Shared Design Tools to Support Research and Development in Soft Robotics

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Abstract— **This paper introduces the Soft Robotics Toolkit, a set of shared resources to support the design and fabrication of soft robotic devices. The toolkit contains design files and guidelines related to soft component technologies as well as open source designs for hardware control platforms.**

Keywords- soft robotics; design tools; open source hardware

I. INTRODUCTION

As a relatively young and growing field, soft robotics stands to benefit greatly from shared resources that ease knowledge transfer between research groups [1]. Such resources would enable researchers to build on each other's work and advance the field more rapidly. Though academic publishing performs this function in part, the format makes it difficult to include all the detail necessary to reliably recreate procedures, and the bias for positive results makes it difficult for researchers to learn from each other's unsuccessful design experiments [2-3]. This is particularly problematic when it comes to the non-standard materials, fabrication techniques, and experimental methods used in the field of soft robotics as compared to traditional "hard" robotics. Therefore, there is a need for a way to communicate this type of knowledge within the soft robotics community.

We present a shared online toolkit, launching June 2014, intended to address this need, containing detailed design guidelines, fabrication protocols, and evaluation methods for a variety of soft robotic devices. The high level of detail not only enables accurate replication of procedures, but also ensures that the kit is useful to the wide range of researchers in this multidisciplinary field. The multimedia guidelines, tutorials, and protocols are complemented by downloadable bills of materials, CAD files, FEM software scripts, and control system source code, which, when used with widely available software and rapid prototyping technologies, facilitate accelerated development cycles for soft robotic devices. Following a process like the one depicted in Fig. 1, researchers can spend less time debugging the basic infrastructure of soft robotic systems and instead focus on developing novel applications, particularly the biomedical ones for which soft robotics are well-suited.

The toolkit is being piloted in ES227, a project-based design course at Harvard where teams of undergraduate and graduate students collaborate with clinicians and researchers to develop novel medical devices. By utilizing toolkit resources, student teams have been able to go from clinical need to completed prototype soft robotic medical device within the short semester timeframe of the course. We have continued to iterate and refine the toolkit, using observations and feedback from the pilot, to ensure that it is sufficiently detailed and useful to a broad range of researchers.

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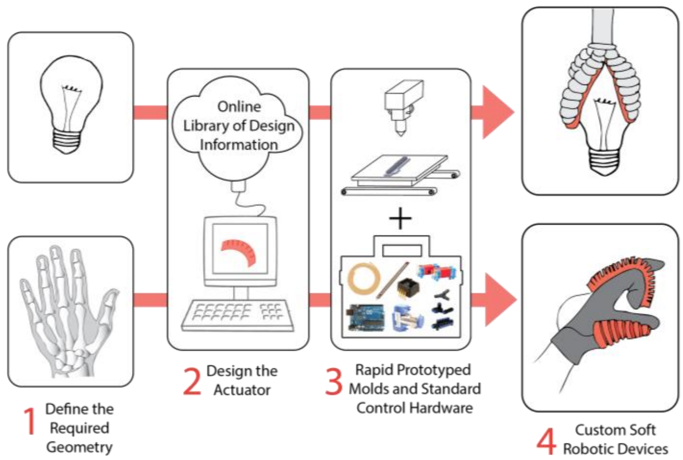

Figure 1. Envisioned design process using common virtual and physical platforms to support a range of soft robotics applications

II. TOOLKIT DESCRIPTION

The toolkit website (Fig. 2) documents a range of soft component technologies as well as a general control platform. The components are categorized into broad classes, such as *Fiber-Reinforced Bending Actuators* [4] or *Soft Strain Sensors* [5]. The documentation for each class contains subsections covering the design, fabrication, modeling, characterization, and control of the component.

A. Design

The *Design* section describes a particular configuration of the component, complete with solid models and engineering drawings of the component and related molds. To enable customization of designs, these files are complemented with tutorials for designing actuators and mold parts in a solid modeling environment. This section also contains information on material selection, general design principles, and discussions of possible design modifications to vary component performance. A collection of case studies provide an overview of how other developers have used the component, providing insight into the design considerations that need to be made to customize it for specific applications.

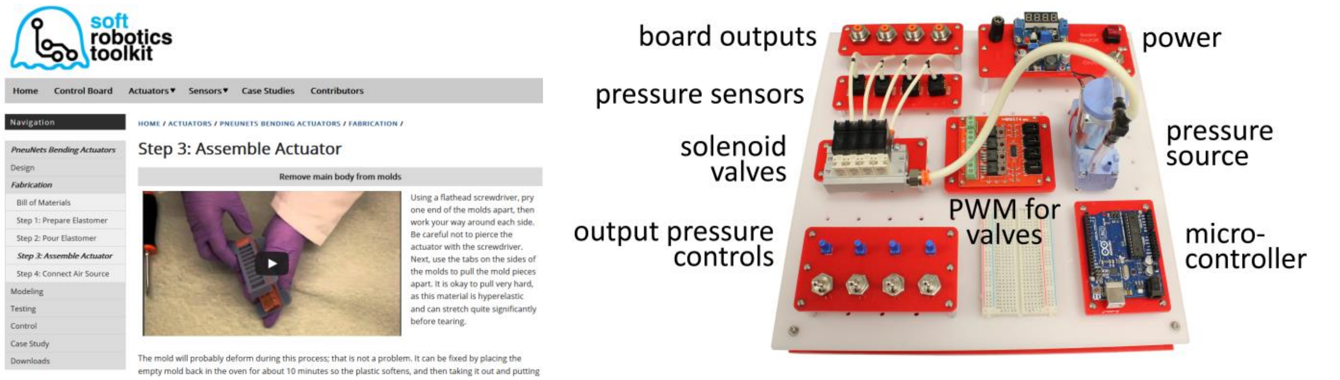

Figure 2. The Soft Robotics Toolkit website (left) and the open source hardware control board (right)

B. *Modeling*

Predicting the performance of a soft actuator or soft sensor design is non-trivial due to complex morphologies, non-linear elastic behavior, and multiple degrees of freedom. Analytical tools are needed to allow researchers to optimize designs in a deterministic manner and to achieve robust control of soft devices. Towards this end, this section of the website contains descriptions of both analytical and numerical modeling approaches, along with detailed derivations or related FEM input files and scripts. Tutorials provide a step-by-step description of using FEM software packages to conduct numerical analyses of particular soft components. Users can follow use these tutorials as a starting point in analyzing their own designs.

C. *Fabrication*

The *Fabrication* section contains all of the information required to build the soft component. Bills of materials, with links to suggested suppliers, assist users in sourcing the required parts and materials. For parts that are not available off the shelf, the provided CAD files can be used to manufacture custom parts with a machine such as a 3D printer, laser cutter, or CNC mill. Detailed multimedia protocols describe the steps involved in preparing molds, casting parts, and assembling the soft component. Each step of the process is described through text, annotated images, and videos to capture as much detail as possible.

D. *Control*

As mentioned previously, much of the hardware required for the operation and control of soft fluidic systems is interchangeable between one system and the next. The website contains documentation for an open source fluidic control board, intended as a general purpose tool that can be used for a range of applications (Figure 2). The board consists of a microcontroller, a pressure source, MOSFETs, solenoid valves, and pressure sensors, controlled manually via the included potentiometers and switches, or programmatically via the microcontroller. The documentation includes downloadable source code that can be run on the microcontroller for PID control of particular actuator-sensor combinations. The control board allows "plug and play" of soft devices across a range of applications, allowing proof of concept prototypes to be rapidly assembled, tested, and demonstrated.

III. Conclusions

The Soft Robotics Toolkit provides in-depth knowledge and resources for designing, fabricating, and evaluating various soft robotic devices, with the aim of enabling a broad range of researchers to innovate and advance the field. To date, our focus in developing the toolkit has been on documenting the work carried out in Harvard research groups. However, our intention is for the toolkit to serve as a broadly accessible platform, and to evolve through contributions from the growing global community of soft robotics researchers. By bringing together the expertise of this community in a shared database, we hope to expand the scope of the toolkit to encompass a wider range of soft component technologies and actuation methods, and to accelerate progress in soft robotics in general.

Acknowledgments

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