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Robust Fabrication of a Soft Mechanosensor based on Pneumatic Measurements

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and Christian Duriez

***Abstract*— In this extended abstract, we complement the work presented in a previous paper where we have shown the modeling of a novel soft pneumatic mechanosensor. With the objective of giving a demo at the RoboTac 2019 workshop, we discuss robust manufacturing techniques that enable us to fabricate such soft mechanosensors out of silicone with embedded cavities in a consistent manner.**

I. INTRODUCTION

This work is a complement to a recent paper of our group, where we presented the modeling of novel soft mechanosensors [1]. For the modeling, we used the FEM, which in recent years has been shown to enable the simulation of the behavior of soft structures at interactive update rates. This is the key to transferring these results to real robots made out of deformable materials. In the work of our team, these methods are implemented within the multiphysics simulation framework SOFA [2], [3].[1] In this approach, we see an opportunity to advance towards generic models that can integrate measurements from a diversity of sensors. For a more in depth discussion of the motivation and related work, please refer to the paper.

In this extended abstract, we present our work on fabricating soft pneumatic mechanosensors made out of silicone. We target to give a demo at the RoboTac 2019 with this newly fabricated sensor and the designs shown in [1]. The specific challenge we address here, is how to reliably fabricate a sensor that has multiple airtight embedded cavities inside, suitable for air-flow and pressure sensing. Our casting techniques are based on 3D-printed molds, which makes them reproducible for Robotics laboratories around the world. We provide step by step instructions and discuss the experiences that lead to our design choices. In Fig. 1 (top) the sensor we fabricated is shown on a test bench. We have also modeled this new design in SOFA (see Fig. 1 below). We aim to make all the files needed for printing the molds and simulating the sensor in SOFA available to the public.

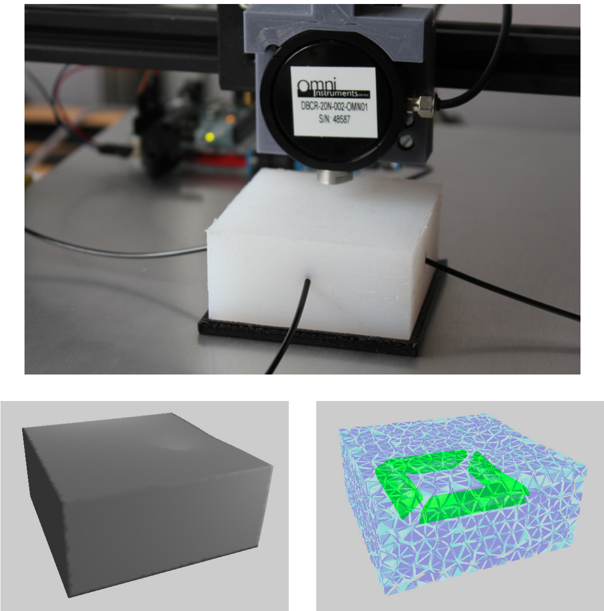

Fig. 1. In our recent line of work we have investigated the modeling of soft pneumatic mechanosensors. Our most recent sensor is depicted in the top. The model in SOFA is shown in the bottom left and right panels.

II. FABRICATION

In [1] we presented a design of a soft pad sensor that has four symmetrical cavities. Several iterations were necessary to fabricate a functioning sensor. Our first approach was to glue two symmetrical parts together, each one containing one half of the cavities' structure. However, when using non-transparent silicone it is impossible to visually assess from the outside whether bubbles have been trapped inside during the glueing process. We therefore face the odds of air being trapped somewhere near to the cavities on the common surface between the two sides. For this reason we had many non-airtight cavities before succeeding with the fabrication. From the experience we gained we developed a new idea: A cavity is sealed not by a surface glueing process, but by a push-in process, similar to a cork. Here, only the seam needs to be glued bubble free for airthightness. This process makes the design of the 3D-printed pieces more complex, because the parts are not symmetric. However, it increases the robustness of the fabrication.

To sequentially cast the two silicone parts, a total of five distinct 3D-printed parts are necessary (four of them are depicted in Fig. 2). The mold-cap can be reused for

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[1] `https://www.sofa-framework.org/`

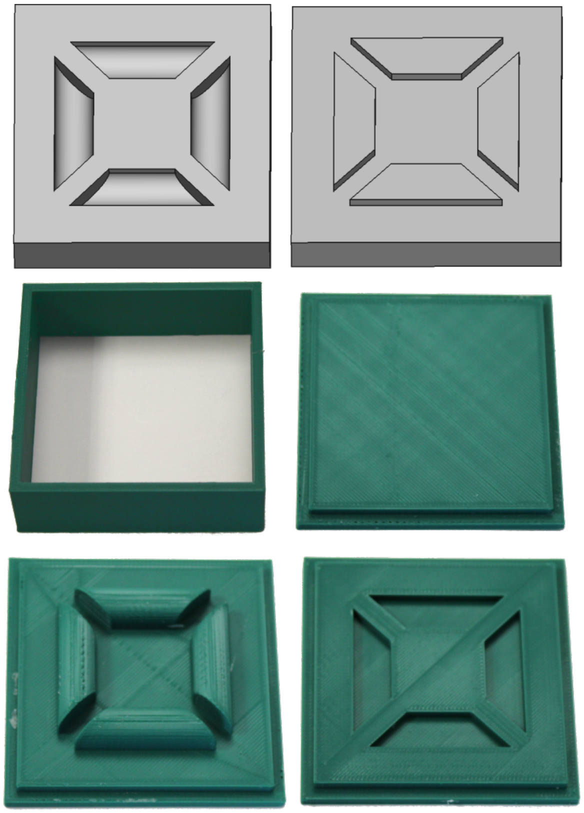

Fig. 2. 3D-printed parts that assemble to a mold in which the individual silicone pieces making up the sensor, depicted in the top, can be casted. The parts are a mold-wall, a mold-cap, a cavity cap and a cork cap. The second mold-wall, which has the same contour but a different height, is omitted for brevity in this figure.

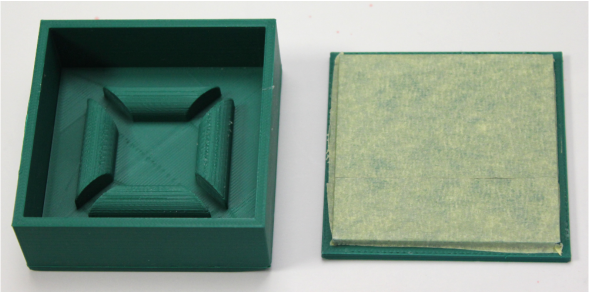

Fig. 3. An assembly of one of the two molds.

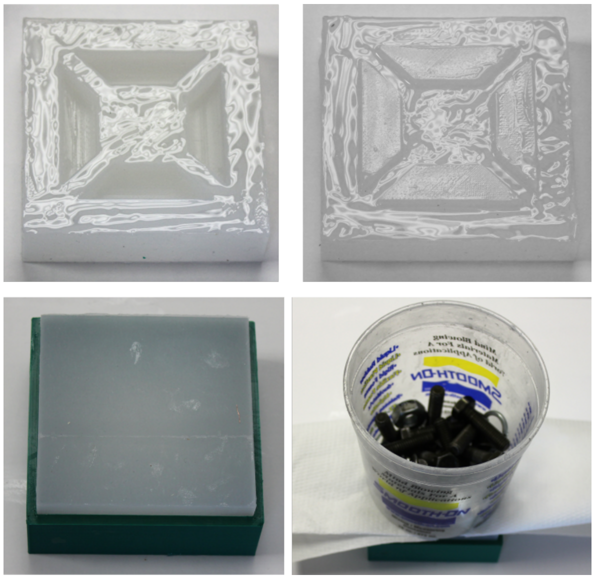

Fig. 4. Top: The two casted pieces covered in glue. Bottom left: The joint pieces inside of the mold-wall, which helps in the alignment and prevents oozing of the glue. Bottom right: A weight is placed on top of the joint pieces.

both molds. We will make the CAD-files available on the homepage of our team.[2] The assembly for each mold consists of three parts, as shown by Fig. 3. We leave the structured part of the mold in the bottom. In this way, when pouring the silicone we can supervise that it adequately fills all the needed structures. In addition, we use a paper-tape to cover the flat cap, which helps at the de-molding stage. Silicone can stick heavily to porous 3D-printed parts. The paper-tape prevents silicone from entering the pores and unsticks more easily from the 3D-printed part or the silicone. In fact, the paper might stick either to the mold-cap or to the silicone when de-molding.

We use the *Dragon Skin A10* platinum cure silicon from Smooth-On [4]. We take the one with a pot life of 20 min. in order to have enough time to degas (extract air trapped inside the silicone mixture) twice. After mixing the A and B components in a 1:1-ratio (as specified), we degas and pour the silicone into the assembly (see Fig. 3) until it is about 70% full. To prevent any air bubbles being trapped in the structured part of the bottom cap, we degas the silicone at this stage again. Then, we pour the rest of the silicone into the mold and press the top cap with the paper-tape to close the assembly. The mold should be filled up to the top with silicone, so that a surplus oozes out when closing it with the cap. This surplus can easily be removed after curing. After each part is cured, we make sure to cut away carefully any surplus silicone that is attached to the part. When we have the two parts casted, we verify that they match together and close nicely. We then mix another small amount of silicone, which will be used as glue. We uniformly distribute the silicone on both surfaces, taking special care that the seam of the cavities has a proper amount of glue (see Fig. 4). The amount should be enough to cover everything uniformly, but not too much either, in order not to ooze into the cavities when both parts are pressed together. It is also important to remark that while the silicone is not yet cured, it can be easily removed from the piece. Therefore, the silicone used for glueing can be applied coarsely at first and then any surplus can be wiped off.

Before glueing the two parts together, we first put the part with the cork structure inside the walls of mold assembly without any cap. We make sure it is flush with the floor by pressing on it until it reaches the bottom of the mold-wall piece. Then, we carefully press the other part onto it

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[2] `https://team.inria.fr/defrost/`

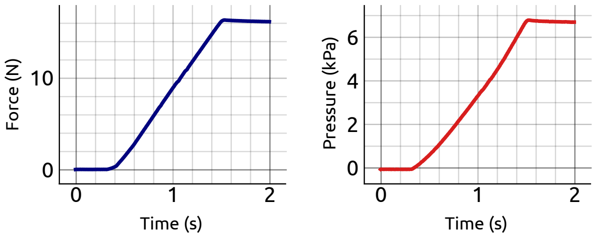

Fig. 5. Left: A graph of the force reading during indentation. Right: The pressure sensor readings for the same event.

inside the wall. In Fig. 4 (low left) the final result is shown. The seam is completely covered by the mold-wall piece. The mold-wall piece prevents the surplus glue silicone from oozing on the outside of the sensor. It also helps in nicely sealing the seam on the exterior of the sensor. As seen in Fig. 4 (low right), we place a weight on the sensor and we let the glue silicone cure. With this, we have finalized the silicone fabrication part.

To equip the soft pad with tubes, we use a needle to perforate it from the outside, reaching just into the cavity. A hollow (seringe) needle allows us to determine whether we have reached the cavity or not, because we can detect the air coming in and out of the cavity through the needle when pushing on the cavity. To reinforce the tunnel we created, we push a rigid rod (e. g. a small allen wrench) through again. We then push a tube through. We do not recommend casting the channel for the tubing directly with the silicone parts, at least not in final diameter of the tubing. A smaller diameter for the channel makes the silicone press on the tubing, increasing the pressure a cavity is capable of handling before it bursts (possibly through the channel). We make sure that the tubes have equal lengths to avoid different behaviors due to the difference in total volume (cavity + tubing). The sensor in its final stage is shown in Fig. 1.

III. CHARACTERIZATION

To verify that we have created in fact four consistent cavities inside our sensor, we performed an experimental validation. The setup is shown in Fig. 1. We place the sensor on a test bed that is equipped with a force sensor. We press five times on each cavity with two predefined indentation levels. We record the pressure change in the cavity with the sensor *MPX5010DP* by Freescale Semiconductor [5]. Each cavity was connected by turns to the same sensor. Additionally, we left the x, y-position of the test bed identical and reoriented the sensor for each measurement. Fig. 5 shows an example plot of one indentation procedure.

The results of our characterization are shown in Tables I and II, where mean values, standard deviations and standard deviations expressed in percent of the means are shown. First, a force of about 10 N is applied (Table I). The pressure is around 4 kPa in this case. For the repeated indentation of each cavity (five times), the results are very consistent, with a variation of less than 0.3%. To compare the cavities between them, we calculated the statistics for all the data collected (last row). Here it is shown that the standard deviation for the pressure over all four cavities is 1.17%. Similar results are obtained when indenting with a force of about 16 N, where the pressure is around 6.6 kPa for the cavities. The percentual deviation between the cavities in this case is 1.01%. These results indicate that the cavities are indeed fabricated in a consistent manner, as the changes in pressure are repeatable between them under same conditions.

	Force (N)			Pressure (kPa)		
Cavity	mean	std	%	mean	std	%
1	10.65	0.03	0.29	4.08	0.01	0.21
2	10.55	0.015	0.15	4.05	0.003	0.07
3	10.45	0.03	0.30	3.95	0.006	0.16
4	10.74	0.04	0.40	4.04	0.01	0.29
All	10.60	0.11	1.04	4.03	0.05	1.17

TABLE I

RESULTS INDENTATION LEVEL 1

	Force (N)			Pressure (kPa)		
Cavity	mean	std	%	mean	std	%
1	16.16	0.05	0.31	6.69	0.006	0.09
2	15.96	0.05	0.29	6.72	0.004	0.06
3	15.90	0.04	0.26	6.54	0.004	0.06
4	16.11	0.04	0.27	6.64	0.004	0.06
All	16.03	0.12	0.74	6.65	0.07	1.01

TABLE II

RESULTS INDENTATION LEVEL 2

IV. CONCLUSIONS

In this extended abstract, we have shown the robust fabrication of a pneumatics-based soft mechanosensor. This sensor has applications in Soft Robotics and can be modeled with the help of our framework SOFA. We discussed the design and fabrication process of the sensor. The structure with embedded air-tight cavities is obtained by casting two parts in silicone, which are glued together. Here, we exploit a cork-like design principle. Finally, we show that the variance of the measurements between the cavities is low, indicating that the fabrication is indeed robust.

REFERENCES

[1] S. Escaida Navarro, O. Goury, G. Zheng, T. Morales Bieze, and C. Duriez, “Modeling Novel Soft Mechanosensors based on Air-Flow Measurements,” *IEEE Robotics and Automation Letters*, 2019. [Online]. Available: https://hal.inria.fr/hal-02239080

[2] C. Duriez, “Control of elastic soft robots based on real-time finite element method,” in *Robotics and Automation (ICRA), 2013 IEEE International Conference on*. IEEE, 2013, pp. 3982–3987.

[3] C. Duriez, E. Coevoet, F. Largilliere, T. Morales-Bieze, Z. Zhang, M. Sanz-Lopez, B. Carrez, D. Marchal, O. Goury, and J. Dequidt, “Framework for online simulation of soft robots with optimization-based inverse model,” in *Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR), IEEE International Conference on*. IEEE, 2016, pp. 111–118.

[4] *Dragon Skin 10 MEDIUM*, Smooth-On. [Online]. Available: https://www.smooth-on.com/products/dragon-skin-10-medium/

[5] *Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated*, Freescale Semiconductor. [Online]. Available: https://www.nxp.com/docs/en/data-sheet/MPX5010.pdf