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Tesis

Conceptual Design of a Soft Robot for Camera Guidance in Endoscopic Surgical Interventions

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Conceptual Design of a Soft Robot for Camera Guidance in Endoscopic Surgical Interventions

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ABSTRACT

Abstract— This paper seeks to implement a soft robotic solution for guiding endoscopic cameras. These soft robots are constructed using pliable materials, granting them the ability to conform to irregular contours and dynamic environments. This intrinsic flexibility renders them particularly adept at navigating through constrained spaces within the human body during minimally invasive procedures. Presently, the manipulation of endoscopes can lead to inadvertent injuries due to the challenges posed by their maneuverability. In response, a novel approach has been proposed: employing a soft robot to guide the endoscopic camera during surgical interventions. To achieve this, the design methodologies of VDI 2225 and VDI 2206 were incorporated, ensuring a systematic and robust development process. Central to this implementation is the integration of a movement control system, synergistically functioning alongside a controller equipped with dual joysticks. This configuration empowers surgeons to operate the robot, dictating its directions and movements with enhanced precision. By introducing this soft robot into the endoscopic procedure, the aim is to mitigate the risk of injuries that can arise from conventional endoscope manipulation, and simultaneously enhance the maneuverability for surgeons. Through the harmonious amalgamation of flexible materials, meticulous design methodologies, and intuitive control systems, this approach has the potential to minimize injuries, optimize manipulation, and elevate the overall efficacy of endoscopic interventions.

CCS CONCEPTS

• Hardware Emerging technologies; • Analysis and design of emerging devices and systems; • Emerging architectures; • Medium Relevance;

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KEYWORDS

Soft robotics, camera orientation, endoscopy, control systems

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1 INTRODUCTION

An endoscopy is a diagnostic procedure used to examine the internal organs of the body. For this purpose, a tool called an endoscope is used, which has a camera at the end that provides images in real time. This equipment is controlled by a single device, which must be pressed with great precision to guide the camera to the areas to be examined [1].

Although this procedure has advantages such as a short recovery time of the patient, a very low risk of death [2]. There are other risks such as the generation of cuts and bleeding or perforation of the organ to be examined, due to the lack of flexibility and maneuverability of the endoscope [3]. In addition, the constant exercise of the wrist performed by the person in charge of the intervention can cause injuries that force them to leave their jobs for months while they recover [4]. Such cases can be seen in Peru thanks to the study entitled "Factors associated with musculoskeletal injuries caused by endoscopic procedures in third-year gastroenterology residents in public hospitals in Peru", which shows the complaints of public sector workers for the performance of endoscopies and colonoscopies. The main complaint corresponds to the need for equipment with better ergonomics to ensure the safety of the workers [5].

Soft robotics is a great option to enhance traditional surgeries, as it allows for the creation of robots that are safer, more precise, and adaptable to the structures and shapes of the human body [6]-[10]. Unlike rigid robots, soft robots can move more smoothly and flexibly, which reduces the risk of damage and injury to the intervened areas. In addition, soft robots can adapt to different body structure sizes and shapes, making them especially useful in difficult-to-access surgical procedures. Soft robotics can also improve surgical site visualization, increasing interventions' precision and safety [11].

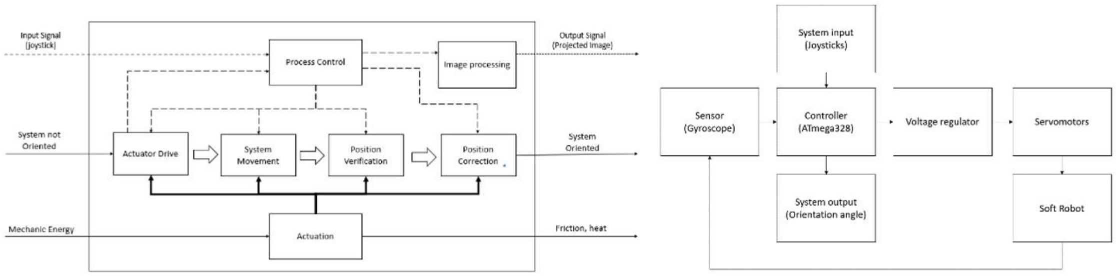

Figure 1: Black box internal process and closed loop control system representation [own elaboration].

Likewise, information dedicated to reducing the risk of endoscopic surgeries and new technologies to develop soft robots were found [12]-[17].

2 METHODOLOGY

The work method began by breaking down the problem to find a systematic and structured approach used in the field of mechatronic engineering for the development and design of mechatronic systems.

VDI 2225: Consists of a decision-making method optimized at minimum cost. As has been repeatedly emphasized, the evaluation of the three preliminary designs will be carried out according to this objective method. Thanks to this, you will be sure that the optimum design has been selected.

VDI 2206: Mechatronic systems are very complex due to the large number of interconnected elements that are also realized in various fields of technology. The guide is a step towards a specific methodology covering the fundamentals of mechatronic systems, procedural Model, techniques, model analysis, computational tools and some aspects of mechatronic organization [17].

2.1 Operation Diagram

Likewise, we subdivide in a sequence of four operations: Preparation, power is supplied to the parts that composed the equipment and the robot determines its position and takes a starting point. Execution, movement is generated with the robot motors and the orientation of the camera begins to be sensed; Control, the position of the robot is verified and the power of the motors and the change of position is regulated to make corrections in the path. Finally, it is verified that the robot has reached the ordered position and the orientation does not cause abrupt movements that reduce the sharpness of the camera.

For this sequence of steps to take place, there are automatic processes such as the determination of the orientation and the tensioning of the ropes, which are complemented or derived from the movement of the robot or the motors, which depend on the manipulation of the joysticks. From the processes as shown in the Figure 01, we perform the following internal black box process [18].

2.2 Morphological Matrix

For the selection of the materials, we made a morphological matrix with the options that we considered most suitable for the realization of the equipment, where multiple combinations can be made that could have met the expectations we had for the project [18]. To determine the best solution, an evaluation was made based on what is indicated in the book "Product Design and Development". In summary, the book mentions that a previous filtering must be made based on indicators that we consider necessary to comply with the project and thus only select a maximum of 3 options that will be evaluated in the technological, technical and economic part [18]. The results are shown in Figure 02.

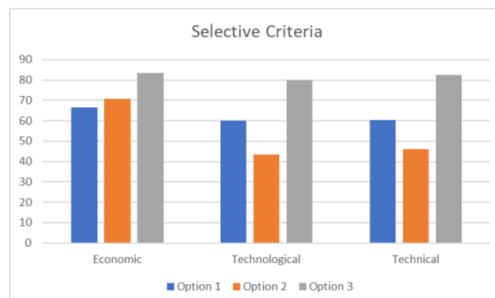

Figure 2: Criteria results [own elaboration].

The solution we chose uses a power supply of 12 V and 9 A, the control system is going to be an ATMEGA328, SG90 high precision servomotors with a torque force of 1.5 kg*cm, which will be manipulated by two joysticks in order to generate a motion control of the robot. Lastly, it will use an ON/OFF switch for the complete system. And the soft robot will consist of two bodies that will allow greater freedom of orientation.

2.3 Mechanic System

The mechanical system concentrates on the movement of the propeller of the servomotors that cause a tension in the respective cable to each one, causing a deformation in the soft robot, and so they change the orientation of the camera, Figure 03 shows the full mechanic system. The model was based on the average size of an ordinary endoscopic camera, which ranges from 8mm to 7mm in diameter; the robot, when covering the final part, which is the widest, was designed in a standard size of 10mm. Figure 03 shows a 3-scaled design of the soft robot and a support base to simulate control and handling.

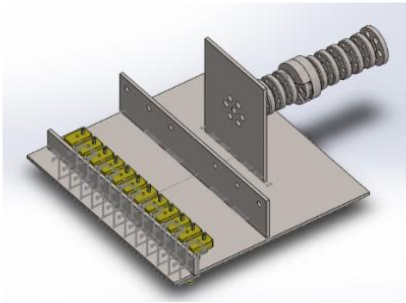

Figure 3: Mechanic System [own elaboration].

For this purpose, a relationship was sought between the angles of deformation and the rotation exerted on the servomotor, and as a result a graph was elaborated based on the following equation.

$$y = \sqrt[171111/20000]{x} \; or \; y = x^{0.85555}$$

Where X is the value derived from the rotation that goes from 0° to 180° in sexagesimals, to obtain a Y deformation expressed in sexagesimals degrees depending on its axis between the values 0° to 90°. It should be noted that at the time of the tests the maximum value obtained was approximately 85°. The graph of the behavior can be seen in Figure 04.

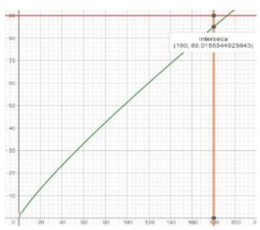

Figure 4: Deformation graphic in GeoGebra [own elaboration].

2.4 Electronic System

The electronic design in EasyEDA has made it possible to create a clear and organized schematic, making it easy to visualize the connections between components and their interaction. In addition, this tool provides an extensive library of components, including the ATmega328P-au microcontroller, the HW-613 DC-DC converter, the 2x3-pin SMD connector, connectors for the joysticks and finally BG300 06 A-L-A for using an FT232 programmer as it can be seen in the Figure 05.

This simplifies the design process and ensures accurate component placement and routing. The ATmega328P microcontroller is a popular choice due to its versatility and ease of use. It features an 8-bit architecture and a clock frequency of up to 20 MHz, allowing it to perform a wide variety of control and data processing tasks. In addition, it offers sufficient input/output pins to handle communication with servo motors and other electronic components required in the design [19]. This design ensures a precise and stable connection between the microcontroller, servo motors and gyroscope, enabling precise motion and position control in the designed electronic system.

2.5 Control System

The control system used was an ATmega328P-au as controller. This is because of the simplicity required to control it, since it is only necessary to translate the signal from the joysticks to the angle of rotation of the servomotors. To accomplish this, it will be programmed using a FTDI FT232 programmer module, and then the code will be passed to the ATmega328P-au of the PCB we designed.

3 DEVELOPMENT

The construction of the prototype for the validation of the system to obtain the parts, took an average of 8 hours per piece, after an analysis of the resin characteristics proposed for its use through the data of its datasheet, which are the 50A elastic and 80A Flexible [8]. It was decided to use the 80A which proved to have a higher tensile strength limit of 8.9 MPa post-cured [20]. The camera that will be used is a submergible endoscopic camera 5.5 mm width with a 640x480p resolution.

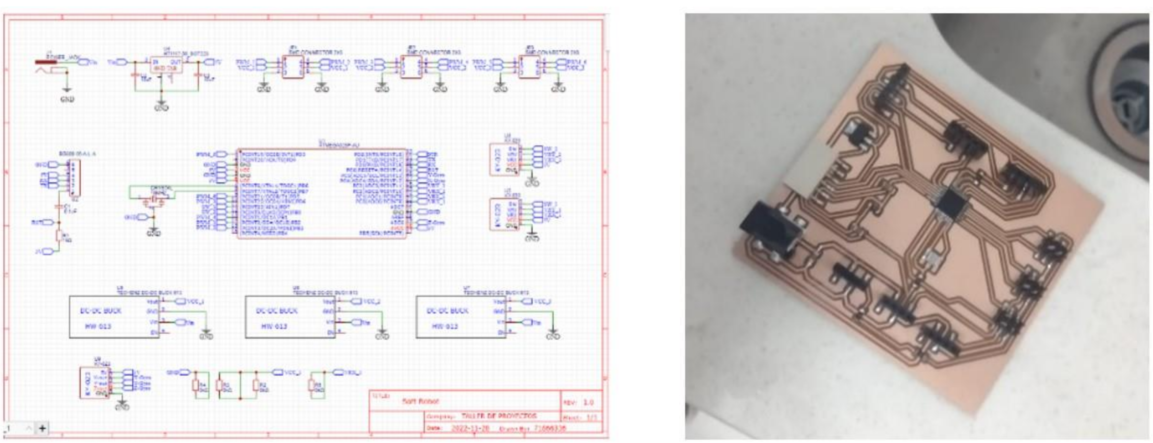

Figure 5: Electronic design made in EasyEDA and physic [own elaboration].

3.1 Prototype construction

It should be noted that the acrylic structure was designed to support the servomotors and the soft robot and that the parts fit together easily in order to facilitate assembly. The electronic board is located on the outside of the robot the input, output, sensor and actuator elements will be connected to the electronic board; the prototype can be seen in the Figure 06. It was implemented in bakelite, with CNC or screen-printing method. The printing was resin-based and then went through a curing and washing process in another machine.

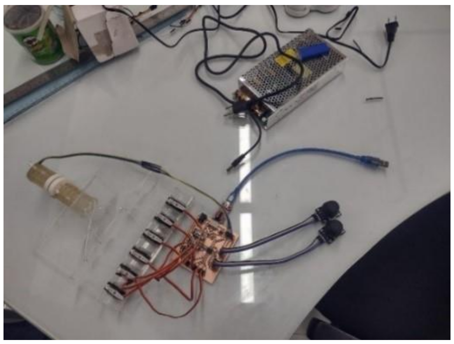

Figure 6: System Assembling [own elaboration].

4 CONCLUSIONS

The results obtained demonstrate that the use of a soft robot offers several advantages compared to conventional systems. The flexible and adaptable design of the robot allows for better adaptation to the patient's anatomy, resulting in reduced tissue trauma and faster recovery time. In addition, the ability to precisely and smoothly control the camera orientation improves visualization during surgery, which can lead to greater procedural accuracy and safety.

In this study, the conceptual design and implementation of a soft robot for the orientation of a camera in endoscopic surgical procedures has been presented. The handling model we use is based on the control of a delta robot driven by cables or ropes and is focused on achieving the desired angle as a function of the force exerted in three possible directions. Reducing the calculation to a simple decomposition, addition and subtraction of vectors in a plane. Likewise, the proposed approach has also proven to be economical using accessible and low-cost materials and components, such as servomotors and medical 3D printing resins, allowing for reduced implementation and maintenance costs, which makes it more viable for adoption in clinical settings.

Finally, this soft robot presents benefits to patients and surgeons such as avoiding the wrist tension that use of conventional systems produce to the surgeon and while being more accurate and easier to maneuver, it is safer for the patients.

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