RESEARCH ON THE DEVELOPMENT OF ROBOTS FOR RECYCLING SYSTEMS AND A CONSTRUCTIVE-FUNCTIONAL APPLICATION

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ABSTRACT: Because of the necessity for physical object sorting, single-stream recycling is currently an exceedingly labor-intensive operation. Soft robotics provides compliant robots which, in a congested environment, use less computing to plan pathways and grab things. Most soft robots, however, are not tough enough to handle the various sharp items found in a recycling center.

KEYWORDS: soft gripper, recycling, sustainability, advanced technology, technological system

1. Introduction

The soft gripper is designed to handle delicate or irregular shaped objects with precision and care, using a flexible, compliant material that securely grips a wide range of items thus being ideal for the recycling processes. The soft gripper design allows it to conform to the shape of the object providing a gentle yet firm hold thus minimizing the risk of damage or breakage. By the use of the advanced tactile sensing capabilities the gripper can adapt to various shapes, sizes and textures, thus being versatile for sorting and handling recycling materials such as paper, plastic, glass and much more materials that come in different size and shapes on the same sorting line.

2. General considerations

2.1. Gripper design and consideration for heavy payload jaw-style/ finger grippers

The parameterization and design of the soft gripper and its process application varies from application to application because of the many interconnected degrees of freedom [1, 2].

When a soft gripper grasps a workpiece a complex contact situation is caused by the actuation force due to the fact that the soft material deforms thus changing the surface area. The modified surface area is affecting the accuracy and holding force of the soft gripper to the specific workpiece, so, the geometry and shape of each jaw/ finger for the soft gripper must be made separately for each grasping situation in the envisioned product scenario in order to have low safety margins and suitable gripper for application. This is also taken into consideration because of the payloads of interests in the envisioned product scenario, and with this, two effects gain importance: first the deformation impacts the achievable assembly accuracy and second the inner forces in the gripper lead to overload or malfunction in elastic structure [1].

2.2. Material selection

A crucial part of a soft gripper is identifying the most suitable material for the jaws based on application. For most soft grippers, the soft material used is polyolefin thermoplastic elastomer, a material that compounds mixtures of various polyolefin polymers, amorphous elastomers and semicrystalline thermoplastics.

The balance in the elastomers composition it is found between polypropylene which is tough and rigid, and the ethylene propylene rubber which is a type of soft, rubbery material made from synthetic rubber. The material is characterized by the following properties:

- Stiffness: the ratio of force to deformation in an object
- Young's Modulus (E): material should be similar to that of soft tissues ($E < 10$ MPa)
- Toughness (T): total energy that the material can absorb before the material reaches rupture point
- High Degrees of Freedom at impact: the material should be able to deform well beyond what a human tissue can without damaging itself or anything nearby
- Ultimate elongation (γ_{ult}): the material should have a very high ultimate elongation so that even in cases of extreme stretching, it doesn't rupture.

Data for polyolefin thermoplastic elastomer are found in Tables 1-3 [1].

Table 1. Properties after Gamma Sterilization of RTP 2800 Series [1]

Material	Sterilization Level (kGy)	Tensile Strength (MPa)	Tensile Modulus @100% (MPa)	Tear (pli)	Shore A Hardness	Yellowness Index
RTP 2800 B-85A	Control	9.4	6.0	263	88	14.03
	25.0–26.1	8.4	5.8	239	86	19.13
	50.8–54.4	7.7	5.7	233	84	19.54
	75.1–76.8	6.9	5.5	218	87	20.42
RTP 2800 B-45A	Control	4.1	1.70	97	54	18.48
	25.0–26.1	3.6	1.59	95	52	21.32
	50.8–54.4	3.2	1.53	84	52	20.61
	75.1–76.8	2.9	1.34	79	51	21.78

Table 2. Residuals after Ethylene Oxide Sterilization and Aging in ExxonMobil Chemical Santoprene Olefinic Thermoplastic Elastomers [1]

Materials	EtO mgs/day		ECH mgs/day	
	1 Day	4 Days	1 Day	4 Days
Allowable limit per ISO 10993-7	20	20	12	12
Santoprene TPV 181-57W180	0.18	0.18	1.554	1.26
Santoprene TPV 281-45MED	0.32	0.18	3.91	1.48
Santoprene TPV 281-64MED	0.40	0.18	4.17	1.78
Santoprene TPV 281-87MED	0.35	0.18	4.13	0.96

Table 3. Effect of Steam Sterilization on Santoprene 281-45 and 281-55 Olefinic Thermoplastic Elastomers [1]

Material Supplier/Name	Santoprene 281-45					Santoprene 281-55				
Exposure Conditions										
Number of cycles	10	25	50	75	100	10	25	50	75	100
Properties Retained (%)										
Ultimate tensile strength	91	68	93	95	91	86	85	84	92	91
Ultimate elongation	103	77	103	101	96	86	81	81	78	80
100% Modulus	88	86	89	95	94	92	95	93	104	99

Depending on the process requirements, we can simulate specific payload of the gripper by means of the response force determined during the simulation. The workpiece adheres to the gripper jaw surface and is securely secured at the start of the simulation. The position is stable at that point, and there are no relative movements between the gripper and the workpiece. When static friction is broken down into sliding friction as a result of imposed displacement (pull-off to pull-out), a relative movement occurs that must be addressed in an application. This phenomenon is typically repeated by the continually enforced displacement and is referred to as stick-slip behavior, which is determined by the surface topology and the elastic/plastic characteristics of the contact surfaces (Fig.1).

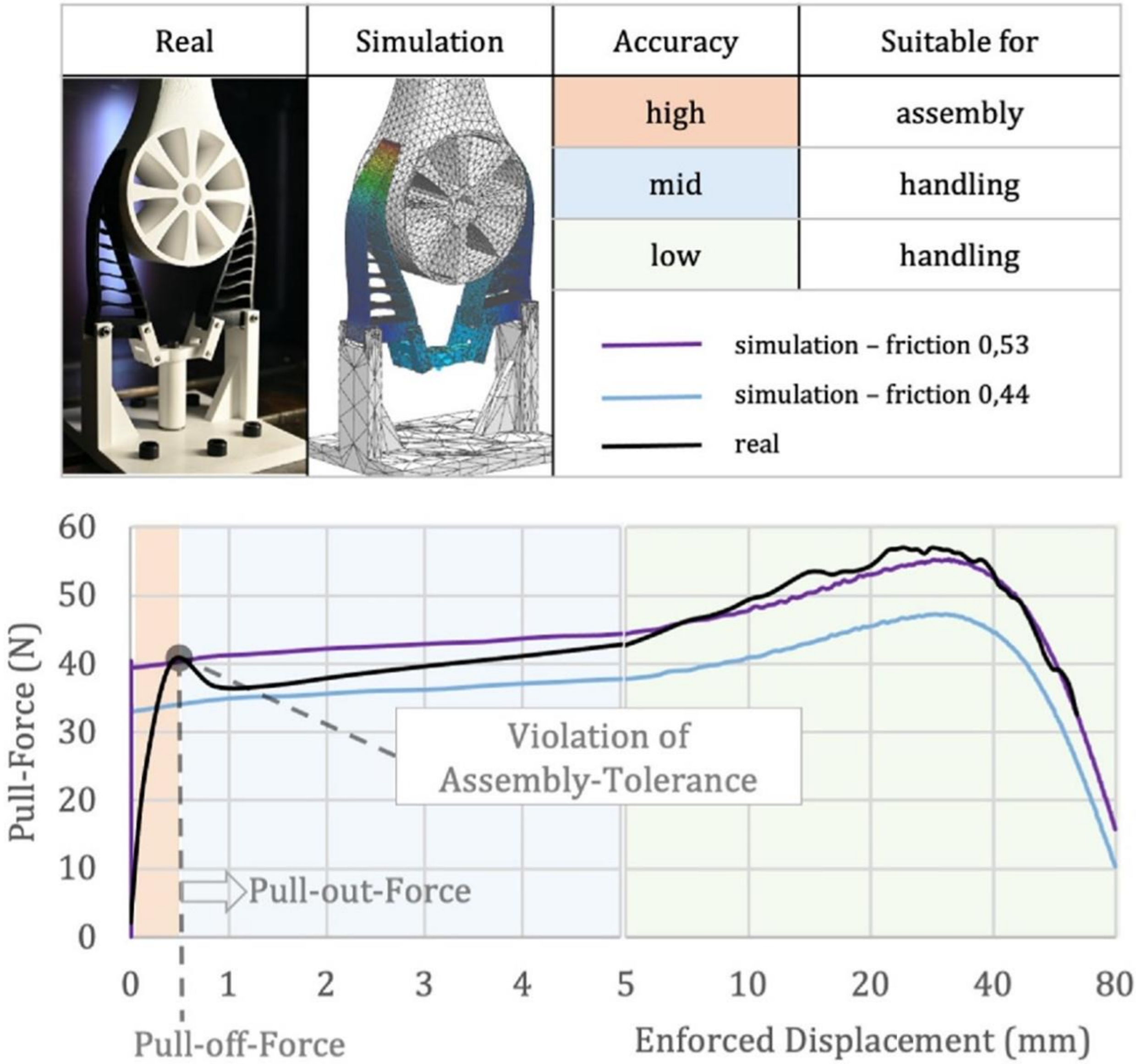


Fig. 1. Pull force and accuracy of soft gripper represented by enforced displacement [3]

Grip simulation assisted in automatically optimizing the configuration in assembly and handling conditions. The projected accuracy margins suit the experiments well enough that experimentation is no longer necessary. Ongoing study focuses on the gripped object's resilience in terms of contour variance (Fig. 2).

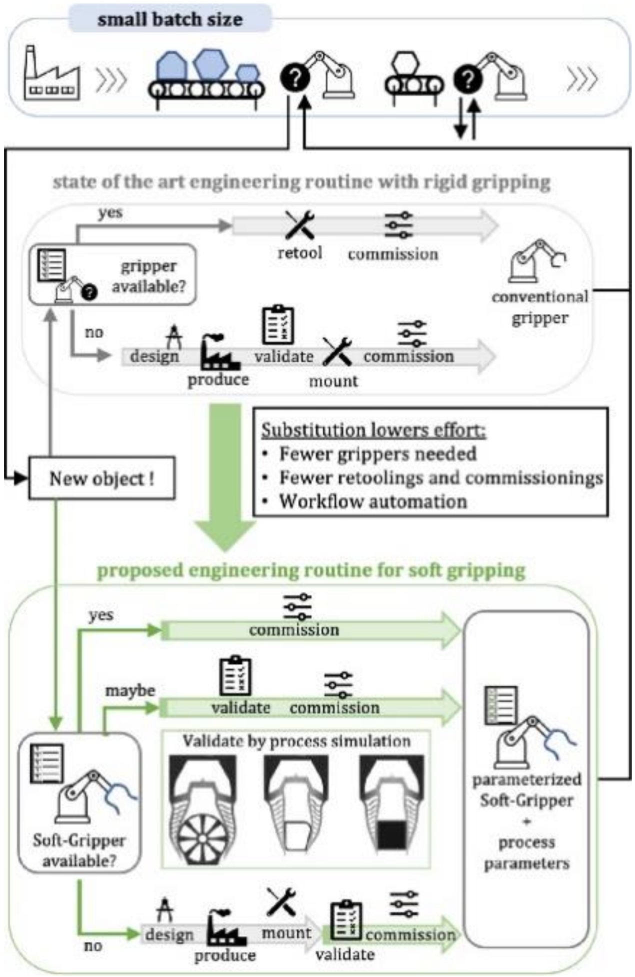


Fig. 2. Structural comparison between rigid gripping processes vs. proposed routine with automated validation for soft gripping [3]

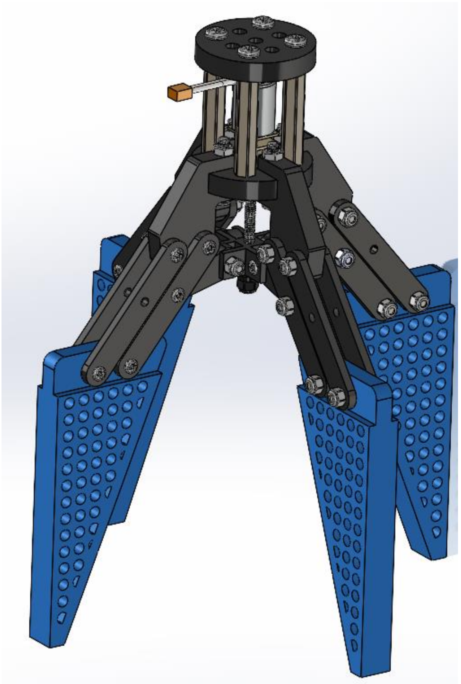
3. Case study

The present study case is concentrated on ways of improving and automatizing the process of sorting recyclable materials by use of robot intervention or independent grippers, as being the Soft Gripper SG 100.

The Soft Gripper SG 100 has been envisaged to be an independent soft gripper, for use in a variety of applications.

The Soft Gripper SG 100 assembly is designed, consisting of identical or distinct components as presented in Fig. 3.

Due to the fact that the recycling industry is in a continuous grow and have many different recycling sectors ranging from paper, cardboard and plastic to tyres, auto shredded residues ASR and so on, the soft gripper can be optimized to the desired application. The base plate is with holes at angular distance of 45°, and by installing another center nut with different geometry, the gripper can switch from a 4-finger soft gripper to 3-finger soft gripper. In the same manner, by changing the center nut and supplementing all parts apart from the base plate, top plate, and servomotor with screw the soft gripper can be with 6 fingers or 8 fingers.



Pos.	Designation	Qty
1	Soft Finger	4
2	Arm	16
3	Connecting Arm	4
4	Servo-motor with threaded screw	1
5	Top plate	1
6	Threaded Pillar	4
7	Connecting link	4
8	Center Nut	1
9	Base plate	1

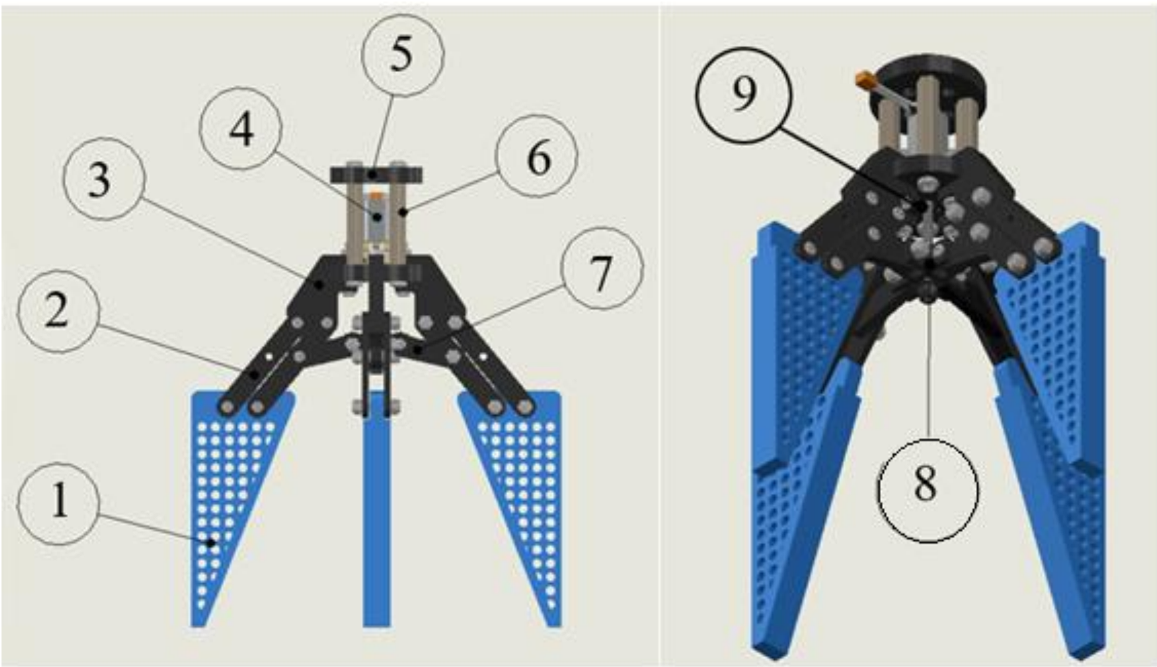


Fig. 3. Soft Gripper SG100

In order to develop an adaptive robotic gripper, compliant mechanisms with integrated actuators are utilized. The synthesis method for these systems involves defining problem specifications, parameterizing the design domain, and applying genetic algorithms as an optimization method to find the optimal solution. The goal of optimization is to find the optimal topology with integrated actuators so that the system achieves maximal structural controllability (adaptability) of its grasping surface [4].

An experimental model of the Soft Gripper SG 100 has been manufactured as presented in Fig. 4. For this model, the jaws are silicone based for easier fabrication.

a.

b.

Fig. 4. An experimental model of the Soft Gripper SG 100 (a, b)

4. Conclusions

The development of robots for recycling systems has made significant progress with the introduction of soft grippers.

The soft gripper with 4 soft fingers has been shown to be a promising solution for handling a wide range of recyclable materials. Its ability to conform to irregular shapes and apply gentle pressure allows for safe and efficient sorting of materials without causing damage. Additionally, the use of soft grippers reduces the need for complex sensors and expensive machinery, making it a cost-effective solution for recycling facilities.

With further research and development, the soft gripper technology can continue to enhance the effectiveness and efficiency of recycling systems, ultimately contributing to a more sustainable future. The use of such systems offers several advantages over rigid-body mechanisms, including reduced complexity, easy manufacturing, and better scalability. The synthesis method involves defining problem specifications, parameterizing the design domain, and applying genetic algorithms for optimization.

An experimental model of the 4-finger gripper with integrated smart material actuators and sensors has been introduced, and it has been shown that such a gripper concept can realize controllable shape morphing of its grasping surface via pressure sensors.

5. References

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