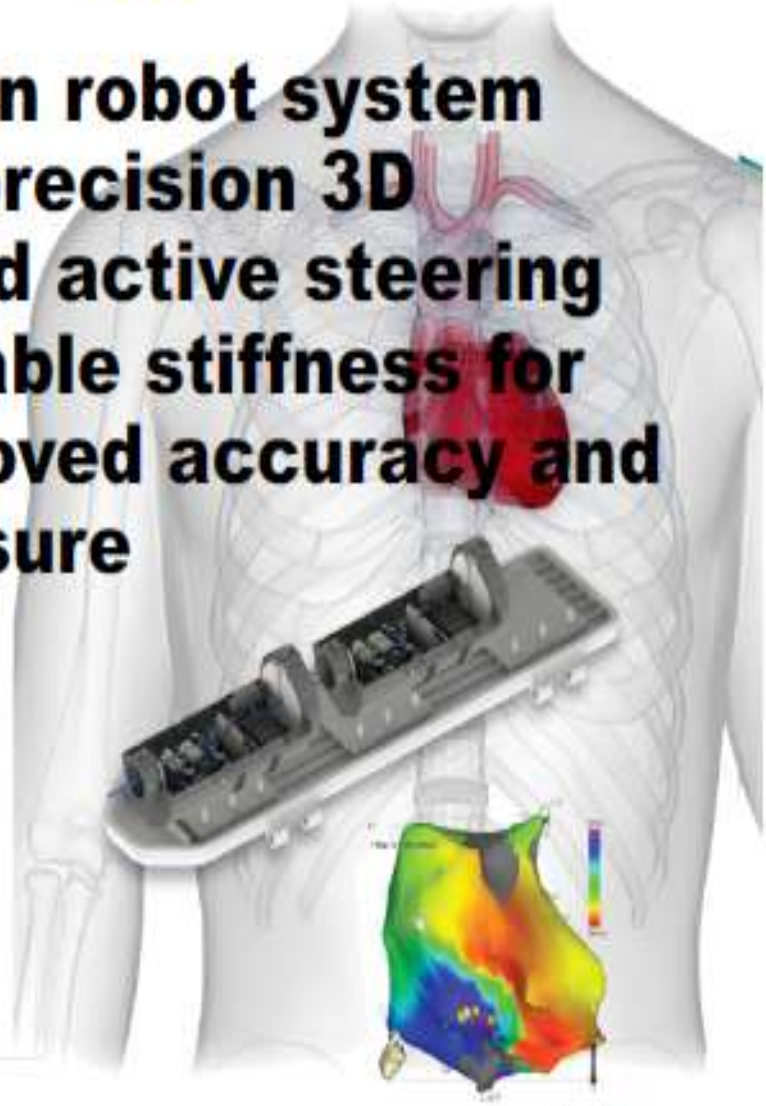
연조직 환자 모델링



KIST 한국과학기술연구원
Korea Institute of Science and Technology

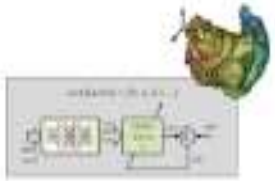
Bionics at KIST MNL Medic

Development of 6 DOF teleoperation robot system technologies including 0.5mm precision 3D electroanatomic mapping system and active steering robot catheter instrument with variable stiffness for cardiovascular intervention with improved accuracy and reduced radiation exposure



Period: **Apr. 01, 2017** – Dec. 31, 2021 (57 months)
Fund: 1,500K USD/year, MOTIE

NEXTURN SWISS TURN LEADER
서울아산병원 Asan Medical Center
GERI 구미전자정보기술원
KAIST
KIRIA 한국로봇산업진흥원
계명대학교 동산의료원 Keimyung University Dongsan Medical Center
KIMM 한국기계연구원
KIST 한국과학기술연구원
KITECH
PURDUE
SNUH 서울대학교병원



Project Description

- Target surgery: catheter ablation for cardiac arrhythmia
- Research objective:
  - Robotic catheter ablation system development for cardiac disease
  - **Precise guidance of robot surgery**

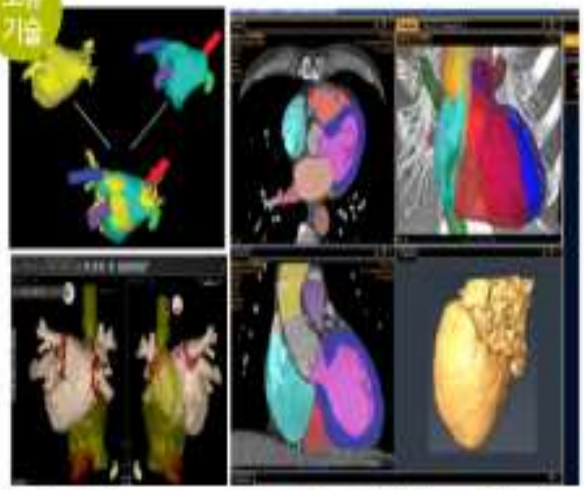
Cardiac arrhythmia

Cardiac Mapping System

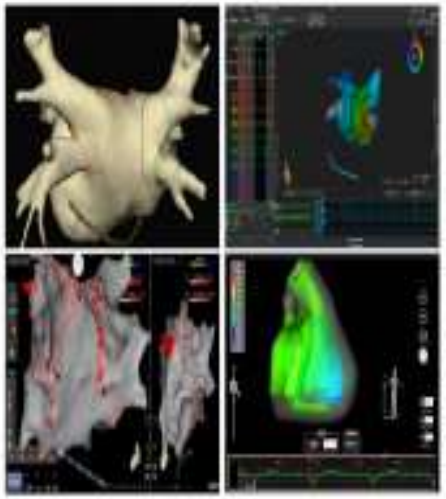
보유 기술

CTA-based cardiac 3D modeling

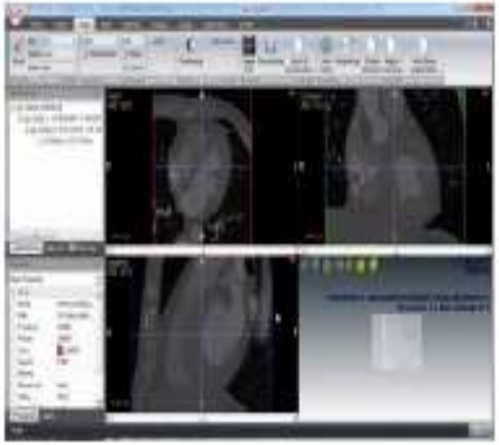
보유 기술



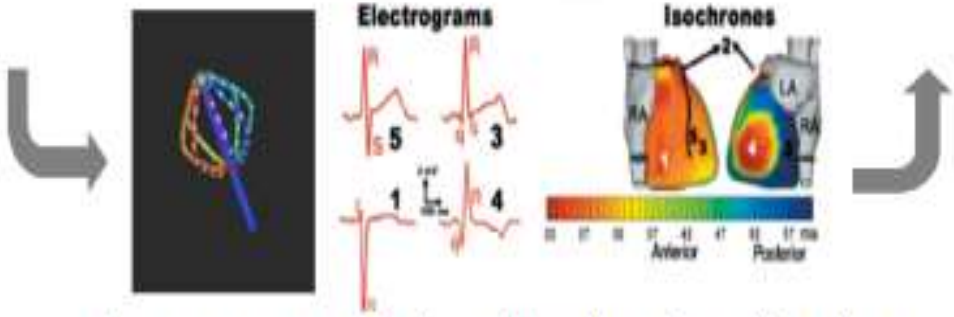
Patient-image registration with heart beat compensation



3D cardiac mapping model generation



3D mapping VR visualization platform



Catheter tip position and electrophysiological signal distribution visualization

Thank you for your attention!

dkylee@kist.re.kr