Design of Soft Fingers for a Surgical Robotic Hand with Hybrid Structure
Hibrit Yapıda Bir Cerrahi El için Yumuşak Parmakların Tasarımı

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***Abstract*— Utilization of robot manipulators started to be preferred in many medical applications due to the rapid technological developments occurred in the last decade. Thanks to the studies and applications in the related literature, leaving the usage of classical industrial robot manipulator structures, new designs with respect to the application constraints have been focused on. In light of this, current study focuses on the design of soft fingers that will allow the usage of a robotic hand with hybrid structure on soft tissue handling that requires high precision and compliance. Throughout the study various prototype trials were carried out and their suitability for the system was discussed.**

***Keywords— medical robotics, hybrid robotic hand, soft robotics, soft tissue handling*.**

***Özetçe*— Robot manipülatörlerin kullanımı son dönemde hızla gelişen teknoloji ile birlikte sağlık alanında birçok uygulamada tercih edilmeye başlamıştır. İlgili literatürde gerçekleşen kapsamlı çalışmalar ve uygulamalar sayesinde tasarlanan robotik sistemlerde, klasik endüstriyel robot manipülatör yapıları terk edilmeye başlanarak, uygulama kriterlerini gözeten tasarımlar ön plana çıkarılmıştır. Bu noktadan yola çıkarak çalışma kapsamında, tıbbi operasyonlarda uygulamayı gerçekleştiren cerraha yardımcı olabilmesi için tasarlanmış hibrit yapıda bir cerrahi robot elin, operasyon hacmi içerisinde bulunan yumuşak dokuların zarar görmeden kavranması ve belli bir noktaya taşınması gibi yüksek hassasiyet gerektiren görevlerde kullanılabilmesini sağlayacak yumuşak parmakların tasarımına odaklanılmıştır. Çalışma boyunca farklı prototip denemeleri gerçekleştirilmiş ve sistem için uygunlukları tartışılmıştır.**

Anahtar Kelimeler—medikal robotik, hibrit robot el, yumuşak robotlar, yumuşak doku etkileşimi

I. INTRODUCTION

Thanks to the rapid development of technology nowadays, utilization of robot manipulators have been started to expand into the various distinct fields from the sole industrial automation. Throughout the course of this technological development, medical areas become one of the most emerging fields for robotics among these areas. Although main reasons for this rapid implementation of robotic systems in medical applications are having high precision, increased dexterity and delicate repeatability, having classical rigid structures, these robotic systems still have their limitations in terms of environment interaction [1]. Utilization of robot manipulators with rigid structures in certain medical procedures increases the risks of the operation with respect to the tissue integrity, biocompatibility and motion constraints. Due to the fact that any unwanted action inside the workspace of the manipulator may result in irreversible vital results, conceptual designs of manipulators with flexible links have gained popularity. In light of this, in order to create safer robotic systems that can interact with patients and surgeons, a new generation of robot manipulators with soft structures have started to be developed via biomimicry inspired from the stretchable body features of animals such as jellyfish, octopus and snails [2]. Having similar structure of natural tissues in terms of rigidity and elasticity, utilization of these robot manipulators in complex surgical operations aims to achieve adaptability by providing efficient integrity with interacted biological structures [3.]

From this point, considering theoretical advantages and disadvantages of soft robot manipulators, throughout this study a hybrid surgical robot hand that will be used in the field of collaborative medical robotics was focused on. As the conceptual design and rigid finger structures of the surgical hand was already proposed in an earlier study [4], this study covers the design and development of soft fingers that will be integrated to the system for soft tissue handling. In light of this various prototypes of elastomer based soft fingers with skin biocompatibility were developed and manufactured in a way that during their actuation via pressurised air necessary grasping geometry can be achieved.

II. Structural Design

The main structure of the hybrid surgical robot hand includes total of six fingers (Fig. 1), where three of them are multi degrees of freedom rigid fingers and remaining three are the soft fingers. Each of the fingers was assembled to the main common body symmetrically in order to be utilized for various operation scenarios.

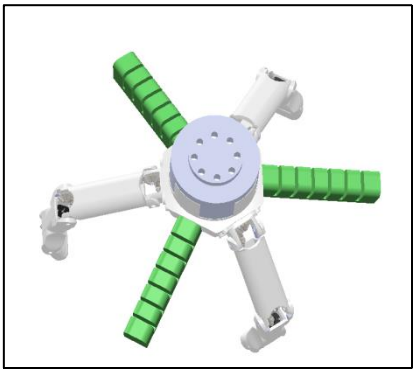


Figure 1. Design of Hybrid Surgical Robot Hand

Having individual three degrees of freedoms, mechanical fingers of the system will be used in scenarios such as grasping a rigid endoscope as a third arm of the surgeon and serving surgical tools to the surgeon during the operation. On the other hand soft fingers will be preferred during the situations where a delicate tissue handling is necessary during operations such as organ transplantation. It should be noted that, structure of the robot hand was designed in such a way that any of the six fingers can be disassembled to be replaced with different devices for visual navigation, lighting, aspiration etc.

A. Soft Finger Mould and Material Selection

Soft fingers designed throughout this study were manufactured by using materials with suitable skin contact biocompatibility. All of the fingers include pneumatic volumes called chambers and channels inside their structures. This chambers were connected together in rows by using a layer that provides limited stretch in one side of the fingers [5]. When these chambers are filled with pressurised air, their volumes are increased as they are inflated. Coupled with the limited stretch layer, this action results like a finger grasping motion. In order to reach proper grasping geometry with desired motion, throughout the study many mould designs were developed and experimented by using different elastic materials.

Prototype 1

Design of the first prototype of the soft finger mould that was proposed in the previous work [4] can be seen in Fig. 2a along with the sections that will produce chambers and air channels. This first mould design was manufactured via rapid prototyping system by using ABS material and classical white mould silicone was used during the casting procedure of the soft fingers (Fig. 2b).

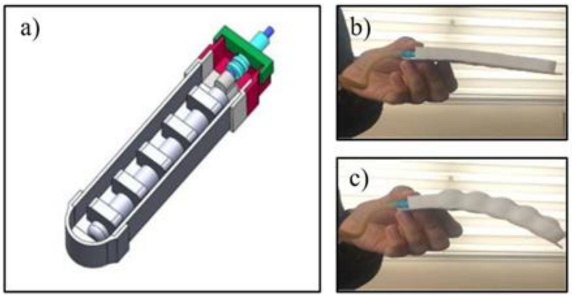


Figure 2. a) Soft Finger Mould Model, b) Soft Finger Initial Condition, c) Actuated Soft Finger

On the other hand, as seen in Fig. 2c desired grasping motion of the finger could not be achieved due to the material selection and the mould design. Thus other prototypes were developed and tried in this study to achieve target motion.

Prototype 2

Design of the mould was improved by using Pneu-Net model [6] as a base design. In order to get rid of bubbles during casting process mould design was enhanced as seen in Fig. 3. This design allows the injection of the material through the towers of the mould and escape airways on top of the chambers were inserted to prevent the formation of bubbles inside the material during injection.

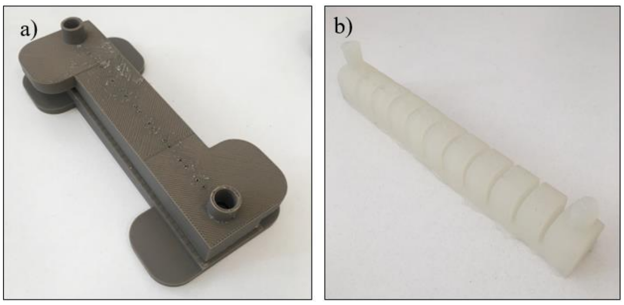


Figure 3. a) Soft Finger Mould Model of Prototype 2, b) Soft Finger Top Extracted from the Mould

In this prototype casting material was selected as a “Smooth-On Dragon Skin” mould silicone with skin contact biocompatibility. Although desired bending motion achieved via pneumatic actuation, bubble formations were observed in the air channels that connect individual chambers. Due to the fact that these air bubbles caused rupture throughout the operation of the finger, another mould design was prepared and manufactured.

Prototype 3

Considering the results achieved from previous experiments and mould designs, final mould design was prepared. In prototype 3 injection towers from the moulds were removed and chamber ceilings were replaced with open air design instead of escape airway design. In order to get rid of bubbles entirely this time, a vacuum chamber was used coupled with a casting material “Smooth-On Ecoflex 00-30” that has longer curing period, less viscosity and still having skin contact biocompatibility. The final prototype of the mould was designed by considering adult human index finger dimensions (Fig. 4).

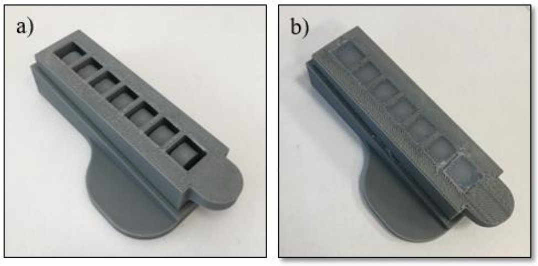
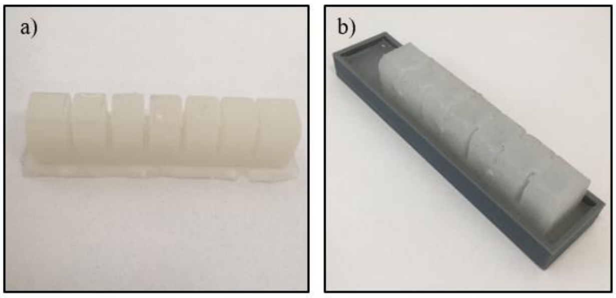


Figure 4. a) Soft Finger Mould Model of Prototype 3, b) Soft Finger Silicone Curing Procedure

After the curing period of the material, the top portion of the soft finger (Fig. 5a) was easily extracted from the two-piece mould. In order to finalize the design, top portion of the finger was combined in another mould with a bottom plane that has a layered structure of the same silicone material and additional rigid film called strain limiting layer to prevent bottom section stretch (Fig. 5b and 5c).



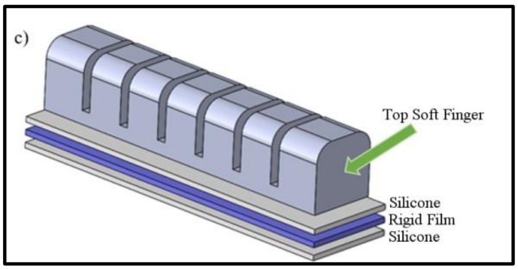


Figure 5. a) Soft Finger Top of Prototype 3, b) Bottom Plane Combination, c) Soft Finger Structure with Layered Bottom Plane

At the end of the casting procedure single air input hole were opened on the outer surface of the finger in order to proceed through the actuation. Also as a last step for finger integrity, air chambers were connected by a continuous elastomer bridge from the top and asymmetrical bridges from the sides (Fig. 6).

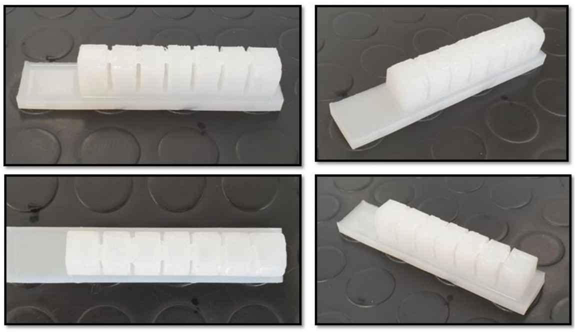


Figure 6. Final Prototype of the Soft Finger

After the given pneumatic actuation on the trials, it was observed that final soft finger prototype was properly actuated via homogeneously filled air chambers with a desired finger grasping geometry (Fig. 7).

Figure 7. Actuation and Grasping Geometry of the Soft Finger

III. RESULTS AND CONCLUSIONS

In this study, soft finger structures of the hybrid robot hand that was previously proposed for medical collaborative robotics were designed. Throughout the design procedure various mould prototypes were utilized and different casting materials were used. Considering the extracted experimental results mould designs and selected materials were improved. Final version of the soft finger produces desired grasping motion efficiently after the pneumatic actuation. Future works of the study will include implementation of rigid and soft fingers together on a macro robot manipulator to be able to execute collaborative tasks during surgery operations.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this manuscript.

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