ICWPT
August 7–9.2026
CHINA · URUMQI
中国电工技术学会
China Electrotechnical Society

International Conference on Wireless Power Transfer & New Power System

Wireless-Powered Capsule Robots for Gastrointestinal Diagnosis and Targeted Therapy

Presented by

KEYNOTE SPEAKER

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University of Technology Sydney

UTS

KEYNOTE SPEAKER

Dr. Heng ZHANG

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www.zhanghengee.github.io

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The Chinese University of Hong Kong

I. Introduction

Gastrointestinal illnesses and endoscopy

II. Platform Shift in Gastrointestinal Screening

Capsule endoscopy and AI medical image diagnosis

III. Gap in Knowledge and Capability

Omnidirectional magnetic field generation, Efficiency optimization using PFM scheme, Planar transmitter design, Wearable and flexible design and Light-weight MHz transmitter and soft-switching

IV. Translation Pathway to Clinical Applications

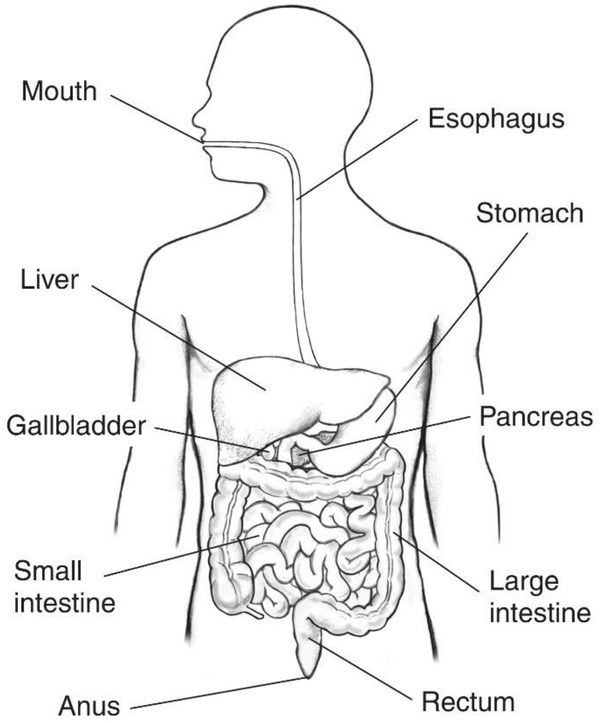
A proof-of-principle prototype and proof-of-concept operation,

in Vivo and vivo experiments, …..

V. Conclusion and Future Outlook

I. Gastrointestinal Illnesses

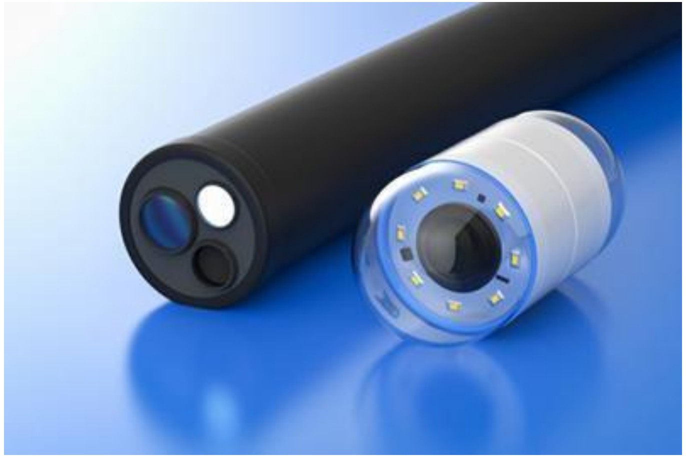
- GI illnesses are disorders that affect the digestive system.
- Various organs involved in the digestive process (mouth, esophagus, stomach, intestines, etc.).
- There are some common types of GI disorder such as
  - Esophageal inflammation,
  - Gastroesophageal reflux disease,
  - Esophageal, stomach, or intestinal cancers, etc
- Effects on health
  - Discomfort
  - Stomach/Abdominal/Esophageal pain,
  - Difficulty swallowing
  - Frequent vomiting
  - Gastrointestinal bleeding, etc



Source: https://www.niddk.nih.gov/news/media-library/18162

I. Endoscopy (1)

- Effective medical procedure for examining GI tract conditions
- Traditional Endoscopy
  - A thin tube down the throat and into the upper digestive system (gastroscopy).
  - Inspects upper esophagus, stomach, and lower colon (colonoscopy).
  - Invasive procedure using a flexible tube.
- Wireless Capsule Endoscopy (WCE)
  - Non-invasive procedure.
  - Patient swallows a small, pill-sized camera.
  - Visualizes the entire GI tract, including the small intestine.



Source: https://www.kevinmarksmd.com/blog/1222495-capsule-endoscopy-vs-traditional-endoscopy-benefits-and-differences/

II. Capsule Endoscopy (1)

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- Limitations of Traditional Endoscopy
  - Limited to specific areas: esophagus, stomach, colon.
  - Requires sedation and recovery time.
- Advantages of WCE
  - Extends examination capabilities beyond traditional endoscopy.
  - Wireless data transmission to an external recorder.
  - Increased patient comfort and ease of use.

- Challenges of Wireless Capsule Endoscopy (WCE)
  - Limited by small internal battery.
- Consequences:
  - Restricts duration of video recordings.
  - Affects video quality.

Source: https://capsovision.com/capsocam-plus/

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II. Capsule Endoscopy (2)

				
Capsule	PillCam @ SB 3 Civen Imaging	EndoCapsule @ Olympus America	Mirocam @ IntroMedic Company	OMOM @ Jinshan Science and Technology
Therapeutic function	No	No	No	No
Battery life	8 hours or longer	8 hours or longer	11 hours or longer	6-8 hours or longer
Resolution	340x340	512x512	320x320	640x480
Frames per second	2 fps or 2-6 fps	2 fps	3 fps	2 fps
Field of view	156°	145°	170°	140°
Size	11.4X26.2 mm	11X26 mm	10.8X24.5mm	13X27.9 mm

II. AI medical image diagnosis

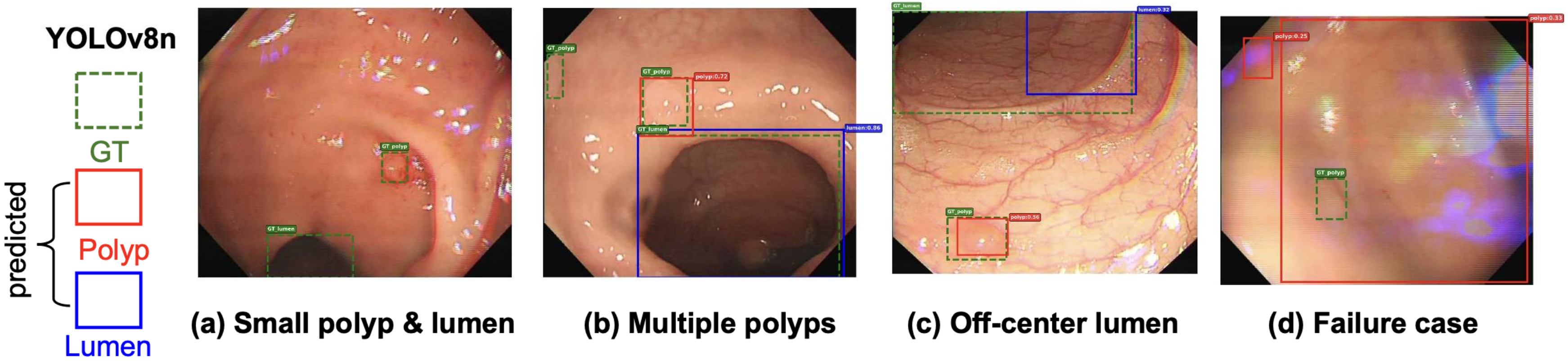

Fig. 3. Detection comparison across challenging scenarios. Green dashed: ground truth, red: polyp predictions, blue: lumen predictions.

II. Platform Shift in Gastrointestinal Screening

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Rationale

GI diseases, remain a major burden in many countries. Current Wireless Capsule Endoscopy (WCE) is limited by short battery life, episodic imaging, and manual, error-prone review. No existing system integrates continuous power, multi-modal sensing, and real-time AI.

Overall Aims

Engineer a next-generation capsule with wireless power transfer, long-endurance imaging, external position control and additional therapeutic functionalities.
Develop AI architectures capable of real-time lesion detection and triage. Co-design clinical workflows with Australian gastroenterologists and screening programs. Establish a preclinical → clinical feasibility development pathway.

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III. Gap in Knowledge and Capability

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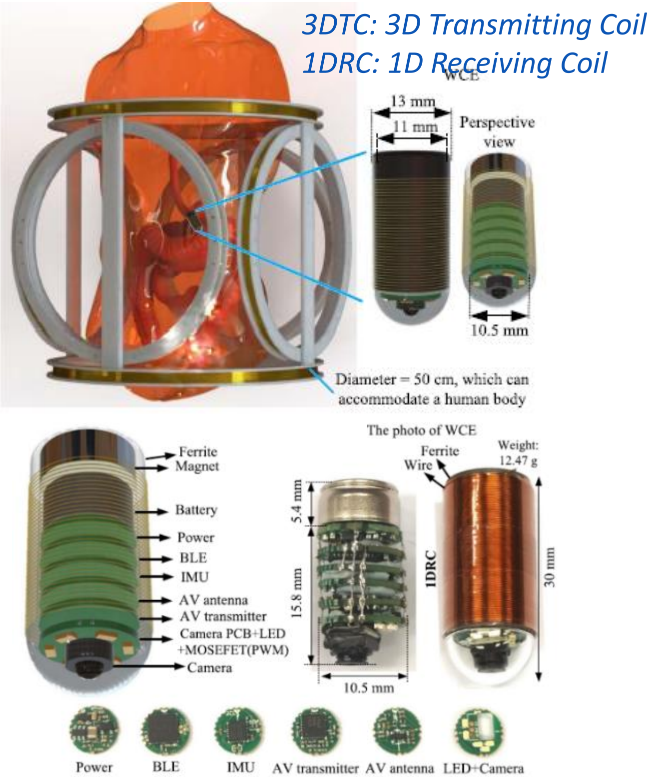
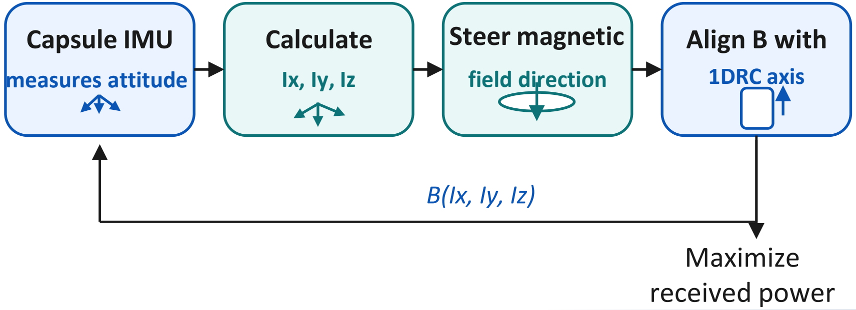
3. Work 1 | Attitude-Adaptive Omnidirectional WPT

- Helmholtz-like 3DTC can generate magnetic field in any direction
- Compact capsule integrates 1DRC + IMU
- Full-attitude / omnidirectional charging

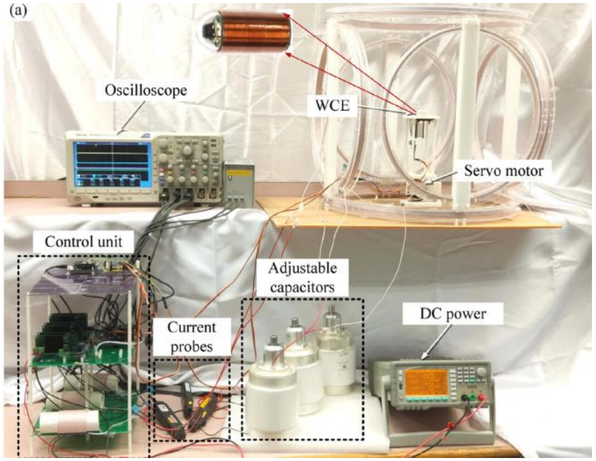
3DTC: 3D Transmitting Coil
1DRC: 1D Receiving Coil

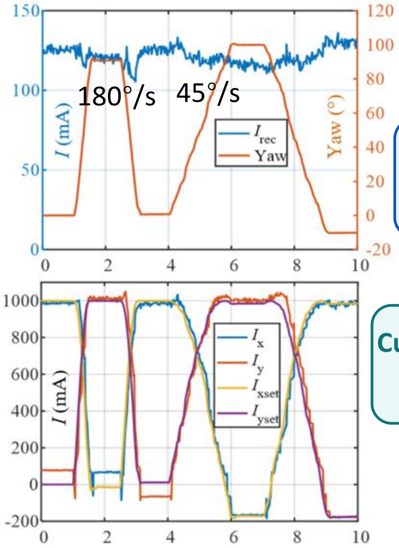


Closed-Loop Field Steering Control



Results





Received power:
Max 1.82 W

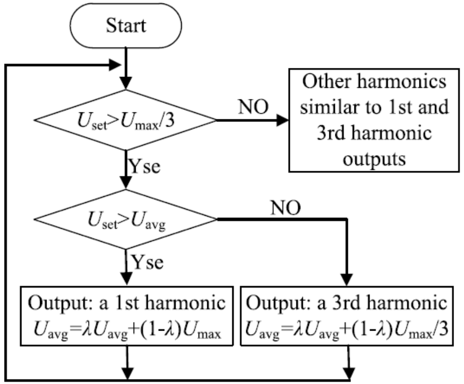
Current response:
~30 ms

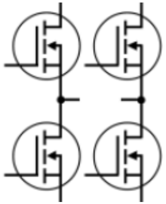
3. Work 2 | PFM-Based Efficiency Optimization

Same 3DTC + compact 1DRC platform

- 3DTC generates an omnidirectional magnetic field
- PFM (Pulse frequency modulation) regulates transmitter current by frequency patterns
- Goal: reduce loss without changing the capsule hardware

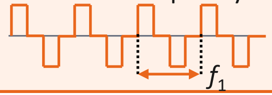
Proposed PFM algorithm: 2.06× faster computation with continuous current control (Compared with the conventional PFM)





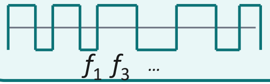
Control Optimization: PSC -> PFM

Conventional PSC
constant frequency



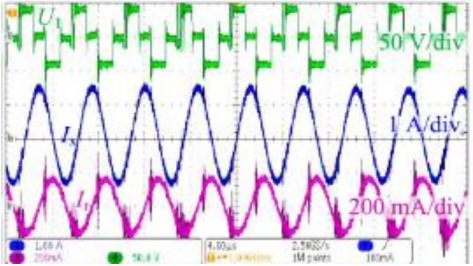
replace

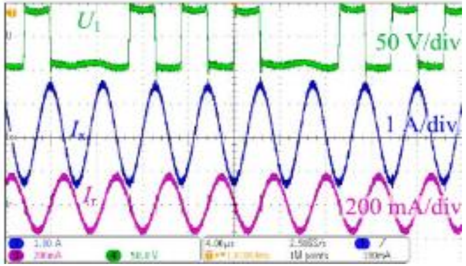
Proposed PFM
subharmonic switching



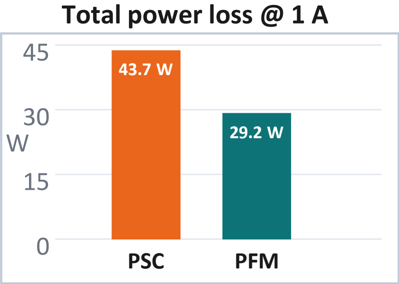
fewer switches

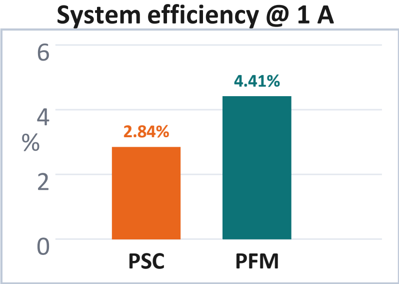
PFM lowers switching-related loss while maintaining continuous current control





Experimental Efficiency Improvement



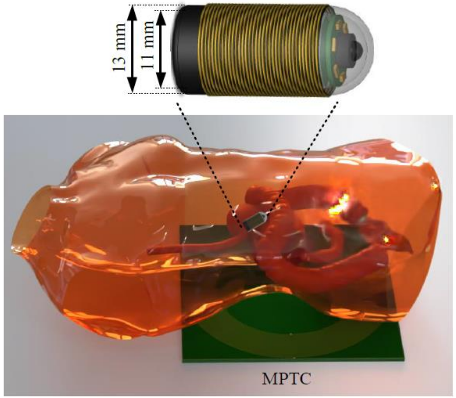


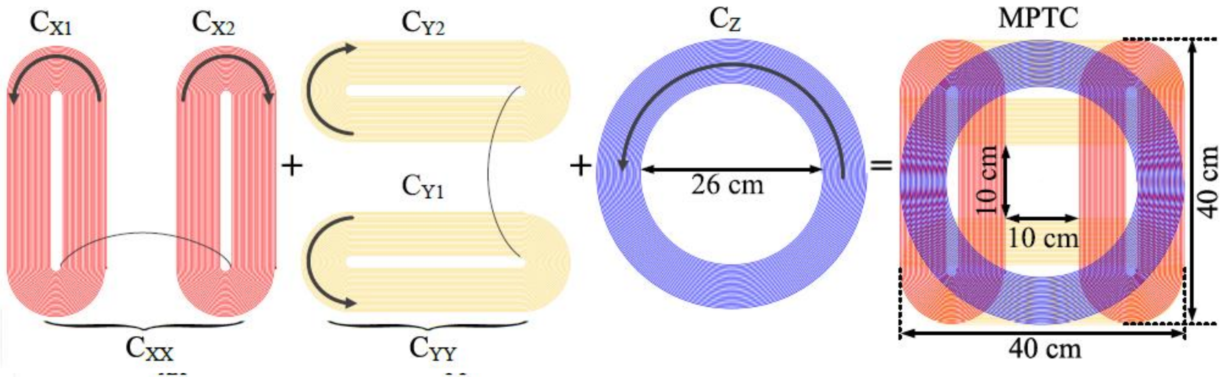
loss **-33.3%**
@ max power

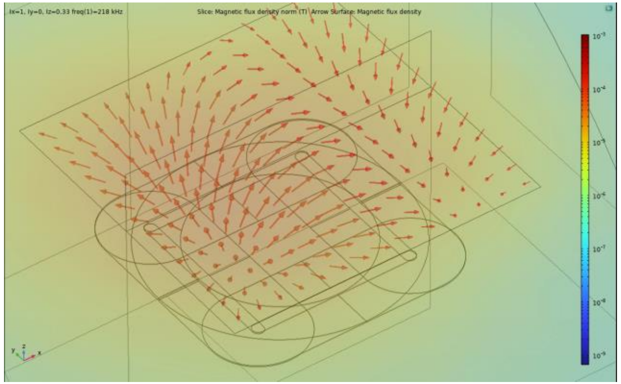
eff. **1.55x**

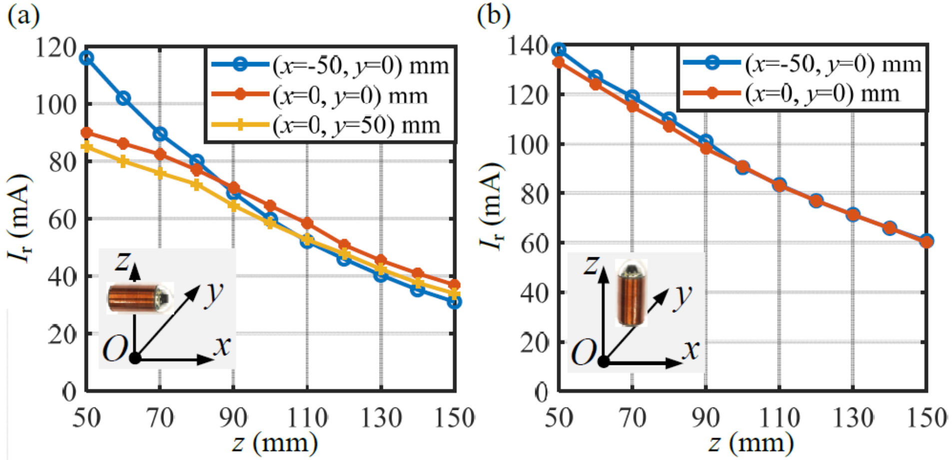
3. Work 3 | Planar 3D transmitter

Rigid 3D transmitter → Planar 3D transmitter









Received power:

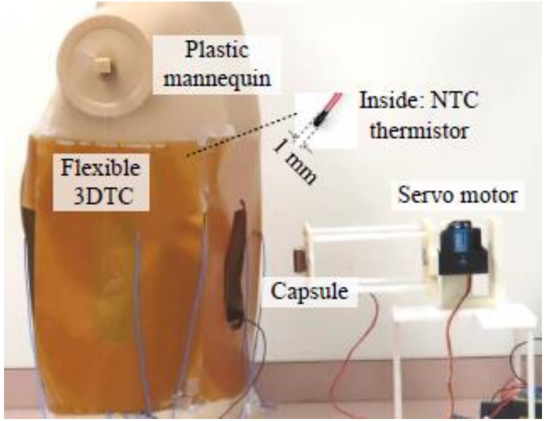
Max 1.9 W (8.7%)

Test Video

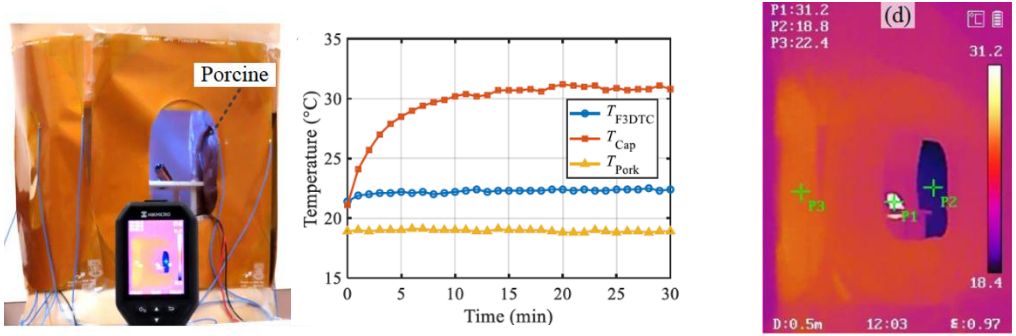

Here's the finished product on display. You can see that no matter how the
battery-less capsule rotates, it consistently receive energy

3. Work 4 | Wearable 3DTC with 1DRC

Rigid 3D transmitter → flexible, body-conformal omnidirectional WPT system



	k_{xr}	k_{yr}	k_{zr}
Work1	0.0084	0.0084	0.0106
This paper	0.0338	0.0760	0.0654



Key advantages over rigid 3DTC

1. **Wearable and patient-friendly**
   Flexible FPCB coils wrap around the body instead of a bulky rigid frame.
2. **Improved coupling and efficiency**
   Closer transmitter–receiver spacing increases mutual coupling by ~4–9×.
3. **Robust under bending and motion**
   LCCL current-source behavior keeps coil current stable under deformation.
4. **Built-in thermal and charging safety**
   NTC + capsule sensors monitor temperature and stop charging when needed.

Peak efficiency
16.09%

Maximum received power
1.69 W

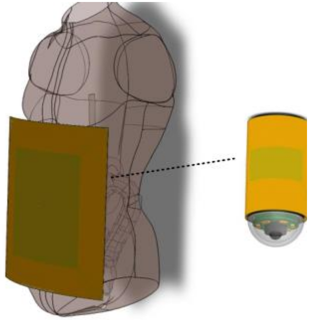
Coupling coefficient
4–9× higher

Transmitter mass
123.2 g

3. Work 5 | Flexible 1DTC with Omnidirectional 3DRC

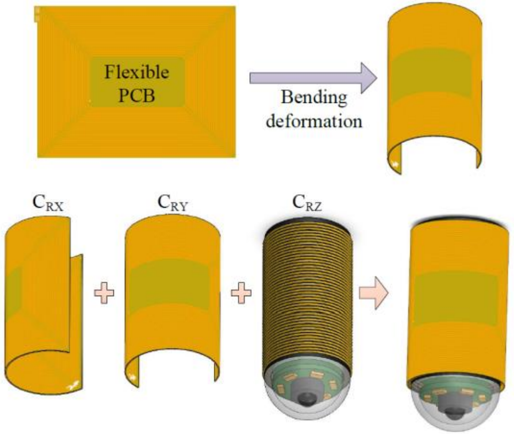
Flexible 1D transmitter + ultra-thin 3D receiver

Flexible 1DTC

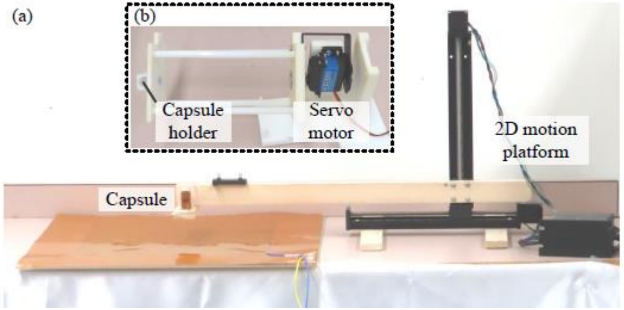


body-conformal transmitter

Omnidirectional 3DRC



0.2-mm FPCB coils on capsule surface



Single-loop voltage regulation

Measure U_R → BLE feedback → PID adjusts I_T → Stable 3.3 V

Directly stabilizes the rectifier output as capsule position and orientation change.

Key advantages of the new architecture

1. **Wearable and body-conformal**
   40 × 40 cm flexible PCB patch can be placed on the abdomen or integrated into clothing.
2. **Omnidirectional reception**
   3DRC receives power without orientation blind spots during pitch / roll rotation.
3. **Stable load voltage control**
   Direct single-loop feedback regulates the rectifier output without extra DC–DC/LDO.
4. **Robust under motion and bending**
   LCCL topology maintains transmitter current under flexible-coil deformation.

Voltage MAE
20.2 mV <1%

Single-loop response
~40 ms

Received power
1.09 W

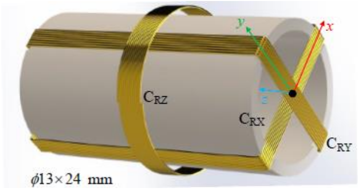
Efficiency
5.1%

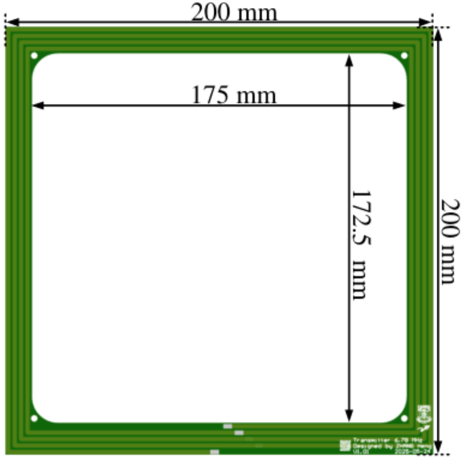
3. Work 6 | MHz Soft-Switching WPT for Capsule Robots

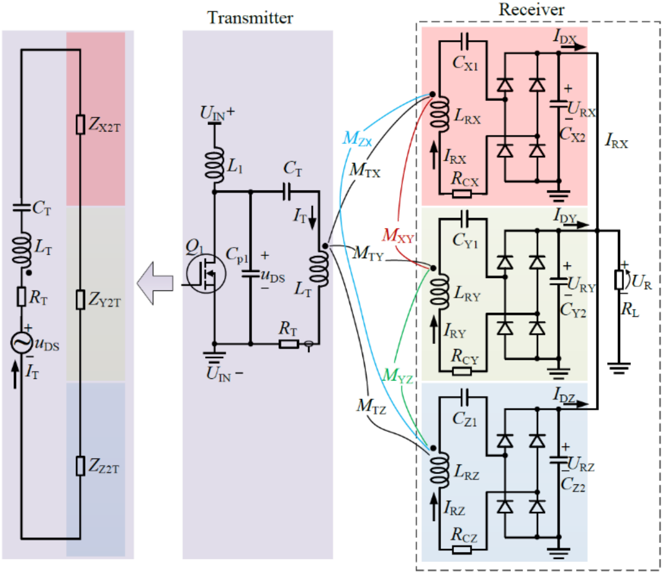
6.78 MHz

1D Transmitting Coil (1DTC) + Type II 3D Receiving Coil (3DRC) at 6.78 MHz

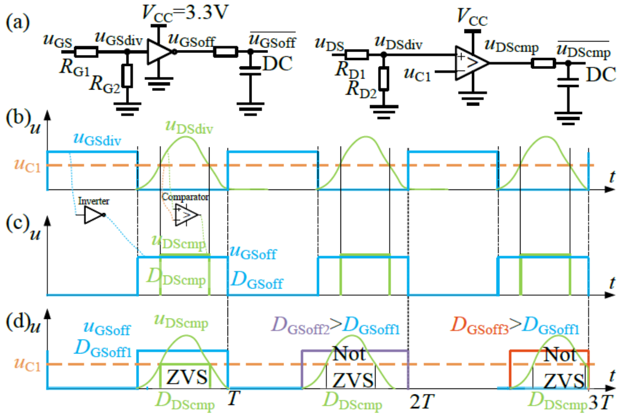
- Receiver miniaturization at MHz frequency
- Type II 3DRC avoids orientation blind spots,
- Reduced inter-coil interference improves reception







Compact MHz receiver architecture



Convert PWM to DC $\overline{u_{GSoff}} = V_{CC}D_{GSoff}$ $\overline{u_{DSoff}} = V_{CC}D_{DScmp}$

Received power	1.681 W
Peak efficiency	23%
Stable output	3.0 V
Translation MAE	14.9 mV

ZVS benefit: GaN temperature rise reduced from 5.0°C to 0.9°C

Average received power along GI trajectory: 240 mW

Test Video

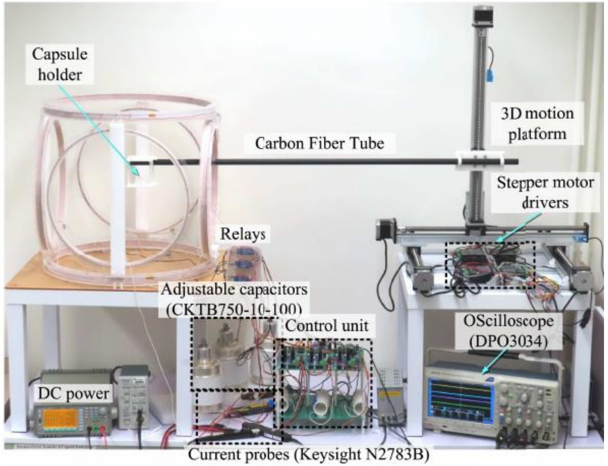
Megahertz Soft-Switching Wireless Power Transfer for Capsule Robots Under Dynamic Position and Orientation Variations

Heng ZHANG, Paul D. Mitcheson, Chi-Kwan LEE

Video 2

3. Work 7 | Integrated 6DoF Localization + WPT

Single apparatus for two functions

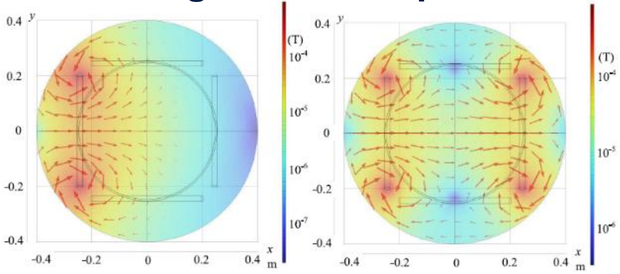


DC gradient — **AC field**

Positioning — Charging

1. Same 3DTC alternates between DC and AC excitation
2. Hall sensor + IMU are integrated in the capsule

Dual magnetic-field operation

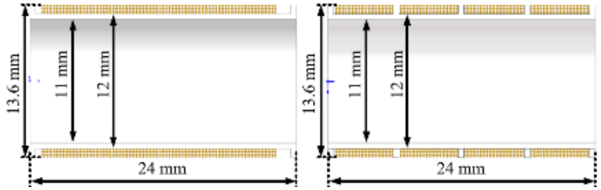


DC field gradient for 3D position

AC field for wireless charging

Hall B-field — **IMU attitude** — **LM fusion 6DoF pose**

Segmented receiver coil

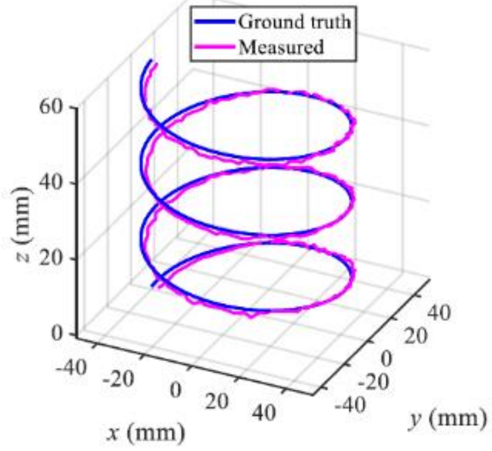


1 segment vs. 4 segments

Parasitic capacitance is greatly reduced

50% more power

Tracking and charging results



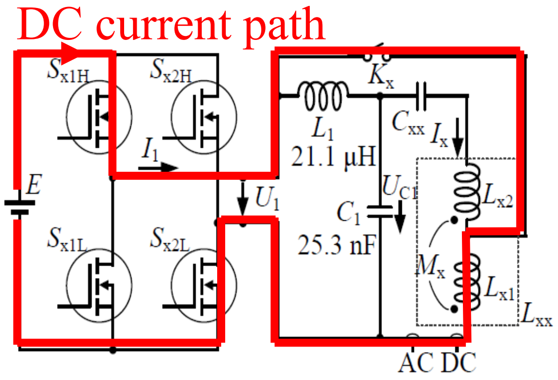
Position MAE < 2.07 mm point tracking

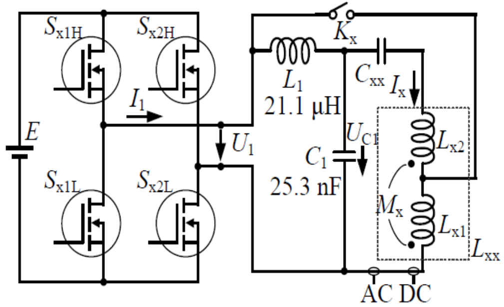
Attitude MAE < 3.80 deg roll/pitch/yaw

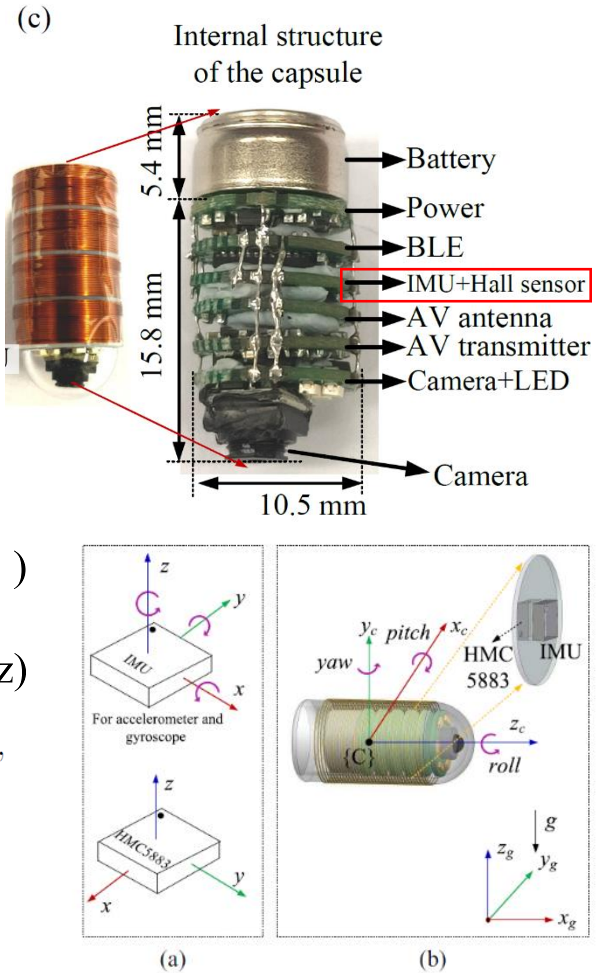
Received power 376 mW average WPT

Charging rate 2C estimated

Technology







DC current control (x as an example)

K_x: close

S_{x2L}: conduct

S_{x1H}: PWM (20 kHz)

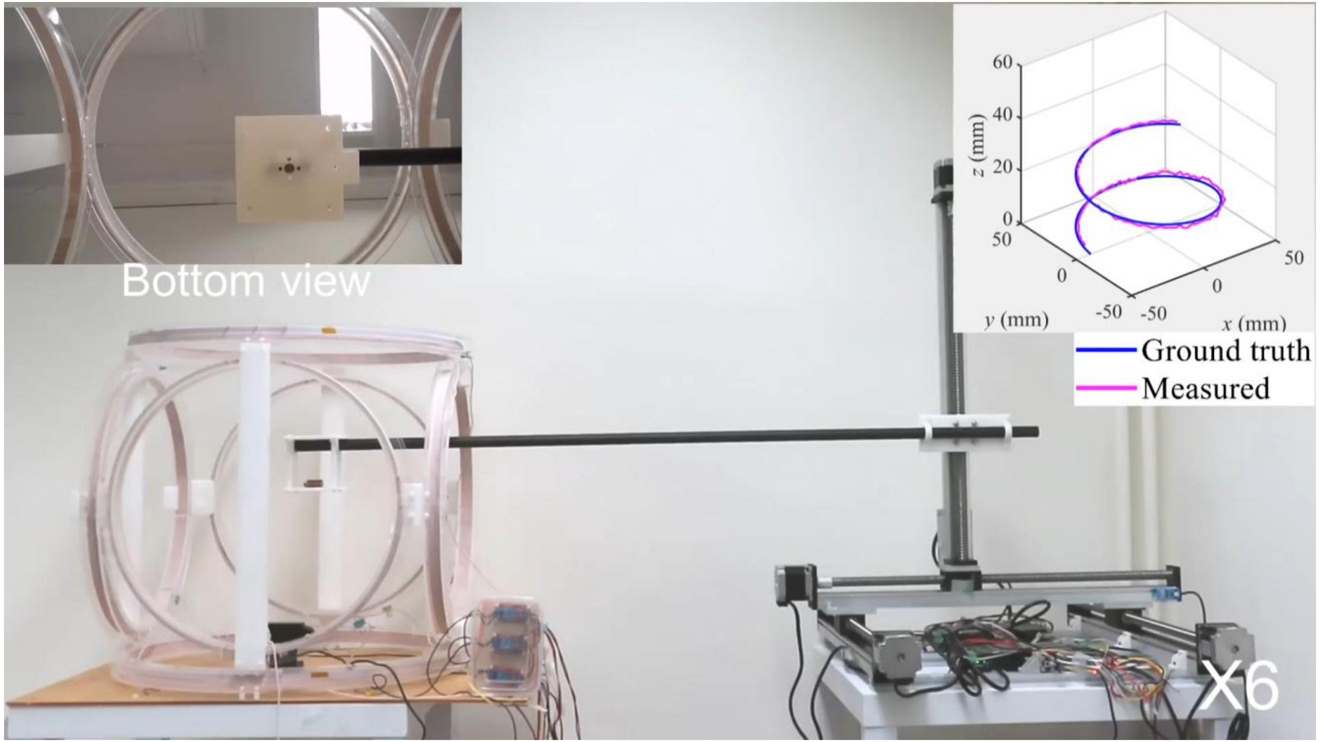
$$\Delta U_1 = K_{xp} e_x(t) + K_{xi} \int_0^t e_x(t)dt + K_{xd} \frac{de_x(t)}{dt},$$

AC current control (x as an example)

K_x: open

PSC control the full bridge (218 kHz)

$$\Delta U_1 = K_{xp} e_x(t) + K_{xi} \int_0^t e_x(t)dt + K_{xd} \frac{de_x(t)}{dt},$$


Bottom view
60
40
20
0
z (mm)
50
0
-50
y (mm)
-50
0
50
x (mm)
Ground truth
Measured
X6

[1] Zhang H, Li Z, Lee C K. “Transmitter adaptation and wireless power control for capsule endoscopy”, *IEEE Transactions on Power Electronics*, 2024, 39(4): 4884-4894.

[2] Zhang H, Liu W, Li Z, , Lee C K*. Pulse frequency modulation of 3D wireless power transfer for capsule endoscopy[J]. IEEE Transactions on Industrial Electronics, 2024, 72(1): 308-317.

[3] Zhang H, Li Z, Lee C K*. Regulating 3D Magnetic Flux Density for Stable Wireless Power Transfer in a Compact Planar Charger for Capsule Endoscopy[J]. IEEE Transactions on Biomedical Circuits and Systems, 2025.

[4] Zhang H, Lee C K*. Wearable 3D Transmitter for Omnidirectional Wireless Energy Delivery for Microrobot[J]. IEEE Transactions on Biomedical Circuits and Systems, 2026.

[5] Zhang H…, Lee C K*. Stable Wireless Power Transfer Using a Novel Omnidirectional Receiver and a Flexible Transmitter for Capsule Robots[J]. IEEE Trans on Biomedical Engg, 2026.

[6] Zhang H, Mitcheson P D, Lee C K. Megahertz Soft-Switching Wireless Power Transfer for Capsule Robots Under Dynamic Position and Orientation Variations[J]. IEEE JESTPE, 2026.

[7] Zhang H, Lee C K, Li Z. Six degrees of freedom tracking and wireless charging for capsule endoscopy[J]. IEEE Transactions on Industrial Electronics, 2024, 72(4): 3643-3652.

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IV Translation Pathway to Clinical Applications

A Multifunctional Capsule Robotic (MCR) System

KEYNOTE SPEAKER

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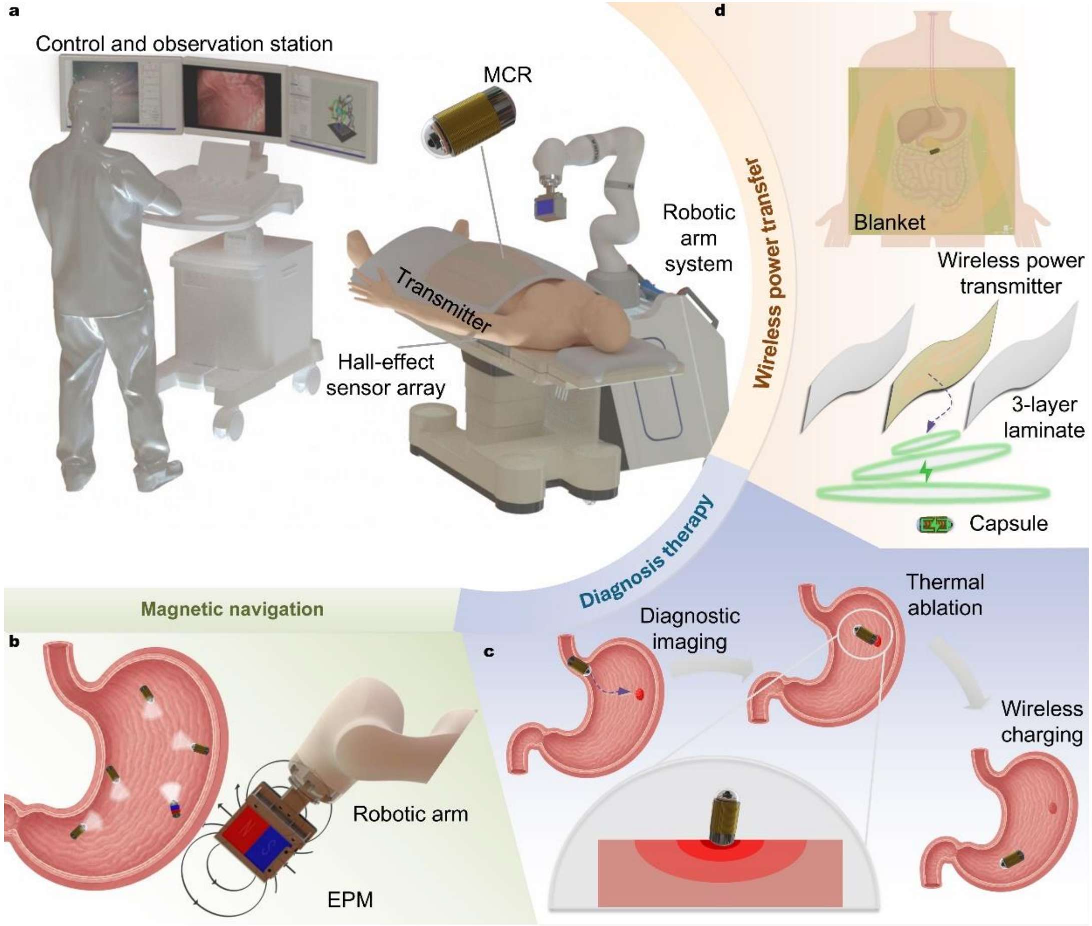
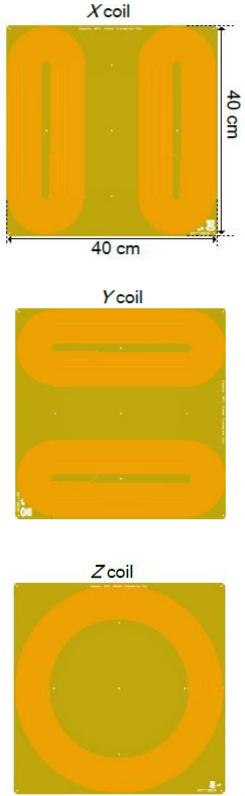
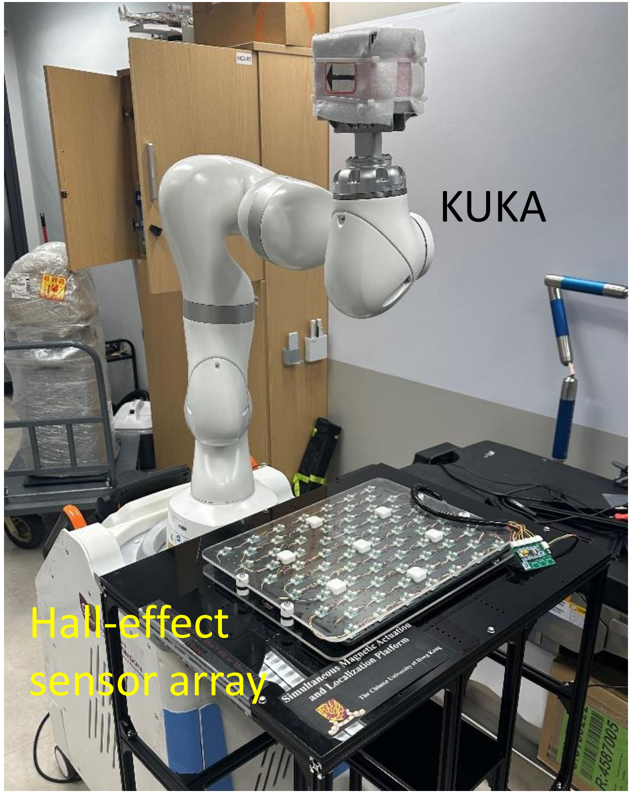
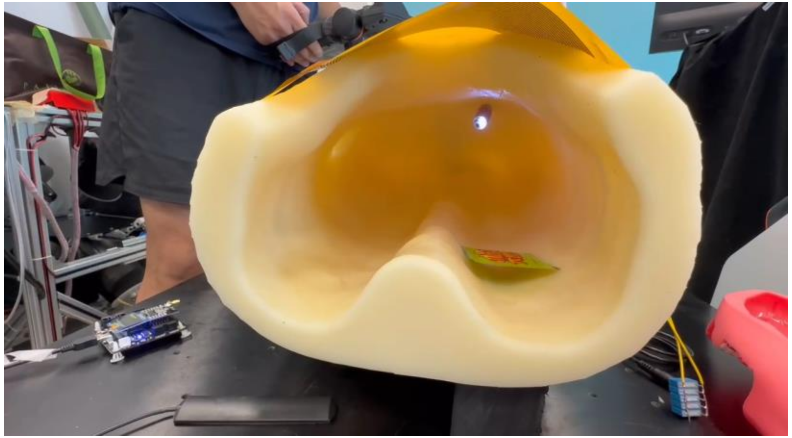

a
Control and observation station
MCR
Robotic
arm
system
Transmitter
Hall-effect
sensor array
d
Wireless power transfer
Blanket
Wireless power
transmitter
3-layer
laminate
Capsule
Diagnosis therapy
Magnetic navigation
b
Robotic arm
EPM
c
Diagnostic
imaging
Thermal
ablation
Wireless
charging

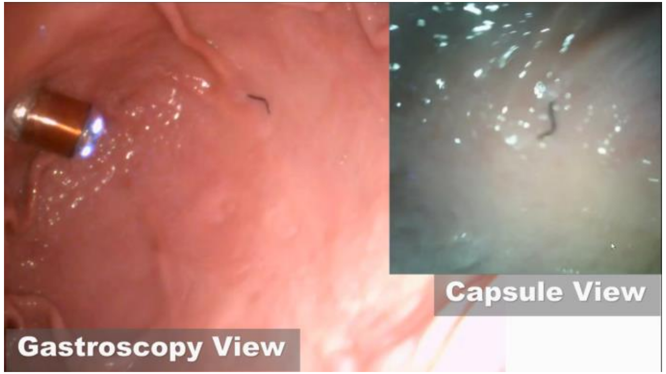

X coil
40 cm
40 cm
Y coil
Z coil

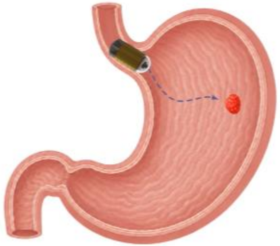

KUKA
Hall-effect sensor array
Simultaneous Magnetic Actuation and Localization Platform
The Chinese University of Hong Kong

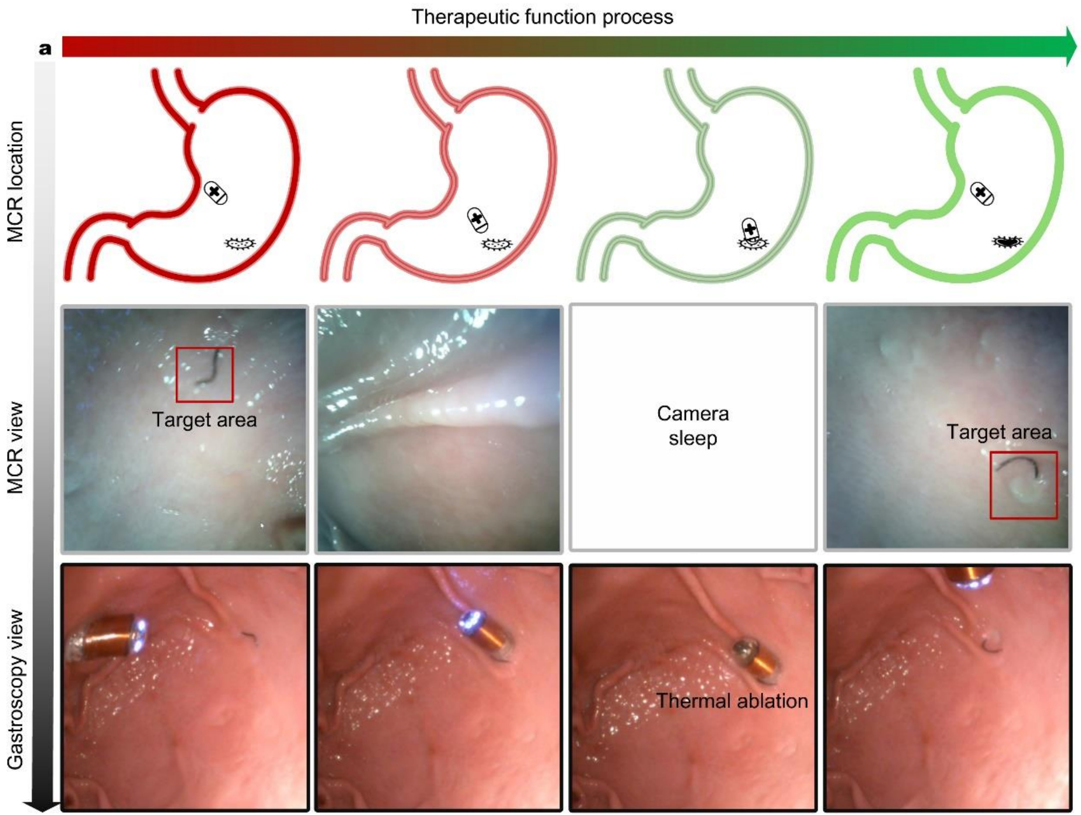

a Detailed capsule structure
FPCB top
FPCB bottom
WPT DCDC
MCU (RF)
IMU
Image sensor
LEDs
Lens
ϕ5.5×3.2 mm
Lens holder
10.4 mm
9.9 mm
Magnet
Copper wire
Ferrite
Batteries
10.4 mm
9.9 mm
ϕ11–13×16mm
13.8 mm
Insulation board
Heater
Top
Bottom



Ex vivo experiment







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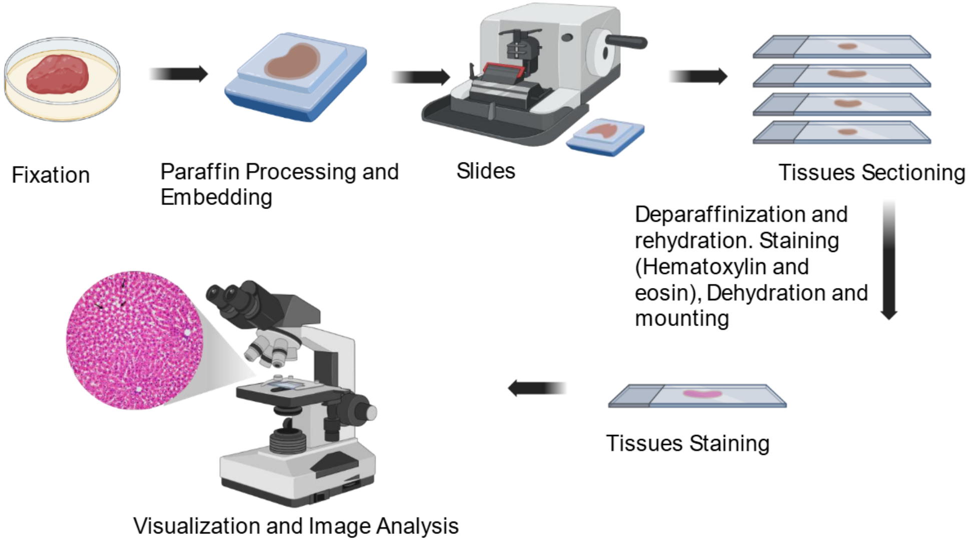
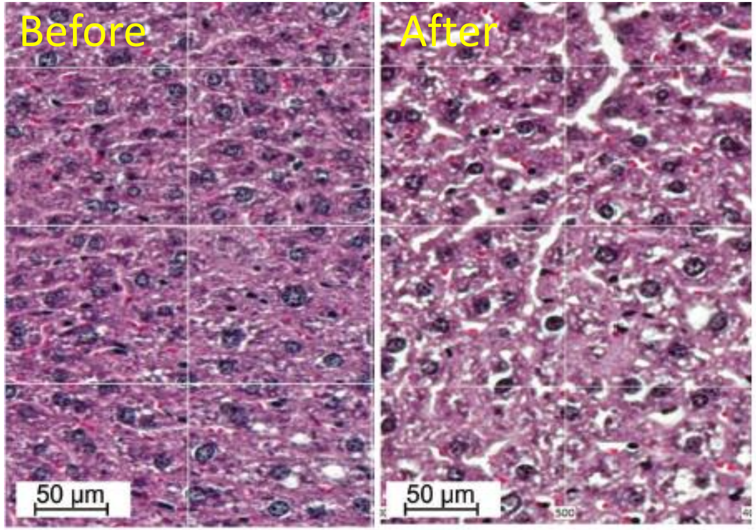
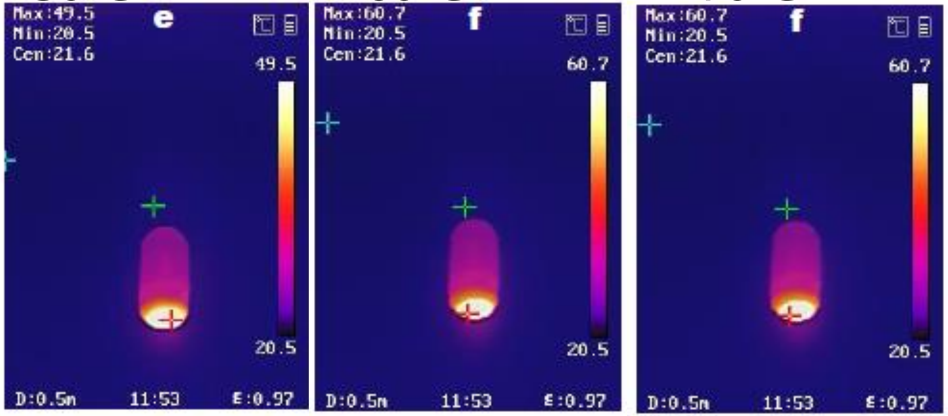
Histological analysis of tissue following thermal ablation

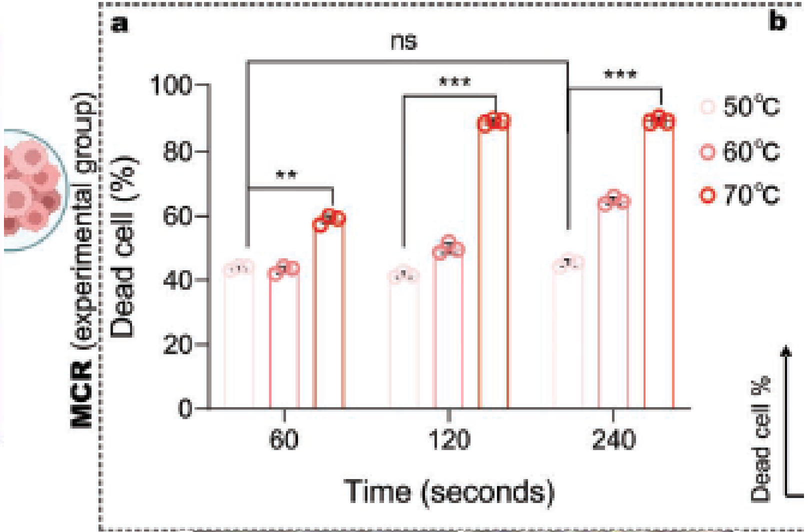




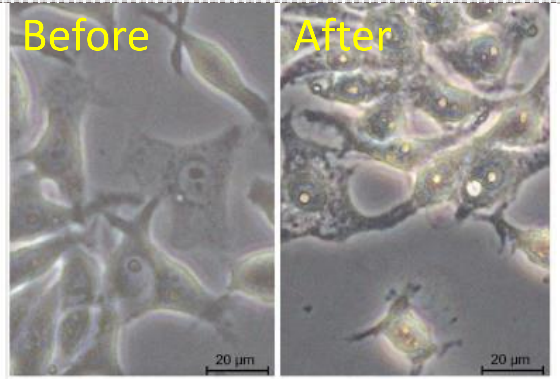
In vitro experiments

50°C 60°C 70°C





CYTEK Northern Lights - Flow Cytometry Instrument (全光譜流式細胞儀)



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Conclusion

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Traditional capsule endoscopy is limited to passive movement and observation, without therapeutic capability.

The multifunctional capsule robot (MCR) developed here integrates diagnostic imaging, magnetic navigation, six-degree localization, wireless charging, and thermal ablation into a single system.

Ex vivo tissue and in vitro cell experiments confirm the feasibility of controlled thermal ablation and reliable imaging, demonstrating the potential to move capsule endoscopy from a purely diagnostic tool toward an active therapeutic platform.

However, challenges remain — localization accuracy and the small ablation area, which could risk unintended tissue damage.

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Future Outlook

Improve localization precision: Enhance magnetic tracking and sensor integration to align treatment accuracy with the capsule's therapeutic footprint.

Optimize power management: Refine wireless charging and energy allocation to support longer procedures and higher-energy therapeutic functions.

Expand therapeutic modules: Explore additional minimally invasive functions such as drug delivery, biopsy, or micro-surgery.

In vivo validation: Transition from ex vivo and in vitro studies to controlled animal and clinical trials to assess safety, efficacy, and workflow integration.

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"Innovation begins where limitations meet imagination — breakthroughs happen when we embrace challenges, think beyond boundaries, and explore new intersections of technology.

Thank you!

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