An Automatic Design Tool for Fluid Elastomer Actuators

Olivia Bridgewater-Smith, Gabriele Maurizi, Sebastiano Fichera,
David Marquez-Gamez, Andrew I. Cooper, Paolo Paoletti

***Abstract*—Soft robotic actuators are a very promising technology to enable use of robotic manipulators in scenarios that are inaccessible to traditional robots. However, their design and fabrication is a laborious process, especially for users with little knowledge of CAD software and 3D printing. The skills and time necessary for making the moulds used to create such actuators, leaves the process open for human errors and design variations, making accurate and repeatable experimental testing difficult to achieve. To reach a better understanding of this new technology, extensive and detailed experimental work should be undertaken, but this is currently hindered by the time-consuming design process. The design software presented in this paper provides the soft robotic community with a user-friendly design tool for generating 3D printed moulds that the users can customise to their needs. The tool aims to simplify the design process for soft robotics and to also make this technology accessible to users without extensive engineering background.**

I. Introduction

Soft robotics is an emerging field within the robotics community. Their bio-inspired nature allows them to use them for a wide variety of scenarios. Novel soft robots design have been developed based on animal and human biomechanics; for example, an octopus project has shown that robots using soft materials can perform tasks that would not be achievable with 'hard' materials [1]. Soft robots can be designed to perform more than one task, so that unstructured or bespoke tasks in chemistry and biology labs can benefit from their adaptability and their ability to bridge the gap between humans and conventional 'hard' robotics [2].

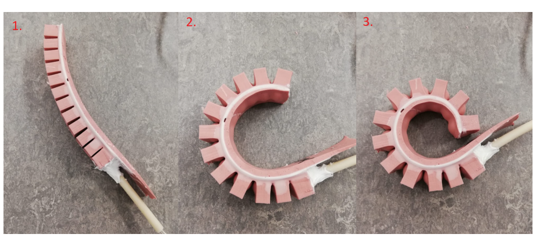

Fig. 1. Soft Robot Actuating

OBS, SF, DMG, AC are are part of the Leverhulme Research Centre for Functional Materials Discovery, Material Innovation Factory, University of Liverpool, Liverpool L69 7ZD, UK. OBS, PP and SF are part of the School of Engineering, University of Liverpool, Liverpool L69 3GH, UK. GM is part of the Dipartimento di Ingegneria dell'Informazione, University of Florence, Firenze I-50139, Italy. sgobridg@liverpool.ac.uk gabriele.maurizi@stud.unifi.it seba84@liverpool.ac.uk David.Marquez-Gamez@liverpool.ac.uk aicooper@liverpool.ac.uk P.Paoletti@liverpool.ac.uk

II. Core Components and Fabrication

The most common design for soft actuators is Fluid Elastomer Actuators (FEA). Such actuators are composed of a series of inflatable chambers mounted on top of a flexible substrate. As each chamber inflates, air exerts a pressure on the chamber's walls. Given that the inner walls of the chambers are thinner than the other walls, they bulge outwards and make contact with each other, thus providing a force that causes the actuator to bend. A typical example of FEA undergoing actuation is shown in Fig. 1.

The typical fabrication process for producing a FEA consists of three steps: mould design, mould manufacturing, and moulding process [2]. When designing the mould, the actuator geometry needs to be determined according to the desired properties and mechanical response of the actuator itself. Typically, the mould is designed on 3D CAD software and it is sectioned into components. The main body consisting of a union of parts A and B (see Fig. 2) and a tray is used to enclose the bottom of the actuator. The main body and tray are manufactured separately and then joined together using a thin layer of silicone.

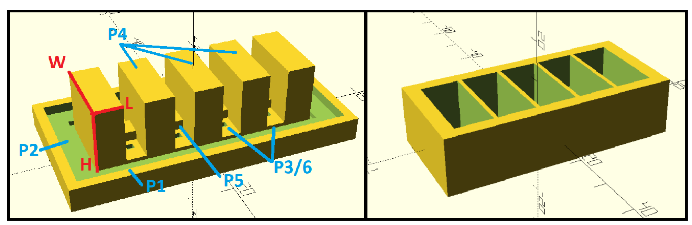

Fig. 2. Example of 3D CAD of a mould produced the automatic design tool: Part A (left) and Part B (right).

There are four essential components that need to be designed to create such moulds, as shown in Fig. 2: chambers (P4), air channel (P5), supports (P3/6) and the base [3]. The air channel runs parallel through the actuator and it is responsible for allowing air to pass through into each chamber. The inner and outer supports are placed to aid the joining process of the main body and the tray, ensuring the air channel and chambers are not impeded by the uncured silicone solidifying. The base encapsulates the chambers and provides a flexible surface to induce bending.

III. Automatic Design Tool

A software tool was developed to automate the design and fabrication of the mould process. The software aim was to provide well-designed moulds based on a limited number of user-defined inputs and to prevent the occurrence of human errors and streamline the design process. The proposed tool uses the 3D model builder OpenSCAD and a bespoke Python-based graphical user interface to automate the design.

The main GUI of the design tool consists of input boxes allowing the user to set: chamber width, length, depth, spacing, number of chambers and tray height (see Fig. 3). The code uses the number of chambers and chamber dimension inputs to calculate the length and width of the whole actuator, and it design layers P1/2 using these values. The chambers are then placed along the length of the actuator using arithmetic progression, alongside a central air channel (P5) connecting all of the chambers. The air channel and inner supports height and width are dependent on a proportional ratio applied to the chamber dimensions, empirically tuned based on testing on a wide range of actuators. The complete Part A mould dimensions, calculated by the code, are then used as inputs to generate Part B and the tray. The tool then outputs three STL and SCAD files in the chosen location which the user can directly use to 3D print their moulds.

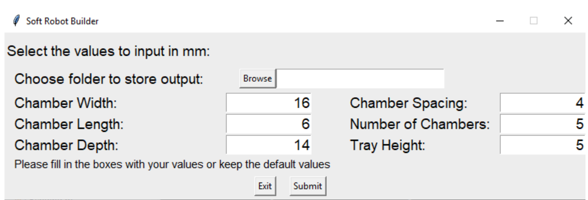

Fig. 3. GUI to select the actuators geometry.

IV. Experimental Results

To test the capability of the code, various designs were produced with varying chamber widths, lengths, height and number. Such moulds were then 3D printed using an Ultimaker S5 printer with PLA filament, and then used to fabricate soft actuators. Finally, the soft actuators were tested to show that the automated design tool can create functional actuators (see Fig. 1) [4]. The ability to design moulds and actuators at a fraction of the time required by manual design allowed the creation of a large amount of actuators to perform a parametric study on how geometry affects the actuator's mechanical response [5]. For the purpose of this paper, the software was used to prove how changing the width of the actuator chamber affects the tip force. This is complementary to the linear relationship between height and tip force reported in [3] [6]. Taken together, these results can form the basis for optimising FEA design based on desired mechanical response.

The initial testing was conducted by clamping the actuator and measuring its tip force at a range of pressures. Experiments were conducted on three actuators of the same length and chamber number. The first two actuators were made from silicone M6401 (Bentley Materials, UK), the second one had an increased chamber width of 5mm. The third actuator was made from Dragon Skin (Bentley Materials, UK) and matched the dimensions of the first. As shown in Fig. 4, increasing the actuator width almost doubles the resulting tip force. This suggests that using materials with lower Young's moduli allows larger variations of tip forces for limited changes in input pressures.

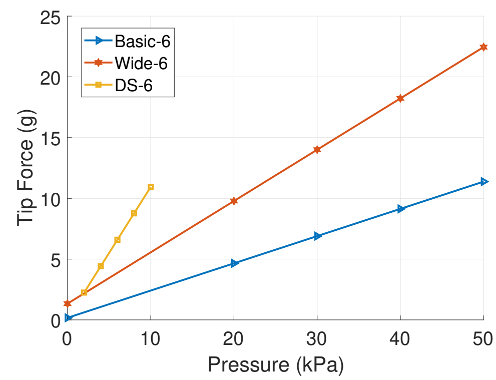

Fig. 4. Force vs. Pressure for three actuators

V. Conclusion

In this paper an automatic design tool for soft robotic actuators is presented. The availability of this tool will allow researchers to streamline the design of such actuators and to perform parametric studies on the influence of geometry on the actuator response. As an example, preliminary results regarding the relationship between chamber width and tip force are presented. The modular and open-source nature of the presented tool will enable encompassing a wider range of soft actuators in the future. The tool is available at http://www.liv.ac.uk/paoletti/public/softdesigntool.zip

To further validate the tool, analytical results will be linked with the design tool to create an input for the desired tip force range of the actuator. The tool will generate the optimal internal geometry to achieve the required force so that actuator design can be optimised based on the applications they will be used for. A variety of moulds will be produced to experimentally verify the tip force output.

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