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V3S, a virtual environment for risk management training

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Abstract

In high risk industries, risk management training has become a major issue. It requires not only to teach rules and procedures, but also to promote a real understanding of the risks that are at stake and to train learners to work in degraded situations (stress, difficult co-activity, damaged equipment...). In this paper, we present the outcomes of the V3S project. This project resulted in a virtual environment focused on the visualization of errors consequences, whether they are made by the learner or by the virtual autonomous characters that populate this environment. To allow the representation of errors and compromises, we developed a task description language to model learners' and autonomous characters' situated knowledge about their tasks. These models are used to monitor learners' actions and to generate virtual characters' behaviours. The evaluation has shown a high satisfaction level and encouraging usability measures. As a future work, we propose to extend the possibilities of the simulation through the creation and monitoring of adaptive scenarios. Our objective here is twofold: support roleplay-like learning situations inspired by game-based learning and interactive storytelling, and dynamically adapt the difficulty to learner's performances by adjusting the behaviour of virtual characters able to assist or disrupt the user.

Categories and Subject Descriptors (according to ACM CCS): K.3.1 [Computing Milieux]: Computer Uses in Education—H.5.1 [Information Systems]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1. Introduction

In high risk industries, risk management training has become a major issue, and its objectives are numerous:

- teach learners best practices, rules and procedures
- train them to react in degraded and/or rare work situations
- assist managers in their decision making tasks by helping them conduct risk analysis as well as *a posteriori* accident investigation.

Virtual reality environments have lots of advantages for addressing the risk-management training problem [FCB*06], among others: the possibility they give to simulate work situations with no actual danger, whether it is for learners, trainers or their environment; the flexibility they offer in the way of presenting information; the precise control on simulation parameters they provide, allowing users to reproduce specific situations.

Though virtual environments for training or learning are numerous [MN11], most of them concern education and not professional training. Moreover, only a few address the issue of human activity in non-ideal situations. Usually the learner is supposed to repeat a technical gesture or a precribed procedure. Yet, particularly in high risk industries, it is vital to train operators to respect best practices in damaged work conditions or difficult situations where co-activity is involved (stress, tiredness, unusual environment or people...), and to react in rare situations.

To address these issues, the V3S (Virtual Reality for Safe Seveso Subcontractors) project has designed a virtual environment taking into account human factors. It consists in a generic framework which can be tailored to fit different training needs through the use of ergonomic and risk analyses. The application is equipped with a learner monitoring module capable of controlling the events happening in the environment according to pedagogical rules. It is also populated with virtual autonomous characters subject to mistakes and compromises. After presenting the different components of the project and the evaluation study that took place, we will expose the perspectives, which include linking these two aspects by introducing adaptive scenarios in the simulation.

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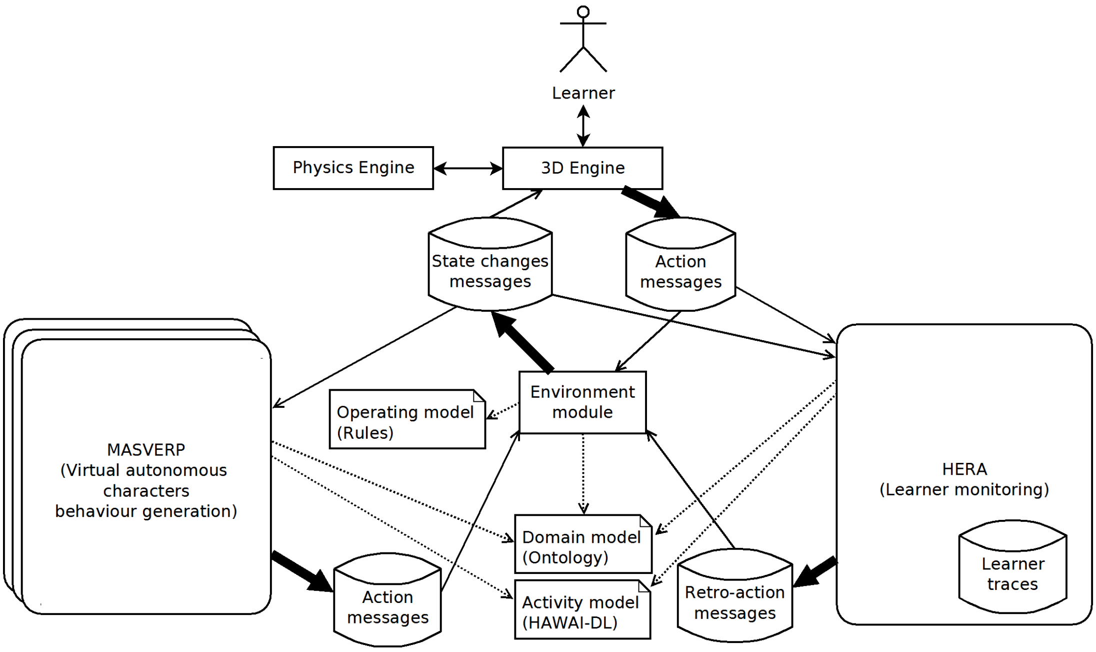

Figure 1: *Architecture of the V3S application*

2. The V3S project

The V3S project addressed the simulation of dangerous work situations related to maintenance activities performed by external companies on high risk SEVESO sites. Because of the subcontracting, these situations are prone to particular problems. Indeed, the lack of control of the manager on the subcontractor's activity leads to a very formal application of procedures, which does not guarantee a true risk control. Thus, industries are in need for tools to promote reflection from the different actors (decision makers, managers, operators...) in order to induce a true understanding of the risks that are at stake.

In order to promote this reflection, the V3S project focused on the consideration of errors in human activity, whether they come from the learner or from the virtual characters who populate the environment. The V3S hypothesis is that the effectiveness of virtual reality in terms of training and decision making for safety management increases when it allows operators and managers to see the impact of their decisions on the technical, organisational and human system they have in charge. The different modules we propose thus enable the user to apprehend the consequences of their actions and the ones of the other operators.

2.1. Activity models

Activity models, or task models, are the ground element of the simulation, on which are based both character behaviour generation and learner activity monitoring. To assist the ergonomists in capturing these models, we developed a specific activity description language called HAWAI-DL (Human Activity and Work Analysis for sImulation - Description Language). It has been inspired by features of two task description languages developed in the ergonomics and HCI communities [CB11], namely MAD* [SS94] and GTA [VLB96].

The HAWAI langage aims to support the description of how the operator cognitively represents their task, i.e. it is not only a logical analysis of the task. Such a cognitive fit of the description is related to both: the concepts provided by the language features; and the methods to collect data about operators representations of their own activity. The main concepts are a set of possible goals/tasks and subgoals/tasks, translating the operator viewpoint on their activity, the relations between these goals, and the possible flow of actions and conditions of their achievement. At this stage, we are still working on how to associate to this description some aspects related to collective actions where several operators have to coordinate and collaborate together.

The language can be directly interpreted by software modules to generate parts of an operating model depicting constraints and possible actions on objects when attempting to achieve the task within the virtual environment. Since objects and actions are also described in the domain model by an ontology, the complete model results from the interpretation of both information sources, including potential inconsistencies that could exist between the two descriptions. Moreover, HAWAI-DL handles the formalization of activity in degraded situations as well as practices resulting from cognitive compromises that could generate risks. It allows the system to deal with errors on two fronts: on the one hand, the detection of errors and risk-taking situations in learner activity; on the other hand, the demonstration of similar behaviours by the virtual autonomous characters. To this extend, HAWAI-DL incorporates the concepts of Boundary Conditions Tolerated by Use (BCTUs) [FGD03]. BCTUs are a concept derived from research in cognitive psychology, which reflect a local – and often informal – compromise between actors of a certain field. For instance, working with chemicals without wearing individual protection equipment (glasses, gloves...) in order to save some time might exist as a BCTU on specific sites, i.e. a tolerated risk practice.

2.2. Autonomous virtual characters

The V3S project aimed to represent some of the cognitive processes leading operators to erroneous behaviours. Most of the work conducted on behaviour generation for virtual characters lean on frameworks inspired by mathematic formalisms, such as Petri networks or state machines. Unlike those approaches, our framework is based on cognitive models, from the field of security and human behaviour in risk situations. Thus, we proposed a multi-agent framework called MASVERP (Multi-Agent System for Virtual Environment for Risk Prevention). This framework is based on the BDI model [Bra87], enriched by taking into account several physical and physiological characteristics (thirst, tiredness, stress...) and personality traits (caution, expertise...) in the characters' decision process.

The MASVERP framework integrates several models from cognitive psychology research, including the COCOM model [Hol94], which defines different control modes depending on the time pressure, that will influence the anticipation and planning abilities of the characters. The integration of task models able to represent degraded activity in these cognitive frameworks enables the virtual autonomous characters to deviate from the ideal procedure and display errors or compromises. Indeed, intentional violations are made possible through their representation in the activity model as BCTUs. For non-intentional errors, we used the error taxonomy proposed by E. Hollnagel in the CREAM model [Hol94]. A more detailed description of MASVERP can be found in [ELL*08].

2.3. Learner monitoring

Learner monitoring in the V3S project can be divided into three objectives:

1. Assist the trainer in their monitoring task by providing traces and performance criteria
2. Help the learner interpret their activity, both in real-time and afterwards, through cause-consequence analysis
3. Adapt in real-time the learning environment to fit learner's profile and learning objectives

Most computer-enhanced learning systems use orchestration techniques to define the sequencing of learning activities, and provide real-time explanations to help the user understand what is going on. In highly interactive environments, the idea would be instead to let the user learn by observing the consequences of their actions. To this extend, [ALB08] proposed a learner monitoring and scenario adaptation module called HERA (Helpful agent for safEty leaRning in virtuAl environments), designed for both learners and trainers. To control the user training and foster a gradual learning process, HERA proposes an adaptive control of the situations complexity and of the disruptions of the simulation. The retro-actions it produces are thus not explanations that would stop the user in their task, but strategies to bring the user to reflection-inducing situations. The system allows the user to make errors, and triggers the risks and/or external disruptions depending on their level. More information on HERA can be found in [ALB08].

2.4. Implementation

The V3S project led to the development of two prototypes. The first one addresses the issue of pipe substitution on chemical-processing sites. The user plays the role of a manager and has to conduct a collaborative procedure while dealing with teammates that can be novice, stressed, tired, etc. The second prototype is based on the case of hazardous matter loading on oil depots, where the user is confronted to the consequences of their own deviations from the procedure.

Figure 2: *Screenshot of the application*

Both prototypes have been integrated in a photo-realistic 3D environment, developped with 3DVIA Virtools. Furthermore, the second prototype has been developped in two distinct versions regarding their human-machine interface. The first one is a desktop version, where the user navigates using a mouse and a keyboard, and interacts with objects by using contextual hierarchical pie menus. The second one is an immersive version, using scale-1 stereoscopic visualization, motion capture with the ARTtrack system, and a high-precision physics engine.

2.5. User study

The evaluations reported in this paper involved the two versions of the second prototype, dedicated to the training of drivers on situations and procedures related to hazardous matter loading on oil depots. The objectives were threefold:

1. to assess the acceptability of the proposed system;
2. to assess the concrete suitability as well as the relevance of its use in real conditions of training with professional trainers and trainees;
3. to measure the degree of usability of the two (desktop vs. immersive) interfaces versions.

2.5.1. Method

The methodological approach has been adapted to the functional differences between the desktop and immersive versions. Indeed, the desktop version provides the environment and functions required to play real training sessions with trainers and trainees, whereas the immersive version offered a simplified version of the environment and was more oriented towards the evaluation of interface and interactions features. Consequently, the desktop version has been evaluated in the context of 2 real training sessions with real users (the same trainer, 10 trainees) that participate in initial training of tanker truck drivers. We carried out an empirical evaluation with the immersive version using a simplified version of the learning scenario – connecting the loading arm to the truck – with a sample of 15 subjects.

2.5.2. Material

Whatever the approach, we used the System Usability Scale questionnaire [Bro96] to evaluate the acceptability and perceived usability of the prototype with the users. We also used two classes of items from the QUIS (Questionnaire for User Interface Satisfaction) usability questionnaires [HN93]: terminology and learnability. Specifically for the immersive version, we also evaluated the subject's experience of immersion during the test with 11 items adapted from the rating scale by Jennett et al. [JCC*08] to assess the experience of immersion in games and virtual environments.

2.5.3. Collected data

We recorded the sessions and conducted interviews with participants in both the real training sessions and the experiment with the immersive version. Furthermore, performance data on the simplified task were automatically recorded during the experiment.

2.5.4. Results

This section provides the main results of the evaluations. Regarding the evaluation in the field with real trainees, questionnaire results showed a high acceptability (average SUS score of 81/100, sd=10) and a good usability level. Indeed, the mean score for the QUIS items about terminology was 7.91/9 (sd=1.22) and the mean score for learnability was 7.71/9 (sd=1.3). These score are far higher than 5/9 which has been proposed as arbitrary value indicating a mediocre level of usability. An analysis item by item indicated two dimensions with a slightly lower score: use of terms and quality messages, suggesting possible improvement in ther interface of the desktop version. More qualitatively, interviews with trainers and managers in the training company showed that they were highly satisfied with the way the demonstrator could fit in their initial training sessions. They have proposed to extend the use of the virtual environment to more specialized "professional" courses, including emergency intervention training. In addition, most of the trainees spontaneously mentioned their interest in accessing an online individual version of the virtual environment in order to go on with their training at home. In addition, a third informal observation has been performed using the desktop version as a basis for a role-play-like training session, where three trainers were in charge of putting a learner on the spot and disrupting him during the simulation. The truck driver made numerous mistakes, which he explained by the fact that he was panicked and rushed. Afterwards, the trainers praised the use of the device to train drivers to act in stressful situations.

Figure 3: *Immersive version of the application*

Performance data in the immersive version showed that subjects achieved the task in about 30 seconds (sd=25.sec) with a high variability. A significant learning effect of trials was also observed ($F(1,14)= 5.33$, $p<0.0368$) with subjects requiring less time to achieve the task when the number of trials increased. Regarding the usability and acceptability of this immersive version, results show that the acceptability was still high (average SUS score of 75/100, sd=13), even if the interfaces were sometimes reported as invasive, particularly for the infrared markers. Subjects with an experience of videogames and virtual reality systems tended to rate acceptability at a higher level (SUS score = 79/100) than those without such a previous experience (SUS score = 71/100). The difference failed however to be significant (t(13)= - 1.1158, n.s.), which could be due to the low number of subjects. It should be also noted that the score is descriptively lower than in the desktop version. This result might be also explained by the lower level of functions of the prototype and the simplified nature of the experimental situations, as well as by the fact that participants were not real trainees and trainer. The specific measure of subjective experience of immersion showed to be moderate (Immersion Subjective Rating = 67/100, sd=5.60). Subjects with a previous experience of virtual games exhibited a slightly lower score (m=66, sd=4.97) than the newcomers (m=68, sd=6.30). The effect failed however to be significant (t(13) = 0.6808, n.s.).

3. Discussion

The results from the evaluations conducted on the prototype raise the possibility of using it in genuine training sessions. As for now, only some of the features have been tested with end users, but the prospects of using the demonstrator as a support in other learning situations already reveal new needs.

The evaluations realized on the prototype focused on the utility, usability and acceptability aspects. It would also be relevant to assess the impact of the different configurations on the learning process, especially for the immersive version that embodies natural interaction in an entirely physicalized environment. Similarly, it would be necessary to study user reaction to virtual autonomous characters and to estimate the contribution of the progressive learning scenario. Moreover, since the evaluation of the immersive version of the prototype showed that subjects found markers to be a potential shortcoming for both acceptabillity and subjective experience of immersion, the development of a new version has started using Microsoft's Kinect to perform motion capture without the need of markers and other invasive devices. It would be interesting to evaluate this version, as the invasiveness of the infrared markers had been criticized in the previous one.

To address the new pedagogical situations suggested by the training company, we propose to extend the work done on scenarios within the V3S project. In emergency intervention training, for instance, the teacher should be able to exert control over the events in the virtual environment, and to guide learner's actions somehow to engender relevant learning situations (a leak, a fire, a storm...). In addition, the transposition of role-plays onto virtual world characters would benefit the trainer, avoiding the need to involve several individuals for a given training session. It could also increase the motivation of the trainee in the context of individual remote training. We propose to draw inspiration from the interactive storytelling field in terms of narratives, while enriching them with pedagogical control allowing to adapt the unfolding of events to learners level and activity.

Currently, scenario control in the V3S project mostly involves feedback, being for the most part textual messages, performance criteria updates and adaptive events triggering (leaks, tank overflows...). The scenario does not take into account the behaviour of the autonomous virtual characters evolving in the environment. Indeed, the module managing their behaviour and the one responsible for the learner monitoring part are completely independent of each other. The characters progress on their own, whith no interaction with the user and no adaptation to their activity whatsoever. We plan to link these modules so that characters would react appropriately to user actions, depending on the pedagogical objectives of the training sessions, pedagogical rules, user level, traces from previous sessions... These characters might then act to maximize or minimize the risks associated to a collaborative procedure, assist the learner when in trouble by providing advice or performing their task, or on the contrary harass or disrupt them to put them under stress when the task seems too easy.

The main challenge we face for the introduction of these adaptive scenarios is related to the fact that our environments contain autonomous entities, whether human users or virtual characters. Moreover, since we foster a learning-by-doing paradigm, it is vital to maintain a high level of user agency. Tradeoffs must therefore be established, on one hand between the user's feeling of freedom and the respect of the desired course of events; on the other hand between the virtual characters' autonomy and the preservation of scenario consistency.

4. Related work

4.1. Virtual reality for training and risk management

Training has been shown as the main expected use of VR in industries dealing with complex systems and the management of critical risk and safety issues. Several orientations and learning objectives can be distinguished ([FCB*06], [GCB*07]):

1. training how to cope with emergency situations; several domains have been concerned up to now like medical emergency [SBGGS97], military peacekeeping [SGH*06], gas emission in refinery operations [HKVW99], Seveso site accident [ELL*08] or terrorism [LZXL06].
2. improving the understanding of the dangerous/critical process or situation to work with, as for example in chemical reaction engineering [BF04];
3. providing initial training [Joh98] [ULM*04], and skill sustenance on dangerous equipment and rare situations, etc.
4. training in safety and hazard detection/evaluation; examples involve the training of health and safety prevention

engineers [GMR05], students in engineering enrolled in a senior plant design course [BF00], training of traffic accidents investigators in the procedures to apply when intervening on a accident [BMR06], etc.

Several technological configurations have been observed in current safety-oriented applications (e.g. Desktop VR, Immersive Room). Most of them are desktop-low-cost VR systems, although more and more immersive multi-users configurations are developed. Based on a review of the systems dedicated to training, a first set of emerging design patterns have been described in relation to their objectives and socio-technical dimensions [FCB*06].

The domain of safety management covers a wide range of activities that includes: planning, organizing, controlling, monitoring, auditing, and reviewing the process of intervening to reduce risk in a plant. As far as we know, no VE has been actually developped to support its main topics, namely ([FCB*06]): managing contractors' performance, evaluating safety plans, involving and convincing plant managers to be supportive to the Health & Safety Management Audit (HSMA) processes.

4.2. Scenarios in virtual environments

In the context of virtual environments, the word "scenario" is widely used, but rarely defined. Usually associated with the temporal arrangement of actions or events in the environment, it can actually refer to distinct concepts.

In the film industry, the scenario is a written work describing the different scenes of a movie. There are actually two different types of scenarios: the screenplay, that defines what to shoot (actions, dialogues...); and the shooting script, which includes instructions on how to shoot it (division into sequences and shots, camera points of vue...) [RKV*09]. Similarly, in virtual environments, a scenario might be used to orchestrate virtual actors' evolution. In [DD03], a hierarchical scripting language based on state machines is used to control semi-autonomous characters at a global level.

In video games, the scenario usually designates the game story, at different levels of detail: from a general setting to a very detailed narrative. In some cases, it is used to refer to the spatial organization of the virtual environment, in a way like game levels [HM09].

In virtual environments, a scenario usually determines what can and/or should happen in the environment. Writing a scenario can then consist in defining the possible actions, their causality links, or scripting linear or multi-linear paths. However, some use the same word to refer to the particular unfolding on events in a given session [CPE05]. In these interactive contexts, the scenario must also deal with user activity. The field of Interactive Storytelling is particularly concerned with this topic, and many solutions have been proposed to specify and control the narratives in virtual environments, whether at a global level with plot-based approaches [ML06] or at a more specific level with character-based approaches [PCP08].

When addressing the issue of training in virtual environments, scenario often refers to sequences of events relating to learning objectives [NR09], or more specifically to the prescribed procedure the trainee has to perform [MA06]. However, the term "learning scenario" (or pedagogical scenario) designates a very precise notion, inherited from the eLearning community. A learning scenario defines what learners and other actors – like the teacher – should or can do within a given set of resources and tools. Usually they consist in a sequence of learning activities associated to a learning environment.

We propose to combine this different notions by defining the virtual environment orchestration as being both the specification of the possible or wanted unfolding(s) of the simulation, and the real-time control (monitoring and fixing) of the virtual world evolution. We will then refer to the scenario as the particular sequence of events planned in one specific session, whether these events have already happened or not.

5. Conclusion

To address the risk-management training issue, the V3S consortium has proposed a virtual environment based on field analysis, taking into account human factors. The ergonomic and risk analyses help increasing the credibility of the environment, through the generation of non-ideal virtual characters behaviours, whose performances are affected by external and internal factors such as stress, and who are prone to compromise depending of their expertise level. The pedagogical control of the simulation is provided by a learner monitoring module, which is able to adapt the reactions of the environment to ensure a gradual training process.

The results from the V3S project already meet many needs of initial or continuing training in risk management. The multiplication of uses of virtual environments for professional training now offers new perspectives, whether in the use of immersive devices to interact with the simulations or in the management of adaptive scenarios underlying them.

We foresee four main advantages to the creation and monitoring of these scenarios:

1. First, it would allow the learner to be guided to relevant learning situations: whether by presenting degraded work conditions (technical failure, missing resource, time pressure...), by leading to the triggering of specific risks (a virtual character might forget to check the emptyness of a tank before loading gas, which would result in the tank overflow), or instead by preventing them (a virtual character could notice the learner forgetting to check that the arm is properly locked and point it out, thus avoiding a leak during the loading operation).

2. Besides, the integration of a narrative could help motivate the learner, by promoting their emotional engagement in a story. Indeed, we believe that injecting a storyline would bring a greater involvement of the learner, both in the virtual environment and in their training process.
3. Moreover, the scenario adaptation would enable the system to automatically control the levels of tension and difficulty. Indeed, to ensure that the learning is effective, we want the simulation to stay in tune with the learner's level. If they seem to struggle with their tasks in a stressful situation, then a virtual character could come and help them. On the contrary, if they seem to handle everything with ease, the virtual characters would act to disrupt them.
4. Finally, precise scenario management would permit the system to replay specific accidental scenarios in order to perform post-accidental risk analysis, which can not be done with the current prototype in the case of collaborative procedures.

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