PneuGelSight:
Soft Robotic Vision-based Proprioception and Tactile Sensing

Ruohan Zhang[1], Uksang Yoo[2], Yichen Li[2], Arpit Argawal[2], Wenzhen Yuan[3]

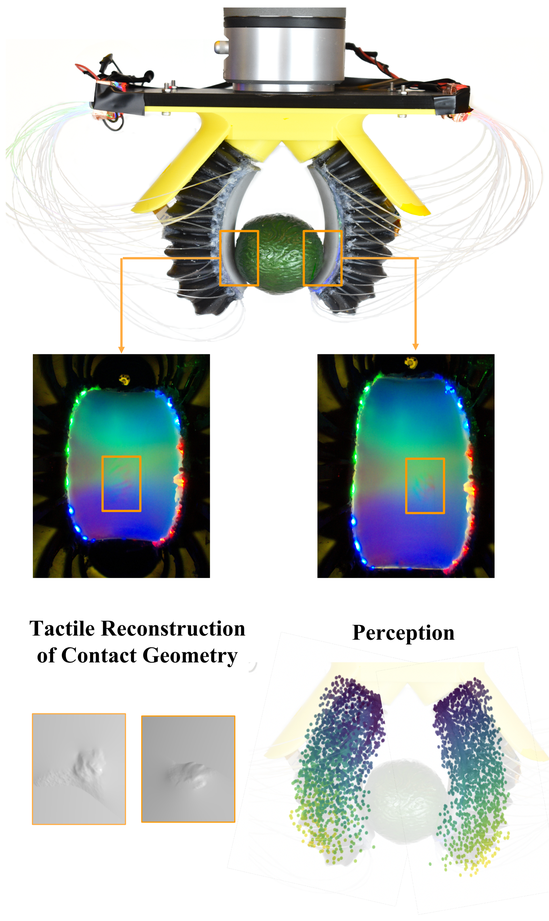
[1]Department of Electrical and Computer Engineering, University of Illinois Urbana-Champaign [2]Robotics Institute, Carnegie Mellon University
[3]Department of Computer Science, University of Illinois Urbana-Champaign

Introduction

Soft pneumatic robots offer high compliance and adaptability, making them ideal for applications in unstructured environments and safe human-robot interaction. However, their continuous and nonlinear deformations pose significant challenges for proprioception and tactile sensing.

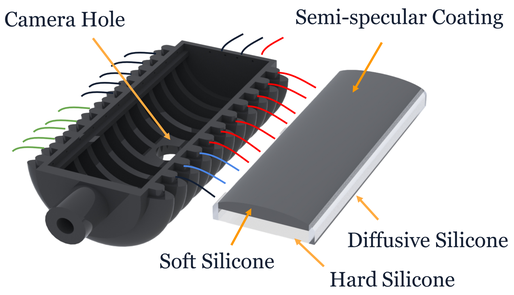
To address these limitations, we introduce PneuGelSight, a novel vision-based sensing system embedded in a soft pneumatic finger. Leveraging deep learning, the system reconstructs deformation and surface texture with high fidelity, offering a compact and scalable solution for sensing in soft robotics.

System Setup

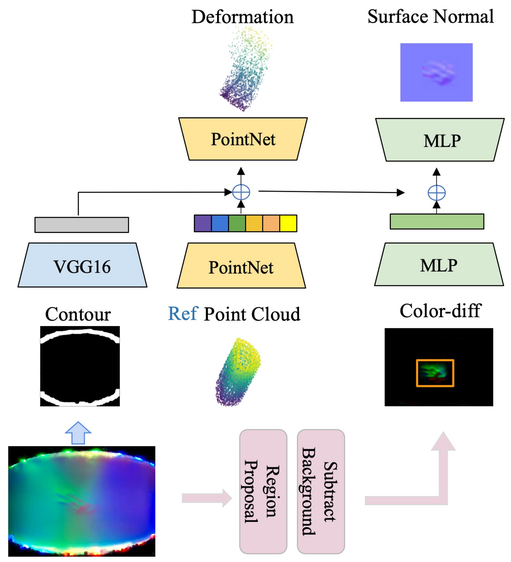


Mechanical Design

PneuGelSight integrates a soft pneumatic actuator with an embedded vision-based sensing system.
An internal Arducam with a 160° wide-angle lens captures deformation and contact information, while 24 optical fibers—arranged with RGB lighting and diffusers—provide uniform, color-coded illumination.



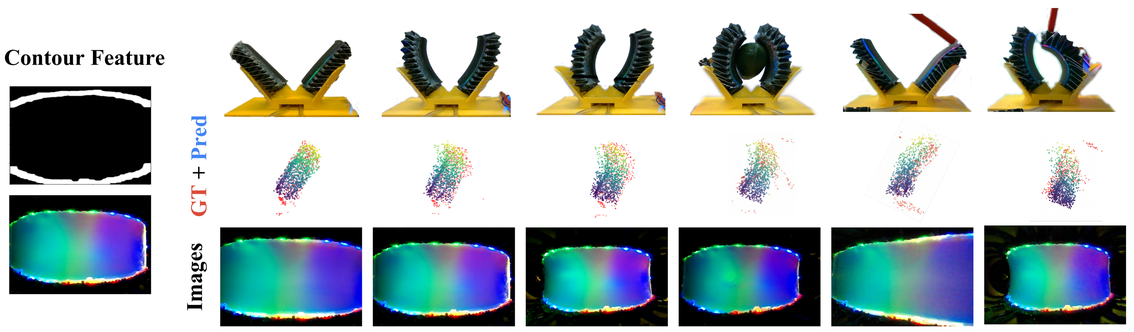
Neural Network Design



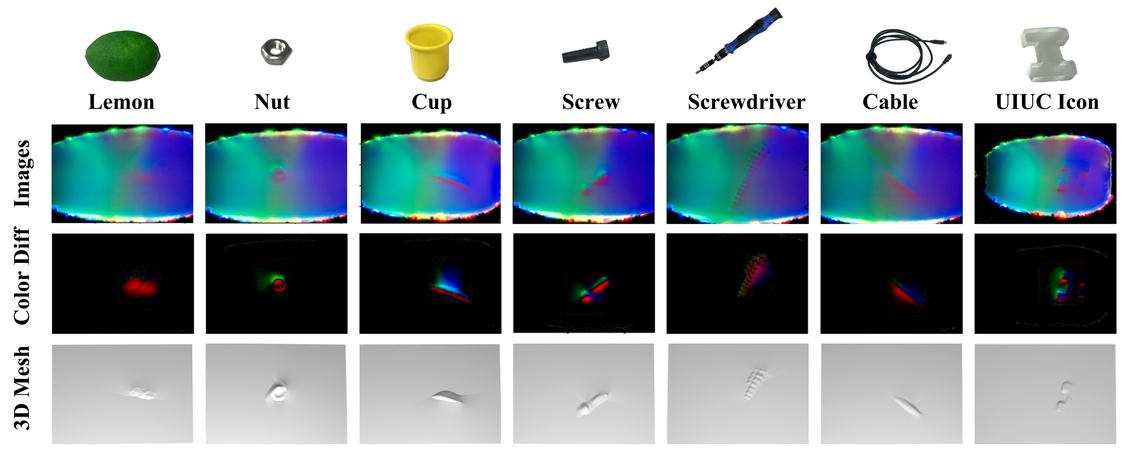
Our pipeline jointly estimates deformation and surface normals from images captured by the embedded camera.

- A VGG16 backbone extracts features from the input image, and a region proposal module isolates the contact area by subtracting the background.
- The reference point cloud is processed by PointNet, and fused with image features to predict the deformed shape.
- This deformation-aware representation is then passed to a two-stage MLP to estimate surface normals, enabling fine-grained tactile reconstruction.

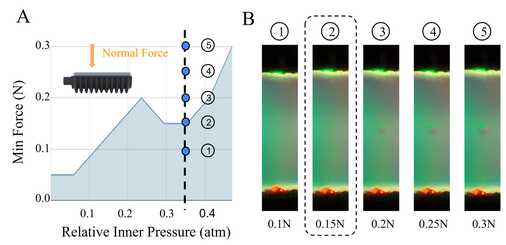
Proprioceptive Sensing Results



Tactile Sensing Results



Sensitivity Evaluation



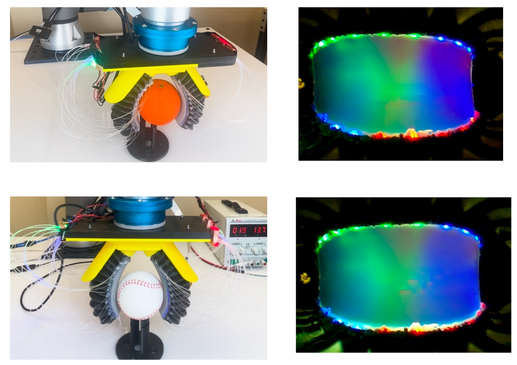
The sensor detects subtle contact with a minimum normal force of 0.15 N, highlighting its high tactile sensitivity under varying internal pressures.

Key Contributions

- Introduce a compact, deformable vision-based sensor embedded into a pneumatic finger
- Achieve ~5 mm accuracy in proprioceptive position estimation using a conditional autoencoder
- Perform texture reconstruction and surface normal estimation with MLPs conditioned on proprioceptive features
- Enable joint proprioception and tactile sensing with a single, embedded vision system

PneuGelSight offers a scalable framework for integrated sensing in soft robotic systems.

Application Scenarios



- Delicate object manipulation in soft grippers for agriculture or food handling
- In-hand object exploration for robotic learning and dexterous tasks
- Shape-conforming sensing in wearable or assistive robotic devices
- Texture-based recognition for surface inspection and classification

By embedding high-resolution sensing into a fully deformable form factor, PneuGelSight supports soft robot deployment in challenging, contact-rich environments.

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