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FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Mecatrónica

Tesis

Proposal for the Design of an Articulable Robot for Taking Low-Cost Measurements in the Preoperative Phase of Maxillofacial Surgery

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Para optar el Título Profesional de
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Proposal for the design of an articulable robot for taking low-cost measurements in the preoperative phase of maxillofacial surgery

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***Abstract*— This research paper presents the design of an articulable robot for low-cost measurement in people needing maxillofacial surgery. It is observed that it is possible to improve the measurement accuracy, significantly reduce the error rate and risk to the patient, while reducing the manufacturing cost. This design presents a stable structure for the maxillofacial surgeon, an intuitive interface for the user, in addition to stepper motor actuators that allow the movement of the axes, worm screws and rack and pinion, where there is greater precision and speed, as well as a Raspberry Pi Pico W microprocessor that controls the articulating robot with great efficiency and with sufficient memory to store and carry out the purpose for which it was designed. In order to consolidate the objectives, set at the beginning, the mixed methodology between VDI 2206 and MIT was developed and used. The results obtained will not only serve to create articulable and controllable robots with low complexity costs, but also to reduce the error rate and reduce the risk for the patient, promoting the use of robotics in medicine and involving the new proposed methodology to research projects.**

Keywords— articulable robot, maxillofacial surgery, actuators, orthognathic surgery.

I. Introduction

According to the World Health Organization (WHO) it specifies that there are between 10% and 14% of potential patients who need maxillofacial and orthognathic surgery[1], taking into account these world statistics, it is observed that slightly more than 66% of the people who need surgery do not do so for economic reasons or because their trusted dental surgeon does not have the necessary equipment to perform these surgeries.

Orthognathic surgery and maxillofacial surgery serve to refer to the same procedure, differing only in the approach, since the first focuses on the proper functioning of the maxillofacial complex and the second focuses on aesthetics based on surgical intervention operated by a highly trained dental surgeon, where you can see the existence of a wide range of procedures that help to abolish diseases, injuries and as aesthetic support was already in the face, jaw or mouth.

In the vast majority of these procedures there are risks in case of incorrect measurements [2,3,4]. The use of robots in a surgical intervention where they are fulfilling the role of being collaborators for the surgery or in some more complex cases the development of the surgical intervention itself, all these robots and technologies are arousing great interest in the development of the same in recent decades, so much more sophisticated and expensive machines or robots are being visualized[5,8,9,10].

Similarly, technologies implanted with robots, whose main function is to deliver a model, having previously measured with what is seen an improvement in accuracy and safety to traditional surgical interventions in these surgeries [5,6,7,11,12,13]. Taking into account that about 5% to 10% of dental surgeries fail [13] Therefore, these methods are being applied, as in the case of robot-assisted oral and maxillofacial surgeries, where the large number of cases using robots to take measurements with the support of 3D printing is mentioned [8,15,15,16,17,18].

The main objective of this research is to design a low-cost articulable robot for detection in the preoperative process of maxillofacial surgery. Also, the robot is driven by a Raspberry Pi Pico W controller and the most important actuators are motors. Step by step.

II. Methodology

In reference to a research project, methodology refers to a set of processes or guidelines that ensure that the goals and objectives previously set are met in a concise and orderly manner [19]. In other words, it is valid as a guide for those who develop the research work in each of the various stages that the project requires to achieve the stated goals [20].

The following paragraphs detail the mixture of VDI 2206 and MIT methodology. The mentioned tools were proposed based on the scope of the research project, which propose a flow diagram of a basic operation of the robot to manipulate and consolidate the movements of the axes, in addition to designing an electrical diagram of the robot. It is worth mentioning that the research project is based solely on theory, mentioning that a later experimental implementation is not left aside.

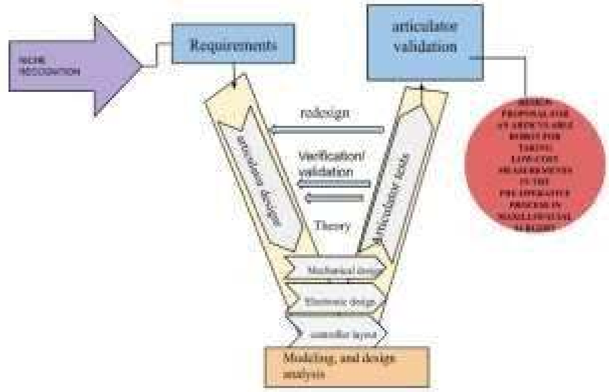

Fig. 1. MIT and VDI methodology.

The mixed methodology used in the research, begins with the MIT method, where the niche search is the entry to the system, this allows identifying the general problem, consequently the requirements are sought, these requirements are based on literature associated with the problem and search for specialists in the field, then move to the VDI 2206 methodology, in this part of the research presents the design, verification, testing and design analysis for the robot to then have a redesign or acceptance of the project. Finally, the MIT methodology is added, which is validated and reaffirms the initial design proposal of the articulable robot for taking low-cost measurements in the preoperative period of maxillofacial surgery.

A. Recognition and selection of the ideal niche.

Traditional rule-based procurement of measures is being imposed, which has led to an increase in failed surgeries. being just over 5%. Since a very alarming number are opting for these measures to include robots in this type of surgery, the attempt to develop a cheap and reliable robot is very attractive and has been under development for years [21].

B. Search for requirements.

The list of requirements is presented according to the needs found in the selection of the ideal niche present in the development of the project.

The system should cost less than a scanner, be able to display on OLED screen accurate measurements for surgery, measurement taking should be very precise and accurate, 5 degrees of freedom down and 4 up, easy to use, long life, easy maintenance, lightweight, with automatic control, compact size, splash proof, easy to clean, easy to read data, low power consumption, certified, readily available components, inspires confidence, self-calibration and wireless device. Metrics include less than +- 0.3 mm margin of error, 45 degrees of rotation, 60 millimeters of linear travel, commercial spare parts, 4-month maintenance, OLED data display, 6061 aluminum frame, intuitive operation, 9-volt charger, ISO 13485 standard, 25x25x35 centimeter dimensions, 9-volt Power Bank, brush and air cleaning.

TABLE I. LIST OF REQUIREMENTS AND METRICS

Need \ Metrics	1 Margin of error less than +- 0.3mm	2 45° rotation	3 60 mm of linear displacement	4 Commercial spare parts	5 Maintenance every 4 months	6 Display of data on led screen 1602	7 6061 aluminum structure	8 Intuitive handling	9 9v charger	10 ISO 13485 standard	11 Dimensions	12 9v power bank	13 Cleaning with brush and air
1 lower cost device to a scanner.				X			X						
2 Being able to visualize the exact measurements for surgery.						X							
3 Taking precise and exact measurements.	X												
4 5 degrees of freedom below and 4 above.		X	X										
5 Easy use.								X					
6 Long useful life.							X						
7 Easy maintenance.					X								X
8 Light.							X				X		
9 Automatic control.	X												
10 Compact size.											X		
11 Anti-splash.					X					X			
12 Easy cleaning.													X
13 Easy data reading.						X							
14 Low energy consumption.									X				
15 Certificate.										X			
16 Components of easy acquisition.				X									
17 Reliability.	X									X			
18 Self calibration.	X								X				
19 Wireless device.												X	

C. Combination of mechanical, electronic and control systems.

In order to carry out the design of the articulable robot for taking low-cost measurements in the preoperative process in maxillofacial surgery, the following block diagram has been made, which shows the functional structure of the design:

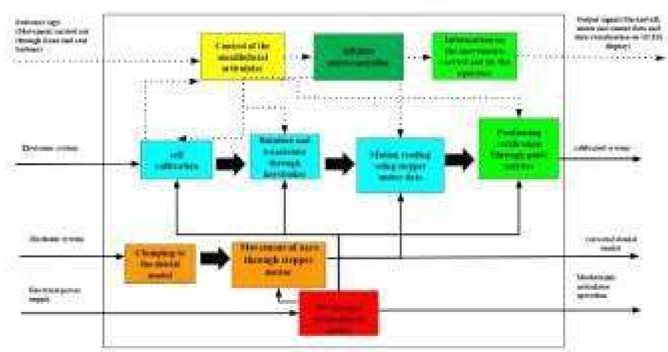

Fig. 2. Function diagram.

The design is divided into three parts: input signal, electronic system, mechanical system and power supply. The input signal through the front and rear buttons supports the movement where these signals are supplied and read in the maxillofacial joint and the latter is located in the Raspberry Pi Pico W (RP2040) microcontroller, this information is carried as output signals that are can be seen on the OLED screen, where you can see the information of the movements made by the operator and along with it the movement of the motors.

The electronic system starts with turning on the display of the machine, which has a self-calibration and this moves a rotation and translation through pulses received by the articulator control, then you see the reading of the movement through the stepper motor data to have a verification of the positioning through guide notches and resulting in a calibrated system.

The design of the mechanical system starts with the attachment to the previously designed patient dental model to mobilize the axes through the stepper motor to correct the dental model. Finally, the power system was simply based on the 9-volt connection of the device to have the mechatronic articulated robot in operation. The proposal was subjected to a

technical and economic evaluation process to consolidate the issue of the good performance of the robot and also the issue of low cost. The technical evaluation data follows the evaluation criteria in relation to the characteristics of the articulation device:

TABLE II. EVALUATION MATRIX

EVALUATION CRITERIA			
Technical criteria	*Economic criteria*	*Structural criteria*	*Control criteria*
Function	drive	Lower cost device to a scanner	Visualization of exact measurements for surgery
Design	expansion boards	3 degrees of freedom below and 3 above	Taking accurate and precise measurements
reliability	actuator	easy to use	Automatic control
Size	Accessories	long useful life	Easy data reading
Lightness	Maintenance	Easy maintenance	—
Intuitive	development boards	Light	—
Feasible	plastic material	Compact size	—
Durable	Durable alloy material	anti splash	—
Standardized	Interface	easy cleaning	—
scalable	Software	—	—

1) *Design analysi:* The specialized design area is divided into four different sections, as shown below:

a) *Data and system analysis:* For data collection, mathematical calculations were performed where the stepper motors were related to the steps and the variation of the movement with the micro step technique where each step is divided into smaller steps to obtain smoother and more precise movements. These measurements obtained thanks to the micro step are processed by the microcontroller where the diameter of the pinion was considered, essentially the distance per step = (Circumference of Algorithm the pulley or transmission mechanism) / (Motor resolution
* Micro step mode), showing on the OLED screen the data in millimeters. To execute the articulable robot prototype, the following elements were needed, which are shown in Table III.

TABLE III. ELEMENTS OF THE SYSTEMS

Necessary elements of the system	
Requirements	*Details*
Entrance	Pushbuttons
Development board	Raspberry Pi Pico W
Movement of platforms	Stepper motors
coupling	Driver A4988
Programming language	Micropython y librerias
Materials	Stainless steel and PLA plastic
Modeling software	SolidWorks
Data visualization	0.96" OLED screen

As for the driver requirements, you need to have at least 85KB of SRAM to store variables and data during program execution, which includes source code, configuration files and other files necessary for script execution . In addition, an additional space of approximately 10KB is needed to store measurement data. As for the interface, the classification tests were performed using the Thonny IDE. To carry out the physical implementation of the prototype, it was decided to use Thony.

b) *Algorithm application:* Through a flowchart, each part of the control stage is detailed, in order to verify our input signals, microcontroller and our actuators.

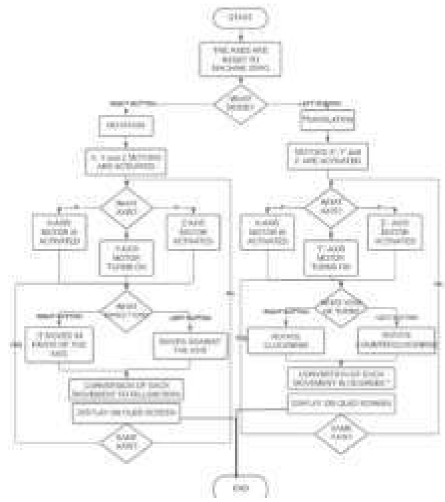

Fig. 3. ANSI flowchart.

The process is defined with the sequence of our flow charts, having a consolidated work. First of all, a reset of all axes to zero machine is performed, turning on the robot, where the robot is self-calibrated to enter the mold of the dental model that has been previously made. Then, it starts with the choice of the mode between rotation and translation, where the choice of this is based on pressing some buttons that are in opposite positions. Then, the motors that were chosen for the mode are activated.

Fig. 4. System operation.

TABLE IV. ACCESS TO THE CONFIGURATION

Configuration of axes by mode		
Axis	Mode	Address
X	Rotation	Right-left
Y	Rotation	Forward-Backward
Z	Rotation	Up and down
X′	Traslación	Counterclockwise-Clockwise as a function of X
Y′	Traslación	Counterclockwise-Clockwise as a function of Y
Z′	Traslación	Counterclockwise-Clockwise as a function of Z

The ones with the apostrophe are the rotation ones. Then, with the same buttons, pressing one of them, the axis moves in its favor and with the other goes against the axis, so that consequently each pulse is added to a memory so that then a conversion is performed. in different ways, one that focuses on longitudinal measures that will be converted to millimeters and another in angular measures that with each step of the motor will focus on the conversion to sexagesimal angles for what will finally be displayed on the OLED screen.

III. RESULTS

A. Mechanical design of the device

The design of the mechanical system, taking into account the aforementioned components to be used. This design represents an articulated robot intended to monitor measurements prior to a maxillofacial intervention, built mainly with a stainless steel structure and PLA plastic for the platforms and joints. The use of this material allows for simple design and machining, as well as fast assembly. In addition, stainless steel is safe and corrosion resistant, which is essential for surgeon handling and sanitary issues. The motion system of the robotic platform is based on worm screw axes, as this mechanism is ideal for moving in two axes, forward and backward. The speed of the robot is controlled by the microsteps of the stepper.

For its power supply, a power supply connected to the standard power outlet is used, which avoids interruptions when activating the stepper motors compared to batteries. As for the control system, a Raspberry Pi PICO W microcontroller, RP2040W, is used for its memory capacity and powerful microprocessor. To process the data, the microcontroller reads the number of times a button has been pressed and the microstep related to the press, and then the microcontroller converts it into millimeter measurements, which will be displayed on the OLED screen.

The final design of the prototype, developed with the Solidworks program, is presented below.

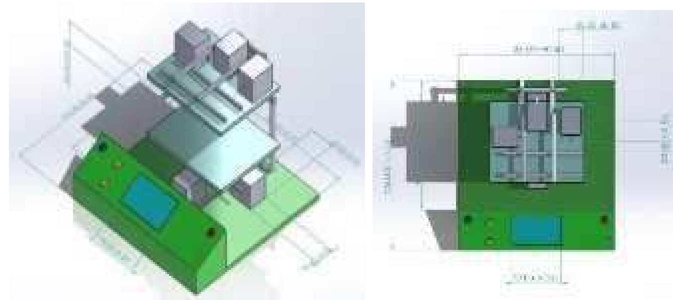

Fig. 5. Mechanical design.

B. Electronic and power systems

The following electronic schematic shows the connection between the Raspberry Pi Pico W and the movement system of the motors that are activated by pushbuttons. It also has an OLED screen, where the processed data will be displayed in millimeters, and also indicator leds to show if the robot is connected to the electric current (blue led), or if maintenance is needed (red led).

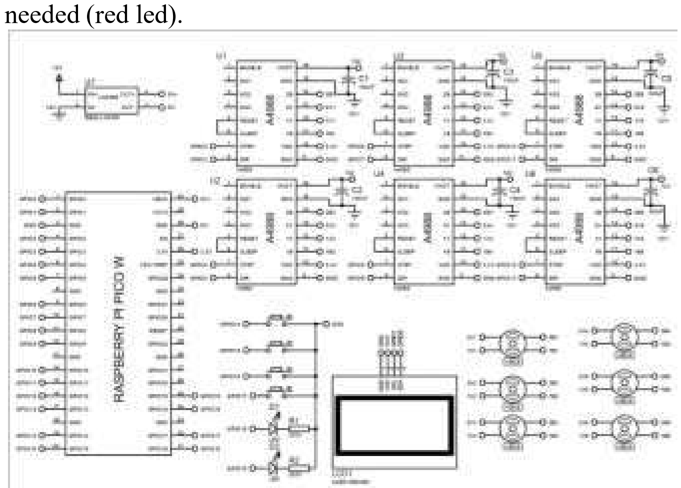

Fig. 6. Electrical diagram of the system.

IV. CONCLUSIONS

First, it was possible to propose and propose the design of a low-cost articulated robot based on the comparison of others, where the robot aims to take measurements in the preoperative process in a maxillofacial surgery, having as main components the 4-wire stepper motors and the Raspberry Pi Pico W based on a CNC machine, being the main cause of its lower cost and along with it the components and mechanisms that are robust as for taking measurements. Previous research [22] has evidenced to have a lower accuracy due to the use of ST8N40P motors, counting itself with an error of 2 degrees of accuracy in each step, this makes them present a lower accuracy than a stepper motor along with the mechanical systems used in this research. It contains a greater precision by the motors and along with it the simplicity of the drive, in addition to the practical design for the manipulation of the operator and along with it the own interface of the system without using additional machines for the data visualization.

Secondly, the characteristics of the method were detailed to remain a mixed design between VDI 2206 and MIT, where the main characteristics of this methodology are described below.

In addition, the design and the new proposal of the mixed methodology that was implemented, having as strengths the search for problems or niches, the design or redesign and validation. Therefore, it is convenient to consolidate the engineering projects to consolidate the final products based on design, prototyping, implementation, etc.

Finally, a bibliometric analysis and a synthesis of the research were elaborated. Where the search for information on the subject was initiated with the help of search algorithms. Likewise, the electronic scheme involving the Raspberry Pi Pico W microcontroller with the components of the robot was proposed. In addition, the mechanical design that manifests the shape of the articulated robot and the flowchart detailing each part of use of the system and the control part were presented.

In a matter of future work, the proposed design tends to be improved based on the Internet of Things IoT, based on the microcontroller containing Wi-Fi and this data can be uploaded to the cloud. In addition, filters can be included in the signals that can cause bounces to avoid erroneous movements in the axes and even the implementation of encoders to improve the accuracy to a great extent, being almost zero.

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