Online Assessment of Training in Virtual Reality Simulators Based on General Bayesian Networks

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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 online evaluator for training simulators based on virtual reality must have a low complexity algorithm to do not compromise the performance of the simulator. Several approaches to perform that evaluation for online or offline training simulators based on virtual reality have been proposed. We propose a new approach for an online evaluation based on a General Bayesian Network. This network was used for modeling and classification of user's skills in pre-defined classes of performance. This method provides the use of continuous variables without lost of information. Then, it solves the problem of low complexity in online evaluators without compromise performance of the simulator.*

Index Terms — General Bayesian networks, virtual reality, assessment of training, online methods.

INTRODUCTION

Virtual reality (VR) has been used to simulate several kinds of training, particularly in areas which involve risk for the trainee or other people [3]. The user is immersed into a virtual world to have realistic training and real-time interactions. Kirner and Kirner showed that simulators based on VR can improve skills of new professionals trained by it [8]. One of the advantages of simulators based on VR for training of procedures is keep safe trainee and preserve materials [1]. Besides, a simulate procedure can be repeated as many time as it is necessary [29].

However, several kinds of training based on VR use to record user actions in videotapes and post-analysed by experts [2, 12] to assess a trainee/user. In those cases, the user receives the assessment after some time, which characterize an offline assessment methodology. This is a problem because probably after some hours, the user will not remember his exact actions what decrease the utility of the assessment information to improve his performance.

In opposition, there are online methods, which can provide an assessment immediately after the training. The existence of an online assessment tool incorporated into a training simulator based on virtual reality is important to allow the learning improvement and users assessment [12]. As VR simulators are real-time systems, the assessment tool must continuously monitor all user interactions and compare his performance with pre-defined expert's classes of performance. The use of online assessment tools allows the user to easily remember his mistakes and learn how to correct them.

Models for online and offline assessment of training have been proposed [5, 6, 10, 12, 13, 14 ,16, 19, 20, 21, 22, 23, 24, 25]. The main problems related to online training assessment methodologies applied to VR systems are the computational complexity and the accuracy. An online assessment tool must have low complexity to do not compromise VR simulations performance, but it also must have high accuracy to do not compromise the user assessment.

A Bayesian network is able to represent knowledge from data [26]. So, a Bayesian network can be obtained from data generated by simulated procedures performed by experts. After this network is obtained, it can be used to assess a training executed by a trainee. This paper presents an online assessment tool for VR systems based on a general Bayesian networks.

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 [3]. More than a technology, VR became a new science that joins several fields as computers, robotics, graphics, engineering and cognition. VR 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 realism of a virtual reality application is given by the graphics quality and by the exploration of users senses. Special devices stimulate the sight, hearing and touch, mainly. As example, head-mounted displays (HMD) or even conventional monitors combined with special glasses can provide stereoscopic visualization, multiple

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sound sources positioned provides 3D sound, and touch can be simulated through haptic devices [17, 28].

Virtual reality systems for training can provide significant benefits over other methods of training, mainly in critical medical procedures. In some cases, those procedures are performed without any kind of visualization and the only information received is noticed by the touch sensations provided by a robotic device with force feedback. These devices can measure forces and torque applied during the user interaction [28] and these data can be used in an assessment [11, 27]. A specific kind of haptic device [18], as the presented in Figure 1, is based on a robotic arm and 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 them in a 3D scene (without see them) by the use of this kind of device [17]. This is especially interesting in medical applications to simulate proceedings in which visual information is not available. One of the main reasons for the use of such haptic devices in medical applications is their manipulation similarity when compared to real surgical tools.

FIGURE. 1
HAPTIC DEVICE USED IN VR SYSTEMS.

Assessment in Virtual Reality Simulators

The assessment of simulations is necessary to monitor the training and provide some feedback about the user performance. User movements, as spatial interactions, can be collected from mouse, keyboard and any other tracking device. Applied forces, angles, position and torque can be collected from haptic devices [28]. Then, assessment tools coupled to a virtual reality systems can use one or more variables, as the mentioned above, to assess a simulation performed by user.

Some simulators for training present a method of assessment. However they just compare the final result with an expected result or are post-analyses of videotape records [2]. Recently, some models for online assessment of training have been proposed, but probably the first one of them was the paper of Machado et al. [11] using of a fuzzy rule-based system to online assessment of training in virtual worlds.

In this paper, we propose a new system for assessment based on general Bayesian network. This system can perform an online training assessment for virtual reality simulators. The system uses a vector of information, with data collected from user interactions with virtual reality simulator, and these data are compared by the assessment system with *M* pre-defined classes of performance. The assessemnt tool intend to be used in a bone marrow harvest simulator [12]. 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 patient 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 that operates with six degrees of freedom movements and provides force feedback to give to the user the tactile sensations felt during the penetration of the patient's body [12]. 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 assessment tool proposed supervised the user movements during the puncture and evaluated the training according to *M* possible classes of performance.

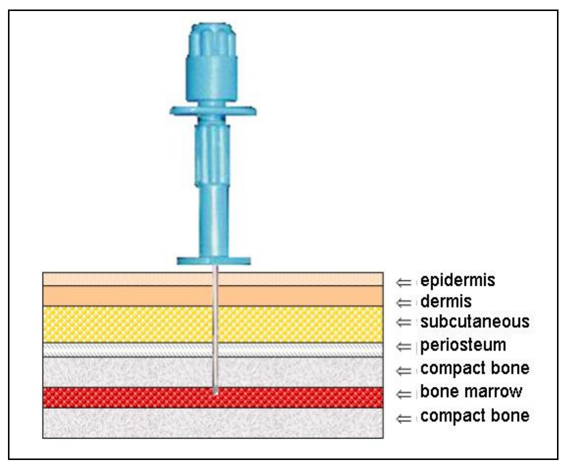

FIGURE. 2
THE TISSUE LAYERS TRESPASSED BY NEEDLE IN A BONE MARROW HARVEST.

THEORETICAL ASPECTS

For the reader's better understanding, we first present a short review about Bayesian networks and general Bayesian networks.

Bayesian networks

A Bayesian network is a probabilistic model, which can represent a set of probabilities distributions from all variables in a complex process and also establish their relashionships [26]. Formally, a Bayesian network is defined as directed acyclic graphs, denoted by *G* and a probabilistic distribution denoted by *P*. The graph *G* is a set of nodes and oriented arcs, where nodes represent variables in process and oriented arcs encode conditional dependencies between that variables [26]. The dependencies are modeled by specific conditional probabilistic distributions [9].

Cheng [4] proposed a classification for Bayesian networks, according to their graph structure, in five classes: Naive-Bayes, Tree Augmented Naive-Bayes, Augmented Naive-Bayes, Bayesian Multi-net nets e General Bayesian Networks (GBNs). Choose a specific structure to knowledge representation depends on dependencies relationship between variables which describe that process. That choice is critical, because it changes the final results. The GBN is a generalized form of Bayesian networks, which allows nodes to form an arbitrary graph, rather than just a tree. Another important characteristic is that each child node cannot be connected to the final classes of assessment.

General Bayesian Networks

The General Bayesian Network was chosen to implement the training assessment due to its generality. In that network, the dependencies between nodes can adjust itself to real dependencies. Thus, it is possible to verify dependencies between variables during network modeling and put them in structure nodes of GBN, which did not occur in other structures.

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_j, $j \in \Omega$ the class of performance for a user and X_i, $1 \leq i \leq n$, represents a node in GBN with n as the number of nodes in a graph. The joint probability distribution in GBN for an event is done by:

$$P(X_1, X_2, \ldots, X_n) = \prod_{i=1}^{n} P(X_n \mid X_{n-1}, X_{n-2}, \ldots, X_1) \quad (1)$$

where $P(X_1, X_2, \ldots, X_n)$ is the joint probability distribution and $P(X_n \mid X_{n-1}, X_{n-2}, \ldots, X_1)$ is the conditional probability of X_n conditioned by its antecessor nodes $X_{n-1}, X_{n-2}, \ldots, X_1$.

If the conditional independence between variables is verified, this permits simplifications in equation (1). Then,

$$P(X_1, X_2, \ldots, X_n) = P(X_1 \mid w_j)\, P(X_2 \mid w_j)\, P(X_3 \mid w_j) \ldots \quad (2)$$

The nodes probabilities are associated to probability distribution. For example, a node *A* can have a Gaussian distribution and a node *B*, which depends on *A*, can have a bivariate Gaussian distribution, with a mean vector and a covariance matrix [7].

The structure of GBN is learned from data, as well as the parameters of conditional probabilities. Using probabilities calculus is possible to find dependencies among nodes in a Bayesian network. If those dependencies are founding and, if is possible to assume Gaussian distribution for nodes, dependencies can be estimated using multivariate linear regression [26]. Scores are used to help estimate the final structure of GBN for each class of assessment. In a first moment a network is created with all independent nodes and an initial score is calculated. Next, all combinations are searched and an arc is designed between two nodes for which an increment of initial score is obtained. Then, the parameters for that nodes set are re-estimated using linear regression. This cycle is repeated until total network score is less than a predetermined value or a fixed number of cycles.

THE ASSESSMENT TOOL

The assessment tool proposed should supervise the user's movements and other parameters associated to them. The system must collect information about positions in the space, forces, torque, resistance, speeds, accelerations, temperatures, visualization position and/or visualization angle, sounds, smells and etc. The virtual reality simulator and the assessment tool are independent systems, however they act simultaneously. The user's interactions with the simulator are monitored and the information is sent to the assessment tool that analyzes the data and 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).

The assessemnt tool intend to be used in a bone marrow harvest simulator [12]. In a first movement on the real procedure, the trainee must feel the skin of the human pelvic area to find the best place to insert the needle used for the harvest. 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 VR simulator the trainee interacts with a robotic arm and his/her movements are monitored in the system by some variables [12]. For reasons of general performance of the VR simulator, were chosen to be monitored the following variables: spatial position, velocities, forces and time on each layer. Previously, the system was calibrated by an expert, according *M* classes of performance defined by him. The calibration process consists in to execute several times the procedure and to classify each one according to classes of performance. The number of classes of performance was defined as $M=3$: 1) correct procedures, 2) acceptable procedures, 3) badly executed procedures. So, the classes of performance for a trainee could be: "you are well qualified", "you need some training yet", "you need more training".

The information of variability about these procedures is acquired using GBN based method. In our case, we assume that the font of information for w_j classes is the vector of the sample data *D*. The user makes his training in the virtual reality simulator and the Assessment Tool based on GBN collects the data from his manipulation. All probabilities of data for each class of performance are calculated by GBN and at the end, the user is assigned to a w_j class of performance, according (1). So, when a trainee uses the system, his performance is compared with each expert's class of performance and the Assessment Tool based on GBN assigns the better class, according to the trainee's performance. At the end of the training, the assessment system reports the classification to the trainee.

RESULTS

An Assessment Tool based on General Bayesian Network was implemented using CyberMed [15] libraries to be tested using a bone marrow harvest simulator developed from the same libraries [29].

In a performance test with simulated data, the implemented Assessment Tool used 19 minutes and 6 seconds for training using 10000 sample vectors. For assessment of 20000 sample vectors, the classes of performance attribution took approximately 0.5 ms. For this test, the correct assessment rate was around 99%.

CONCLUSIONS AND FUTURE WORKS

In this paper we presented a new approach to online training assessment in virtual reality simulators. This approach uses an Assessment Tool based on General Bayesian Network and solves the main problems in assessment procedures: use of continuous variables, low complexity and high accuracy. Systems based on this approach can be applied in virtual reality simulators for several areas and can be used to assess a trainee into classes of performance giving him a status about his skills.

The methodology proposed here was tested with simulated data from a bone marrow harvest simulator, which was constructed to train new doctors to execute the bone marrow harvest, one of the stages of the bone marrow transplant.

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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