

Interpedicular Screw Placement Image Guided Navigation Surgery Simulator.

M.C Jose Ruben Huerta Osnaya
Ingenieria Electrica, Sección Bioelectronica
CINVESTAV-IPN
Ciudad de México. México
joser.huertao@cinvestav.mx

Abstract-Image guided surgery it's one of the most useful tools to perform precise procedures that otherwise would be impossible, and therefore the need of a risk free training method is one of the most imperative needs in the field of medicine, this project has the goal to develop a prototype for a spine interpedicular screw placement surgery training simulator, achieving both the effective practice to deliver the dexterity needed, along with the safety of avoiding ionizing radiation risks.

Two high definition webcams were used to digitize passive markers on the surgical tools in a MATLAB processing algorithm to recreate 3 bidimensional perspectives reading their spatial position and orientation, on each one insertion depth and angle is calculated. Then through MATLAB's user interface generator the information is displayed to the user, both in graphical and numerical form. Laboratory proof of concept test sets were run in order to prove the precision, accuracy and reliability.

The system was tested, both section by section and as whole prototype, in both cases the results were satisfactory. Section by section achieving the specific purpose, and as a whole prototype being able to successfully identify the used tool, it's spatial position, depth and angle of the insertion, and showing the information on the users interface by graphic and numeric display.

The interpedicular screw placement training system developed, successfully digitized the tool's position and orientation relative to the vertebra, displaying a 3 perspective bidimensional graphic representation of both, along with the insertion depth and angle, and identifying the tool's name. In the aftermath the trajectory of the tool's point is tracked on every perspective, along with a tridimensional recreation of such. Since only laboratory proofs were done, the prototype is yet to be validated as an effective training system, however the proof of concept test shows the efficiency and accuracy to be acceptable.

Keywords—Spine surgery, Surgery simulator, Lumbar surgery, Image guided surgery, Spine training simulator

I. INTRODUCTION

Radiography and tomography image guided surgery are used for clinical procedures that otherwise would be too difficult, have catastrophic consequences, or directly impossible to perform [1]. And even when this kind of surgery has their own problems and complications, a common denominator is the high exposure to ionizing radiation, every time an image of the body is obtained, everyone in the room is bombarded with a high energy electromagnetic radiation dose, ionizing radiation [2].

For the patient this risks are often eclipsed by the need of the procedure itself, however it's different for the medical staff, since they not only don't need the procedure, but also will perform more than one surgery along their life, or even within a single year [3].

Then the risks for exposure to ionizing radiation it's a major risk. This can be lowered by lowering the amount of radiation they are exposed to, which can be achieved when they practice to the point of completing the procedure with the minimal amount of shoots taken, and the less time possible. Therefore the practice, more specifically the safe practice becomes a priority to this research [4].

There are plenty of simulators and medical training systems, and all of them prove to be helpful in the development of the required skills, however there is a breach that can't be solved. The act of simulating or controlling the parameters itself, forces the situation to be different from the reality, therefore creates gaps between the practice and the live experience [5]. The most useful practice would be the most realistic, that is performing the surgery itself, or using a dead body corpse to reduce the risk of damaging a patient.

However in this type of surgeries the use of ionizing radiation to obtain the images, makes this just as risk full as the real surgery [6]. We enter in a vicious cycle where we need to practice to avoid risk, but the practice it's a risk itself. And knowing that the more we simulate the less effective the practice is. And the more realistic the practice is less we can control and track progress. Most of the simulators often wave between this two sides, some of them make the situation to real but with no practice tracking or evaluation, while others go for the most controlled or monitored parameters but losing realism in the practice [7].

The present work tries to approach specific parameters to track, and specific aspects to keep as real as possible. Focusing on training the transition from binocular tridimensional sight, to navigation guided by three perspective monocular bidimensional sight and hand dexterity to maneuver specific tools used in the operation room. While keeping the realism using vertebrae replications and real surgery tools, making a safe practice through the use of web-cams for tool tracking to replicate the tomography equipment and a computer to show all the information. All the registered depths and angles through the entire practice are reported at the end.

II. MATERIALS AND METHODS

A. Physical structure

The prototype is described as a box with a Lumbar model (Lumbar spinal column model: MS/SK1_109) including the

coccyx, intervertebral discs, sacrum with flap, spinal dura matter and lumbar vertebrae 1-5, replacing L3 showed in Fig. 1a, with a disposable PLA model to perform the procedure of drilling a hole, measuring depth and angle see Fig. 1b.

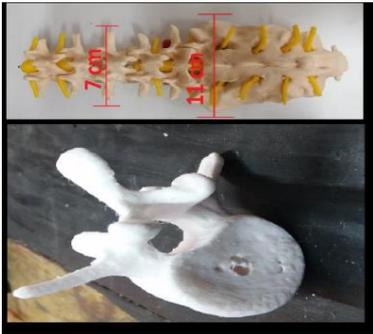


Fig. 1. a) Right side, lumbar model b) left side, PLA vertebra replication

This vertebra was selected because it's the closest to the center of the training box area, since the process is rather the same for any, this will help us to avoid collisions without excluding any practice, the 3d model was obtained from *artec3D* an online free use gallery. Two fixed web cams on the sides captures and digitize the position and orientation of the tool as showed in Fig. 2a. While software developed in MATLAB (MathWorkss, Natick, Massachusetts, USA) calculates the angles in two perspectives and general depth, identify the tool, and show this info in a virtual interface see Fig. 2b.

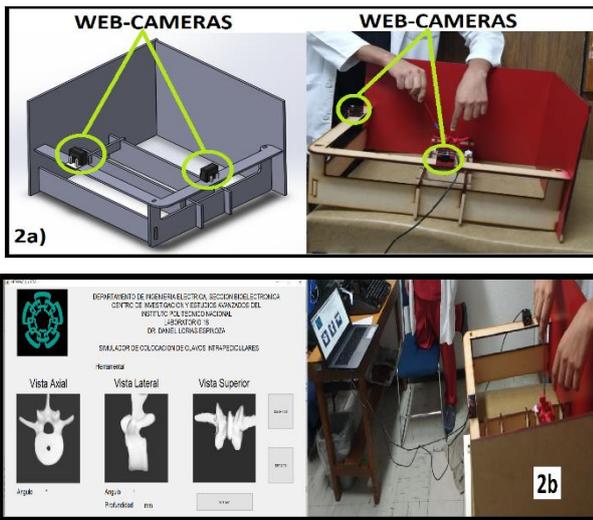


Fig. 2. a) Training box design with 1=lumbar model place and 2=fixed cameras b) left side, PLA vertebra replication

Along with three perspective vertebrae sample showing the position and orientation of the tool (two obtained from the cameras and third one generated with the data). When practice is finished, the interface saves an excel file with the angle and depth measured on every shot, and four graphics representing the trajectory followed by the tip of the tool, one for each perspective and a tridimensional perspective, rebuilt from the gathered data.

B. Image acquisition and data procesing

The images are acquired through pair of megapixel web cams from "L&T" model PC001-zoom webcam, with a 2.7MP Megapixel-CMOS type sensor, reaching resolution of

1920*1080 at 30 FPS, this were placed in a custom made housing to avoid orientation calibration problems [8].

Through the USB port, MATLAB acquires the image and executes the developed algorithm, this algorithm consist in two stages the image conditioning and the math for the metrics, image conditioning consist of two color elimination filters that aided with the background screens identify the blue markers placed on the tool, followed by a three stage filter reaching a binary image [9] with the perspective spatial position of the mentioned markers a comparison is made on Fig. 3.



Fig. 3. Image acquired (left) vs image proceded (right)

Reading the Cartesian coordinates on the image calculates the angle, and the relative depth to the vertebrae's edge, also knowing the distance between the markers the computer is able to identify the tool. The final objective is to use the coordinate's information to recreate a graph over a perspective vertebra sample that accurately represents the position and orientation of the tool [10], [11] example observed in Fig. 4.

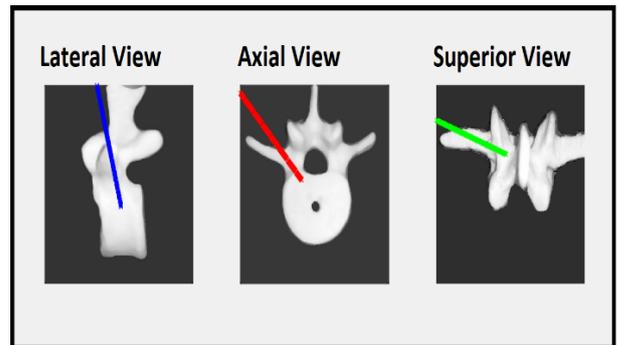


Fig. 4. Three perspective position and orientation graphs

III. DELIMITATIONS IN FUNCTIONALITY AND PARAMETERS EVALUATED

As mentioned in the introduction, the reach of the simulator must be defined, regards on how realistic practice can be and how much can be controlled and monitored in order to design an appropriate practice methodology. The simulator provides through the interface, three images showing three different perspectives of the same vertebra, this will be axial, lateral and superior (front, side and above), as well with the general depth and the angle observed in axial, and lateral views.

This provides a good training in the transition of tridimensional visual feedback, to bidimensional perspective views feedback, as well using the real tools helps in the development of the hand dexterity needed for the process [12].

On the other hand, having only two cameras for the image acquisition, means we won't have depth perception in either view, forcing the work to be done on only one vertebra at the time and on one side of the same [13]. As well the use of visual markers means that if we pretend to track the surgical nail, it will be impossible once it's inside the vertebra, along with the lack of anything simulating the muscular tissue or the skin, limits the practice exclusively to the procedure of drilling the bone and measuring the hole using the perspective image assisted navigation system.

IV. CONCEPTUAL PROOFS AND PROTOTYPE TESTING

Two mayor type of conceptual proofs were applied, the first one was the color elimination/highlighting, eliminating different wavelengths of light from the obtained image, it was showed that eliminating red color was the most effective combination, since this eliminates other colors and highlights blue, therefore background screens and tools were painted red, and markers blue, visualization on Fig. 5.

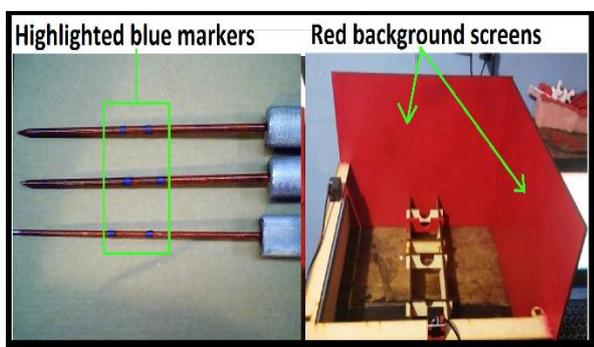


Fig. 5. Highlighted blue markers on the tools (left), red background visual noise canceling screens (right)

Second proof of concept was the filtering and conditioning of the images, through digital filters markers pixel's intensity is risen and the rest is lowered, leaving a binary image with two smooth circles see Fig. 3.

As for the whole prototype testing three protocols were applied, ensuring the functionality of every part. First the binarization test, where we only focused on replicating the image processing to obtain the binary image where the information is gathered. Second testing if the prototype can accurately and constantly measure the angle and the depth, for this the tool was attached to a robotic arm, which hold it fixed in known angle and depths, comparing the real with the prototype measured one, also testing in the process if the interface showed the graphics representing the position and orientation of the tool over the vertebrae sample. And third was proof the whole system function as if it was the final user.

For every proof sessions of 100 tests were made through the course of 5 to 10 days leaving us with around 500-1000 results. In this stage of development performance testing is yet to be made, but considering the advance made and the results observed, the odds are promising.

V. RESULTS

A. Performance, precision and accuracy

At the end of testing stage efficiency was proven to be around 95% after five sessions done in a loop cycle results on Table 1.

TABLE I. PROTOTYPE EFFICIENCY.

Interface		
Session	OK	N/A
1	94	6
2	98	2
3	96	4
4	92	8
5	96	4
Total	95%	5%

The prototype showed average depth error of 7.8 mm with of 2.9° average error in angle measurement look Table 2. For depth error we use an offset adjustment to make it more accurate leaving us a precision and accuracy of 2mm, while the angle error behavior was not fit to adjust, however since the precision is 6° and accuracy 3° the parameters were accepted [14].

TABLE II. ERROR IN DEPTH AND ANGLE.

Depth			Interface		
Real	Measure	Error	Real	Measure	Error
30	23	7	30	33	3
25	17	8	30	27.04	2.96
20	11	9	30	27.2	2.8
15	7	8	30	32.9	2.9
10	2	8	30	32.93	2.93
5	-2	7	30	27.09	2.91

The interface shows the graphs previously addressed as well with the metrics for each shot, and at the end of the practice the tracking of the trajectory is deployed in 3-perspective graphs, with a tridimensional recreation as showed in Fig. 6. Excel file with the recorded metrics is saved to the root file of the simulator.

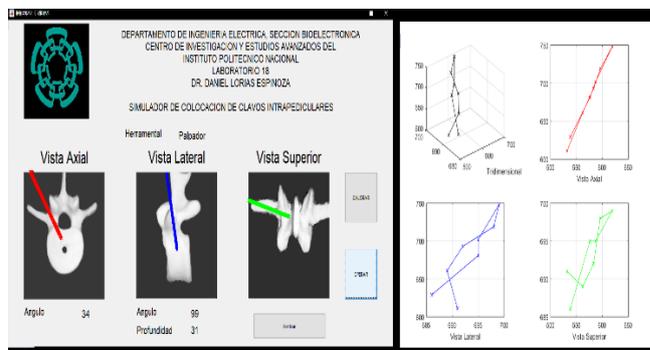


Fig. 6. Interface with graphs and metrics (left), trajectory graphs

B. Advantages and disadvantages of the prototype

Far beyond the safe and acceptable accurate practice which was the primary objective of this work. Using passive motion tracking, light materials and daily using computer as work terminal, keep the cost of the project to the minimum and its portability to the maximum. The double color elimination filter plus the triple noise filter, along with the background screens gives the prototype a strong and reliable signal processing core. The use of quirurgical tools with anatomically accurate vertebrae help with the immersion to the surgery process [15].

Finally the measurement of the parameters involved in the procedure will help track the progress of the skill development in the trainees.

Speaking of the disadvantages, the strong processing algorithm reduces the scanning frequency giving us a maximum of 8 seconds in between shots and a minimum of 6 seconds, also depending of passive motion tracking forces to rely on the visibility of the cameras which can be either blocked or disrupted by light sources, even when the prototype prove to work in different light conditions this turn out to be hard to compensate. Finally since the users test protocol is yet to be done, the definition and calibration of a material resembling the different densities of the bone lacks of accuracy along with the surgical training methodology that will be followed, as for now there was no specific surgical technique used on any of the test.

VI. DISCUSSION

The primary goal was to help the surgery staff to practice in a safe way, focusing in the transition of real sight to the image guided navigation, and deliver metrics that could be used in an objective evaluation of their progress. A narrow down process to a single activity makes possible to have the most of both sides, making it as much realistic as possible while we keep some control and monitoring of the movements.

Reaching to a portable surgery simulator, based on passive motion tracking using two Megapixel web-cams as image sensors, reporting accuracy of 2mm and 6° and 95% efficiency, with real surgery tools and anatomically accurate spine recreation. This makes it a good option to perform a further study where the learning curve is taken in consideration, testing the development and efficiency of the practice, far beyond the technical aspects of the prototype.

The software developed was exported to a portable application, which can be installed in any computer with the following parameters: 4 GB of RAM, 1 GB storage space, two USB ports.

The prototype specifications as a training device are the following:

- Computer using portable training box, with real surgery tools.

- USB connection.
- Three views¹, shot by shot virtual tool positioning graphic representation.
- Two views² angle measurement.
- General drilling depth measurement.
- Tool identification.
- 6-8 seconds delay between shots.
- Three views plus 3-d recreation, trajectory tracking graphs.
- Full practice recorded metrics.

VII. CONCLUSION AND FURTHER WORK

The need of realistic yet measurable practice in medical training is a priority along with the safety. This project tries to narrow down what we could evaluate and what we could make realistic to reach a middle point.

It was made a comparison with other training systems in market, in the following table there is a list of the parameter we focus to compare, even though some comparisons are subjective or merely convenience, such as the fact of being a portable device considered better than a fixed workstation, the results seemed match or even out pass such devices. Then we conclude this work made merits for further research and development.

From this point the next step is starting validation as a training system to proof such efficiency not in the technical side but in the academic aspects.

However technical improvement is always in order, for this prototype the including of a bone resembling material jumps to the top of the list. The implementation of new metrics would be the second, measuring the time of the practice and the time between shots would help to objectively evaluate the surgical performance.

As well a full spine instrumentation would be desired, however this last point needs redundant cameras and or a different motion tracking technology since the need of depth perception in both views is needed, this comes hand to hand with the tracking of the nails that disappear from camera view, when they enter the vertebra.

TABLE III. COMPARISON WITH OTHER TRAINING SYSTEMS

Prototype	Physical feedback	Visual feedback	Data Acquisition	Evaluation	Portability	Showed Metrics	Measured variables
“Mixed reality situation of rasping procedure in artificial disc replacement (ACDR) surgery” [16].	Haptic interface Bony models	Immersive virtual reality	Redundantly visual, Haptic interface.	Subjective.	Fixed workstation	Vertebra and tool position (VR 3D), Tool displacement, Surgery progress.	Applied force, Tool position, Tool displacement, vertebrae position and attrition.
“Development of a low-cost endoscopic box trainer for percutaneous lumbar disectomy” [17].	Bony models	Medical equipment simulation	Passive visual	Recorded Metrics.	Portable box and personal computer.	Surgery time, Traveled distance, Surgery Speed, Tool position (graphic), Tool angle (number), Reached depth (number).	Tool angle, position, displacement, surgery time.

“Designing NeurosimVR: a stereoscopic virtual reality spine surgery simulator [18].	Computer simulation/Haptic interface	Immersive virtual reality	No acquisition simulation	None	Fixed workstation	Surgery time, Traveled distance, Surgery speed	None
“A new virtual reality based environment for surgical training” [19].	Computer simulation	Screen virtual reality	No acquisition simulation	Subjective	Desk computer	Surgery time, Real time tool position (VS 3D), Surgery progress	Physical movements directly observed in the simulation.
“Virtual surgery simulation versus traditional approaches in training of residents in cervical pedicle screw placement” [7].	Haptic Interface	Screen virtual reality	Haptic interface	Subjective	Portable interface and personal computer	Column and tool position (VR 3D), Tool angle, Reached depth	Tool angle and position, applied force.
“Improved spine surgery and invention with virtual training and augmented reality” [20].	Haptic interface/ Bony models	Screen augmented reality	Passive visual / Haptic interface	Recorded Metrics / Subjective	Portable models, personal computer and tablet	Cuts precision, Followed path	Tool position and displacement.
“A force feedback pedicle screw implantation surgical trainer with automatic vertebra segmentation” [21].	Haptic Interface	Screen virtual reality	CT images/ Haptic Interface	Recorded Metrics	Portable interface and personal computer	Cutting coefficient (images), Applied force, Tool displacement and trajectory	Tool speed and acceleration.
“Elaboración de un simulador tridimensional para la práctica de cirugía abierta y artroscópica de la columna vertebral” [22].	Bony models	Direct vision	No acquisition	Subjective	Portable models	None	None
“Design of a training System for interpedicular screw positioning in the lumbar region” [23].	None	Medical equipment simulation	Passive visual	Recorded Metrics	Portable box and personal computer	Reached depth, Tool angle, Tool position (graphic), Surgery tool	Tool position and displacement, surgery time,
Our project	Bony models (Pending to characterize)	Medical equipment simulation Bony models	Passive visual	Recorded Metrics Subjective (Pending to validate)	Portable box and personal computer.	Tool position (graphic), Tool identification, Tool angle (number, 2 perspective), Reached depth, Followed path (3 perspective plus 3d reconstruction)	Tool position and angle, tool identification, tool displacement.

REFERENCES

- [1] Mark, B. Kabins, J. (2011). “The history of vertebral screw and pedicle screw fixation” *The Iowa Orthopedic Journal*. pp. 127-136.
- [2] Daniel S. Mulconrey, M. (2016). “Fluoroscopic Radiation Exposure in Spinal Surgery” *Clinical Spine Surg*. pp.331-335.
- [3] Daniel Cushman, R.M. (2016). “The effect of body mass index in fluoroscopic time and radiation dose during lumbar transforaminal epidural steroid injections” *The Spine Journal*. pp.876-883.
- [4] Oliver, P. Gautschi, B.S. (2011) “Clinically relevant complications related to pedicle screw placement in thoracolumbar surgery and their management: a literature review of 35,630 pedicle screws.” *Neurosurg focus*.
- [5] Michael, P. Milac, L. Philip S. Patrick, W. Matthias W. (2017). “Virtual Reality-based simulators for spine surgery: a systematic review” *Elsevier the spine journal*.
- [6] Jeremy, K.T. Kam, C. (2019). “Learning curve for robot-assisted percutaneous pedicle screw placement in thoracolumbar surgery” *Asian Spine Journal*. pp.920-928.
- [7] Yang Hou, Jiangang Shi, Yanping Lin, Huajiang Chen, Wen Yuan. (2018). “Virtual Surgery Simulation Versus Traditional Approaches in Training of Residents in Cervical Pedicle Screw Placement” *Orthopedic and Trauma Surgery Archive*.
- [8] Martel. G.J. (2011). “Que es un sensor de imagen, VGA vs Megapixel” *Magazin Digital-Online Media*. pp 27-39.
- [9] Dougherty, G. (2009) *Digital Image Processing for Medical Applications*. New York: Cambridge University Press.
- [10] Flores, J. M. (2013). *Analisis y procesamiento de imagenes*. CDMX: CADET UNAM.
- [11] Vilet, J.R. (2005). *Procesamiento Digital de Imágenes*. San Luis Potosi: UASLP print.
- [12] Jaime Jesus Martinez-Anda, “Uso de simuladores para entrenamiento en neurocirugía; Cambio en el paradigma de entrenamiento quirúrgico” *Anuales Medicos Centro Medico ABC*. Pp.106-113.
- [13] Moses, ZB. M.R. (2013) “Neuronavigation in minimally invasive spine surgery” *Neurosurg Focus*. pp. 35-42.
- [14] Eldin, M.M. (2014). “Cervical pedicle screw fixation: Anatomic Feasibility of pedicle morphology and radiologic evaluation of the anatomical measurements” *Asian Spine Journal*. pp.273-280.
- [15] Hamid Abboudi, M.S (2012). “Current status of validation for robotic surgery simulators-a systematic review”. *BJU international*. pp.294-305.
- [16] Tansel, H. Sinah, K. Coskun, B. Richard, R (2010). “Mixed reality simulation of rasping procedure in artificial cervical disc replacement (ACDR) surgery” *BMC Bioinformatics*, 11(Supl 6): S11.
- [17] Paul Pagem, N. James Liu, P. (2020). “Development of a low-cost endoscopic box trainer for percutaneous endoscopic lumbar disectomy” *CNS ACCEPTED ABSTRACTS AND PAPERS*. pp.238-245. In press.
- [18] Ahmed E. Mostafa, Won Hyung A. Ryu, Sonny Chan, Kazuki Takashima, Gail Kopp, Mario Sousa, Ehud Sharling (2017).

- “Designing NeuroSim VR: A Stereoscopic Virtual Spine Surgery Simulator” *Calgary Tohoku University*. Daniel S. Mulconrey, M. (2016). “Fluoroscopic Radiation Exposure in Spinal Surgery” *Clinical Spine Surg.* pp.331-335.
- [19] Sanchez-Gonzalez, I. Opresa, M. Davis, M. Rodriguez, D. Camba, E.J. Gomez. (2018). “A new virtual reality based environment for surgical training” *Grupo de bioingenieria y telemedicina*.
- [20] Kellerman, K. Salah, Z. Monch, J. Franke, J. Rose, G. Preim, B. (2011). “Improved spine surgery and inventionation with virtual training and augmented reality” *International Workshop on Digital Engineering*. pp. 8-15.
- [21] You-Ren Chen, C. -P. K. (2016). “A force feedback pedical screw implantation surgical trainer with automatic vertebrae segmentation” *International Conference on Intelligent Systems and Image Processing*. pp. 249-299.
- [22] Zepeda, A. (2018). “Elaboracion de un simulador tridimensional para la practica de cirugia abierta y artroscopica de la columna vertebral” *Universidad Nacional de Colombia, Facultad de Medicina, Departamento de cirugia*.
- [23] Nataly, A. Garcia, D.L. (2014) “Design of a training system for intrapedicular screw positioning in the lumbar region” *Recent Advances in Biomedical & Chemical Engineering and Materials Science*. pp.46-50.
- [24] Cossete, M. Stall, Q.C. (2016). “Vascular and interventional Radiology Review”. *AJR focus on*, pp. 737-744.
- [25] Wainschenker, R. (2011). “Procesamiento Digital de Imágenes (guia de curso, dentro del programa de Procesamiento de señales)”, *UPV-online library*.
- [26] M. Young. *The TechnicalWriter’s Handbook*, Mill Valley, CA: University Science, 1989.
- [27] Daniel Lorias Esponzoa, V. G.-P. (2016). "A low cost, Passive navigation training System for image guided spinal intervention." *World Federation of Neurosurgical Societies*, 323-328.