ConTac: Continuum-Emulated Soft Skinned Arm with Vision-based Shape Sensing and Contact-aware Manipulation

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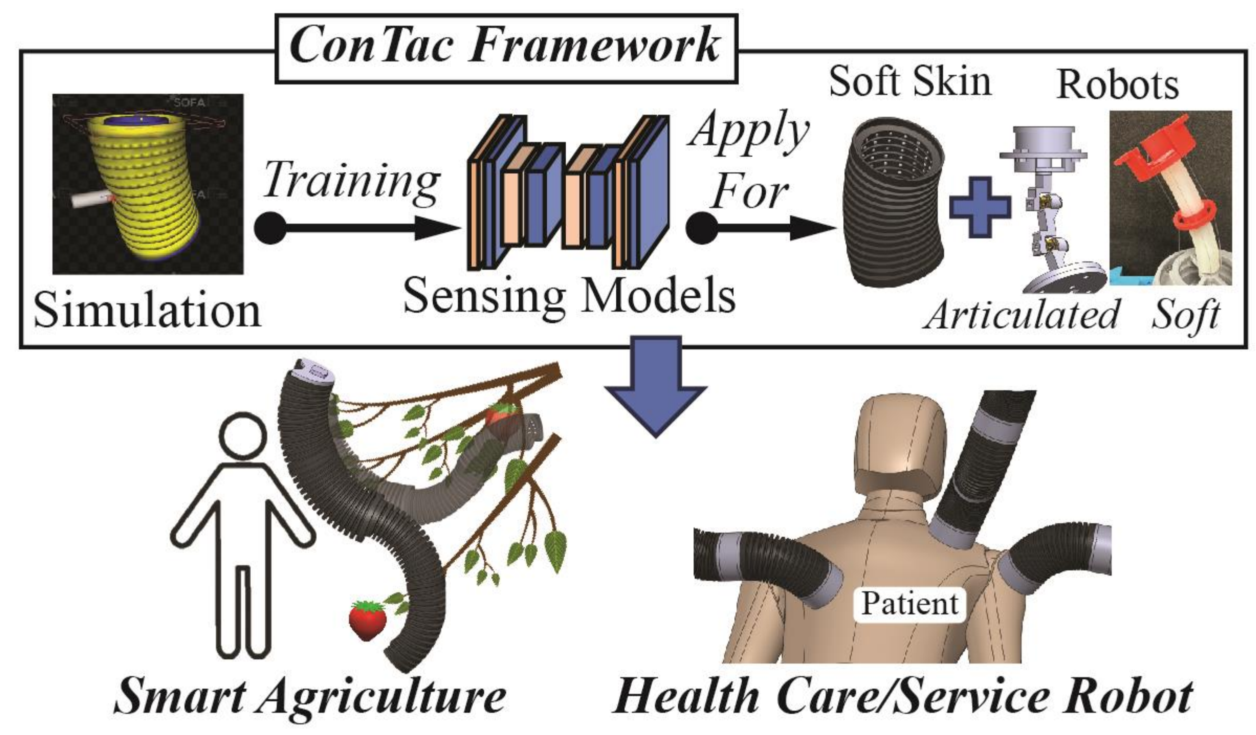
Introduction

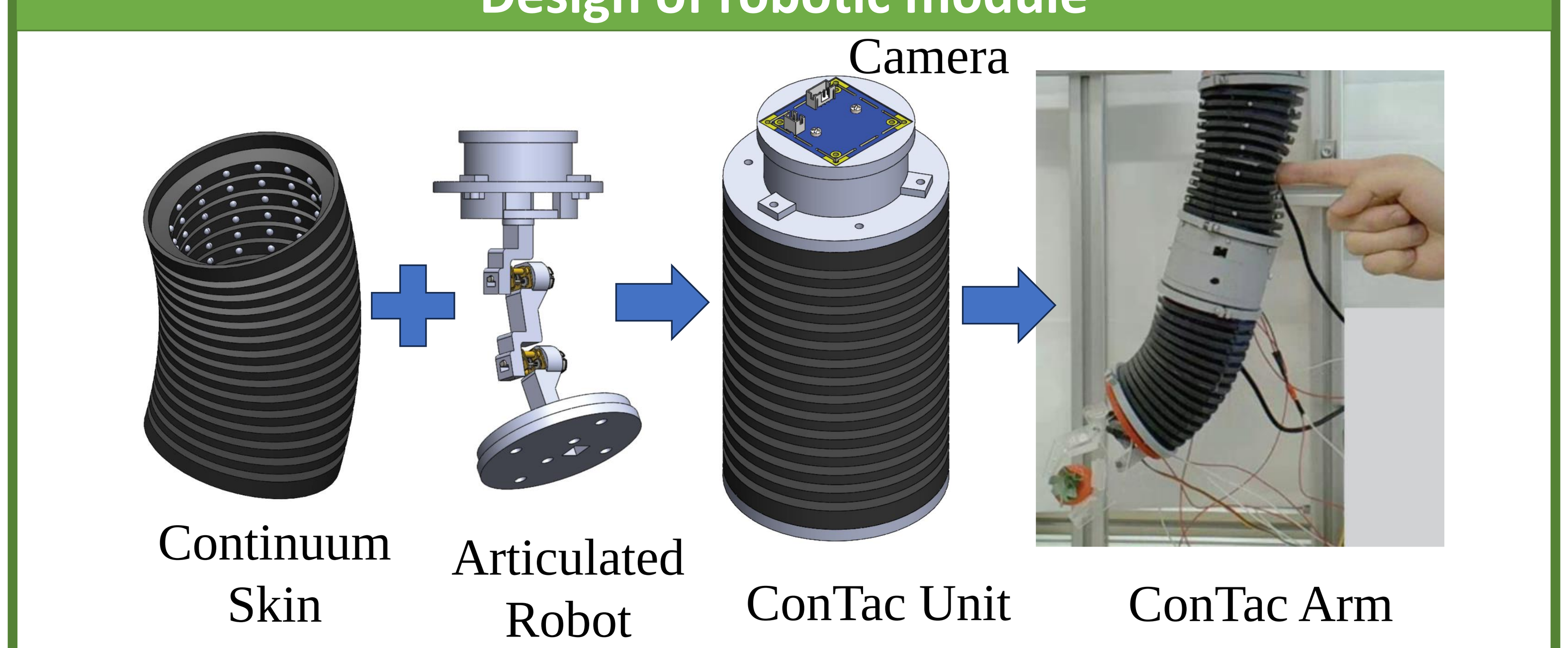
Hyper-redundant and continuum robots provide great advantages in flexibility, dexterity, and the capability to handle unexpected situations. However, providing them with perception solutions remains a challenge. In this work, we present the *ConTac framework* that can **estimate the shape and contact** of a *continuum-emulated robot with soft skin*.



Project's website

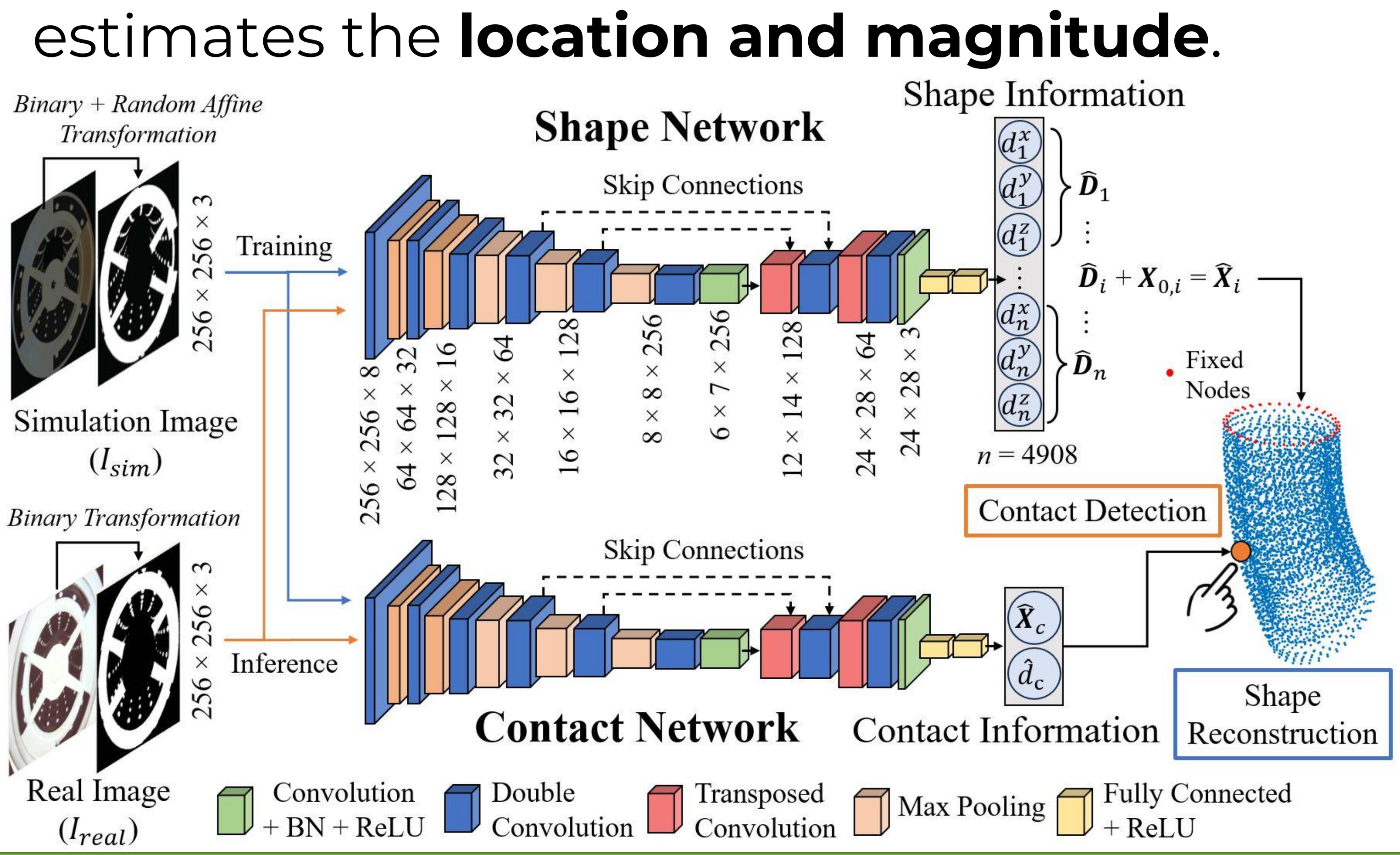
Methods

Design of robotic module



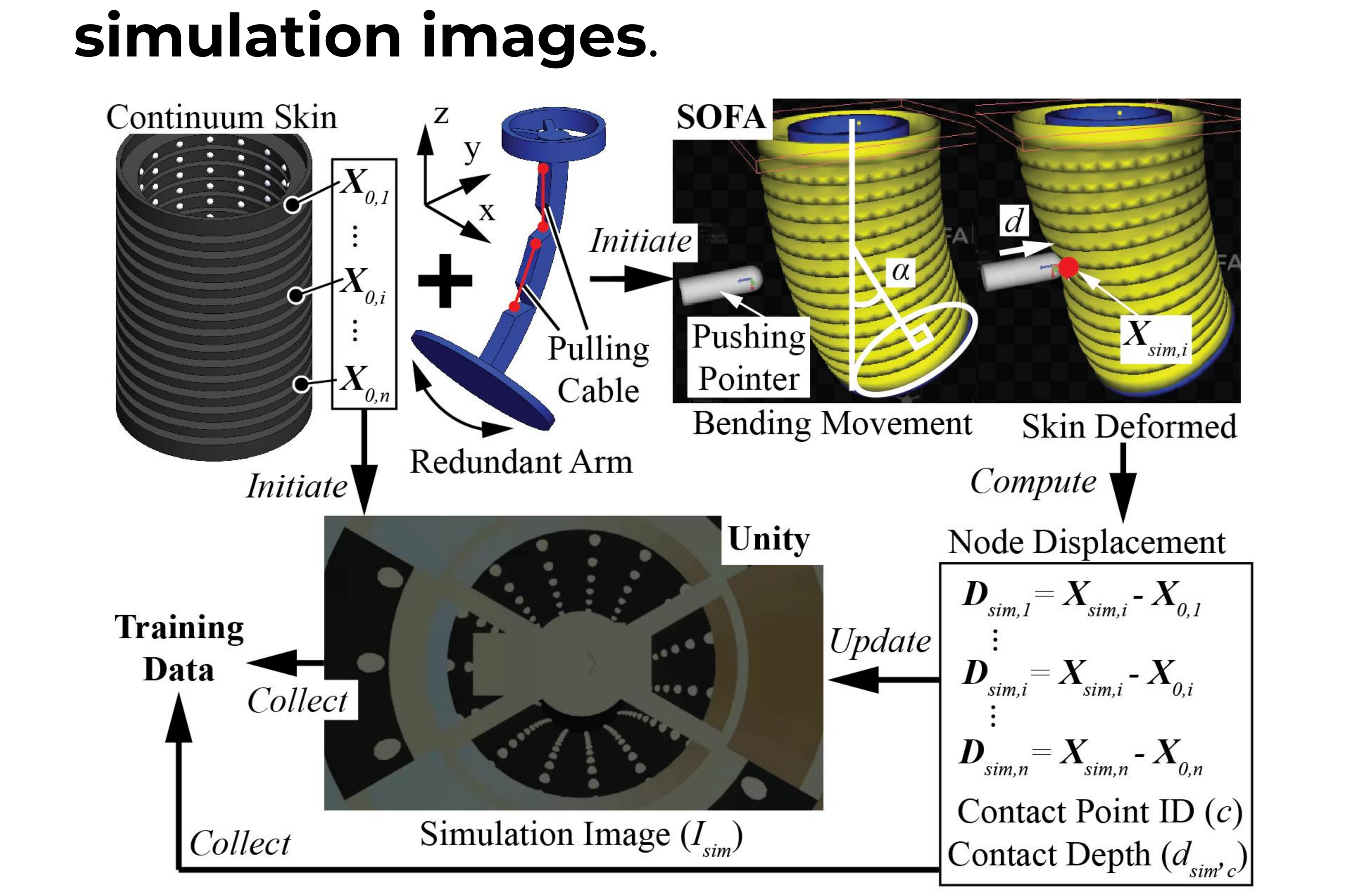
Sensing principle

From a tactile image, the *Shape Network* predicts the **displacement of the skin**, while the **of the contact**. *Contact Network* estimates the **location and magnitude**.



Data acquisition

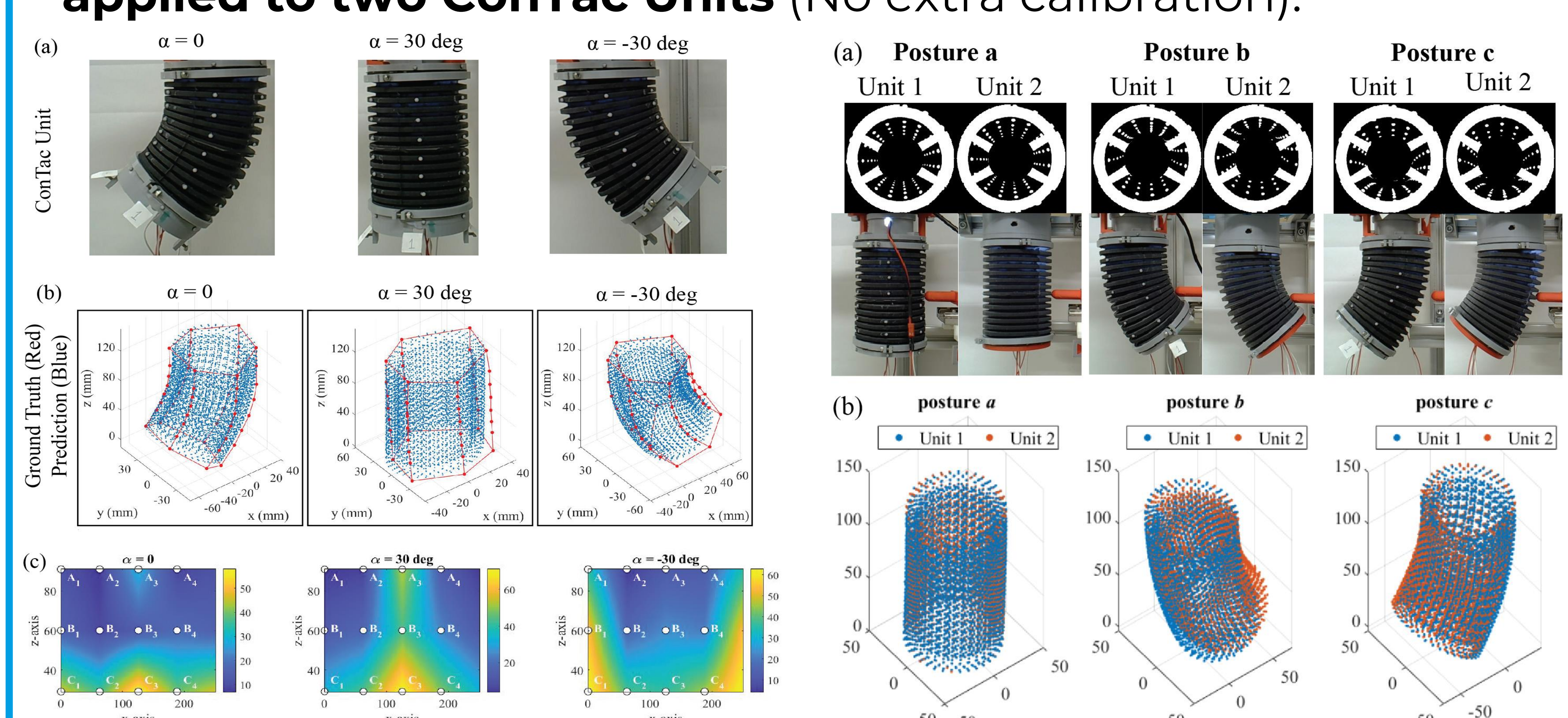
We use *SOFA* to acquire **physical deformations** and *Unity* to collect **simulation images**.



Results

Sensing capabilities

The sensing models **trained with simulation data** can be **applied to two ConTac Units** (No extra calibration).



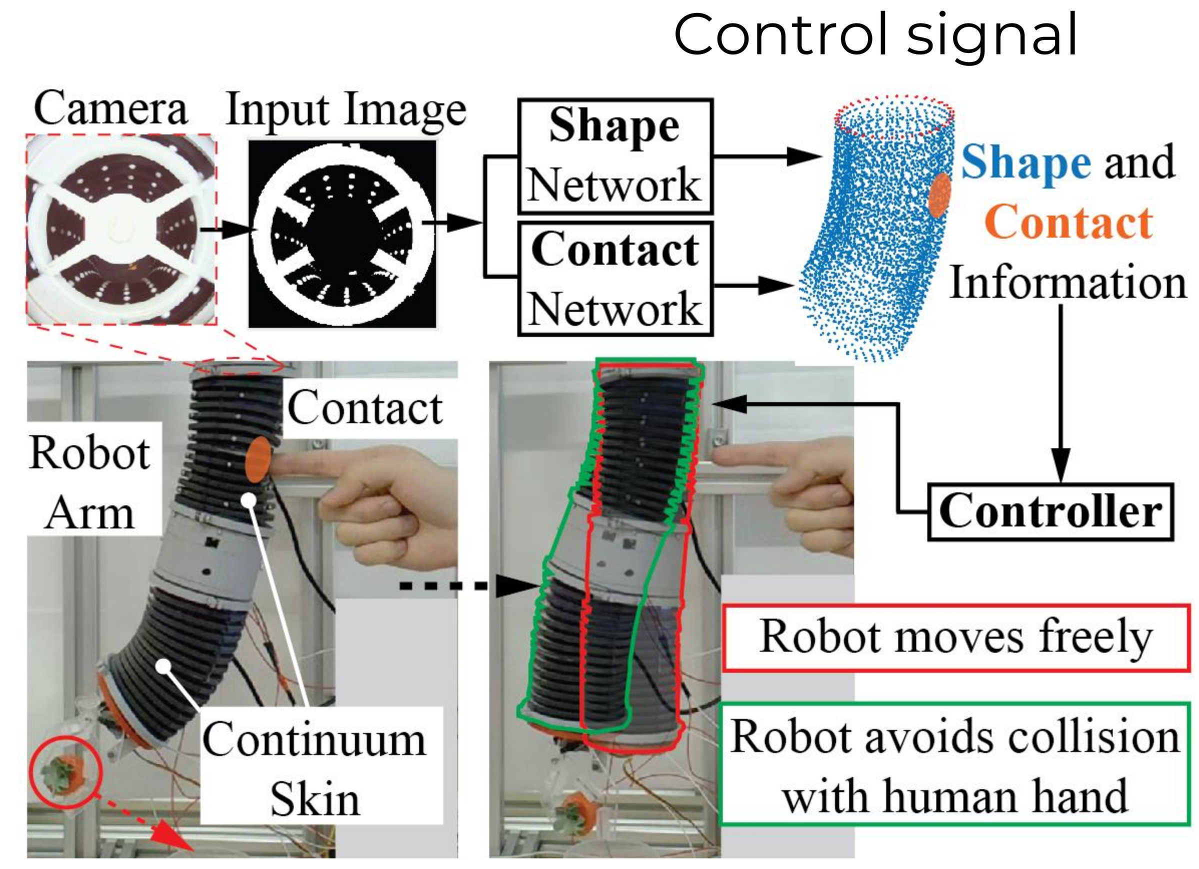
(a) Robot. (b) Shape reconstruction (c) Contact error

Applications

Admittance-based control: $\ddot{\alpha}_d = m^{-1}\left(f_c - c\,\dot{\alpha} - k\,\alpha\right)$

Acceleration — Contact force — Velocity — Shape

Control signal — Sensing models

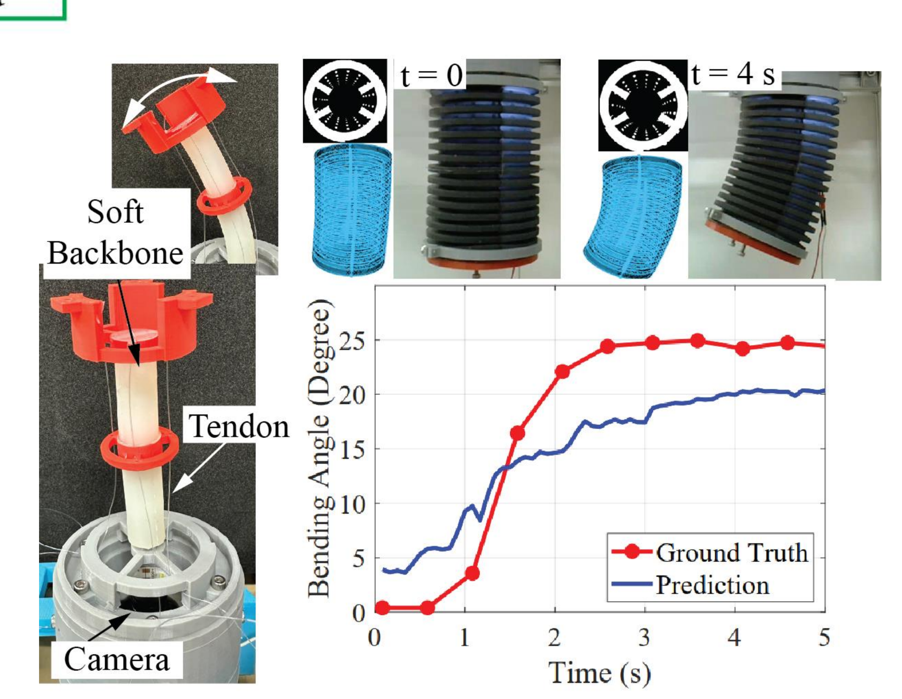


Robot can:

- detect, avoid collision,
- adjust its trajectory.

Shape sensing for soft robot:

The ConTac system can be immediately used to estimate the bending of a soft robot (No extra calibration).



Future work: ConTac for true continuum robots.

WaveTouch:

Active Tactile Sensing Using Vibro-Feedback for Classification of Variable Stiffness and Infill Density Objects

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Abstract

The perception and recognition of surroundings are essential for robotic manipulation tasks such as rolling motion, palpation, and force control. We introduce a novel tactile sensor utilizing **active vibro-feedback** to classify object properties during gripping that opens perspectives for effective object handling.

This approach can be especially beneficial for object manipulation with **deficient vision systems**. Our experiments demonstrate the efficacy of our approach in distinguishing **variable levels of elasticity and porosity (infill) based on vibration absorption and amplification patterns.**

Why vibrations?

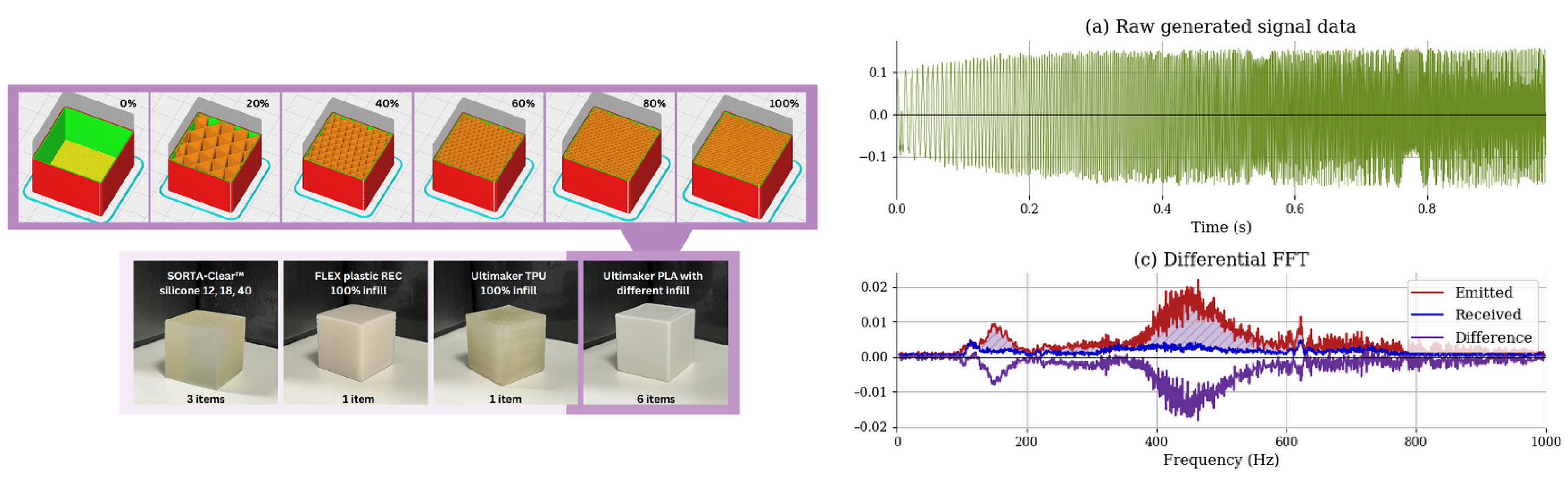
Vibrations play a crucial role in tactile sensing, as evidenced by human tactile perception, such as detecting slippage through changes in vibration patterns. Inspired by this, our study explores active vibration sensors for object property classification. This technique could significantly enhance manipulation tasks by reducing sensor wear and potential damage to objects.

Experiments

A **static force of 1N** was applied to each test cube, and a **chirp signal (100-800 Hz)** was generated and propagated through the cube. The accelerometers recorded the signals for analysis. FFT data from 50 trials were denoised using a uniform filter with a 50Hz window.

TEST OBJECTS:

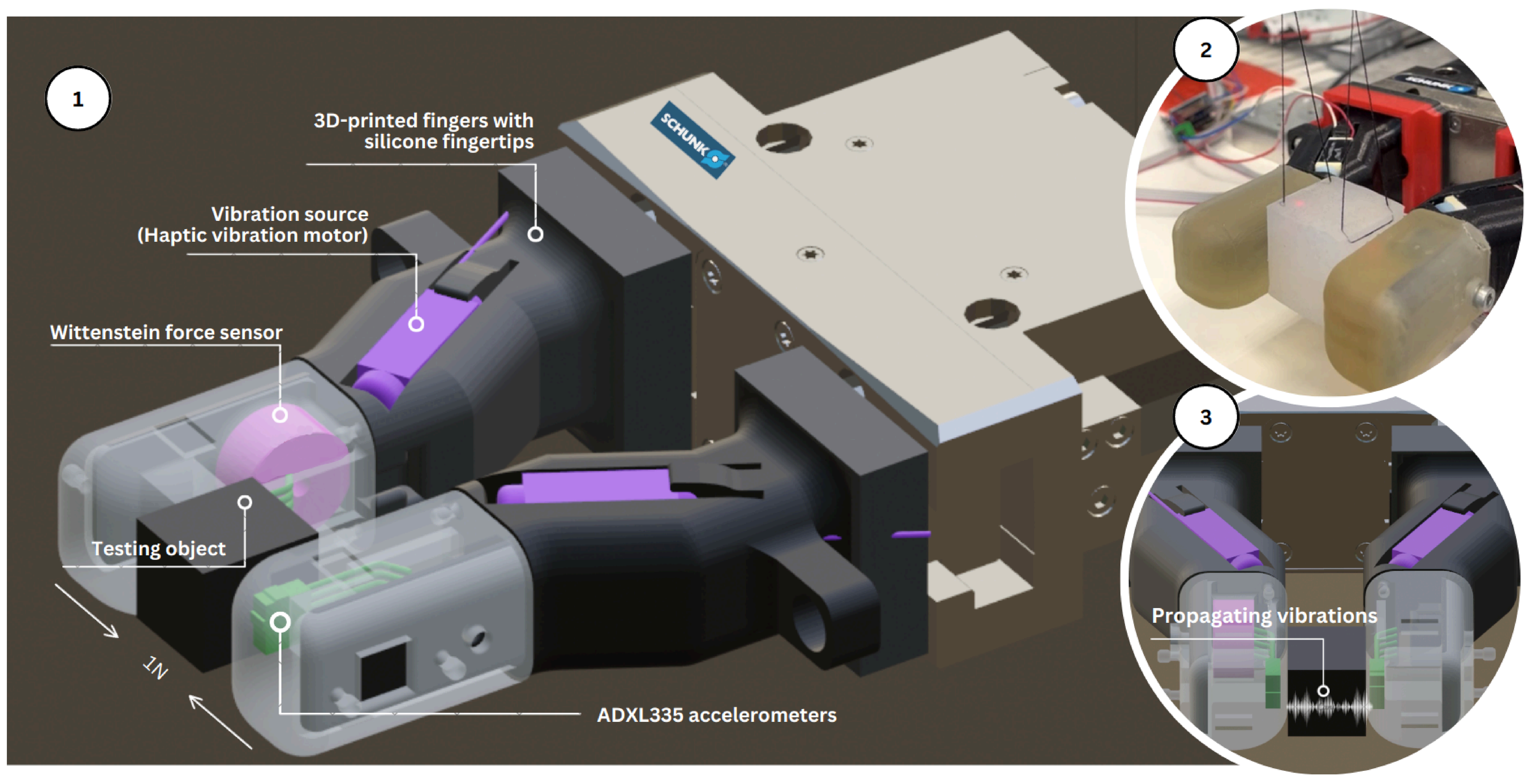
- **SORTA-Clear™ Silicone Rubber:** Different grades (12, 18, 40) representing varying stiffness levels.
- **FLEX Plastic REC:** Flexible plastic material.
- **Ultimaker TPU:** Thermoplastic polyurethane with elastic properties.
- **Ultimaker PLA:** Polylactic acid with varying infill densities (0%, 20%, 40%, 60%, 80%, 100%)



Hardware

We utilized a Schunk ENG 100 robotic gripper with 3D-printed plastic fingers and silicone tips. One finger was equipped with a haptic motor (Haptuator Mark II) and ADXL335 accelerometers to emit and receive vibrations. A Wittenstein HEX-21 F/T sensor was used for force control.

The STM32F4 microcontroller generated a chirp signal to the haptuator, recorded by the right accelerometer, and propagated through the cube to the left accelerometer.

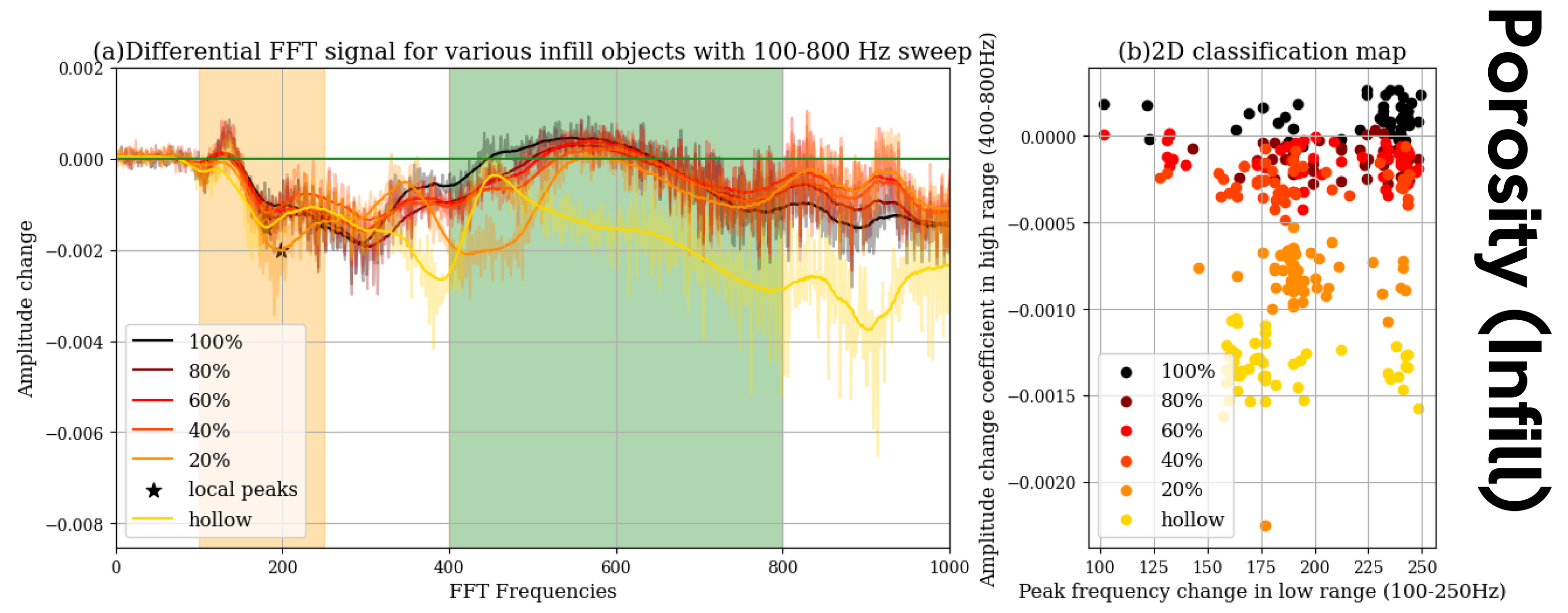


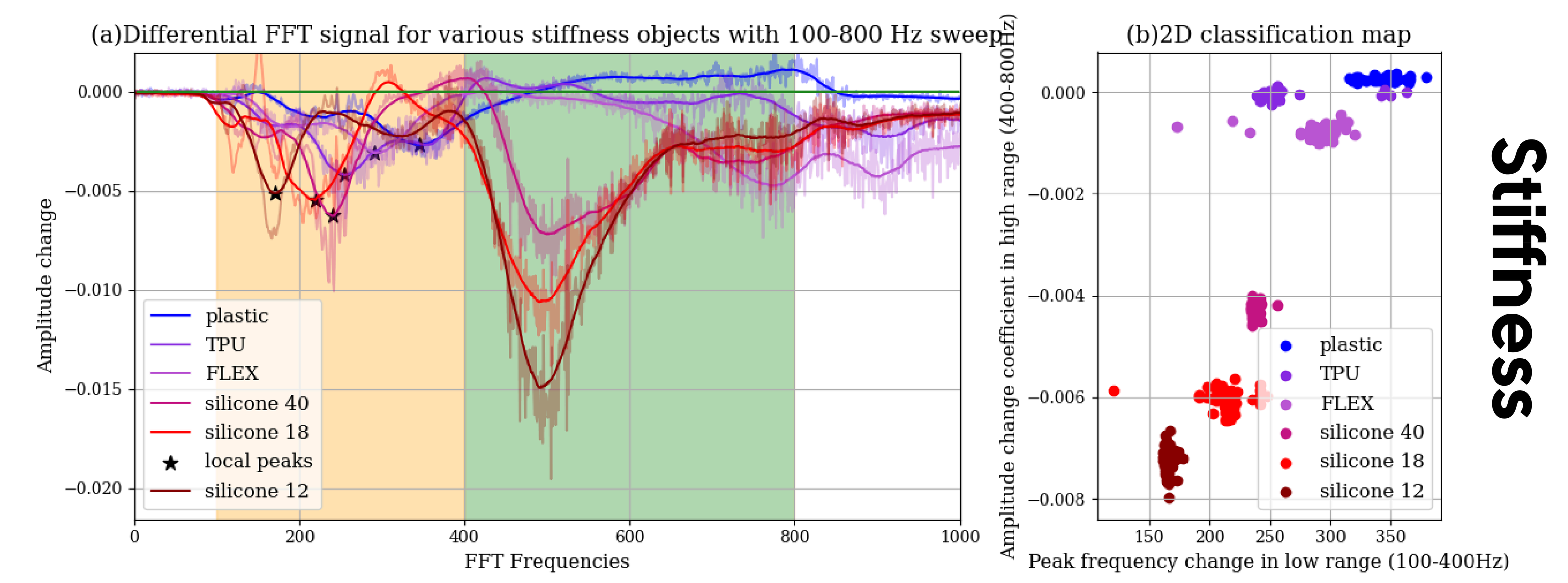
[1] D. Sandykbayeva, Z. Kappassov, and B. Orazbayev, "VibroTouch: Active tactile sensor for contact detection and force sensing via vibrations," Sensors, vol. 22, no. 17, p. 6456, Aug. 2022. doi:10.3390/s22176456

Results

The final features used for classification are low-range peak changes and high-range trends.

- **Stiffness:** The high-range trends have been shown to exhibit increasing signal absorption with increasing object elasticity. For the low-range frequencies, peak changes on the contrary are happening at decreasing frequencies with increasing elasticity.
- **Infill:** The hollow subjects showed significant absorption of the emitted signal, while more solid cubes demonstrated less absorption and even amplification in the higher frequency range (450-600Hz)





Key Insights & Future Work

Our research confirms that active vibro-feedback can effectively classify objects by their stiffness and infill density, enhancing tactile sensing capabilities in robotics.

- **Hollow subjects:** High signal absorption
- **Solid subjects:** Signal amplification at 450-600Hz
- **Soft objects:** 30-50% peak amplitude absorption
- **Rigid objects:** Peak amplitude amplification

Future work will focus on refining force control mechanisms, improving classification algorithms, and exploring additional object properties.

Simulation of GelSight Tactile Sensors Wear and Tear

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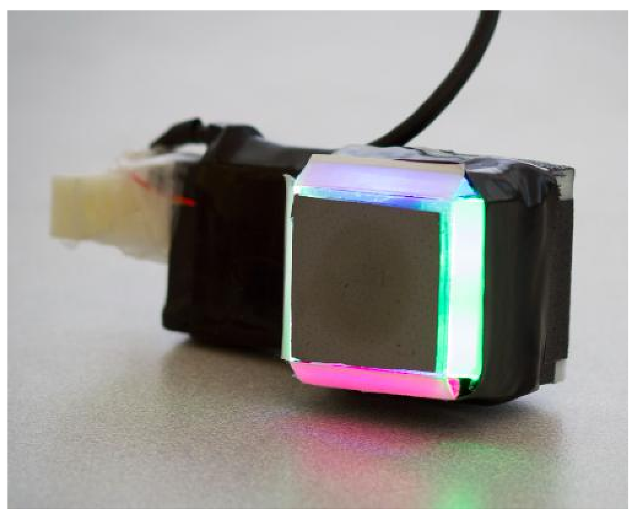
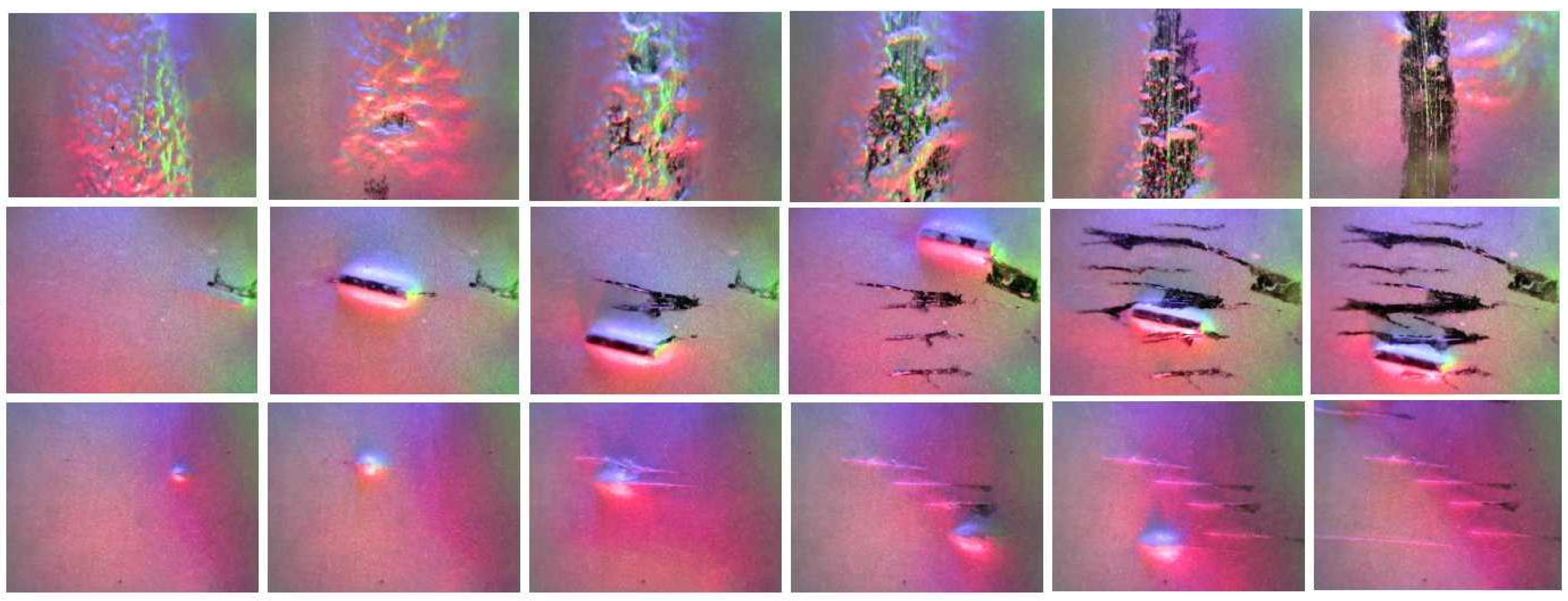


Abstract

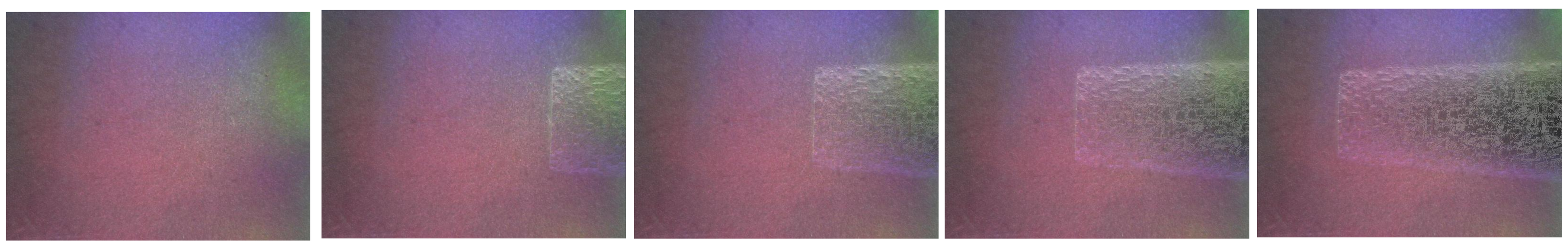
Optical tactile sensors are prone to wear and tear.
However, existing simulation methods only consider undamaged sensing membranes.
We extend our previous simulation method [1] to address these defects.

Real



Wearing and tearing of the real tactile sensor. First row shows the membrane being worn by sliding over sand paper. Second and third rows, tearing the membrane using different screwdriver bits.

Simulation



Synthethic membrane getting gradualy transparent over time due to the sliding against the synthethic sand paper. The artificial sandpaper is generated using a paramterizable randomly generated heightmap.

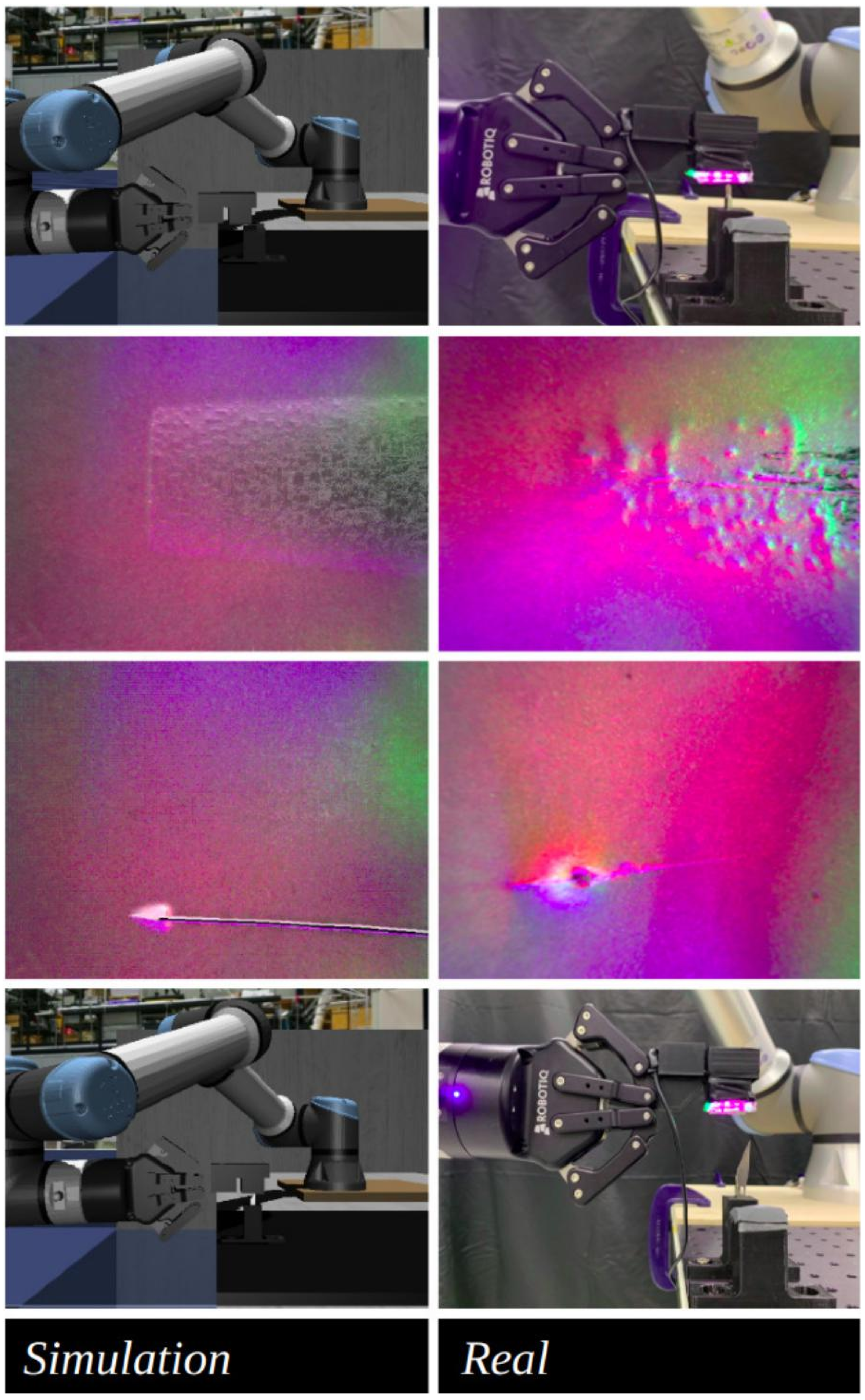
Limitations and Conclusions

The quantitative evaluation of the methods is challenging due to the difficulty in aligning the real and synthetic wear and tear.
Future research should focus on addressing this issue, as well as leveraging this capability to learn sim2real policies that actively avoid sensor damage.

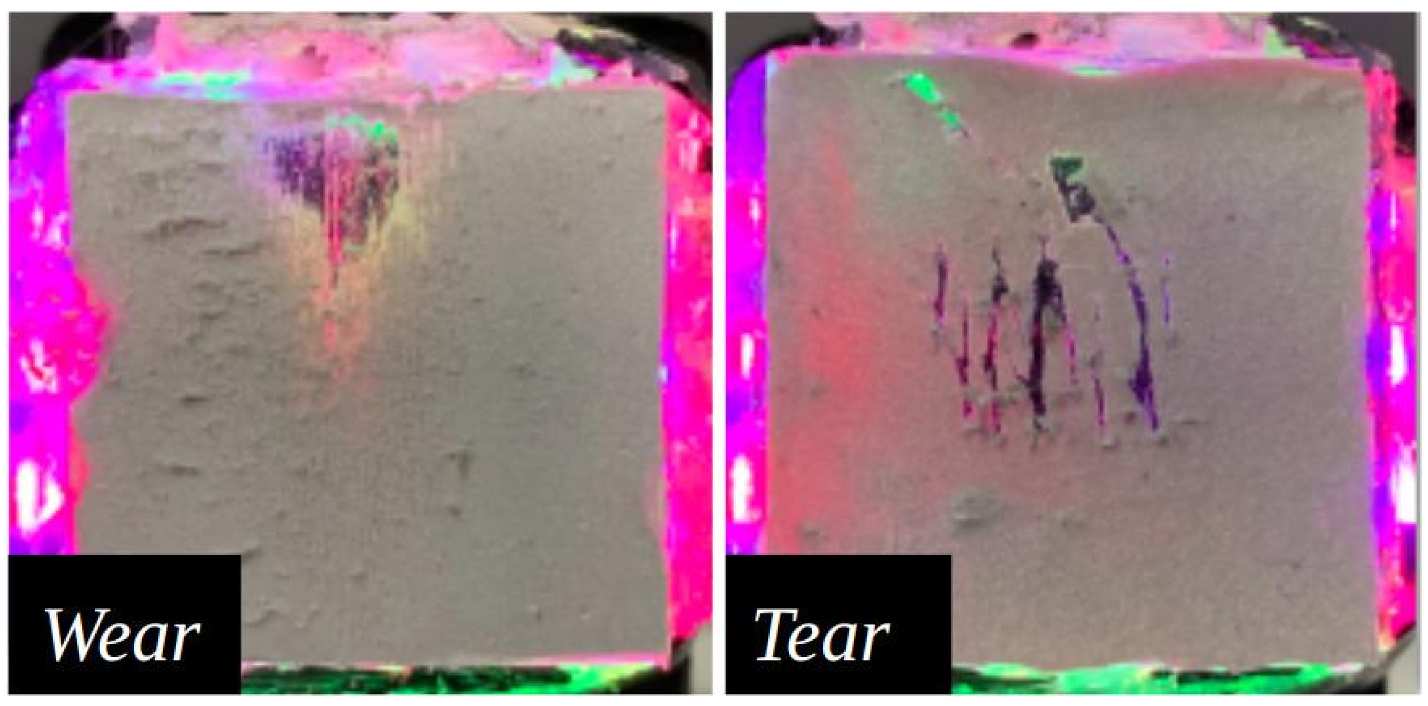
References

[1] D. F. Gomes and P. Paoletti and S. Luo "Generation of GelSight Tactile Images for Sim2Real Learning" RA-L 2021

[2] D. F. Gomes and P. Paoletti and S. Luo "Beyond flat gelsight sensors: Simulation of optical tactile sensors of complex morphologies for sim2real learning" RSS 2021



We investigate the simulating of the wear (resulting in transparent areas) and tear (punctures and cracking) of the membrane of optical tactile sensors.



Damaged membranes after collecting real tactile data. On the left, the worn membrane after sliding over sandpaper. On the right, the torn membrane after sliding over a scalpel.

A Neuromorphic Tactile Sensor based on Soft Optical Fiber

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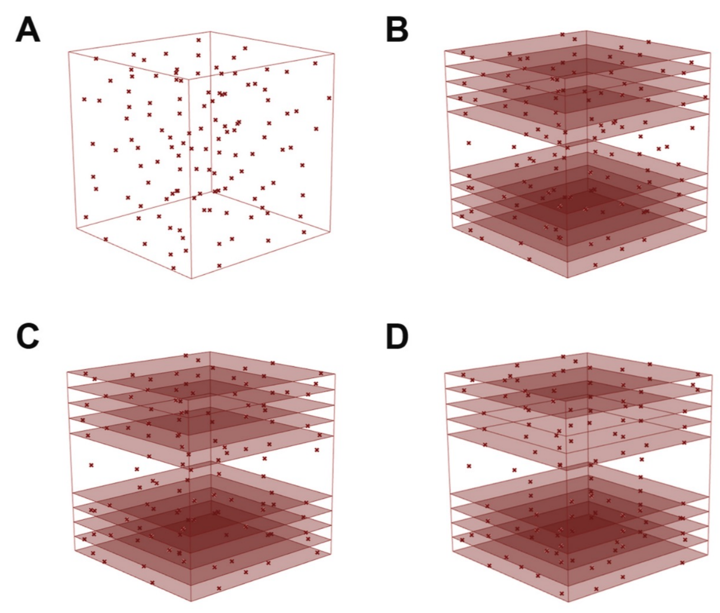
The University of Hong Kong [1], Centre for Transformative Garment Production [2]

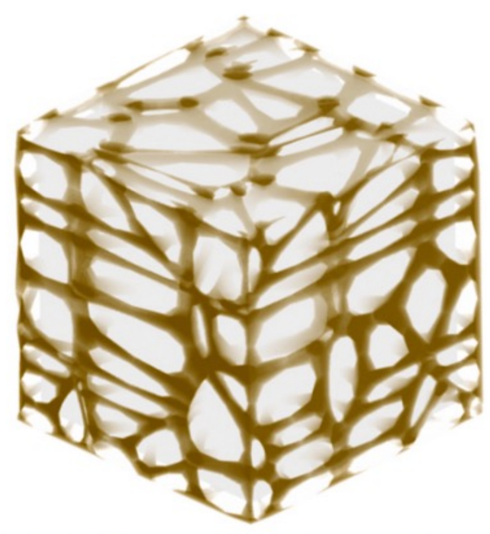
Problem Statement

- The robot needs a full history of force during the impact process, in order to code with the impact mitigation problem.
- This requires a novel type of sensor capable of enduring a distance of stroke longer than previous tactile sensor.
- Inspired by mammal nervous system, we propose a tactile sensor for impact robotics, with 3D-printed soft porous scaffold and soft optical fibers, analogous to mammal skin and mammal nerve.
- We use an encoder-decoder machine learning approach to recover the history of impact force from the optical fiber signal time series.

Workflow and Result

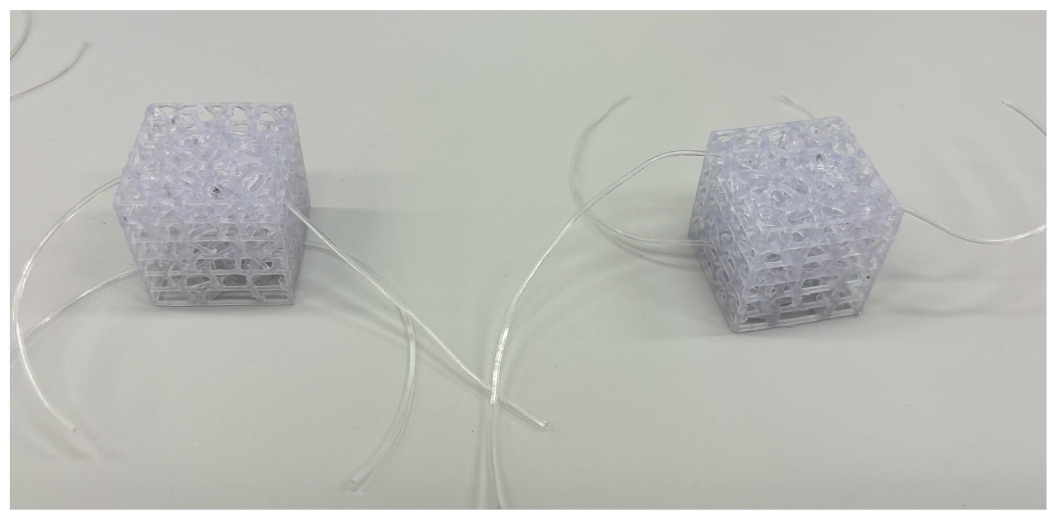


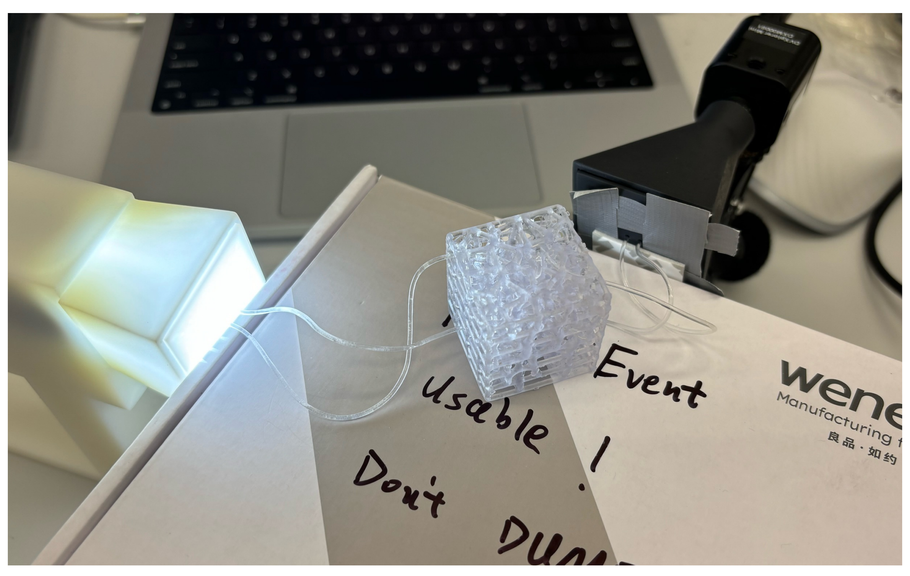
Separate the design space with multiple planes. Then propagate the planes with dots (seeds).



Use the Voronoi approach to generate struts within the design space and form the porous scaffold.

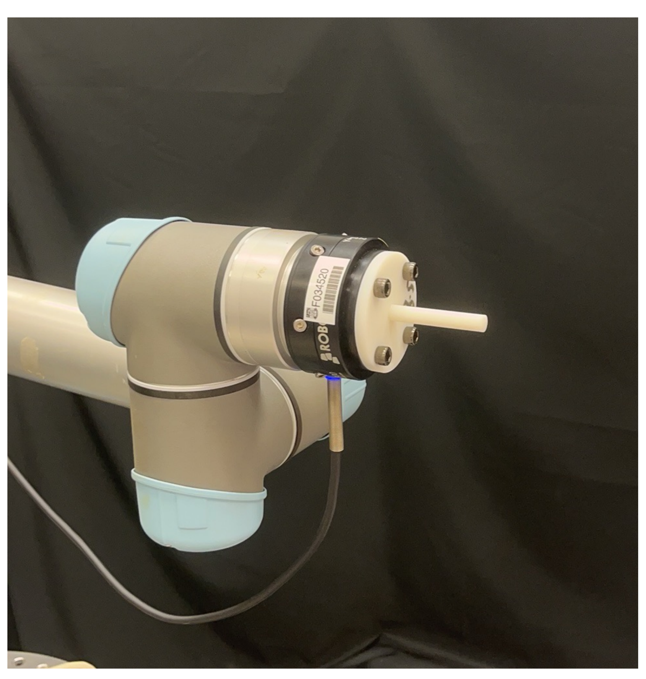
Use high-precision stereolithography (SLA) 3D-printing to produce the macroporous structure. Embed the soft optical fiber afterwards.





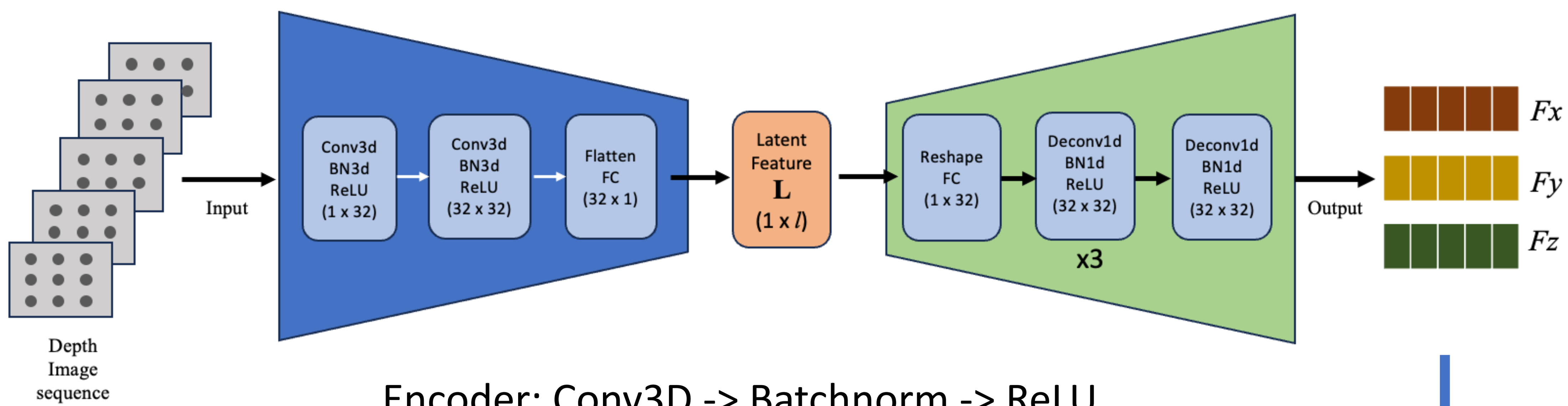
Connect the optical fibers to the stable light source and the high-speed camera.

+

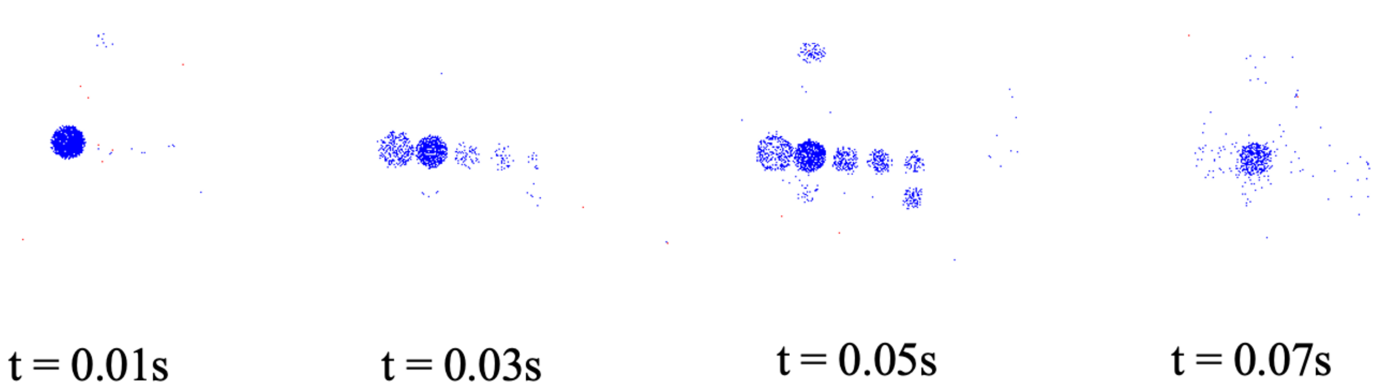


Impact the sensor with the end-effector on the robot arm at multiple speeds, and record the time history of forces.

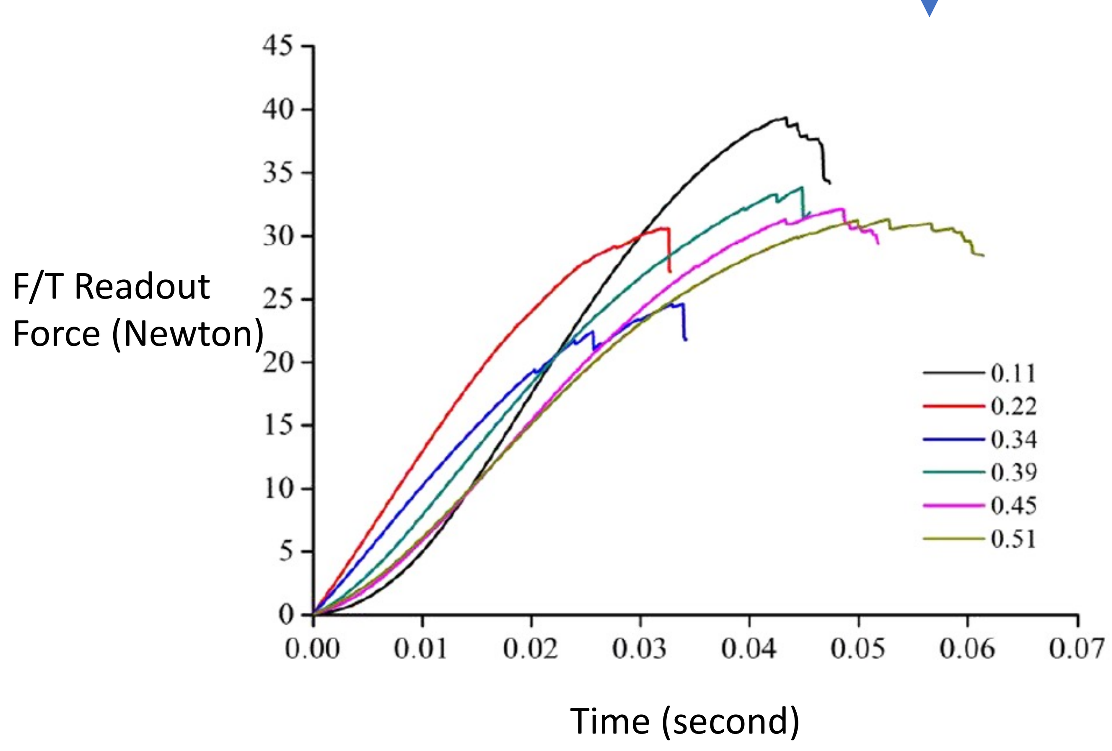
Use an encoder structure to obtain a latent feature from the depth image sequence. The latent feature is then decoded into time serials for forces in different directions.



Encoder: Conv3D -> Batchnorm -> ReLU
Decoder: Deconv1D -> Batchnorm -> ReLU



Example snapshots within the depth image sequence, showcasing the time-serial response of optical fibers.



Example history of normal force within 0.1 seconds, under different impact speeds.

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