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# Sliding Touch-based Exploration for Modeling Unknown Object Shape with Multi-fingered Hands

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## Introduction

**This work presents a multi-finger sliding touch strategy for efficient unknown object shape exploration. We learn an implicit function $g^{\text{IS}}(x)$ to represent object geometry:**

$$g^{\text{IS}}(x)\begin{cases} < \ 0 & \text{if } x \text{ is } \textbf{below} \text{ the surface} \\ = \ 0 & \text{if } x \text{ is } \textbf{on} \text{ the surface} \\ > \ 0 & \text{if } x \text{ is } \textbf{above} \text{ the surface} \end{cases}$$

$$\Sigma = (k_{\text{RBF}}(\boldsymbol{X},\boldsymbol{X}) + \sigma^2\boldsymbol{I})^{-1}$$

$$\overline{g}(\boldsymbol{x}_*) = k_{\text{RBF}}(\boldsymbol{X},\boldsymbol{x}_*)^{\text{T}}\Sigma\boldsymbol{Y}$$

$$\mathbb{V}(\boldsymbol{x}_*) = k_{\text{RBF}}(\boldsymbol{x}_*,x)^{\text{T}}\Sigma k_{\text{RBF}}(\boldsymbol{x}_*,x)^{\text{T}}$$

**Main contributions are organized as follows:**

- **A visuo-tactile perception approach based on continuous sliding touches.**
- **A hand agnostic single-leader-multi-follower strategy perform smooth tactile sensing.**
- **We demonstrate that the visuo-tactile perception can be performed with limited arm motion without re-establishing contact.**

## Robotic System Setup

**Robotic Platform:**

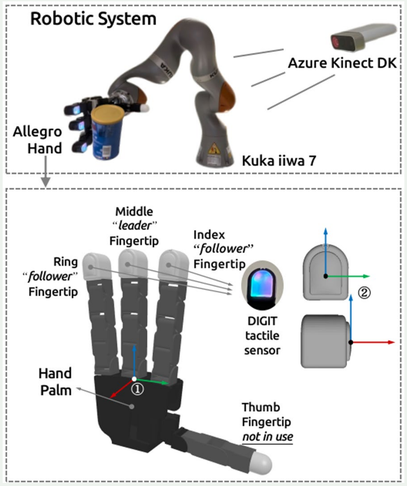
**KUKA IIWA 7 and**

**Allegro Hand**

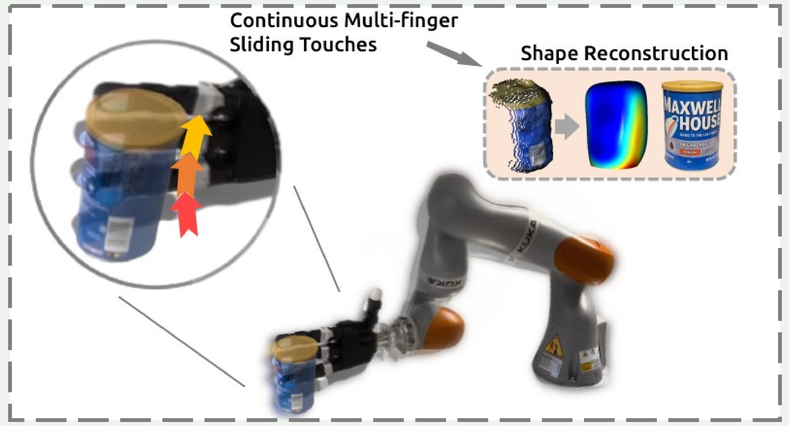
**Sensors:**

**Visual: Azure Kinect DK**

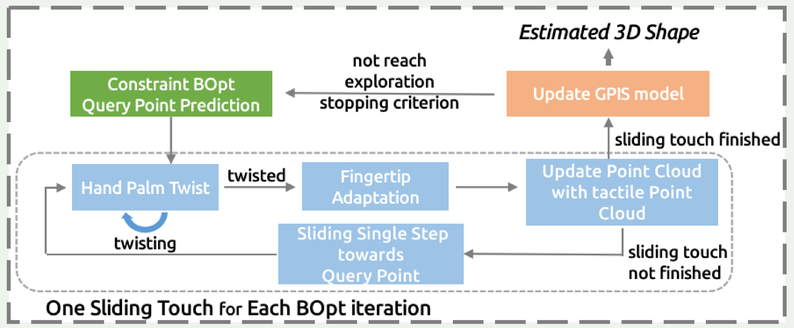
**Tactile: DIGIT**



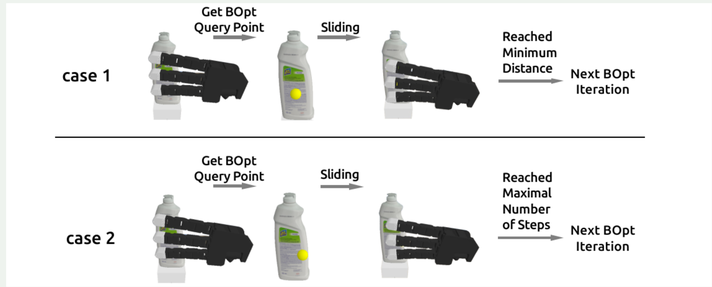

## Methodology




**We model the target object using a probabilistic representation, *Gaussian Process Implicit Surface* (GPIS).**



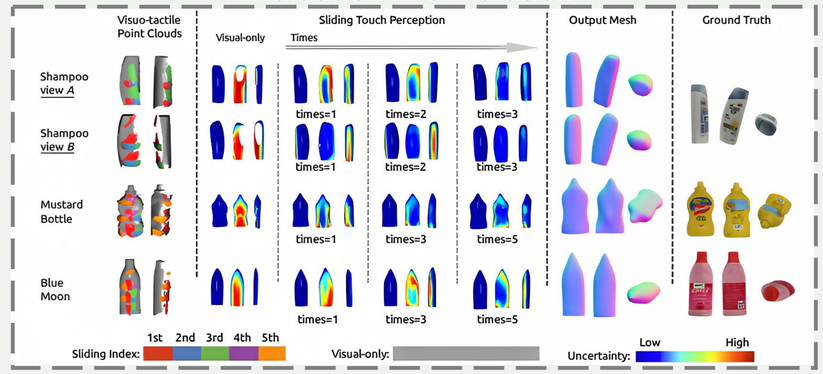

**GPIS provides uncertainty for exploration guidance based on *Bayesian Optimization*.**



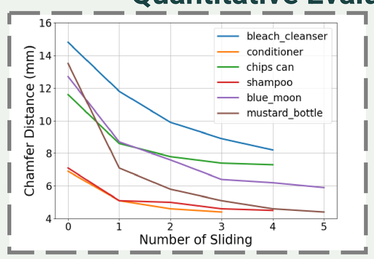

**A successful shape modeling only requires a few continuous sliding touches.**

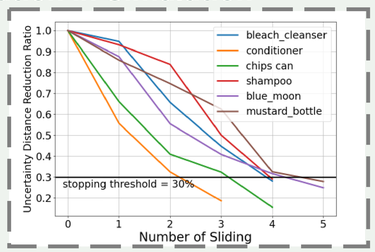
## Experimental Results

### Evaluation in Simulation

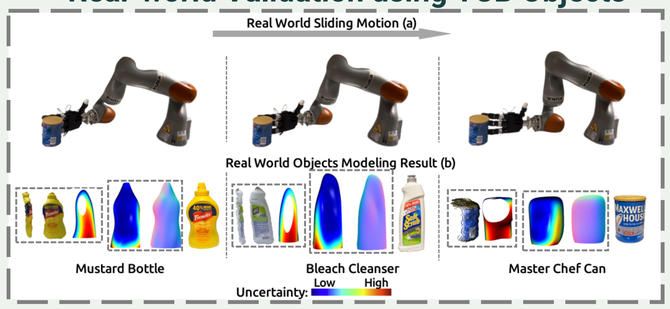



### Quantitative Evaluation in Simulation




### Real-world Validation using YCB Objects




## More Details ...

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