An Optics-based Tactile Sensor: Design and Operation

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Tactile sensors can provide important information to improve the dexterous manipulation capability of robotic hands. We propose a low cost, easy to manufacture tactile sensor based on light transport through a polymer. Light emitting diodes and photodiodes are edge mounted around the sensing area, which is filled with an optically clear elastomer (PDMS). An indentation on the sensing area deforms the elastomer and affects how light is transported through this medium, resulting in a measurable signal by the receivers.

Multiple light emitters and receivers results in a one-to-many relationship that provides us with a rich set of signals when pairing each emitter against each receiver. We have used this all-pairs approach in the past on a piezoresistance-based sensor and showed it can lead to high localization accuracy [1]. We use a data-driven approach to directly learn the mapping between these signals and our variables of interest, such as indentation location and depth. We show that using optics as the underlying transduction method yields increased performance in contact localization, and additionally allows to learn the indentation depth when compared to our previous piezoresistive sensor. Depth is used here as a proxy for indentation force, assuming a known stiffness for the underlying material.

Tactile sensing via light transport. Our sensor is comprised of a 3D printed mold with exterior dimensions of 45mm x 45mm. The interior cavity measures 32mm x 32mm and represents our active sensing area. 8 LEDs and 8 photodiodes are mounted in sockets on the walls of this cavity.

Light will reach any given photodiode either through a direct path, or through a reflection off the surface of the elastomer. Reflections off the base of the mold are purposefully disabled by having a thin layer or carbon black infused PDMS. Reflections off the surface of the sensor are enabled by the difference in refractive index between our elastomer and air. Based on Snell's law, light rays hitting this surface below the critical angle are reflected back completely into the elastomer.

As the probe makes initial contact with the sensor surface, light scatters where it was previously reflected. Furthermore, surface normals are disturbed in the vicinity of the indentation. *This is the first mode of interaction that our sensor captures*. It is sensitive to initial contact and requires very little penetration depth to produce a strong output signal.

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A more detailed study of the sensor described here is under review for IEEE ICRA 2017.

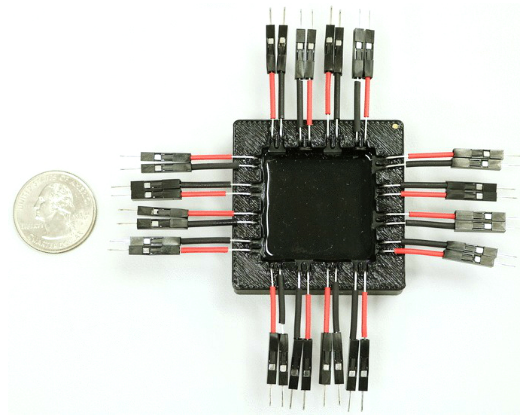
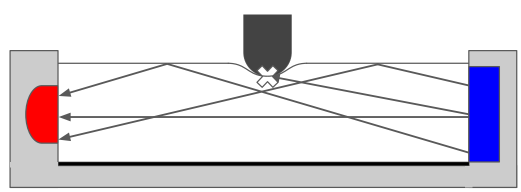
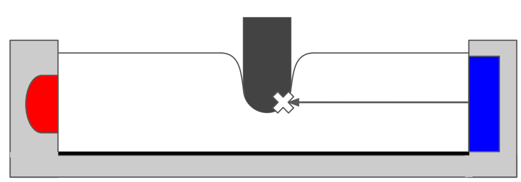


Fig. 1: Sensor consists of a square mold with edge-mounted LEDs and photodiodes and a cavity is filled with an elastomer. We measure how the light is guided through this elastomer to learn the location and the depth of an indentation.

As the probe indents the sensor deeper, the object penetration starts to block some of light rays that were reaching the photodiode through a direct path. *This is our second mode of interaction*. It is sensitive to deep indentations, where the probe physically blocks the photodiode from an LED's vantage point.



a) First mode of detection



b) Second mode of detection

Fig. 2: Indentation sensing via light transport. The first mode of detection (a) is the result of light scattering and surface deformation when the indenting object makes contact with the sensor surface. The second mode (b) is the result of the indenter tip physically blocking the direct path of light

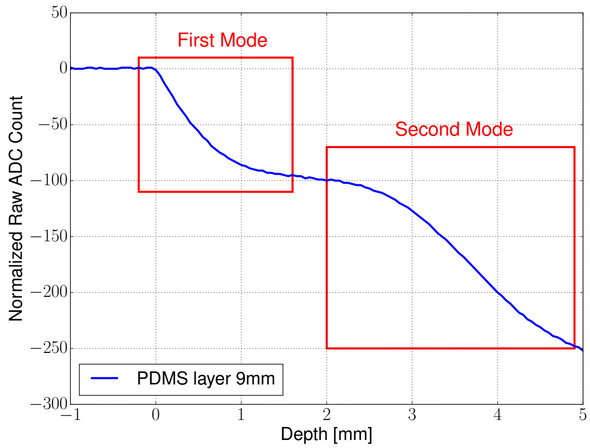


Fig. 3: Two detection modes are identified when the indenter tip interacts with the elastomer. The first mode happens upon light contact and manifests as a sudden drop in the signal. The second mode is activated with a heavier contact

Figure 3 shows the signal output where the two interaction modes can be clearly identified. We can control the transitions between these two modes to our advantage and make them continuous by adjusting both the thickness of the PDMS layer and its stiffness.

Indentation Localization and Depth Prediction. The main objective is to learn the mapping between the signals from the photodiodes to the indentation location and depth. To this effect, we measure the signal from all diodes as each LED is switched on. We feed this feature vector to a two stage learning algorithm. The first stage is a touch vs no-touch classifier. The second stage is used when the classifier predicts a touch event. At this point a regressor predicts both the location and depth of the indentation. More details on the learning algorithm are available in a companion presentation [2] and a complete study of the system is currently under review [3].

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.

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[3] ——, "Accurate contact localization and indentation depth prediction with an optics-based tactile sensor," in *IEEE Intl. Conf. on Robotics and Automation*, 2017 (under review).