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Development of a Laparoscope Prototype Based on the Continuous Redundant Cable Robot Tested in a Simulated Abdominal Pelvic Cavity

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Abstract— The applications of continuous-redundant robots in the medical field, thanks to their hyper-flexibility and their ability to slide through complex curvilinear lines, make them ideal for surgical procedures. This paper describes the design, construction and control of a continuous redundant robot, driven by tension cables, based on the robotic model. Tests were carried out in a simulated physical environment of the Abdominopelvic cavity. Regarding the control of the system, inverse kinematics were used, which allowed to relate the different variables of the same, using the MatLAB and Arduino programs; its manipulation was carried out by means of a joystick and a PID control. Evaluation, performance of the system, position of the end effector, the length of the tension cables in each movement, as well as their respective curvature and angles were recorded through calculations.

Index Terms— Continuous redundant robot, laparoscope systems, position control, PID control.

I. INTRODUCTION

Over the years, the study of robotics has potentially increased, allowing the development of an endless number of new technologies that enable new solutions to certain daily, industrial, or medical needs.

This article focuses specifically on the development of a redundant continuous type of robotic prototype (Snake cable robot), based on the functional principles of a laparoscope for the exploration of a simulated physical environment of the abdominopelvic cavity, since it offers advantages kinematics with respect to classical robots (Berthet-Rayne et al., 2018). The structure of the continuous-redundant robots allows them to perform fluid movements with wide degrees of freedom, thus achieving a greater ability to avoid obstacles, have a greater range of vision and an adaptation in confined spaces.

Thanks to the type of locomotion made possible by the multiple segments that make up the Snake cable robot, in addition to providing the kinematic advantages mentioned above, it also allows the user (in this case a MIS surgeon (Minimally Invasive Technique)) greater ergonomics and a greater range of visualization of the abdominal area that is being inspected at the time of performing a surgical procedure. Conventional laparoscopes not only cause the doctor to present visualization limitations and therefore loss of perception of the area, but also cause the doctor to only perform rigid movements, causing multiple ailments in the arm and back area, thus causing musculoskeletal problems (Millán, 2016);

This is why the robotic prototype built in the present work was based mainly on the redesign of redundant continuous robots developed in various studies, specifically adapting it to the few ranges of vision that surgeons have when performing a laparoscopic appendectomy, due to that the conventional laparoscopy only allows a two-dimensional view and does not make it possible to see the depth of the abdominal pelvic space that is being inspected in a complete and comfortable way (García-Galisteo, Tejero, Vílchez, García-Galisteo & González, 2011); in such a way that its redesign was planned to be capable, optimal and favourable to achieve certain DOF (Degree of freedom) without ceasing to be a minimally invasive surgery.

On the other hand, the construction of the software and hardware for the control of the robot consisted in the previous analysis of mathematical models by means of inverse kinematics, which allow us to know what is the position of the end effector of the robot in space. Likewise, it allows to know the length changes of the tension cables in each movement generated by the segments; Resulting in the development of a control system, the mechanism developed.

Finally, for both mechanical and control evaluation of the developed robotic device, a simulated physical space of the abdominal pelvic cavity was constructed taking as reference the appearance of the anatomy involved in the laparoscopic appendectomy examination.

II. BIOENGINEERING MATERIAL

Surgical techniques are those that are implemented during the synchronous and orderly execution of operative manoeuvres for the benefit of the patient (Luján, Bertone, Cocco, Aramayo & Boatti, n.d.). Laparoscopy is a practice of this type, which consists of the revision of the pelvic-abdominal cavity through small incisions through which a video camera is inserted, allowing the medical team to observe the surgical field (anatomy) within the patient and work on it (López & Quijano Collazo, nd). This surgical technique is considered MIS type, and is used to diagnose pathologies such as: protocolized abdominal tumours, colitis, appendicitis, ulcers, staging (degree of extension of a malignant tumour) and lymphomas present in the abdominal area (American Society of Colon and Rectal Surgeons).

Despite the advantages of this examination, the execution of this technique presents limitations in terms of the visualization of the area to be inspected, since the surgical instrument (laparoscope) that is usually used presents instability in the platform of the examination. Camera, has few degrees of movement and only allows a two-dimensional view, that is, it only allows images of the abdominal cavity from one perspective, preventing a detailed observation of it (García-Galisteo, Tejero, Vílchez, García-Galisteo & González , 2011). It is for this reason that when a surgeon performs this type of surgical intervention, he tends to lose the perception of space, causing him to be unable to perform a specific analysis of the patient's anatomy and that when predicting a specific result presents greater difficulty, led to a possible extension of the disease (Díaz, 2016).

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In addition to the aforementioned, in addition to the visual limitations that the laparoscope presents, it also causes ergonomic complications for the surgeon during the examination, since on average of every 78 specialists dedicated to laparoscopy, 81% of them present two or more musculoskeletal symptoms located mainly in the neck (25%), shoulders (19%), wrists (25%), elbows (19%) and back (46%) during the execution of the surgery (Millán, 2016). Thus causing the surgeon to be exposed to rigid movements caused by ailments and in some cases that his procedure is not the most appropriate when determining a specific diagnosis on a patient.

Currently, thanks to technological advances, there are different types of surgical robots (Octavio et al., 2012), which have been gradually incorporated into minimally invasive surgeries, having advantages in examinations such as laparoscopic appendectomy. These robots can help the surgeon throughout this surgical procedure, due to the fact that they have a three-dimensional view with high definition (HD), a greater inspection range in the area and greater degrees of manoeuvrability in the instrument without affecting the ergonomics of the specialist (Campero et al., 2018). Likewise, robotic surgeries present a lower percentage of complications with respect to conventional surgeries (48.5% and 76.5% respectively), and the operation time is decreased by approximately 2% (García-Galisteo, Tejero, Vílchez, García-Galisteo & González, 2011).

There is a redundant continuous robotic model called Snake cable robot, which uses a bio-inspired locomotion with flexible continuations, having as a peculiarity a redundant physical property (possibility of ergonomics) (Berthet-Rayne et al., 2018). This special feature helps to improve visualization, to have greater accessibility to confined places and to minimize access trauma in intra-abdominal surgeries, thus obtaining better results in these surgical procedures and more precise diagnoses (Wright et al. 2007).

It should be noted that current robots have disadvantages such as the increased cost of the equipment and their robustness, causing failures in the robotic arms or in the control console, causing a sudden change in the procedure that was being carried out. (CGDES, 2015), for this reason continuously redundant robots are ideal for MIS-type surgeries, because these models are easier to manipulate, their maintenance is not so complex and they can be miniaturized to the scale required by surgery, in order to provide flexible access to the area and operate with greater dexterity.

III. PROTOTYPE DEVELOPED

3.1 Development of the mechanical structure for the laparoscopic prototype.

The design of the mechanical structure of the prototype was carried out by means of the FUSION 360 software, in order to characterize the appropriate materials, and thus identify both their advantages and disadvantages in order to carry out the construction of the prototype.

Both constructive aspects (size, colour, shape) were taken into account, as well as those that are related to the performance of certain specific tasks such as: the visual inspection of an area that simulates the abdominopelvic cavity and the ability to perform smooth movements and accurately in confined spaces.

The dimensions of 20 cm long and 7 mm were defined for the mobile structure of the robot, since this is the size of the laparoscope that professionals use when performing a laparoscopic appendectomy.

A compression spring was used, with an elongation constant of 125.83 N / m, which allowed smooth movements such as the spinal column, since this being an elastic piece arranged in a spiral allows the mechanism to recover its original position after having been deformed. Because of some external movement that has been made. This prototype was used with segments and modules, where the modules would be composed of a tension spring, with an elongation constant of 1235.1 N / m, which allowed the desired internal curvatures to be carried out, so that in this way, each module will remain with a type of washer whose main function is to allow the passage of the tension cables along the entire mobile structure (Figure 1).

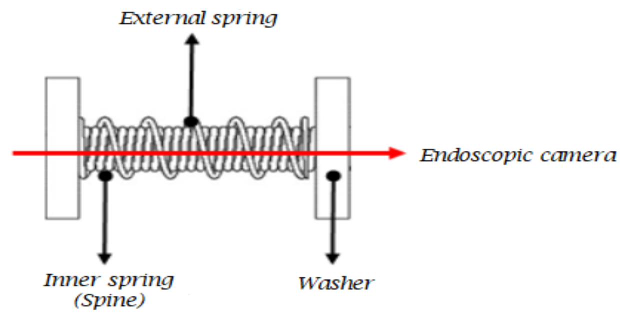

Figure: 1 Based mechanical design of one module

For the case of this design, it was determined that the backbone of the structure would have an internal spring 20cm long and 7mm thick, in addition to this, each module would be integrated by an external spring 4 cm high and each One of the washers that allow the passage of the tension cables were to have a height of 1 cm. (Figures 2, 3)

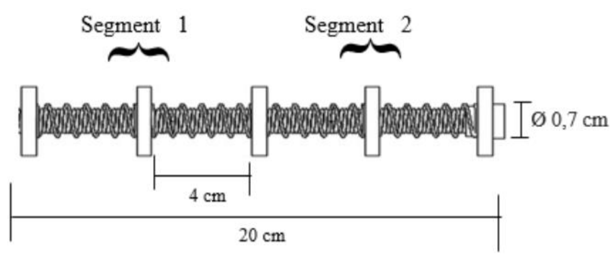

Figure: 2 Distribution of the robot in two segments each made up of two modules.

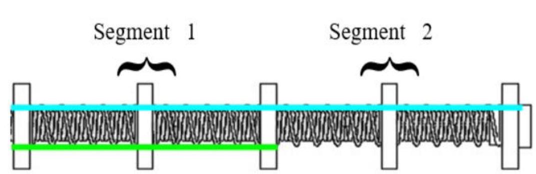

Figure: 3 Side view of cable layout

The segment located in the distal part has three tension cables, these pass through the first segment, thus generating that the proximal segment (1) has six cables and the distal segment (2) has three cables.

I. For the assembly of prototype showing in figure 4, MDF plates were joined by means of 4 endless screws to hold and support the whole structure.

II. Located in the corners of each one of these (See figure 3), leaving a distance of approximately 10 cm between the first two plates, in order to accommodate in this space the actuator cables and the circuit that allows the control; and a distance of 12 cm between the second and third, where the mechanism's actuation box was integrated.

III. Once with the MDF plates arranged along the 4 screws, the 6 aluminium boxes were placed with their respective actuator organized in the asymmetric distribution also used in prototype No. 2 and the tension cables of each one of the motors through the third MDF plate that had the respective integrated holes.

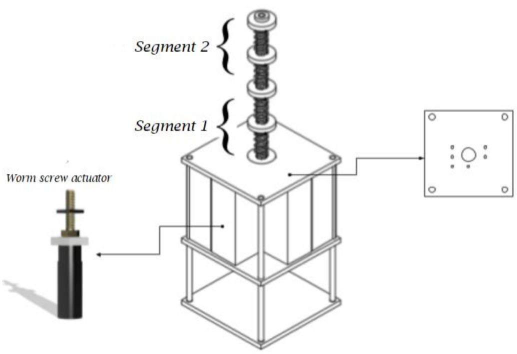

Figure: 4 Final assembly of the mechanical structure of the robot

IV. With the tensioning cables in place, we proceeded with the assembly of the robot's mobile structure; For this, the internal spring that forms the backbone of the mechanism was passed through the central hole of the third MDF plate.

V. Subsequently, an external spring was added that surrounded the spine of the mobile mechanism and then a washer was placed, this process was repeated 4 times until the washer was integrated into the tip of the internal spring, thus forming 4 modules. and two segments, showing in figure 5.

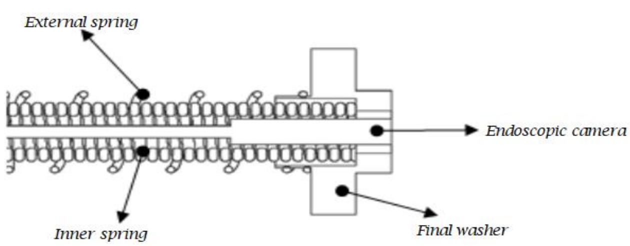

Figure: 5 Side view of the internal structure of the end washer

VI. After accommodating both the washers and the external springs, the tension cables were passed through each washer following the following distribution: segment 1: 6 cables; segment 2: 3 cables. See Figure: 3

3.2. Development of the laparoscopic prototype control.

Parameters and requirements survey were established for each of the electronic components, characterizing and identifying the appropriate ones for later use. Making use of inverse kinematics, direct kinematics and equivalent equations from the DH matrices to establish the appropriate movements of the prototype, and also the angles, lengths and speeds obtained in it.

Requirements based on user needs, which were: Ensure the comfort of the user when handling and operating the laparoscopic prototype, since at no time should its ergonomics be affected. The movements made by the laparoscopic prototype by means of the control knob (joystick) must be synchronized with respect to the movements made by the robot's mobile mechanism. The laparoscopic prototype will have an integrated lighting system that will allow the user to adjust the light intensity depending on the area that he wishes to inspect. The workspace must allow movements with 360 ° angles in the (x, y) plane. The resolution of the camera must be 1900x1080 pixels, which will allow obtaining clear and quality images. Guarantee the user intuitive handling of the built laparoscopic prototype.

3.3. Inverse kinematics for the simulation in Matlab.

Inverse kinematics was used in the present degree work, the movements of the segments of the mobile structure of the robot were determined, which allowed the end effector to be located in a desired position.

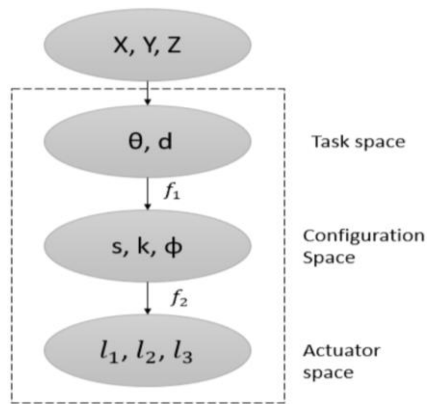

Figure: 6.Parameter transformations

I. To begin, it should be taken into account that the inverse kinematics requires changes of spaces, because these are the ones that gather the variables that govern the prototype.

II. Once the spaces were defined, each one of them was related by means of functions called “f1 and f2”, which allowed the passage from one space to another.

III. Once these functions were established, it was defined that f1 was going to be the function that would allow the passage from the workspace to the configuration space in which the curvature parameters are found, as shown below.

IV. The relationship between the desired coordinate for the length of the tendons and the curvature parameters is elaborated, resulting in the desired end effector position.

$$l1 = 2n * \sin\left(\frac{ks}{2n}\right) * (\frac{1}{k} - dsin(\varphi)) \qquad (1)$$

$$l2 = 2n * \sin\left(\frac{ks}{2n}\right) * \left(\frac{1}{k} + d\sin\left(\varphi + \frac{\pi}{3}\right)\right) \quad (2)$$

$$l3 = 2n * \sin\left(\frac{ks}{2n}\right) * \left(\frac{1}{k} - d\cos\left(\varphi + \frac{\pi}{6}\right)\right) \quad (3)$$

The equation 1to 3; express the tensioner length of L1, L2, L3

Where:

- *n:* are the number of modules it is composed of.
- *d:* is the distance from the center to the tendons.
- *l1, l2, l3* is the length of the tendons.

3.4. Direct kinematics for Matlab simulation.

By means of direct kinematics, the reduction of the DH matrix is carried out, obtaining a homogeneous matrix relating the position and orientation of the robotic prototype, in the defined workspace (24cmx24cmx8cm).

Regarding the production of movements generated after the transformation of the aforementioned inverse kinematics, direct kinematics is responsible for transforming these data again to generate the movements produced.

● The lengths of previously acquired tendons are taken.

● Counting the lengths, three spaces are planted in the same way as in the inverse kinematics.

Working parameter (*s*):

$$s = \frac{(n * d)}{\sqrt{\Sigma(1^2) - 1(1) * 1(2) - 1(2) * 1(3) - 1(1) * 1(3)))}}$$

$$s = \frac{s * \cos(\sqrt{1^2 - 1(1) * 1(2) * 1(3) - 1(1) * 1(3)})}{(3 * n * d)} \quad (4)$$

Curve parameter (*k*):

$$k = 2 * \sqrt{\frac{\Sigma(1^2) - 1(1)(2) - 1(2) * 1(3) - 1(1) * 1(3)}{d\Sigma 1}} \quad (5)$$

Where the three parameters comply with:

- *n:* will be the number of modules
- *d:* distance from the centre of the support to the tendons.
- *l:* length of tendons

3.5. Direct kinematics for the physical plant.

The operation of the actuators is identified and, in turn, how the motors influence the movement of the prototype's mobile mechanism, so that a geometric approach was carried out, obtaining the appropriate formulas to determine how the stresses exerted on it determines the angle. pitch and rotation of the moving mechanism.

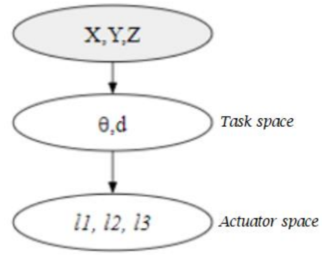

Figure: 7 Parameter transformation for direct kinematics

$$l_1 = 10 - [1\,cm * \theta * \cos(\gamma)]$$
$$l_2 = 10 - [1\,cm * \theta * \cos(\gamma + {}^\circ)]$$
$$l_3 = 10 - [1\,cm * \theta * \cos(\gamma - {}^\circ)] \quad (6)$$

Where:

- l_{1-2-3} are the lengths of the cables.
- 1 cm is the radius of the washers.
- θ corresponded to the pitch angle of the mechanism (45° for testing.)
- γ corresponded to the angle of rotation of the mechanism (30° for the tests.)
- ° will be the angles of two of the three tensors that are in the end effector.
- 10 value corresponded to the initial length of the segment

3.6. Inverse kinematics for the physical plant.

Direct kinematics is performed, that is, having a certain position x, y, z.

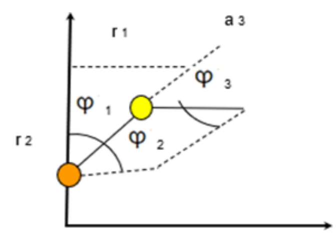

Figure: 8 Inverse kinematics

$$\theta_1 = \tan^{-1}\left(\frac{y}{x}\right) = a_2 \quad (7)$$

$$r_1 = \sqrt{x^2 + y^2}$$
$$r_2 = z - l$$
$$\phi_1 = \tan^{-1}\left(\frac{r_1}{r_2}\right)$$
$$r_3 = \sqrt{r_1^2 + r_2^2}$$

$$a_3^2 = a_2^2 + r_3^2 - 2a_2 r_3 \cos\phi_2$$
$$\phi_2 = \cos^{-1}\left(\frac{a_3^2 - a_2^2 - r_3^2}{-2\,a_2\,r_3}\right)$$
$$\gamma_1 = \phi_1 - \phi_2$$
$$\phi_3 = \cos^{-1}\left(\frac{r_3^2 - a_2^2 - a^2}{-2\,a_2 a_3}\right)$$
$$\gamma_2 = 180 - \phi_3$$

Where, eq. 7 ii inverse kinematics and projection formula:

- a_2 *corresponds to 2 times the length of the moving mechanism, that is, 2l = 10 cm*
- r_{1-2} *distance of the right triangle*
- φ_{2-3} *Obtained by the cosine law*

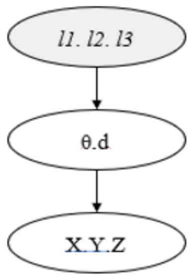

Figure: 9 Parameter transformations for inverse kinematics

3.7. Development of the abdominal pelvic cavity simulator.

The organs involved in laparoscopic appendectomy were identified in order to carry out an anatomical simulator of the physical environment limited to the dimensions of a child (11 years old), using previously selected materials taking into account the requirements and making use of matrices that allowed its characterization.

IV. IMPLEMENTATION OF THE LAPAROSCOPIC PROTOTYPE IN THE SIMULATED PHYSICAL ENVIRONMENT

It was carried out by adjusting the laparoscopic prototype on the simulator, verifying its operation without damaging the organs and satisfying the requested bending, position and speed angles.

In order to achieve the proper location of the organs that were selected for the simulator one 3D model was initially developed using the FUSION 360 program, as described below:

I. To begin with the design, the first thing that was done was to create a base with dimensions of 42 cm long x 52 cm wide. The finished digestive mock-up simulator can be seen it in figure 23.

Note: These measurements were established since the simulator that was carried out is based on the anatomy of a child of approximately 11 years, with a height of 1.52 cm and a weight of 48 kg.

II. After having the base created, the organs involved in laparoscopic appendectomy were downloaded through the gallery of pre-created designs of FUSION 360, which are: Stomach, spleen, gallbladder, liver, small intestine and large intestine. (Figure 10 - 11).

III. Once these organs were arranged in an anatomically correct way, we proceeded with the design of the structure that will cover the organs. Because when a patient undergoes a laparoscopy, the surgeons expand the abdominal pelvic area with CO_2 approximately 15 cm, the height of the cover was placed 20 cm high, since the organs measure in a range of 5 cm at 9 cm thick.

IV. A 4cm x 4cm hole was added to this cover through which the robot will enter, thus concluding the simulator design.

V. Finally, to the 3D model of the proposed simulator, the developed robot was added to be able to observe a possible future vision of the project evaluation

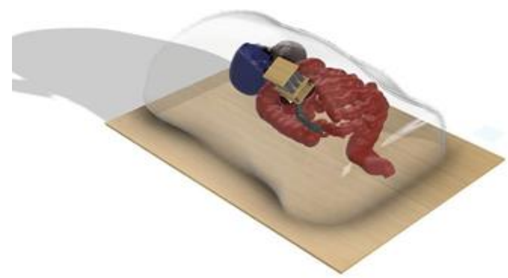

Figure: 10. Isometric view of the CAD Design in FUSION 360 of the environment simulator.

Figure 11. Close caption of side view with the snake cable robot inside the physical environment simulator.

V. SYSTEM TEST LAYOUT

Evaluation matrices were made against the requirements set for each of the phases mentioned above, determining the variability of the data obtained at the time of implementing the laparoscopic prototype.

The robotic prototype test plan developed consisted of three fundamental phases for its evaluation and validation, this with the aim of verifying compliance with each of the established requirements. Therefore, these are the two evaluation methodologies: first: subsystem test plan (sensors, controller); second: test plan for the field of view allowed by the device; finally: the device speed and recurrence.

VI. RESULTS AND DISCUSSION

1. Modules and segments

The segments as in the modules of the mobile structure of the robot, two were used, one that works as a backbone and another that works so that the washers do not slip through the internal spring and allows the realization of curvatures generated by the movement that is elaborates when positioning the robot at some point.

Figure: 12 Final designs of end effector prototype

2. Transmitters (tension cables).

It was necessary for the transmitters to go directly to the mobile prototype of the robot without having contact with other support sheets, since when passing through said support the tensioners deviated and finally reached the mobile mechanism, adding to this that they were This will cause friction and the tensioner has a greater chance of breaking during operation.

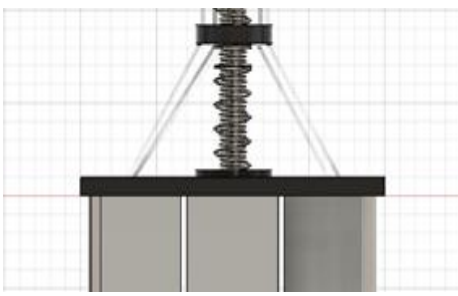

Figure: 13 Location of the guide wires

3. Actuation box.

Performance tests are carried out; no drawbacks were found in terms of asymmetric distribution; this actuator box was implemented with 12V geared DC motor with encoder. Its cable requires one motor to be controlled. The internal mechanism to converted the rotational motion into extended and contracting the cables is an own design witch. The details of the mechanism will be present in further publication.

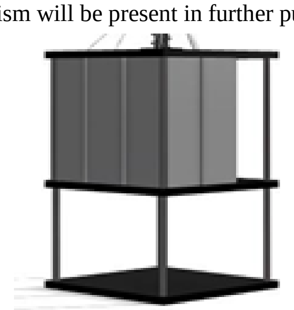

Figure: 14 Positions the Actuation box.

4. Construction of the Robot Structure

The built structure manages to comply with specified mechanical properties such as malleability, ductility, toughness, among others; In addition to this, it also presented great performance in terms of performing flexible and versatile movements (See figure 15 - 16), which allow the robot to get as close to the desired point. Likewise, being able to perform harmonious movements, it specifically complies with being based on a "Snake Cable Robot" model.

Figure: 15 Mechanical structure

Figure: 16 Sequence of Movements performed by the laparoscopic prototype based on the robotic model Snake cable Robot

5. MATLAB simulation of the robotic prototype workspace

The working space of a segment of the mobile structure of the laparoscopic Snake cable robot prototype was simulated; graphs were obtained (see Figure 17 and Figure 18) that allowed visualizing and knowing in a three-dimensional space the limit points that the distal end of a segment.

Using direct kinematics, the working space of a 5 cm high segment is determined. It is possible to observe the different points through which the end effector would pass in a real environment when the actuators pick up or release the tension cables; There the maximum point that the segment would reach is indicated, where in the x, y plane it reaches points of approximately 3 cm with respect to its original position, and in the z plane it manages to reach a point 5 cm high, due to that this is the distance of the segment when it is completely straight.

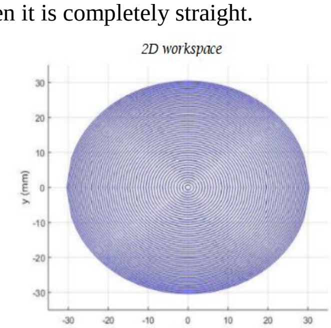

Figure: 17 Top view of the simulated workspace of a segment of the robot's mobile structure

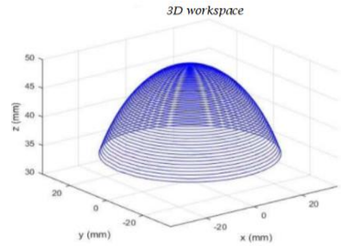

Figure 18. Isometric view of the simulated workspace of a segment of the robot's moving frame

Current laparoscopes only allow movements with a maximum angle of 60 °, since said instrument, being made up of a rigid structure, does not allow curvatures to be made that can expand said range of movement, thus obtaining that the prototype made presents advantages Regarding the workspace, as this in addition to allowing 300 ° more of movement, it also allows the viewing range of the area to be inspected to be much greater (Figure 19).

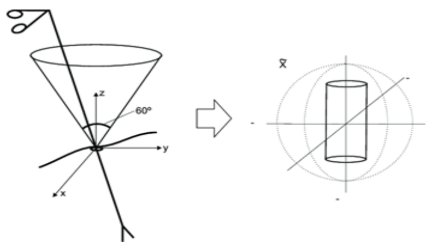

Figure: 19 . Workspace of a Conventional Laparoscope (OpenSurg, 2013)

The location of the MPU sensors in the mobile structure of the mechanism was determined based of the efficient joint position to obtain the location data from end effector of the robot. The figures 20 and 21 are showing the location of the sensors made on the washers, which establishes the end of each of the segments. Therefore, the first IMU was positioned on the second washer and the second IMU was positioned on the fourth washer (end effector). (Figure 22)

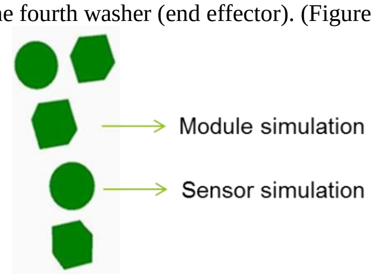

Figure: 20 Simulation in PROCESSING of the position of the sensors in the mobile structure of the robot for any position obtained by the IMU

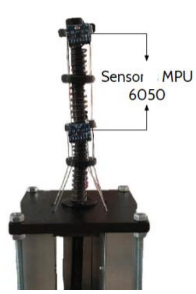

Figure: 21 Location of the MPU 6050 sensors on the mobile structure of the robot prototype

6. *Final assembly of the mechanism with the integrated control system*

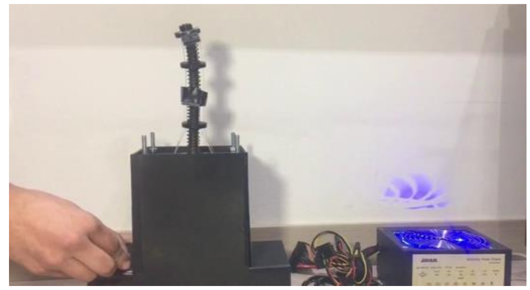

Figure: 22 Final structure of the laparoscopic continuous cable robot prototype outside of digestive mock-up simulator

The structured prototype was adapted to produce the specific movements that are being sought; It is determined that even though two segments were built, they are dependent on each other due to the fact that they share three tensional cables within each other; furthermore, the two can perform different curvatures at the time of making them reach a certain position.

To determine the curvature angles to which each of the segments that make up the mobile structure of the robot could reach, several field tests are carried out by means of the use of the equations of geometric approach, thanks to these, it was determined that the maximum angle that segment one could go would be 45 ° and the maximum angle that segment 2 would go would be 90 °. It is worth mentioning that these tests were performed by varying the values of theta and gamma present in the equations mentioned above. On the other hand, for the calculation of the z axis, this was carried out depending on the points obtained in the x & y axes that the joystick took in order to make a more intuitive operation.

Regarding the actuators used to control the position of the robot's mobile structure, it was detected that they presented backlash problems, which means that when the mechanism was asked to perform short movements, it did not do so because the motor cannot make such small turns.

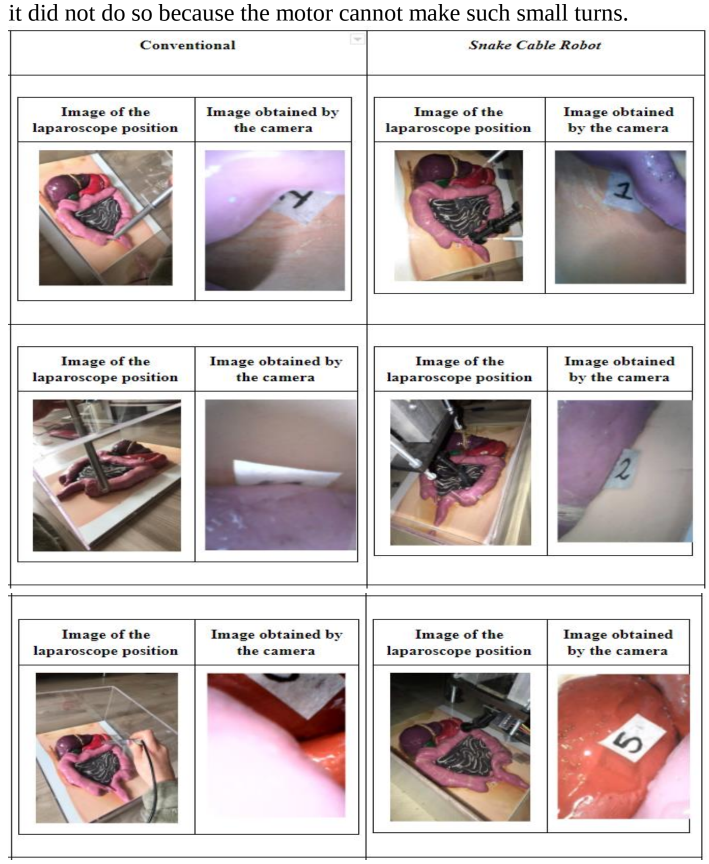

Figure: 23 Final prototype with the display test plan results.

Figure 23 shows the photographs obtained by means of the endoscopic camera in the different visualization tests that allowed the comparison between a conventional laparoscope and the mechanism developed in the present degree work, it was determined that the robotic prototype based on the snake cable model The robot allowed a greater range of visualization in terms of inspection of the simulated physical environment of the abdominopelvic cavity, since of the six markers that were placed in it, in five of them better images of the registered areas were obtained.

VII. CONCLUSIONS

From the tests carried out with each of the prototypes developed throughout the degree project entitled "Development of a Laparoscope Prototype Based on the Continuous Redundant Snake Cable Robot Model to Be Used in a Simulated Physical Environment." identify that for the movements to be executed in the most suitable way according to the requirements established in the mobile mechanism, it was necessary to use a support in the internal cavity of the same (vertebral column), because this allows it to generate support to the system and at the same time that it had sufficient ergonomics to execute the movements desired by the user, so that prototype No. 3 was the only one that met the possibility of returning to its initial position (Home) and to the points established by the user without any interruptions.

On the other hand, in terms of transmitters, these beyond complying with a high rating in terms of resistance, it was also determined that these must have the possibility of adapting to reduced spaces and with a range of flexibility, since if not allow flexibility, they would prevent the mobile structure of the robot from making the curvatures that it can make when reaching any position, likewise, it is also important that the tension cables are structures that do not tend to tangle, since otherwise Thus, they can cause serious damage to the system, totally affecting its operation.

Being the prototype of an assisted robot, it allows the user not to be upright on the abdominal cavity at the time of inspection, since as it is controlled remotely, it allows the user to be located in a workplace that helps him. to improve its ergonomics and thus not suffer injuries or damage to the extremities by maintaining the same position for long hours, additionally, thanks to the visualization tests carried out, it was found that clearer images with better quality are obtained through the laparoscopic prototype of the abdominopelvic cavity, implying that when performing a real exam, it does not take so long, since the area to be inspected can be seen more clearly.

Additionally, it was also found that the response of the IMUs in real time varies depending on the connection of the program with the serial port, because sometimes this is saturated and caused the simulation in PROCESSING of the position of the two segments of the robot freezes, causing the system to have to reboot. On the other hand, it was decided to use a single joystick to control the two segments of the robot's mobile structure, since if two were used (one for each segment) it would cause the handling of the same by the user to become more complex.

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