

SAILOR: a 3-D medical simulator of loco-regional anaesthesia based on desktop virtual reality and pseudo-haptic feedback

Lazar Bibin*
Université Paris Descartes

Anatole Lécuyer†
INRIA Rennes

Jean-Marie Burkhardt‡
Université Paris Descartes
Madeleine Bonnet¶
Université Paris Descartes

Alain Delbos§
Clinique du Cours Dillon (Toulouse)

Abstract

Anaesthesia is a medical act which eliminates the feeling of pain as well as the motor reactions of a person, before performing a surgical operation. Loco-Regional Anaesthesia (LRA) concerns only a part of the body such as the front arm or leg. This practice is increasingly used today notably because the patient can remain conscious and can recover more rapidly. However, LRA still remains a risky procedure. In this paper, we introduce a novel medical simulator called SAILOR for the training for LRA with neurostimulation. SAILOR is based on desktop virtual reality, realistic 3-D rendering and interactive techniques with a classical mouse and keyboard. It simulates the various biological phenomena which can occur during an anaesthesia procedure. We also introduce a novel pseudo-haptic effect to enhance the palpation of the virtual patient's body and feel the inner organs. The first feedback from users of the commercialized DVD version of SAILOR as well as the results of pilot tests suggest that this simulator is a very promising tool for education and training for LRA.

CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information SystemsArtificial, augmented, and virtual realities— [H.5.2]: Information Interfaces and Presentation— User InterfacesInteraction styles, User-centered design K.3.2 [Computers and Education]: Computer and Information Science Education—;

Keywords: medical simulator, loco-regional anaesthesia, interactive technique, desktop virtual reality, pseudo-haptic

1 Introduction

Historically, doctors learnt or were trained in new procedures through observation, practice on animals or corpses or by assisting another doctor. Nowadays, with computer science progress, young doctors can train on virtual models, in a virtual environment or on hardware simulators (mannequins) coupled with virtual devices.

*e-mail: bibin@math-info.univ-paris5.fr

†e-mail: anatole.lecuyer@irisa.fr

‡e-mail: jean-marie.burkhardt@univ-paris5.fr

§e-mail: alaindelbos@wanadoo.fr

¶e-mail: bonnet@math-info.univ-paris5.fr

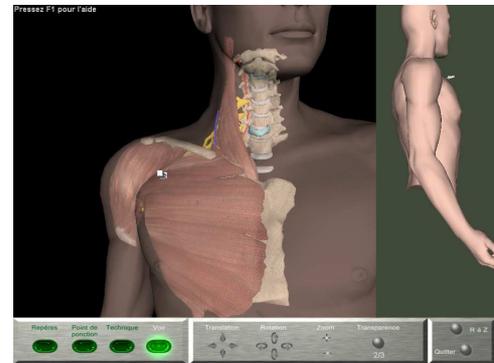


Figure 1: View of the loco-regional anaesthesia simulator

The history of anaesthesia simulators is retraced in [Rall and Gaba 2005]. Simulation in anaesthesia has existed for about forty years. [Abrahamson 1969] describes in details the first anaesthesia simulator: *Sim One*. Nowadays there are more evolved simulator like the *PatSim* [Rettedal et al. 1996] or the *SimMan*¹ [Hesselfeldt et al. 2005], used to simulate the intubation during a general anaesthesia. But these simulators are expensive and voluminous.

In this paper we introduce the first virtual reality simulator for loco-regional anaesthesia (LRA) with neurostimulation (Figure 1). The simulator has been created with an educational purpose to allow training in various cases.

Our objective is to develop a realistic, interactive simulator that reproduces an LRA with fidelity. It must be portable, inexpensive, user-friendly, in order that most people can train with it. That is why our simulator only requires a personal computer equipped with standard mouse and keyboard. The simulator renders the virtual patient on the screen with which the user can interact using the classical mouse.

2 Loco-regional anaesthesia

Anaesthesia is an act which eliminates the feeling of pain as well as the motor reflexes of a person. Anaesthesia can focus on a small part of the body (local anaesthesia), on a region like the arm or the leg (regional anaesthesia), or on the whole organism (general anaesthesia).

Loco-regional anaesthesia is induced by injecting an anaesthetic close to the nerve or group of nerves which serve the purposeful territory. The main difficulty is to approach the nerve with the needle without harming the nerve or the adjacent organs. Loco-regional anaesthesia is therefore not without risk and requires skill and concentration.

A loco-regional anaesthesia consists in three stages:

¹www.laerdal.com/simman/

- the search for the landmarks where anaesthetist palpates the patient body in order to find the organs that allow to determine the puncture site and draws the landmarks with a marker pen directly on the skin;
- the placing of the puncture site and the choice of the needle. Depending on the patient corpulence and the nerve to be anaesthetized, the needle length can vary from 25 mm to 150 mm;
- the nerve research with the needle called "technique", in order to inject the anaesthetic without damaging the nerve nor the adjacent tissues.

To anaesthetize efficiently and minimize the risks, the choice of the puncture site is primordial. With anatomic studies, anaesthetists have developed several methods allowing to determine a suitable puncture site according to the part of the body to be anaesthetized.

To search the nerve, the anaesthetist uses a stimulator: a needle at the end of which a discontinuous electric current circulates. When the end of the needle is close to the nerve, it is stimulated by the electric current which induces a motor response: the contraction of the muscles served by the stimulated nerve. This action is called neurostimulation. Each nerve has its own motor response. Thus, when the anaesthetist looks at the response, s/he can tell where the needle is. When the intensity is equal to 0.5 mA and when the appropriate stimulation is obtained, the needle is close enough to the nerve, the anaesthetic can be injected. Figures 2 and 3 show a loco-regional anaesthesia with neurostimulation of the femoral nerve.



Figure 2: *Loco-regional anaesthesia with neurostimulation*

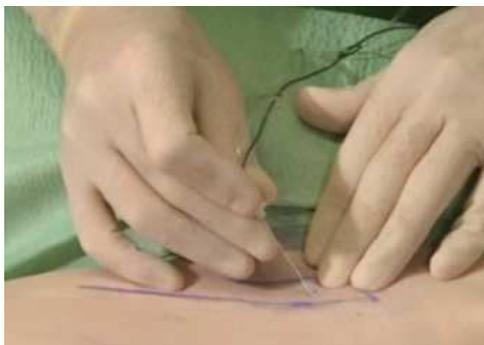


Figure 3: *Needle insertion in the puncture site (femoral nerve)*

3 Presentation of SAILOR

SAILOR (Simulator of Anaesthesia for Loco-Regional procedure) is a simulator for the LRA based on desktop virtual reality for training and education of medical students and doctors.

The objective of SAILOR is to create a realistic, inexpensive, portable and interactive simulator using a simple computer.

The simulator displays a virtual patient and his 3-D organs. It provides various tools in order to simulate an LRA and interacts with the user simulating biological phenomena. It includes a pseudo-haptic feedback to improve the sensations of the user during the palpation step.

3.1 Graphical models

In order to create the simulator, we need a virtual three-dimensional patient with all the organs playing a role in anaesthesia: bones, muscles, vessels and of course nerves.

To have a real anatomy, we choose to use the 3-D organs provided by *Visible Human Project* [Ackerman 1998]. We apply textures onto the meshes to render them with more realism. Due to the cryogenization, some organs are distorted so we reshape them. Other organs are missing because of their thinness so we create them. To keep a realistic anatomy, we follow the anatomical description and rules given by [Rouvière and Delmas 1997] and [Netter 2006].

To create the skin of our virtual patient, we use the software *Poser*², which allows to create 3-D characters, to position them in any posture and to make animation movement (like a motor response).

3.2 Performance

As a result we could propose and simulate 14 different anatomical blocks, i.e., 14 different types of anaesthesia with 14 different areas of the body with different nerves or groups of nerves. However, the 3-D organs given by the *Visible Human Project* are still very complex. To increase performances, we optimized the meshes by reducing their number of points and triangles without impairing the general shape and aspect of the 3-D organs. Moreover, we only load the organs or the organ parts implied in the selected nerve anaesthesia. As a result, the simulator's minimal requirements are 512 Mb of RAM (with Windows XP), a 1 GHz processor and a graphic card (Geforce 2 or equivalent). With this configuration we obtain more than 24 frames per second.

4 Interactive simulation of the LRA

4.1 Visual display

The visual display of the simulator is divided into three parts:

- the main screen where a close up of the patient body is displayed in order to have a good view of the needle movements;
- the secondary screen where a long shot of the patient body is displayed in order to see the different motor responses;
- the control panel displaying buttons, different options and menus.

Figure 4 shows the different parts of the visual display and the graphical user interface of SAILOR. We have implemented a contextual graphical user interface. The user can move from one stage

²<http://graphics.smithmicro.com/>

to another by clicking the corresponding button. According to the current stage, the simulator provides different controls.

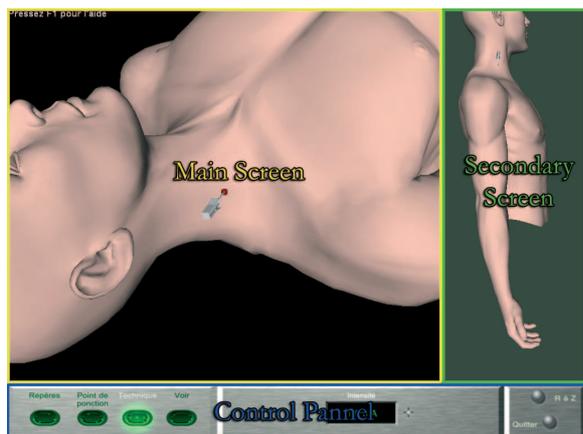


Figure 4: The different parts of the simulator

4.2 Interactive manipulation

Palpation

To simulate organ detection, the user moves over the body with the mouse. When the mouse cursor is brought over a palpable organ, its name is rendered. To determine the organ which is under the mouse, a ray is projected from the 2-D position of the cursor into the 3-D scene. The first organ encountered by the ray is considered as the palpated organ.

3-D Drawing

The simulator provides a tool to draw 3-D lines and curves on the virtual body skin. The user left-clicks on the body then moves the mouse and releases the button to draw lines or curves. To create the 3-D lines, we first create 2-D lines in accordance with the 2-D cursor positions. Then, we project rays from each pixel of the 2-D line onto the body. We obtain a list of 3-D points which, once connected, give the 3-D lines that fit the body (Figure 5).

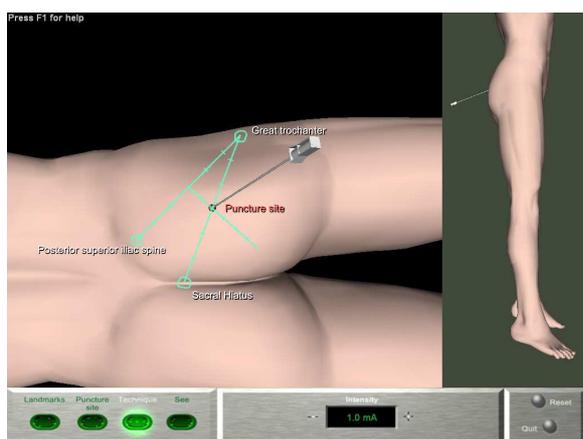


Figure 5: Landmarks and puncture site of a sciatic block

Puncture site placement

To place the puncture site, the user clicks on the body at the desired site (Figure 5). In order to prevent the user from making a

nonsensical gesture, a delimited area, corresponding to each nerve that can be anaesthetized, is defined.

Needle manipulation : the "Technique"

It concerns the simulation of the needle's movements inside the patient body in order to get a motor response.

To rotate the needle, the user maintains the right mouse button pressed then moves the mouse. To drive the needle into the body (respectively redraw), s/he maintains the left mouse button pressed then moves the mouse upwards (respectively downwards).

Of course, the needle's movements must be limited: the needle cannot penetrate the bones and the needle-shield cannot enter the body. Moreover, the deeper the needle, the smaller is its rotation angle. To restrain the rotation angle, a maximal angle is computed according to the distance covered by the needle.

Biological events simulation

During an LRA, the simulator can detect several biological events : (1) a paresthesia, when a nerve is punctured with the needle, that can lead to a paralysis ; (2) a bone contact, when the needle is stopped by a bone ; (3) a pneumothorax, when the lung is perforated (in this case, the operation must be stopped immediately to make a thoracic drainage); and (4) a vessel puncture, when some blood is drawn by the needle. Each time one of these events occurs, the simulator informs the user instantly using visual displays(text messages, color changes, etc).

5 Pseudo-haptic feedback

One of the simulators' weaknesses, in comparison with a real anaesthesia, is that users cannot palpate the body rendered on the screen. This can be frustrating for the anaesthetist who is used to touching the patient body. In a first version of SAILOR, the organs' names were rendered when they are flown over by the mouse. This allowed the user to easily find the landmarks but did not give a clear idea of the organs' shape and relief. Thus, in a more evolved version of SAILOR, we propose to enhance the manipulation sensation of the user when palpating the body of the virtual patient by using a pseudo-haptic effect.

The aim of pseudo-haptic textures [Lécuyer et al. 2004] is to give the ability to feel the relief of a picture only using an input device (such as a mouse) and visual feedback. To do so, the system must know the picture's relief, which means the depth of each pixel. Then, when the mouse moves from one pixel to another which is higher, the mouse's movement is decelerated. This gives the user the impression that the movement is harder (ascent effect). In the reverse case, when the mouse moves from one pixel to another which is lower, the mouse movement is accelerated. This gives the user the impression that the movement is easier (descent effect). Thus, the user has the impression of a haptic feedback allowing to interpret the picture's relief. For example, on the picture of a face, one can feel the nose relief or the eyes' cavity. This work has been carried out mainly for 2-D pictures [Lécuyer et al. 2004]. It was recently extended to another component of the interaction, by playing also with the size of the cursor (zoom-in and zoom-out effects) to reinforce the texture sensation [Lécuyer et al. 2008].

In SAILOR, using the computer mouse, the anaesthetist manipulates a spherical cursor which follows the surface of the skin of the patient in order to palp the under skin organs. The pseudo-haptic textures technique is then applied to the visual motions of the cursor to simulate the bumps and holes corresponding to the

presence of organs and arteries under the skin. With such a technique, the user is expected to explore the body of the patient more physically and realistically.

In the simulation, the patient body and the organs are 3-D objects, so we can know their depth precisely and in real-time. We can easily determine the depth of the picture pixels rendered by the simulator. Then, we use the algorithm described in [Lécuyer et al. 2004], to change the speed of the cursor as function of the height of the pixels. In addition we also modify the size of the cursor as in [Lécuyer et al. 2008] to improve the pseudo-haptic sensation. As a result both the speed and size of the cursor inform the user about the shape and location of the inner organs located under the skin and a priori invisible.

6 Experimental evaluation

6.1 Method

Thirteen medical doctors participated in this experiment. They had between 2 to 36 years of experience in anaesthesia (mean=12 ; sd=10).

First, the participants had to fill a questionnaire to collect biographical data. Then there was a learning phase during which they were trained with the simulator and explained how to manipulate the interface. It was followed by a practice trial with the "sciatic block". The experimental evaluation of the simulator began with the subjects being given the task of successively performing four different trials/blocks. The blocks were presented in different orders and in different conditions depending on the group and condition. For each trial, the participants were seated in front of the screen. They were told to perform the block and follow the first steps of the procedure, i.e., from the determination of the landmarks on the considered block (and its associated body part), to the determination and simulation of the puncture site. At the end of the four blocks, they were given a questionnaire to support their evaluation of the system usability. The session was ended by a short debriefing interview to collect more informal thoughts about the simulator and how it could evolve the most relevant way.

6.2 Results

The subjects were asked to fill the System Usability Scale questionnaire [Brooke 1996]. The questionnaire had 16 assumptions on which the subjects had to indicate their agreement by rating on a 4-item scale (0 to 3). We computed a global score of satisfaction by summing the score of all items. Globally the subjects expressed a high level of satisfaction and a good evaluation of the system usability with a mean score of 36.38/48 (sd=4.25). In other words, subjects rated most items with a score situated between agree and strongly agree (positive items) or disagree (negative items). Among all the items in the questionnaire, some subsets can be analyzed separately since they address more specific aspects of usability. Interestingly, we found that ease of use (m=2.54/3; sd :.38), learnability (m=2.62/3; sd=.65) and precision/satisfaction related to the task (m=1.71/3; sd=.45) were highly rated. This high level of satisfaction was confirmed by the spontaneous comments and verbal evaluation observed during the interviews at the end of the experiment.

Taken together, these results suggest that the simulator was rated as very usable, easy to use, and satisfying by practitioners in anaesthesia at hospital. The participants seem to be very positive and enthusiastic about the actual and future uses of SAILOR for vocational training.

7 Conclusion

In this paper, we have introduced a new medical simulator for Loco-Regional Anaesthesia procedures called SAILOR. SAILOR is based on desktop virtual technology and the interactive manipulation of 3-D realistic anatomical models. SAILOR proposes several interactive techniques for achieving the different stages of the LRA like palpation, drawing on the body, needle manipulation, etc. SAILOR simulates the various biological phenomena of the LRA like paresthesia, bone contact, vessels puncture. During the palpation stage, we introduce a novel usage of pseudo-haptic feedback to give the sensation of feeling the organs located under the skin, by playing with the size and speed of the 3-D cursor. SAILOR is included in a DVD, commercialized by the Lippincott company, for medical students and doctors. The first feedbacks from SAILOR users suggest that the simulator is a promising tool for education and training in safe conditions.

Acknowledgements

We would like to thank Pr. Denis Safran, chief of the anaesthesia and reanimation unit of the HEGP-Broussais (Paris), Dr. Chantal Lory who helped us to find participants, and Valérie Lancelle who led the tests.

References

- ABRAHAMSON, S. 1969. A computer-based patient simulator for training anesthesiologists. *Educ Technol*, 10.
- ACKERMAN, M. J. 1998. The visible human project. *Proceedings of the IEEE* 86, 504–511.
- BROOKE, J. 1996. A quick and dirty usability scale. In *Usability evaluation in industry*, P. W. Jordan, B. thomas, B. A. Weerdmeester & I. L. McClelland, 189–194.
- HESSFELDT, R., KRISTENSESN, M. S., AND RASMUSSEN, L. S. 2005. Evaluation of the airway of the simman full-scale patient simulator. *Acta Anaesthesiol Scand* 49, 1339–1345.
- LÉCUYER, A., BURKHARDT, J. M., AND ETIENNE, L. 2004. Feeling bumps and holes without a haptic interface: the perception of pseudo-haptic textures. In *Conference on Human Factors in Computing Systems*, 239–246.
- LÉCUYER, A., BURKHARDT, J. M., AND TAN, C. H. 2008. A study of the modification of the speed and size of the cursor for simulating pseudo-haptic bumps and holes. In *ACM Transactions on Applied Perception*.
- NETTER, F. H. 2006. *Atlas of Human Anatomy*. Elsevier.
- RALL, M., AND GABA, D. 2005. Patient simulators. In *Anesthesia*, Miller, Ed., 3073–3104.
- RETTEDAL, A., FREYER, S., KLEPPA, R., AND LARSEN, P. 1996. Patsim, simulator for practising anaesthesia and intensive care. *Int. J. Clinical Mon. Comp.* 13, 147–152.
- ROUVIÈRE, H., AND DELMAS, A. 1997. *Anatomie humaine descriptive, topographique et fonctionnelle*. Masson.