Advancing Robotics for Human-Centricity

Intelligent Robot, Vision & Control

May 28, 2024 | Beijing

基于机理建模的医疗手术机器人设计与开发

Model-Based Design & Development in Surgical Robotics

Liangjing Yang, Zhejiang University

MATLAB EXPO

自我介绍

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浙江大学伊利诺伊大学厄巴纳香槟校区联合学院

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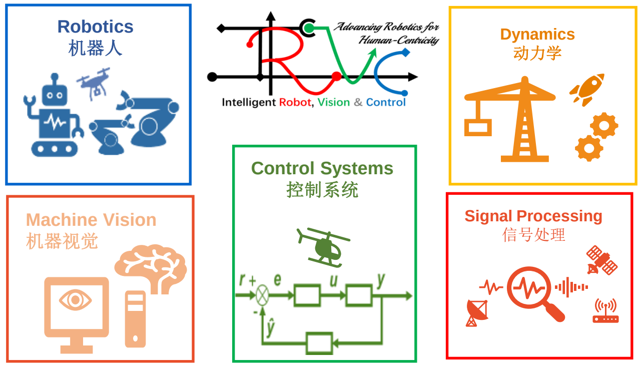
研究领域：机器人、机器视觉、控制系统



教育背景

NUS National University of Singapore
東京大学 THE UNIVERSITY OF TOKYO

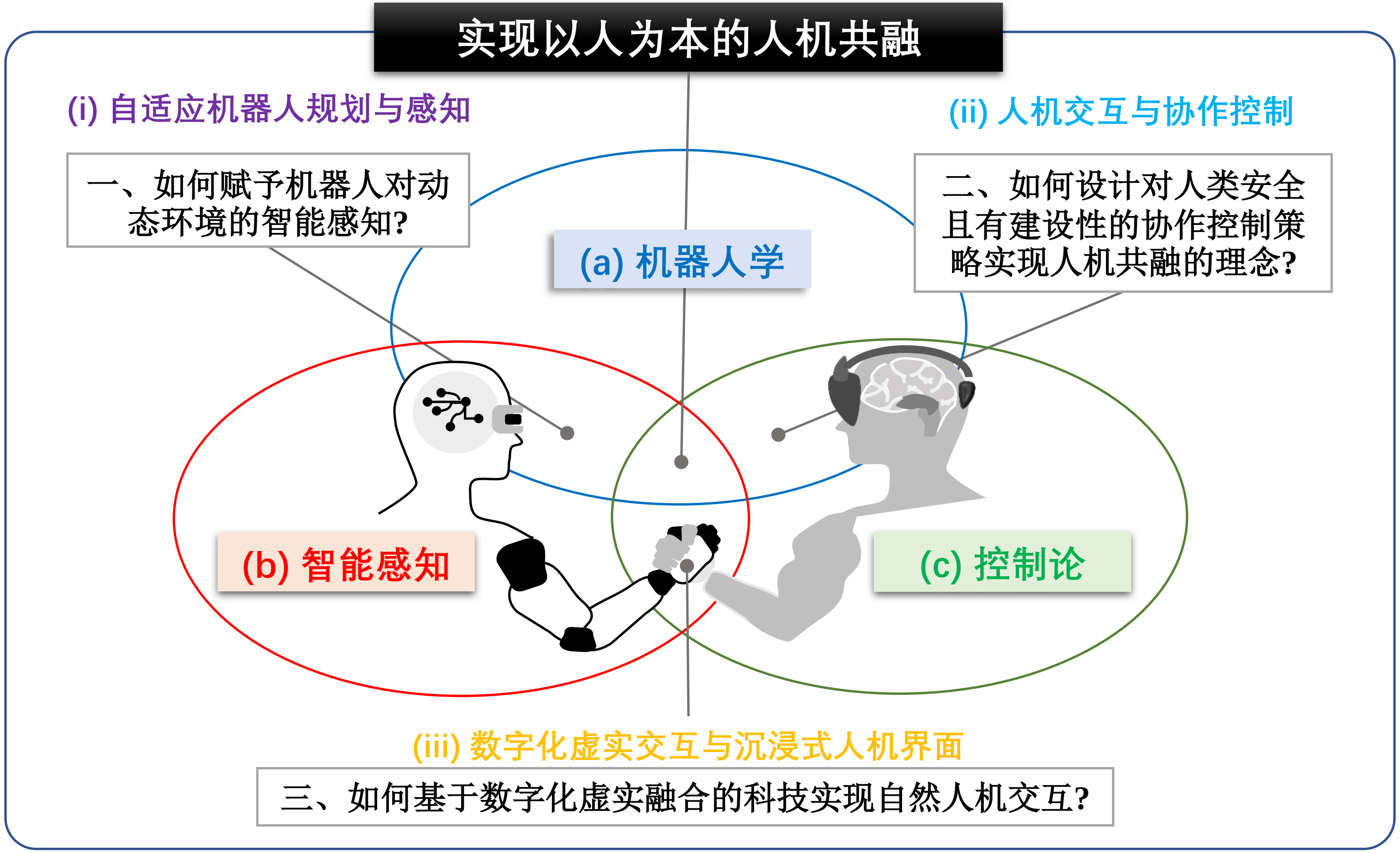
2011/10-2014/09	*日本东京大学*	工学博士（精密工学）
2008/08-2011/07	*新加坡国立大学*	工程硕士（机械工程）
2004/08-2008/07	*新加坡国立大学*	工程学士 （机械工程）

工作经历

SUTD SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN
MIT Massachusetts Institute of Technology
ZJU-UIUC INSTITUTE
Zhejiang University/University of Illinois at Urbana-Champaign Institute
浙江大学伊利诺伊大学厄巴纳香槟校区联合学院

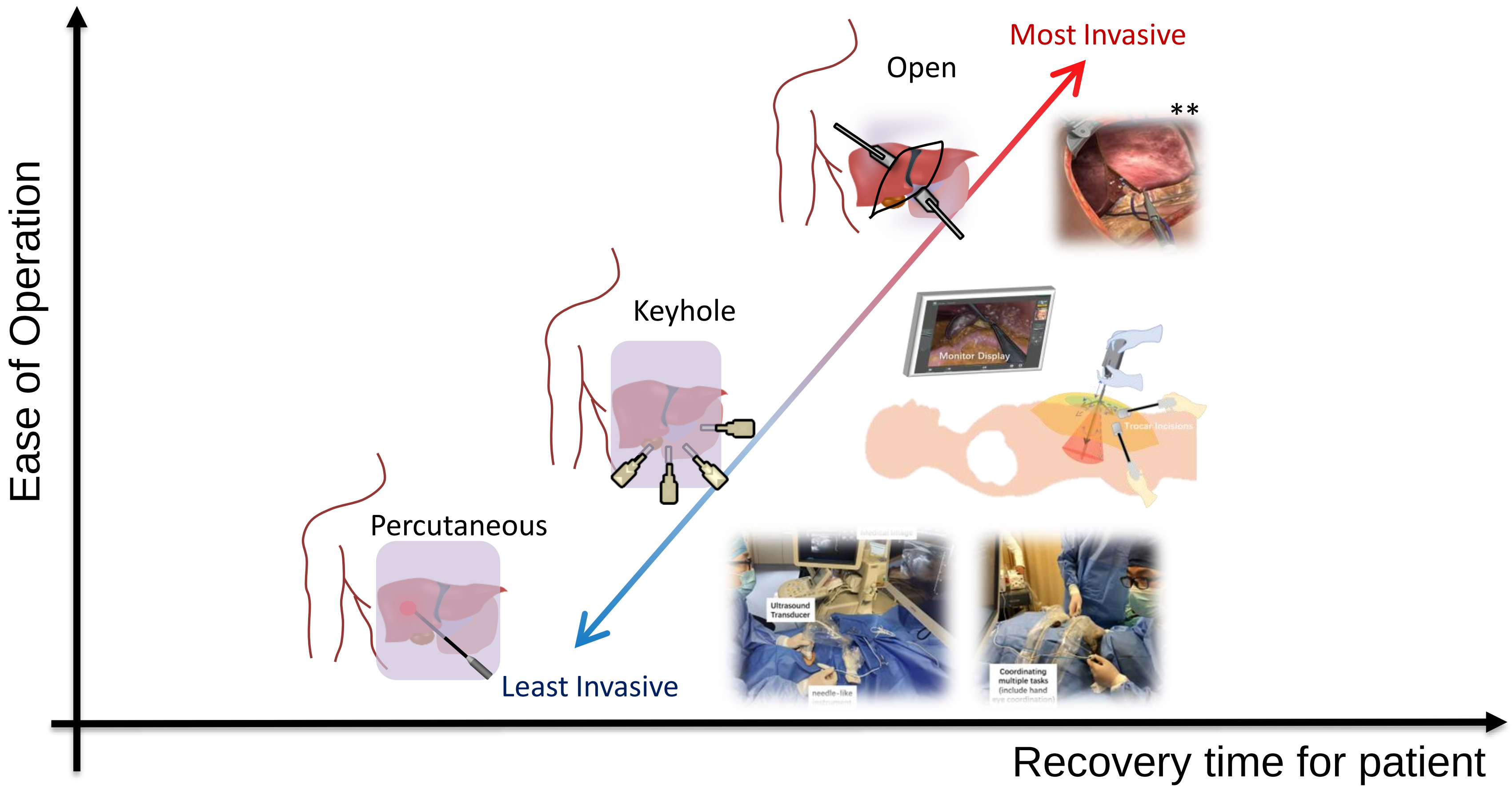
2018/03-Present	*浙江大学国际联合学院*	研究员 | 博士生导师
2018/03-Present	*美国伊利诺伊大学厄巴纳香槟校区*	客聘助理教授
2016/11-2017/10	*美国麻省理工*	博士后学者
2015/11-2017/12	*新加坡科技设计大学*	博士后学者
2014/10-2015/10	*日本东京大学*	博士后特聘研究员
2008/07-2011/09	*新加坡国立大学*	项目研究员

科研方向


实现以人为本的人机共融
(i) 自适应机器人规划与感知
一、如何赋予机器人对动态环境的智能感知?
(ii) 人机交互与协作控制
二、如何设计对人类安全且有建设性的协作控制策略实现人机共融的理念?
(a) 机器人学
(b) 智能感知
(c) 控制论
(iii) 数字化虚实交互与沉浸式人机界面
三、如何基于数字化虚实融合的科技实现自然人机交互?

Surgical Technology in Different Era

Level of Invasiveness



Computer-Aided Surgery

Robot Mechanism Design, Control & Vision

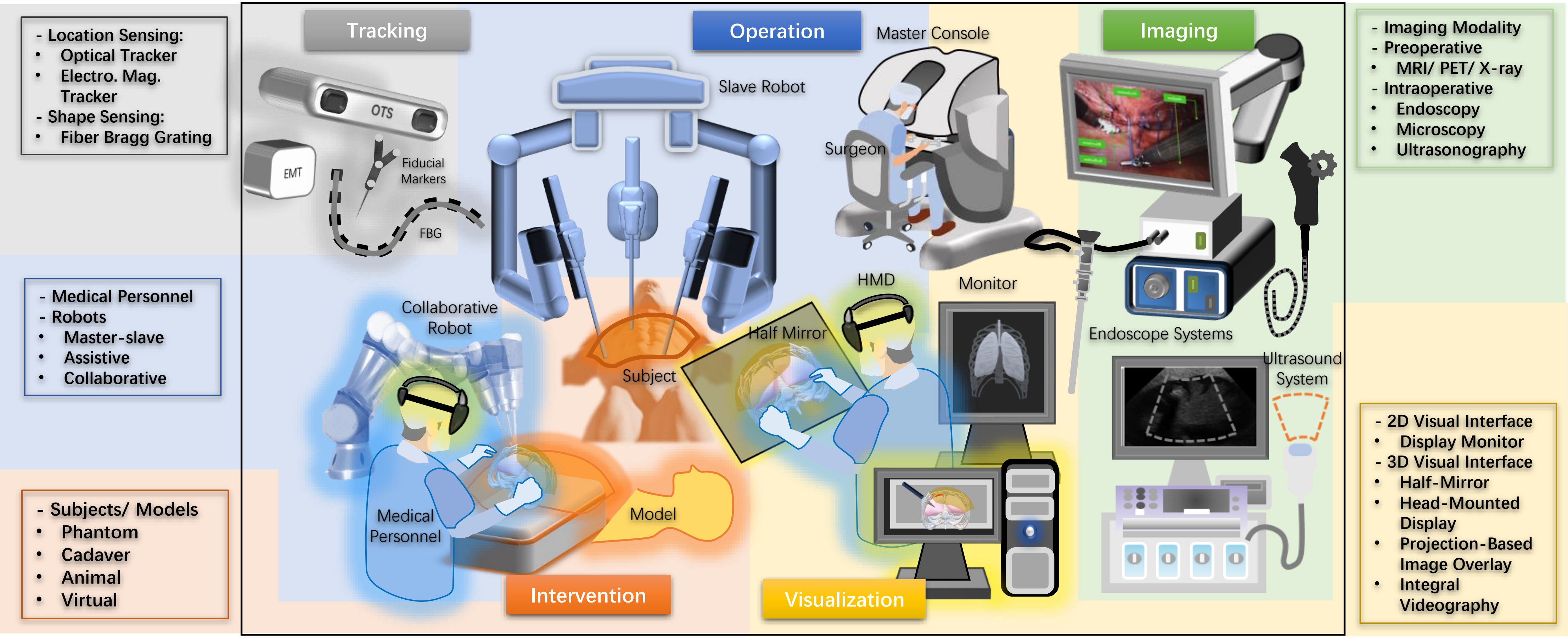


Image-Guided Minimally Invasive Surgery: Design & Development

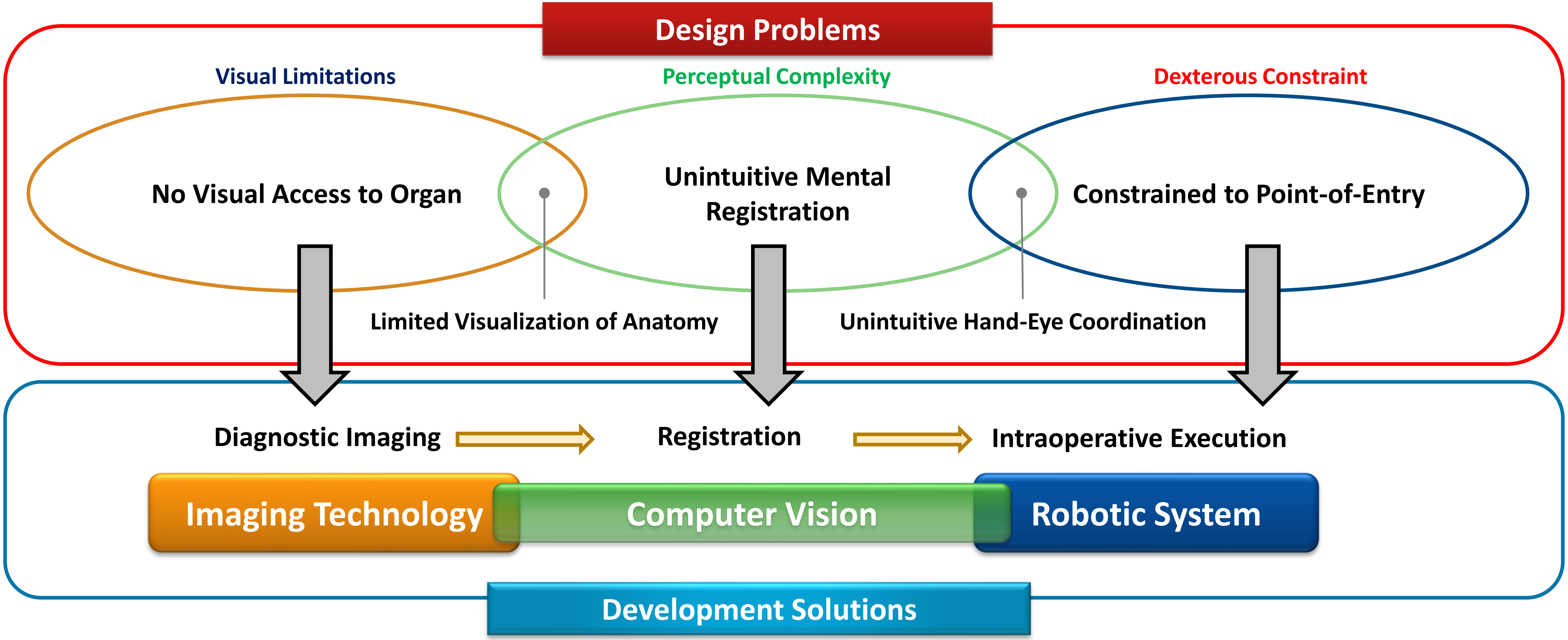
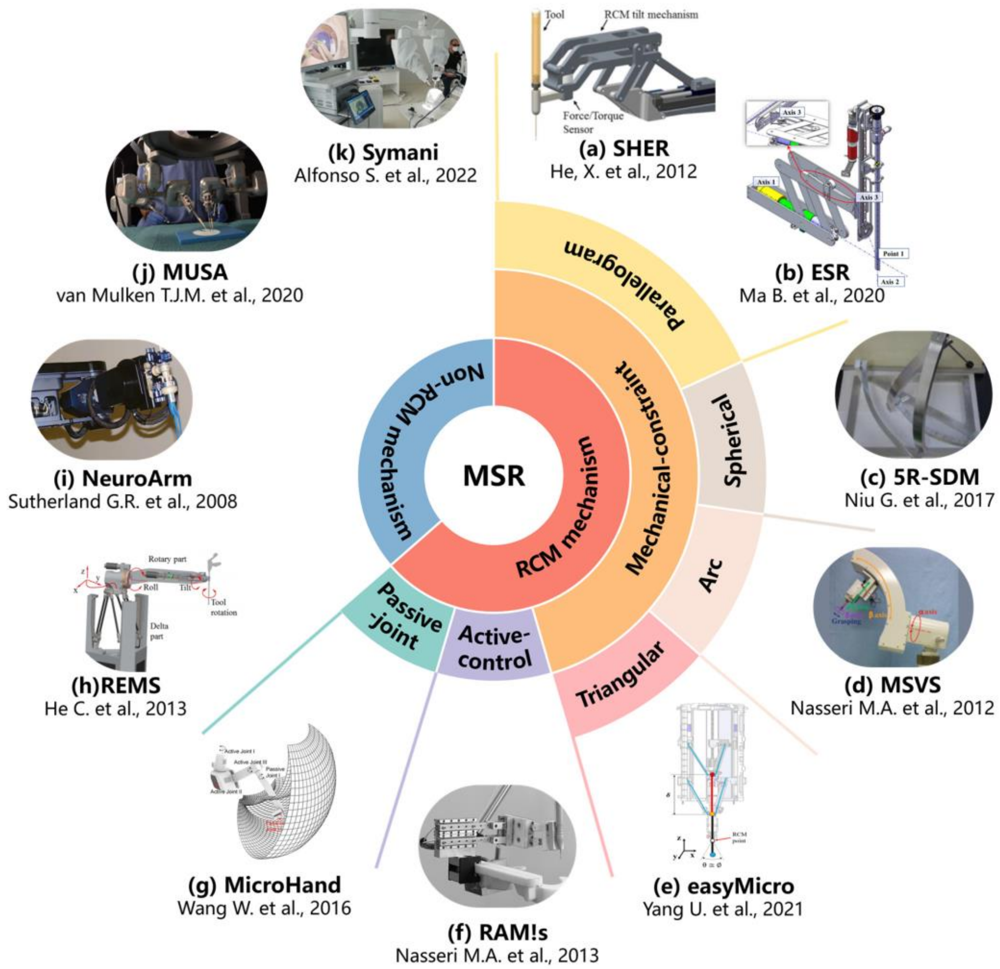


Image-Guided Minimally Invasive Surgery: Design & Development

- Problem Identification
- Design Conceptualization
- Technical Specification
- Functional Analysis
- Operational Simulation
- Physical Prototyping & Testing
- Performance Assessment

Microsurgery Robotic Systems



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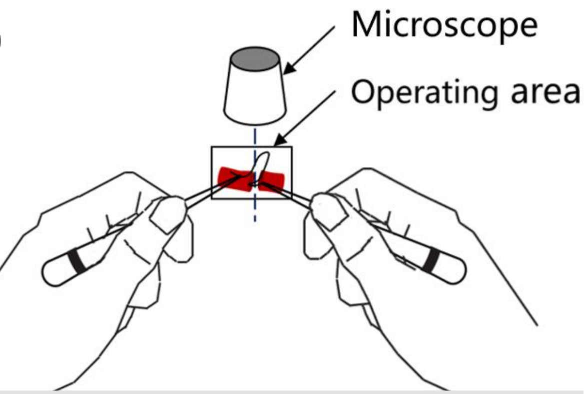
Problem Identification

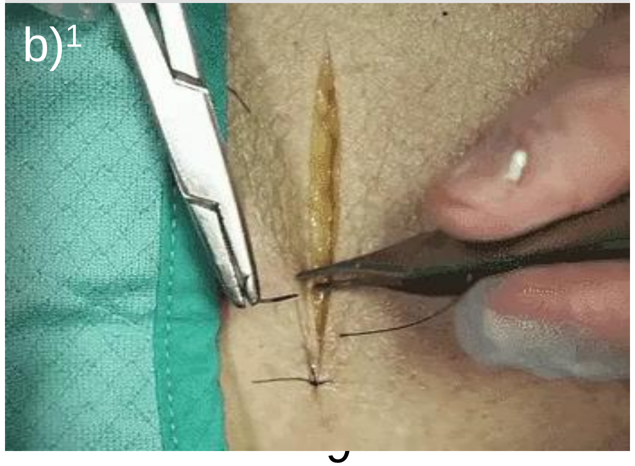
In the Application of Anastomosis

- Surgeons perform **anastomoses and sutures** on blood vessels, nerves, and lymphatic vessels under a microscope
- Narrow workspace, between 0.3 and 0.8 mm
- Inevitable physiological tremor
- Operative technical skill qualities

a)



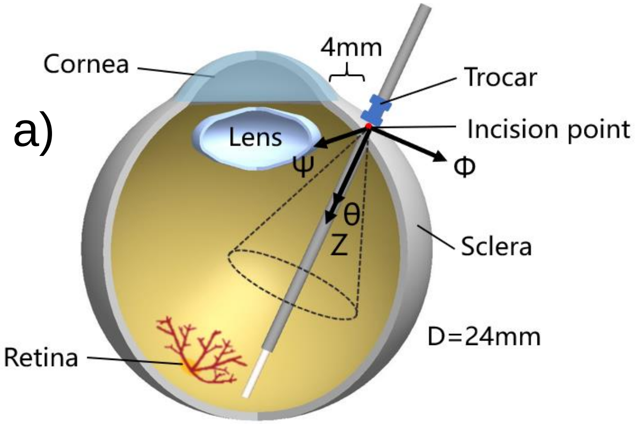
Anastomosis



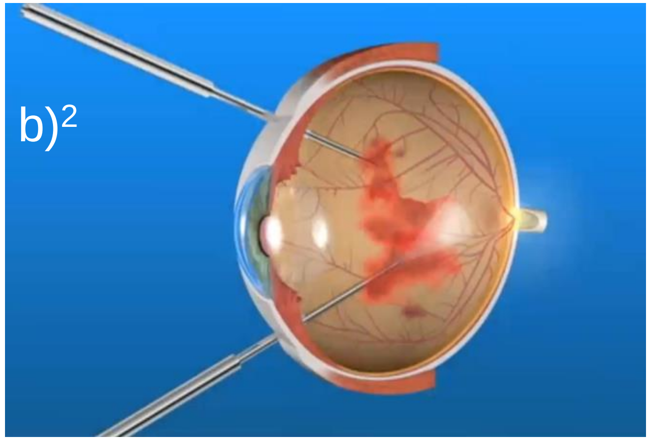
Problem Identification

In the Application of Ophthalmic surgeries

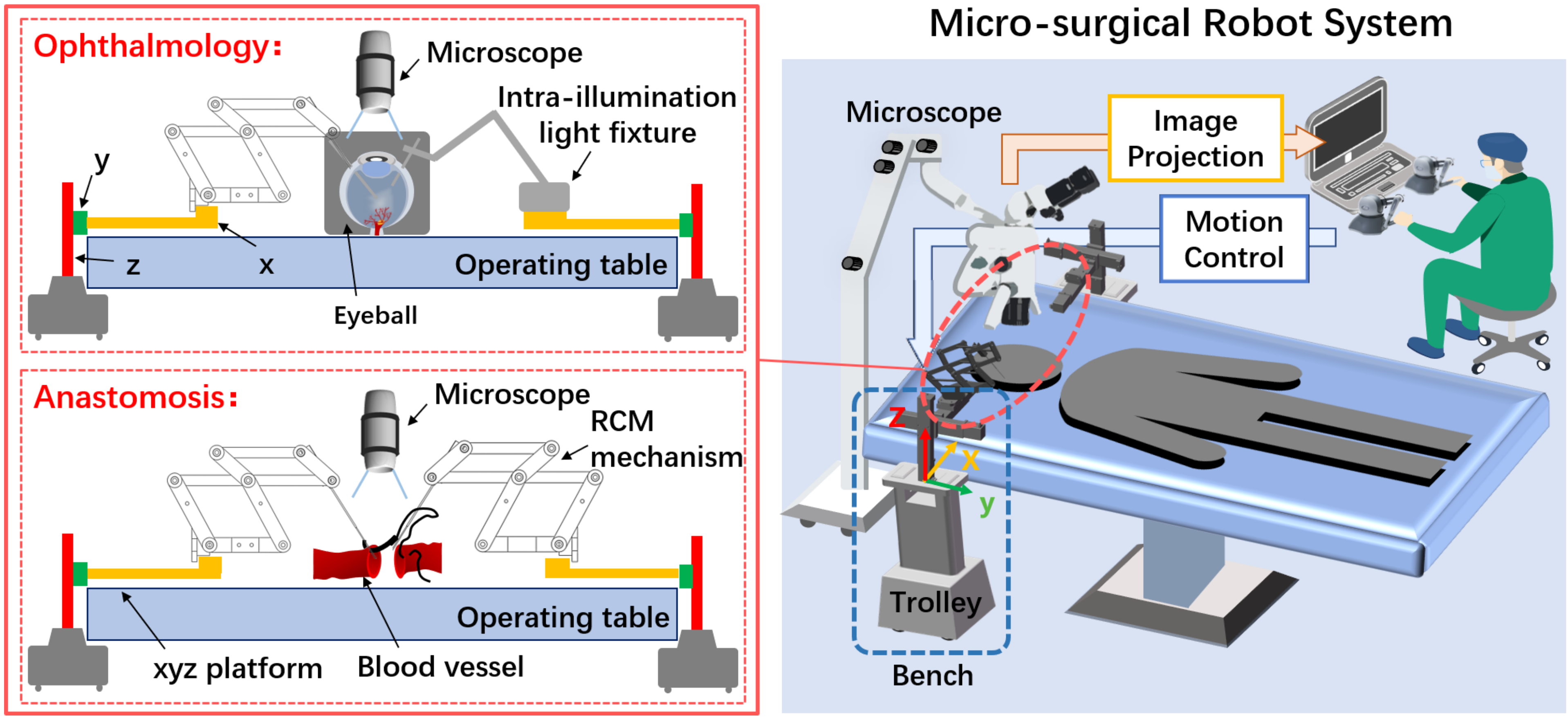
- Surgeons manipulates the instruments to enter the eyeball through a trocar in the sclera.
- Ophthalmic procedure is a kind of MIS, the movement of the instrument is remote center of motion (RCM).
- Narrow workspace, a small (24 mm) enclosed spheroid
- High precision operation & Inevitable hand tremor



Ophthalmic surgeries



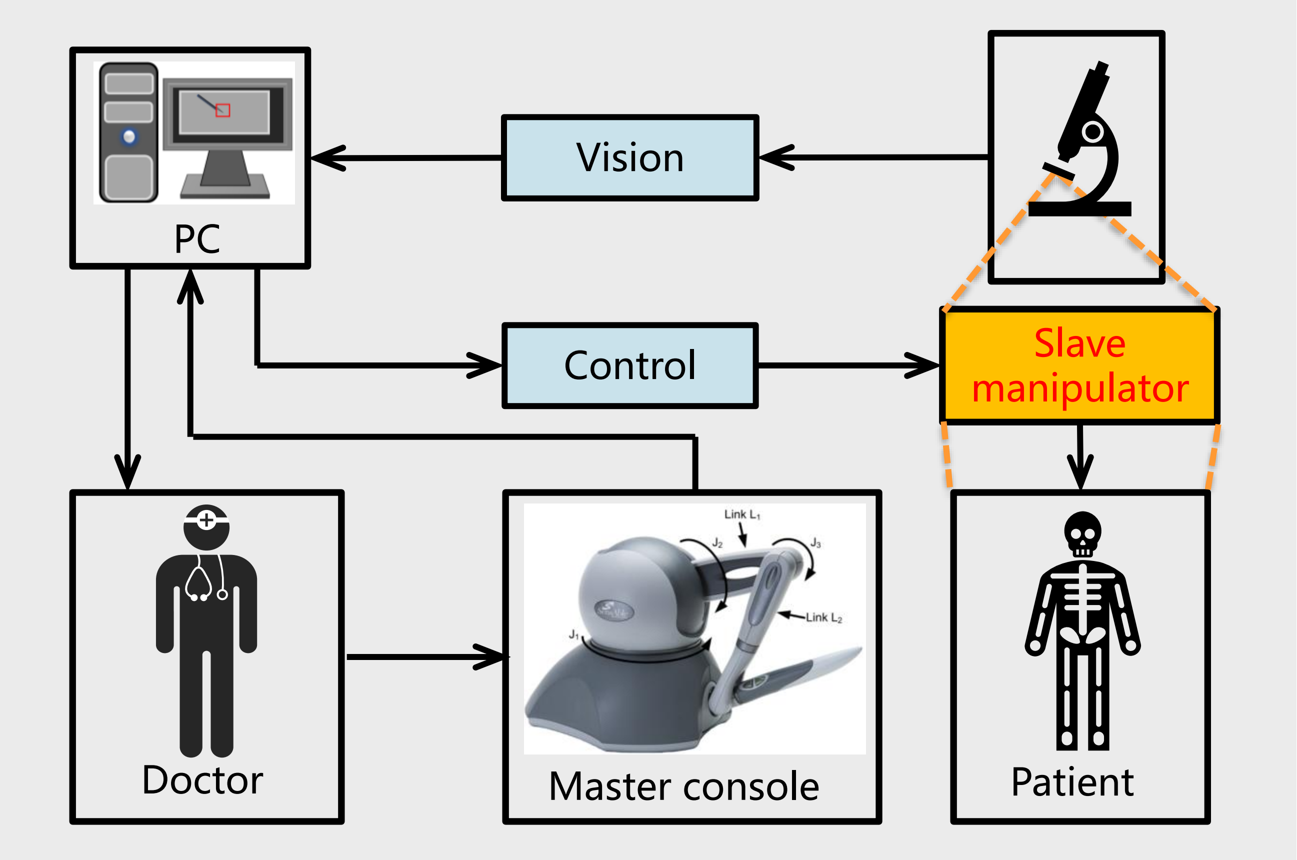
Design Concept



The application scenario of the system

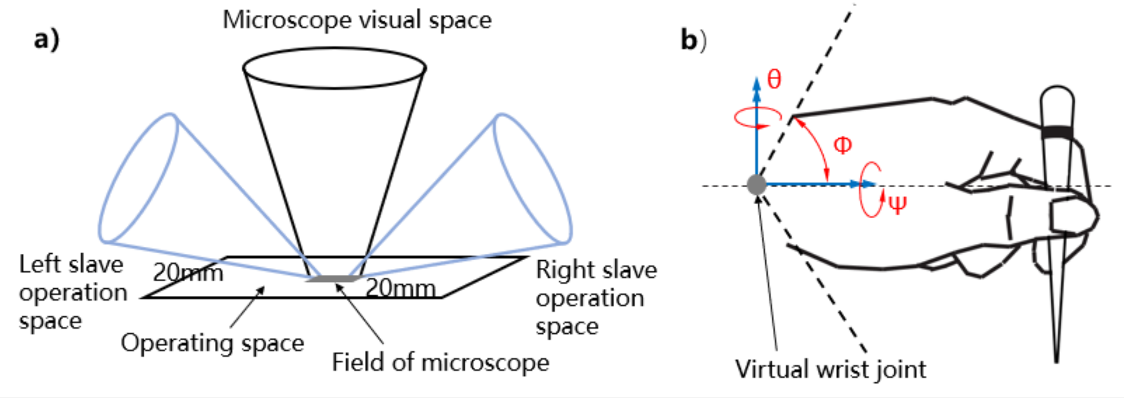
Design Concept

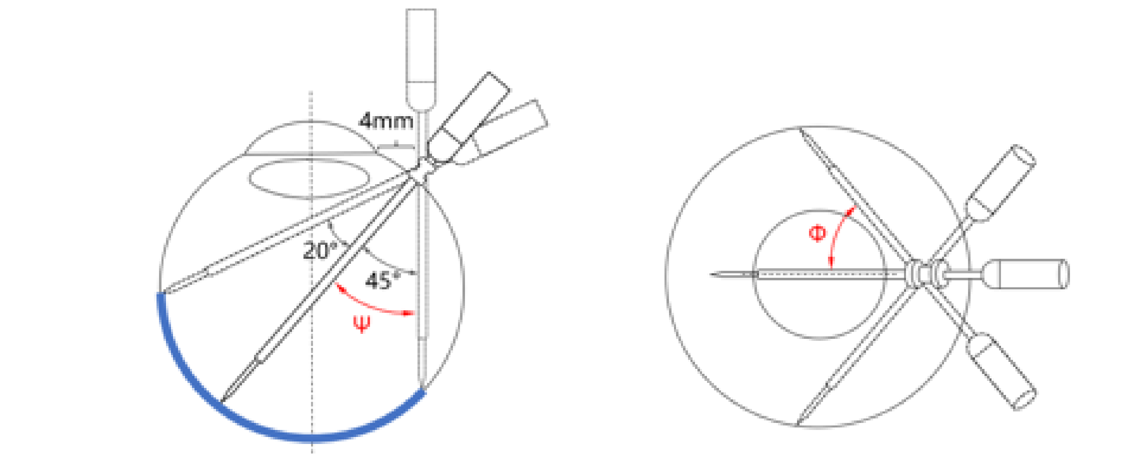
Design goals	Description
Mode of operation	Master-slave teleoperation
Structural stiffness	>100 N/mm
Degree of freedom	7: among 3 of xyz platform and 4 of RCM mechanism
Motion range of XYZ platform	$20*20*40mm^3$
Motion range of tip	ψ: ±45°; ϕ: ±75°; θ: 360°; Z: 32mm;
Positioning accuracy of RCM point	<10μm



- Layout of the system

Technical Specification

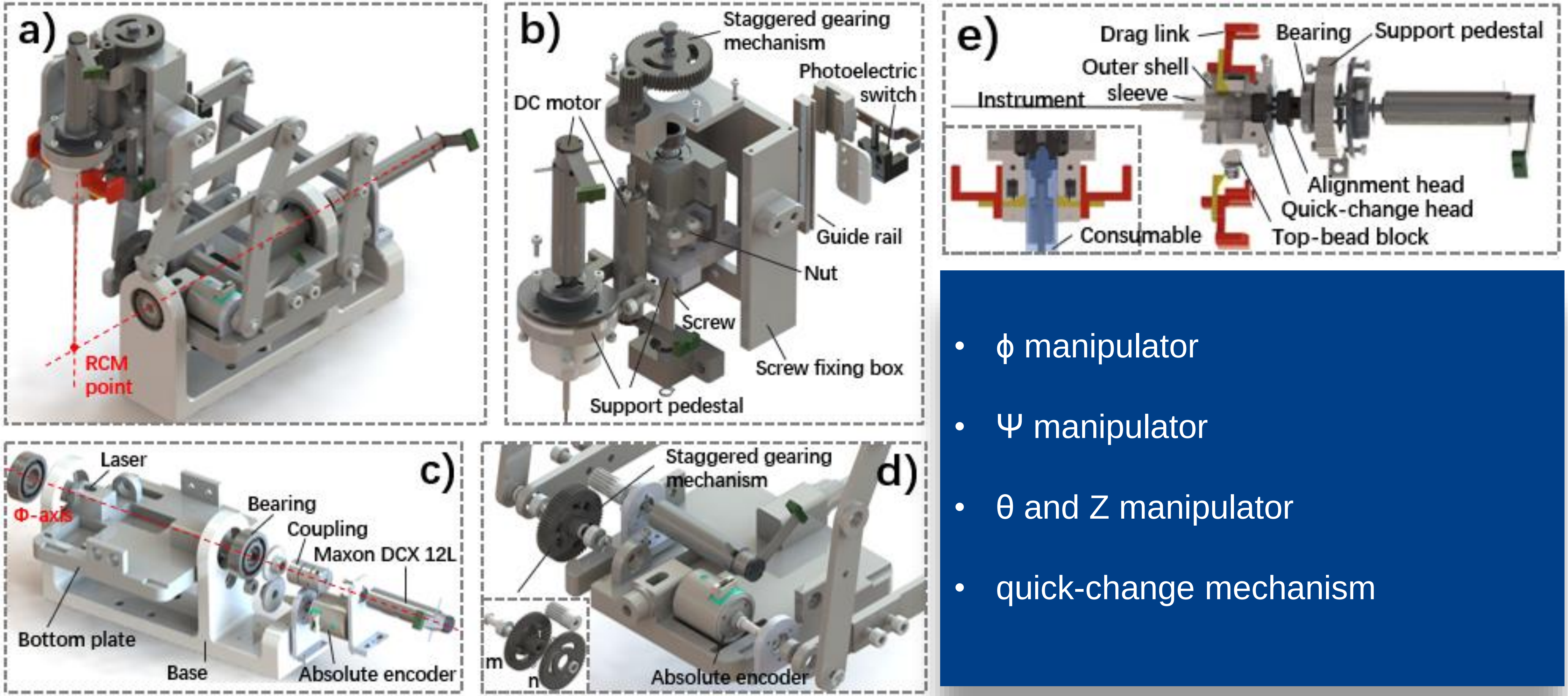




	Anastomosis	Ophthalmology
Operating area	$20*20*20mm^3$	/
Angle	ψ: ±45° ϕ: ±75° θ: ±30°	ψ: −20°~ 45° ϕ: ±45° θ: 0~360° Z: 32mm
Accuracy	<50μm	<10μm
Speed	10mm/s	25mm/s

Analysis

Functional features

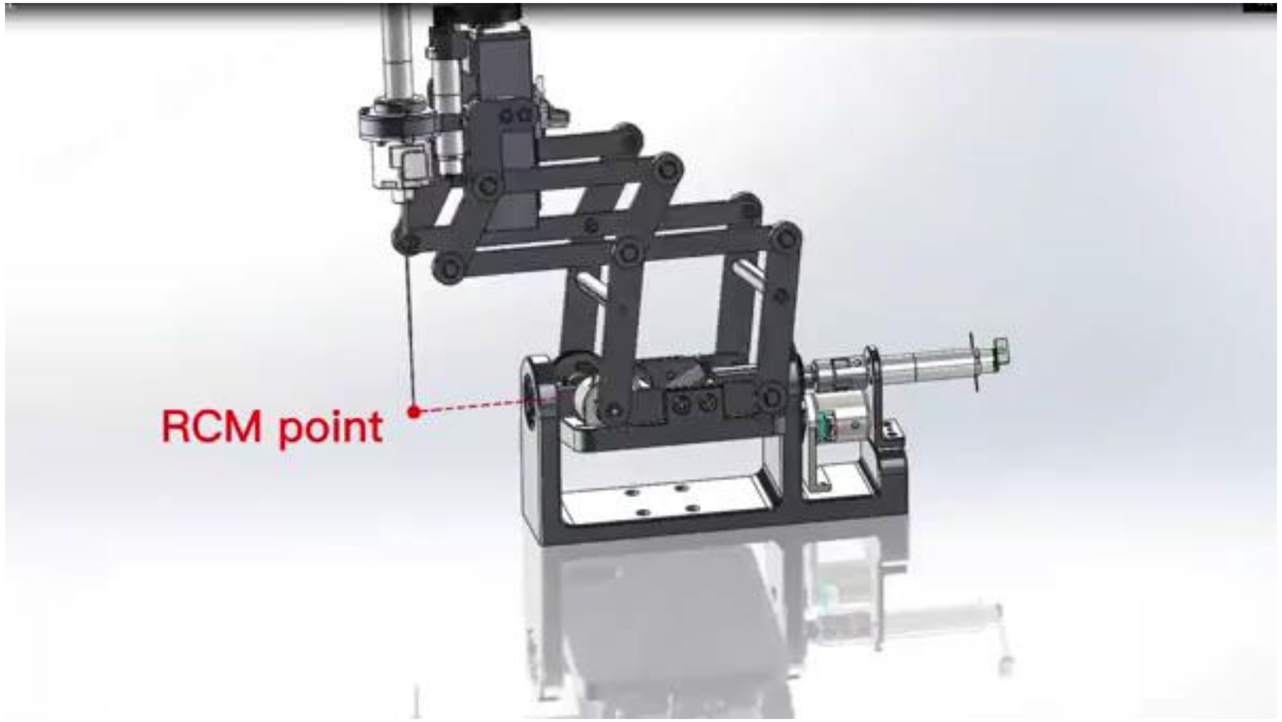


- ϕ manipulator
- Ψ manipulator
- θ and Z manipulator
- quick-change mechanism

Analysis

Functional features: Remote Center of Motion + Quick-Swapping Mechanism

- ϕ manipulator
- Ψ manipulator
- θ and Z manipulator
- quick-change mechanism



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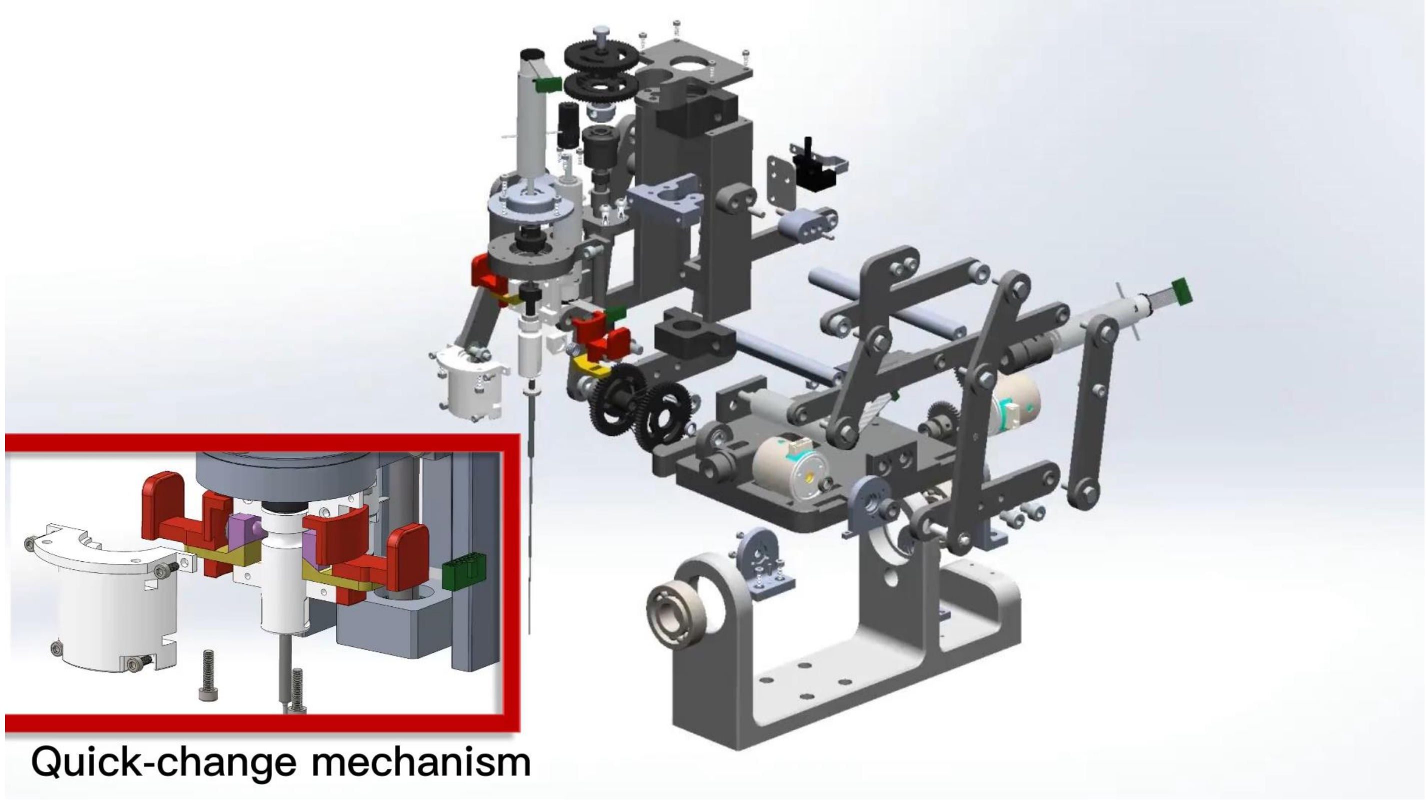
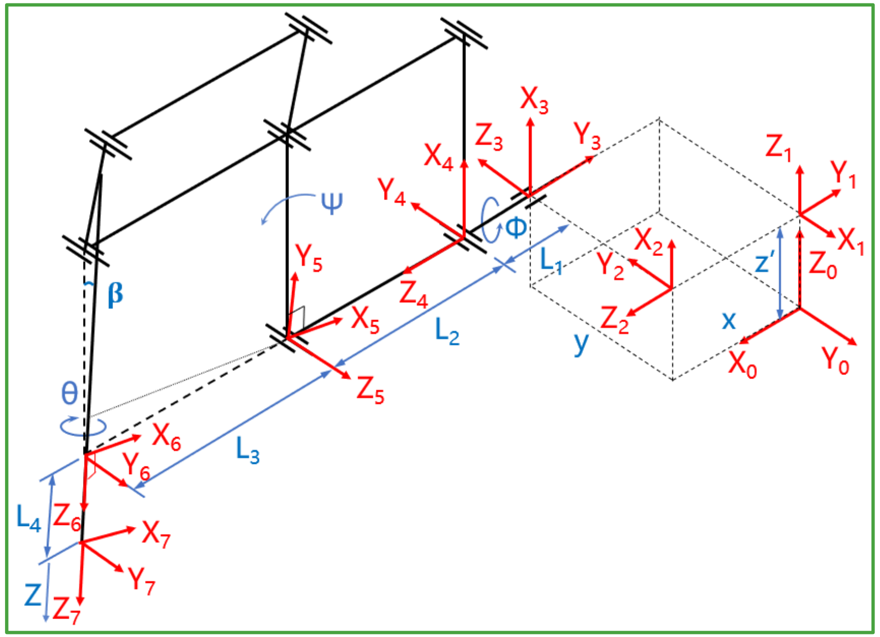


Analysis

Mechanism Kinematic Analysis



$$ {}^{i-1}_{\;\;i}T = Rot(x_{i-1},\alpha_{i-1})\ Tran(x_{i-1},\alpha_{i-1})\ Rot(z_i,\theta_i)Trans(z_i,d_i) \qquad (1)$$

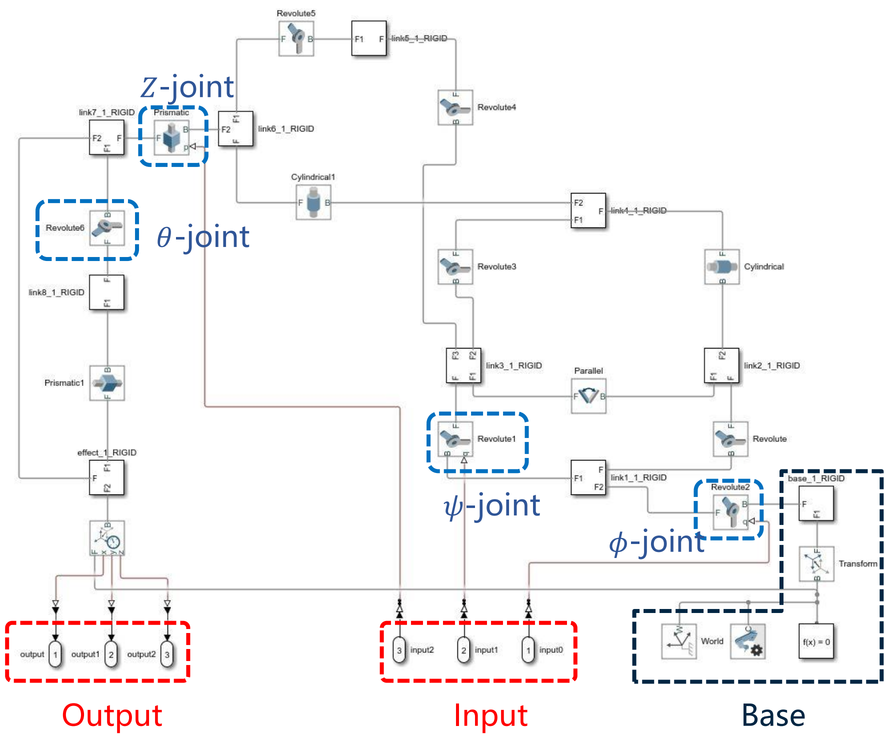
$$ {}^{0}_{7}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\ {}^{3}_{4}T\ {}^{4}_{5}T\ {}^{5}_{6}T\ {}^{6}_{7}T \qquad (2)$$

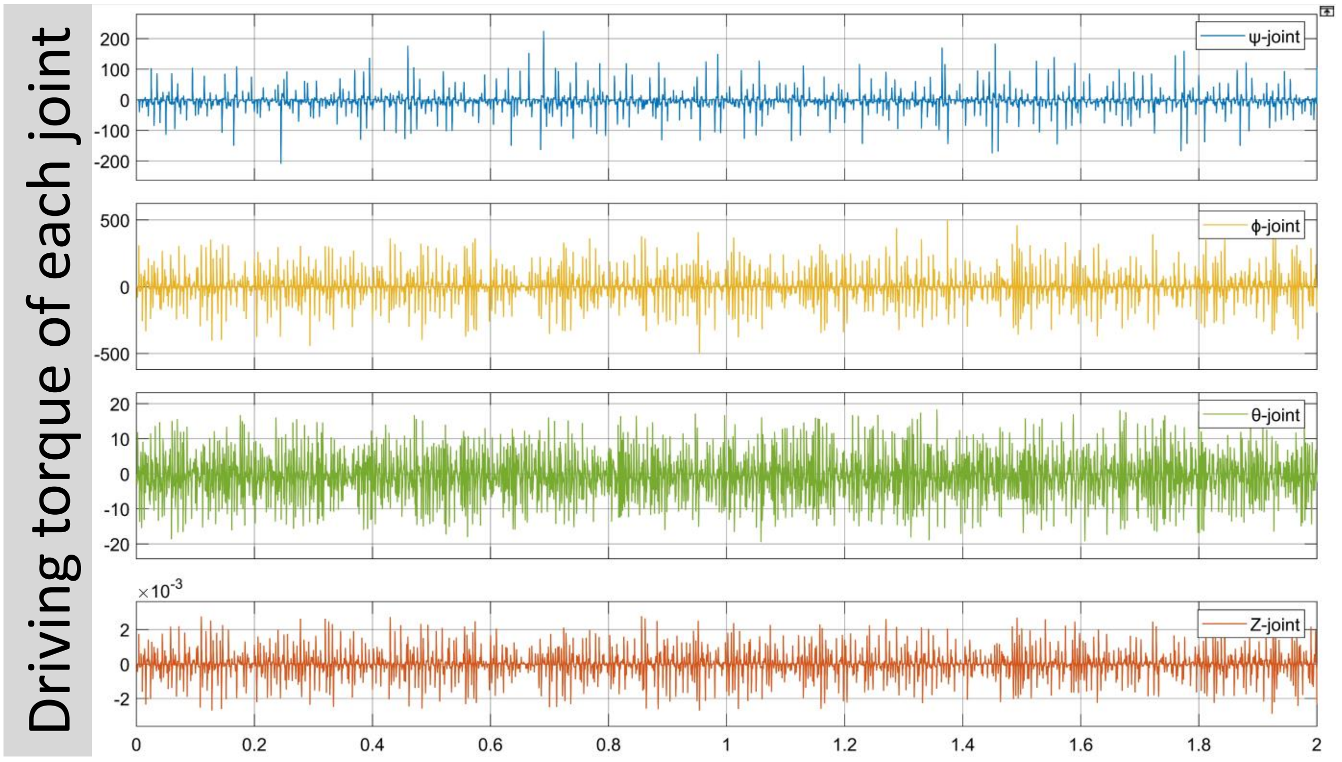
$$ l'\sin\beta' - l'\sin\beta \le 10\mu m \qquad (3)$$

$$ B = \frac{j_t}{r\times 1000}\times\frac{180}{\pi}\times 60 = 3.4378\times\frac{j_t}{r} \qquad (4)$$

Operational Simulation

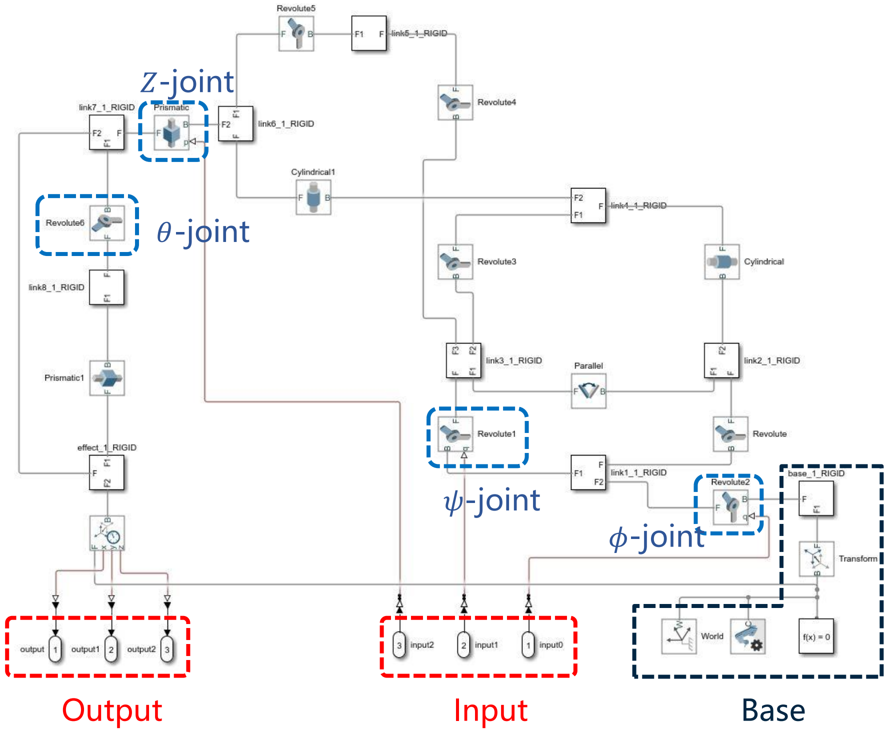
Mechanism Kinematic Analysis



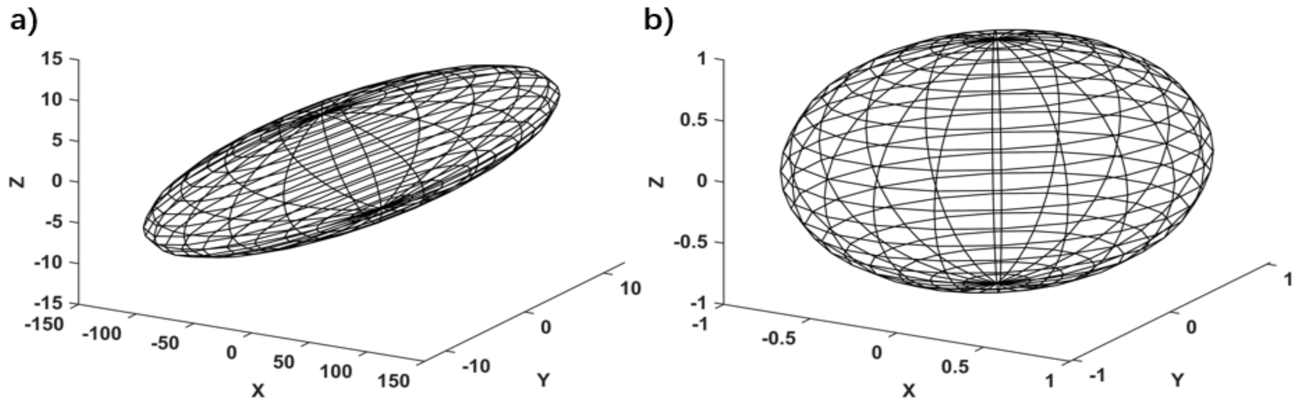


Operational Simulation

Mechanism Kinematic Analysis



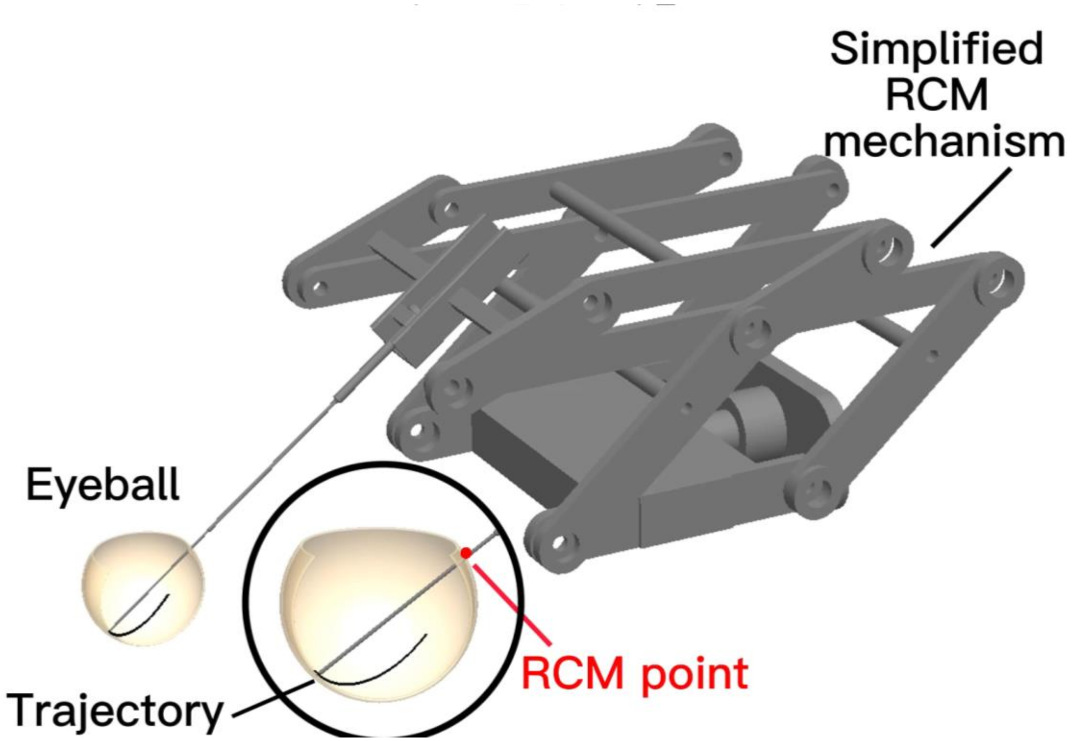
Manipulability ellipsoid at the certain posture

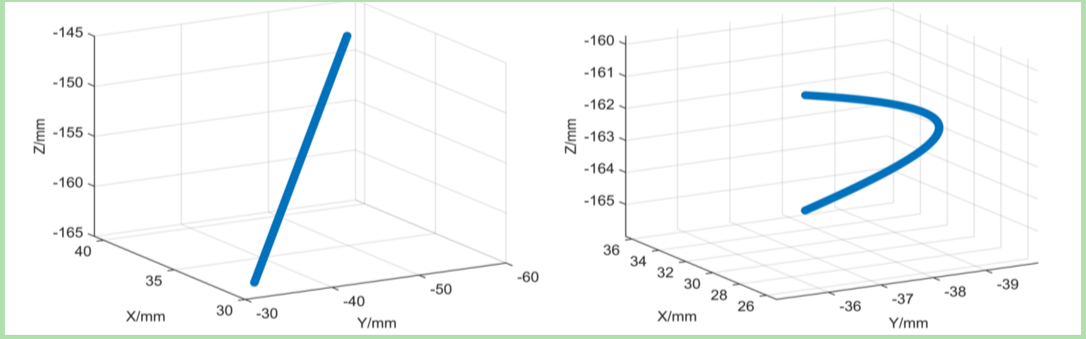


(a) Line velocity ellipsoid (b) Angular velocity ellipsoid

Operational Simulation

Mechanism Kinematic Analysis

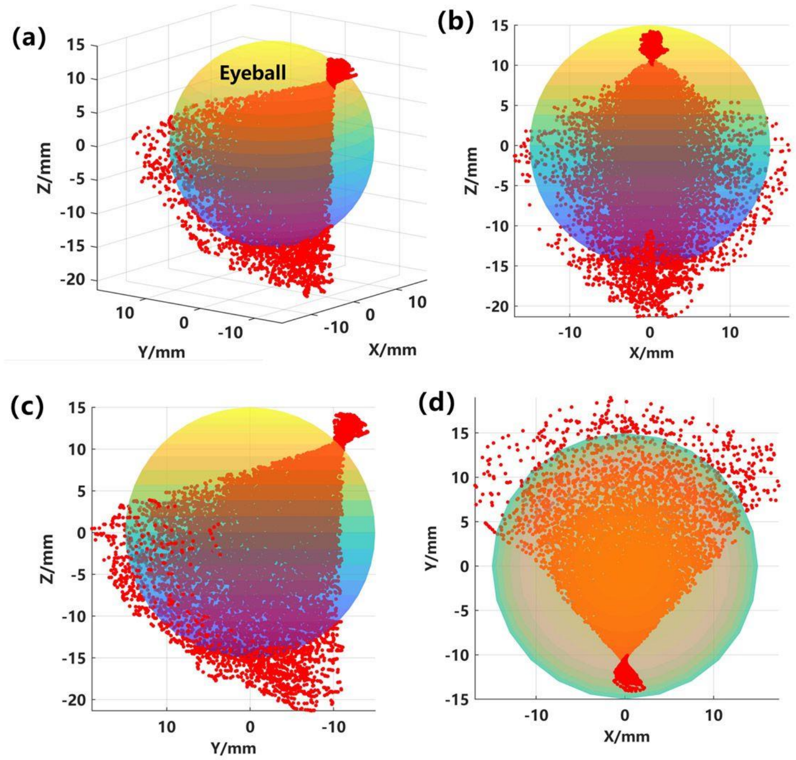


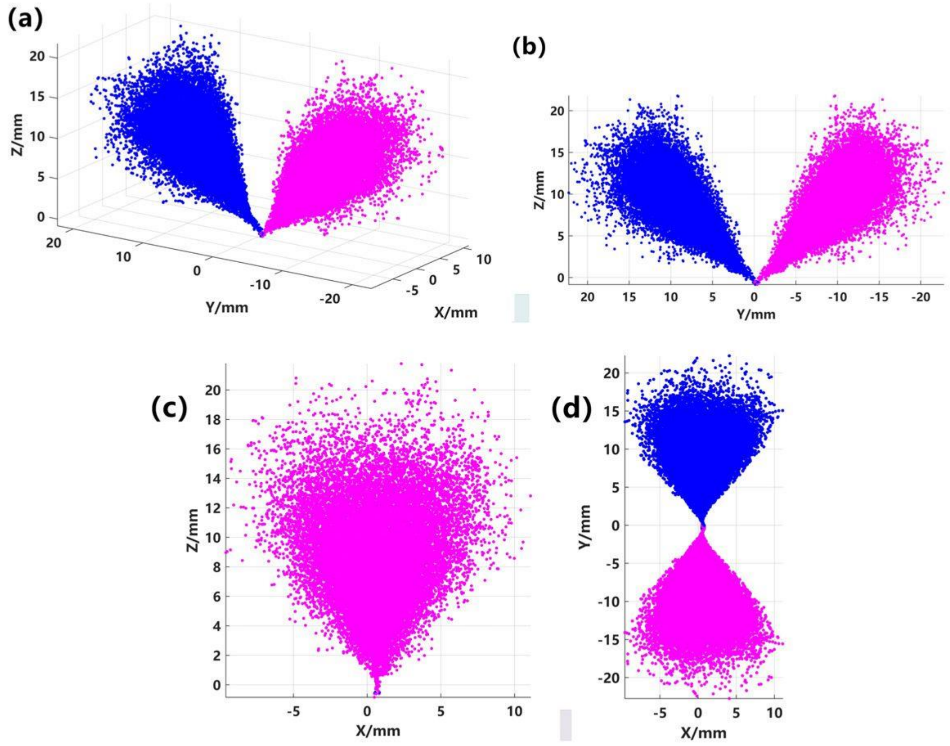


The trajectory simulation test results

Operational Simulation

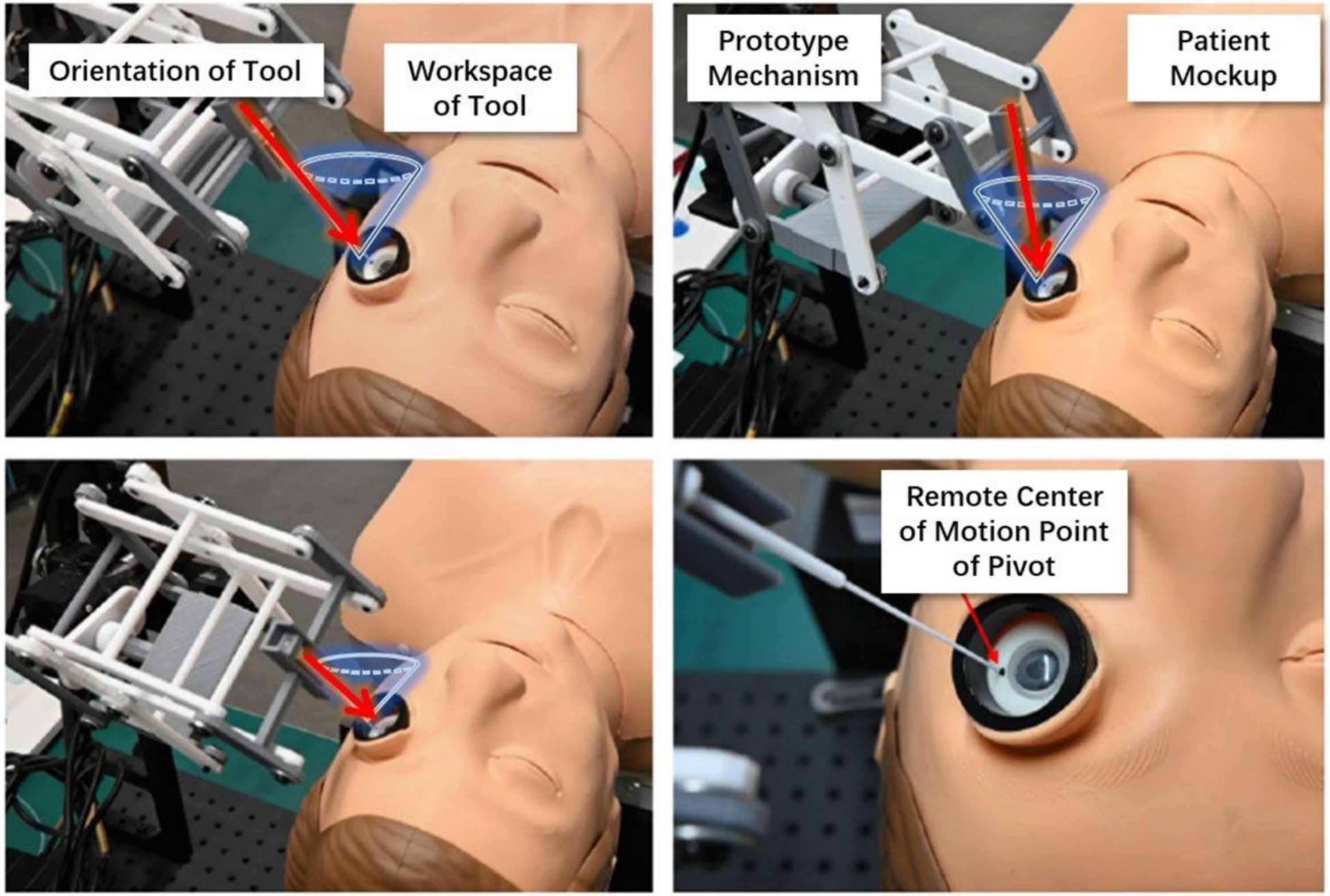
Mechanism Kinematic Analysis





Physical Prototyping

Rapid prototyped Mechanism tested RCM



Conclusion

- Leverage Mode-based Design for microsurgery robotic systems:
  - Satisfy operational requirements of **anastomosis** and **ophthalmology**
  - Developed novel design features of **RCM Repositioning** & a **quick-change** mechanism
- Accelerate design iterations with extended modeling capability in the digital realm prior to physical implementation
- Shorten development lead time facilitated by rapid prototyping of digital concept
- Enable systematic design via computational simulation and analysis
- Coordinate research effort about team members of different background

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Thank you

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