PPRIME Forum on Mechanical Design and Mechatronics of Robotics Systems

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Applications of Mechanism Design Theories for Surgical Robotics

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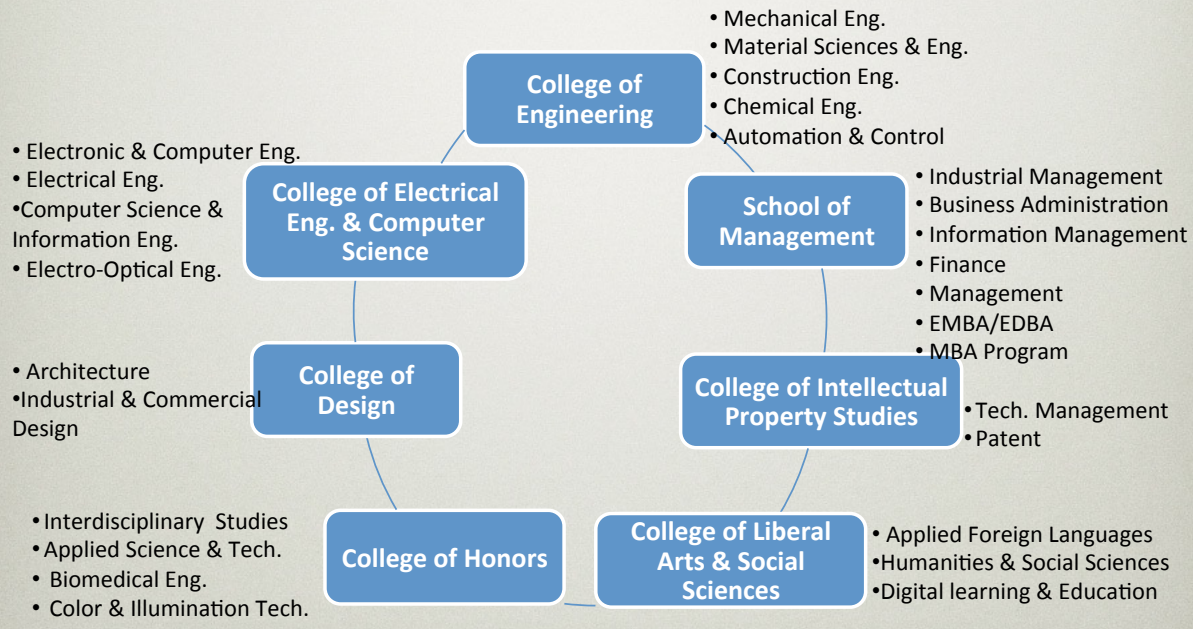
Healthcare Mechanisms and Robotics Lab

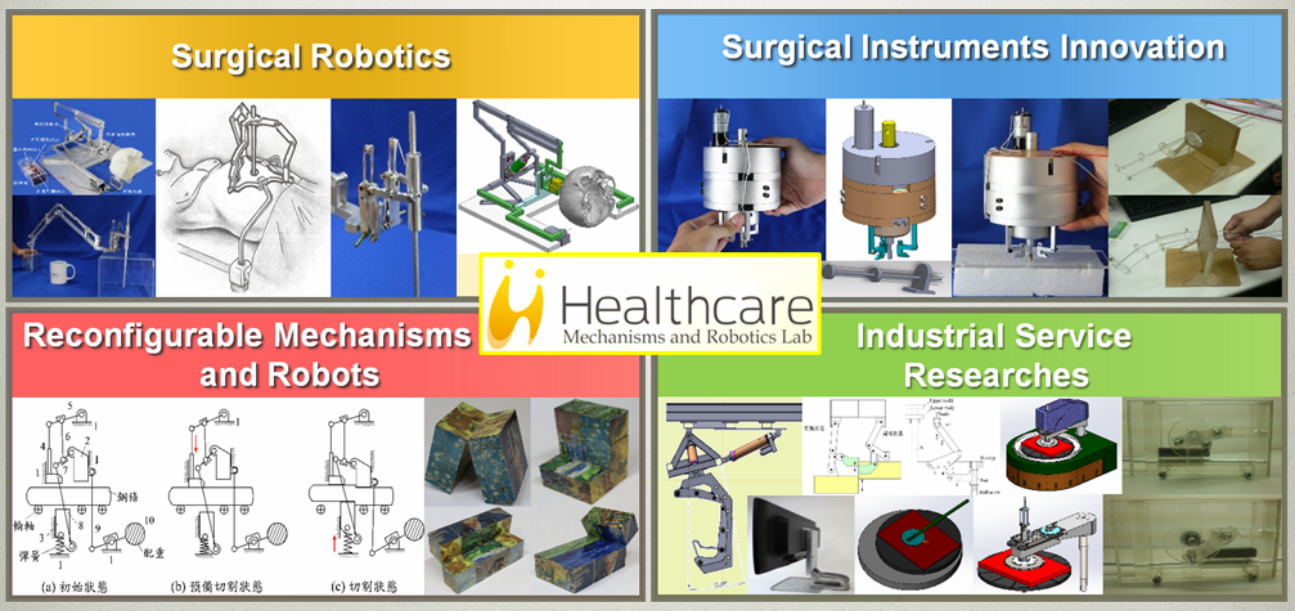
About Taiwan Tech

About Taiwan Tech



Student No.: ca. 10000
Faculty No.: ca. 450

HeMaR Lab



Feb. 2011 ~ present

Our Approach

Surgical instruments

Robotic Manipulators

Actuation

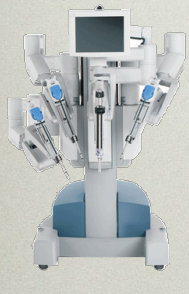
Surgical Instruments

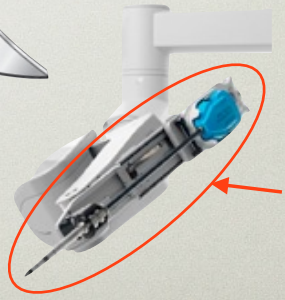
Control

Medical Imaging

Surgical Robotics

Mechanism Design Theory





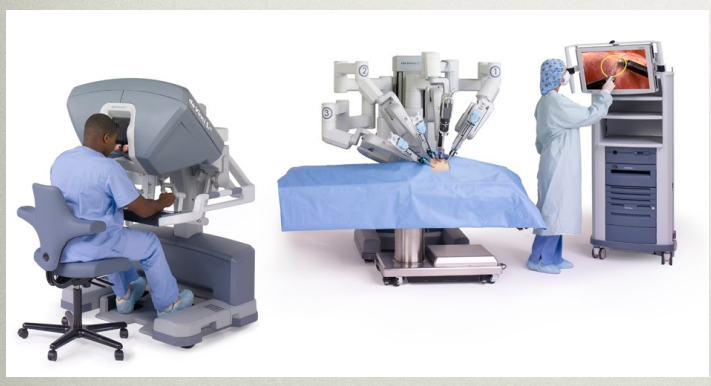
Surgical instrument module

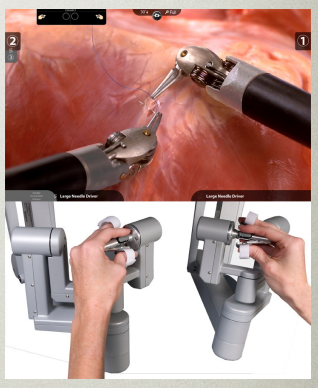
Robotic Surgery

- *Robotic surgery* is a technology that employs **robotics** to assist surgical procedures.

Why "Surgical Robotics" ?

Precision & *Dexterity*





(from *Intuitive Surgical* Co., http://www.intuitivesurgical.com/)

Engineering for Surgical Robotics

- Medical Imaging
- Registration
- Navigation
- Control
- Robot hardware design (mechanism design)
- …..

Mechanism Design

- Motion and force transmission
  - Surgical instruments
  - Surgical holders
  - Surgical robots

Clinical Area of Robotic Surgery

- Minimally invasive surgery *(major)*
- Non-minimally invasive surgery

Non-MIS

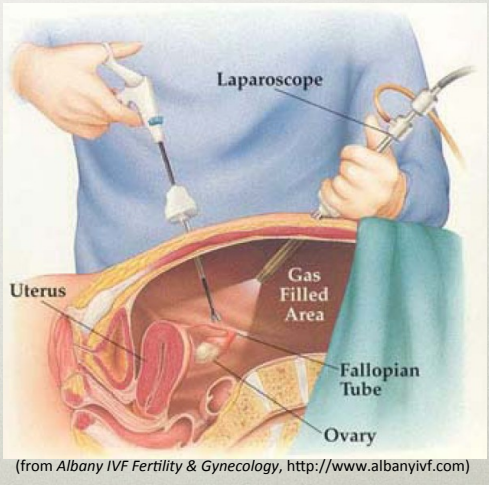
MIS

Minimally Invasive Surgical Robots

Minimally Invasive Surgery

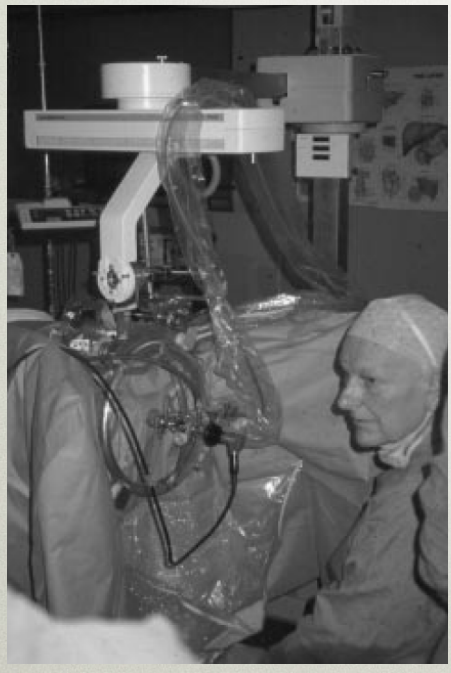
- *Minimally Invasive Surgery* (MIS) is a class of surgical procedures whereby the surgical operation is done through small incisions.

Advantages:
- reduced risk of infection
- less pain and scarring
- less bleeding
- shorter hospitalization
- decreased recovery time
- ...



(from *Albany IVF Fertility & Gynecology*, http://www.albanyivf.com)

The First Special-Purpose MIS Robot

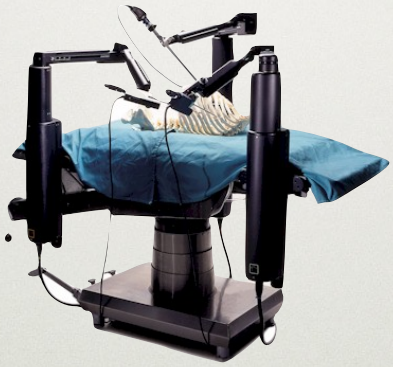


(photo from Davies, 2000, *Proc. IMechE: Part H*)

Robot Name: Probot
Developer: Imperial College London, UK
Clinical trail: **1991**

Commercial MIS Robots

AESOP (1991)
Computer Motion



Zeus (1995)
Computer Motion

da Vinci (1999)
Intuitive Surgical

Lab Works

(Kuo *et al.*, 2012, *Int. J. Med. Robot. Comp. Assist. Sur.*)

MIS Robots Worldwide

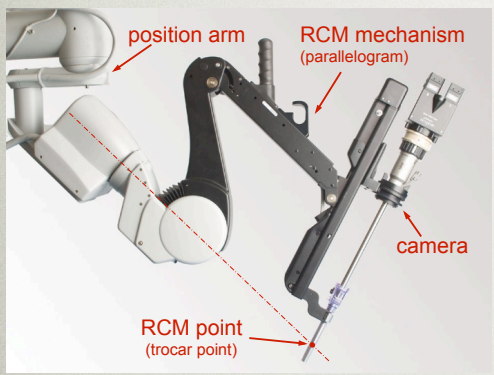
- **Business:** Intuitive Surgical (da Vinci)
- **Research:**
  - ✓ **USA**: JHU, MIT, Stanford, Harvard, UMD, CMU, UW-Seattle, etc.
  - ✓ **UK**: Imperial College London, King's College London, etc.
  - ✓ **Europe**: Karlsruhe Research Center (Germany), DLR (Germany), IIT (Italy), Scuola Superiore Sant' Anna (Italy), LIRMM (France), PPRIME (France), etc.
  - ✓ **Asia**: Tokyo Univ. (Japan), Tianjin Univ. (China), Natl. Central Univ. (Taiwan), Taiwan Tech (Taiwan), etc.

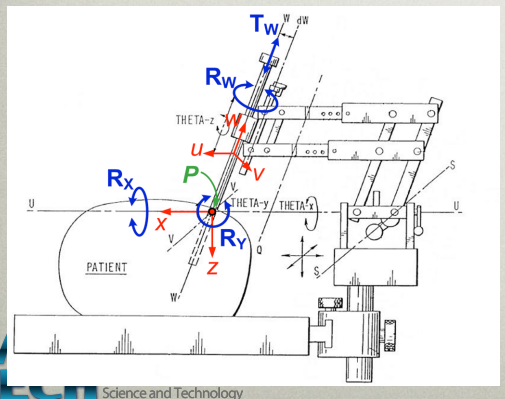
and many others….

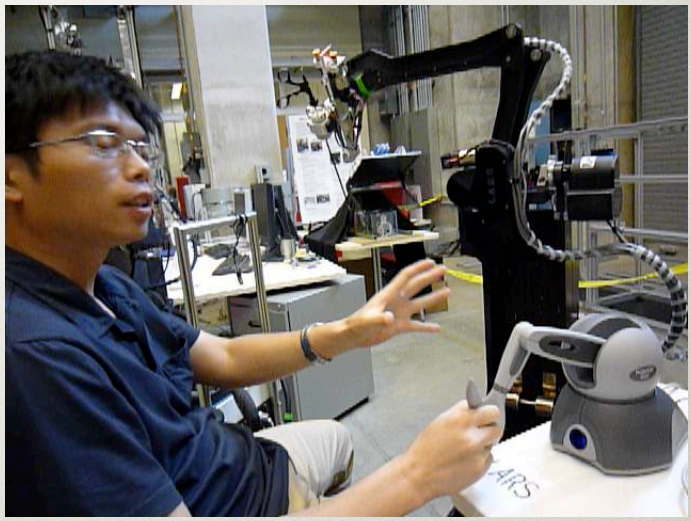
Mechanism Design

- Special kinematic motion demand
- Limited transmission space
- Immersive human interaction
- Dextrous manipulation
- Safety issues

Special Kinematics: Remote Center-of-Motion



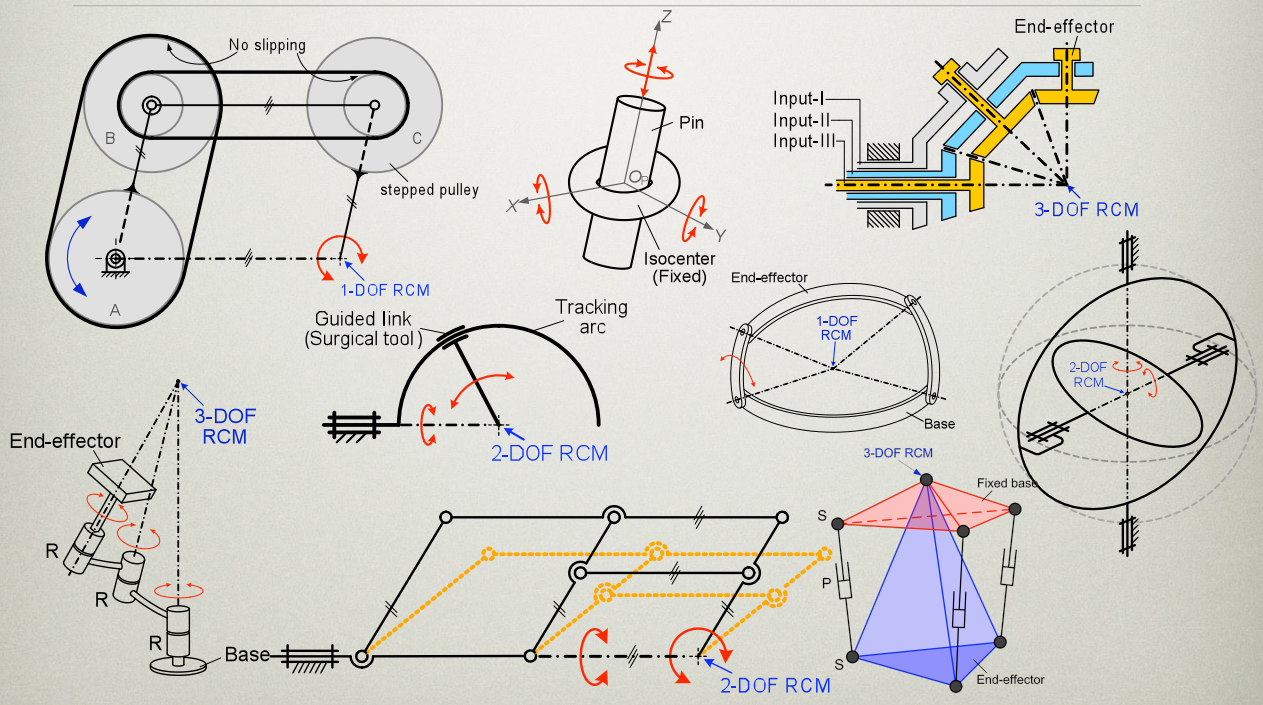




LARS robot, Johns Hopkins Univ., 2009

1. 4-DOF
2. Pivoting motion
3. Extracorporeal workspace
4. Decoupled motion

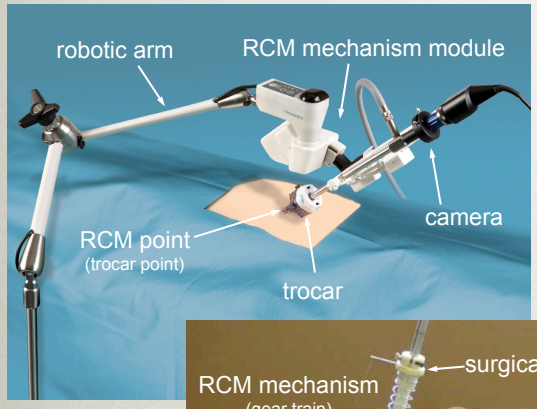
Available RCM Mechanisms



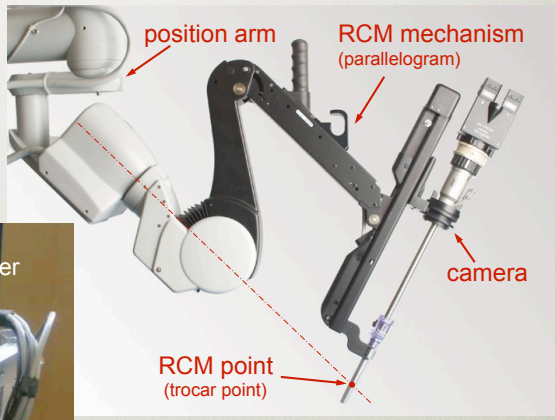
(Kuo *et al.*, 2012, *Int. J. Med. Robot. Comp. Assist. Sur.*)

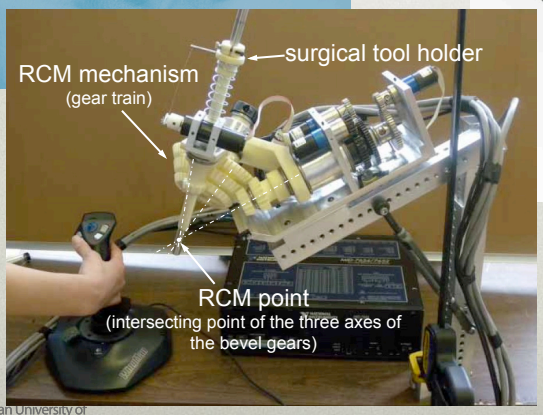
Implementation of RCM Mechanisms in MIS Robots

A. Attach an RCM module to robotic arm



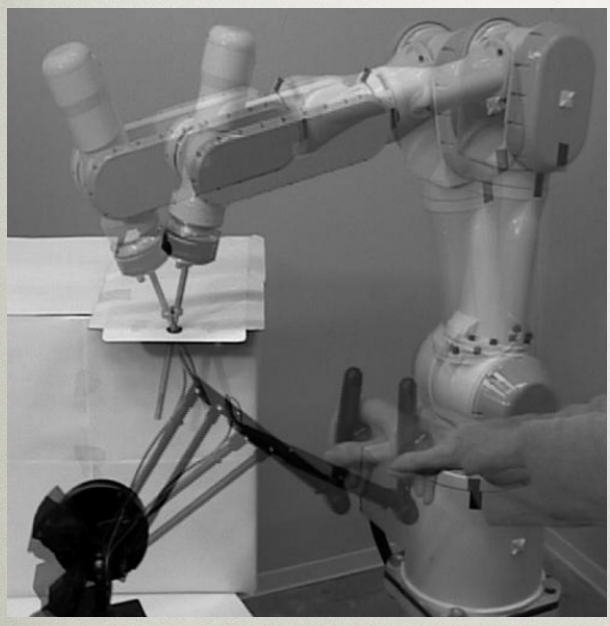
B. Embed RCM into robotic arm





C. Make robotic arm itself as an RCM mechanism

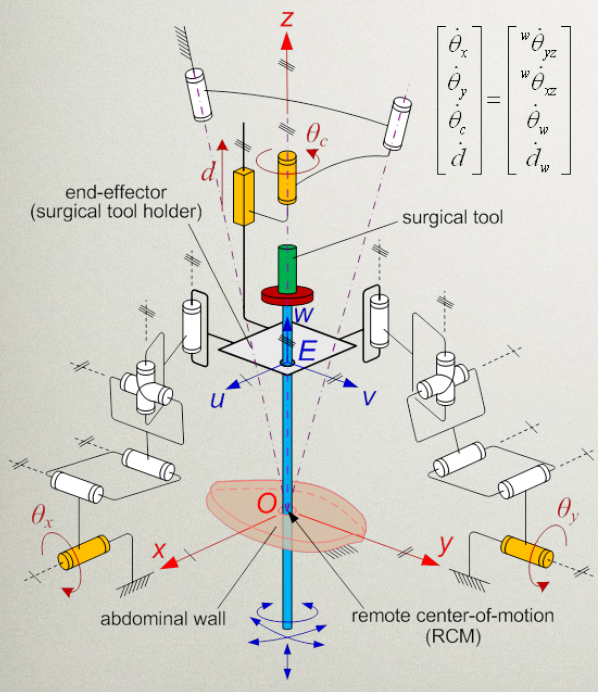
Non-Mechanical RCM

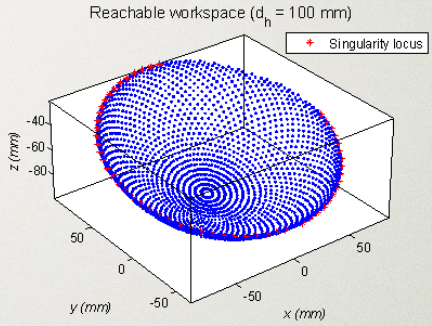


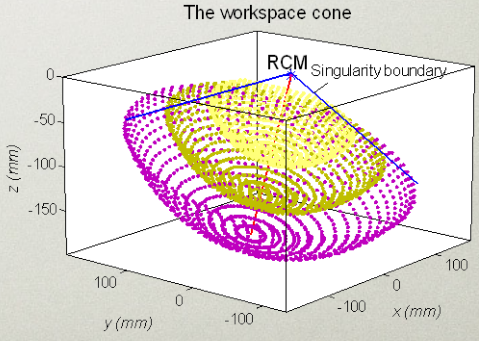
(Dombre *et al.*, 2004, *Proc. MICCAI*)

- Require very fine control

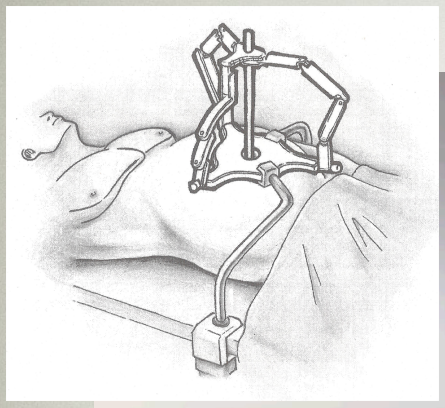
A Fully-Decoupled MIS Robot

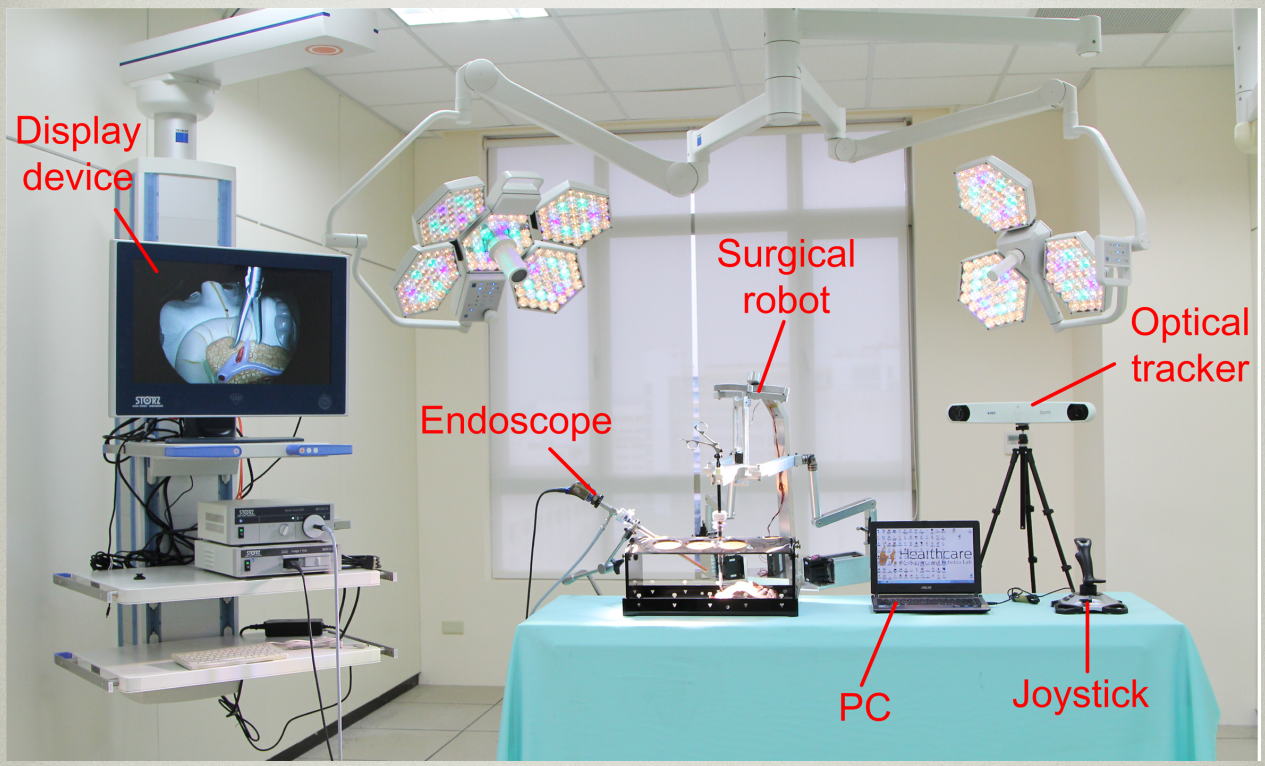






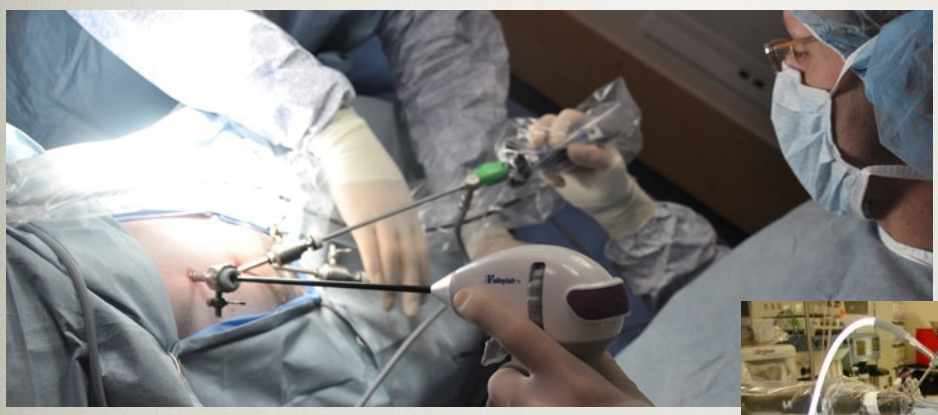
(Kuo & Dai, 2012, *ASME Journal of Medical Devices*)





July 2014 @ **Taiwan Tech**, Taipei, Taiwan.

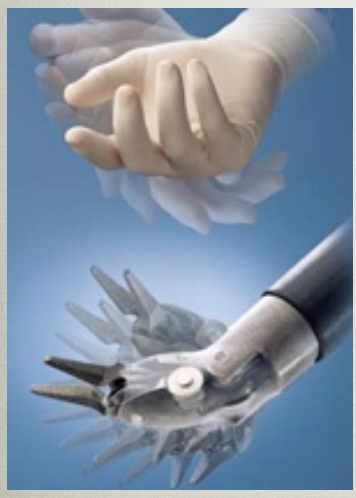
Limited transmission space

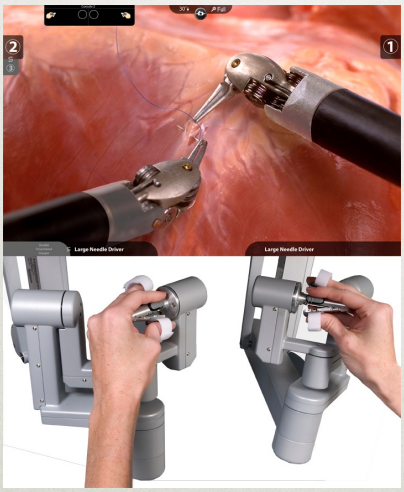


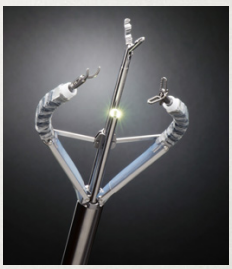
Immersive Human Interaction

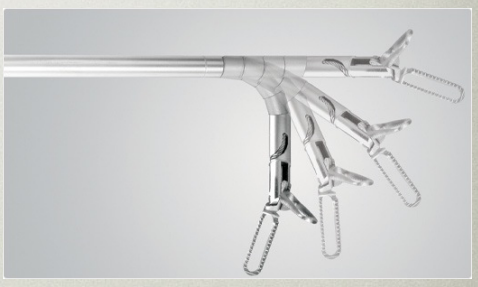
The surgical instruments need to interact (touch or insert into the body) with the patient immensely, so the mechanisms will have special requirements on **lubrication**, **sterilization**, **instrumentation**,…, etc.

Dexterous manipulation









(from *Intuitive Surgical* Co., http://www.intuitivesurgical.com/)

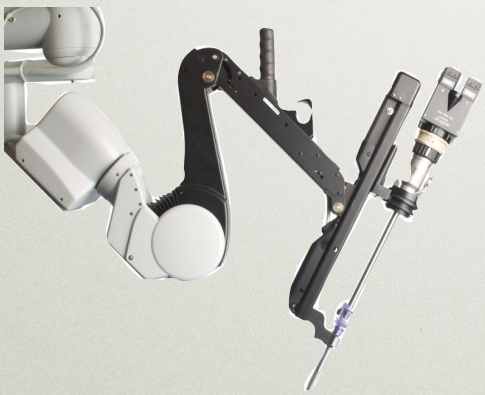
Safety Issues

- **Workspace** (Small working space vs. large mobility)
- **Collision avoidance** (robot ⇔ surgeon、assistants, & patient)
- **Emergency control** (e.g., emergency stop)
- **Back-drivability**

Mechanism Design for Laparoscopic Holders

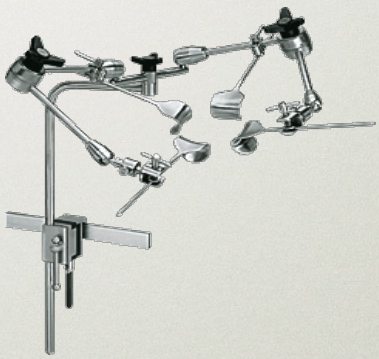
Laparoscope Holders

Active type



da Vinci arm

Passive type

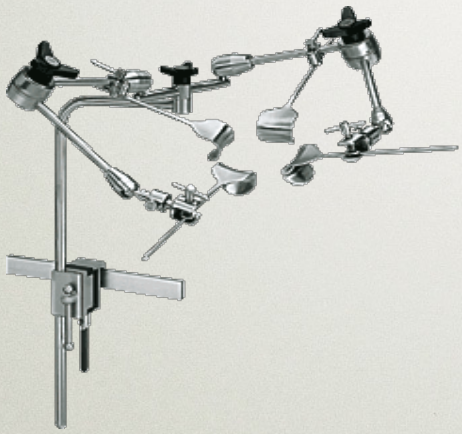


ASSISTO holder

Active vs. Passive Holders

Property	Active type	Passive type
Control Precision	Better	Not good
Control Institution	Not good	More intutive
Weight	Heavy	Light
Price	Costly	Budget

The Problems

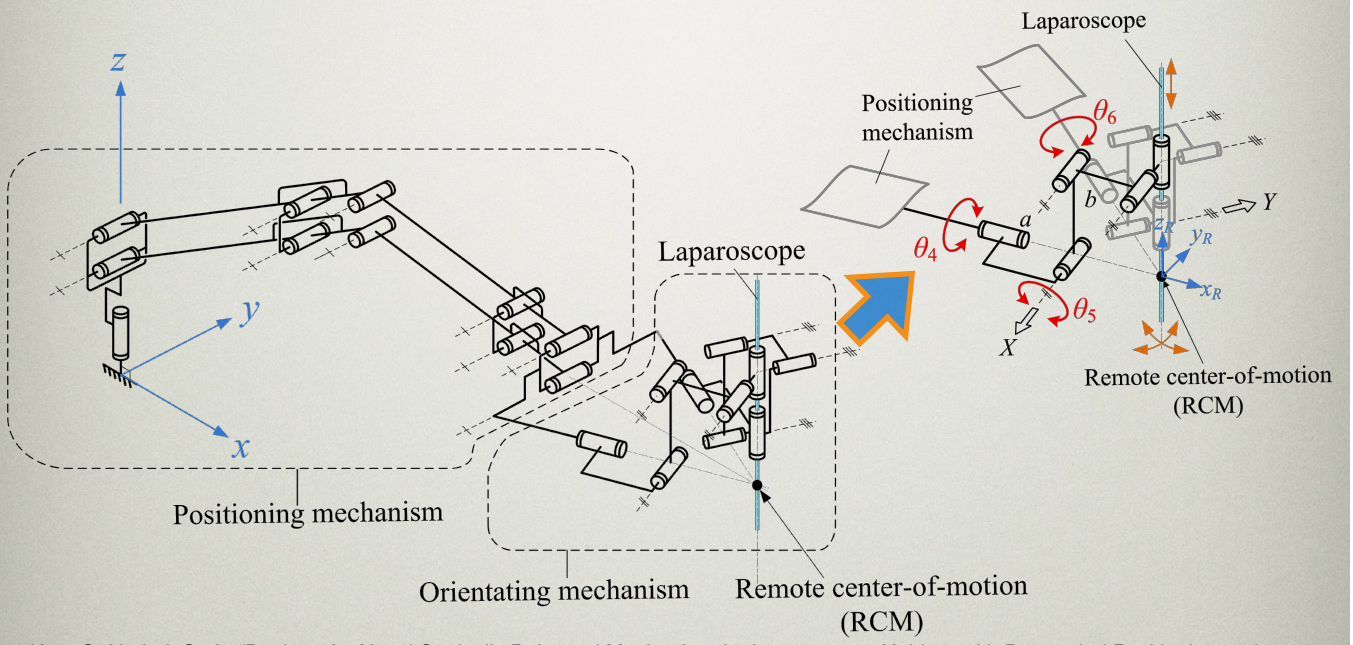


- **Bimanual operation**
- **Mechanical safety**

Design Goals

- Passive design: No actuation unit
- Decoupled manipulation: Positioning and orientating
- Gravity-free: No mechanical lock required
- Safety: Remote center-of-motion provided

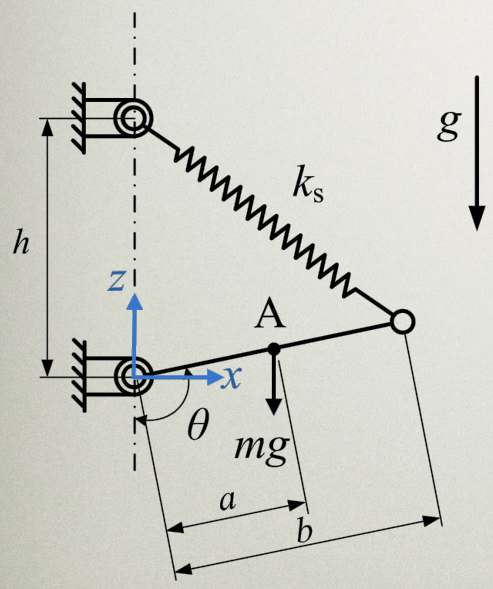
The Design



Kuo, C.-H., Lai, S.-J., "Design of a Novel Statically Balanced Mechanism for Laparoscope Holders with Decoupled Positioning and Orientating Manipulation," ***ASME 2014 International Design Engineering Technical Conferences (IDETC 2014)***, 17-20 August 2014, Buffalo, NY, USA.

Statically Balancing Design:
Fundamental Concept

$$G_{\text{All}} + E = \text{constant}$$



$$G_{\text{All}} = -mga\cos\theta$$

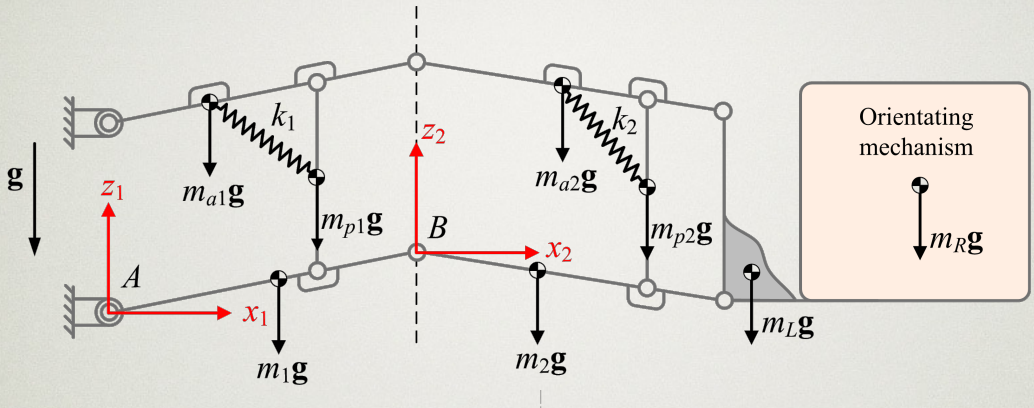
$$E = \frac{1}{2}k_s(h^2 + b^2 + 2hb\cos\theta)$$

$$-mga\cos\theta + \frac{1}{2}k_s(b^2 + h^2) + k_s bh\cos\theta = \text{const}$$

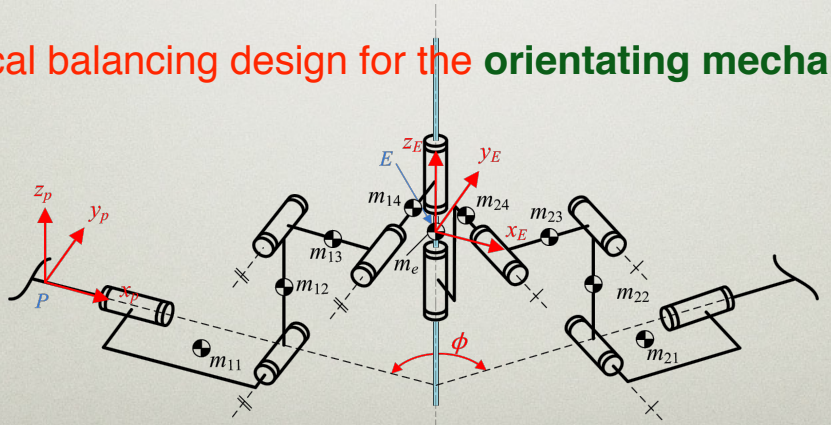
$$-mga\cos\theta + k_s bh\cos\theta = 0$$

$$k_s = \frac{mga}{bh}$$

Statical balancing design for the **positioning mechanism**

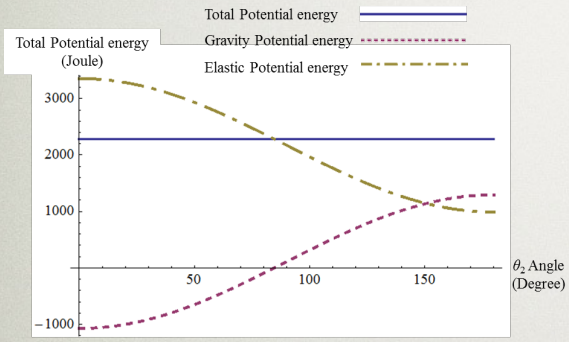


Statical balancing design for the **orientating mechanism**

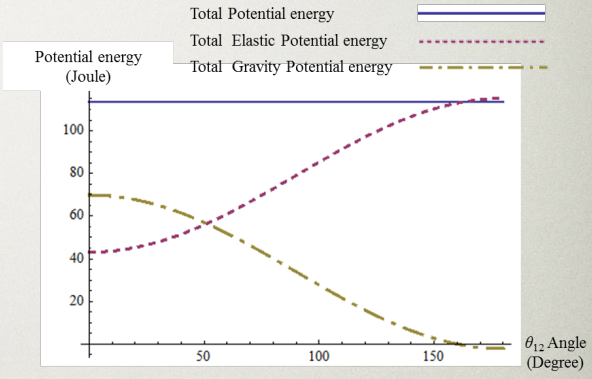


Statical balancing: *Design result*

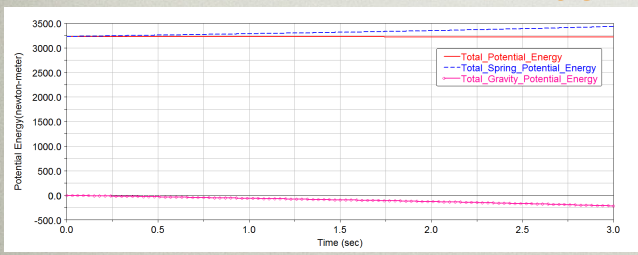
Positioning mechanism

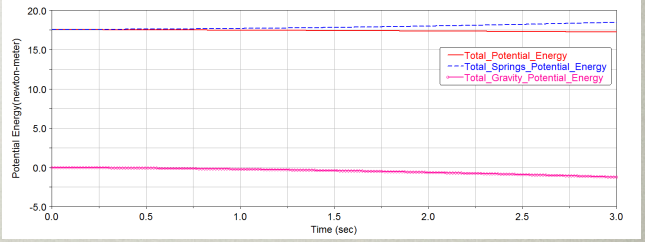


Orientating mechanism



MD Adams simulation

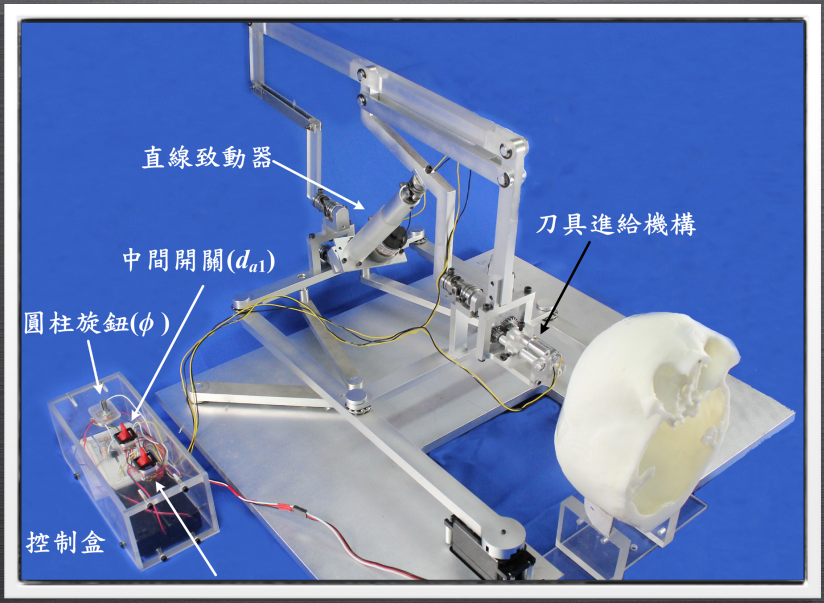




TAIWAN TECH National Taiwan University of Science and Technology
Healthcare Mechanisms and Robotics Lab

Novel Passive Statically Balancing Laparoscope Holder

HeMaR Lab @ Taiwan tech



Mechanism Design for Craniotomy Robots

CRANIOTOMY

The Problems

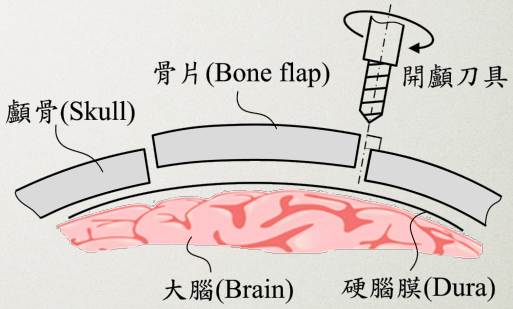
Two main steps in craniotomy:

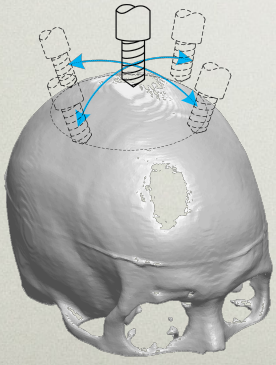
- **Drill the burr holes** → **Drilling tool**
- **Cut the bone flap** → **Cutting tool**

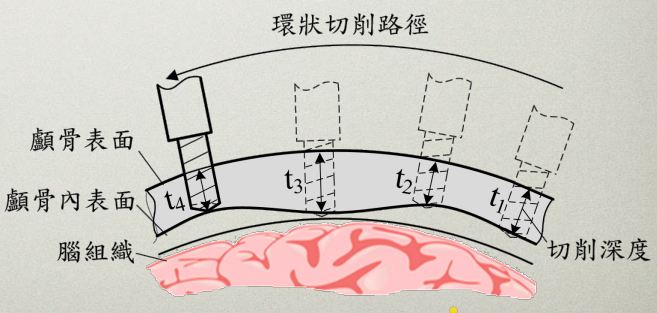
Can we do these two operations by using ONE tool only ???

Motion Requirement

(1) 2-DOF cutting trajectory
(2) 1-DOF cutting depth
(3) "trapezoidal" bone cutting

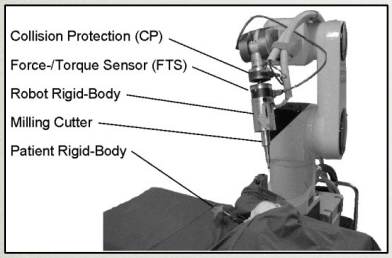




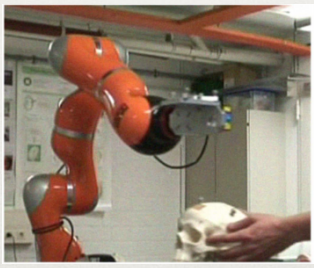


Existing Craniotomy Robots

Karlsruhe Univ., Germany



RobaCka



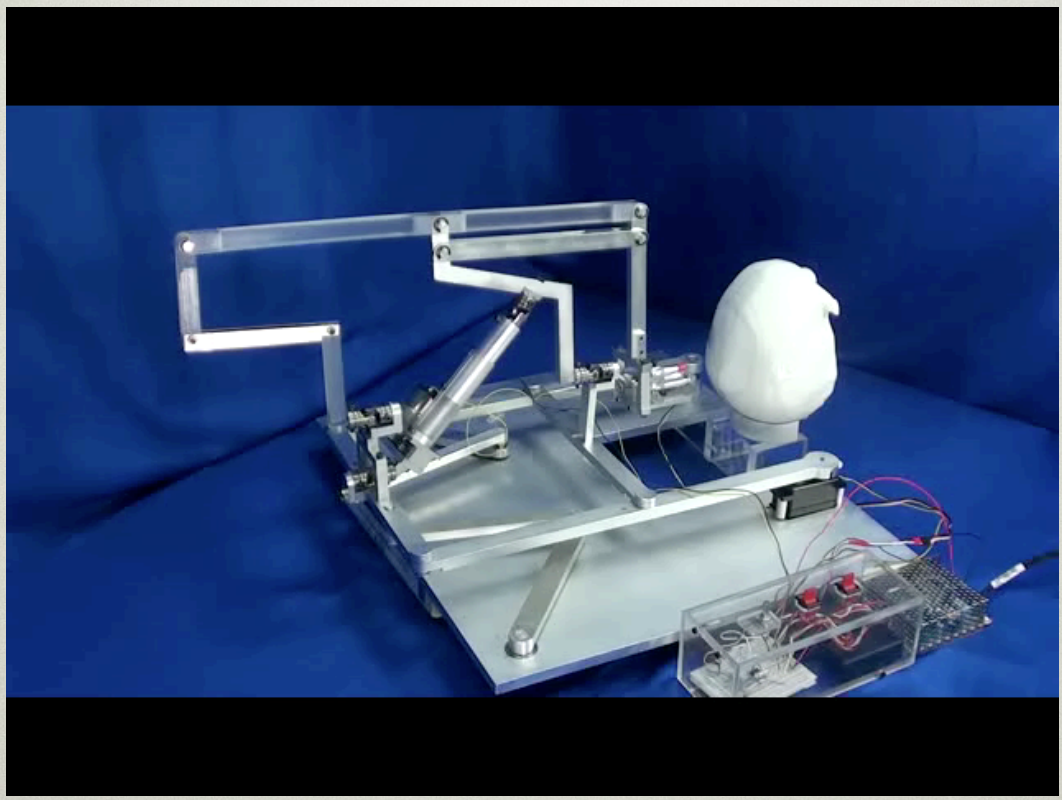
KUKA LWR

Lung-Hwa Univ., Taiwan

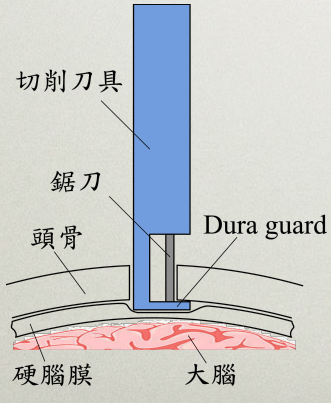
LR Mate 200iB

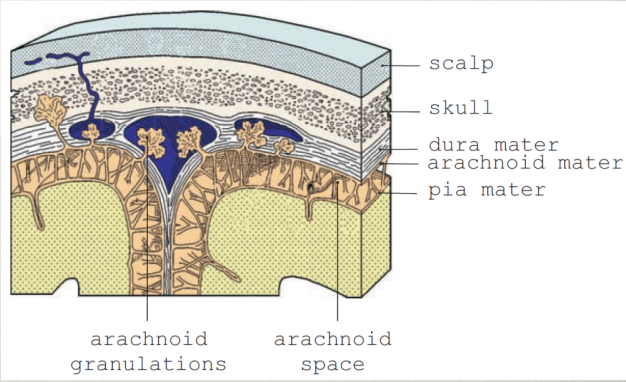
The problems

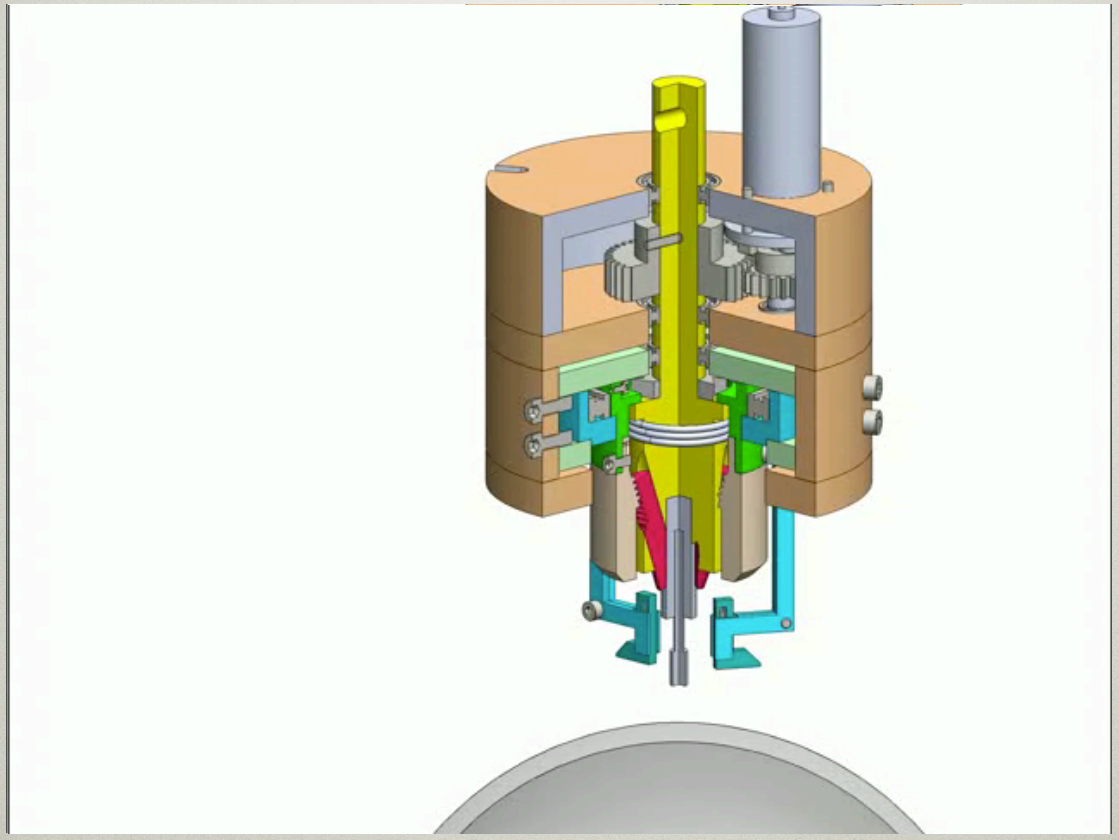
- All robots are industrial serial robot, i.e., not specifically designed for craniotomy application.
- Due to the serial structure, the rigidity is not convinced.
- The robots provide redundant DOFs—the craniotomy operation only requests 3 DOFs

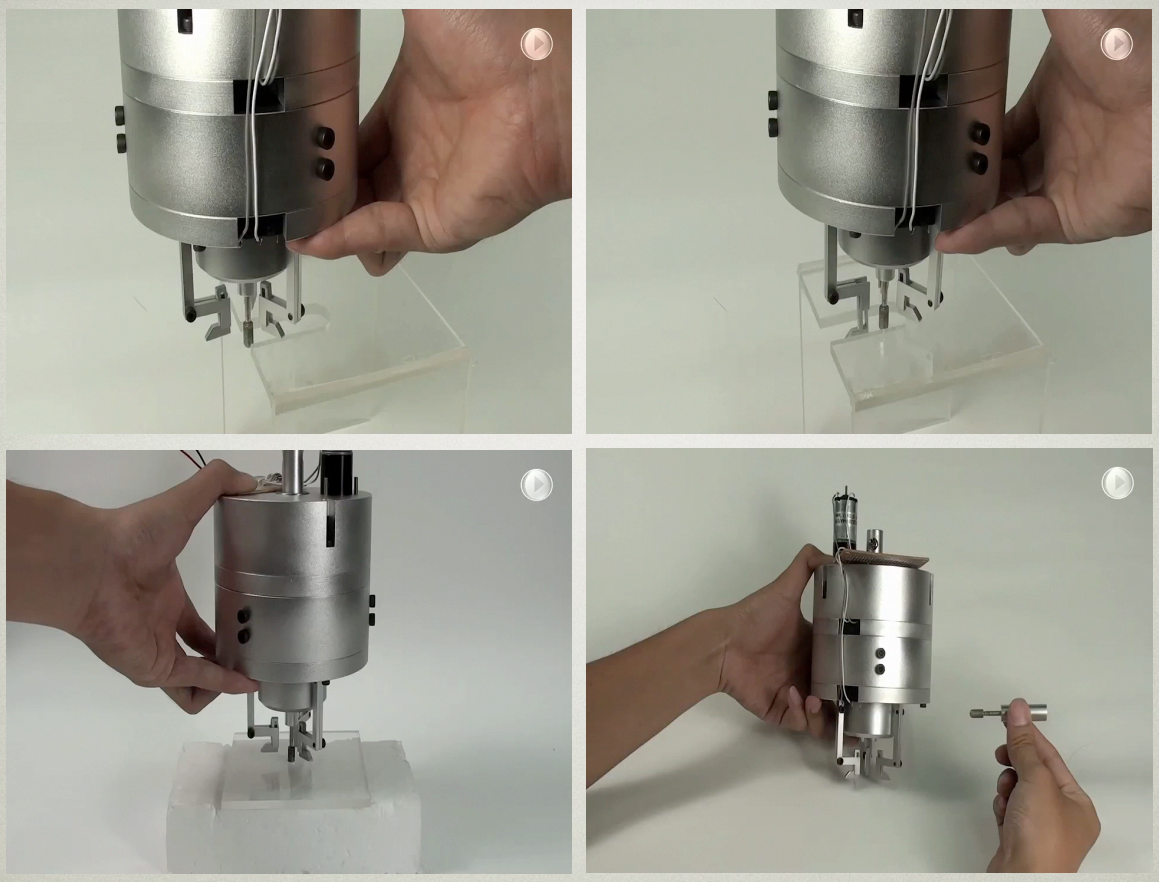


Commercial Skull-Cutting Products





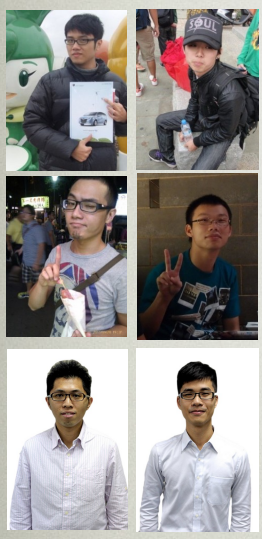


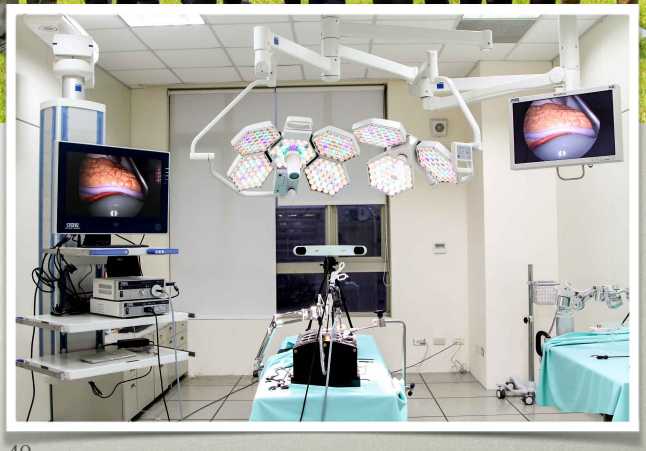


Conclusions

- Mechanism design is vital for surgical robots
- There are still many challenges of mechanism design in surgical applications
- Safety is the uppermost requirement
- Talk to the surgeons and understand their needs

Acknowledgement





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