A FUZZY LOGIC BASED ASSESSMENT TOOL FOR VR SIMULATED MEDICAL ENVIRONMENTS

Alysson D. Santos[1], Renata G. S. Gomes[2], Ronei M. Moraes[3], Liliane S. Machado[4]

Abstract *—Virtual Reality (VR) systems allows the design of interactive and immersive environments for the simulation of a wide range of situations. These features has been exploited to build realistic applications in order to provide study and training in several areas, particularly in medicine. In this sense, the addition of techniques to assess the actions of users can provide simulations based on virtual reality more efficient for medical training, especially by helping the measure of users' skills after the execution of procedures in such virtual environments. This work details the implementation and integration of an assessment module based on fuzzy logic to a framework for development of virtual reality applications for medical training. Tests to measure the performance of the assessment module were designed over a gynecological examination simulator based on VR.*

Index Terms — fuzzy logic, medical simulation, skill assessment, virtual reality

INTRODUCTION

In recent decades, the Virtual Reality (VR) has proven its power as a tool for education and training in various fields such as aviation, business management and oil, nuclear and military industries [1]. Simulations based on VR intends to recreate immersive and interactive environments which can be used to provide training and learning through a personal experience [2].

An important feature related to VR systems for simulation and training is the ability to monitor the user's actions in the system. It allows the use of the interaction informations for many purposes, like the quantification of the understanding, the usability and user's skill assessment [5,6]. Usually, this process is supported by some type of assessment method which computes the classification of collected data from user's interaction. It can be seen an increasing importance given to assessment methods in the context of VR simulations [5,7-9].

In this work is carried out a study of the basic concepts related to monitor and assess user's actions in the context of VR simulations focused on teaching and training of medical procedures. Additionally, it is detailed the implementation, integration and testing of a module for assessment based on fuzzy logic to a framework for development of applications based on VR for medicine, named CyberMed [15]. The module introduces a new assessment method in the framework, which allows reusability and utilization in a wide context of applications.

VIRTUAL REALITY MEDICAL SIMULATORS

VR is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. In this sense, 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 [3]. The immersive, interactive and multisensory nature of VR applications have allowed the conception of systems which recreate real life situations, as education or training in risky procedures [12].

Over the years, VR environments have been proposed to simulate various medical procedures, such as puncture procedures, palpation tests and complex surgical procedures (Figure 1) [9]. The benefits of using simulation systems based on VR include: the improvement of training processes, once that initial mistakes could occur in virtual models instead of real patients, training of rare and unusual situations, possibility of creating tasks and scenarios on demand, repetition of procedures as many as necessary, and objective assessment of user's skills [4].

ASSESSMENT IN MEDICAL SIMULATORS

The assessment of simulations is necessary to monitor the training quality and provide some feedback about the user performance [13]. This feedback is used to assess the users' skills and, according to their performance, inform their dexterity degree to perform the real procedure. In addition, various types of training cannot be classified as good or bad, due to its complexity. In such cases the existence of an assessment tool built into a VR based simulation system is important to serve as an auxiliary tool for decision-making about the success or failure in the transmission of knowledge to the student [5].

[1] Alysson Diniz dos Santos, *alyssondiniz@yahoo.com.br*
[2] Renata Grigório Silva Gomes, *renatagrigorio@gmail.com*
[3] Ronei Marcos de Moraes, Department of Statistics, Federal University of Paraíba. Cidade Universitária s/n, Castelo Branco, João Pessoa-PB. 58051-900. Brazil. *ronei@de.ufpb.br*
[4] Liliane dos Santos Machado, Department of Informatics, Federal University of Paraíba. Cidade Universitária s/n, Castelo Branco, João Pessoa-PB, Brazil. 58051-900. *liliane@di.ufpb.br*

To realize the user’s assessment, virtual reality systems can use one or more variables collected from user’s interactions such as: spatial movements (collected from mouse, keyboard or any other tracking device), applied forces, angles, position and torque(collected from haptic devices) [14]. In Figure 2, it can be seen the Phantom Omni device, widely used as haptic interaction device in VR environments. From this device can be collected forces, angles, position and torque data.

FIGURE 1
VR simulated environments to medicine: a) anesthesical needle insertion simulator [25], b) throat diseases simulator [24] and c) anesthesia procedure simulator ARCM [23].

FIGURE 2
Haptic device Phantom Omni used in vr environments.

The assessment methods can be characterized as offline or online. Once the training ends, an online assessment can provide a quick feedback to the user. In an offline assessment the classification of training takes some time and depends on experts analyses of the training session. For didactic reasons, it is preferable the use of online evaluators, since users must have the classification of the training as soon as it is finished [10].

The main problems associated with online assessment methodologies applied to VR systems are: complexity, accuracy and efficiency. An online assessment tool requires, by its mathematics and statistics nature, the resolution of calculations that can increase the computational complexity of the system. This complexity must be addressed in order to does not compromise the performance of the simulation, but should also allow the evaluator to be accurate to avoid compromising the assessment of the user [11].

Fuzzy Logic Theory

The fuzzy logic allows to model vague and imprecise information using numerical values as inclusion of human experience in computer control, enabling decision making on complex problems. It is applied in systems modeling, control, manufacturing, communications and decision-making systems [16].

In the context of VR simulations of medical procedures, the representation of imprecise concepts and the possibility of human experience inclusion allows to assess the users' interaction comparing their actions with the professional interaction. The use of fuzzy logic to perform users' assessment also helps to identify possible errors and inaccuracies performed by users.

In classical set theory, an element belongs to a set or is absent of it. Thus, given a universe U and a particular element x ϵ U, the membership function μ_A (x) means that a classical set A contained in U is given by:

$$\mu_A(x) = \begin{cases} 1 & se\ x \in A \\ 0 & se\ x \notin A \end{cases}$$

A fuzzy set can be seen as a representation of a set in classical set theory, which is only known an imperfect knowledge. In this case, the relevance of an element in a set given not by the values 0 or 1, but by any value in the interval [0,1], i.e. the relevance of an element in a set can be partial [17]. Given a universe U and a particular element x ϵ U, the membership function μ_F (x) representing a fuzzy set F contained in a universe U, is of the form:

$$\mu_F(x): U \rightarrow [0,1]$$

In fuzzy logic, truth values are expressed linguistically (e.g., true, very true, not true, false, very false ,...), where each linguistic term is interpreted as a fuzzy subset of the unit interval [22]. The issue is the rigidity of conventional logic, it not lets to classify the facts as partly "true" or partially "false". In summary, the fuzzy logic is a generalization of classical logic, making it flexible in the interval [0,1].

To express knowledge in a fuzzy system, typically are used rules of type condition-action. In general, a fuzzy rule is of type:

$$\textbf{IF}\ (x \text{ is } a_i)\ \textbf{AND}\ (y \text{ is } b_i)\ \textbf{OR} \ldots \textbf{THEN}\ (z \text{ is } c_i)\ (w \text{ is } d_i)\ldots,$$

where x and y are input linguistic variables, z and w are output linguistic variables and a_i, b_i, c_i and d_i represent realizations of these variables.

Expert Systems

The basic idea in an expert system (ES) is to model the actions from expert's knowledgment. This approach is different from conventional methods, where the actions are developed via mathematical modeling. A structure of a generic ES was proposed by Mandani and can be seen in Figure 3.

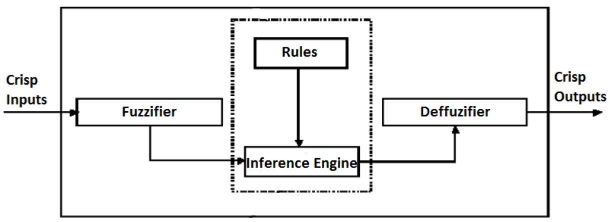

FIGURE 3
GENERIC MANDANI FUZZY EXPERT STRUCTURE [18].

A Mandani's structure for expert system has four basic components: a fuzzification interface, a knowledge base, an inference engine and a defuzzification interface.

a) *Fuzzification Interface*

The values of input variables are scaled to constrain the values to the universes of discourse. So it's realized the fuzzification of standard values, transforming numbers into instances of linguistic variables.

b) Knowledge Base

The knowledge base contains a set of rules and a database. The set of rules characterizes the goals of the ES, while the database stores the required settings on discretizations and normalizations on the universes of discourse, on the fuzzy partitions of the input/output spaces and on the membership functions. In general, difficulties in the design of expert systems consist on the specification of the rules and the definition of membership functions. The specification of the rule base can be obtained by different ways, highlighting the following:

- Based on expert's knowledge and experience;
- Based on observation of the expert's actions;
- From the linguistic description of the dynamic process characteristics;
- Utilization of learning algorithms for a posterior converstion of knowledge into rules.

c) Inference Engine

The Inference Engine processes the fuzzy input data through the rules, applying the operator of fuzzy implication and the inference rules of fuzzy logic, in order to infer the fuzzy actions. In this step is calculated the pertinence of the antecedents, combined with the methods of connection (AND or OR) for the extraction of a single value. Then, this value is combined by implication methods with the pertinence of the consequents. This step ends when the values of similar rules are aggregated.

d) *Defuzzification Interface*

The Defuzzification Interface performs a scheduling in order to match the normalized values, coming from the previous step, with the values of the real variables' universes of discourse. An approach based on the centroid or based on peak values that occur in the resulting membership function can be used to select the appropriate method of defuzzification.

FUZZY LOGIC ASSESSMENT TOOL

In this work it was implemented a fuzzy logic assessment module to a framework for the development of applications of VR for education and training in medicine called CyberMed [15]. It was also carried out performance tests on the implemented module using a model purposed for a gynecological examination VR simulator. This case study and the framework are detailed in the next two sessions.

Case Study: Gynecological Examination VR Simulator

In [20] it was proposed the utilization of a fuzzy logic expert system to assess user's performance in a VR simulated gynecological exam. The simulation provides the same phases of a real gynecological exam. The first phase allows the observation of the patient cervix. The visualization presents a model of female pelvic region with a device, called speculum, inserted on it. The second phase corresponds to a tactile inspection, when the physician use two fingers to fill patient's vagina and cervix in order to get information of internal structures and identify the presence of ulcers, blisters or swellings. In this second phase of the exam (phase tactile), a haptic device, which operates movements with six degrees of freedom, provides force feedback to give tactile feedback to the user, similar to the experienced during the tactile examination of real body structures. At this point, the definition of appropriate haptic properties was made by a medical professional who, based on his experience, described the haptic properties of the walls of the vagina and cervix in healthy, inflammed or with herpes or HPV cases. The knowledge related to each case was refined and organized according to Table I.

TABLE I

Description of visual and haptic properties of structures used in the gynecological examination VR simulator [19].

	Coloration	Texture	Viscosity	Elasticity
Normal	Rosy	Similar to buccal mucous membrane	Smooth	Similar to an ortopedic rubber
Herpes /HPV	White	Spongy	With bubbles	Very Soft
Inflamed	Red	Similar to buccal mucous membrane	Smooth	Hard/Tense

The CyberMed Framework

A framework can be defined as an abstract implementation and project, used in the development of applications in a previously defined domain, allowing the reuse of components [21]. The CyberMed framework was developed to facilitate the development of VR simulators with medical purposes. It consists on a set of classes that provides functionalities to create simulators based on VR and offers support to a variety of devices. These features provide a high-level system that eliminates the demand for specific knowledge about devices and their APIs (Application Programming Interface) [15]. The current version of the framework has modules that support three-dimensional visualization, haptic interaction, collision detection, deformation, motion tracking, collaboration between users and assessment of user's actions. A diagram of CyberMed modules can be seen in Figure 4.

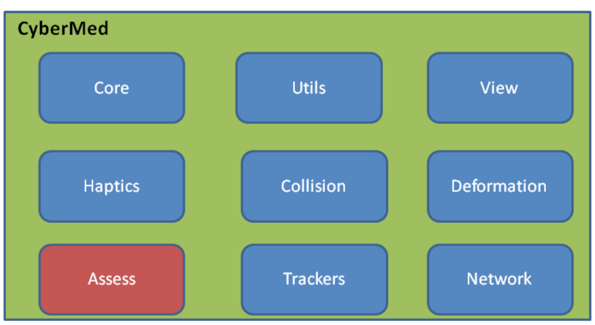

FIGURE 4

Modules Structure of the CyberMed, highlighting the Assess module responsible to realize user's assessment. Adapted from [15].

The module responsible to assess users' performance is the Assess module (highlighted in Figure 4). This module collects data and perform assessment of them without compromise real time requirements necessary for the success of the simulation. It still has the implementation of two methods of assessment, based on maximum likelihood and on general bayesian networks, and defines a common interface that must be taken to the inclusion of new methods of assessment.

Results

To verify the performance of the module, it was generated a statistical set of samples to represent user's interactions in a VR simulator. The amount of data used for the assessment stage is equivalent to a 10 seconds simulation with a haptic device frequency set at its maximum (1000 sample data/second). Thus, the simulation was conducted using the maximum frequency allowed by the haptic device. Table II presents a comparison of response time during the assessment stage for different samples sizes, varying from 1000 to 10000.

TABLE II

Comparison of average time of response for the performance tests made on the assessment module.

Number of Samples	Average Response Time (in seconds)
1000	0,220
2000	0,421
3000	0,757
4000	1,044
5000	1,304
6000	1,577
7000	1,689
8000	1,795
9000	1,967
10000	2,221

For an online assessment the user must receive the assessment report until 2 seconds after the end of training. The results observed in the Table II showed that the system is capable of processing up to 9000 entries (9 seconds of interaction) and returned the response in this interval of time. In this case, the main difficulty in returning the response at the appropriate time is associated with the high frequency (1000 Hz) of the haptic device. For interactions that last longer than 9 seconds, adjustments can be made, as the decrease of the frequency of the haptic device, since it does not compromize the quality of the tactile sensing. The simulation tests were made in a PC with an INTEL Core-2-Duo 1800 processor, with 4GB of RAM running a Ubuntu Linux.

Conclusions

This work presented the implementation and integration of an assessment module based on fuzzy logic to a framework for development of virtual reality applications for medical training. The design of the module allows a high-level use of assessment methods for programmers and leaves the implementation details internal to the system. However, a low-level access is also available, once that it is a free and open source tool, and can be used by expert programmers.

Tests to measure the performance of the assessment module were designed over statistical data generated according to a gynecological examination. The results showed that the module can process users' interactions performed in a VR based simulator and provide an assessment report in real-time. When a haptic device was used at its maximum frequency (1000 Hz), up to 9 seconds of interaction could be processed in less than 2 seconds.

Future works include the utilization of the implemented module in a virtual reality environment. In this case, the gynecological exam simulator has been developed with CyberMed and should use this assessment module. This assessment module based on fuzzy logic is already integrated to the CyberMed framework. The version 1.6 of the framework is available for download in http://www.de.ufpb.br/~labteve/projects/cybermed.html.

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