3D Printed Variable Infill Soft Fingers for the SIMPA Prosthetic Arm

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***Abstract*— The SIMPA (Soft- grasp Infant Myoelectric Prosthetic Arm) prototype prosthetic arm for toddlers features soft 'fingers' made from silicone-rubbers. The manual multi-stage moulding process to produce those soft-fingers presents several practical challenges that limit the design freedom and degree of customisation. This work demonstrates the potential for 3D printing highly flexible and soft fingers (Shore hardness 60A) that can achieve the desired grasping performance of the original gripper fingers by introducing variable infill densities. This initial result presented here highlights the potential of this approach to further miniaturise and improve upon the initial soft gripper design**

Keywords—Soft-Robotics, Medical Devices, 3D-Printing

I. INTRODUCTION

Soft-grippers are increasingly being explored within the field of robotics [1] with a particular focus on delicate grasping tasks [2], such as the handling food products like strawberries [3]. These soft-grippers have many advantages over the traditional rigid systems, primarily the ability to passively adapt to geometric features, allowing a wide range of objects to be securely grasped. The concept of incorporating soft-grippers into the design of a prosthetic arm has only recently been explored. The device (Fig. 1), "SIMPA: Soft-grasp Infant Myoelectric Prosthetic Arm" [4], presented an alternative to the rigid approach taken by other comparable devices [5]. This approach proved successful, resulting in a device capable of grasping a wide range of objects securely, whilst also incorporating safety features such as removing sharp edges and pinch points.

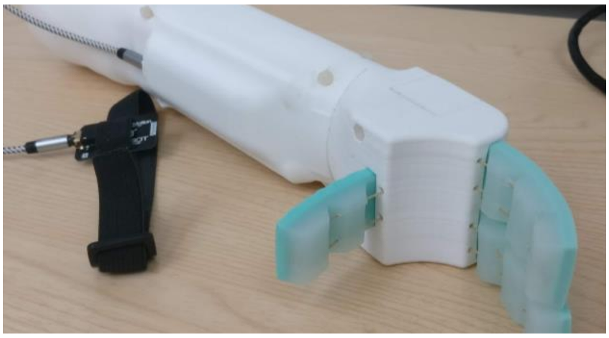

Fig. 1. SIMPA Prototype

The prosthetic was primarily 3D-printed, with only the grippers being moulded. This proved to be a major manufacturing challenge, due to the intricate nature of the small-scale design, and the requirement for an internal structure through which cables are threaded. The result was many failed attempts and a forced redesign of the device in order to consider the difficulty experienced during gripper prototyping. Recently, access to novel soft-filament (COEX-Flex TPU 60A[1]), has opened up the possibility of additively manufacturing the grippers directly. The material is one of the most flexible fused deposition moulding (FDM) filament currently available and has yet to be explored as a means of manufacturing soft-grippers. The feasibility of producing wire driven soft-grippers for the SIMPA prototype directly via (FDM) 3D-printing will be explored here, with the specific focus on the effect of infill parameters on the adaptability of the soft-fingers.

II. DESIGN, MANUFACTURE AND INITIAL VERIFICATION

The grippers featured in the prototype device are simple 3-segmented (2-segments in the case of the 'thumb') wire-driven "finger" like structures (Fig. 2) [6]. The "finger" utilises the elastic energy stored within a soft material to extend the gripper once the cables driving the flexion are relaxed. The gripper is constructed out of two silicone rubbers, Smooth-Sil® 960 (Smooth-On, Inc.) and Dragon Skin® 30 (Smooth-On, Inc). The material properties are such that the Smooth-Sil® 960 acts as the spline of the gripper, providing the elastic storage required for the extension. Conversely, the Dragon Skin® 30 provides a skin like feel and subtleness.

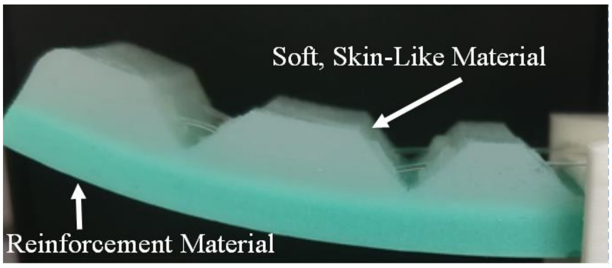

Fig. 2. Original Silicon-rubber Soft-gripper Design

In the case of additively manufacturing the grippers, the performance of this composite structure must be considered. By altering the infill density throughout the design, the effective rigidity of the material can be altered; with lower infill percentages increasing flexibility. By using this approach, it is hoped that the gripper can be additively manufactured, whilst maintaining comparable elasticity and grasping performance.

The CAD model of the grippers was imported into Cura (Ultimaker BV) for pre-print processing. This model is the inverse of the mould used for the original grippers. For the initial test a line infill of 25% was used for the more rigid spline of the device (Fig. 3). The top surface of the gripper was conversely given 0% infill (Fig. 4) to approximate the feel of the soft contact pads. The grey box seen in Figures 3 and 4, represents a custom infill area, allowing multiple infill settings to be used on the same model.

1 Data-sheet can be found at https://flexionextruder.com/shop/x60-ultra-flexible-filament-black/

TABLE I. OVERVIEW OF PRINT PARAMETERS USED

Property	Value
Base Infill	25% (Line)
Pad Infill	0%
Number of Top/Bottom Layers	2
Number of Walls	3
Top/Bottom Layer Pattern	Concentric
Layer Height	0.2mm
Nozzle Size/Line Width	0.5mm

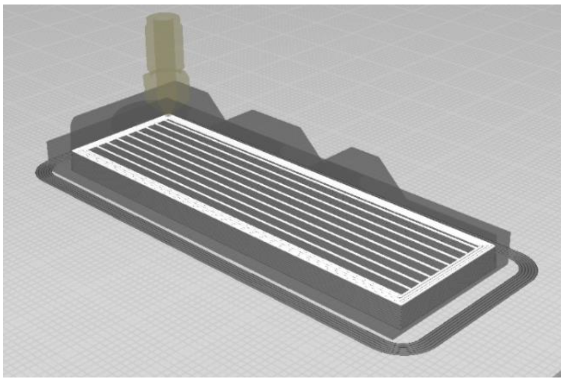

Fig. 3. Reinforcement Infill Structure, Lines 25%

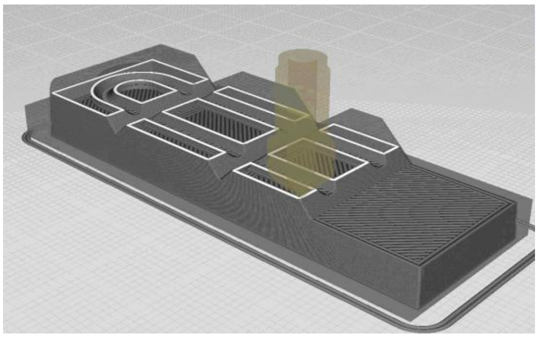

Fig. 4. Contact Pad Infill Structure, 0%

The gripper was manufactured on a Lulzbot Taz 6, modified with a Flexion Extruder (Diabase Engineering). The full detail of the grippers is captured in the print (Fig. 5), and takes approximately 2 hours to complete; this compares to an average of 2 days when manufactured using silicon, this is due to the multi-stage nature of the process and the required cure times of the materials used.

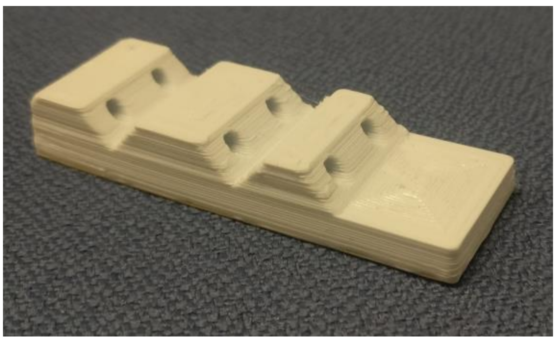

Fig. 5. Printed Gripper Sample with an in-built Passage for Tendons.

The additively manufactured grippers from an initial manual inspection (pulling on a cable threaded through the gripper), appear to be slightly stiffer than the silicon version. As this is the first attempt, there is no optimisation in terms of the print properties or CAD model yet. It is assumed that with further refinement it should be possible to improve on this performance, in terms of reducing the force required for actuation.

For the supporting structure (replicating the Smooth Sil®), it would be simple to set-up a rig that compares the force required for a set amount of deformation, characterising the relationship between infill and apparent stiffest for grippes produced with the COEX-Flex material. The procedure should first determine the force required for full contraction of the original silicone fingers, to act as a benchmark value. The same experimental procedure should then be performed on the printed grippers, with various modifications to print parameters such infill percentage and pattern, number of walls, line thickness, layer height, etc. A relationship between these several parameters and the performance of the grippers can then be determined.

To the touch, the grasping surface is considerably more rigid than the Dragon Skin® 30 surface of the silicone grippers. A Shore Hardness test or comparable procedure would need to be used to determine the actual surface hardness, though this has not yet been performed. The internal tubes are predominately reason for the increased apparent stiffness, as they effectively add additional infill on the top surface. The size of these could be reduced as a simple method of improving the design. Alternatively, a redesign utilising the flexibility in design that 3D-printing offers can potentially negate these issues.

III. CONCLUSIONS AND FUTURE WORK

This paper presented preliminary results on 3D printing highly flexible and soft fingers for the previously developed SIMPA prototype to address the manufacturing challenges with the manual multi-stage moulding of the original silicone-rubber fingers. The initial gripper design, which was unable to be produced by moulding, featured the same geometry but was only 10mm wide, rather than 20mm. The small scale prevented the inner tubes from being inserted correctly and ultimately led to a redesign of the hand utilising 3 grippers, instead of 5. The smaller gripper has successfully been printed, opening up the possibility for this design concept to be re-examined, producing a 5 fingered variant of the SIMPA. Further optimisation of the design will be investigated to benefit from the design freedom offered by 3D printing. The validation would then consist of performing the same experimental procedures used to verify the SIMPA prototype, using the 3D-printed grippers. The inclusion of 3D-printing remains consistent to the ethos of the SIMPA prototype, which aims to be predominantly additively manufactured, moving away from the traditional approach to producing such devices, which still relies heavily on the skill of the craftsman.

The proposed relationship study between print parameters and actuation force would serve a more general purpose to characterise the material's use in FDM printing. This could be used in the design of general purpose soft-grippers and in other applications where variable stiffness may be required.

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