Tactile Sensing with Overlapping Optical Signals

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Tactile sensing can provide critical contact information for closed-loop manipulation. Here, we explore a method for building a tactile sensor as a continuous volume of a transparent polymer, with light emitters and receivers embedded along the perimeter (Fig. 1). Indentation of the sensor area affects how emitted light is transported through the medium, producing a signal that is measured by the receivers. We use indentation depth as a proxy for contact force, assuming a known stiffness for the underlying material.

Based on this sensor, we use data-driven methods to directly learn the mapping between a rich extracted signal set and our variables of interest. For our sensor architecture, such a rich data set can be obtained by measuring the signal between every emitter and every receiver. In the past, we have used an all-pairs approach on a piezoresistance-based sensor and showed it can lead to high localization accuracy [1]. Here, we show that with optics as the underlying transduction mechanism we can significantly increase performance, and additionally learn to identify indentation depth.

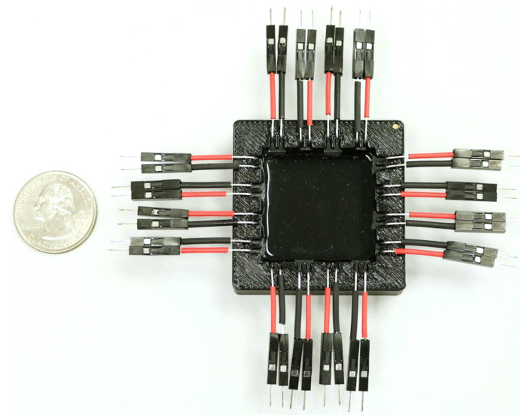

Fig. 1: Sensor consists of a square mold with edge-mounted LEDs and photodiodes and a cavity is filled with an elastomer. We measure how the light is guided through this elastomer to learn the location and the depth of an indentation.

Multi-pair Sensor Design. We validate our concept on a sensor comprised of 8 LEDs and 8 photodiodes. To build the sensor we use a 3D printed square mold with exterior dimensions of 45mm x 45mm. The cavity in the mold is 32mm x 32mm, which represents our active sensing area. Both LEDs and photodiodes are mounted in sockets on the walls of this cavity, which is then filled with PDMS.

Light travels from emitters to receivers via multiple paths that cover the sensing area. This way any LED excites several photodiodes. For each LED-photodiode pair, an indentation changes the amount of light that can travel between them, and thus the signal measured by the diode. First, during initial contact, the indenter alters the geometry of the surface and changes the refraction of the light. Second, as indentation becomes deeper, the indenter blocks direct paths between the LED and the diode.

Our multi-pair approach gives us a very rich signal set, with cardinality equal to the number of emitters multiplied by the number of receivers. We read signals from all diodes as different LEDs turn on, plus one signal with all LEDs off to measure the ambient light as captured by each diode.

Indentation Localization and Depth Prediction. Our main objective is to learn the mapping between our photodiode readings and the indentation location and depth. We split this problem into two components. First, we use a classifier (linear SVM) to determine if touch is occurring; this classifier is trained both on data points where a probe indents the surface, and on data points where no indentation is taking place. If the classifier predicts that touch is occurring, we use a second stage regressor (kernelized ridge regression with Laplacian kernel) that outputs continuous predicted values for indentation localization and depth. This regressor is trained only on training data where indentation is occurring.

The results shown in Table I, aggregated over a test set of 100 indentations at random locations, show that we achieve sub-millimeter accuracy in predicting both the location and the depth of the indentation. These results represent a first step towards integrating such sensors on robotic fingertips, and using them to close the loop for manipulation tasks.

References

[1] P. Piacenza, Y. Xiao, S. Park, I. Kymissis, and M. Ciocarlie, "Contact localization through spatially overlapping piezoresistive signals," in *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems*, 2016.

TABLE I: Localization and depth accuracy (all units mm)

True Depth	Localization Accuracy		Depth Accuracy	
	Mean Err.	Std. Dev	Mean Err.	Std. Dev
0.5	0.838	0.616	0.060	0.048
1.0	0.744	0.530	0.065	0.051
3.0	0.413	0.256	0.047	0.041
5.0	0.359	0.222	0.092	0.062

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A companion presentation on the geometry of light transport for tactile sensing will be presented at the IEEE Humanoids 2016 Workshop on Tactile Sensing for Manipulation. A more detailed study of the sensor described here is under review for IEEE ICRA 2017.