Encouraging the application of Virtual Environments for space training

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***Abstract*—The technological advances have enabled the development of many arenas. In this sense, one of the main research topics that is gained importance and visibility is *Monitoring*. In a general way, it consists of observing an event, situation or process in order to check its quality and discover anomalies. Monitoring/simulating the data helps to detect problems in a short period of time and reduce costs if the monitoring process can be embedded in a (3D graphical) environment that avoids the need of duplicating, sometimes, very expensive artifacts.**

In this paper we review the virtual environments research that has been produced for simulation or training in different areas such as medicine or education. Our aim is to encourage the use of this kind of tools into the dangerous and expensive space domains. For that, we propose a virtual environment that combines a 3D graphical interface and an intelligent tutoring system that emulates, as far as possible, a training/instruction with a human tutor.

Monitoring, Simulation, Planning, Space training, Virtual environments

I. Introduction

Monitoring is nowadays vital in most areas such as medicine, education or vehicle assistance because it helps to detect problems in a short period of time. Monitoring applied to the educational arena is the activity of tracking each student's progress as it progresses through the training sequence. If this process can be embedded in 3D graphical environments the benefits for the users are straightforward since the results are graphically accessed [29]. A Virtual Environment (VE) allows the development of dangerous or high cost activities without taking risks. The combination of VEs with Intelligent Systems resulted in Intelligent Virtual Environment (IVEs). Finally, if the environment is used for training is named Intelligent Virtual Environment for training (IVETs) [1]. IVETs are basically composed of a VE and an Intelligent Tutoring System (ITS). Thereby, the benefits of 3D environments, such as the simulation of high risk, very expensive or difficult-to-reproduce situations combined with the ITS advantages, like customization or adaptation of the tutoring strategy to the user, provide more personalized training solutions [2].

The classical structure of an ITS is composed of four main modules: Student (record the student's actions), Expert (contains preconditions and consequences), Tutoring (provides a list of the available activities) and Communication (relate the student and tutoring modules) [3]. Nevertheless, these modules, which were responsible to store the data, were not designed taking into account the possibilities of interaction derived from the use of VEs. The new information obtained in the learning process becomes essential, for the evaluation and diagnosis of the knowledge state, allowing the software tutor to select the most suitable tutoring strategies. Thus, it is necessary for the classical ITS structure, embedded in the IVET, to be enriched by these aspects, while keeping a clear, structured and well defined architecture [2]. There are numerous works and studies displaying the relevance of VEs for training purposes. These environments were really expensive some years ago, nevertheless, new emerging technologies have reduced the costs associated with VEs. Nowadays, two of the most used platforms for developing virtual worlds are OpenSim [4] and Second life [5].

In this article we want to review the VE research that has been produced for simulation or training in different areas. Our aim is to describe the benefits of adopting this kind of tools in Aerospace domains, characterized by high risk and cost. The paper is structured as follows. It begins with a brief description of some important related work on the training process (in general and in space). The paper continues with actual space training needs where IVETs can be useful. The paper carries on with a description of the proposed solution including a general overview of its architecture, composed of a learning management system and an ontology network. Finally, some conclusions are outlined.

II. State of the Art

There are many virtual-reality based training simulators used in different areas. Next we revise the main proposals.

In the field of medicine, we can basically mention:

(a) **LAHYSTOTRAIN** is a surgery training environment based on VR developed to prepare surgeon in Laparoscopy and Hysteroscopy operation. The tool consists of an advanced training system (ATS) divided in pedagogical and support agents and a GUI. Personal and surgical data are stored in a very simple student model [6].

(b) **VI-MED** is a nursing IVET based on a game thereby preventing possible hurts or risks to patients. This project is

978-1-4799-7007-0/14 $31.00 © 2014 IEEE
DOI 10.1109/EST.2014.29

composed of a simulation game and an evaluation system divided into a tutor and an assistance agent. Information is stored in a student model throughout a web-based system. The student profile is updated by means of rules and the difficulty level is modified according to the data [7].

(c) **DTS** is an intelligent dental training simulator with objective skill assessment and the feedback was developed to provide students an IVE for dental surgical practice. The student data is first recorded and then analyzed according with expert techniques. This tool is not based on agents and provides a small student model [8].

Other works are focused on the educational arena such as:

(a) **STEVE** is an animated agent created to help students to do physical activities based on a determined procedure. Steve does not provide a complete student model and does not know the next steps a student should do [9].

(b) **ADRI** is a framework built in a VE and created to teach how to play the piano to multiple users at the same time. The system is based on multiple agents: Visualizer (display the 3D world), Midiator (captures the sounds), Expert (provides the songs), Analyzer (transforms the sound), Navigator (plans the next song according to the user's level), Feedback and Observer (evaluates the student) and supervisor (controls the agents). Data is stored in a very simple student model [10].

(c) **TLCTS** aims to teach autochthonous languages to the military staff who participates in abroad missions. The application provides: a student model which contains the student capacities, a simulation engine that offers the answer and an action planner to communicate the data to the graphical engine [11].

(d) **MAEVIF** is a platform created for students to easily interact with the scenario by means of devices (mouse, keyboard, gloves, etc.). The project architecture is divided into a VE and an ITS (composed of many agents) and provides a wide ontology-based student model [12].

Other projects are linked with the use of vehicles such as:

(a) **MASCARET** is a model based on a multi-agent system to simulate an IVET created to fireman training in operation management. The model is organized in different entities (Organization, Role, Agent and BehavioralFeature) to simulate a realistic physical and social environment and communicates with the ITS (divided into domain, learner, pedagogical an interface model). MASCARET does not provide customization but they recommend the use of machine learning techniques to adapt the environment [13].

(b) **Virtual crane** integrates an affective computing concept for measuring the level of satisfaction and knowledge throughout bioelectrical-signals to adapt the user's affective status in a real case. The project contains two IVETs to simulate crane movements and allows customization [14].

(c) **Aircraft training** is a project where a VE was created for studying aircraft evacuations under panic or stressful situations. The platform is composed of many expert agents that control the data [15]. The project does not contain any student model neither an ITS.

Other projects based on IVEs are:

(a) **JACOB** is an animated agent integrated in a 3D VE**.** The project aims to solve the Hanoi Tower's problem by means of VR techniques. There are two simple models (task and instruction) which control the Agent. Nevertheless, the student model has not been implemented in JACOB [16].

(b) **HERA** is an ITS integrated into a VE which was proposed to the high-risk training. HERA is a model-tracing tutor that communicates with other components such as the world model (based on an ontology network) an interface module (communicate the VE with other modules), recognition module (contain the information of student tasks) a learner module (store the activity trace) and a risk module (warn about the possible mistakes) [17].

(c) **MRE** was a learning environment where users tried to solve determined problems in simulated scenarios where sights, sounds or circumstances of real-world scenarios can be found. It is based on STEVE [18].

In the specific scope of space training/instruction, some VE projects are:

(a) **Virtual reality for aircraft visual inspection training** is a VR system for aircraft inspection training. The tool offered an engine to develop the simulator and a binocular to produce effects to the user. The VR environment is based on analytic methodology, data are stored by means of observation and capturing techniques, nevertheless the project was too expensive, lack of intelligence and used hardware is nowadays deprecated [19].

(b) **Virtual glovebox** is an immersive 3-D virtual desktop environment for training astronauts developed by NASA and integrated to the International Space Station (ISS) [20]. The system integrates real time simulation technologies, gravitation mode and different scenarios. The tool monitors the data but is not intelligent.

(c) **VE-View** is a modular platform based on PC created to evaluate VEs for astronaut training in zero-gravity conditions. VE-View software is the responsible for implement the zero-gravity technique and develops an astronaut training prototype. This training is composed of General Astronaut Skills (flying, survival or language), Advance Training for a year (generic ISS operations) and Increment-Specific Training for eighteen months (tasks to a particular mission). VE-View hardware provides the material for mounting the projectors, screen frames, etc. This platform is neither intelligent nor active [21].

(d) **SimStation** is an engineering decision support tool which provides an environment for the ISS. This project is currently in application phase and the main customer is the Space Station Vehicle Integrated Performance and Resources (VIPER) Team. SimStation allows an environment customized adaptation and monitor information such as solar angles. The platform does not contain intelligent agents [22].

Table 1: State of the art on IVETs tools and platforms

NAME	TECHNOLOGY	EXPERT MODEL	TUTORING MODEL	STUDENT MODEL	APPLICATION PHASE
VI-MED	WEB, DATABASE, 3D	✗	✓	ADVANCED	ACTIVE
TLCTS	WEB, LMS, DATABASE	✓	✓	BASIC	EXPERIMENTAL
MAEVIF	ONTOLOGY, 3D	✓	✓	ADVANCED	NON-ACTIVE
AIRCRAFT TRAINING	WEB, 3D	✓	✗	NONE	EXPERIMENTAL
HERA	ONTOLOGY	✓	✓	ADVANCED	NON-ACTIVE
SIMSTATION	DATABASE, 3D	✓	✗	ADVANCED	ACTIVE
DTS	DATABASE, 3D	✗	✓	BASIC	NON-ACTIVE

Table 1 summarizes the main features of the IVETs described above. We can see different technologies (Database, 3D, Ontology, Web, LMS), the importance of expert and tutoring model in IVETs tools, the need for providing an advanced Student Model (four tools and platforms contain an extensive student model) and finally the current use of these tools (only two are active projects).

III. SPACE TRAINNING NEEDS

Nowadays, one of the most notorious challenges faced in space is the ISS. It is a joint collaboration project among the most prestigious space agencies in the world. It provides a platform with zero gravity to perform scientific experiments as well as a new environment to study how humans can adapt to these new conditions as well as the effects of long-term space exposure.

The current resources constraints and the high risk in the missions suggest a need to monitor the data to quickly detect the problems. Applying this strategy to the training system, it is possible to control all the information about the astronauts or other associated people to the mission. At the present time, there are some ESA/NASA works closely related to improve the training system (general, specific, team work, etc.) and people related to the space area require testing themselves in as many challenging situations as possible. So, upgrading training methods and preparing personalized plans will increase the skills quality. On going work in this area is guarantied as shown by the ESA's Intended Invitations To Tender (ITT): *Crew Information System*, which main goal is to provide support to the crew in their daily activities.
Another important research line to take into account is the development of virtual environments through Virtual reality (VR). VR allows us to simulate any physical environment (real or imaginary) including sensory experiences. Thanks to the artificial intelligence (AI), the space agencies can simulate any experiment without any risk such as a space shuttle takeoff or the process of repair a piece in a limited period of time. VE are currently applied in some space missions, in this way, NASA started to develop in 2008 a VE Interface for Remote Inspection. The aim of this interface is monitor a simulated free flying inspection vehicle that is designed to detect damage to an Orbiter's thermal protection system [23].
Moreover, this virtual environment project intents to be safer (less life problems), cheaper (only success experiment are executed) and faster (problem detected are corrected in the instant) than activities in a real one.

Rover drivers can also be trained using this type of tools. Actually, they use duplicates of the rovers on Mars for learning how to use them by means of simulating similar terrains on Earth. This training process is long and it usually takes one year until the person can full operate the rover. They also simulate the rover behavior along the terrain is going to traverse, using in the case of Curiosity, the RSVP [27] rover sequencing and visualization program. Unfortunately, it does not provide any kind of feedback on how to properly operate the rover.
Then, training in space opens the possibility of using IVETS for improving and reducing the cost and duration of the training procedures.

IV. OUR APPROACH

The IVETs are especially useful in the field of computer-based learning for training in procedures or tasks which involves some risk in the real world, or the real scenario in which they perform are hardly reproducible or, even, irreproducible for training scope. In this regard, some interesting examples of application domains of IVETs are operations of astronaut training missions for Space Exploration: EVA (Extra-Vehicular Activities), training of Rovers Control, training in emergency situations, in order to avoid risks, such as training in spacecraft emergencies, training of emergencies during a spacewalk, etc. It is in this area where we focus on the application of our architecture proposal shown below (see Figure 1). This architecture is an extension of the Clemente et al. [2] work regarding to Student Model.

A. Ontology Network

The use of an ontology network for modeling the information is appropriate because: (a) it is easily extensible in different application context, (b) it allows the diagnosis throughout rules, (c) it supports the representation of abstract concepts and properties and (d) it enables the reasoning on the information contained in the ontology.

Related to procedural knowledge, actions become especially interesting in an IVET, because astronauts/operators own an avatar which is physically present in the virtual space and allows him to move around and interact with the virtual objects. The ontology will incorporate an entire taxonomy of actions classified from different perspectives and based on a multiple inheritance scheme. Aside from the taxonomy of actions, the ontology network will contain some concepts for specifying the plan structure.

B. Summary

The general functioning of the architecture is as follows:

The student will start a training session when he connects to IVET. Then, according to the profile of the student, their past performance in the course and instructional design of the course itself, *Training Tutoring Module* (see Figure 1) must decide what exercises or training activities are available to the student (astronaut, scientist, etc.).

Information concerning the student is stored and managed by the Student Model -*Student Module* in Figure 1- (student profile, knowledge objects involved in the course, learning objectives for each activity/ practice of the course, dependencies between learning objectives and knowledge objects, information on previous learning sessions through EVIE including: student traces trajectories, actions performed, etc., cumulative status for each student –objective states, etc.-). For more details, see Clemente et al. work [2].

C. Expert Module

Once the student has chosen one of the activities available, the *Training Tutoring Module* needs the *Expert Module* (and, specifically, our Integrated Planning and Scheduling Systems *PIPSS* [28] as shown in Figure 1) provides the right way to solve that activity. If the objective of the course is training in procedures/tasks, which is frequent in such environments, the activity solution is a plan of actions or sequence of actions that the student must perform to complete the task successfully. An action in the IVET is defined as the application of an operator that is associated with a set of preconditions and consequences. *PIPSS* allows dynamic construction of solution plans, taking into account the current state of the learning environment, the desired end state, and the possible student's actions. If a student at a given time deviates from the initial activities in the plan, *PIPSS* may provide the re-planning of a solution plan.

D. Tutoring Module

The Tutoring Module is responsible for their specific tutoring strategy (see *Tutoring Strategy* in Figure 1), that is, its behavior during the development of the training/instruction course. This strategy should mainly include a set of phases (among others, the start of the session or control of the student activity execution comparing it with the activity plan, as seen above), an evaluation strategy of activities executed by the student during the course learning, a help system which can include different levels of hints provided to student, several categories of questions asked by the tutor proactively to guide students when they do not know what to do next, and its own algorithm, etc. Therefore, the Tutoring Module is also responsible for deciding when the learning activity must end taking into account the varied scenarios that may occur during the student training. For example, the student has been able to carry out the activity plan successfully and then, depending on how the activity has been executed, the tutoring module selects the next learning activity to do, or the student has reached a "dead end" because he had a knowledge gap and Tutoring Module could redirect him to previous topics to address these gaps, or the student could exceed the maximum working time stipulated for the activity because he has made too many mistakes (in this case, the tutor may recommend to the student, for example, some specific training activities directed to correct them), or because the student's behavior indicates that he is too tired or distracted, etc. In all scenarios, the tutor must decide the most appropriate time to end the activity.

E. Training Tutoring Module and Student Module

Inside the VE, the student can perform actions such as picking up objects or pushing buttons. All of these actions will be sent to the *Training Tutoring Module* and registered by the *Student Module* in form of a trace of the student's activity in *Student Ontology*. Also, every time the student executes an action (or, at least, tries to do it) in the VE, the *Student Module* must update its beliefs about the learning objectives that the student has already achieved or not. In this way can inform the *Training Tutoring Module* that the student's knowledge state.

F. Pedagogic Diagnosis Module

Throughout a training session an astronaut/operator/driver rover can perform different actions in the IVET. Each specific

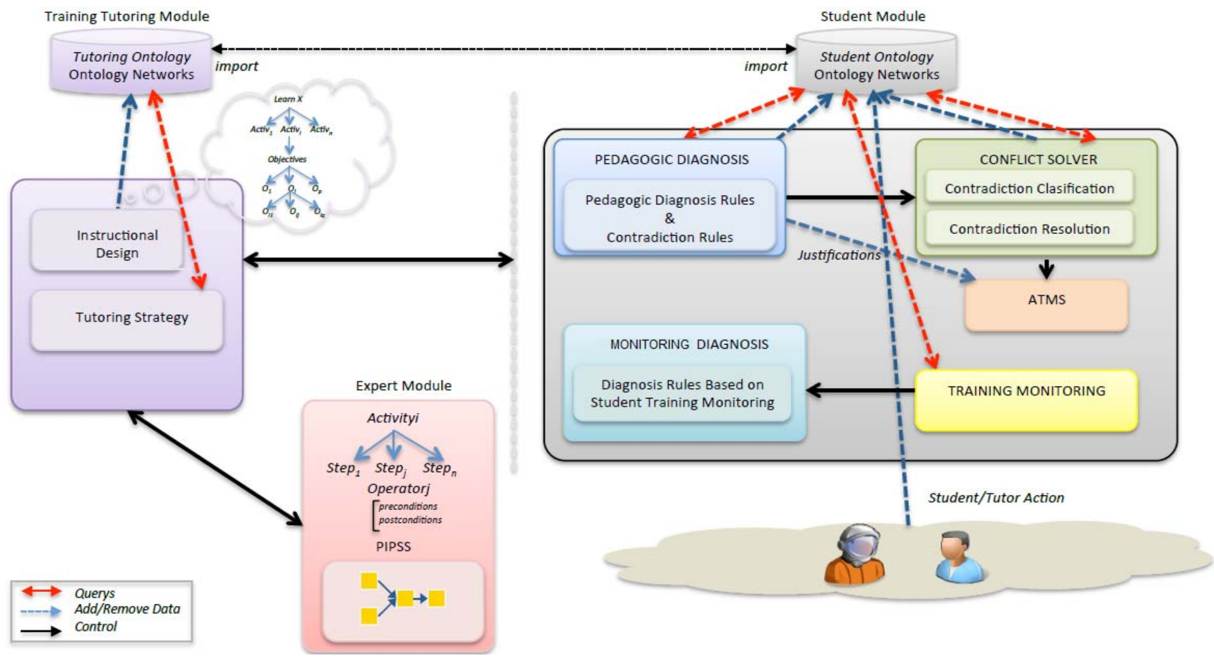

Figure 1: Overview of architecture proposal to Intelligent Virtual Environments for Training.

action executed causes the triggering of some diagnosis rules (see *Pedagogic Diagnosis* Module in Figure 1).
Then, the proposed platform can help in reusing knowledge from mission to mission as well as sharing the information between space agencies that are going to face similar projects with similar training procedures.

G. Conflict Solver and ATMS

Thanks to these rules, we can infer the objectives that have been achieved or not by the student and the state of his/her knowledge. Rather than inferences, the diagnosis provides reasonable assumptions, since some of assumed objectives and knowledge elements may be refused later, when more recent evidence provokes inconsistencies in the beliefs of the model (the *Conflict Solver* Module in Figure 1 is responsible for this task). Taxonomy of conflicts that may arise during the diagnosis process in the set of model beliefs is defined, as well as the resolution mechanisms for restoring the consistency. This taxonomy and the Assumption-based Truth Maintenances System *(ATMS)* module role (see Figure 1) for contradiction management are explained in [24].

H. Monitoring module

To further improve the monitoring of student learning in our proposal we have also included a new module so-called *Monitoring* Module which allows the tutor software (*Training Tutoring* module) or the student himself to track the evolution of their learning during training and, on the basis of monitoring indicators [26], to infer by a set of diagnosis rules (*Monitoring Diagnosis* module in Figure 1) an additional information source on the learning student state to provide the tutor / student a teaching/learning more adaptive, according to the characteristics and student's knowledge state in each moment of his training.

V. Conclussions

In this paper we have firstly reviewed the VE-based projects and platforms that were produced for training in different areas. The technological advances are the responsible VEs are increasingly used at present time. New platforms such as Second Life or OpenSim allow the creation of Virtual Worlds and IVETs easily and in an inexpensive way. These platforms are especially useful when the environment is dangerous or expensive. Some analyzed research incorporated a not complete student model (LAHYSTOTRAIN, DTS, STEVE), others lack of an ITS (STEVE, VE-VIEW, SimStation), many of them are based on tutoring or supporting agents (MAEFIV, Aircraft Training) but only a few of them are in an application phase (VI-MED, MRE, SimStation).

Secondly, space training needs have been shown. Space missions are often expensive and dangerous so, the use of VE in many activities helps to reduce or avoid the risk. Besides, monitoring the data is essential in this environment to detect almost instantly any anomaly found. In general, Space Agencies need to control each detail meticulously because a simple mistake can ruin a mission.

We have thirdly described a solution to create an IVET for the astronaut/operators/rover drivers training. This IVET is composed of a Student Module and a Training Tutoring Module based on an ontology network, an Expert Module that provides the way of solving the problem, a pedagogic and a monitoring diagnosis module to infer knowledge and offer a personalized and adaptive system according to the individual characteristics respectively, a conflict solver and an ATMS for managing inconsistent situations and a monitoring module which allows teacher and students to track the evolution of the student learning process.

We should emphasize the importance of the use of VEs and, specially, of IVETs and its advantages, including its possible lower cost or limited risks. It can benefit and enrich greatly the monitoring and supervision of space training and, ultimately, encourage advance towards the improvement of learning processes, essentially the goal of our future work.

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