

Intra-operative MRI-guided Robot for Bilateral Stereotactic Neurosurgery

術中磁力共振圖像導航的立體定向雙側腦神經手術機器人

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Stereotactic Neurosurgery

立體定向神經手術



- **Deep Brain Stimulation (DBS) 腦深層刺激手術:**
 - Implantation of electrodes 電極植入
 - Electrical impulses on brain nucleus 電訊號刺激腦深層特定區域
 - Treatment to Parkinson's disease (PD), essential tremor, major depression, etc. 可治療帕金森症，原發性震顫，重度抑鬱等
- **Surgical challenges 手術挑戰:**
 - “Brain shift” 腦移位
 - Time-consuming: >6 hours 手術耗時大於6小時
 - Awake patient 清醒的病人

Patient still awake to surgeon's question!!!
病人需要清醒著回答醫生的問題!!!

*Courtesy: [1] Weaver FM et al. Neurology, 2012.
[2] Violinist Still Making Music After DBS Surgery - Mayo Clinic
<https://www.youtube.com/watch?v=T3QQOQAILZw>*



Why MRI-Guided Interventions? 為何使用磁力共振圖像導航手術？



• Strengths 優勢:

- No radiation 無輻射
- High-contrast images of soft tissue
高對比度的軟組織圖像
- Ablation monitoring 監控消融過程
- Fast imaging 快速成像

Why we need robot?
為什麼我們需要機器人?

**MR images of a
beating heart at
33 ms resolution**
磁力共振圖像:
跳動中的心臟
(時間分辨率約
33毫秒)

**Post-ablation
edema (MRI)**
磁力共振圖
像可分辨消
融后的水腫
組織

**VISIUS® Intra-operative
MRI system**
VISIUS® 術中磁力共振
掃描器

**Real-time MR
thermometry
(Visualase®)**
實時磁力共振溫度
成像 (Visualase®)

Courtesy: Ying Meng, MD



Current Apparatus 現有裝置



- Manual operation - Clearpoint®
手動裝置 - Clearpoint®系統

- General anesthesia 病人全身麻醉
- Long and flexible screwdrivers 可彎曲的長型螺絲批
- Manual adjustment of aiming 手動調整瞄準裝置
- Patient moved in-and-out the bore 病人需頻繁移入/移出磁力共振器孔道

Courtesy: [1] S. Chabardes, et al, *Acta Neurochir. (Wien)*, 2015. [2] Ostrem J L, et al., *Journal of neurosurgery*, 2016.



- MRI-guided neurosurgical robotic systems:
磁力共振圖像導航的神經手術機器人系統:

*NeuroArm/SYMBIS®
(Deerfield Imaging, USA)*

*NeuroBlate®
(Monteris Medical,
Inc, USA)*

*MRI-compatible
neurosurgical robot
(Worcester Polytechnic
Institute, USA)*

*MINIR-II robot
(Georgia Institute of
Technology, USA)*

- Unmet technical challenges:
未解決的技術挑戰:

- MR Safe actuation (No EM interference) 磁共振安全的驅動裝置（零電磁干擾）
- Fixed to patient's skull and operated within the MRI head coil 與病人頭骨錨定并可在MRI頭線圈的狹小空間中運作
- Independent bilateral manipulation for faster workflow 對雙側大腦可獨立同時進行手術以加快進程

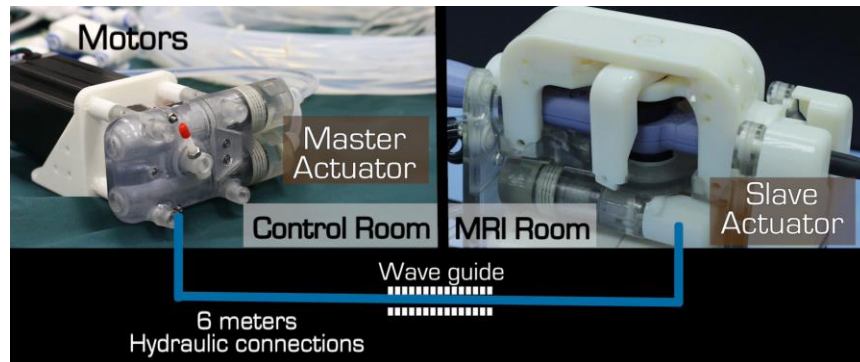
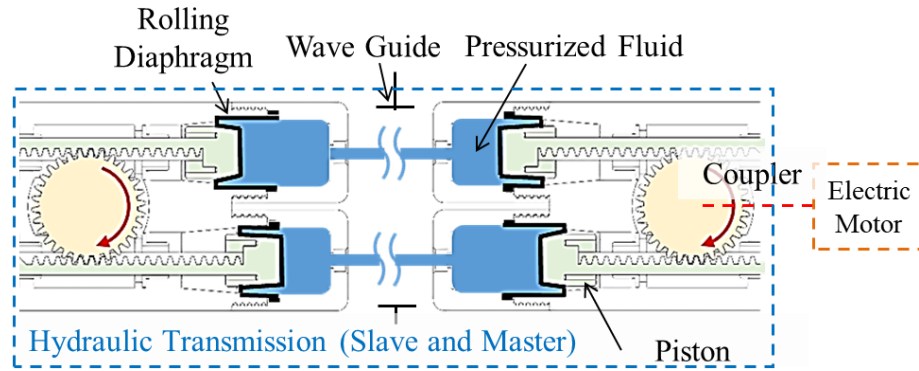


Hydraulic Actuation 液壓驅動裝置

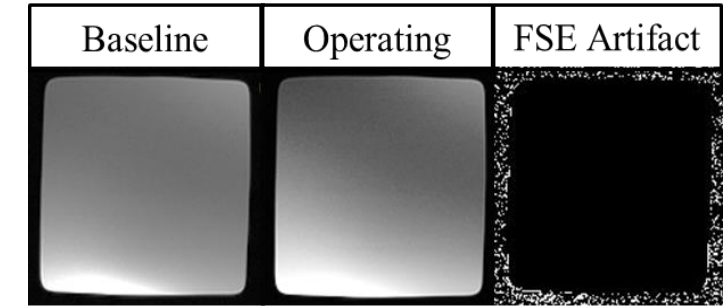


• Low-friction Hydraulic Transmission 低摩擦的液壓傳動

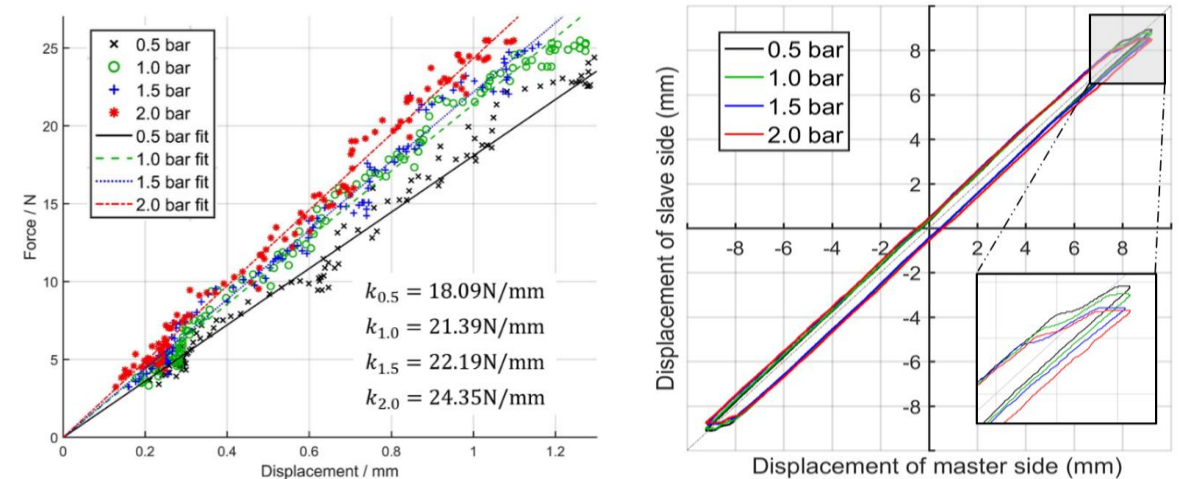
- Zero EM Interference; Intrinsically MR safe 零電磁干擾；本質上為磁共振安全
- 10-meter long transmission via waveguide 經波導孔道的10米遠距離傳動
- Quick response; Small backlash 傳動響應快速；虛位極小



No observable image artifact when in full motion
機器人運動對MRI成像質量無觀測到的影響



Transmission stiffness 傳動剛度 $\geq 18 \text{ N/mm}$



Ref: [1] Fluid-powered transmission for MRI-guided interventions. *US Prov. Patent: US62/640,302.* [2] MR-safe Robot Platform for MRI-guided Intra-cardiac Catheterization. *TMech*, 2018.

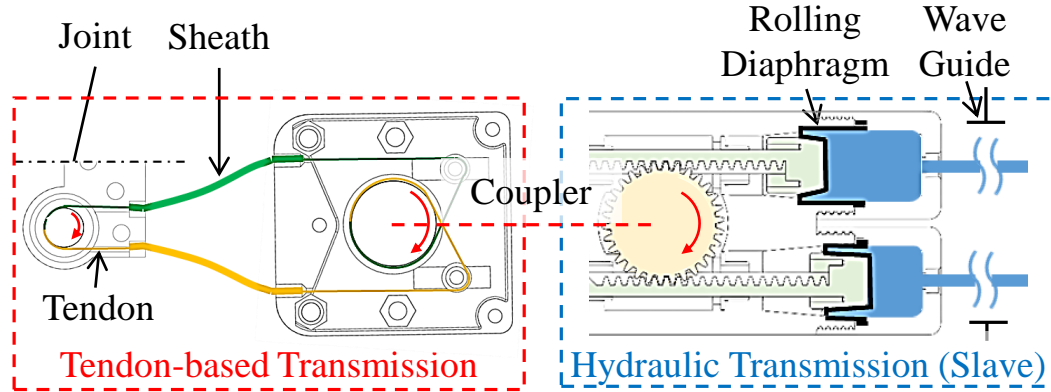


Bilateral Manipulator 雙臂機械手

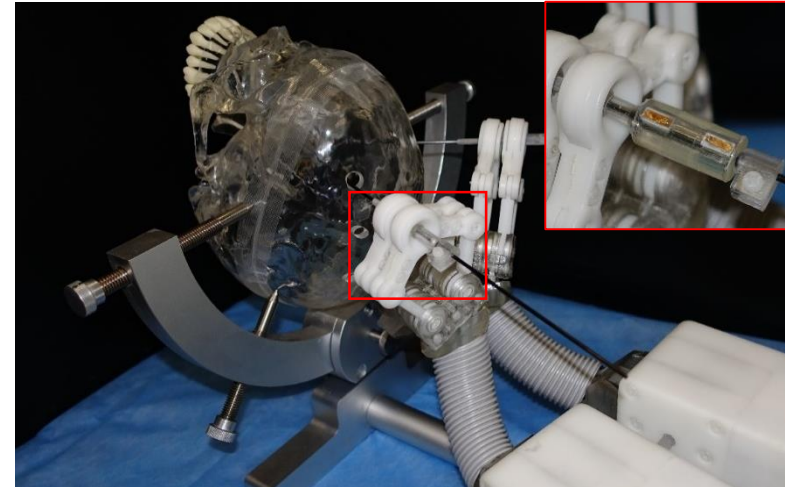
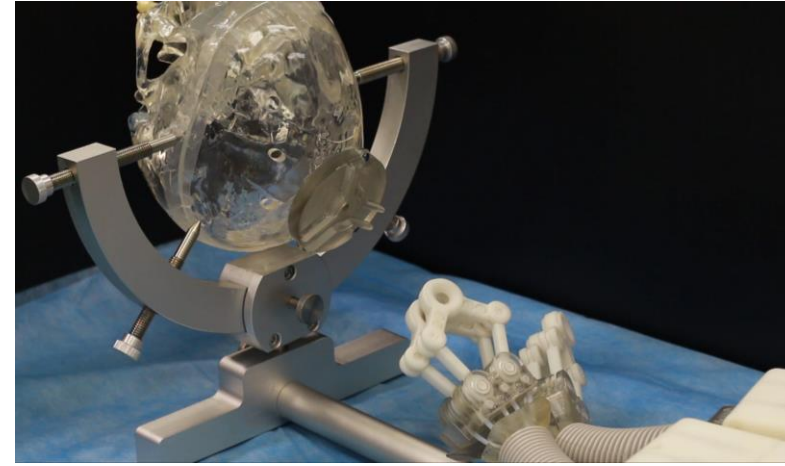
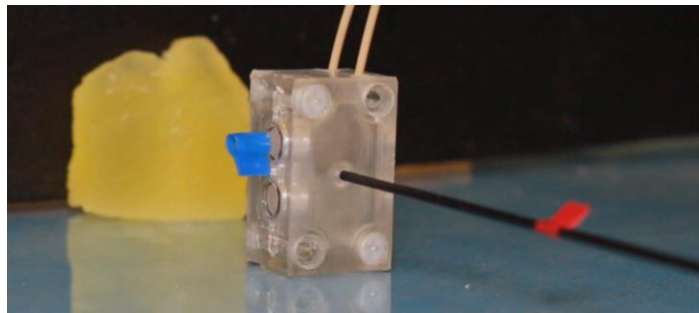


• Compact dual-arm 緊湊簡潔的雙臂設計

- Five-bar planar parallel mechanism 五連桿平面並聯機構
- Four DoFs for each manipulator 單臂具有四個自由度
- Bowden cables coupled with hydraulic actuators
Bowden線組與液壓驅動聯結



Linear actuator for
needle insertion
可用於穿刺的直線
驅動裝置



Robot mounting is
simple and reliable
簡單可靠的機器
人錨定機制

Robot (slave) for
bilateral DBS
可執行雙側腦深
層刺激手術的機
器人（從動部分）
(accuracy 精度:
 $1.73 \pm 0.75 \text{mm}$)

Ref: Robotic stereotactic system for MRI-guided neurosurgery, US Prov. Patent: US62/623,280



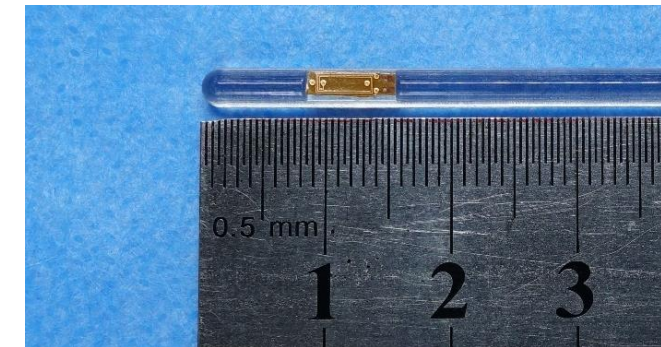
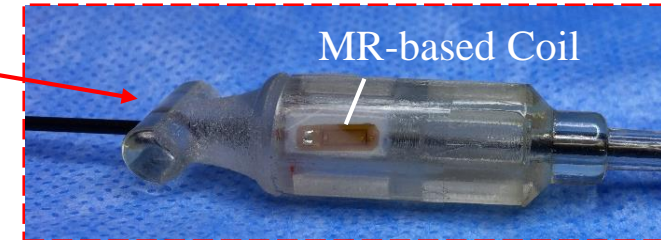
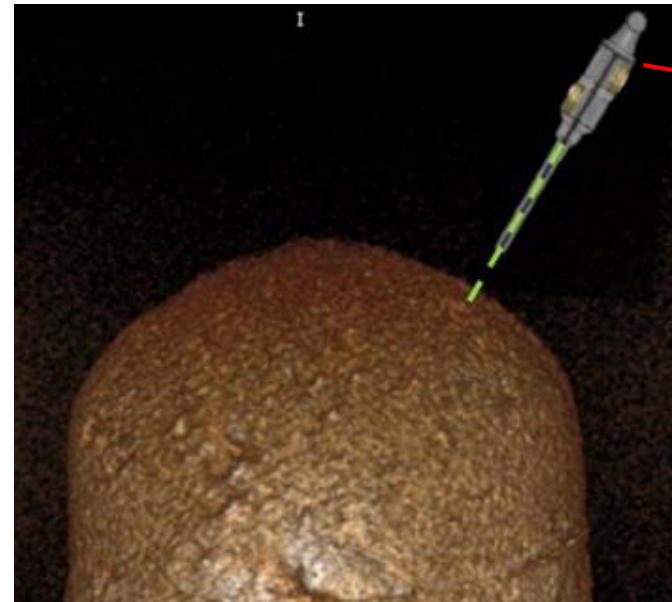
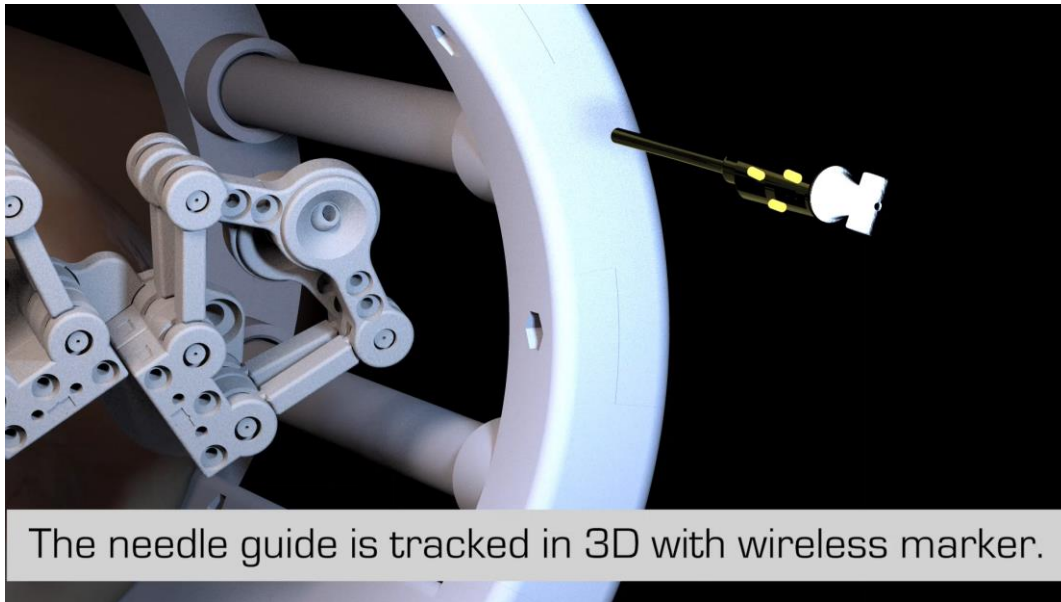
MR-based Tracking Coil

基於磁力共振的追蹤線圈



- **Wireless tracking coil units**
無線追蹤線圈元件

- Tiny coils ($1.5 \times 5 \times 0.2 \text{mm}^3$) 微小線圈($1.5 \times 5 \times 0.2 \text{mm}^3$)
- Resonate with MR Larmor frequency 可與磁力共振器的Larmor頻率共振 ($1.5\text{T} \rightarrow 63.87\text{MHz}$, $3\text{T} \rightarrow 127.7\text{MHz}$)
- Pick up MR gradient signals along 3 principal directions 可在三個主方向上拾取MR梯度信號



Ref: MRI Tracking Device Design, Fabrication, and Methods of use for MRI-guided Robotic System, **US Prov. Patent: US62/640,798**

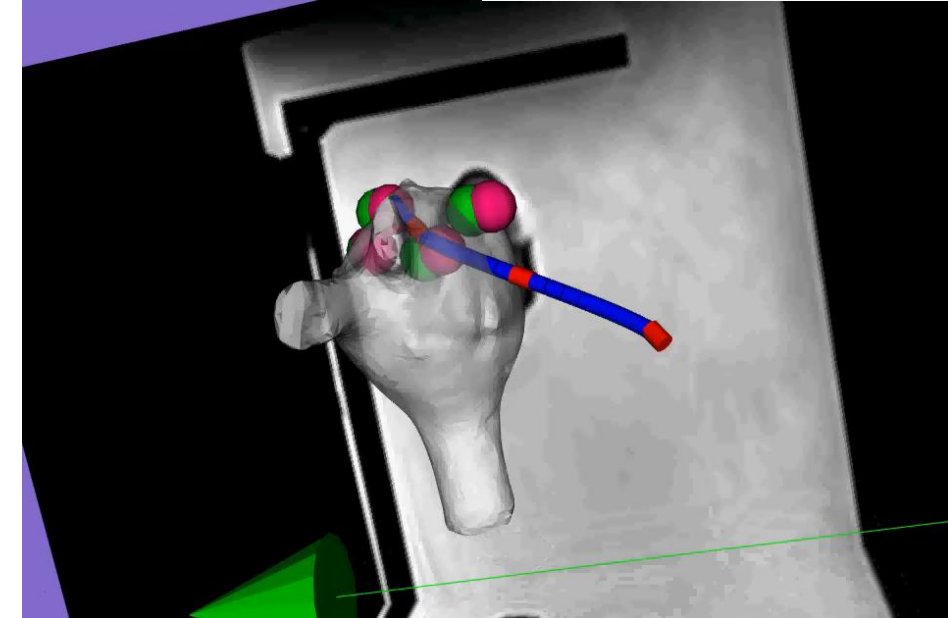
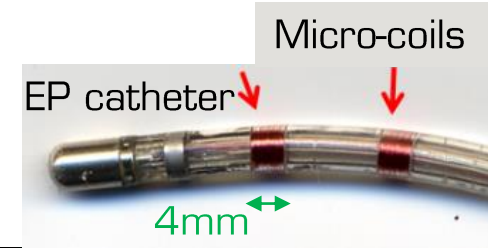
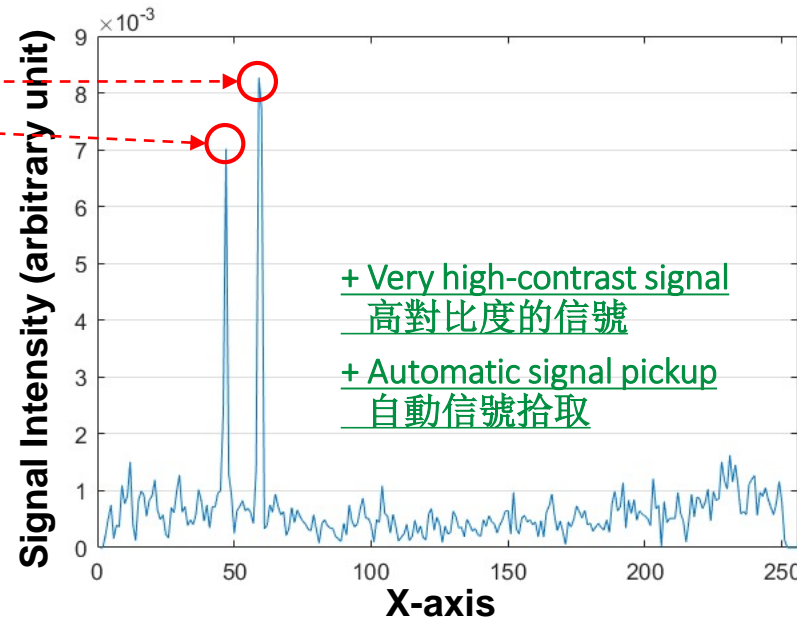
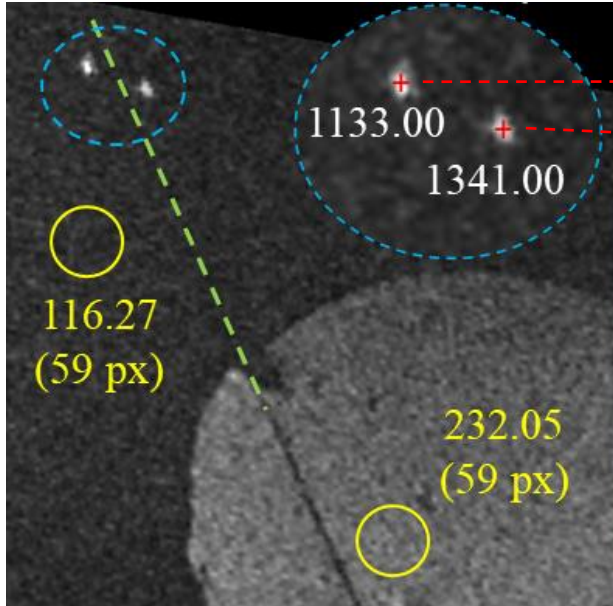


MR-based Tracking Coil 基於磁力共振的追蹤線圈



- Positional feedback in image coordinates 在圖像坐標中的定位反饋
 - ✓ Spatial res: $0.6 \times 0.6 \times 0.6$ mm 空間分辨率: $0.6 \times 0.6 \times 0.6$ mm
 - ✓ Temporal res. 40Hz 時間分辨率: 40Hz

MRI navigation with wireless tracking coils 基於無線追蹤線圈的磁力共振圖像導航



Intra-op MRI Pre-clinical Trial

術中磁力共振圖像導航的臨床前測試



• Workflow Validation 流程驗證

- Targeting error <math><1.8\text{mm}</math> 瞄準誤差<math><1.8\text{mm}</math>
- No rigid mounting on MRI table 無需與MRI床剛性固定
- Simple installation 安裝簡單

瞄準精度測試結果

TABLE I NEEDLE TARGETING ACCURACY TEST

Accuracy (mm)	Needle tip		Normal to the needle	
	Left	Right	Left	Right
	1.73 ± 0.75	1.21 ± 0.63	1.61 ± 0.72	1.15 ± 0.62

**Proposed Robot-assisted DBS:
conceptual system setup**
機器人輔助的腦深層刺激手術:
系統佈置概念圖

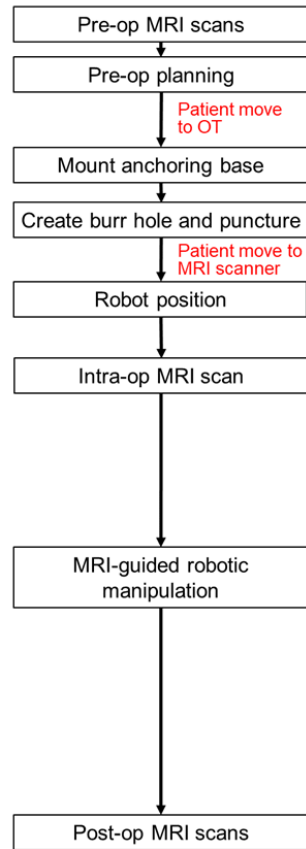


Intra-op MRI Pre-clinical Trial

術中磁力共振圖像導航的臨床前測試



MRI-guide stereotaxy with robot

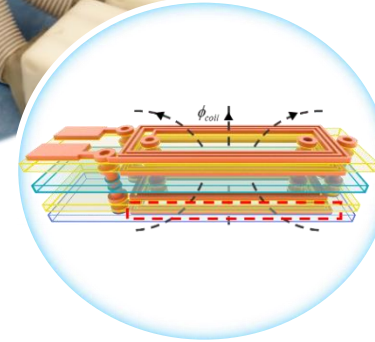
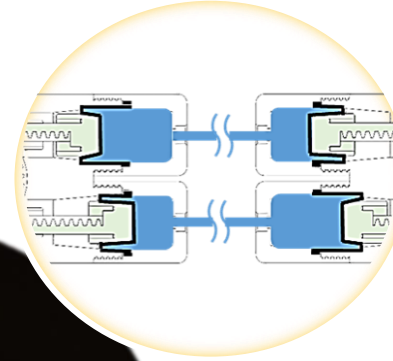
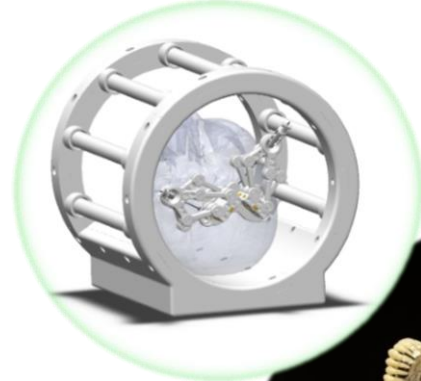


Ref: Z. Guo, et al. *Techniques for Stereotactic Neurosurgery: Beyond the "Frame", Towards the Intraoperative MRI-guided and Robot-assisted Approaches*[J]. *World Neurosurgery*, 2018.



Compact Robot Design 簡潔的機器人設計

- Bilateral needle manipulation
雙側穿刺瞄準操作
- Single anchorage
單次錨定
- Fit with standard head coil
適用於標準頭線圈



Hydraulic Actuation 液壓驅動裝置

- MR Safe
磁力共振安全
- High-fidelity teleoperation
高保真度的遠程操縱
- No EM interference
無電磁干擾

Small Wireless Tracking Coil 微型無線追蹤微線圈

- Real-time 3D localization
實時三維定位
- Tracked in image coordinate
于圖像坐標系內追蹤
- No manual calibration/registration
無需手動標定或配准

Patents 專利:

[1] Robotic stereotactic system for MRI-guided neurosurgery,

US Prov. Patent: US62/623,280

[2] Fluid-powered transmission for MRI-guided interventions,

US Prov. Patent: US62/640,3029

[3] MRI Tracking Device Design, Fabrication, and Methods of use for MRI-guided Robotic System, **US Prov. Patent:**

US62/640,78; **PCT Patent:** PCT/CN2017/089701



- The project won the Best Conference Paper Award in ICRA'18

該項目論文在2018國際機器人與自動化會議獲頒「最佳會議論文獎」

- World's top and largest robotics conference
最大規模的機器人國際頂級會議
- More than 3,000 participants from academia and industry
每年有超過3,000名來自學術界和工業界的與會者
- ICRA paper: 6-8 pages, usually accompanied with videos to demonstrate the innovative robotic systems
ICRA論文：6-8頁論文和演示視頻以綜合展示機器人系統創新點
- Journal papers accepted by IEEE Robotics and Automation Letters (RA-L) can also be presented in ICRA and compete for the Best Conference Paper
發表在IEEE機器人與自動化通訊 (RA-L) 上的期刊論文亦可在ICRA會議中做演示報告并競逐最佳會議論文獎



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- 2,539 papers reviewed in ICRA'18, from 61 countries
今年大會共審閱了來自全球61個國家的2,539篇論文
- Best Paper Award: 35 finalists from 9 fields, including Robot Vision, Cognitive Robotics, Robot Manipulation and Unmanned Aerial Vehicles, etc.
共35篇論文入圍最佳論文獎，覆蓋九大研究領域，包含機器人視覺、機器人認知、機器人操作和無人機等。
- Other shortlisted universities and companies include MIT, Harvard, Stanford and DeepMind.
其他入圍的大學及企業包括麻省理工學院、哈佛大學，史丹福大學和DeepMind等。



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