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FUZZY CONTROL FOR SOFT ROBOTIC GRIPPER ORIENTED TO NO RIGID AND THING OBJECTS

CONTROL DIFUSO PARA PINZA ROBÓTICA BLANDA ORIENTADA A OBJETOS NO RÍGIDOS

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Abstract: This paper presents the design of a robotic effector built with internal sensors in flexible material. Based on the bio-inspired grasping of thin, typically non-rigid objects made with two fingers by humans, the characteristics of model 3 are established, which serves as the basis for the printing of this model, including internal space for a flex resistance that allows identifying the percentage of flexion for grasping, using the effector. A fuzzy controller is designed to control the effector, and, given the tolerance of the sensor, a Mamdani type-2 fuzzy inference system is used. The results show an adequate grip that allows obtaining a steady state error close to zero, allowing one to grip thin objects such as a handkerchief or toilet paper.

Keywords: Bio-inspired grip, Fuzzy control, 3D Impression, Soft robotics.

Resumen: El presente artículo expone el diseño de un efector robótico construido con sensórica interna en material flexible. Basados en el agarre bioinspirado de objetos delgados típicamente no rígidos realizados con dos dedos por los humanos, se establecen las características del modelo 3 que sirve de base para la impresión de este, incluyendo espacio interno para una flexoresistencia que permita identificar el porcentaje de flexión para agarre, mediante el efector. Se diseña un controlador difuso para control del efector y dada la tolerancia del sensor se emplea un sistema de inferencia difusa Mamdani tipo-2. Los resultados muestran un agarre adecuado que permite obtener un error de estado estacionario cercano a cero, permitiendo agarrar objetos delgados como un pañuelo o una pieza de papel higiénico.

Palabras clave: Agarre bio-inspirado, Control difuso, Impresión 3D, Robótica suave.

1. INTRODUCTION

The field of robotics and its impact on today's society has marked many lines of application and research. (Fox & Griffy-Brown, 2023), where one of the relevant aspects is focused on the actuation system or end effector (Amin et al., 2023). These have begun to diversify their development to the extent that their design involves sensors and instrumentation (Bi et al., 2018), and even the ability to grasp deformable objects (Wang et al., 2021). Along with the design, the effector requires a control system, for example, the classical system based on proportional, integral and derivative (PID) error (Sarkar et al., 2023), which in case of flexible and instrumented design systems can become complex and require adaptations (Han et al., 2023). A clear alternative is knowledge-based control techniques such as fuzzy control (An et al., 2023)(Mehrjouyan et al., 2023)(Xu et al., 2019). Robot control techniques using fuzzy systems are now integrated with artificial intelligence algorithms because of their benefits over modeling (Zheng et al., 2023), However, compared to some types of sensors that have tolerance ranges or variability, type 2 fuzzy systems are the best alternative (Z. Zhang & Niu, 2023)(Zhao et al., 2023), clearly applicable to robotic manipulators that may have a design based on a nonlinear model (Kumar et al., 2023).

An additional aspect to control that concerns the design of the end effector is its adaptive capacity (Jorg & Fantoni, 2023) and this one is associated to its application, for example, if it is oriented to assist elderly people, it will require certain specifications (Chen et al., 2023). For these cases and some in industry, soft effector designs are available (Dinakaran, Balasubramaniyan, Le, et al., 2023)(Lee & Cha, 2023). Bio-inspired effector design, for example, finger type (Park et al., 2023) with associated instrumentation, it features designs known as Smart [19], which, given the printing systems developed today, allow tests that iterate results until optimization is achieved (Ren et al., 2023), whether under 3D printing. (Goh et al., 2022)(Yeong et al., 2022) or 4D printing (Ma et al., 2023)(Gu et al., 2023). For which the material selection also appears to be a design parameter. (Dinakaran, Balasubramaniyan, Muthusamy, et al., 2023)(Y. Zhang et al., 2022) that impacts both the internal sensorics and the effector controller.

In order to grasp thin objects such as paper or light cloths such as handkerchiefs, there have not been found end effectors that allow to guide an assistive application to people with some kind of motor problem to perform this task by themselves. Therefore, and given the trend in the state of the art, it is proposed and presented the design of a robotic effector bio-inspired in the grip of the fingers, printed with flexible material and instrumented with internal sensorics, which by means of a fuzzy control allows the grip of thin and light objects such as paper or handkerchiefs.

The following document is divided into four sections composed of the present introduction; section two, where the design methodology of the effector and the control system is presented; section three, where grip results are presented; and finally, section four, where the conclusions achieved are stated.

2. METHODOLOGY

In order to evaluate the integration of soft and assistive robotics, a design objective is established oriented to the grasping of thin objects and for the initial tests the focus is on the grasping of objects such as handkerchiefs, hand towels and paper. This determines the grip characteristics with which the final effector is designed, which is oriented on the human grip, so a bio-inspired two-finger design is employed. To control the grip force, a fuzzy controller is implemented, which is parameterized according to the sensor used. Both aspects of design and control are explained below.

2.1 Effector design

For the design of the effector, which is aimed at being part of an assistive robot capable of providing a user with thin, non-rigid objects such as towels, handkerchiefs or paper, a bio-inspired design is determined based on the human two-finger grip, as shown in Figure 1.

For this type of object, the grasping process involves retracting the fingers towards each other, which implies an orientation of one finger in front of the other. So, the design of the effector is established under this replication by two fingers facing each other when retracting and each implemented with two phalanges and a joint (see Figure 1) for each side of the grasping involved.

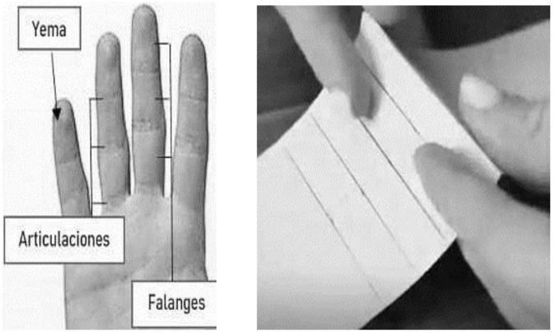

Fig. 1. Bio-inspired gripping system

For the final design, CAD tools were used to iterate the dimensions of the proposed effector. Through iterative tests, a length of 9 cm, a width of 1.4 cm and an articulation distance from start to tip of the finger of 40% were determined as final measurements. Figure 5 illustrates the final effector used, where the printing parameters were adjusted for the use of flexible TPU material, with extruder at 200°C, bed at 60°C and a filling density of 60%.

The TPU printing allows a non-rigid structure that facilitates the retraction of the effector, to this structure a transverse hollow section is made for insertion of a sensor that allows to establish the degree of retraction in the gripping operation. Iterative tests of the design allowed determining the convenience of including in the design a protrusion at the point of the grip yolk type.

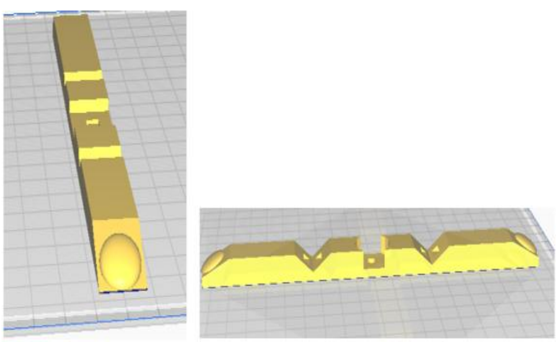

Fig. 2. CAD design of the effector

Due to the impression of the effector with flexible material, the atirculation used and the cavity of the sensor, a material tension test was performed to ensure the integrity itself (see Figure 3). Finally, the effector did not give a break point and the deformation is significant due to the elasticity of the material used.

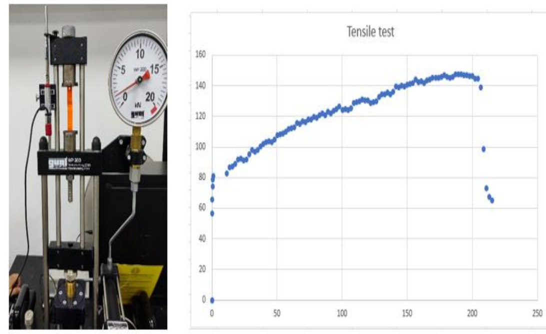

Fig. 3. Tension tests of the effector on flexible material

2.1. Controller design

In order to design the controller and given the flexible nature of the gripping effector, a fuzzy control system is established as a regulation strategy to adjust the closing level. Actuator corresponds to a reference servomotor dynamixel AX12 that can handle a maximum torque of 15.3 kg - cm and the feedback sensor to a 74mm flex sensor type flex-resistance that features 25K Ohm ±30% tolerance and a range of variation of resistance in bending from 45K Ohm to 125K Ohm.

Fig. 4. Servomotor and flexo-sensor applied

The control circuit is shown in Figure 5, where the controller is a proportional derivative type, and since the flex-resistance has a tolerance of ±30%, an algorithm based on a Mamdani type-2 fuzzy inference system is used; the simulation model is obtained approximately using the MATLAB® identification tool

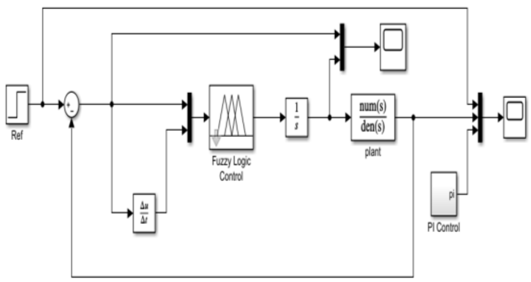

Fig. 5. Fuzzy control circuit used for the effector.

These fuzzy sets are established in the normalized range of minus one to one, which allows to parameterize the control action of the reference to ±100% error. Five belonging functions are employed for both the error and the error derivative, with linguistic labels are negative high (nh), negative low (nl), zero (zero), positive low (pl) and positive high (ph). The tolerance range of ±0.3 is used to establish the internal belonging functions as shown in Figure 6.

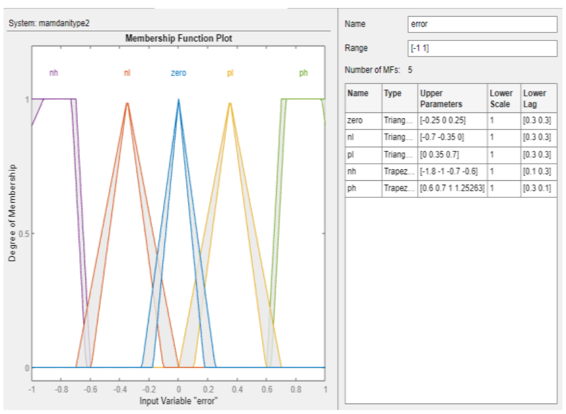

Fig. 6. Input fuzzy set

The fuzzy output (Figure 7) corresponds to the desired angular movement of the servomotor, which for the case is characterized within a range of ±45°, which establishes the percentage of opening and closing of the effector for grasping and releasing objects. In order to have a precise and continuous control over the different angles within the variation range, 10 belonging functions are established to allow a slight variation of the angle.

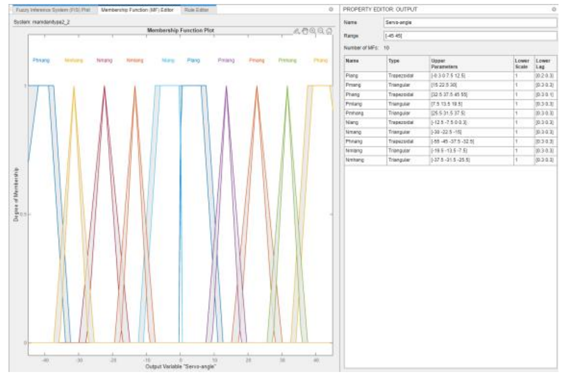

Fig. 7. Output fuzzy set

Figure 8 illustrates the resulting behavior of the control surface, derived from the established rule base. It can be seen that the trend is smoothed and continuous throughout the controller's operating range, with the error parameter being slightly more incident than its rate of change. It should be noted that the sensor instrumentation stage has a gain of 10.

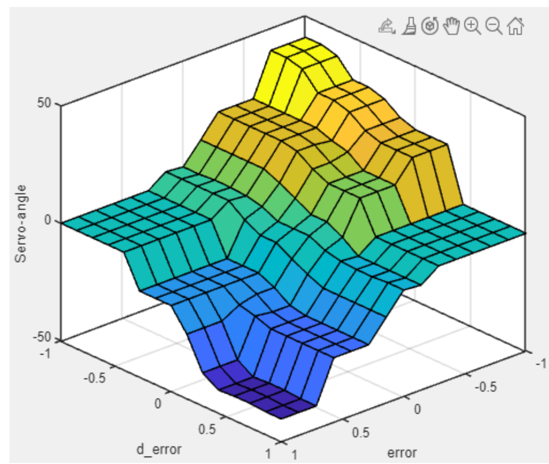

Fig. 8. Diffuse control surface

3. FINDINGS AND DISCUSSION

The printed end effector can be seen in Figure 9, the sensor and retraction wires (tendons) are inserted through the internal holes and the connections to the actuator through the central circular hole.

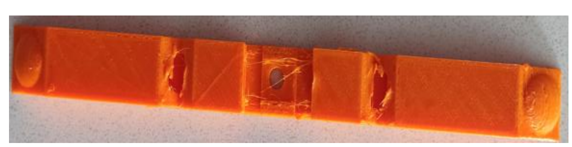

Fig. 9. 3D printing of the final model.

The tests of paper and handkerchief like cloth grasping are tabulated in Table 1, showing in an iterative process of grasping twenty tests per object (see Figure 10), a performance of 92.5% efficiency in the effector's work.

Table 1. Grip tests

OBJET	SUCCESSFUL GRIPS
PAPER	19
HANDKERCHIEF	18
AVERAGE PERCENTAGE	92,5%

Fig. 10. Grip tests.

Failed tests occurred for cases where the thickness of the gripping surface was very thin, e.g., a single layer of paper or the handkerchief extended at the folded location. Since the surface was not rigid and cold as a metal or plastic effector might be, the interaction with the user felt natural, as the object was delivered into the hand. The finger-like shape aids the visual perception of a less rigid or forced interaction in front of a robotic agent.

Figure 11 illustrates the control action of the fuzzy inference system where the hardware in the loop (HIL) technique is used, so that the sensor information reaches the interface in simulink (MATLAB®), where, depending on the thickness of the grip element, a greater action is generated to increase the pressure and to support the object.

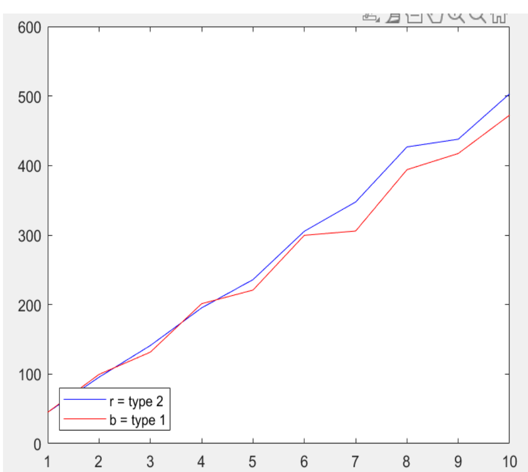

Fig. 11. Grip control tests.

Within the control algorithm, the user can adjust the grip parameter as input to the system so that the user initially determines the magnitude of the control action and the controller adjusts the actuator to maintain that parameter. It is observed that the compensation of the fuzzy system under the Mamdani type-2 algorithm is coupled to the measurement variations by tolerance of the flex-resistance stabilizing the system.

4. CONCLUSIONS

It was possible to obtain a robotic effector in flexible material that accommodates to the grip of thin objects allowing to pick up and deliver to an end user in an accurate way such object. The structure used in the design of the effector and the material proved to achieve a natural interaction with the user and maintain the structure of delicate objects such as paper.

The design parameters and the 3D printing configuration are the most influential elements in the construction of the effector, for which it became evident that an adequate pre-design and establishment of prerequisites is necessary to reduce iterations both in the CAD design environment and its printing.

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