Development and Control of 3D Printed Soft Touch Robotic Manipulator

Ivan Ćirić*, Nikola Ivačko*, Dušan Stojiljković*, Stefan Lalić*, Petar Đekić**, Milan Pavlović**and Nenad Pavlović*
*Faculty of Mechanical Engineering University of Niš, Niš, Serbia
** College of Applied Technical Sciences Niš, Niš, Serbia
ciric.ivan@masfak.ni.ac.rs; nikola.ivacko@masfak.ni.ac.rs; dusan.stojiljkovic@masfak.ni.ac.rs; stefan.lalic@cbotics.org; petar.djekic@akademijanis.edu.rs; milan.pavlovic@vtsnis.edu.rs; nenad.t.pavlovic@masfak.ni.ac.rs

***Abstract*— Compliant grippers are used in the macro and micro world for capturing and manipulating objects, when it is necessary to manipulate fragile objects, such as surgical instruments, in biomedicine for manipulating individual cells, etc. In addition, grippers with a rigid contact between the grippers and the rigid objects can lead to damage to the objects, so in these cases, a control system is required to control the contact forces. Development of compliant finger-like gripper for soft touch application is described in this paper. This paper provides an answer to the question how to design, model and implement such compliant gripper. The developed compliant fingers are inspired by the real human fingers. Machine learning methods where proposed for realization of non-distractive grasping of fragile objects where feedback information is acquired by computer vision system while intelligent algorithms where considered for motion control and grasping. The complexity of lays not only in non-destructive grasping but also in adequate force implementation in order to avoid dropping the grasped object. Hence, nonlinear simulation of compliant gripper, by means of finite elements method (FEM), is provided in this paper. Several experiment where done to provide real life conformation of such analysis.**

***Keywords*: Soft Touch Grasping, Compliant Mechanism, Finite Element Analysis, Intelligent Control.**

I. MOTIVATION

As of the current state of the technology, standard types of grippers used in industrial applications are not suitable for precise manipulation of fragile objects. It is a safe assumption that in multitudinal fields of industry such as medical or agricultural, there emerges a need for soft touch grippers, capable of dexterously handling sensitive objects of manipulation. Implementation of compliant mechanisms in robotic grippers, having been proved suitable in aspects of manipulation regarding high precision and usability in cleanrooms, enables soft touch adaptive grasping abilities. The main idea encompassing above mentioned remarks is development of a robotic gripper which simulates the haptic function of a human hand as closely as possible.

II. RESEARCH QUESTIONS

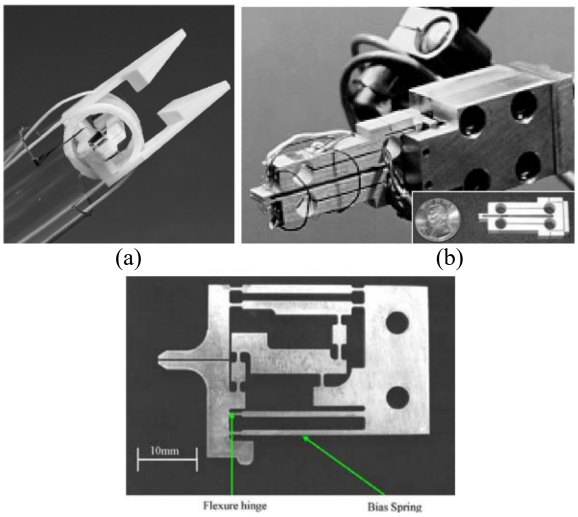
This paper provides an answer to the question how to develop and implement compliant grasping fingers on pneumatic Festo industrial gripper DHPS 16 A for soft touch application. The developed compliant fingers are inspired by the real human fingers while intelligent algorithms where considered for motion control and grasping. Machine learning methods where proposed for realization of nondestructive grasping of fragile objects where feedback information is acquired by computer vision system. The complexity of the problem lays not only in nondestructive grasping but also in adequate force implementation in order to avoid dropping the grasped object.

III. METHODOLOGY

3D printing is a modern technology for the production of three-dimensional parts and there are several techniques of 3D printing. For the production of the robotic manipulator FDM technology was used, where the dissolved material is applied layer by layer along a predetermined path and joined into the final product. The most common materials used in FDM technology are PLA, ABS, PVA, HIPS, PET and TPE. Print quality is affected by many factors such as print temperature, nozzle size, material, print speed, substrate temperature etc. The printers used in the production process of the robotic manipulator are of lower and medium quality without a cooling chamber. The working surfaces of the printer are 220x220x250 mm and 235x235x250 mm. These printers have a print error of ± 0.1 mm. This error can seriously affect assembly due to bearings fit and parts connecting. This printing error is influenced by many factors such as vibrations during printing, outside temperature, material, print speed and even the color of the filament.

Compliant mechanisms are mobile materially coherent structures that can transmit forces and transform motion only due to the elasticity (elastic deformation) of the corresponding segments of the structure [1]. Compliant mechanisms, unlike traditional mechanisms, can be considered as a structure that has the appropriate rigidity due to which it can withstand external loads because it does not contain classical joints. The role of joints is replaced by flexure members (compliant joints) in which structural deformation is a desirable effect because it enables the mobility of the mechanism itself. In other words, compliant mechanisms are a combination of structure and a mechanism that has a specific function. Due to the many advantages over rigid classical mechanisms, compliant mechanisms are used in medical and biomedical devices, such as precision systems, motion/force transmission amplifiers, positioners, grippers...

Compliant grippers are used in the macro and micro world for capturing and manipulating objects, when it is necessary to manipulate fragile objects, such as surgical

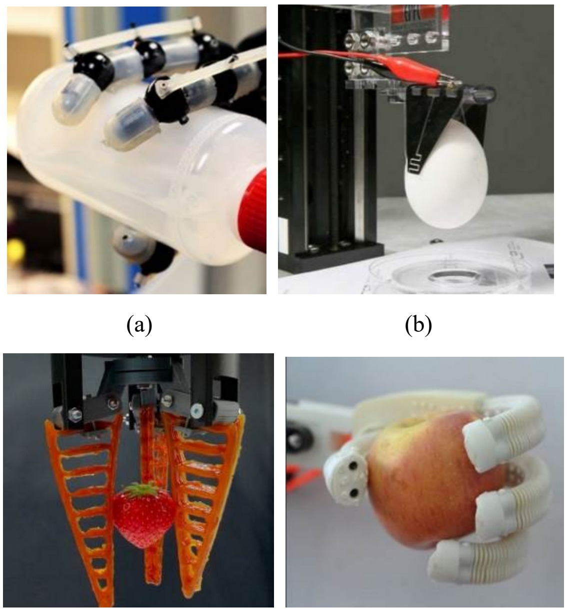


(a) (b) (c)

Figure 1. (a) Compliant L-Arm gripper, (b) Goldfarb flexure-based gripper, (c) Zubir microgripper [2-4]

instruments, in biomedicine for manipulating individual cells, etc. For example, a compliant L-Arm gripper [2] used in medicine (Fig. 1 (a)), a Goldfarb flexure-based gripper [3] controlled by force (Fig. 1 (b)) and a single degree of freedom of movement or ultra-precise Zubir microgripper [4] (Fig. 1 (c)).

Universal grippers of manipulation robots are most often used for the manipulation of objects, which can be used to capture objects of various dimensions. Developing a gripper that could manipulate objects of unpredictable shape is a very challenging task. For safe and reliable manipulation of such objects, it is necessary for the gripper to be adaptable and very flexible, especially when it comes to manipulating easily breakable objects or objects of different stiffness. In addition, grippers with a rigid contact between the grippers and the rigid objects can lead to damage to the objects, so in these cases, a control system is required to control the contact forces. A gripper is expected to be able to carry any object, regardless of its weight, shape regularity, operating with diverse types of texture whether having sharp to smooth edges. Main problem needed to be addressed is one of poor stability when gripping such objects, and another of weak gripping forces handling the heavy loads. Therefore, various universal soft robotic grippers have been developed [5-14]. In this way, the gripper can realize the adaptability that the human hand has (Fig. 2). However, most of these grippers are complex, require an external drive like a compressor or electric motor and a high voltage power source.



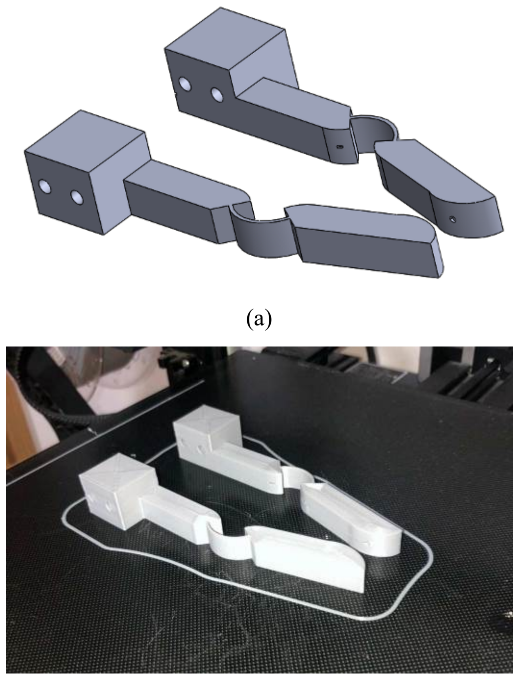
(a) (b) (c) (d)

Figure 2. (a) Robotic hand incorporating fiber Brag grating (FBG) sensors, Credit: Carnegie Mellon
(b) Soft robotic gripper gets a grasp on fragile objects using electro-adhesion, EPFL/Alain Herzog,
(c) A 3D printed self-healing gripper holding a strawberry. Source: Vrije Universiteit Brussel,
(d) A robotic hand made from soft materials grips an apple. Courtesy of Changyong Cao.

IV. SOLUTION/DISCUSSION

For this reason, this paper resorted to the creation of a biologically inspired compliant gripper that would completely mimic a human hand. The finite element analysis (FEA) results are presented as well as the pilot experiment of two symmetrical index fingers with one proximal interphalangeal (PIP) joint. Finger lengths were taken as the average values given in [15] as well as their average angles of movement [16].

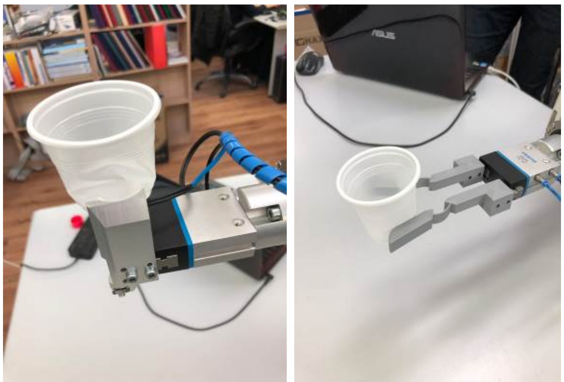
The CAD program SolidWorks 2016 was used to create the compliant gripper (Fig. 3 (a)). The compliant gripper joint is a proximal interphalangeal (PIP) joint that can achieve a movement of about 110 degrees. The compliant



(a) (b)

Figure 3. (a) CAD model, (b) 3D printed model of a compliant gripper

gripper modeled in this way completely replaces the movement of the human finger with the help of a curved compliant joint with a notch in the shape of a rectangle. The curvature of the joint is 14.95 degrees, which represents the natural relaxed position of the finger. The simplicity provided by the compliant mechanisms allows the model to be quickly adapted to any robotic arm (Fig. 4 (a)). In addition, their easy construction thus gives additional adaptability (Fig. 3 (b)). The material that was used for 3D printing is Polylactide/polylactic acid (PLA) with the modulus of elasticity E = 3450 N/mm2 and bending strength of σbs = 54.1 N/mm2.



(a) (b)

Figure 4. Fragile object grasped by: (a) Compliant gripper, (b) Festo industrial gripper

For the further analysis to be commenced, the soft compliant gripper was to be assembled with the 6 degrees of freedom robotic manipulator (Fig. 5) developed at University of Niš in collaboration with the Fazi© company, inspired by an open source project Annin Robotics 3 [17]. Robots chassis and majority of the constitutional components were modeled and built using FDM method, while the joints of the robot were steered by six stepper motors.

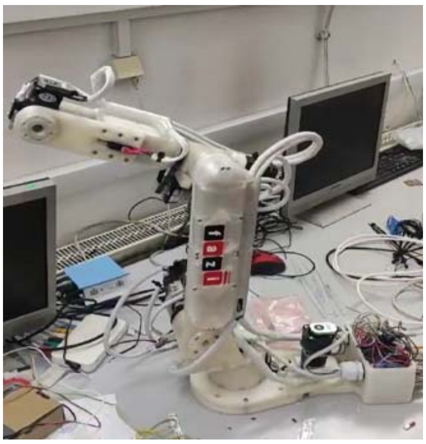


Figure 5. 3D printed robotic manipulator

A stepper motor control is being regulated by using a feedback loop, formed with a perforated disc-shaped relative encoder with evenly distributer apertures, attached to the motor shaft. The position of four IR diodes and photo-transistor pairs from the sides of the disk is defined as such, for it to be possible that only one pair can pass signal through the aperture at one moment (Fig. 6) thus measuring the position of a robot joint. Said measurement describes a feedback signal, which in subtraction with the signal input passes an error signal into the controller (Fig. 7).

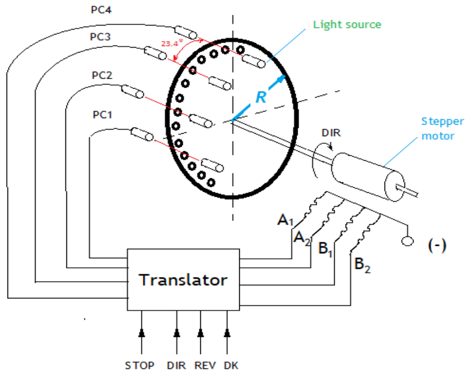


Figure 6. Generation of a digital feedback of the stepper motor

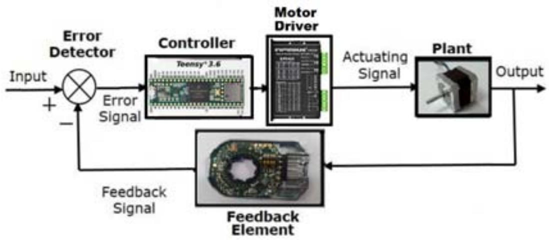


Figure 7. Feedback control of the robots stepper motors

To perform finite element analysis (FEA) it is necessary to define the static and dynamic characteristics of the mechanism itself. Hence, the geometric constraint of compliant joints and the compliant mechanism must be fully defined. In Fig. 5, these constraints can be seen in the form of the boundary conditions (fixed supports A and D) and the load (force B and C) acting on the compliant gripper with the force of 1.4 N. Using the "Edge Sizing", a finite element mesh is created at the places of compliant joints (Fig. 5). The resulting mesh of the finite element model was composed of 10085 elements and 10856 nodes for both bodies.

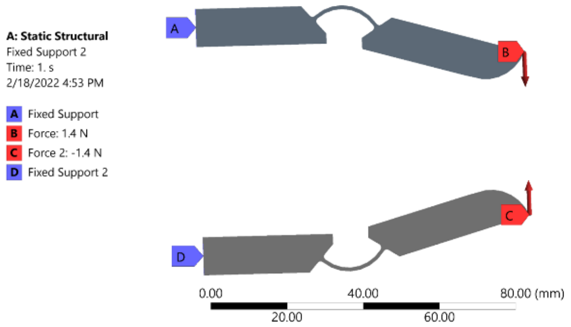


Figure 8. The boundary conditions and load with finite element structure of flexure hinge

Fig. 6 shows the results of the FEA done in ANSYS 19.2 program. The results show the value of total deformation (Fig. 6 (a)), the equivalent von-Mises elastic strain (Fig. 6 (b)) and the highest value of the output angle (Fig. 6 (c)).

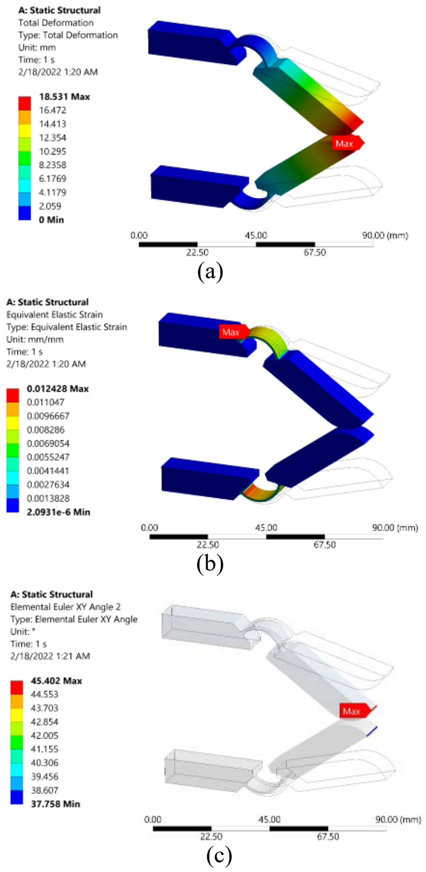


Figure 9. FEA of compliant gripper: (a) Total deformation, (b) The equivalent von-Mises elastic strain, (c) Value of the output angle

It can be observed that the highest elastic strain is 1.2428% on the compliant joint itself for a maximum angle at the output of 45,402 degrees. The upper limit above which the compliant joint turns into plastic deformation is 3%, which allows this joint to more than double the angle, which was the idea of this joint that mimics the proximal interphalangeal (PIP) joint on the human index finger.

In order to develop cost effective robotic manipulator committed to the task of handling sensitive object, 3D printing of structural parts was used for production. Later possible advancements of high level control of robotic manipulator include vision based measurement of a finger deformation as an input in determining the restriction of applied force.

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