SMA Actuated Dual Arm Flexible Gripper

by

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in

ADVANCES IN ROBOTICS - 2019
(*AIR-2019*)

IIT Madras, Chennai

Report No: IIIT/TR/2019/-1

Centre for Robotics
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Hyderabad - 500 032, INDIA
July 2019

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ABSTRACT

Robotic grippers have been designed for grasping a wide variety of objects. This paper presents a novel design of a flexible gripper suitable for gripping circular objects having variable curvatures and different textures. Two rubber belts form the gripper arms, which are used for gripping objects. These rubber belts are attached to DC motors. The motors are fitted in the gripper base . Magnets are attached on the other ends along with an interlocking mechanism. The primary actuation in the gripper is brought about by the Shape Memory Alloy (SMA) wire fitted along the inner side of the rubber belts. On energizing the SMA, the rubber belts bend along with the pre-programmed SMA and the magnets on the two belts come closer. Subsequently, locking is achieved. This forms a loop around the gripping object. The grip of the rubber belts around the object is further tightened by winding them around the shafts of the motors to which they are attached. This helps the gripper to firmly grasp objects of variable diameters. Gripping has been successfully tested on pipes, metal poles, trees with thin and thick stems.

CCS CONCEPTS

• **Design Rules , Robotic components**;

KEYWORDS

Flexible gripper, rubber belts, SMA

*Both authors contributed equally to this research.

AIR '19, July 2–6, 2019, Chennai, India

ACM ISBN 978-1-4503-6650-2/19/07…$15.00
https://doi.org/10.1145/3352593.3352669

1 INTRODUCTION

End-effectors of robots are the parts through which a robot directly interacts with foreign objects. Among various types of end effectors, grippers are the most common and widely used type. The design, mechanism and control of grippers are greatly dependent on their applications which range from industry to construction [5] and military to agriculture [15] [8]. Bicchi and Kumar [4] have performed a detailed study of robotic grasping for various applications by enlisting grasping properties and kinematic and dynamic models. Tai et al. [15] have presented a recent survey in robotic grippers by stressing on the materials and mechanisms used for manufacturing of grippers and their functionality in areas of robot surgery, manipulation and industry. Dong et al. [7] have underlined the necessity of optimal gripper design in gripping by proposing a universal genetic algorithm for conventional tendon-driven gripper. Four-bar linkage based adaptable gripper design for service robots has been proposed by Jung and Oh [10]. Taking inspiration from the fish fin, Basson et al. [3] have presented a modified gripper design to incorporate the rib structures based on Fin Ray Effect for greater shape conformity. Moving away from the conventional rigid grippers, soft grippers having fingers made of silicone for easy shape adaptability to the grasped objects have been put forth. [9]. However, the use of pneumatic actuation involves a complex and expensive manufacturing process as compared to that of the gripper proposed in this paper. Additionally, our gripper is fabricated out of materials which are easily available, cheap and which meet our requirements. The use of soft materials for robot fabrication has made robot mobility easier and has introduced new applications [2]. Extensive report regarding mechanisms, materials and sensing of soft grippers can be found in [14].

Apart from classifying grippers based on application, they are also classified on basis of type of actuation, mode of gripping, and type of mechanism. Mechanical jaw-type, vacuum, hydraulic, magnetic, pneumatic, etc. are categories based on different types of actuation. Mechanical grippers, which have finger like appendages for gripping, enclose the object fully or partially and rely on friction between the two surfaces. Soft material finger pads or finger pads having shape similar to the gripping object are used for effective gripping. Magnetic grippers have two categories, namely, permanent magnets and electromagnets. Such grippers are useful in pick and place of magnetic substances only [12]. Pneumatic grippers are employed to grasp objects by using compressed air for parallel or angular piston movement [1]. Vacuum grippers use rubber or polyurethane suction cups to hold objects [1]. Although hydraulic grippers are highly powerful and provide a huge amount of force, their design becomes bulky due to auxiliary needs of compressor and tanks [1][13]. Flexible grippers having multiple fingers with several phalanges have become popular for grasping a variety of items [3].

The emergence of soft robotics has been extremely advantageous in enhancing the versatility and usefulness of several robots and mechanisms. The use of flexible materials has eased interactions with items of different shapes, sizes, texture and strength which was a major challenge before when only rigid substances were used for the manufacturing of robots. Additionally, smart materials like hydrogels, electro-active polymers, piezoelectrics and bi-component fibers, shape memory polymers, which have properties that react to change in their environment, have widened the scope of applications in the fields of medicine, textile, construction and industry [1]. Drawing inspiration from these developments, we propose a novel design of robotic gripper made using a combination of flexible and smart materials. The rubber belts are actuated using SMA wires made from Nickel-Titanium alloy [11]. The use of rubber belts has made it possible to grip circular objects within a range of diameters and different textures and standard convex-shaped objects. The choice of SMA is attributed to its unique property of phase transformation from Martensite to Austenite phase on heating [6]. The proposed gripper is developed with an aim to create a simple yet efficient gripping mechanism applicable for objects having variable diameters. The use of 3D printed gripper base ensures that the design remains lightweight and compact. The paper is organized as follows : Section 2 describes the design and fabrication of the gripper and its parts. Mathematical analysis of the proposed design is done in Section 3. Further, Section 4 explains the mechanism of gripper in steps of locking and gripping action. Section 5 enlists certain characteristics and experimental observations regarding the gripper. Finally, section 6 concludes by proposing future scope for the gripper.

2 DESIGN AND FABRICATION OF THE GRIPPER

The gripper consists of 4 main components , namely , gripper base, gripper arms, SMA wires, motors. (Figure 1)

2.1 Gripper Base

The base of the gripper (Figure 2) provides a platform for the rubber belts which are the main gripper arms . It contains two holes for fitting DC motors (Figure 2a). To keep the overall weight of the gripper less, the base has been fabricated using PLA in 3D printer. The tapering shape of the gripper acts as a support platform for the belts. A three teethed belt support structure made in ABS as shown in Figure 1 has been fitted at the tapering corner of the gripper base. This provides an independent channel for the free movement of each belt and also prevents them from rising above the surface of gripper base while gripping.

2.2 Gripper Arms

The gripper arms are made using two rubber conveyor belts as rubber is flexible and can easily wrap around the object to be gripped. Rubber provides sufficient friction while gripping objects of variable surface textures. The pattern of alternate ridges and valleys on the belt ensures effective gripping. The rubber belts are attached to motor using specially fabricated aluminium belt holder which fits on the motor shaft (Figure 5). Two slits in the rubber belt go in the two teeth of this part and are locked using nut and bolt. Small pieces of high temperature grade silicone wires are used to fasten the SMA wire to the belt at regular intervals (Figure 6). At the end of each belt, 2 pieces of square magnets of dimension 1cm are fixed such that both the belts bear magnets with opposite polarity. These magnets are helpful to keep the belts closer to each other while locking of belts around the object. In order to interlock the two belts properly during the gripping action, one belt has been fitted with a small, light weight DC motor having a T-shaped shaft. A rectangular slit has been made in the another belt such that the T-shaped shaft of the motor goes through it while locking the belts (Figure 3). The rubber belts along with the SMA are covered with cylindrical rubber grips. (Figure 1) These grips ensure that the gripper arms remain straight and do not slack.

Parameters	Value (mm)
Length	530
Width	25
Thickness	4.5

Table 1: Properties of Rubber belt

2.3 SMA

The use of Shape Memory Alloy is an important idea in the design of the gripper. Ni-Ti alloy wire (Nitinol), which is made of approximately equal amounts of Nickel and Titanium, has been chosen owing to its characteristics of high stability, superelasticity, large deformation, excellent fatigue strength and shape memory effect. SMA wire is initially trained or 'programmed' to bend in a circular manner when it is in the Austenite phase (or the high temperature phase). Training is done by heating the wire in required shape over a candle flame for approximately 20 minutes. 2.5 m length of such wire having 1 mm diameter is used for each belt. It is fitted on the inner side of the belt in form of 4 parallel tracks.The phenomenon of Shape Memory Effect, occurring due to thermoelastic martensitic transformation [16] [6] is mainly employed for the gripping action. The SMA wire recovers its parent shape on heating over the transformation temperature. This heat is provided by the electric current supplied to the SMA through single stranded wires soldered at their ends. On powering up Nitinol wires of each belt, both the belts start bending in a curve and their tips start coming closer, thus creating ideal conditions for their locking.

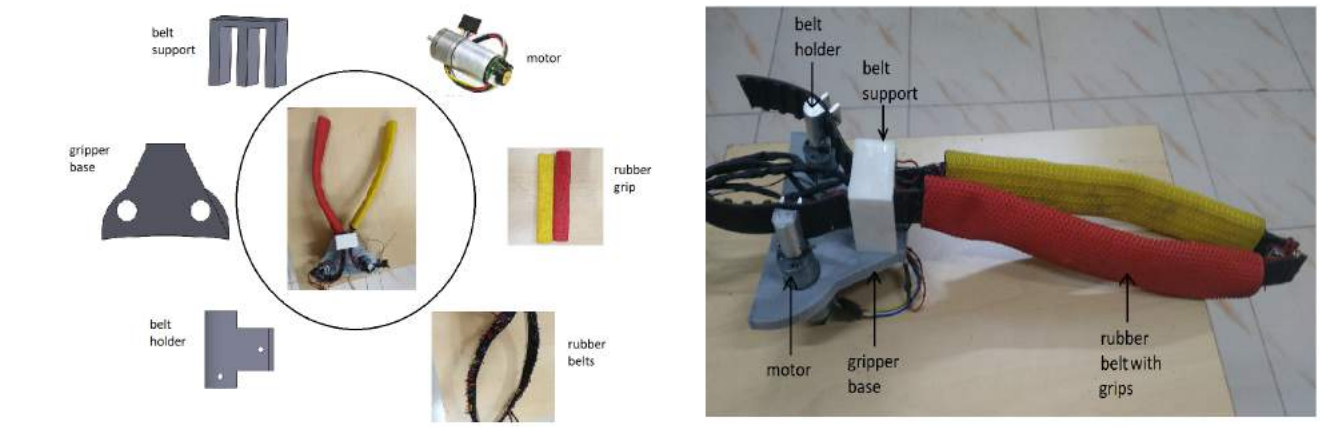

Figure 1: Prototype of flexible gripper.

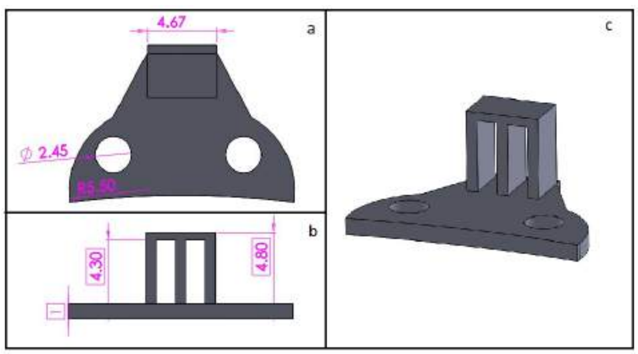

Figure 2: a)Top view of gripper base. b) Front view of gripper base. c) Gripper base (all dimensions are in centimeters. Figure not to scale)

Figure 3: Rubber belts with locking motor and slit

2.4 Motors

Two high power 6V brushed DC gearmotors have been used as primary actuators in the gripper. A distance of 65 mm is maintained between the central axes of the motors to prevent the belts from colliding into each other while and after winding around the motor. After the SMA comes closer and the belts get locked by the locking motor, the DC motors rotate enabling the belts to wind around their shafts. Aluminium belt holders are used atop the motor shafts. The rubber belts go in their two teeth and are locked on the opposite

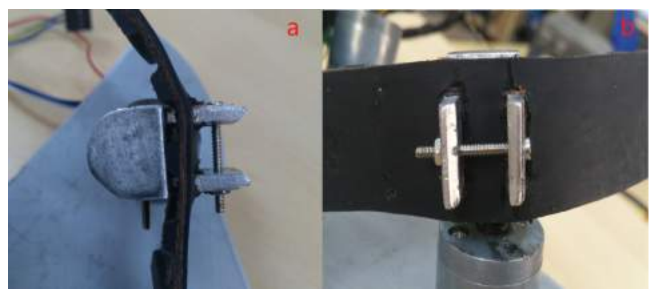

Figure 4: Rubber belts attached on belt holders in a) Top view b) Front view

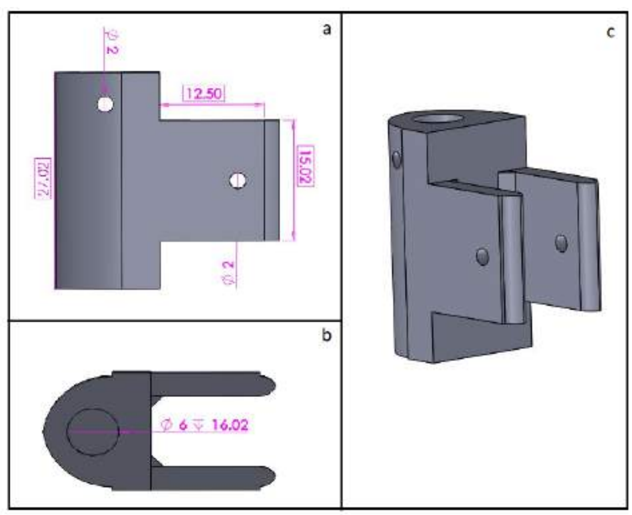

Figure 5: a) Front view of belt holder. b) Top view of belt holder. c) belt holder (all dimensions are in millimeters. Figure not to scale)

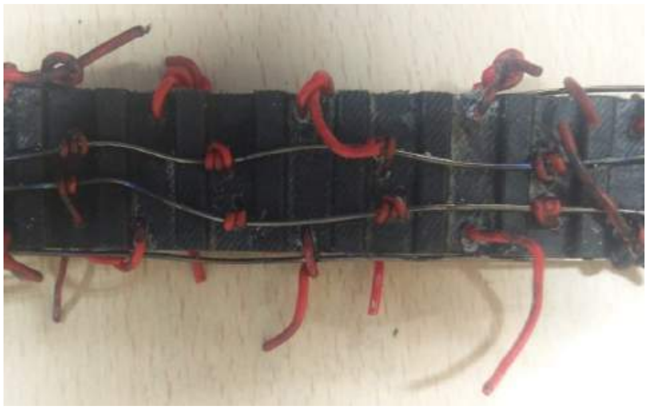

Figure 6: SMA fastened on rubber belt using high temperature grade silicone wire

Parameters	Value
Density	6.45 gm/cu.cm
Melting Point	1300 deg.C
Transformation Temperature	-200 to 110 deg.C
Transformation Strain	8% (single cycle) 6% (100 cycles) 4% (100000 cycles)
Thermal conductivity	0.18 W/cm*deg.C (Austenite) 0.086 W/cm*deg.C (Martensite)

Table 2: Specifications of SMA-Nitinol

side by nut and bolt to prevent them from coming out while the motor rotates (Figure 4).

Parameters	Value
Model	172:1 Metal Gearmotor 25Dx56L mm HP 6V with 48 CPR Encoder
Weight	106gm
Operating speed	56 RPM (6V)
Stall torque	25 kg-cm , 350 oz-in (6V)
Gear ratio	172:1
Motor diameter	25mm
Shaft diameter	4mm

Table 3: Specifications for motor of the gripper

3 MATHEMATICAL ANALYSIS AND OPERATION

Mathematical analysis has been done in order to find out the torque of DC motors while winding. Subsequently, the payload capacity of the gripper is calculated assuming maximum motor torque.

3.1 Torque Calculations

The mathematical analysis for the gripper has been done assuming static gripping and hence equilibrium conditions are maintained.

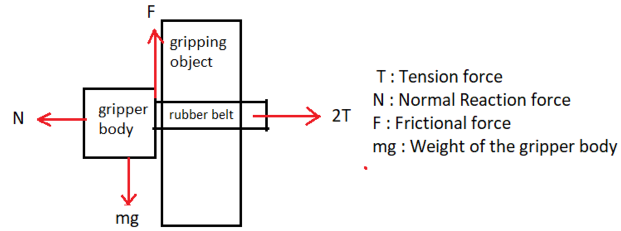

Figure 7: Schematic diagram of gripper showing all the forces

Figure 7 shows a schematic diagram of the gripper during gripping. Tension force (T) is present in each rubber belt due to the motors, while the gripping object exerts a Normal Reaction Force (N) on the gripper body. The weight of the gripper body (mg) is balanced by the frictional force (F) that acts between the gripping object and gripper body in upward direction. Assuming equilibrium in horizontal and vertical direction, we have the following equations:

$$N = 2T \quad (1)$$

$$mg = F \quad (2)$$

Frictional force depends on the normal reaction force and the coefficient of friction between contact surfaces. Hence:

$$F = \mu N \quad (3)$$

Equations (1), (2) and (3) give the tension force generated in the rubber belts. Using this tension force and the radius of motor 'r' , we can calculate the torque applied by the motor during gripping as follows:

$$\tau = T \times r \quad (4)$$

Given the motor torque, we can also find the maximum weight that the gripper can lift. By using equations (1) to (4) and rearranging, we can give the expression for maximum weight(m_{max}) that the gripper can hold as follows

$$m_{max} = 2\mu\tau/gr \quad (5)$$

$$m \leq m_{max} \quad (6)$$

3.2 Operation of Gripper

The entire gripper is powered using Li-Po (Lithium-Polymer) battery (7.4V, 2500 mAh). The SMA wire on both the belts are controlled individually by a simple switch. DPDT (double pole double throw) switches are used to control the DC motors in clockwise and counter clockwise direction. The locking end DC motor is separately controlled by a similar DPDT switch. The operation of the gripper is explained in the following steps:

1 Each of the SMA coils are individually operated with their respective switches to bring the two rubber belts closer to each other.

2 The magnets which come closer as a result of Step 1, get attracted to each other, and get stuck, hence providing ideal condition for locking of the belts as the T-shaped motor shaft of the locking end motor passes through the slit in the opposite rubber belt.
3 The locking end motor is manually operated using switch to rotate through an angle of 90 degrees to interlock the two rubber belts.
4 The SMA coils are individually operated to sufficiently bend and take the shape of the gripping object.
5 Finally, the motor attached to the rubber belts are rotated using switch to wind the extra portion of belt that remains loose, thus tightening the grip around the object.

4 MECHANISM

4.1 Locking action

In order to grip tight, it is utmost important that the the rubber belts lock with each other after they go around the gripping object. For locking, the rubber belts are brought close to each other by the bending of the SMA. As a result of this, the opposite polarity square magnets fitted at the ends of the belt, get attracted to each other and get stuck. This facilitates the easy sliding of the T-shaped DC motor shaft (Figure 8) into the horizontal slit in one of the belts. After this, the motor is rotated through an angle of 90 degrees so that the T-shaped shaft becomes vertical. This enables the two belts to stay interlocked with each other. The locking of the two belts ensures that the belts surround the object to be gripped for the entire duration of the gripping action.

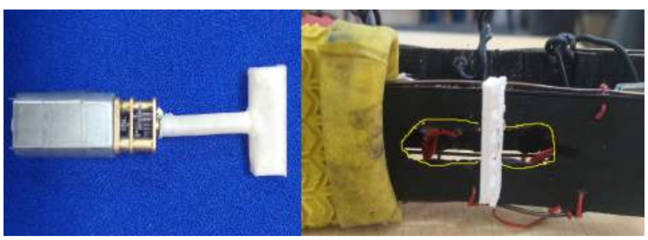

Figure 8: a) Motor with T-shaped shaft for locking b) After locking together both belts(yellow line shows slit through which the shaft passed)

4.2 Gripping Mechanism

Once the two belts are locked around the object to be gripped, gripping action begins. Four tracks of SMA wire have been fitted along the length of the rubber belts. SMA wire is programmed to bend into circular shape upon heating. Thus, when the SMA is powered after locking both the belts, it comes closer to the gripping object held between the belts. Following this, the motors are rotated to wind the loose length of the belt around their shafts and hence tighten the grip.

5 EXPERIMENTAL OBSERVATIONS

The proposed gripper can be used to grasp circular or semi-circular objects such as trees, poles, rods, bottles, etc. By experimenting on different objects we have found that this gripper can grip objects having diameter in range of 25 mm to 190 mm. The SMA wire draws a current of 9.2 A at 7.4 V. The entire gripper weighs 574 grams. In order to keep the weight of gripper as small as possible, the gripper base is fabricated using PLA. Successful gripping has been obtained on metal pole, square pole, tree and PVC pipe (Figure 9). In addition to gripping larger diameter objects, our gripper can firmly grasp bamboo stems of 25 mm diameter (Figure 10 b).Thus, it is evident that the gripper is able to tightly grip objects of various curvatures and textures.

Figure 9: Gripping on a) Round metal pole (diameter : 80 mm) b) Square wooden pole (diagonal : 137.8 mm) c) Tree (diameter : 117.8 mm) d) Circular PVC pipe (diameter : 165.6 mm)

Figure 10: Gripping on a) thick tree trunk (diameter : 120 mm) b) Bamboo stem (diameter : 25 mm)

Parameter Name	Value
Total weight of robot	574 gm
Weight of rubber belt	78gm
Weight of belt holder	15gm
Weight of gripper base	78gm

Table 4: Specifications of the gripper

We have tested gripper on objects made of wood, concrete and aluminium. Hence, using equation (4) and values of friction coefficients between rubber and these materials, we found the torque required by the motors during gripping as listed in Table 5

In the similar way, equation (5) can be used to find out the the maximum mass carried by the gripper. Table 6 lists these values for surfaces of wood, concrete and aluminium.

Material of surface	Friction Coefficient	Torque (kg-cm)
Concrete	0.6	0.299
Wood	0.7	0.256
Aluminium	0.8	0.224

Table 5: Motor torque while gripping on various material surfaces.

Material of surface	Friction Coefficient	Maximum Mass (kg)
Concrete	0.6	4.3184
Wood	0.7	5.134
Aluminium	0.8	5.9492

Table 6: Maximum mass that can be lifted while gripping on various material surfaces.

6 CONCLUSION AND FUTURE WORK

This paper proposes a new design of flexible gripper made up of rubber belts for gripping and SMA wire for actuation. The use of rubber belts allows for a range of different surface textures and shapes while gripping. Our gripper is powered using 7.4 V Lithium-polymer battery. It is suitable for gripping circular and semi-circular objects likes pipes, bottles, poles, tree, etc. This gripper, weighing nearly 574 gm, can grip objects with diameters ranging from 25 mm to 190 mm. Gripping has been successfully tested on tree, PVC pipe, light pole, square-shaped pole, bamboo stem. Thus, it has been demonstrated that the gripper can function on objects having a wide range of curvatures. In future, this gripper can be mounted on any base robot. By installing additional sensors like cameras, such robots can be employed for surveillance and monitoring operations in risky environments.

REFERENCES

[1] Albert Aparisi i Escriva. 2016. Design of Smart Gripper for Industrial Applications. (2016).

[2] Hritwick Banerjee, Neha Pusalkar, and Hongliang Ren. 2018. Single-motor controlled tendon-driven peristaltic soft origami robot. *Journal of Mechanisms and Robotics* 2, 6.

[3] Christian Ivan Basson, Glen Bright, and Anthony John Walker. 2018. Testing flexible grippers for geometric and surface grasping conformity in reconfigurable assembly systems. *South African Journal of Industrial Engineering* 29, 1 (2018), 128–142.

[4] V. Bicchi, A. Kumar. 2000. Robotic grasping and contact: a review. In *Proceedings. IEEE International Conference on Robotics and Automation (ICRA),2000.* IEEE, 348–353.

[5] Thomas Bock, Jens Herbst, Carlos Balaguer, and Mohamed Abderrahim. 2000. Design of a Gripping System for the Automated Assembly of Large Building Modules. *2000 Proceedings of the 17th ISARC, Taipei, Taiwan* (2000), 1–8.

[6] J Chopade, R Barjibhe, and B Kumar. February 2013. Critical Review On Shape Memory Alloy. *International Journal of Engineering Research and Technology* 2, 2 (February 2013), 1–6.

[7] Huixu Dong, Ehsan Asadi, Chen Qiu, Jiansheng Dai, and I-Ming Chen. 2018. Geometric design optimization of an under-actuated tendon-driven robotic gripper. *Robotics and Computer-Integrated Manufacturing* 50 (2018), 80–89.

[8] Samuel J Flood. 2006. *Design of a Robotic Citrus Harvesting End Effector and Force Control Model using Physical Properties and Harvesting Motion Tests.* Vol. 73.

[9] Jan Fraś, Mateusz Maciaś, Filip Czubaczyński, Paweł Sałek, and Jakub Główka. 2016. Soft Flexible Gripper Design, Characterization and Application. In *International Conference on Systems, Control and Information Technologies 2016 SCIT 2016: Recent Advances in Systems, Control and Information Technology.* Springer, 368–377.

[10] Tae-Jin Jung and Jun-Ho Oh. 2013. Design of a Robot Gripper for a Rapid Service Robot. *Robotics and Computer-Integrated Manufacturing* 46, 5 (2013), 319–324.

[11] L' Miková, S Medvecká-Beňová, M Kelemen, F Trebuňa, and I Virgala. 2015. Application of shape memory alloy (SMA) as actuator. *Metalurgija* 54, 1 (2015), 169–172.

[12] Karokh Mohammed. 2010. Design of a gripper tool for robotic picking and placing. *Dissertation* (2010).

[13] Sameer Raval and Bhavesh Patel. 2016. A Review on Grasping Principle and Robotic Grippers. *International Journal of Engineering Development and Research* 4, 1 (2016), 483–490.

[14] Jun Shintake, Vito Cacucciolo, Dario Floreano, and Herbert Shea. 2018. Soft Robotic Grippers. *Advanced Materials* (2018), 1–33.

[15] Kevin Tai, Abdul-Rahman El-Sayed, Mohammadali Shahriari, Mohammad Biglarbegian, and Shohel Mahmud. 2016. State of the Art Robotic Grippers and Applications. *International Journal of Engineering Research and Technology* 5, 2 (2016), 1–20.

[16] Chen Zhang, Ralph H Zee, and Paul E Thoma. 1996. Development of Ni-Ti based shape memory alloys for actuation and control. In *IECEC 96. Proceedings of the 31st Intersociety Energy Conversion Engineering Conference.* IEEE, 348–353.