Fuzzy Rule-Based Evaluation for a Haptic and Stereo Simulator for Bone Marrow Harvest for Transplant

Liliane dos Santos Machado [1]
Ronei Marcos de Moraes [1,2]
Marcelo Knorich Zuffo [1]

[1] Laboratório de Sistemas Integráveis - Universidade de São Paulo
São Paulo – SP – Brazil
{liliane, ronei, mkzuffo}@lsi.usp.br

[2] Statistics Departament - Federal University of Paraiba
João Pessoa – PB – Brazil
ronei@de.ufpb.br

Abstract. Virtual Reality has been used to simulate procedures in several fields, especially those where critical tasks are involved as simulation of some invasive medical procedures. We are developing a low-cost haptic and stereo simulator for bone marrow harvest for transplant. The system includes an intelligent evaluation procedure that allows classify the trainee learning. The present paper describes the proposed system, details of its implementation and results we just obtained.

Introduction

Bone marrow transplant, despite commonly held perceptions, is not a usual surgery. Basically, the bone marrow transplant consists of an infusion of healthy cells, capable of generating identical copies of themselves and producing blood cells. This blind invasive procedure is relatively simple, but the success of the procedure will depend on the physician's dexterity, and his ability to manipulate the needle in a complex anatomical region.

This work presents a virtual reality system to simulate bone marrow harvest for transplant. Bone marrow transplant, despite commonly held perceptions, is a semi-invasive procedure that depends on the physician's dexterity, once there is no visual information of the patient body internal structure.

In this simulator we are using a haptic device and stereo view glasses to give an immersion degree satisfactory to the user trainee. To give an evaluation of the training we add to the system an intelligent evaluation tool based on fuzzy rules. This way, the expert doctor knowledge is modeled by fuzzy rules by four variables to give a classification of the procedure performed by the trainee.

Motivation

The bone marrow transplant is a relatively new medical procedure to treat recently considered incurable diseases. The first success transplant was made in 1968, and since then has been a current procedure for patients with leukemia, aplastic anemia, lymphomas, multiple myelomas, disturbs in the immunology system and in some solid tumors such as the breast cancer and ovarian cancer [Oncolink, 1999].

The process to extract the bone marrow is made through many material aspirations from the iliac crest bone marrow (sometimes it includes the sternum bone also) from the donator under general anesthesia. The procedure is a blind procedure without any visual feedback except the external view of the donor body, the physician need to feel the skin and bone layers trespassed by the needle to find the bone marrow and then start the material aspiration. From the physicians point of view the bone marrow harvest demands great ability, which will offer a better recovery to the donator and less pos-harvesting pain. Particularly on children the bone marrow harvest for transplant is critical considering that bones in this case are thin and soft, and that the patient receive a smaller degree of anesthesia. The Children's Institute of Hospital das Clínicas de São Paulo - Brazil realize on average 15 procedures every year. Currently the only training procedure available for novice doctors is training with guinea pigs, real procedure observation and further supervision by physicians in real procedures.

In the same way, it is known that expert physicians evaluate trainee learning observing the needle position, its angle when inserted in the body of the patient and how deep it is, beyond the fact the trainee extract the bone marrow (goal of the procedure). That means, the expert doctor evaluation is partially subjective. One way to model subjective knowledge is using fuzzy sets [Dubois and Prade, 1980]. In our system physicians knowledge in bone marrow harvesting is modeled by fuzzy rules by the four variables described bellow (needle position, angle, depth and bone marrow extraction) to give a classification of the procedure done by the trainee.

With our system, we intend to improve the learning for novice doctors once the dexterity necessary will be acquired through the training on a virtual reality system, which will simulate and evaluate the procedure with a force-feedback device integrated. We expect to reduce and improve the learning curve affecting donors' rehabilitation.

Intelligent Evaluation Systems

Intelligent evaluation is called the one made by an expert. In intelligent evaluation systems, the expert knowledge is stored in a knowledge database using some logic representation, generally by rules. The rules utilization control is done by an inference system. The architecture formed by the knowledge database and the inference system is called "expert system". When there is subjectivity in the knowledge database its representation can be done by fuzzy models [Zadeh, 1988], where the subjectivity is modeled by fuzzy sets.

In fuzzy expert systems the expert's knowledge about a specific task is modeled by fuzzy rules. The variables of interest are collected by a subsystem and sent to the expert system. The data provided by the variable values will be analyzed by the rules database. Each rule is related to a variable of interest and each expert can have his own conclusion about a specific fact. The several conclusions about one rule are aggregated to compose a new fact. This fact will be analyzed by the rules set providing a conclusion about the facts presented.

For the evaluation, we utilize an expert system joined to the simulator. To evaluate a trainee, the expert knowledge about the procedure is modeled by fuzzy rules. The variable values are "collected" by the haptic device and sent to the expert system to be analyzed by the rule database. The pertinent facts of a rule are joined and analyzed to provide a final classification of the trainee. We are using five types of fuzzy classifications to a trainee: *you need much more training*, *you need more training*, *you need training*, *your training is good* or *your training is excellent*, allowing identify if more training is or is not necessary.

Proposed System and Implementation

The proposed system is a semi-immersive virtual reality system [Pimentel, 1995] where the trainee and some expectators doctors (tutor and trainee) can share the same stereoscopic view of the bone marrow harvest procedure simulation [Machado, 2000]. A high end PC Pentium III 600Mhz platform with and AGP 3Dlabs Oxygen GVX1 board including a time-multiplexed Stereo Graphics Crystal Eyes shutter glasses [Stereographics, 1997] and a Phantom Desktop haptic device composes our simulator [Sensable, 1999 and Sensable, 2000]. The simulator consists in a force feedback virtual interactive model of tissue layers from the pelvis region and its hardness and texture characteristics.

Using a virtual syringe with tactile feedback (simulated by the Phantom Desktop) the user can penetrate thought the several tissue layers feeling the transitions among tissues, as well as feeling the texture associated to each layer.

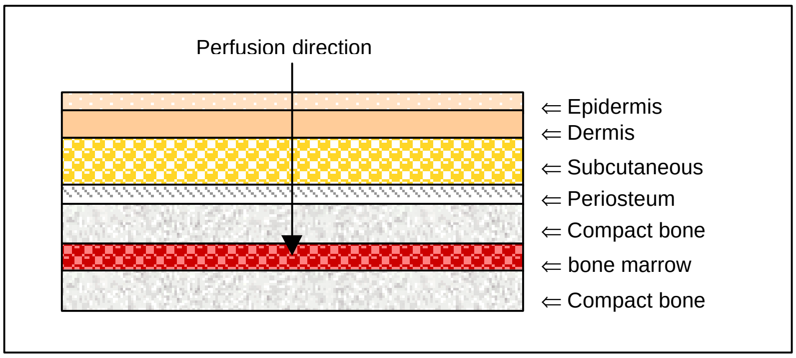

Figure 05 - The Perfusion Tissue Layers

The feedback sensation associated to each layer was modeled from tactile sensation descriptions done by specialists. So, we modeled the several physical properties of the tissues in the iliac crest in the following layers:

- Epidermis: approximately 2 mm thick, elastic and slippery tissue;
- Dermis: approximately 7 mm thick, elastic tissue;
- Subcutaneous: approximately 4 mm thick, soft and non-resistant tissue;
- Periosteum: approximately 2 mm thick, resistant, slippery, lubricated and smooth tissue.
- Compact bone: approximately 5 mm thick, hard and resistant tissue;
- Bone marrow: approximately 10 mm thick, soft tissue, without resistance.

The fuzzy rules of our expert system are modeled by membership functions according to specifications of experts. Several types of membership functions can be used as trapezoidal, triangular and pi-functions and the fuzzy inference system used is Mamdani-type [Mamdani, 1975]. An example of rule for this expert system is:

IF Position_x is *left_center* AND Position_y is *up_center* AND Position_needle is *acceptable* AND Marrow_harvest is *yes* THEN Trainee_class is *you_need_training*

where: Position_x, Position_y are coordinates which the needle touch the patient body; Position_needle is the angle of needle input to body of patient; Marrow_harvest shows the success or failure of trainee to harvest bone marrow and Trainee_class is the classification of trainee.

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