



Robotics $\Leftrightarrow$ Haptics

Sensor Fusion & SLAM to Haptic Device



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Passive Haptic Rendering to Robot Simulator



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Jaemin Yoon
(윤재민)



Dongwon Son
(손동원)

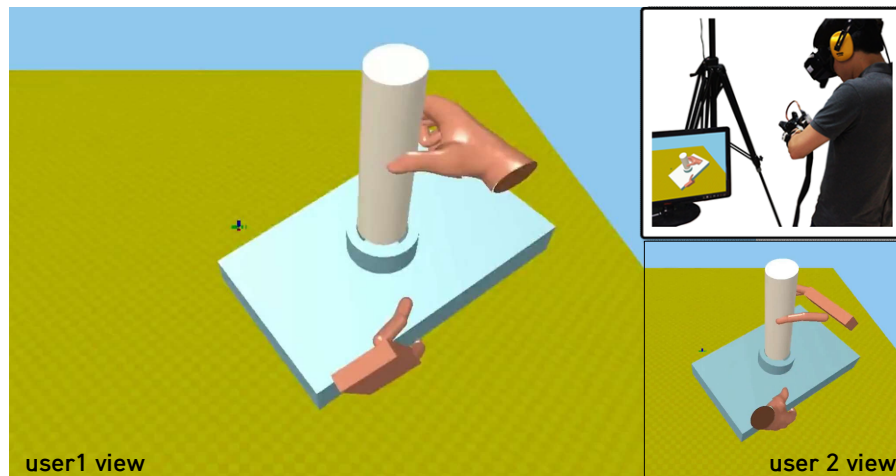
Dongjun Lee
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Department of Mechanical & Aerospace Engineering
Seoul National University

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iNRoL



Remote Dual-User Haptic Interaction



- Remote dual-user virtual collaborative manipulation with time-delay in VR

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Device

Wearable Cutaneous Haptic Interface

- WCHI = Hand tracking module + Cutaneous haptic feedback module
- HTM: multi-DOF finger/hand tracking using soft sensors & IMUs
- CHM: 3-DOF cutaneous haptic feedback rendering using soft sensors & a FSR



HTM
Hand Tracking Module



WCHI
Wearable Cutaneous Haptic Interface
Integration of HTM and CHM



CHM
Cutaneous Haptic Feedback Module





Onboard Flight Experiment
3) Indoor-Outdoor Transition Flying

- UAV path (estimated)
- GPS measurement
- map point

• Sensor fusion, SLAM, soft robotics

Rendering

Egg Delivery with WCHI

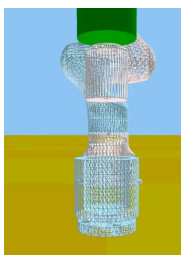


[With Haptic Feedback]



[Without Haptic Feedback]







• Fast/stable/accurate robot simulator → ML

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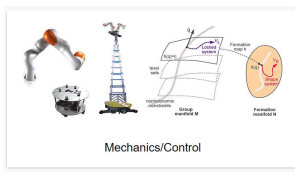


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Aerial Manipulation



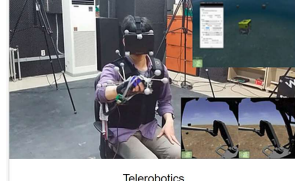
Mechanics/Control



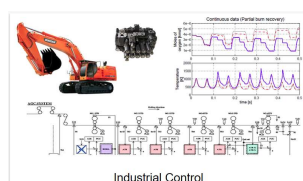
Haptics/VR



Autonomous Mobility



Telerobotics



Industrial Control

SNU iNRoL Website: <https://www.inrol.snu.ac.kr/>

SNU iNRoL Youtube: https://www.youtube.com/channel/UCk8xozp2_B-6qkN9XKzH_RA

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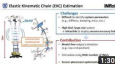
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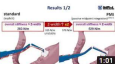
Autonomous Non-Steady-State Drift-Driving Control...

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Model-Free Optimal Sensor Placement and Estimation...

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Dental Simulator with Increased Z-width with PMI...

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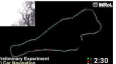
Data-Driven Contact Clustering for Fast, Stable...

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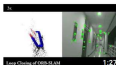
Outdoor Autonomous Flying of Flying-LASDRA with...

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GPS Fused VINS for Indoor-Outdoor Transition Flying of...

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Outdoor-Indoor Autonomous Flying with Camera-GNSS...

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Teleoperation of a Platoon of Distributed Wheeled Mobile...

200 views · 11 months ago



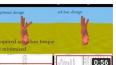
Wearable Cutaneous Haptic Interface (WCHI) with Soft...

376 views · 11 months ago



Shared Peg-in-Hole Teleoperation of Stage-Arm...

180 views · 11 months ago



Design of Under-Actuated Tendon-Driven Robotic Fing...

180 views · 11 months ago



LASDRA (large-size aerial skeleton w/ distributed roto...

2:00



QDAR: Aerial Manipulation Platform Enabling Omni...

3:58



Smo Platform: A Novel Robotic Platform for Aerial...

3:43



QDAR: Aerial Manipulation Platform Enabling Omni...

2:00



QDAR-8 (Omni-Directional Aerial Robot w/ 8 rotors)

2:05



Design of Under-Actuated Tendon-Driven Robotic Fing...

1:58

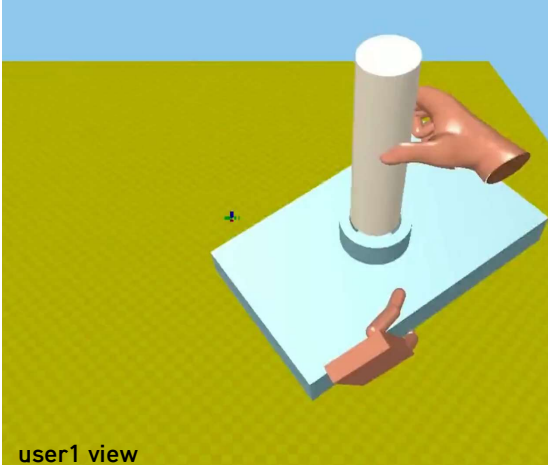
SNU iNRoL Website: <https://www.inrol.snu.ac.kr/>

SNU iNRoL Youtube: https://www.youtube.com/channel/UCk8xozp2_B-6qkN9XKzH_RA

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Remote Dual-User Haptic Interaction



user1 view



user 2 view

- Remote dual-user virtual collaborative manipulation with time-delay in VR

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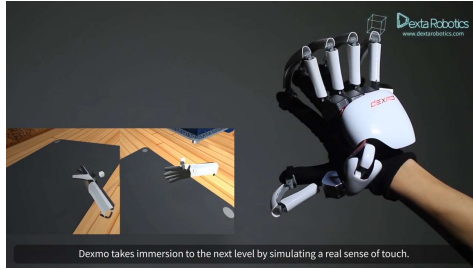
iNRoL

3

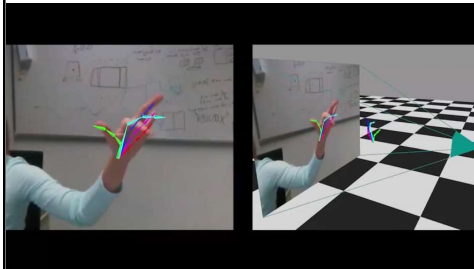
State of the Art



• Oculus Touch with haptic feedback



• Dexmo - Dexra Robotics



• Finger/hand tracking with RGB-camera



• Leap Motion finger tracking

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Wearable Cutaneous Haptic Device (TMech19)

- Issues on wearable haptic interface
 - Finger tracking: camera (occlusion), IMU (drift, magnetic interference)
 - Haptic feedback: kinesthetic (bulky), cutaneous (finger tracking)
- Wearable cutaneous haptic interface
 - IMU/SS based finger tracking + 3-DOF fingertip cutaneous feedback
 - Drift/noise/interference → 9-DOF IMU sensor fusion + soft sensor (SS)
 - User fingertip variability → closed-loop control w/ FSR ($||F||$) + SS ($\vec{F}$)

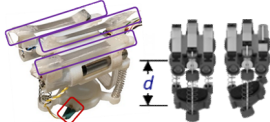
Hand tracking module



IMU x 4

Stretch sensor x 3

Haptic feedback module

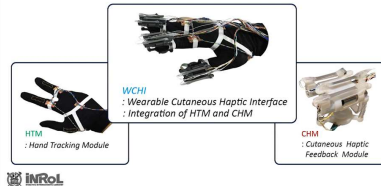


FSR x 1

Stretch sensor x 3

Wearable Cutaneous Haptic Interface

- WCHI = Hand tracking module + Cutaneous haptic feedback module
- HTM: multi-DOF finger/hand tracking using soft sensors & IMUs
- CHM: 3-DOF cutaneous haptic feedback rendering using soft sensors & a FSR



Y. Lee, M. Kim, Y. Lee, J. Kwon, Y.-L. Park and D. J. Lee, Wearable Cutaneous Haptic Interface for Multi-Fingered Virtual Manipulation, IEEE/ASME Transactions on Mechatronics, 2019 (Online)
Y. Lee, I. Jang and D. J. Lee, Enlarging Just Noticeable Differences of Visual-Proprioceptive Conflict in VR using Haptic Feedback, World Haptics Conference, 2015

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IMU Sensor Fusion



- Head mounted display for VR (Oculus Rift)



- Whole-body tracking with IMUs (Xsense)



- Omni-directional aerial robot (SNU-IRoL, TMECH18)



- Flying large-size aerial skeleton (SNU-IRoL, ICRA19)

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IRoL

Flying-LASDRA (ICRA19)



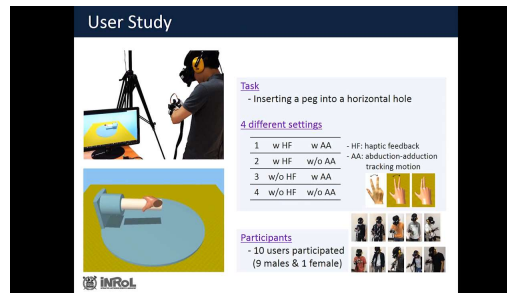
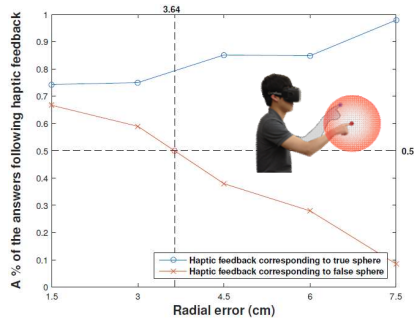
- Autonomous flying with serpentine-like undulatory motion of three-link LASDRA system (3m, 12-DOFs)

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IRoL

From Perception to Device (WHC15)

- Wearable cutaneous haptic interface
 - IMU/SS based finger tracking + 3-DOF fingertip cutaneous feedback
 - Drift/noise/interference → 9-DOF IMU sensor fusion + soft sensor (SS)
 - User fingertip variability → closed-loop control w/ FSR ($||F||$) + SS ($\vec{F}$)
- WCHI device specification from haptics
 - Permissible VR finger-tip tracking error increases (1.5cm → 3cm) w/ haptics
 - Abduction-adduction (AA) finger motion important for dexterous VR

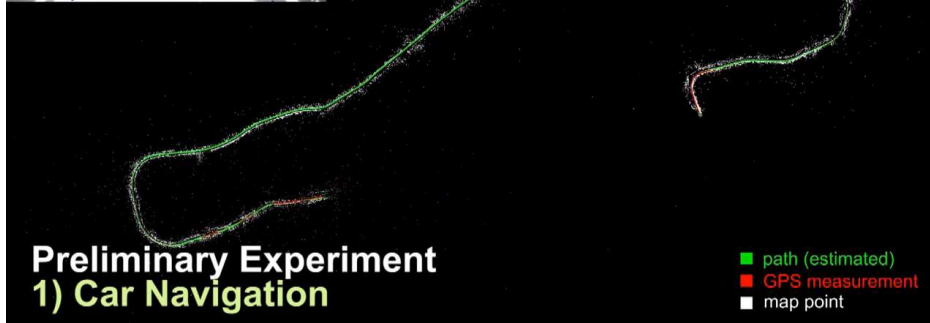
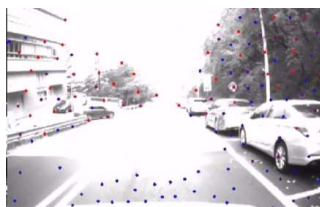


Y. Lee, M. Kim, Y. Lee, J. Kwon, Y.-L. Park and D. J. Lee, Wearable Cutaneous Haptic Interface for Multi-Fingered Virtual Manipulation, IEEE/ASME Transactions on Mechatronics, 2018 (To Appear)
Y. Lee, I. Jang and D. J. Lee, Enlarging Just Noticeable Differences of Visual-Proprioceptive Conflict in VR using Haptic Feedback, World Haptics Conference, 2015

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VIN+GPS SLAM

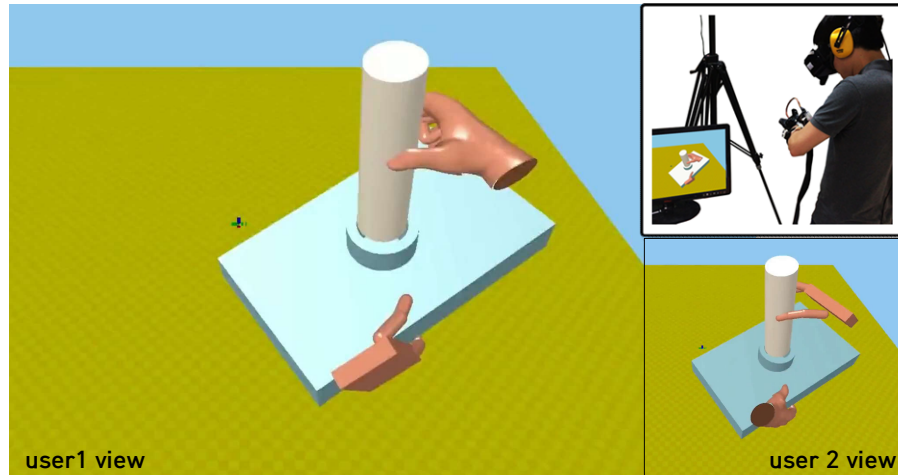


- Factor-graph-based GPS-VIN (visual-inertial navigation) SLAM for indoor-outdoor operation (KROC19)

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Remote Dual-User Haptic Interaction



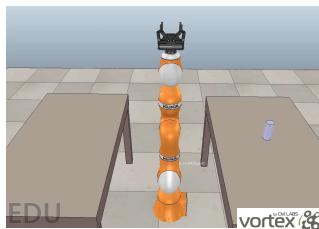
- Remote dual-user virtual collaborative manipulation with time-delay in VR

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Open-Source Robot Simulators

- 경량/고강성 물체 시뮬레이션



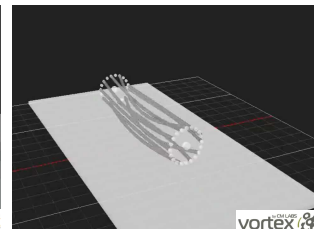
- 조인트 PD-토크제어 시뮬레이션

- 다중접촉 시뮬레이션

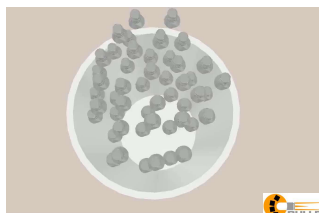


- 로봇손 컵 파지 시뮬레이션

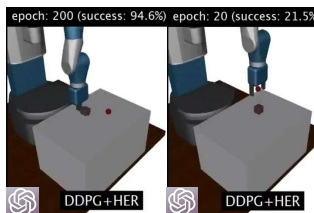
- 유연체 시뮬레이션



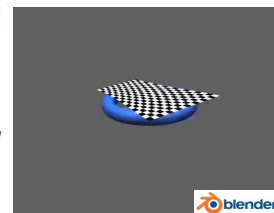
- PRB 유연케이블 시뮬레이션



- M3 볼트 시뮬레이션



- 블록 조작/파지 시뮬레이션



- 게임엔진 유연체 시뮬레이션

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PMI (Passive Midpoint Integration, IJRR17)



- Dynamics integration (PMI in maximal or generalized coordinates)

$$\hat{M}_k \hat{V}_k = M_k V_k - d\bar{\psi}_k^T + \bar{N}_k \lambda_k^n + \bar{D}_k \lambda_k^t \quad \hat{\star}_k := \frac{\star_{k+1} + \star_k}{2}$$

midpoint velocity potential term normal contact tangential friction

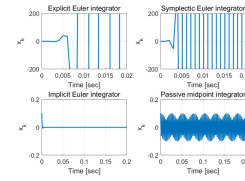
- Multi-point constraint (PMI-LCP)

$$\begin{aligned} 0 \leq \sigma_k^n \perp \lambda_k^n &\geq 0 & \sigma_k^n &:= \bar{N}_k^T \hat{V}_k \in \mathbb{R}^{l_c} & \rightarrow \text{normal direction velocity} \\ 0 \leq \sigma_k^t \perp \lambda_k^t &\geq 0 & \sigma_k^t &:= \bar{D}_k^T \hat{V}_k + U \lambda_k^f \in \mathbb{R}^{l_c \times \bar{p}} & \rightarrow \text{tangential direction velocities} \\ 0 \leq \sigma_k^f \perp \lambda_k^f &\geq 0 & \sigma_k^f &:= \bar{\mu} \lambda_k^n - U^T \lambda_k^t \in \mathbb{R}^{l_c} & \rightarrow \text{Coulomb friction} \end{aligned}$$

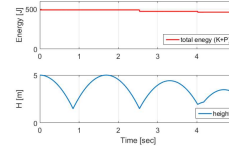
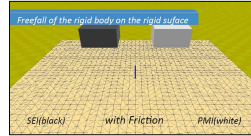


- Physical principle (passivity) preservation in discrete-time

$$\begin{aligned} \frac{dKE}{dt} + \frac{dPE}{dt} &= (u + f)^T v - v^T B v \\ \rightarrow (KE+PE)_{k+1} - (KE+PE)_k &= [(u_k + f_k)^T \hat{v}_k - \hat{v}_k^T B \hat{v}_k] T_k \end{aligned}$$



- Stable simulation of **very light/stiff** objects
- Contact passivity $\rightarrow$ enhanced **multi-contact stability**
- Stable simulation **regardless** T_k
- Damping is really **damping**
- **Modular** simulation possible



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PMI (Passive Midpoint Integration, IJRR17)



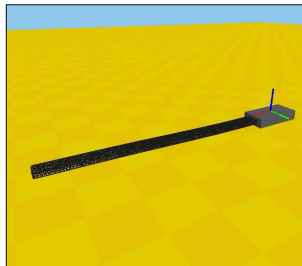
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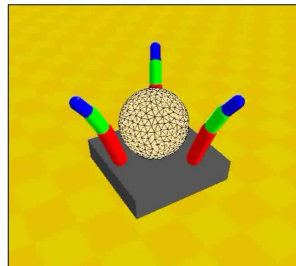
midpoint velocity potential term normal contact tangential friction

- Multi-point constraint (PMI-LCP)

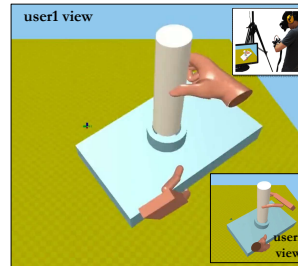
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• 알루미늄 빔 진동 시뮬레이션 (11/75/210Hz)



• 텐던 구동부족 로봇손 파지 시뮬레이션

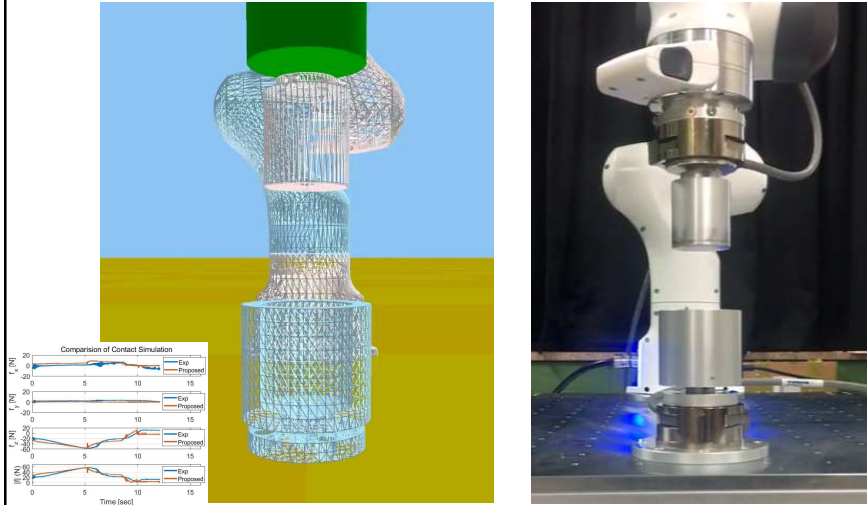


• 다중사용자 원격 가상조립

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PMI: Peg-in-Hole Simulation (ICRA19)



- Fast, stable and accurate peg-in-hole PMI simulation with data-driven multi-point contact solver

$$\text{RMS}\left(\frac{\|F_{\text{sim}}\| - \|F_{\text{exp}}\|}{\text{mean}(\|F_{\text{exp}}\|)}\right) = 28.88\%$$

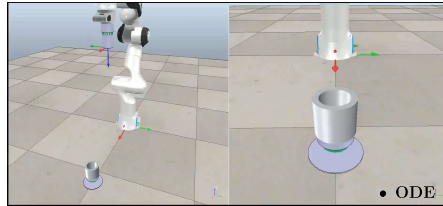
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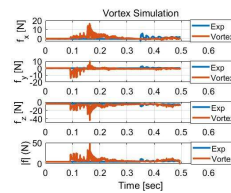
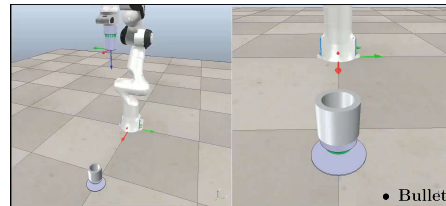
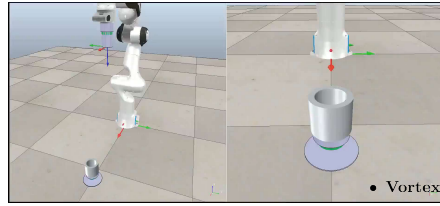
Open-Source Robot Simulators



1) ODE/Bullet → 접촉 채터링 발생 및 팩 삽입 불가



2) Vortex → 실시간 시뮬레이션 시 불안정 거동 발생



Performance	
Simulator	RMS(%)
ODE	207.06
Bullet	231.28
Vortex	101.64

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Data-Driven Contact Clustering



- **High-precision peg-in-hole operation & data acquisition**

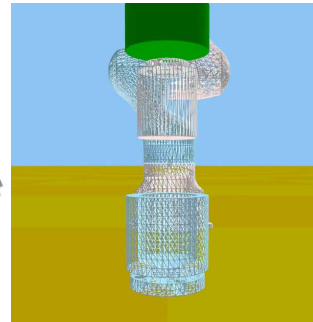
- Necessary in robot automation industry field, but not in existing robot simulator
- Diameter 50mm, **hole tolerance 0.065mm** (below sensor resolution)
- End-effector impedance control using robot manipulator
- Perform peg-in-hole task with various peg entry direction/angle
- Records peg position/rotation/velocities, F/T sensor readings on wrist and base



- Peg-in-hole experiment using PANDA manipulator



- Various entry direction(top) and angle(bottom)



- Peg-in-hole simulation using our developed PMI-based simulator

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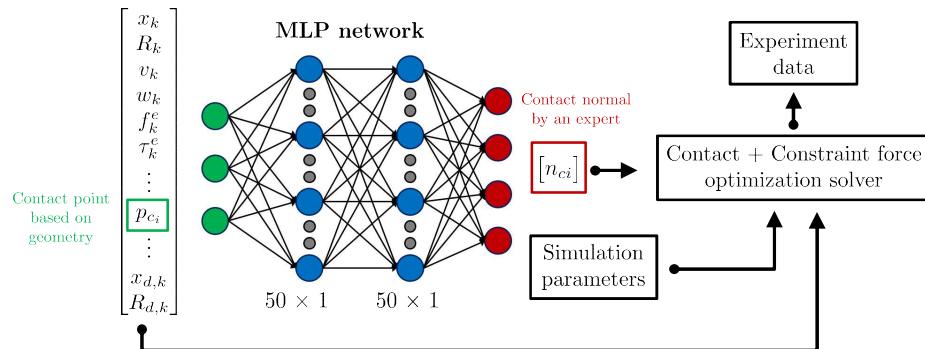
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Data-Driven Contact Clustering



- **Data-driven/learning-based contact clustering**

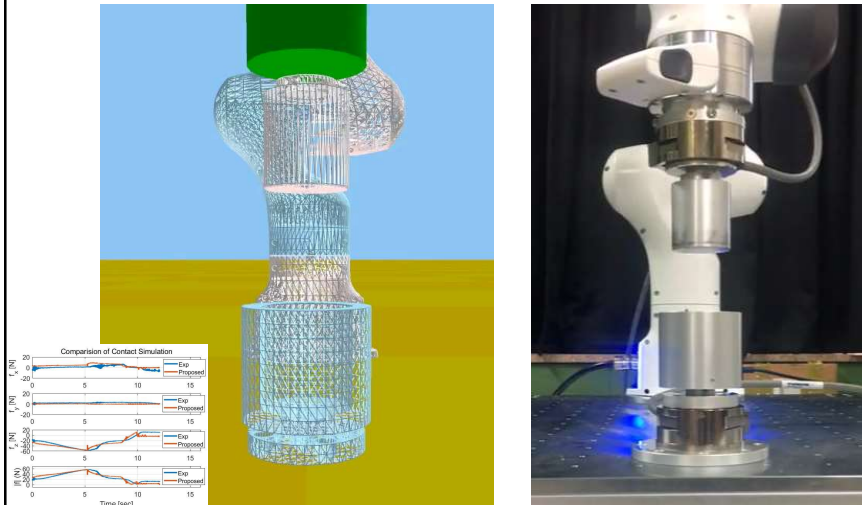
- Determine contact point based on **geometry** (max 6 points)
- **Tune simulation parameters** so that the behavior of the robot is similar to that of the actual experiment
- **Determines the contact normal by an expert** to match the contact wrench with experiment (like learning from demonstration)



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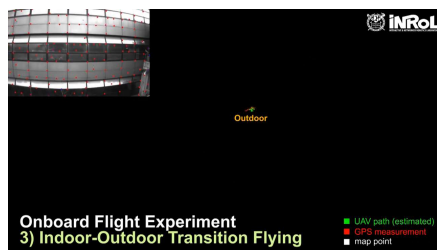
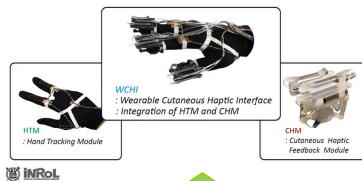
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Device

Wearable Cutaneous Haptic Interface

- WCHI = Hand tracking module + Cutaneous haptic feedback module
- HTM: multi-DOF finger/hand tracking using soft sensors & IMUs
- CHM: 3-DOF cutaneous haptic feedback rendering using soft sensors & a PSR

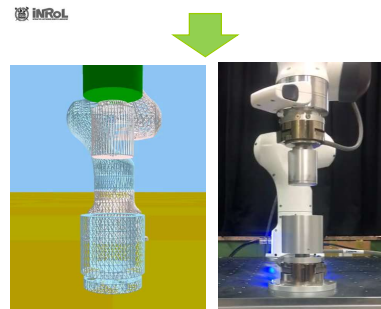
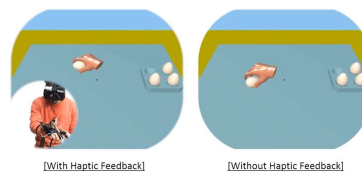


- Sensor fusion, SLAM, soft robotics

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Rendering

Egg Delivery with WCHI



- Robot simulator, machine learning

INRoL



Yongseok Lee
(이용석)



Yonghan Lee
(이용한)



Yongjun Lee
(이용준)



Myungin Kim
(김명신)



Jaemin Yoon
(윤재민)



Dongwon Son
(손동원)

תודה
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Thank You Tak
感謝您 Obrigado Teşekkür Ederiz
Σας Ευχαριστούμ 감사합니다
Bedankt Děkujeme vám
ありがとうございます
Tack