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MAKER: Taking Soft Robotics from the Laboratory to the Classroom

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Taking Soft Robotics from the Laboratory to the Classroom

Abstract

Soft robots are an emerging technology which causes us to rethink the design and fabrication of robots. The pliable material they are made of—often things like silicone or fabric—adapts to objects and tasks and have increased potential for safe human interaction. However, the driving principles behind soft robot fabrication and operations are also fundamentally different; soft robots are fabricated by material synthesis and operate using material deformation, whereas traditional robots are typically built using pre-fabricated, rigid materials, and operate using mechanical assemblies. We have adapted laboratory procedures for making soft robot grippers to fit classroom equipment and constraints. We have also extended previous outreach efforts to make these grippers by developing a 3D printed mold which affords design variation. This paper describes the roots of our work and gives an overview of a classroom process for soft robot fabrication. Other resources describing the breadth of our research with classroom-integrated soft robot design are mentioned.

Soft Robots

For decades we have envisioned robots that work beside us, with us, for us, enhancing our lives by assisting us with tasks that are boring, inefficient, dangerous or beyond our capability. Widespread use of automation seemed a stepping stone along the way and the drastic miniaturization and increased power seen in computing and electronics over the last decade appeared to put the final tools in place. Despite these advances in technology, intelligent co-robotics is still frustratingly just beyond our grasp. A cause is that robots have evolved to work in factories, born out of classical design practices and cordoned off from the world; the technology has evolved without regard for its surroundings. Systems are built out of rigid components, metal and motors, and as a result are clumsy and unforgiving when they interact.

With soft robotics, we can now trade off rigidity (which has to be bought expensively with high-stiffness, high-weight, and high-cost materials) for sophisticated sensing and software control. In effect, we can build cheaper, lighter, and more performant machines by substituting software complexity for structural mass and materials. Beyond mere cost savings, soft machines can perform tasks that their rigid counterparts will never be able to. This is particularly true for interactions between humans and robots: current industrial robots are caged to protect nearby human workers. Soft robots embed safety at the material level, encouraging their employment in tasks alongside humans.

Laboratory Process

There are a variety of soft robot applications with different manufacturing processes. At a high level, the process usually involves combining two materials of varying elasticity such that air pressure causes asymmetrical actuation. In our case this includes a stage of making the extensible—stretchy, silicone—top half of the robot in a mold, then attaching the bottom inextensible layer—fabric. In the laboratory environment, specialized equipment enables the consistent fabrication of soft robots. For example, high quality 3D printers or laser cutters enable precise mold creation. Next, a centrifugal mixer is used when preparing the two-part silicone mixture since this reduces the air bubbles of the mixture. Further, after the silicone is poured, but before it cures, a vacuum desiccator is used to draw out any air bubbles created from filling the mold. Finally, an incubator may be used to accelerate the curing process.[1, 2]

Previous Outreach Process

A previous report adapted this process for use in an outreach effort.[3] The one-piece mold was printed in advance, allowing elementary students to focus on mixing and pouring the silicone during the first session. The one piece mold, however, did not provide students with design freedom regarding the shape or configuration of the gripper. After allowing it to cure for four hours at room temperature (or for 10 minutes at 150°F in a toaster oven, if available) students could mix more silicone and adhere the two parts. Then students used tubing and a squeeze bulb to inflate it manually. The long time for curing is acceptable if multiple outreach sessions are planned: students can take two sessions to work on their robot and then come back to test it in a third session allowing the silicon to cure between sessions. However, Finio et al.[3] noted there were no learning outcomes specified in the outreach experience and it was better if students could make two robots because the success rate was low (B. Finio, personal communication, June 2, 2016).

Classroom Process

Our procedures have adapted the laboratory processes and previously designed materials with the goal of an inquiry-based experience for students. We have redesigned and tested the mold so that it offers design flexibility to students without overcomplicating the process and without reducing the success rate of the robot grippers. Below, we describe mold preparation which should be done prior to the curriculum and fabrication steps for the soft robot grippers. In many respects, the steps are the same as in outreach experiences but emphasis on design variation, learning principles, and iteration make this approach unique.

In class, students are exposed to applications of soft robotics and the pneumatic principles by which they operate. Namely, the configuration of the inner air chambers and difference of elasticity between the top (extensible) and bottom (inextensible) layers cause our soft robot grippers to curve as they inflate. A pair or trio of students work as a design team throughout the project. The fabrication steps are repeated iteratively as students investigate these pneumatic principles and try to design a gripper which can successfully be used to sort soft and inconsistently shaped produce such as tomatoes without damaging them.

3D Printed Mold

All 3D print files and curriculum materials are available upon completion of a short survey about intended use of the materials: http://tiny.cc/SRMolds. Stereolithography (.stl) files are provided for each mold part with appropriate tolerances with ABS material on either a Lulzbot Taz 6 or Stratasys uPrint, which we have tested. (If you intend to use the files with other printers, the tolerances may need to be modified.) After printing a completed kit, mating faces are sanded for a better seal and pins are inserted to keep the parts aligned during assembly (see 2.6.7SR Mold Assembly Instructions supplemental file). Each kit also includes several rubber bands and a finish nail for use later in the process.

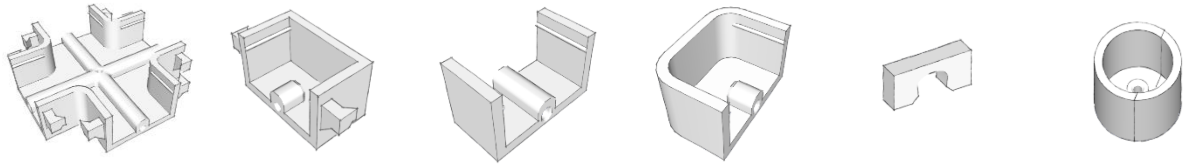

Figure 1. Reconfigurable mold parts (from left to right): 4-sided hub, finger end cap, middle section, finger tip, pneunet clip, and coupler parts A and B. When building individual fingers for testing, finger end caps are used in place of the hub.

Extensible Layer

The first fabrication phase begins by assembling mold pieces in the desired configuration (see Figure 2); we have students make fingers first, to investigate the underlying pneumatic principles and collect data to inform the design of their entire gripper. A single rubber band is used to hold the mold pieces together. The desired number of clips can be inserted on the ridge in the mold, creating air chambers. Inspecting the mold for any gaps is also helpful.

Ecoflex 00-30, a two-part silicone rubber made by Smooth-On, is mixed in a 1:1 ratio by volume, then poured into the mold. It cures in 10-15 minutes at 150°F or after 4 hours at room temperature. Cure inhibition or slow curing can occur with Ecoflex 00-30 if the silicone is exposed to certain materials. Latex and nitrile, both common glove and rubber band materials, do slow or prevent curing. Therefore, we recommend polyurethane rubber bands and polyethylene gloves. While curing, the surfaces are level so that silicone remains distributed evenly while it is viscous. In cases with shorter class sessions (45 minutes), students should have time to plan, prepare, and pour their molds, letting them cure overnight. We have used toaster ovens as incubators during longer class sessions (90 minutes) to accelerate the cure time allowing students to complete multiple fabrication stages during one period. Note that material used in making the molds must be tolerant of 150 degree Fahrenheit temperatures. After the soft robot part is cured, it can be removed from the mold.

Inextensible Layer

The bottom layer of the gripper is adhered with more Ecoflex 00-30. This less-elastic layer of the robot gripper creates the curve of the gripper when inflated; it is essential that the bottom and seal are airtight so that they inflate! Students use wax or parchment paper as a work surface (see Figure 3). A piece of fabric, slightly larger than the finger or gripper, is placed on the work surface and covered in Ecoflex. The silicone mixture should saturate the fabric (you can help it by spreading forcefully with a plastic knife) and evenly cover the area where the top half of the robot will sit. The top layer of liquid Ecoflex should be deep enough that there is good surface contact with the top of the gripper or finger—looking at an angle, the surface should be smooth and reflective, not pocked by the fabric surface—but not so deep that it fills the air chambers.

Attach the top half by placing it on the silicone and pressing around the edges to create a good seal. The attachment can be strengthened by spreading extra Ecoflex around the bottom edge of the gripper or finger. If students are making a gripper, they should attach the top coupler at this point. Ecoflex is spread on the coupler and the finish nail is used to line up the coupler and hub center. A video in the supplemental files demonstrates this process. After connecting the soft robot layers, the silicone needs to cure—10-15 minutes at 150°F or 4 hours at room temperature.

Figure 2. Fabrication phase 1 (from left to right, top to bottom): Ecoflex silicone containers and mixing cup, mold parts, assembled finger design, pouring mixed Ecoflex into the mold, cured finger, and demolding the finger.

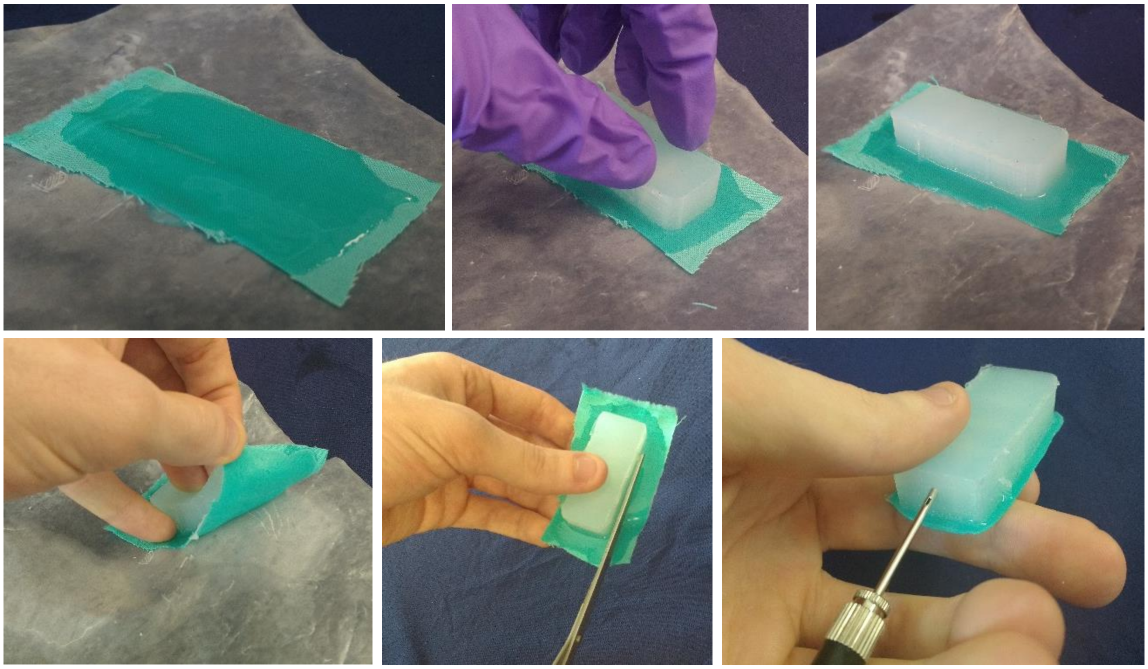

Figure 3. Fabrication phase 2 (from left to right, top to bottom): Ecoflex spread smoothly on fabric, attaching the extensible layer, curing the finger, removing the finger from a work surface, trimming excess fabric, and inserting a pump to test.

Testing and Troubleshooting

Students can inspect the fabrication quality when the robot finger or gripper is completely cured. Air bubbles in the silicone, poor adhesion between layers, or clogged air chambers may be visually apparent and can be addressed before testing (by applying more silicone and curing again, for example). To inflate a finger, access the inner air chambers by puncturing (such as a soccer/volley ball inflation needle); to inflate a gripper, remove the needle and insert the hand pump tip into the coupler on top. Inflating each robot shows the intriguing actuation—it is curved because of the different materials used and different clip configurations will yield different actuation. Students will likely encounter problems with their design or robot fabrication, so opportunities for iteration (inquiry, redesign, and remaking a robot) are an important part of the experience. To be most effective, this iteration should be deliberate: students should test their robot, identify problems, and brainstorm ways to address the problems through a different design or improvements to the fabrication steps they took.

Students should eventually arrive at a gripper design that addresses the needs given during instruction—to build a gripper that can sort produce without damaging it. We simulated picking up tomatoes by picking up golf balls. They can demonstrate the gripper's ability to pick up (and securely hold onto) produce while they manually move the gripper (see Figure 4). This demonstration, and a presentation about their overall design process, reinforces the need for documentation and iteration in design.

Figure 4. Inflated gripper demonstration.

Soft Robotics to Broaden the STEM Pipeline

This material is based upon work supported by the National Science Foundation under Grant No. 1513175. This project aims to increase female interest in science, technology, engineering and mathematics (STEM) careers through the emerging field of soft robotics. This project will advance efforts of the Innovative Technology Experiences for Students and Teachers (ITEST) program to better understand and promote practices that increase students' motivations and capacities to pursue STEM careers by exploring the inspiration that soft robotics might afford. Results of this project will include the development and testing of our soft robot curriculum which has the potential to broaden participation. Specifically, this project will test the hypothesis that the implementation of soft robot design experiences improves learning, motivation, engineering self-efficacy and interest in engineering careers as compared to traditional robot design experiences. This development and study is contextualized in a course required of many 9th grade students called Foundations of Technology, which is the freshman-level technology and engineering education course provided by the Engineering byDesign core program. It is taught in over 270 school districts across 23 states to about 100,000 students annually. The study will employ a design research framework to develop the 8-hour unit and study its implementation in 11 classrooms in two school districts. Measures include the Situational Motivation Scale and the Engineering Self-Efficacy Scale. In Year 3, the project will implement an efficacy study to compare results of the soft robotics unit with the unit implemented traditionally in the Engineering byDesign program. Evolving drafts of our curriculum materials are available at http://tiny.cc/SRMolds.

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