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Psychomotor skills assessment in medical training based on virtual reality using a Weighted Possibilistic approach

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ABSTRACT

Virtual reality has been used to provide training systems in several areas, particularly in medicine. In that area, user's interactions in a virtual environment are modeled and compared with predefined classes of performance to know how much users are prepared to perform that procedure on human beings. In this paper is proposed a new approach for online Single User's Assessment System (SUAS) using Weighted Possibility and Necessity measures. Those fuzzy measures provide an interval-based estimator to check the compatibility between interactions of an user and previous stored classes of performance. This approach integrates the kernel of a decision support system and it contributes to improve the user's assessment taking into account the individual relevance of variables in a procedure. It was verified in performance tests, when this new SUAS approach achieved better results, according to Kappa Coefficient, when compared with other previous approaches.

1. Introduction

The advent of Virtual Reality (VR) brought new possibilities and applications to computer systems. The environments created by VR techniques include immersive and interactive features that allow users taking part of virtual simulations having their senses explored by special devices. Thus, these users can act and receive information from the system in a similar way this could be performed in the real world. An important focus of Virtual Reality simulators are risky tasks, that can cause injures, or those related to expensive procedures. In some areas, VR systems for training have been used to provide metrics to a proficiency criterion of learning, as in commercial aviation [16].

Assessment systems have been used with VR simulators to allow objectively determine the user's performance. In some areas, it is done by an expert, which observes user actions and movements, and emits an assessment afterwards. In others, the assessment is based on videotapes post-analysis [28]. Despite the informality of many assessment methodologies, Carter [4] cites the reliability as an important factor related to the assessment since it indicates that an assessment tool must provide consistent results with minimal errors of measurement. In the same direction, Lammers et al. [13] indicate that the need of methods to assess technical competence with minimal errors is a consensus.

The risk present in several medical procedures make them a potential area for VR simulators and they have been pointed as an important learning tool in the educational process of new physicians [1,2,26]. The use of realistic simulators is based on the constructivism theory in which users can have active experiences, acting and receiving feedback. However, a common point of reflection rests on the methodology that can be used to objectively assess the user's psychomotor skills in these simulators [4].

Although the benefits of training based on VR be known [27,30], one of the main concerns about assessment is related to the definition of metrics that allow defining the steps and factors necessary to guarantee the assessment of the user's psychomotor skills, as well as which variables are relevant in the assessment process. At this point, the lack of well defined and accepted metrics is still a problem [32]. Some authors have pointed out specific variables which can contribute for user's assessment in medical training, as hand-motion [10], applied forces [8,14] and elapsed time [12], among others [11]. Those variables allow measuring differences between experts and novices surgeons [3,24].

However, the assessment problem can be solved by a decision support system (DSS) coupled to the VR simulator. The main idea behind DSS rests on the automatic composition of performance classes. Thus, the experts do not need to verbalize what is wrong or right in the procedure, but perform the simulation in the VR

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system and have their actions monitored by a DSS to compose a knowledge model to be used further by users in training [16]. Thus, the assessment system is a knowledge-based system which analyze data from users' interactions in a training system based on VR and provides a decision making support on the users' proficiency for performance in real procedures [21].

Since 90's, several Single User's Assessment System (SUAS) have been proposed [16,18,21,23,25,29] for VR simulators, mainly for medical training. With continuous advances on capacity of computers, SUAS evolved too. Nowadays, a SUAS must continuously monitor all user interactions on the VR environment and compare their performance with pre-defined expert's classes of performance to recognize user's level of training. Basically, there are two types of SUAS: off-line and on-line. Off-line SUAS can be defined as methods coupled or not to VR systems, whose assessment results are provided some time (which can be minutes, hours or days) after the end of the training. On the other hand, on-line SUAS are coupled to the training system and collect user data to provide a result about their performance at the end of the simulation [16,19], which is characterized by time of response lower than one second. Because many processes are running simultaneously in a VR system, an on-line SUAS must have low complexity to does not compromise the simulation performance. However, it also must have high accuracy to does not compromise the assessment results.

Recent researches focused on finding good methodologies for assessment that could be integrated to simulation systems based on VR. The main concern has been related to the quality of the assessment, which is relevant when the simulations are used for training purposes. This way, alternative methods using interval-based information are welcome to improve assessment accuracy and provide a more comprehensive use of the interaction data.

This paper presents a new training assessment system based on weighted Possibility and Necessity Measures. This method uses fuzzy measures to construct an interval-based estimator to provide users' assessment support based on their actions in VR simulator and takes into account the relative weighting of variables in the simulation. It is an innovative idea, once a simple interval-based approach was proposed recently [17,20] but it did not use any weighting on assessment variables. From the user's point of view, it is expected that an objective assessment of a procedure could be more adequate and accurate when it takes into account weighting of variables relevance in that procedure.

This paper is organized as follows: the next section presents some requirements of VR training simulators. Section 3 brings some theoretical aspects of the assessment methodology proposed on Section 4. Results obtained, as well as their analysis, are presented in Section 5, followed by some considerations in Section 6.

2. Training simulators based on VR

Training simulators based on VR are real time computer systems used to provide realistic environments for the practice of activities. The specificity of the activity simulated will determine the features of the system and also the variables necessary to be monitored by the system. In VR systems is possible to deal with details and particular issues and also augment features related to the procedure, exploring human senses as sight, hearing and touch, to provide interactive and immersive virtual experiences.

The quality of VR systems depends on the graphics, textures, use of deformable objects, lighting, sounds and physical properties of objects [16]. The objects in the simulation, as example, can be programmed to respond to users interactions, deforming by contact and providing touch feedback. Additionally, stereoscopy have been frequently used to provide more immersion, detaching images from the screen and positioning them in the space. In these cases, specific devices have been integrated to the simulators to allow users to interact in a natural way, as when manipulating real tools. However, each new routine integrated demands processing and synchronization, which depends on the necessities of the procedure simulated. Since obtaining high levels of realism can compromise the real time, the definition of features of a simulator usually focuses on the most important elements of the real procedure.

In simulators based on VR, the interaction devices can be used not only by users, but also by an assessment system (SUAS) to collect data about users' actions and movements. Fig. 1 shows examples of data from a VR simulator that can be used by an online assessment system.

3. Theoretical aspects

For better understanding of the assessment method proposed, some considerations and definitions need to be previously provided. Firstly, it is defined the concept of fuzzy sets, followed by definitions of measures of possibility and necessity. Finally, it is presented the assessment method.

Definition 1. Let X be a universal set, in which each element is denoted by x. Then, a fuzzy set A in X is given by $A = \{x, \mu_A(x)\}$, $x \in X$, where $\mu_A(x)$ is called the membership function, which provides a grade of membership of a element x in the fuzzy set A and $\mu_A : X \to [0;1]$. The value 0 denotes that x does not belong to the set A and value 1 indicates that x fully belongs to the set A. This interpretation is analogous to classical sets [33].

Definition 2. Let $F(U)$ a set of fuzzy subsets of U. The possibility measure Π is a function of $F(U)$ to $[0;1]$, which satisfies the following axioms [6]:

(1) $\Pi(\emptyset) = 0$;
(2) $\Pi(U) = 1$;
(3) For any collection A_i of subsets of $U, \Pi(\cup_i A_i) = \sup_i \Pi(A_i)$.

Definition 3. Let $F(U)$ a set of fuzzy subsets of U. The necessity measure N is a function of $F(U)$ to $[0;1]$, which satisfies the following axioms [9]:

(1) $N(\emptyset) = 0$;
(2) $N(U) = 1$;
(3) For any collection A_i of subsets of $U, N(\cap_i A_i) = \inf_i N(A_i)$.

Definition 4. Let A be a subset of U, with its membership function μ_A and let X be a variable which assumes values u in U. Then, the possibility distribution function associated to X is defined as [33]:

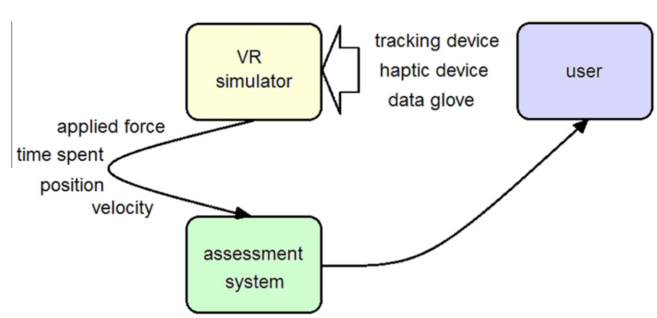

Fig. 1. Data fluxogram from a VR simulator.