Shared Online Resources to Support On-Demand Design and Fabrication of Soft Robotic Devices

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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; on-demand design; open source hardware

I. Introduction

Traditional "hard" robotic systems that can perform complex functions typically have a long engineering design cycle. They contain expensive components and precision machined parts, which require time and expense to source, manufacture, assemble and ship. The hardware architecture is pre-determined and additional functionality is achieved through reprogramming the software of the robot. If a particular task changes beyond what software adjustments can accommodate, these systems can be expensive to replace or modify. Furthermore, it is unlikely that those who are operating these machines have the capacity to quickly modify the hardware to suit the changing conditions with adaptation typically limited to modifications to the software. Ideally, it would be possible to rapidly and inexpensively fabricate new custom robotic end-effectors on-site as needed.

Soft robotics offers a new paradigm that can enable this vision. It is a field that combines classical principles of robot design and control with soft materials, where complex motions can be pre-programmed into flexible and elastomeric materials. The behavior of soft robotic devices is determined by the morphology of custom-made actuators and sensors that are typically made from low-cost elastomers cast in molds. These molds can be quickly and affordably produced due to the increased availability of rapid prototyping technologies such as 3D printers and laser cutters. Given widespread access to such technologies, we propose that a shared database of design files, source code, and fabrication protocols could enable the on-demand development of custom soft robotic devices.

Furthermore, we propose that a common hardware control platform could support a range of applications including surgical, wearable, locomotion, and manipulation systems. The main expense of a soft robot typically relates to the external hardware used to control these soft customized actuators. This part of the system is often interchangeable between one device and the next with little customization necessary. For example, all fluid-operated soft robots are controlled using a pressure source, pressure regulator, and valves. Multiple types of fluidic robots can be operated using the same control hardware.

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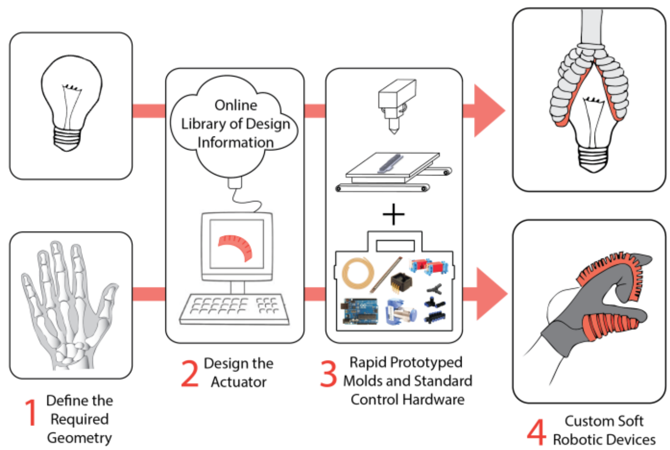

Figure 1. Envisaged design process using common virtual and physical platforms to support a range of soft robotics applications

The proposed collection of hardware and virtual resources would enable a design process like the one depicted in Figure 1, allowing the technical community to focus on developing innovative applications rather than dedicating resources to debugging the basic infrastructure of soft robotic systems. At the Harvard Biodesign Lab, we have developed the Soft Robotics Toolkit, a set of shared online resources for soft robotics research and development. The toolkit contains information on the design of soft devices, instructions on fabricating soft components and characterizing their behavior, and design documents describing the assembly and operation of hardware control platforms for use with fluidic soft devices.

II. Toolkit Description

The toolkit website (Figure 2) documents a range of soft component technologies as well as a general control platform. The components are categorized into broad classes of actuators and sensors. The documentation for each class contains subsections covering the design, fabrication, modeling, 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

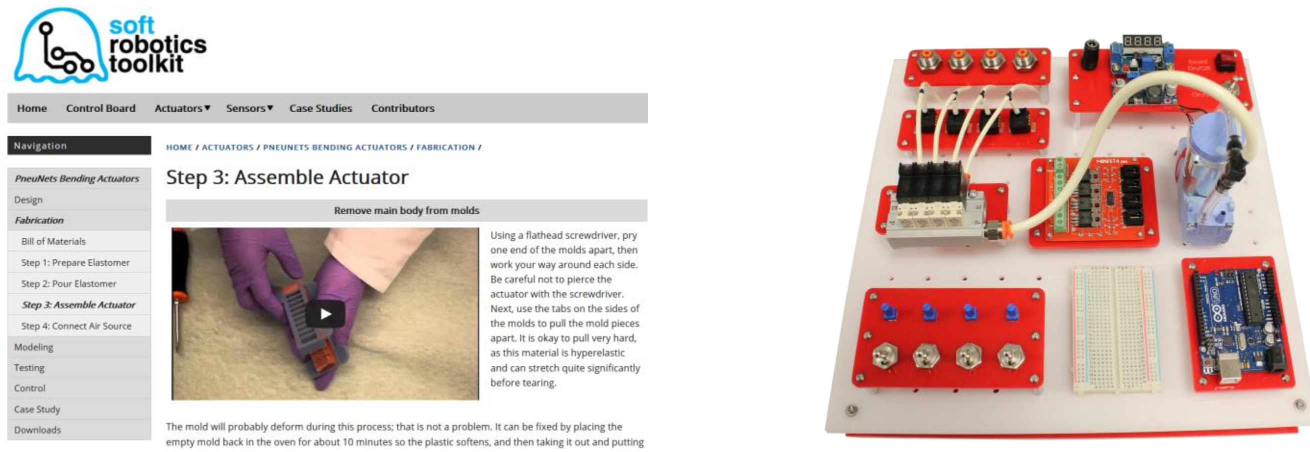

Figure 2. The Soft Robotics Toolkit website (left) and the open source hardware control board (right)

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.

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 toolkit presented here is intended as a shared resource to support the on-demand design and fabrication of soft robotic devices. The current content is drawn from work carried out by a number of Harvard research groups and the toolkit's main focus is fluidic devices, as that has been the most popular application among the toolkit's users and developers. We hope to expand this focus in the future as use of the toolkit increases. This expansion will include both additions to the component technology database, and hardware for a wider range of control boards capable of more actuation methods, such as voltage regulation for shape memory alloys and dielectric elastomers. Our intention is for the toolkit to continue to evolve through contributions from the growing global community of soft robotics researchers. To this end, the website contains templates and guidelines to support contributors. The website will be publicly launched in summer 2014, and we invite all interested researchers to make use of the toolkit and to help shape its future by providing feedback and contributing new content.

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