Final report of the SunSet Project
« Scrub Nurse Non-Technical Skills Training System »

1 Context and proposed approach

According to the *Haute Autorité en Santé*, there are between 6 and 8 millions of surgical procedures per year in France (250 millions worldwide). The quality of their performance has a direct and strong impact on patient's morbidity and mortality. A reference report from the Institute of Medicine in the US estimated that between 40.000 and 100.000 serious adverse events appeared every year with mortality consequences [1]. In France, it is estimated that yearly between 60 000 and 95 000 adverse events (1%) occur in the peri-operative process, from which the half is considered to be avoidable and coming from non-technical errors, specifically related to interpersonal non-technical skills such as teamwork and communication issues [3]. From them, a third is considered to be serious events. To ensure patient safety and reduce serious adverse events, several strategies have to be implemented. In its report on simulation in healthcare [2], the *Haute Autorité en Santé* (HAS) outlined the need for better teaching and evaluation of surgeons using simulation systems, covering the different required **surgical skills**.

The SunSET project specified, developed and assessed a new generation of virtual reality based surgical training systems covering non-technical skills (NTS), known to be responsible for a majority of adverse events in surgery [3]. For demonstrating the feasibility and added value of the approach, we studied, implemented and evaluated methods, as a proof of concept, in the context of neurosurgical scrub nurse training.

2 Main results

The results of the project cover 5 different areas:

- **1**: Analysis of NTS and specification of corresponding training scenarios
- **2:** Development of authoring tools for defining VR based training scenarios
- **3**: Implementation of VR based NTS training scenarios
- **4**: Development of training performance evaluation tools
- **5**: User experiments to assess the developed scenarios

2.1 Analysis of non technical surgical skills and specification of corresponding training scenarios

The project started by an analysis of medical non technical skills including cognitive and interpersonal [3,4]. We performed and published a review of the literature about the use of VR environments for training medical NTS. Main conclusion was the limited number of such systems. Then, we focused on two aspects of NTS: situation awareness which is an important cognitive skill and communication which is an important aspect of interpersonal skills. For situation awareness, we decided to implement a scenario consisted in an operating room of the errors (which is a usual tool to train situation awareness). We identified the main categories of possible errors within an operating room with interviews and observations of professionals, including study of frequencies and degree of associated risks (divided into three categories: low, middle, high). This results in 5 categories: 1. Identity monitoring, 2. Hygiene and infective risk, 3. Wrong surgical site, 4. Patient safety, and 5. Rupture of continuity of care. Then, we selected examples for each category, resulting in 25 examples. Nineteen were selected for implementation in VR.

2.2 Development of authoring tools for defining the training scenarios

We have developed a set of tools that facilitate creation and evaluation of VR based training scenarios. Both are considered as a major bottlenecks in VR based training.

2.2.1 Hybrid engine

We used the #FIVE engine, as a higher-level layer to easily set up interactions with many parameters like what button to press, which hand to use, what type/colour of highlight to use when the action is possible (Figure 1), what pose should the hand take. We also developed the possibility to define humanoid virtual avatars (Figure 1) that can follow actions written in a scenario, and with realistic animations, used for VR replay in SunSet eval (see above). A logging system has been developed to store information for later quantitative evaluation by SunSet Eval software (see above), including user's position (head and both hands), buttons pressed on the controllers, performed actions as well as used objects.

2.2.2 Sevenario

We developed Sevenario software to speed up the creation process of #SEVEN scenarios by giving the possibility to an expert in a field (like a surgeon or a nurse) to directly create a scenario with little assistance. The idea behind it is to put the expert in the scene without constraints and record their actions as a scenario, this is called "Create by doing". We also developed Demodocos to synthetize scenarios into a single generic scenario (the initial methodology was developed in the S3PM project).

2.2.3 Authoring AR Interaction by AR

We developed a tool that allows the user to add #FIVE interactions to real or virtual objects using Augmented Reality. In the example seen in Figure 2, we scanned several real tools and created some virtual objects. We configured them in our app to complete sequences of DIY actions such as screwing, cutting and pasting a paper etc. The goal, like Sevenario, is to allow a domain expert to create his/her application using a database of real and virtual objects and interactions. This may facilitate the extension of the work developed in both S3PM and SunSet projects to AR based training scenarios in the future.

2.3 Implementation of VR based NTS training

Based on works from sections 2.1 and 2.2, we developed two applications as simulations of a medical environment in a virtual scene for training and evaluating non-technical skills for scrub nurses: one for situation awareness and one for communication.

2.3.1 Situation Awareness scenario: Error spotting in a virtual operating room

The first application is a reproduction of an existing surgical operating room in virtual reality just before a neurosurgical procedure. We implemented a total of 19 errors (selected from the 25 defined and sampling the 5 main categories - see section 2.1) in some objects of the environment that the trainee must find (Figure 3). Errors typology came from NTS analysis. We used photographs from an existing OR along with advices from professionals to reconstitute the room as realistically as possible (Figure 5). The simulation has two settings: normal and "stressful". The stressful mode has a visible clock indicating the remaining time, as well as ticking noise when the time is running out. The goal is to evaluate the influence of stress on performance. Most users were inexperienced in VR for this experiment, so we implemented a small tutorial at the beginning to help them familiarize with the interactions and VR in general.

2.3.2 Communication: speaking up scenario on tablet

The second application takes place in the same surgical bloc, but this time errors are automatically revealed to the user, who now has to describe how likely he/she will them and how they would do it. This scenario was implemented on a tablet PC to facilitate its use and demonstrate the genericity of the developed methods (Figure 4). At first, the user can freely move around with directional arrows to explore the room. When he/she is ready, he/she can click a button to move to the next stage in which one of four errors will be presented, chosen randomly. Each user has to indicate with free text if he/she would mention the error to their colleague with different hierarchical positions, if they felt embarrassed to do it and which strategy would be used to mention the error.

2.4 Development of training performance evaluation tools

During this project, we have developed SunSet Eval, a software environment for making easier post training debriefing assessment. This software gives access to both qualitative and quantitative performance metrics on the results of simulations as well as replay of the simulation sessions. These tools were developed upon an open source Learning Management System (LMS) environment: AcademicsToday. In SunSet Eval, trainers can create courses with pedagogical contents (Figure 6), simulation training, questionnaires, and share them with students. Trainers can access student resume and statistics about results on a specific course (Figure 7).

Within this environment, qualitative metrics were implemented as forms to be filled in and address social, cultural, educational, and personal aspects: Situation awareness, Anxiety, Mental Workload, Immersion, VR simulator acceptability questionnaires (Figure 8). Statistics on these questionnaires are automatically calculated (Figure 9). Nineteen **quantitative metrics** were implemented and allow automatic and quantitative analysis of performances based on data generated during the virtual simulation. The objective is to create hypotheses, either by observing phenomena that they reveal (analysis segmentations, groupings...), or by searching for similarities between patterns. Three kinds of quantitative metrics were implemented in SunSet Eval based on the logs (Figure 10) : 1) basic statistics (time, number of objects affected, number of actions,...), 2) calculation of metrics from kinematic data including 19 Metrics (such as acceleration, jerk, frequency, bimanual dexterity), 3) calculation of procedural metrics about the repeatability of sequences.

A visual support for post-review evaluation have been implemented to allow the reviewer to replay the simulation session in the VR environment (Figure 11). A **VR replay** of the trainee's performance in the operating room is a significant tool for non technical skills observation and assessment. For hesitations, doubts or stress, VR replay enables better understanding and feeling about the state of mind of the trainee during the performance. There are two kinds of approach in this module : from the trainee's point of view, replaying his/her movements, the direction of his/her look, and from an external viewer ; the trainer can move around the room and follows the trainee's actions and moves in the operating room.

Finally, SunSet Eval was developed as a generic environment whereas additional simulation scenarios, questionnaires and metrics can be easily implemented.

2.5 User experiments

One important objective of this project was to demonstrate the acceptability and added value of VR based simulation for non technical skills training and evaluation with a special focus on scrub nurses. We conducted three user studies during the SunSet project with scrub nurses in initial and professional training.

2.5.1 Study 1: learning procedural skills with a virtual reality simulator: an acceptability study

The aim of this study was to assess acceptability and usability of a new VR simulator for procedural skill training among scrub nurses, based on the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The simulator training system was tested with a convenience sample of 16 non expert users and 13 expert scrub nurses from the neurosurgery department of a French University Hospital. The scenario was designed to train scrub nurses in the preparation of the instrumentation table for a craniotomy in the operating room (OR). Questionnaires and semi-structured interviews were conducted after the simulation in the VR simulator. Acceptability of the VR simulator was demonstrated with no significant difference between expert scrub nurses and non-experts. Workload, immersion and simulator sickness were also rated equally by all participants. Most participants stressed its pedagogical interest, fun and realism, but some of them also regretted its lack of visual comfort. Thanks to this study we demonstrated that this VR simulator designed to teach procedural knowledge can be widely used as a tool in initial or vocational training.

2.5.2 Study 2: training situation awareness through error recognition in an immersive virtual operating room

The objective was to evaluate the situation awareness (SA) training scenario for scrub nurses who are responsible for hygiene and security and for whom SA is a major NTS. Eighteen first-year students from the scrub nurse school and 8 professional experts scrub nurses followed the scenario. They had a max of 14 minutes to find the 19 errors. The training session was followed with a collective debriefing and questionnaires: Situation awareness, Anxiety, Mental Workload, Immersion, and VR simulator acceptability. Results showed expected and unexpected contents: 1) acceptability and situation awareness were high for both populations, 2) students found more errors than experts, except on severe errors, and 3) trainees who found more errors had higher immersion, situation awareness and satisfaction and lower workload. Six months after, for all trainees, number of detected errors increased, as well as acceptability demonstrating the impact on learning.

2.5.3 Study 3: speaking up in an immersive virtual operating room

The objective of this user study was to understand the importance of open communication with other surgical team members (Okuyama, Wagner, & Bijnen, 2014) and evaluate the acceptability of the VR based scenario implemented in a tablet PC. Eighteen second-year and eighteen first-year students from the scrub nurse school and 15 five or six-year medical students had to follow the speaking up scenario followed by a self-debriefing and an acceptability questionnaire. The study is still in progress (last sessions on end of October 2019) but initial results showed that there is no effect of hierarchy in 2-year nurse students but there are differences in the used strategies.

A system was installed at the scrub nurse school of Rennes in May 2019 to be used as a teaching tool.

3 Outcome

3.1 Publications

- Journals
    - Bracq, M.S., Michinov, E., & Jannin, P. (2019). Virtual Reality Simulation in Nontechnical Skills Training for Healthcare Professionals: A Systematic Review. *Simulation in healthcare: Journal of the Society for Simulation in Healthcare, 14(3),*188-194. doi: 10.1097/SIH.0000000000000347
    - Bracq, M.S., Michinov, E., Arnaldi, B., Caillaud, B., Gibaud, B., Gouranton,V., & Jannin, P. (2019). Learning procedural skills with a virtual reality simulator: An acceptability study. *Nurse Education Today, 79,* 153-160. https://doi.org/10.1016/j.nedt.2019.05.026
- International Conferences
    - Bracq, M.S., Michinov, E., & Jannin, P.: Virtual Reality Simulation in Non Technical Skills Training for Healthcare Professionals Simul Healthc: 2018
    - Bracq, M.S., Michinov, E., Arnaldi, B., Audinot, A. Caillaud, B., Gibaud, B., Gouranton, V., Henaux, P.L., Lamercerie, A., Nogues B., & Jannin, P. (2019). Modeling, Simulation and Training Procedural Skills: User experience and acceptability of a virtual reality simulator for scrub nurses in neurosurgery. International Meeting on Simulation in Healthcare (IMSH) 2019 – San Antonio, TX. 26-30 Janvier 2019.
    - Flavien Lécuyer, Valérie Gouranton, Adrien Reuzeau, Ronan Gaugne, and Bruno Arnaldi. "Create by Doing–Action Sequencing in VR." In *Computer Graphics International Conference*, pp. 329-335. Springer, Cham, 2019.
    - Flavien Lécuyer, Valérie Gouranton, Adrien Reuzeau, Ronan Gaugne, Bruno Arnaldi. Authoring AR Interaction by AR. *ICAT-EGVE 2019 - International Conference on Artificial Reality and Telexistence - Eurographics Symposium on Virtual Environments*, Sep 2019, Tokyo, Japan.
- National Conferences
    - Bracq, M.S., Le Duff, M., Michinov, E., Arnaldi, B., Gouranton, V., Descamps, J., & Jannin, P.: Training situation awareness through error recognition in an immersive virtual operating room, Oral presentation at ICMASim conference : 2019
    - Bracq M, Le Duff M, Michinov E, Arnaldi B, Gouranton V, Descamps J and Jannin P. (2019). Training situation awareness through error recognition in an immersive virtual operating room. *Conference Abstract in Frontiers: ICMASim 2019 1st International conference for multiarea-simulation*. Angers. 7-9 Octobre 2019.
    - Bracq, M. S. (2018). Evaluation et développement des compétences non-techniques des infirmières de bloc par la simulation en réalité virtuelle - Projet SunSet. Oral presentation at « *Technologies éducatives et formation* » conference Plateforme LOUSTIC- MSHB, Rennes, 15 Novembre 2018.
    - Bracq, M.S., Le Duff, M., Michinov, E., Arnaldi, B., Gouranton V., Descamps, J., & Jannin, P. (2019). Situation awareness in the « Virtual Operating Room of Errors »: A pilot study. Oral presentation at 6th Surgetica Conference. Rennes, France, 17-18 June .

3.2 Software

Three software were submitted to the French Agency of Software Protection

- Semantic description of the virtual OR in #FIVE format
- 3D models, spatial description and graphical rendering of a virtual OR
- Scenario of table preparation for scrub nurse in a virtual OR

Three other software were developed and will be submitted as well soon.

- SunSet Eval
- Scenario, 3D models, spatial description and graphical rendering of the error spotting application
- Scenario, 3D models, spatial description and graphical rendering of the speaking up application

3.3 Valorization

Technological transfer was targeted from the beginning of the project. Different companies were contacted. The SATT technological transfer institute supported the action by funding two one-year software engineers to work on #Five and #Seven software.

4 Peoples

4.1 Involved partners

Name	Team	Position	Role in SunSet
Pierre Jannin	MediCIS/LTSI INSERM Univ Rennes 1	DR2 Inserm	Principal Investigator
Bernard Gibaud	MediCIS/LTSI INSERM Univ Rennes 1	CR1 Inserm	Supervision of ontology and symbolic reasoning aspects
Bruno Arnaldi	Hybrid, IRISA/Inria	Professor in VR	Supervision of VR aspects
Valérie Gouranton	Hybrid, IRISA/Inria	Associate professor	Supervision of VR aspects
Benoit Caillaud	Hycomes, IRISA/Inria	DR2 Inria	Supervision of the model synthesis aspects
Estelle Michinov	LP3C University de Rennes II	Professor in Psychology	Supervision of the interpersonal aspects of the non-technical skills
Pierre-Louis Hénaux	MediCIS/LTSI, CHU Pontchaillou Rennes	Neurosurgeon	Neurosurgeon
Emmanuelle Mondin	CHU Pontchaillou Rennes	Manager of the Operating rooms	Specification and user study design
Benedicte Nogues	CHU Pontchaillou Rennes	Scrub nurse	Specification and user study design

4.2 Personnel

The following peoples were recruited for the project:

Name	Supervizion	Position	Topic	Current activities
Marie Le Duff	LTSI	17 month engineer	SunSet Eval and user studies	Engineer in another project at MediCIS

Marie-Stéphanie Bracq	LP3D	PhD	PhD in psychology on training non technical skills in VR	PhD defense planned for march 2020
Javier Rojas Balderama	LTSI	9 month Postdoc	Ontology, data acquisition	Post doc at Inria
Gautier Picard	INSA/IRISA	13 month PhD	Ontology and automatic scenario generation	PhD stopped after one year. Engineer at Audensiel Technologies
Guillaume Claude	INSA/IRISA	8 month engineer	VR development	VR Engineer in artistic school
Adrien Reuzeau	INSA/IRISA	6 month engineer	VR development	Engineer at INSA
Alexandre Audinot	INSA/IRISA	2 year 4 month engineer	VR	Recruited as engineer in another project at Hybrid
Aurélien Lemercier	INRIA	12 month engineer	Methods for scenario generation	PhD at Inria

5 Self assessment

We were able to achieve what we initially committed to study. We were even able to go further on several points: 1) different tools were developed for facilitating scenario development such as the AR extension or “Create by doing” paradigm, 2) quantitative analysis was implemented in the SunSet Eval module based on kinematics analysis, and 3) three studies demonstrated the high acceptability of the VR tools by both professional and students.

Despite important efforts conducted within the project partners and with a significant support by the SATT technological transfer institute to try transferring our technology to the medical education industry, we were not able yet to have any transfer. However, some technology developed in the project was transferred to a company related to building industry. User studies were conducted thanks to an important logistic and time effort due to the limited availability of medical professionals. We believe that the system installed at the nurse school will help transferring our developments in the next future.

6 Annexes

6.1 Figures

Figure 1: Virtual actors with highlighted elements

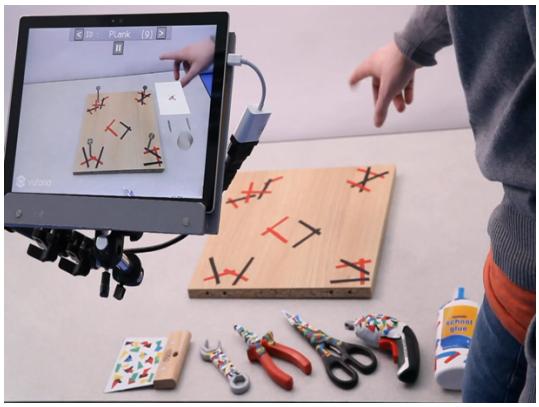

Figure 2: Real plank with virtual screws in AR

Figure 3: OR of the errors scenario

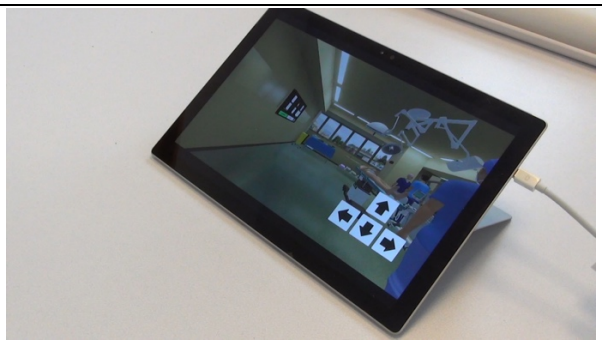

Figure 4: Speaking up scenario on tablet

Figure 5: Virtual and real instrument table showing the visual realism of the virtual environment

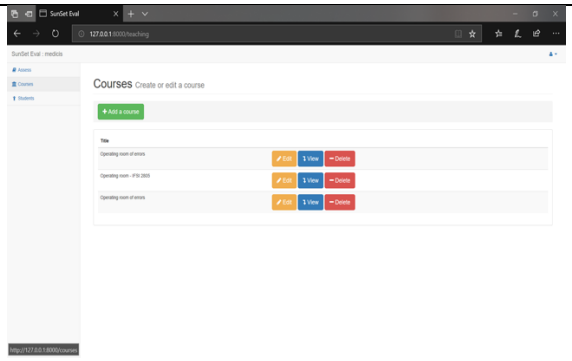

Figure 6: SunSet Eval: Access to different teaching scenarios

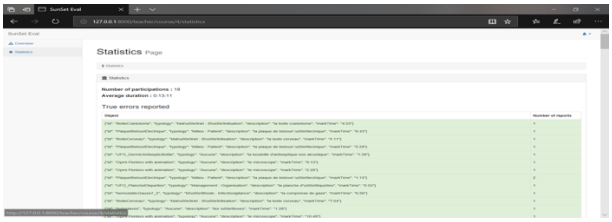

Figure 7: SunSet Eval: Access to statistics about one study (OR of the errors)

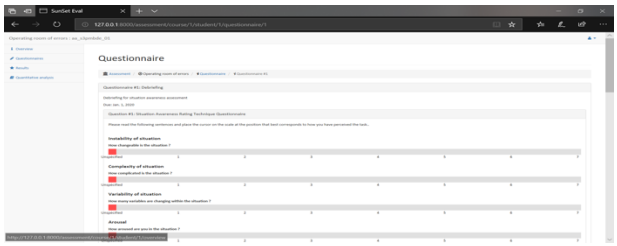

Figure 8: SunSet Eval: Questionnaires of subjective measurements implemented : Self debriefing, acceptability of the environment

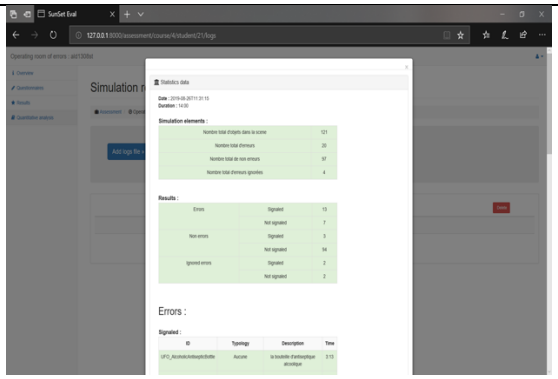

Figure 9: SunSet Eval: Statistical analysis : individual and global answers on the scales

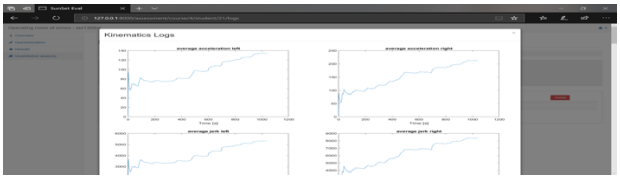

Figure 10: SunSet Eval: Kinematic analysis: Metrics (acceleration of the hands, trajectories in the operating room …)

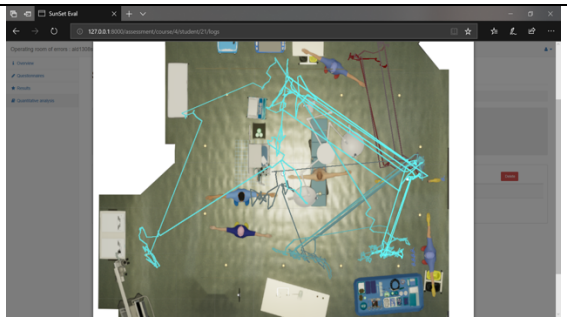

Figure 11: SunSet Eval: Visualization of trainee's trajectories

Figure 12: The French Ministry of Education and Research trying our virtual OR environment

6.2 References

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4. Mitchell, L., R. Flin, et al. (2013). "Development of a behavioural marker system for scrub practitioners' non-technical skills (SPLINTS system)." J Eval Clin Pract 19(2): 317-323.