Interactive Design of GelSight-like Sensors with Objective-driven Parameter Selection

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***Abstract*— Camera-based tactile sensors have shown great promise in dexterous manipulation and perception of object properties. However, the design process for vision-based tactile sensors (VBTS) is largely driven by domain experts through a trial-and-error process using real-world prototypes. In this work, we formulate the design process as a systematic and objective-driven design problem using physically accurate optical simulation. We introduce an interactive and easy-to-use design toolbox in Blender, OptiSense Studio. The toolbox consists of (1) a set of five modularized widgets to express optical elements with user-definable parameters; (2) a simulation panel for the visualization of tactile images; and (3) an optimization panel for automatic selection of sensor designs. To evaluate our design framework and toolbox, we quickly prototyped and improved a novel VBTS sensor, GelBelt. We fully design and optimize GelBelt in simulation and show the benefits with a real-world prototype.**

I. Background

Touch sensing enables dexterous manipulation and perception of object properties, like hardness and textures. Vision-based tactile sensors (VBTS), specifically GelSight [1], offer high-resolution tactile signals that has significantly improved robotic regrasping, dexterous manipulation, enabled dense object shape perception, and incipient slip detection. The current design space of sensors in GelSight family covers a wide range of features, including illumination system [2], [3], curvature [4], [5], [6], mirrors [7], and compliance [8]. One major barrier to the creation of camera-based tactile sensors is the lack of a systematic framework for exploration and creation of these sensors. There are two primary challenges in creating a standardized design toolkit for the rapid prototyping of camera-based tactile sensors. The first is a *design guideline*: given a desired robotic application, how and when to add optical elements. The second is *parameter selection*: given an optical sensor setup, a simulation-driven forward and inverse parameter selection based on performance metrics is needed. To address the challenge, we propose a modular way to generate the GelSight sensor design that is parameterized. We also propose an objective-function-driven parameter selection pipeline for selecting the optical properties of the sensor.

II. Current results

Fig.1 shows the conversion of the GelBelt concept design into a parameterized VBTS sensor design using OptiSense Studio modules. In Fig.1(**A**), the user designs an initial CAD that contains the locations and shapes of the sensor components. In Fig.1(**B**), the CAD design is converted to a full sensor design in OptiSense Studio. We automatically parameterize the optical design and optimize it using new sensor evaluation criteria in our simulation-driven framework. Fig.1(**C**) The final design can then directly be manufactured and tested in the real world. In Fig.2, we introduce an interactive sensor modeling and optimization toolbox, the OptiSense Studio. Fig.2.i) Importing CAD shapes and setting them as reference geometries for optical elements; Fig.2.ii) Assigning material properties to the component from the component library or using user-defined materials; Fig.2.iii) Adding lights and the camera using reference geometries. The lights and the camera are chosen from the component library. Fig.3 shows a pictorial representation of the design evaluation process. Intuitively, the idea behind our objective function is that the trend between color value and surface normal along the spherical indenter axis should be as linear as possible. In Fig.4, we compare the tactile images generated in the simulation to that of the optimal GelBelt design prototype. The tactile images are a close match quantitatively and quantitatively with an average SSIM of 0.88 (with the best value being 1.0).

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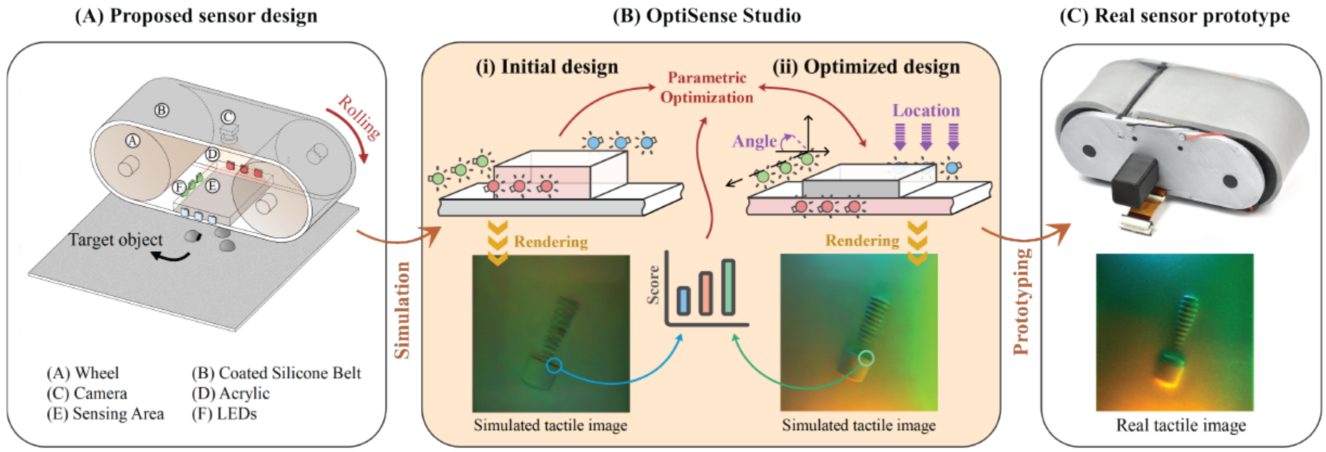

Fig. 1. Framework for modularizing and parameterizing camera-based sensor

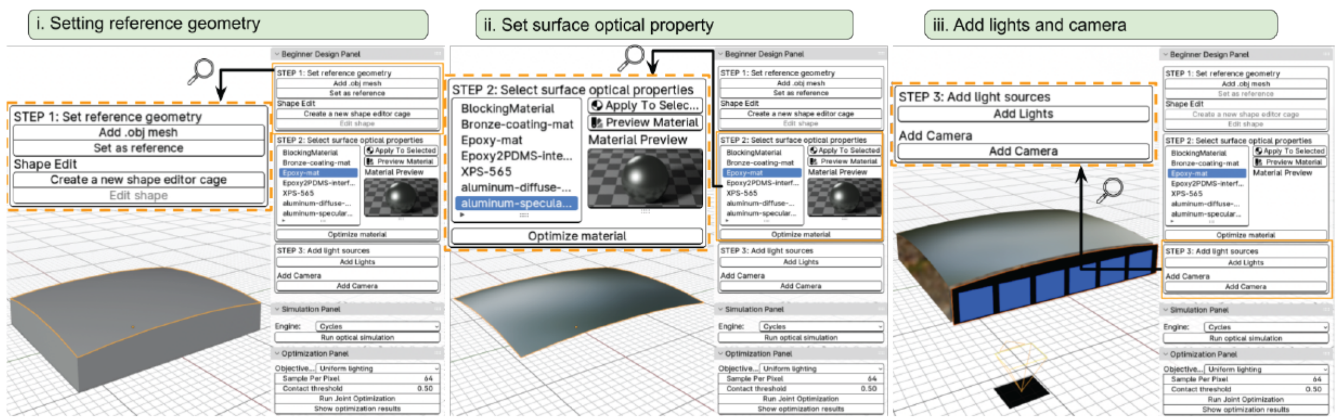

Fig. 2. OptiSense Studio and Digital design guideline

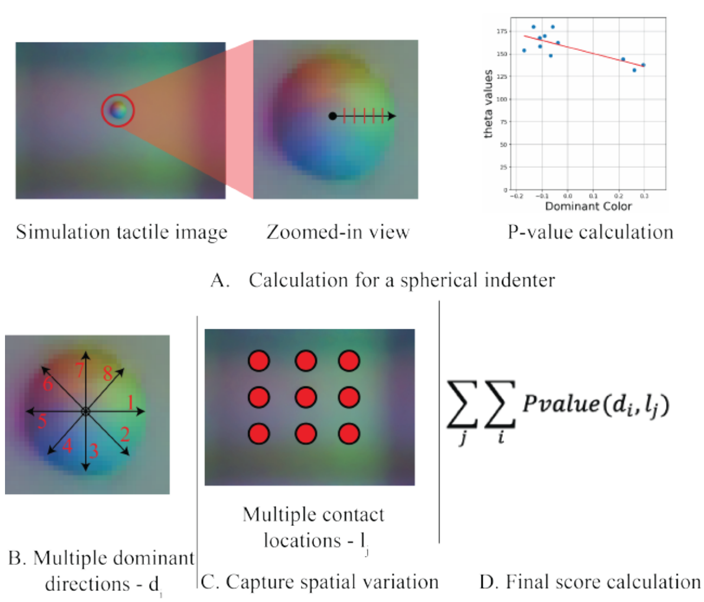

Fig. 3. Sensor evaluation procedure

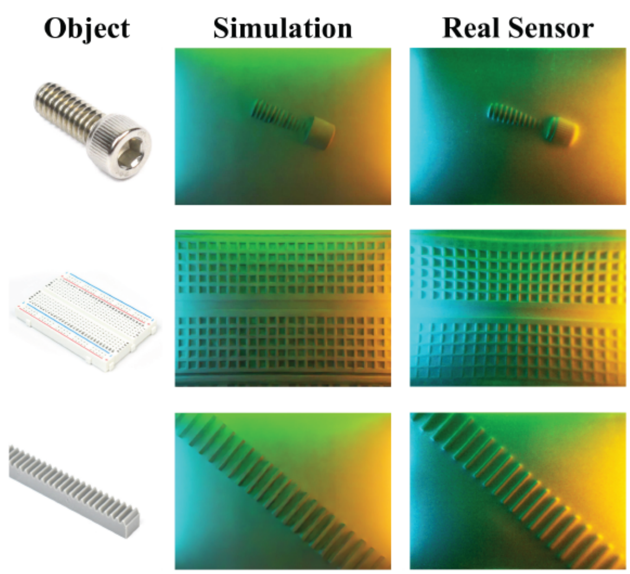

Fig. 4. Simulation-to-real comparisons