iCub Tactile Sensing System: Current State and Future Directions

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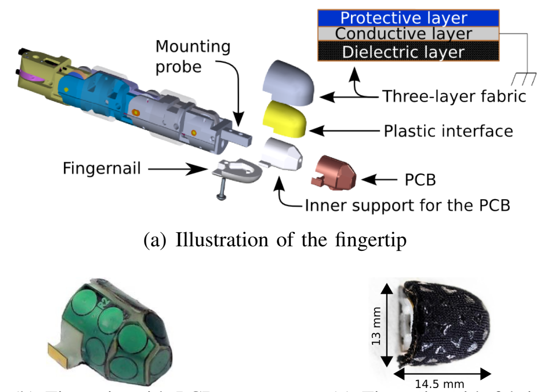
Robots that can dexterously manipulate objects are important in applications such as domestic robots, industrial robots and emergency response robots. Several tactile sensors have been proposed, however, only a few can be fully integrated with robotic hands. A typical problem that prevents integration is lack of sensors that can be deployed on curved surfaces. In this paper we present a new fingertip for the hands of the iCub robot.

Researchers have used different physical phenomena to develop tactile sensors. These include capacitive [1], piezoresistive [2] and optical [3], [4]. Attempts have been made to build sensors that can provide all three components of force [3], [5]. Similarly, multi-modal tactile sensors that can sense force, temperature [6], [7] and vibration [6] have been investigated. Majority of the sensors discussed are rigid, i.e., they don't lend themselves well to applications where the sensors have to be attached to curved surfaces such as the fingertip of a humanoid robot. To this end, tactile sensors using flexible printed circuit boards (PCB) have been developed [4], [8]. Others have used skin patches specifically designed for different body parts of the robot [9].

The proposed fingertip, illustrated in Fig. 1, is capacitive, made from a flexible PCB and a multi-layer fabric that includes the dielectric material and the conductive layer. It builds on previous work on the iCub tactile system [10], [11]. The shape of the fingertip was chosen to make the fingertip compatible with the existing mounting probe on the iCub hand. Typically the dielectric layer is made of an elastomer covered by a conductive layer. This complicates the production process and limits the durability of the sensor due to aging. The novelty of this design is that it replaces the elastomer and the conductive silicone with a three-layer fabric that comprises of a deformable dielectric layer, a conductive layer and a protective layer [11]. The three-layer fabric is manufactured using industrial techniques. As a result the fingertips are consistent, reliable, robust and easier to manufacture. We show that the proposed fingertip is able to detect forces as low as 0.05 N with high spatial resolution and low cross-talk.

The fingertip is $14.5\,mm$ long, $13\,mm$ wide with 12 taxels. Its assembly comprises 5 layers (see Fig. 1(a)). The inner support is made of plastic. The inner support attaches to the finger of the robot through a mounting probe. A flexible PCB is wrapped around the inner support (Fig. 1(b)), the 12 taxels are deployed on locally flat planes that are cut on the inner support. The PCB hosts the chip that performs capacitance to digital conversion. A $1\ mm$ plastic conforms to the PCB on the inner side and adheres to the three-layer fabric on the outside. The outer shell of the sensor is made up of a three-layer fabric that incorporates: a deformable neoprene layer, a conductive textile material (lycra) and a protective textile layer. The conductive lycra is connected to ground. This assembly forms a capacitive sensor. An applied pressure on the fingertip deforms the soft neoprene, thus reducing the distance between the PCB and the surface of the fingertip. Consequently, the measured capacitance value changes. It is possible to estimate the applied pressure from the capacitance value by calibrating the output of the sensor against known values. Fig. 1(c) shows a complete fingertip.



(a) Illustration of the fingertip

(b) Fingertip with PCB

(c) Fingertip with fabric

Fig. 1. The proposed fingertip

The experimental validation of the proposed fingertip was done using an Omega.3 robot from Force Dimension. As depicted in Fig. 2(a), this setup consists of an ATI Nano-17 force/torque sensor sandwiched between the robot and a probe. The probe has a 4 mm diameter. To stimulate the fingertip the robot applies and maintains a given force at a location of interest. Figure 3 summarizes the results of the validation experiments, namely, sensitivity and spatial resolution, which will be described in the following paragraphs.

The sensitivity of a taxel was studied by applying an increasing step-force in 0.01 N increments. The experiment indicated that the fingertip can differentiate forces as low as 0.05 N. To verify our findings the taxel was stimulated by applying a step-force in the range 0.06 N and 0.51 N with 0.05 N increments. In each step, the force is applied for 5 seconds, then the probe is lifted vertically up. We wait 20 seconds for the sensors to reach their baseline value before another stimulus is applied. Each step was repeated 10 times. Figure 3(a) shows that the fingertip can resolve a 0.05 N force with statistical significance.

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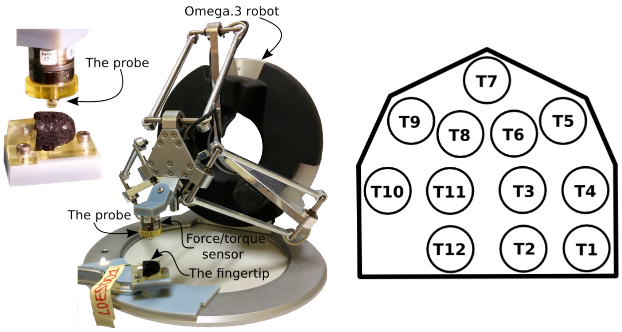


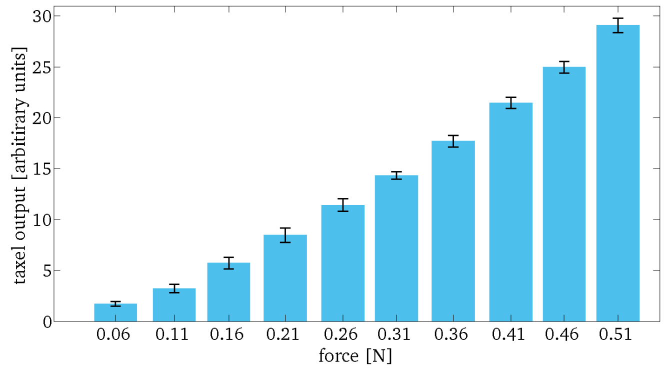
(a) (b)

Fig. 2. a) The setup and b) a map of the taxels of the fingertip used for the experimental evaluation.

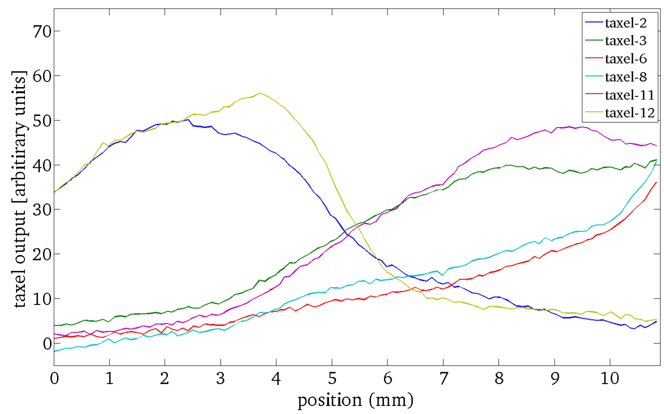
To test the spatial resolution of the fingertip, we used the Omega.3 setup to apply a stimulus of 4 N at multiple locations. The starting position was at the back of the fingertip, between taxel-12 and taxel-2 (see Fig. 2(b)). The stimulus was applied, in 0.1 mm intervals, along a straight line that ended at the midpoint between taxel-8 and taxel-6. At each location the 4 N stimulus is maintained for 2 seconds, then the probe is lifted vertically up waiting 5 seconds to allow the sensors to reach their baseline value before another stimulus is applied.

Figure 3(b) shows the response of the taxels averaged over 10 samples, just before the probe is lifted up. At the starting point taxel-2 and taxel-12 have the highest response levels. As we move away, taxel-3 and taxel-11 start to respond to the stimulus. Finally, as we approach the tip of the finger, taxel-6 and taxel-8 respond. Not surprisingly, it matches the taxel map of Fig. 2(b). We also notice that not all sensors respond at the same level. This can be explained by the fact that the probe placement is approximately in the middle of the taxels in question. Moreover, there is no cross-talk between the taxels. The response of the taxels is consistent with the probe location, that is, only the taxels stimulated by the probe are activated. The spatial resolution and cross-talk effects are better visualized in the accompanying video [12].

We have presented a robotic fingertip based on capacitive technology that can be fitted to the hands of a humanoid robot. The novelty of the fingertip is that it replaces previously used silicone foam and conductive silicone with a three-layer fabric; the advantage of which is, that there are well developed industrial processes for manufacturing which result in easier manufacturing, better repatibility and robustness. We showed that the fingertip can sense forces as low as 0.05 N, there is no cross-talk between taxels and has a good spatial resolution with overlapping receptive fields. The latter is useful property that can be exploited for hyperacuity [13] and force reconstruction [14].



(a) Taxel sensivity: taxel outputs are averaged over 10 sampler per force step (force step = 0.05 N). The error bars represent one standard deviation.



(b) Spatial resolution. Only the taxels that were activated are shown.

Fig. 3. Experimental validation results.

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