Docket #: S21-409

DenseTact: Optical Tactile Sensor

Inspired by the "last inch" problem in robotic manipulation, the Kennedy group at Stanford has developed a tactile sensor and calibration method for machine-learning-based robotic manipulation. The core of this design is an optical tactile sensor using hemispherical silicone fingertips combined with a camera capable of measuring fingertip surface shape and forces. The camera is used to observe reflective boundaries, which are altered when the fingertip interacts with an object. To help build the calibration model, this has been done for a number of known objects and forms the basis of the machine-learning model.
As object grasping ranges in configurations and stability, the need for grasp planning and execution is critical for successful tactile sensors. The soft-contact nature of this design increases the range of motion and manipulation complexity, making the machine-learning model critical to precise execution and widespread application of this system. Automated manufacturing, assembly robotics, as well as collaborative robotics requiring humanoid manipulation are all possible applications of this system.

DenseTact: Optical Tactile Sensor for Dense Shape Reconstruction

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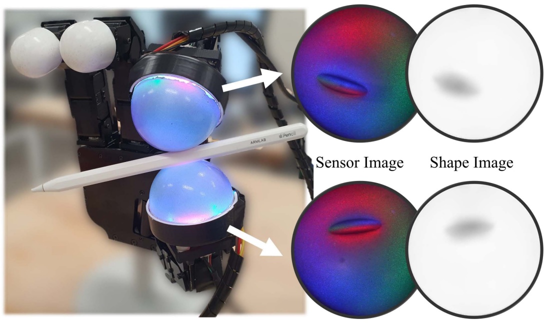
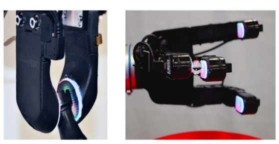
Introduction - DenseTact



1. A new 3D-shaped, vision-based soft tactile sensor design with a very soft elastomer contact surface with low construction cost and high sensing resolution
2. Novel calibration process for model which performs 3D shape reconstruction from single image with high resolution in real time, and
3. Adapted deep neural network for estimating sensor surface from interior sensor image.

Related Works

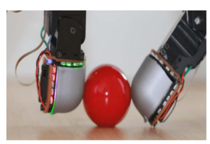
2D-shaped vision-based sensor



- Gelslim[1], DIGIT[2]

✓Flat surface limits the manipulation task.

3D-shaped vision-based sensor

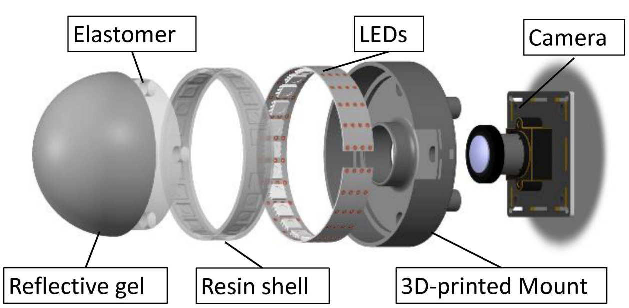


- Fingertip sensor[3], OmniTact[4]

✓Expensive and no shape reconstruction

✓Both type of sensor have relatively small resolution / depth

DenseTact Design



References

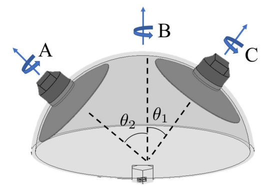
[1]: Taylor, Ian, Siyuan Dong, and Alberto Rodriguez. "GelSlim3. 0: High-Resolution Measurement of Shape, Force and Slip in a Compact Tactile-Sensing Finger." arXiv preprint arXiv:2103.12269 (2021).

[2]: Lambeta, Mike, et al. "Digit: A novel design for a low-cost compact high-resolution tactile sensor with application to in-hand manipulation." IEEE Robotics and Automation Letters 5.3 (2020): 3838-3845.

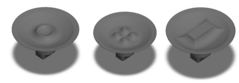
[3]: Romero, Branden, Filipe Veiga, and Edward Adelson. "Soft, round, high resolution tactile fingertip sensors for dexterous robotic manipulation." 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2020.

[4]: Padmanabha, Akhil, et al. "Omnitact: A multi-directional high-resolution touch sensor." 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2020.

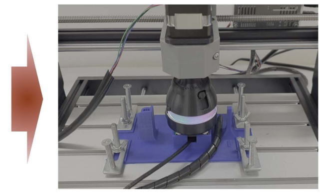
Data Generation



Hemispherical indicator

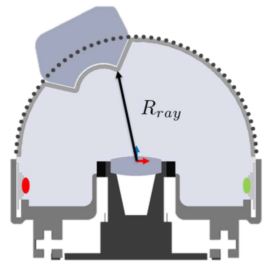


Different type of indenters

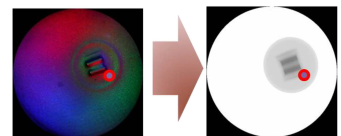


Generated depth data by contacting a known 3D surface model (0.1mm error, about 30,000 configurations).

Calibration



$(R_{ray}, \theta, \psi) = f_{Raycast}(x_{stl}, y_{stl}, z_{stl})$

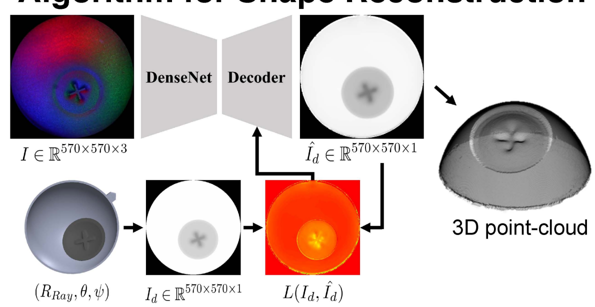


(u, v, I_R, I_G, I_B) (u, v, R_{ray})

$R_{ray}(u,v) = f_{raycast}(Mesh_{stl}, \theta(u,v), \psi(u,v))$

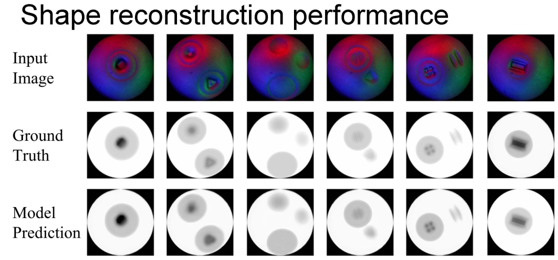
Matched the corresponding depth and input image from STL file using Ray casting algorithm and Gaussian Process

Algorithm for Shape Reconstruction



Results

- Shape reconstruction performance



- Reprojection error

DenseTact sensor performs the shape reconstruction with an absolute mean error of 0.281mm (training set: 0.2381mm, test set: 0.2811mm). Statistics are shown for the training (29,200 images) and test sets (1000 images).

Poster Description: DenseTact: Optical Tactile Sensor for Dense Shape Reconstruction

Video Description: DenseTact: Optical Tactile Sensor for Dense Shape Reconstruction (ARMLab)

Stage of Research

- Prototype

Applications

- Automated manufacturing and assembly robots: especially small, delicate objects
- Collaborative robotics: robots working in conjunction with humans that need to replicated human tasks

Advantages

- Quick adaptation to each task
- Large range of motion versatility for manipulation tasks

Publications

- Won Kyung Do, Monroe Kennedy III, "DenseTact: Optical Tactile Sensor for Dense Shape Reconstruction" *arXivLabs,* arXiv:2201.01367 (2022)

Patents

- Published Application: WO2023101859

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