ON THE USE OF VIRTUAL REALITY TO TEACH ROBOTICS

Marcelo da Silva Hounsell[1], *Alexander Pimentel*[2]

Abstract *-- This article discusses criteria to the use of Virtual Reality (VR) for engineering and computing teaching, in particular the teaching of robotics (robots anatomy, functioning and off-line programming). How a web-based VR system for teaching purposes has been implemented will not be discussed but the advantages and potentials that such implementation can bring to the teaching of robotics. These expected benefits will be compared against what was actually achieved considering limitations of the technology as well as human (students') factors and expectations. Therefore, a borderline will be suggested to help identify the suitability of an application to be implemented using a specific VR approach (high-end immersive or low-end non-immersive). It was found that there is a great enthusiasm that surrounds the topic but a lot has to be done in order to find a proper matching between VR and traditional teaching resources, in particular, to the teaching of robotics.*

Index Terms -- Immersive and Non-Immersive Systems, Robotics, Teaching, Virtual Reality.

INTRODUCTION

Robotics and Virtual Reality (VR) are two distinct concepts surrounded by a lot of misconceptions. The former is usually related to intelligent and mobile human-like robots. The later is usually related to computer-generated and visually appealing reproductions of the world, good enough to confuse the viewer and his/her sense of reality. In fact neither of them are at this marvelous stage yet. These understandings however, could be put as goals for the (still distant) future. Despite the confusion, Robotics has been evolving fast as well as VR [4] and it is not difficult to see how the second can help understand the use of the first ([8]-[14]).

Much has been said and researched on the use of high-end VR into education and this has proved very successful ([5] and [12]) despite the fact that it can not be easily widespread to a bigger audience due to costs restrictions. What seems to be very important to investigate is the use of low-profile VR environments into education because these tend to be the entry-level environment that most learners are destined to face in the near future, at least in developing countries.

This paper not only discusses the use of VR for educational purposes but also the requirements and suitability of an application to a specific VR system implementation.

DEFINITIONS

Rescuing Virtual Reality Basics

Virtual Reality is considered the most advanced computer interacting technology which can promote multi sensorial experience and involve the user in such a way that s/he will not bother to acknowledge if it is the real world or a synthesized one. The user involvement with the system is much more important than the graphics which, not always, is trying to model a real environment [11]. Therefore, the term Virtual Reality (VR) was severely criticized and the term Virtual Environments (VE) came later. Despite the fact that the scientific community has accepted the arguments, people in general refuses to use the correct terminology because VR became very popular. It is important though, to the discussion in this paper, to understand the technology's correct goals and definitions.

VR systems can be divided into two main approaches: Immersive VR (**IVR**) and Non-Immersive VR (**NIVR**). The distinction is not really related to the ability to promote the immersion sensation but to the use of devices that hides the real world from the user, or not.

IVR imply the use of output (such as a Head Mounted Display - HMD) and input (such as a Data Glove) devices which transfers the user's gestures to the synthesized world. Because of the extra hardware configuration and the need to produce better and fast graphics, the computer power is of high requirement. In addition, there were reports that users of IVR experienced motion sickness and fatigue [10].

NIVR, on the other hand, do not imply any specific hardware beside the existing user's monitor, CPU and mouse. This simplification eases the hardware requirement at the same time that widespread the technology's concepts. Even to graphics, it can be said that NIVR do not need to look good but roughly good; on the verge of the reasonable. In this way, it does not demand much computational performance.

Special cases of NIVR systems are those that can be explored through the Internet and which became feasible much thanks to VRML (Virtual Reality Modeling Language) technology (www.VRML.org). Web-based NIVR is considered a great advantage of Non-Immersive VR over Immersive VR approach. It also allows the use of VR-like

[1] Marcelo da Silva Hounsell, B.Eng., M.Eng., PhD. DCC-CCT-UDESC, Campus Universitário, Bom Retiro, Joinville, SC, Brazil, 89223-100, marcelo@joinville.udesc.br
[2] Alexander Pimentel, B.Sc. DCC-CCT-UDESC, Campus Universitário, Bom Retiro, Joinville, SC, Brazil, 89223-100. Alepmtel@ig.com.br

applications for marketing and collaborative works at acceptable costs. Although Web-based NIVR is much simpler than IVR, it cannot be confused with Simulation softwares. IVR excels in interactivity while Simulation is far the best in accuracy. In most cases, VR needs to **look** accurate, not necessarily to **be** accurate. Table 1, summarizes the differences between Simulation, Non-Immersive VR and immersive VR softwares.

TABLE I

COMPARISON OF SIMULATION, NIVR AND IVR SOFTWARES

Simulation	Based on complex mathematical models, must be accurate Aims at precision and completeness High computational cost for calculations Not very much interactive Useful for detailed analysis via playback
Non-Immersive VR	Based on simpler mathematical models Do not demand much calculations and graphics Aims at interactivity on conventional hardware Promotes immersion by intense interaction Do not need to be correct but, look correct
Immersive VR	Based on mathematical models, focused on the phenomena of study Demands special hardware and high computational costs Allows highly interactive environments Immersion is facilitated by the hardware

While promoting VR, developers are used to convince clients to adopt it based on the benefits and advantages that outcome from high-end IVR implementations. But due to cost restrictions, contracts are usually settled on low or medium-end NIVR implementations, only to end up with frustrated clients. The benefits that can outcome from IVR and NIVR implementations are not fully clarified nor completely identified. Application's features need to be analyzed against the suitability to an IVR and NIVR implementation. What this paper discusses is the actual borderline of potential benefits for different approaches and discusses if it is really interesting to consider VR implementation at all.

EDUCATION AND TRAINING

Another clear distinction that must be drawn is between education and training to help identify the role of VR in this context [11]. The later has found in IVR applications great proficiency and productivity. The former is yet to be proved, although there is a general feeling that many benefits can come from it. Education is related to concepts, knowledge and understanding while Training is related to reflex development, know how to do and, handling skills.

For educational (not training) purposes there must be a pedagogical paradigm to guide the experience and direct the development. Interactivity is the concept that will allow the students to explore the environment which therefore, must be implemented in a way to make clear the knowledge structure and hierarchy and consider all types of pertinent media (text, graphics, animation, video, etc.) as well as when, how and why use that specific media for that specific information. The visuals of a VR application also help build a motivating environment if modeled as interesting scenarios.

For training purposes, the use of the environment is different. Training requires a realistic response to events. Also, a better degree of realism (real time rendering) is also required due to the fact that the sequencing of events should not be compromised or the whole experiment would be also compromised.

The trainee should develop motor skills as well as strategies to solve them problems. To assess the trainee performance it is much more difficult because most of the metrics are based on a mix of strategies and timing.

ROBOTICS FUNDAMENTALS

A standard "robotics fundamentals" syllabus would include: History, Concepts Evolution, Robots Classifications, Anatomy, Kinematics (direct and inverse, Denavit-Hatenberg calculation), Task Planning, Teaching and (off line) Programming [13]. The ideal scenario would be to allow the students to have hands-on the actual robot for some experimentation in order to give them the sense of complexity, to understand the relationship and co-ordination of the robot links movements and hierarchy as well as their response to pitch, yawl, roll and other commands either at joint spaces (Robot coordinate system) or world space (Euclidean coordinate system).

To that aim, schools face the problem of offering enough robots for all students and, at the same time, giving continuous assistance and supervision in order to help the students avoid accidents to themselves and to the robots. This dilemma can be better handled (not fully answered though, as we will see later) if some sort of specific Robot Simulation package is used. However, specific Robot Simulation softwares are very expensive, tailored to a specific robot manufacturer, can not be experienced through the internet, have closed codes that do not allow the students to understand how they work and do not allow them to interfere into the code (for post-graduate students, for instance). An alternative approach must be considered.

GENERAL EXPECTED BENEFITS OF USING RV FOR ROBOTICS TEACHING

Computer graphics as a whole has evolved considerably and has aided a lot on engineering teaching and, VR applications are no exception. The use of a VR approach to implement robot simulators could be very training effective. For instance, McLachlan [8] has developed a NIVR robot simulator that paid special attention to the interface: it could be via 3D mouse or by a robot's specific Teach Pendant model. There is a lot more convincing evidence that one can use VR systems for educational purposes ([12] and [14]).

Some of the most significant expected benefits related to the use of VR to teaching robotics are summarized as follows:

Space and Proportion. VR applications can be used very effectively to develop the sensation of space and proportion at the same time that it can be totally non-dimensional as it can model and present galaxies in the same way it can show molecules and atoms. Robots are composed of articulated limbs that reach objects within a specific working volume. A working envelope is a spatial and proportional feature of all robot's limbs working together.

Automatic Monitoring. As an educational aid, a VR application must offer a way to assess the experience automatically and this can be made explicitly and textually via direct questioning but also by monitoring all the interactions implied by the user to achieve his/her tasks. Continuous monitoring not only guarantees the contents understanding but also help on their apprehension.

Scenario Variability. The option of various scenarios is a must in case of training because the trainee must be able to perform consistently despite of the details of the experience. To that effect, the system should be able to automatically construct different situations intelligently and with a high degree of integrity to what is being learnt, promoting both variety and quality. For educational purposes there is the same requirement but it is because of the boredom of unchanging environments.

Availability. Simulators as a whole (including VR ones) are much cheaper than the actual apparatus and because of this can be much more available. Details that contribute less or nothing to the actual operation can be filtered out of the virtual environment and installing a software is, most of the time, a much easier task than installing a complex, big and expensive machine (those that are complex enough to justify an exhaustive, detailed and rigorous training program).

Security. Security issues are one main advantage of using a VR approach at all. Not only the equipment and the whole investment are protected from misuse and accidents but also, the students' integrity are guaranteed. Other real and specific security measures can be imposed by the system, making sure that the student get used to them before going after the actual robot and, even better, this can also be assessed automatically and individually by the system. These features are considered of much importance because they relate to attitudes before the technology.

ACTUAL BENEFITS

A Web-based NIVR robot simulator implemented. Particular interest has been paid to allowing off-line programming, not yet fully implemented though. The technology applied was Virtual Reality Modeling Language (VRML).

Handling Proficiency. It was found that a Web-based NIVR robot simulator could help the student get acquainted with the interrelationships between the robots limbs. Students explore and start to develop strategies to get around fast in order to complete a task. This exploration allow proficiency on controlling the robots movements one degree-of-freedom (DOF) at a time and this is very useful for a later Teach Pendant programming task.

Open Source. One very important feature of the Web-based NIVR approach is the fact that the students can have free access to the source code of the VRML implementation and thus, they can investigate how the calculations are performed but also, they can modify the code to comply to new situations on teacher's demand. Further, the code can be re-used and fine-tuned to more complex models (with an extra DOF, for instance).

Supervision. Although thought unnecessary to supervise the students on performing a task, it was found later that some students feel more comfortable to have the teacher's continuous assistance and to do this, a Web-based NIVR approach can also be useful because it allows various students to get together in a lab and the teacher to assist all of them at the same time.

Strategies. Better than simply allowing off-line programming, which is a reasonably simple task if compared to computer programming, exhaustive repetition of the same experiment allows benefits that resembles a training approach. Beyond this, due to the high availability of the "virtual robot" the student can be freed of the pressure to complete a task but concentrate on establishing better strategies to solve the task. Strategies usually come from a lot of experimentation and experience and are difficult to teach because it is a complex mental model on how to solve a problem. To that aim, a Web-based NIVR can be very helpful.

PROBLEMS FOUND

Analyzing the actual use of the Web-based NIVR robot many problems can be pointed out:

Expectations. NIVR are not up to the user's expectations standard (built upon distorted concepts that came from science fiction novels). Although useful, NIVR approach would not substitute "the real thing" because they lack the ability to involve the user in such a way that can promote an effective immersion. This is so because the environment in focus does not actually provide, and is not much interested, in the exploration or navigation resource once the object of study is a fixed location object (manipulator robot).

Visuals. The visual fidelity was not an issue at the beginning because it was understood that "RV is not really about perfect graphics and perfect visual aimed to confuse the viewer but RV is actually an interactive technique demanding satisfactory graphics that could transport the user to another world" ([3] and [11]). In addition, as the object of study is fixed to a position this also compromises some of the great benefits advocated to IVR: exploration. Therefore, as the user's attention is most of the time focused on a specific object (robot), the visuals start to become an important issue.

Timing. The robot that was implemented did not actually take the time that a real robot would take to move about. This was thought as an advantage at the beginning because it could speed up the experimentation process and analysis. However, the sense of mass and fast/slow response was found to be an important information to be embedded in the virtual robot in the same way that a giant do not move about so fast and that a dolly lady has a high-pitch voice, which are well established 3D character animation features that brings real live constraints to viewers subconscious [7]. Fast-forward simulations go in the opposite direction of those well-accepted and mature ideas from 3D character animation. This could give the students an extra and important information: common sense relationship between inertia and movement. Also, students would value the fact that robots do not respond as fast as they want and that inertia and other physical phenomena are controlling the robot movement.

Despite of the virtual environment, students have shown interest in using the actual robot, maybe because of the limitations of a Web-based NVR approach that is not really very suitable to develop a proper perception of mass, proportion and dimension.

Cost-benefit analysis. The enthusiasm on VR applications has diminished the need of a proper cost-benefit analysis. It must be said that there are a lot of situations where the use of the "real thing" is feasible and cost-effective or where other cheaper techniques can be very appropriate [2].

Care must be taken because VR has been considered as a "silver bullet' for every graphical application. This is also a misconception but VR potentials must be recognized. VR is a good alternative if one of its basic concepts (immersion, interaction and imagination; [3]) is effectively implemented or if, preferably, all of its concepts are thoroughly explored. However, we have found many applications where **some** of VR concepts are roughly explored. This unsuitable and unmatching attempt raises the questioning not only on the applications of VR to that specific application but also on VR as an interesting and feasible aid to teaching at all.

No methodology. It is worrying to find that, although some claims have been made on new methodologies targeted on developing VR applications ([1], [6] and [9]), no specific development methodology targeted could be found. A specific methodology would emphasize and maximize the potentials of VR concepts (immersion, interaction, navigation and exploration) in the same way that it would exclude graphics-oriented-only applications. Even more, if no specific VR development methodology were found, one can tell how difficult it could be to find a methodology that comply to a sound teaching-learning paradigm and, to our knowledge, no pedagogical-didactical theory yet have suggested the use of VR as an inherent medium.

Therefore it is still important to discuss how VR can be used for educational purposes, what sort of content's features could be better valued on a NIVR or IVR approach. This paper aims to bring some findings into this discussion.

It seems promising to borrow and adapt methodologies from web-sites design and multimedia development to build NIVR applications because there are some similarities.

TABLE II
MATCHING OF VR APPROACHES TO APPLICATION'S FEATURES

Feature	NIVR	IVR
User need to alter the source code for free experimentation	++	--
Availability through the internet/ Can be used for distance learning	++	--
Allow collaboration between students (Taxen:594)	++	--
Cost effective	++	--
Availability of "developing methodologies"	++	--
Single fixed object of study	++	--
User need to interact with textual media (access and run an off-line program, for instance)	++	--
Interactivity	-	++
Sense of Immersion	-	++
Allow eavesdropping supervision/monitoring	++	--
More than one user at a time in the same room	++	--
Requires better graphics and realism	++	+
Motivational Environment	+	++
Facilitate interaction with "the real thing"	-	++
Need to develop skill related to proportion and dimension	--	++
Resembles science fiction devices, which raises the user's (misconceived) expectation	--	++
Resembles simulation packages, which raises lower expectations	++	-

Because of this NIVR applications development is closer to mature into a more adequate tailored methodology if compared to IVR applications.

Table 2 shows of the application's characteristics highlighted above together with others and the suitability of them to be better implemented as an IVR or a NIVR approach. The sign "++" indicates a feature to be most suitable to that specific VR approach while "--" indicates that it is not really suitable to that approach.

CONCLUSIONS

This paper has briefed robotics and virtual reality (VR). VR systems have been divided into two main approaches (immersive - IVR - and non-immersive - NIVR) and these have been compared altogether with simulation softwares. It was highlighted that a big gap exists between NIVR and IVR systems in a way that the first is tied to simulation or video game standards and expectations while the last is much more productive but requires a much better financial background.

It was found that some high expectations exist by the audience due to misconceptions broadcast through science fiction films and novels. These expectations are even farther from reality if considering a NIVR approach. The tricky business is to morph expectations into a motivational drive in a way to avoid frustration instead.

The paper have shown potential benefits of an IVR and of a Web-based NIVR approach which were then discussed against actual benefits. A comparison of these benefits have shown clearly that a big gap exists between them and a clear borderline can be drawn to the suitability of one approach to achieve an specific application's feature.

Despite great advantages, VR do not give students the confidence to play with the real thing and some skills (mainly related to the equipment and its surroundings security) need to be further developed. It is believed that students have shown interest in using the actual robot because of the limitations of a Web-based NIVR approach that is not very suitable to develop a proper perception of mass, proportion and dimension.

Researchers are still exploring development methodologies that could be adequate to VR applications, in the way that it assess the fitness of the application as well as matches and emphasizes the conceptual framework backing VR: immersion, interaction, navigation, involvement.

It can be finally concluded that a Web-based NIVR approach to develop an application to teach robotics is an ideal tool because it is cheaper, more easily available and allow more intensive trial and error use of the concepts. Also, the basics of robotics seems to be better explored if using an IVR approach while programming seems to be better implemented if using a NIVR approach and, valuable benefits outcome from both approaches that suffices to maintain the enthusiasm on using VR to teaching robotics.

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