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# Postural Mechatronic Assistant for Laparoscopic Solo Surgery (PMASS)

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## 1. Abstract

Laparoscopes used in laparoscopic surgery are manipulated by human means, passive systems or robotic systems. All three methods accumulate downtime when the laparoscope is cleaned and the optical perspective is adjusted. This work proposes a new navigation system that autonomously handles the laparoscope, with a view to reducing latency, and that allows real-time adjustment of the visual perspective.

**Methods.** The system designed is an intuitive mechatronic system with three degrees of freedom and a single active articulation. The system uses the point of insertion as the invariant point for navigation and has a work space that closely resembles an inverted cone.

**Results.** The mechatronic system has been tested in a physical trainer, cutting and suturing chicken parts, as well as in laparoscopic ovariohysterectomies in dogs and pediatric surgeries. In all the procedures, surgeons were able to auto-navigate and there was no visual tremor while using the system. Surgeons performed visual approaches in real time and had both hands free to carry out the procedure.

**Conclusion.** This new mechatronic system allows surgeons to perform solo surgery. Cleaning and positioning downtime are reduced, since it is the surgeon him/herself who handles the optics and selects the best visual perspective for the surgery.

## 2. Introduction

Laparoscopic surgery, which is at the vanguard of technology, has encompassed various technological fields. Given its characteristics, this type of surgery demands that the specialty surgeon acquire new abilities and quickly adapt to new technology. Technological advances in assistance with holding and handling the laparoscope during surgery focus on solo surgery, in which the surgeon is provided with the technological means to perform the surgery alone. At present, in addition to “passive” electromechanical systems, such as Tiska[1], Endofreeze[2] and Passist[3], there are various “active” robotic positioning systems, such as Aesop (Sackier et al., 1994), Endoassist (Dagan et al., 1982), FIPS (Buess et al., 2005) and Tonatiuh (Minor et al., 2002), with which to perform solo laparoscopic surgery. The work space of all these systems is an inverted cone. However, depending on the

application or subspecialty, the real work space is limited to half or less than half of an inverted cone, which is normally located in front of the surgeon.

A tool such as a robotic assistant is very advantageous if it can be used in all laparoscopic specialties. However, considering transportation, installation and maintenance costs, the tool becomes very expensive if its use is limited to a few specialties. In addition, downtime due to manual or voice-activated repositioning of the laparoscope is cumulative and generally not taken into account during the evaluation process. Nevertheless, downtime can be reduced if the laparoscope is handled intuitively and, preferably, in real time. We therefore propose an optimized tool, based on the Postural Mechatronic Assistant for Laparoscopic Training (PMAT) (Minor et al., 2005), which can be applied selectively to solo surgeries, easily installed and transported, and used to provide functional assistance during surgery.

### 3. Material and Methods

The PMAT comprises a harness, an electrically activated linear guide and a pair of passive articulations to which the laparoscope is coupled. Before the surgeon scrubs his/her hands, he/she places the harness on his/her body. The passive articulations are sterilized in a solution before the procedure and the linear guide is covered in sterile plastic.

The surgeon, having scrubbed his/her hands and assisted by the nurse, places the surgical dress over the harness. Port positions are located and a manual visual exploration is carried out. Once the entry ports are in place, the linear guide of the mechatronic system is coupled to the harness, with a quick push over the surgical dress, and secured. Lastly, the passive module of the mechatronic assistant is secured to the linear guide and the 30° laparoscope is attached. Once the optical system is coupled to the mechatronic system, it is introduced into the cavity to carry out the exploration and begin the procedure Figure 1.

Development of the mechatronic system evolved from a modified PMAT which was conceptualized for selftraining in the specialty. This assistant requires the postural movements of the surgeon to position the laparoscope within the training cavity. Although the PMAT offers significant advantages for self-training, it is limited to use in the operating room. The PMAT uses a linear guide to switch between the up and down visual perspectives, but the guide has two main limitations. Firstly, if the work space is to be enlarged, the guide needs to be lengthened, which implies increased weight and a poor fit on the chest of the surgeon. Secondly, the guide, which must be sterilized for routine procedures and fitted after the surgeon has donned his/her surgical coveralls, may rip surgical wear, thus compromising sterility. In order to remove these limitations, the new design still uses the harness and postural movements to position the laparoscope, but the linear guide is replaced by a rotary articulation.

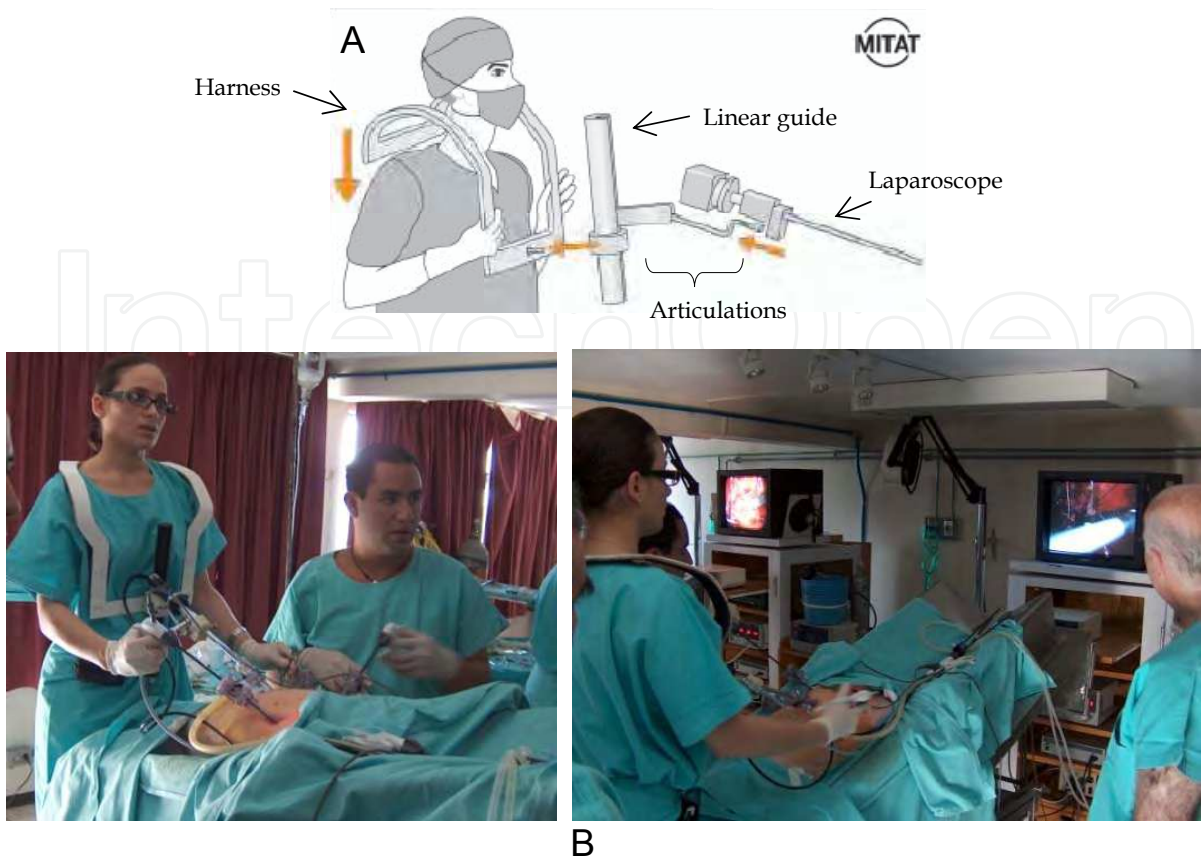


Fig. 1. (A) Conceptual model of non human laparoscopic assistant (B) Surgery without human laparoscopic assistant in pig.

The new system consists of three articulations, as shown in Fig. 2a. Two articulations are passive and one is active. The first articulation is active and rotary (1). The second articulation (2) is rotary, but passive; it operates in the same plane as the first articulation. The third articulation (3) is passive and rotary; it operates in a plane perpendicular to that of the first two articulations.

The system uses the entry point as the fixed and invariant point for exploration and navigation. Laparoscopic navigation with 0° optics requires six basic movements: right, left, up, down, in, and out. To pan horizontally right or left, the surgeon turns his/her torso right or left. The third articulation (3) and the point of insertion complete this movement (Fig. 2b). To establish the entry angle, which corresponds to the change in optical orientation above and below the laparoscope, the system uses the first articulation, which is active and rotary, together with the second articulation, which is passive. This mechanism has an almost linear displacement, as shown in Fig. 2c. The surgeon activates this articulation by means of two proximal switches.

To move the laparoscope in or out, the surgeon moves his/her body towards or away from the patient. The trajectory is almost linear, so there is no visual loss when moving in or out from tissues and organs during the procedure (Fig. 2d).

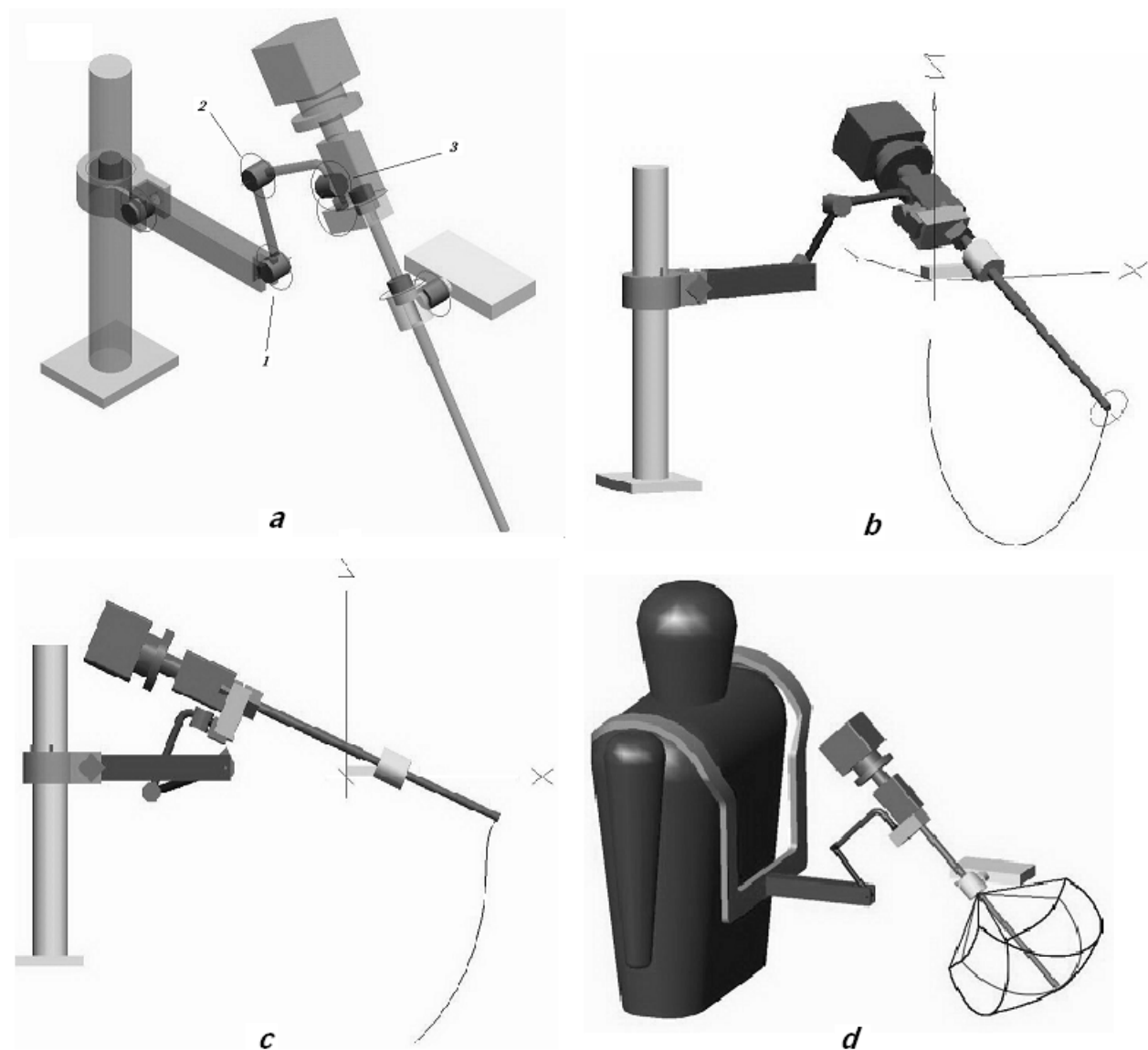


Fig. 2 (A) Concept design of the mechatronic assistant. (B) Model of the system for right-left perspective change. (C) Model of the system for above-below perspective change. (D) Work space of the mechatronic system using Visual Nastram 4D and Mechanical Desktop. The point of entry is invariant throughout the entire navigation

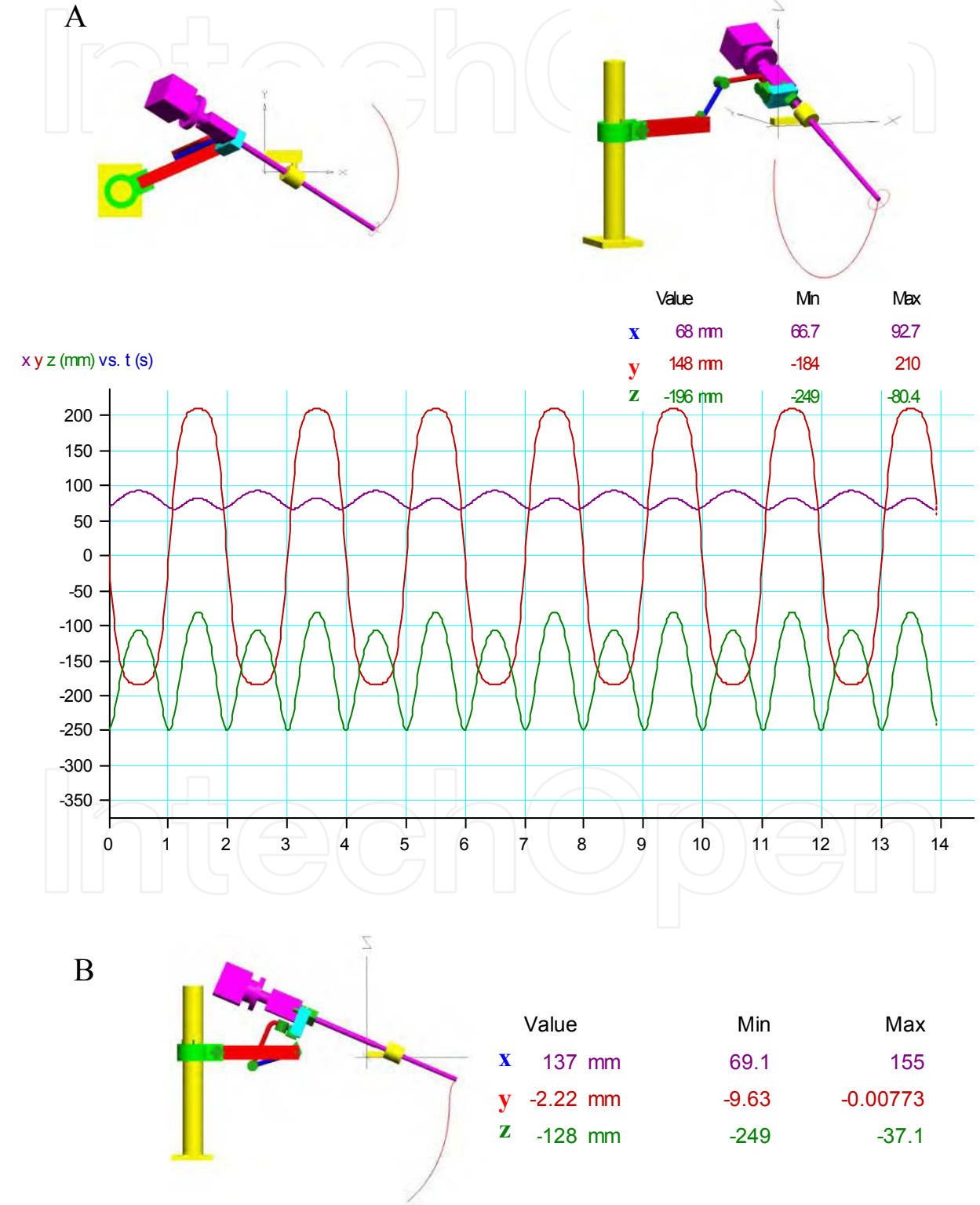
The simulation also determines the position in all moment of the laparoscope tip and the displacement magnitude inside the abdominal cavity for the movements right-left and in-out figure 3.

Once the mechatronic system had been modeled, a multidisciplinary group met to establish the following criteria:

- The system should be mountable in modules, so setup in the operating room is quick and trans-operative sterilization is maintained.
- The system should allow quick disconnection of the laparoscope, so the surgeon can perform unforeseen explorations of anatomic spaces and maneuvers during any standard surgery.

- The system should be manufactured from a material that can be sterilized.
- The system weight should be kept to a minimum.
- 

The system was manufactured from medical-grade steel, together with Teflon-steel parts, to allow for sterilization. The system, which weighs half a kilogram, is set up in a three-step procedure.





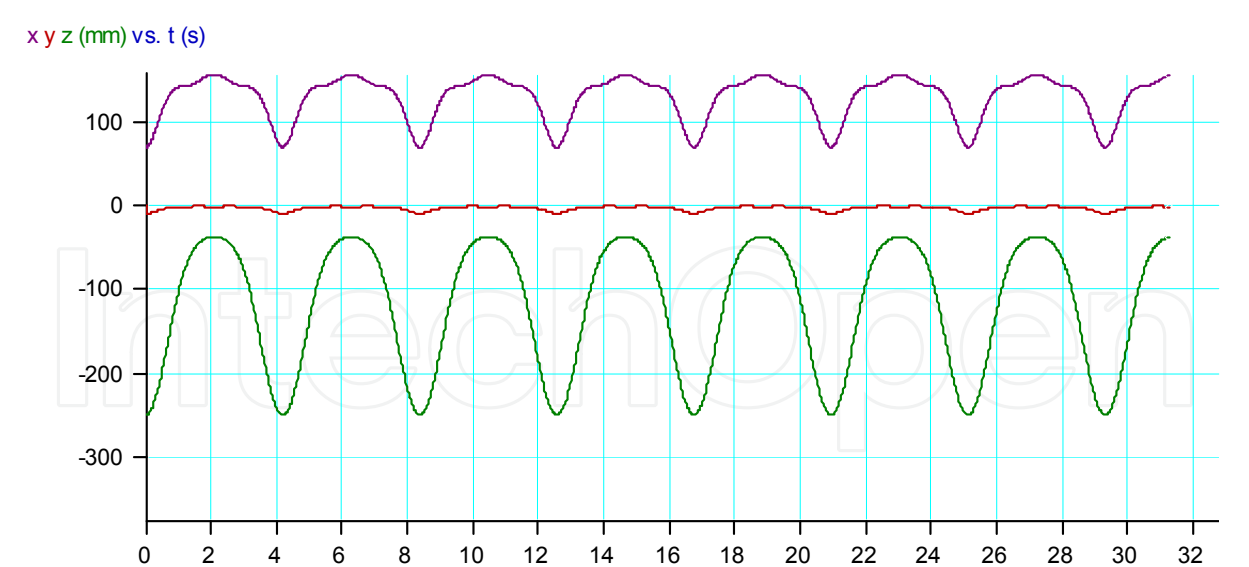


Fig. 3. Space location of the laparoscopy tip during the sailing (A) right-left perspective change. (B) above-below perspective change

Step one is to fit the harness onto the surgeon, under his/her surgical coveralls. Step two is to place on the harness, but over the coveralls, the motor which drives the active articulation and is wrapped in sterile plastic. Step three is to connect to the motor the passive articulations, which are sterilized by normal procedures. The mechatronic system is fitted onto the surgeon in two minutes. The laparoscope connects to and disconnects from the system with ease

4. Test

The PMASS was evaluated by experienced doctors, who first dissected, cut, and sutured chicken parts using 0° optics and performed maneuvers to change optical perspective and explore surrounding areas (Fig. 4 a, b). Surgeries were chosen so that the surgeon approach was frontal to the patient and ergonomic. The next evaluation consisted of three ovariectomies in dogs, using 0° optics (Fig. 4 c, d). The final evaluation consisted of two pediatric surgeries for which the selected procedure was a Nissen fundoplication to correct gastroesophageal reflux disease, not corrected by pharmacological treatment and with persistent esophagitis and alimentary tract bleeding. The surgeries were performed on two 1-year-old patients, whose cases were fully studied prior to the surgery and for whom, in accordance with the Helsinki Treaty, there was informed parental consent. These surgeries were performed solo and using 0° and 30° optics. Also five appendectomies, four ovarian cystectomies and four laparoscopic sterilizations - were performed by three experienced surgeons (Fig. 5).

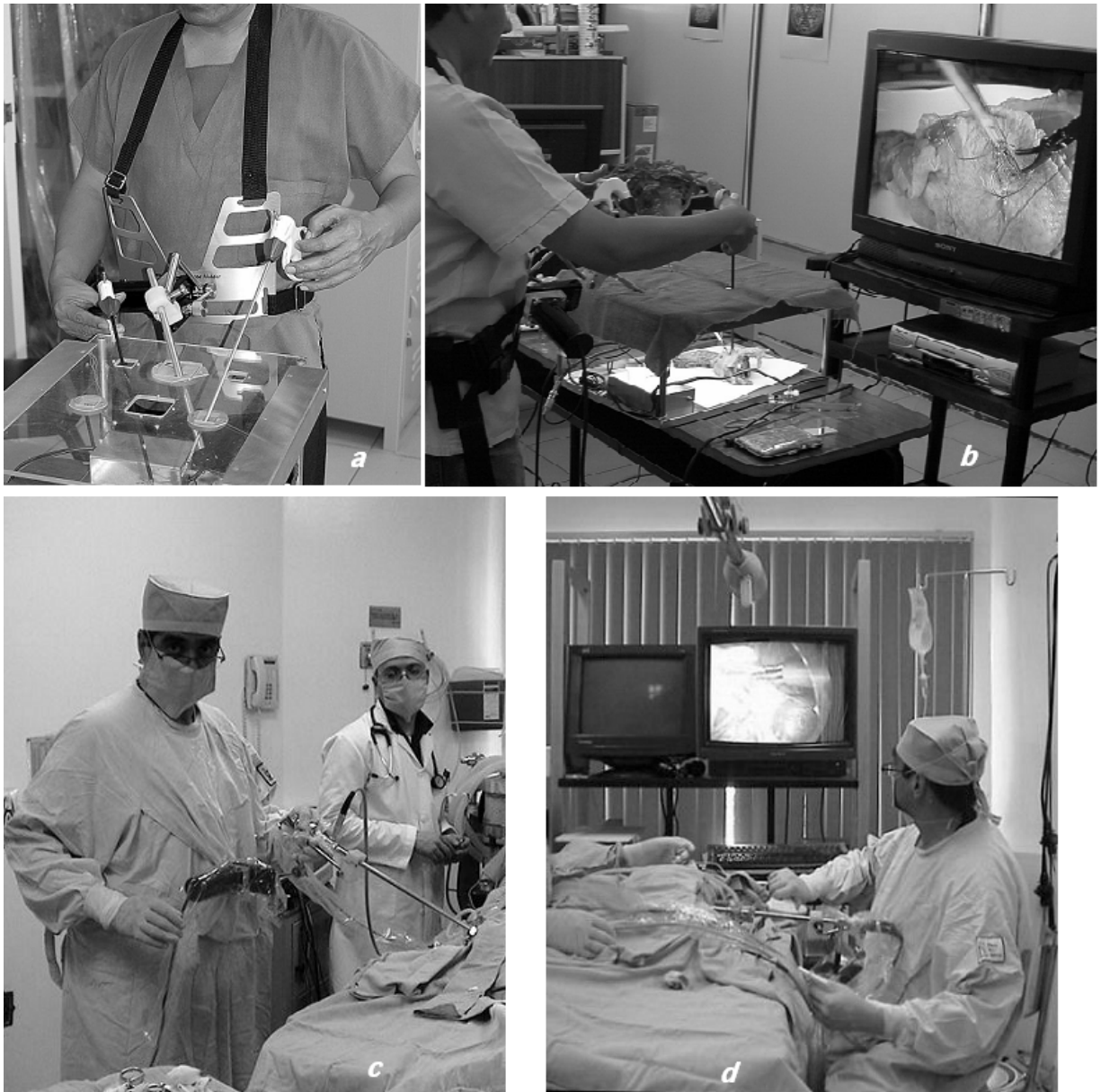


Fig. 4. (a) From concept to design. (b) Adaptation to suturing of chicken parts. (c) Coupling of the PMASS prior to the laparoscopic ovariohysterectomy. (d) Solo laparoscopic ovariohysterectomy surgery in dog.





Fig. 5. Configuration and arrangement of the PMASS in the surgical scenario.

## 5. Result

The mechatronic system was fitted onto the surgeons in an average time of 1 min. The surgeons required an average of 5 min for adaptation to establish hand-eye feedback with the system. Surgeons used postural movements and visual feedback to achieve the required positions while keeping both hands free to perform their procedures. Optics showed no sign of tremor, and exploration, while moving in and out, was intuitive and took place in real time. It was also observed that the system worked equally well whether the surgeon stood or sat, and that postural changes did not limit visual perception. Simulations using the prototype showed that its in and out movements are not exactly linear. However, when operated with visual feedback, the mechatronic system does not have this limitation. The mechatronic system does not afford a view of the roof of the pneumoperitoneum when using 0° optics, so some surgeries, such as the Nissen surgery, are better performed using 30° optics, although the visual correction is manual. In order to clean the laparoscope, the surgeon steps back from the patient, cleans the device, and then returns to optics that have naturally taken up their last visual position. The average time required for cleaning and repositioning was 1 min, which is less than that required by the human assistant (Arezzo et al., 2005), (Buesset et al., 2005), (Arezzo et al., 2000) and much less than that required by the Aesop robot, Endoassist, Tiska, etc. (Arezzo et al., 2005), (Buesset et al., 2005), (Arezzo et al., 2000) or Tonatiuh (Minor et al., 2002). With respect to comfort, the subjective evaluation of the surgeons is that the harness is not uncomfortable to wear (average surgery time was 1.5 h), but that initially they feel anchored to the patient.

## 6. Discussion

The use of new technology in surgery is enabling surgeons to operate solo in some procedures. The advantages are adequate work space on the operating table and maneuverability. However, although active and passive systems offer these advantages, the time required to relocate or reaccommodate optics and clean the laparoscope between operations has not been reduced. In addition, there is a perceptual difference between what the surgeon wishes to see and the proximity he/she achieves with the active or passive system via the robot. There will always be the feeling that there exists a greater visual perspective to perform the procedure. The new mechatronic system shows that it is possible to have solo surgery in which the surgeon auto-manipulates the laparoscope to obtain the best optical perspective and has both hands free to perform the procedure.

One of the maneuvers that causes most delay during surgery is cleaning the laparoscope, whether the laparoscope is soiled or steamed up. Such delays, which are cumulative, are greater for robotic systems than for human assistants, given the set of verbal orders that must be given to the robot and the time required to mechanically couple and uncouple the laparoscope. The new design reduces cleaning time without affecting surgical quality. This assistant facilitates work on the operating table, as do active and passive assistants. Still pending are tests in the various laparoscopic subspecialties and a randomized clinical study to measure downtime under standard conditions. The clinical study will also seek to determine the advantages and limitations of the system, as well as the possibility of selectively applying the system to certain types of surgery in which it offers advantages over other known assistants. Presently under development is a prospective study for application

to cholecystectomy, given that these surgeries are among those with the highest demand at first-level hospitals in Mexico, and are well suited to the PMASS approach.

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Mechatronics, the synergistic blend of mechanics, electronics, and computer science, has evolved over the past twenty five years, leading to a novel stage of engineering design. By integrating the best design practices with the most advanced technologies, mechatronics aims at realizing high-quality products, guaranteeing at the same time a substantial reduction of time and costs of manufacturing. Mechatronic systems are manifold and range from machine components, motion generators, and power producing machines to more complex devices, such as robotic systems and transportation vehicles. With its twenty chapters, which collect contributions from many researchers worldwide, this book provides an excellent survey of recent work in the field of mechatronics with applications in various fields, like robotics, medical and assistive technology, human-machine interaction, unmanned vehicles, manufacturing, and education. We would like to thank all the authors who have invested a great deal of time to write such interesting chapters, which we are sure will be valuable to the readers. Chapters 1 to 6 deal with applications of mechatronics for the development of robotic systems. Medical and assistive technologies and human-machine interaction systems are the topic of chapters 7 to 13. Chapters 14 and 15 concern mechatronic systems for autonomous vehicles. Chapters 16-19 deal with mechatronics in manufacturing contexts. Chapter 20 concludes the book, describing a method for the installation of mechatronics education in schools.

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