# Using Embedded Systems to Improve Performance of Assessment in Virtual Reality Training Environments

*Ronei Marcos de Moraes[1], Liliane dos Santos Machado[2]*

***Abstract*** *— Several techniques for training assessment in virtual reality environments have computational complexity incompatible with commodity computers performance. Even advanced computers could be unable to process, simultaneously and in real-time, 3D stereo graphics, haptical tasks, users interactions and assessment system. Advanced programming techniques, using specific hardware, can decrease costs of processing, allowing the utilization of low end computers. However, such strategies can be insufficient to guarantee the main features of virtual reality systems. In this paper it is proposed the use of embedded systems to compute specific tasks, to prevent those problems and allowing the use of low end computers. Consequently, embedded systems could contribute to minimize the lose of information and improve performance of assessment in virtual reality training environments.*

*Index Terms — Embedded Systems, Virtual Reality, Training Assessment, Computational Performance.*

## INTRODUCTION

Military war games, problem fixes in outside space, rescue operations into risk areas and medical surgeries are examples of tasks in which there is risk for human being. Realistic environments based on virtual reality have been developed to immerge users into a virtual world, in which critical situations can be simulated. Due to cost reduction, security and facilities of execution, several kinds of training are already performed in these virtual reality environments. In general that simulators demand high performance computers to provide realistic environments with stereoscopic visualization, tactile interaction, object deformation, textures, etc. [5]. However, it is important to know users performance in those training in order to correct deficiencies and improve skills and psychological conditions to execute the real task.

In several kinds of training in the medical area expert physicians assess trainees through videotapes. Such modality characterizes an offline assessment. In this kind of assessment the trainee will receive a feedback with critics and suggestions only some days after the training. This fact offers a great inconvenience for his learning, because the user will not remember several details of that training.

The first papers in training assessment probably belongs to Dinsmore and his collaborators [10, 11, 19]. They proposed a virtual reality environment for detecting subsurface tumors in which the trainee is assessed by a training quiz. The trainee is asked to identify the location and hardness of tumors and to provide a diagnosis. Similarly, Wilson et al. [49] create a minimally invasive surgical trainer (MIST) in which each task could be programmed to deliver several degrees of difficulty. The trainee's performance could be recorded and saved for later replay to be used by the supervisor or for statistical analysis.

In parallel, the assessment of surgical skills has been subject of several authors. Some of them use statistical methods to create models [9]. Others use statistical methods to show that virtual reality systems could help to distinguish between experienced surgeons and inexperienced surgeons [45, 13]. It was shown also that surgeons trained using virtual reality can obtain better results [12] and, besides the considerable variability in their performance [14], it is possible use virtual reality systems to provide metrics for a proficiency criterion to the learning experience [7] [15]. The assessment of psychomotor skills inside a virtual reality simulator using haptic devices can quantify surgical dexterity with advantages over traditional subjective evaluation, as provide unbiased and objective measurement of surgical precision [7]. For these attributes, it was presented the assessment of psychomotor abilities as part of the future of medical teaching and training [25].

In this decade, the research area of training assessment received new impulses, where could be mentioned relevant papers of Rosen et al. [43], Machado et al. [21], Rosen et al. [44] and Moraes and Machado [26, 27, 28]. In those works, the assessment system used Hidden Markov Models and rule-based fuzzy expert systems. Additionally, it was defined two modalities of assessment systems: the traditional offline, in which the information collected during the training are analyzed later, and the online, in which the assessment is accomplished immediately at the end of the simulation.

After 2003, online assessment received several contributions and new techniques proposed by Moraes and Machado: Gaussian Mixture Models [29], Fuzzy Gaussian Mixture Models [28], conexionist models based on neural networks [23], probabilistic networks [35], Maximum Likelihood [30] and Fuzzy Bayes Rule [33, 37]. Nowadays, they proposed also assessment models by Internet [31, 24],

1 Ronei Marcos de Moraes, Department of Statistics, Federal University of Paraíba. Cidade Universitária s/n, Castelo Branco, João Pessoa-PB. 58.051-900. Brazil. ronei@de.ufpb.br
2 Liliane dos Santos Machado, Department of Informatics, Federal University of Paraíba. Cidade Universitária s/n, Castelo Branco, João Pessoa-PB, Brazil. 58.051-900. liliane@di.ufpb.br

continuous assessment [32, 34] and multiple assessment [36]. However, advanced techniques that could be used as basis of assessment systems have high computational complexity and are incompatible with commodity computers. Even medium port computers could be unable to simultaneously run in real time 3D stereo graphics, haptic loops, users interactions and assessment systems [5][6].

Advanced techniques of programming combined to dedicated hardware could result in lower costs of computers and processing, allowing the use of low end computer systems. Thus, in this paper it is proposed the use of embedded systems [41] to perform specific tasks to improve performance of simulators based on virtual reality. This approach is justified by the increase of complexity of training systems based on virtual reality in which it is necessary to monitor simultaneously a large number of variables.

## METHODOLOGY

### Methods for Training Assessment

Advances of training systems based on virtual reality demanded methods to assess users to improve psychomotor skills, psychological conditions and to correct deficiencies in order to prevent mistakes when they execute a real task. As an illustrative example of that necessity [20], the Figure 1 shows a simulator to training new doctors to execute the bone marrow harvest, one of the stages of the bone marrow transplant.

FIGURE. 1
THE VIRTUAL REALITY BASED SIMULATOR FOR BONE MARROW HARVEST TRAINING IN USE.

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. 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 during the penetration of the patient's body [20]. In the system the robotic arm simulates the needle used in the real procedure and the virtual body visually represented has tactile properties similar to real tissues.

Assessment systems can be used coupled to any virtual simulator. In particular, in medical area, invasive procedures simulated in virtual reality can easely demonstrate the advantages and justify the necessity of assessment systems [20]. Assessment system can offer to trainee a report about his performance during the training and with this results, the trainee can improve his dexterity.

The assessment is proceeded by the comparison of patterns with user's parameters obtained during the execution of training. In order to do that, patterns are previously stored by experts, according to M classes of performance. The number of classes is defined by experts, which also supplies their meanings. For example, for *M=3* classes of performance, the meanings could be: 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". However, that number can be defined according to the application. The assessment subsystem must provide also a measure of adaptation of trainee performance for a specific class or for all the possible classes of performance.

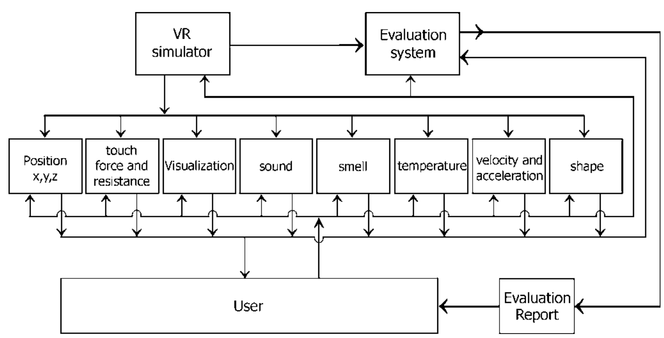


FIGURE. 2
ARCHITECTURE OF AN ASSESSMENT SYSTEM FOR TRAINING BASED ON VIRTUAL REALITY. ADAPTED FROM MORAES AND MACHADO [36].

A training simulator based on virtual reality and its assessment subsystem are interdependent subsystems, which works simultaneously. All subsystems of a simulator (visualization and interaction) and assessment subsystem works together inside of a same computer system. Thus, general performance of simulation must guarantee always to run in real time [5]. Then, the assessment subsystem must obey an important restriction: it must work without compromise the simulator performance and its realism. This way, the research of assessment systems for complex training, in which it is necessary to monitor a large number of variables simultaneously, is strongly dependent of four factors: a) computational complexity of the virtual reality environment; b) computational complexity of the assessment method; c) accuracy of method, once validated its basic assumptions for the specific problem and c) the computer system available to execute training environment and assessment subsystem. The balance of that four factors is not easy to solve. Very realistic virtual reality environments demand high computational costs, as well as may demand interactions using haptic devices and the use of deformable models. These requirements have priority over other subsystems as the assessment. A solution is use methods of low computational cost for assessment. Unfortunately, this solution can cause negative impact over assessment subsystem accuracy. To solve this problem, embedded systems can be used to run high accuracy assessment methods and, for instance, reduce computational costs for the main computer and allow the use of low end computer systems.

**Embedded Systems**

The evolution of computational technologies allows that big equipments used some years ago were replaced by equipments with reduced size, with larger functionalities and higher processing power [3]. Hardware components used in commercial products as cell phones, cameras, palm tops, switches, routers and microwaves with intelligent control were target of that evolution. Some technologies were directly responsible for those progresses, as FPGAs (Field Programmable Gate Arrays) [18], reconfigurable hardware components [45, 8], embedded systems [50], Systems on Chip (SoC) [4] and multiprocessed SoCs (MPSoCs) [49].

Among the technologies mentioned before stand out the embedded systems and their variations [38]. An embedded system is a computational system which does not have a unified definition, but several descriptions according to the knowledge evolution. Some of them are:

- An embedded system is designed to carry out a dedicated function [38];
- An embedded system is a combination of hardware, software and eventually mechanical parts or other, delineated to carry out a specific function [2];
- An embedded system is a computational system with a special purpose, which is design to carry out a small set of activities [41];
- An embedded system is a computational system with more quality and reliability than other kind of computational systems [38].

In this paper the descriptions above are combined and the embedded systems are definied as systems able to execute specific functions with high reliability, reduced size and low energy consumption. They can present similar functionalities to general purpose computers. In some cases, embedded applications in those systems also possess requirements of real time. In other words, they should possess the ability to make certain calculations or to make decisions in a limited time [2]. As example of that systems, can be cited air traffic control, video image processing, pattern recognition, robotic vision, and others [1] [46].

The architecture of an embedded system can variate according to kinds of inputs and outputs. However, it follows the typical architecture of any computational system, as it can be seen in Figure 3. In assessment of training based on virtual reality, embedded systems possess a requisite of time response of a complete assessment of one second or less. Thus, some special requirements of hardware should be observed, as the speed of the processor, amount of main memory and maximum speed of the net connection, among others. However, those requirements are inferior to the specifications of computers available in the market.

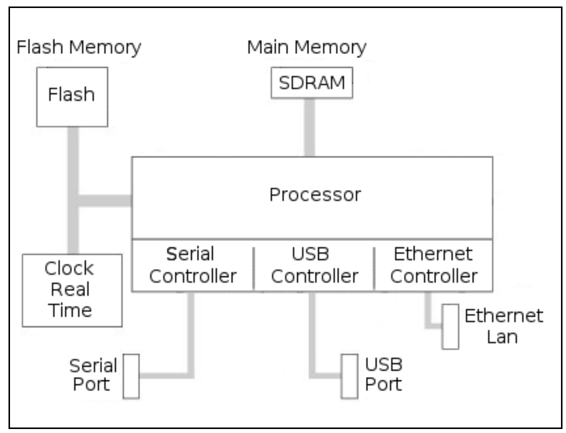


FIGURE. 3
ARCHITECTURE OF AN EMBEDDED SYSTEM.
ADAPTED FROM HALLINAN [16].

In some cases, the processing speed can be accelerated if a differentiated configuration was used, associating a FPGA to a processor in the same system. In that configuration, specific functionalities are moved from processor and programmed in the FPGA, reducing the computational time of the application [39]. That solution use the principle that a combination of hardware and software with high efficiency can take to mixed solutions (called hardware/software co-design), where components that need intensive computation can be executed on dedicated chips [40]. As advantage, only one low-cost processor can be used to solve a complex problem, in opposition to a high-end processor to execute all tasks by itself. Other possible solution can be found by the use of multi-processor embedded systems, with division of tasks among each processor (or core into a only one processor), what can contribute to reduce computational time [47]. In this case, the main advantage is the execution of tasks in real time without the use of a real time operating system (RTOS).

Beyond the choice of a embedded system hardware, the operating system and programming language should follow rigid patterns according to their utilities and minimum performance required to execute the set of tasks for which they are designed. Recently, among several operating system and programming language, the combination of Linux and GNU C/C++ has received some highlight in the literature [2, 16, 17] mainly due to its adaptation to small hardware and high flexibility of services [50].

Some aspects about design of embedded systems were treated by Barros and Moraes [3], as the management of memory for some kind of advanced applications. It is important to note that the requirements strongly depend on the assessment systems proposed to goal the performance planned. From that requirements, it will be possible to define the system specifications and which of the three categories of embedded systems could be used to attend them.

## CONCLUSIONS

Several techniques for training assessment in virtual reality environments have computational complexity incompatible with commodity computers performance. Even advanced computers could be unable to process, simultaneously and in real-time, 3D stereo graphics, haptical tasks, users interactions and assessment system. Some strategies using advanced programming techniques and specific hardware can be used with relative success, but cannot solve some kinds of problems of assessment, specifically when several variables and classes are set to this task.

In this paper is proposed solve this problem using embedded systems to execute the assessment tasks, allowing the utilization of low end computers for virtual reality tasks. This approach is justified by increase of complexity of training systems based on virtual reality. In that systems can be necessary to monitor a large number of variables simultaneously, according to the kind of training.

Embedded systems can also contribute to minimize the lose of information and can improve performance of assessment in virtual reality training environments. Besides, it can contribute to allow to reduce costs of virtual reality platforms and to popularize that technology for commodity computers.

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