# A FUZZY BAYES EVALUATOR FOR ON-LINE TRAINING EVALUATION BASED ON VIRTUAL REALITY

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***Abstract*** *— Virtual reality systems for training provide significant benefits over other methods, mainly in critical procedures. The evaluation of simulations is necessary to assess the training quality and provide some feedback about the user performance. An on-line evaluator for training in simulators based on virtual reality must have a low complexity algorithm to do not compromise the performance of the simulator. Several approaches to perform on-line or off-line evaluation for training simulators based on virtual reality have been proposed. We propose a new approach to on-line evaluation using a Fuzzy Bayes evaluator for modeling and classification of simulation in pre-defined classes of training. This method allows the use of continuous variables without lost of information. So, it solves the problem of low complexity in on-line evaluators without compromise performance of the simulator.*

*Index Terms — Online Training Evaluation, Fuzzy Bayes Evaluator, Virtual Reality.*

## INTRODUCTION

With the technological progress several kinds of training are already executed in virtual reality simulators [2]. There are many purposes for virtual reality systems, but a very important one is the simulation of procedures for training. Virtual reality systems for training provide significant benefits over other methods, mainly in critical procedures. One example of training based on VR systems is the flight simulators used for the pilots' training in the civil aviation [25]. In medicine, the use of virtual reality systems for training is beneficial in cases where a mistake could result in physical or emotional impact on patients. Systems for different modalities in medicine have been developed, as training in laparoscopy [28], prostate examination [1], ocular surgery [12] and bone marrow harvest [5].

In several kinds of training based on virtual reality, the user performance is recorded in videotapes and post analyzed by experts. After some time, the user receives his evaluation. This is a problem because probably after some hours the user will not remember his exact actions when was performing the simulation. This situation will make difficult the use of the evaluation information to improve his performance. Besides of that, in several cases a training cannot be simply classified as bad or good due to its complexity. So, the existence of an on-line evaluation tool attached to a simulation system based on virtual reality is important to allow the learning improvement and users evaluation.

Recently, new methods of evaluation for on-line training in virtual reality simulator have been proposed [4, 6, 7, 8, 9, 10, 14, 16, 17, 18, 19, 20, 21, 23, 24]. In medicine, some models for off-line or on-line evaluation of training have been proposed too. However, great part of these approaches depends on a large computational structure, which is very expensive to be available in some Medical Centers in Brazil and several other countries.

Simulators based on virtual reality (VR) for training need high-end computers to provide realistic haptics, stereoscopic visualization of 3D models, interactive deformation and textures. On-line evaluators must have low complexity to do not compromise performance of the simulations, but they must have high accuracy to do not compromise the evaluation. A method based on Fuzzy Bayes Rule can be a good option for an on-line training evaluator in virtual reality simulators.

## VIRTUAL REALITY AND SIMULATED TRAINING

Virtual Reality refers to real-time systems modeled by computer graphics that allow user interaction and movements with three or more degrees of freedom [2, 27]. More than a technology, virtual reality became a new science that joins several fields as computers, robotics, graphics, engineering and cognition. Virtual Reality Worlds are 3D environments created by computer graphics techniques where one or more users are immersed totally or partially to interact with virtual elements. The quality of the user experience in a virtual reality world is given by the graphics resolution and by the use of special devices for interaction. Basically, the devices stimulate the human senses as vision, audition and touch: head-mounted displays (HMD) or even conventional monitors combined with special glasses can provide stereoscopic visualization; multiple sound sources positioned provides 3D sound; and touch can be simulated by the use of haptic devices [11, 13].

Virtual reality systems for training provide significant benefits over other methods of training, mainly in critical medical procedures. In some cases, those procedures are

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done without visualization for the physician, and the only information he receives is done by the touch sensations provided by a robotic device with force feedback. These devices can measure forces and torque applied during the user interaction [13] and these data can be used in an evaluation [4, 23]. An example of this kind of device is the Phantom Desktop presented in Figure 1.

FIGURE. 1
THE PHANTOM DESKTOP IS A ROBOTIC DEVICE FOR FORCE FEEDBACK IN VIRTUAL REALITY SIMULATORS.

Phantom Desktop is a haptic device that provides force feedback and tactile sensations during user manipulation of objects in a three dimensional scene. This way, user can feel objects texture, density, elasticity and consistency. Since the objects have physical properties, a user can identify objects in a 3D scene without see them by the use of this kind of device [11]. This is especially interesting in medical applications to simulate proceedings which visual information is not available. One of the main reasons for the use of robotics arms in medical applications is their manipulation similarity when compared to real surgical tools.

## EVALUATION IN VIRTUAL REALITY SIMULATORS

The evaluation of simulations is necessary to assess the training quality and provide some feedback about the user performance. User movements, as spatial movements, can be collected from mouse, keyboard and any other tracking device. Applied forces, angles, position and torque can be collected from haptic devices [24]. So, virtual reality systems can use one or more variables, as the mentioned above, to evaluate a simulation performed by user.

Some simulators for training have a method of evaluation. However they just compare the final result with the expected one or are videotape records post-analyzed by an expert [1]. Recently, some models for off-line or on-line evaluation of training have been proposed, some of them use Discrete Hidden Markov Models (DHMM) [22] or Continuous Hidden Markov Models (CHMM) [22] to modeling forces and torque during a simulated training in a porcine model. Machado et al. [4, 6] proposed the use of a fuzzy rule-based system to on-line evaluation of training in virtual worlds. Moraes and Machado [16, 21] proposed the use of CHMM for on-line evaluation in any virtual reality simulators. After that, the same authors proposed another approach for on-line evaluation learning using Fuzzy Hidden Markov Models (FHMM) [17]. Using an optoelectronic motion analysis and video records, McBeth et al. [14] acquired and compared postural and movement data of experts and residents in different contexts by use of distributions statistics. Machado and Moraes proposed the use of Gaussian Mixture Models [18], Fuzzy Gaussian Mixture Models [19], and recently Neural Networks [8], Evolving Fuzzy Neural Networks [9] and Maximum Likelihood [10]. They proposed also two evaluator with two-stage: the first one using Gaussian Mixture Models and Relaxation Labeling [20] and after the Fuzzy Gaussian Mixture Models and Fuzzy Relaxation Labeling [7] to provide an on-line evaluation for simulators or training systems based on virtual reality.

In this paper, we propose the use of the fuzzy statistical classification based on Fuzzy Bayes Rule for an on-line training evaluator in virtual reality simulators. The system uses a vector of information with data collected from user interactions with virtual reality simulator. These data are compared by an evaluation system with *M* pre-defined classes of performance.

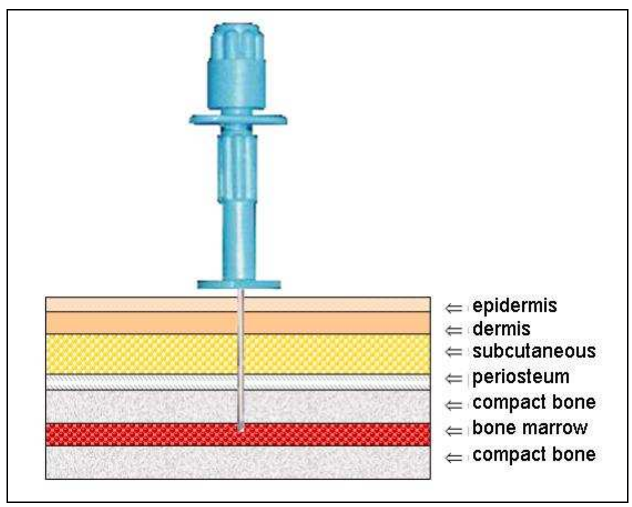


FIGURE. 2
THE TISSUE LAYERS TRESPASSED BY NEEDLE IN A BONE MARROW HARVEST.

To test the method proposed, we are using a bone marrow harvest simulator [5]. This simulator has as goal to training new doctors to execute the bone marrow harvest, one of the stages of the bone marrow transplant. The procedure is done blindly, performed without any visual feedback, except the external view of the donor body, and the physician needs to feel the skin and bone layers trespassed by the needle to find the bone marrow and then start the material aspiration (Figure 2). The simulator uses a robotic arm (Phantom Desktop) that operates with six degrees of freedom movements and force feedback to give to the user the tactile sensations felt during the penetration of the patient's body as showed in the Figure 3 [15]. In the system the robotic arm simulates the needle used in the real procedure, and the virtual body visually represented has the tactile properties of the real tissues. The evaluation tool proposed should supervise the user movements during the puncture and should evaluate the training according to $M$ possible classes of performance.

FIGURE. 3
THE VIRTUAL REALITY BASED SIMULATOR FOR BONE MARROW HARVEST TRAINING IN USE.

## FUZZY BAYES EVALUATOR

This section presents the method for training evaluation, based on Fuzzy Bayes rule. For reader's better understanding, we first present a short review about Bayes rule. After that, we present fuzzy sets and fuzzy Bayes rule.

### Bayes Rule

Formally, let be the classes of performance in space of decision $\Omega=\{1,...,M\}$ where $M$ is the total number of classes of performance. Let be $w_i$, $i \in \Omega$ the class of performance for an user. We can determine the most probable class of a vector of training data $X$, by conditional probabilities [3]:

$$P(w_i \mid X)=P(w_i \cap X) / P(X), \text{ where } i=1,...,M. \quad (1)$$

The probability done by *(1)* gives the likelihood that for a data vector $X$, the correct class is $w_i$. Classification rule is performed according to

$$X \in w_i \text{ if } P(w_i \mid X) > P(w_j \mid X) \text{ for all } i \neq j. \quad (2)$$

However, all the probabilities done by *(1)* are unknown. So, if we have sufficient information available for each class of performance, we can estimate that probabilities, denoted by $P(X \mid w_i)$. Using the Bayes Theorem:

$$P(w_i \mid X) = [P(X \mid w_i) P(w_i)] / P(X),$$
$$\text{where} \quad P(X) = \Sigma^M_{i=1} P(X \mid w_i) P(w_i)]. \quad (3)$$

As $P(X)$ is the same for all classes $w_i$, then it is not relevant for data classification. In Bayesian theory, $P(w_i)$ is called *a priori* probability for $w_i$ and $P(w_i \mid X)$ is *a posteriori* probability for $w_i$ where $X$ is known. Then, the classification rule done by (2) is modified:

$$X \in w_i \text{ if } P(w_i \mid X) P(w_i) > P(w_j \mid X) P(w_j) \text{ for all } i \neq j. \quad (4)$$

Equation *(4)* is known as Bayesian decision rule of classification. However, it can be convenient use [3]:

$$g(X) = \ln [P(X \mid w_i) P(w_i)]$$
$$= \ln [P(X \mid w_i)] + \ln [P(w_i)] \quad (5)$$

where $g(X)$ is known as discriminant function. We can use *(5)* to modify the formulation done by Bayesian decision rule in equation *(4)*:

$$X \in w_i \text{ if } g_i (X) > g_j (X) \text{ for all } i \neq j. \quad (6)$$

It is important to note that if statistical distribution of training data can assume multivariate Gaussian distribution, the use of *(6)* has interesting computational properties [3]. If training data cannot assume that distribution, the equation *(6)* can provides a significant reduction of computational cost of implementation.

### Fuzzy Sets

In classical set theory a set $A$ of a universe $X$ can be defined by a membership function $\mu_A(x)$, with $\mu_A$: $X \rightarrow \{0,1\}$, where $1$ means that x is include in $A$ and $0$ means that x is not include in $A$.

$$\mu_A(x) = \begin{cases} 1, & \text{if } x \in A \\ 0, & \text{if } x \notin A \end{cases} \quad (7)$$

Lofti Zadeh [29] introduced the fuzzy set theory in 1965. A fuzzy set can be seen as a representation in classical set theory, of which we only have an imperfect knowledge. In this case, the membership function can not be done by only one value *0* or *1*, but by a value in *[0,1]* interval.

The probability of a fuzzy event is defined by [30]: let be $(R^n, \phi, P)$ a space of probability where $\phi$ is an σ-algebra in $R^n$ and $P$ is a probability measure over $R^n$. Then a fuzzy event in $R^n$ is a set $A$ in $R^n$, with membership function $\mu_A(x)$, where $\mu_A: R^n \rightarrow \{0,1\}$ is Borel-mensurable. The probability of a fuzzy event $A$ is defined by Lebesgue-Stieltjes integral:

$$P(A) = \int_{R^n} \mu_A(x) dP = E(\mu_A) \quad (8)$$

In others words, the probability of a fuzzy event $A$ with membership function $\mu_A$ is the expected value of the membership function $\mu_A$.

### Fuzzy Bayes Rule

Again, let the classes of performance for an user done by $w_i$, $i=1,...,M$, where $M$ is the total number of classes of performance. However, now we assume that $w_i$ are fuzzy sets over space of decision $\Omega$. Let be $\mu_{wi}(X)$ the fuzzy membership function for each class $w_i$ given by a fuzzy information font (for example, a rule composition system of the expert system, or a histogram of the sample data), according a vector of data $X$. In our case, we assume that fuzzy information font is a histogram of the sample data.

By use of fuzzy probabilities [30] and fuzzy Bayes rule [26] in the classical Bayes rule, we have the fuzzy probability of the $w_i$ class, given the vector of data $X$:

$$P(w_i|X) = \frac{\mu_{w_i}(X).P(w_i).P(X|w_i)}{P(X)}, \text{ with } \sum_i \mu_{w_i}(X) = 1 \quad (9)$$

However, as the denominator is independent, then the fuzzy Bayes classification rule is to assign the vector of training data $X$ from the user to $w_i$ class of performance if:

$$w_i, \text{ if } \mu_{w_i}(X).P(w_i).P(X|w_i) = \max_{j \leq M} \mu_{w_j}(X).P(w_j).P(X|w_j) \quad (10)$$

## THE EVALUATION TOOL

The evaluation tool proposed should supervise the user movements and others parameters associated to it. The system must collect information about positions in the space, forces, torque, resistance, speeds, accelerations, temperatures, visualization and/or visualization angle, sounds, smells and etc. The virtual reality simulator and the system of evaluation are independent systems, however they act simultaneously. The user's interactions with the system are monitored and the information is sending to the evaluator system that analyzes the data and it emits a report on the user's performance at the end of the training. Depending on the application, all those variables or some of them will be monitored according to their relevance to the training.

In the virtual reality simulator used for the tests the trainee must extract the bone marrow. In the first movement, he must feel the skin to find the best place to insert the needle. After, he must feel the tissue layers (epidermis, dermis, subcutaneous, periosteum and compact bone) trespassed by the needle and stop at the correct position to do the bone marrow extraction. In our system the trainee movements are monitored by variables as: acceleration, applied force, spatial position, torque and angles of needle.

For the calibration of the evaluator system, an expert executes several times the procedure for each one of $M$ classes of performance available, for example: "well qualified", "need some training yet", "need more training", "novice", etc. So, the information of variability about these procedures is acquired using fuzzy membership functions and gaussian probability models. In our case, we assume that fuzzy information font for construction of fuzzy membership function for $w_i$ classes is the histogram of the sample data. The user makes his training in virtual reality simulator and the Fuzzy Bayes Evaluator collect the data from his manipulation. All probabilities of that data for each class of performance are calculated by *(9)* and at the end the user is assigned to a $w_i$ class of performance by *(10)*.

## CONCLUSIONS AND FUTURE WORKS

In this paper we presented a new approach to on-line evaluation in training simulators based on virtual reality using a statistical classification based on Fuzzy Bayes Rule. This approach provides the use of continuous variables without lost of information. So, it solves the problem of low complexity of on-line evaluators, without compromise performance of simulator and with good accuracy evaluation.

Systems based on_this approach can be applied in virtual reality simulators for several areas and can be used to classify the trainee into classes of learning giving him a real position about his performance, through the reports of performance of each training. In medicine, it provides an appropriate methodology for blind made procedures.

As future work, we intend to test and to make a statistical comparison between others methodologies and the methodology proposed in this paper.

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