

Natural and virtual environments for the training of emergency medicine personnel

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Abstract EMERGENZA (emergency in Italian) is a ‘serious’ game, developed in the context of the RIMSI project and designed to improve the training of emergency medicine operators. To achieve this goal, it adopts natural interaction paradigms in immersive environments. Virtual reality systems have been used recently in combination with natural interface systems for enhancing patients’ rehabilitation procedures though are proving especially effective in the development of clinical decision support and medical training systems. The use of immersive simulations in medical training is extremely useful to confront emergency operators with scenarios that range from usual (e.g. unconscious person on the ground) to extreme (car accident with several injured people) without exposing the simulation participants in any harm. It is critical to exploit 3D virtual worlds in order to provide as much contextual information as possible to the operators. In fact, each emergency procedure needs to be adapted depending on the environmental threats and the presence of multiple injured people in need of assistance or bystanders. EMERGENZA allows to simulate a first-aid scenario with a configurable

virtual environment using interactive 3D graphics. Users can interact through a natural interface for navigation and interaction with the virtual environment. In order to evaluate the prototype, several heuristics have been chosen and tested to measure the overall system usability. Results show that the adoption of natural interaction in immersive virtual environments receives good feedback from users.

Keywords Virtual reality · Serious games · Natural interfaces · Medical operators training

1 Introduction

In the field of emergency, medicine simulation is extremely useful to teach emergency medical technicians (EMTs) and medics to operate in harmful or critical situations. Medical simulations have been enacted for centuries, even if in primitive forms [1]. Practice is a key component for the maintenance and learning of skills in medicine [2], and in this regard, medical simulation encompasses different solutions. According to the pioneer David Gaba [3], there are five categories of medical simulation: verbal simulations, standardized patients, part-task trainers, electronic patients and computer patients. A verbal simulation is a role playing game. Standardized patients are actors employed to train junior doctors in communication and physical examination skills as well as patient history taking. Task trainers usually depict body parts, and the most complex versions are also used as surgical trainers. Electronic patients are probably the most realistic devices for simulations. They are full-size heavy mannequins¹ with

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¹ “Harvey mannequin” was one of the earliest electronic patients, currently sold by Laerdal Corporation.

human-like behaviour (eye blinking, breathe and pulse) and are usually computer controlled in order to induce disease symptoms. Electronic patients and task trainers are the most expensive devices, however, with respect to standardized patients and verbal simulations ease the repeatability of the simulation scenarios. Computer patients can be used to reduce the cost of simulations, and they are software-based interactive characters that have the same purpose of standardized patients but can also in part replace electronic patients.

The interesting feature of computer-based medical simulation is the possibility to replicate very complex scenarios at a very low cost. As an example, imagine the scenario of a bus crash on a highway. Such a scenario requires the intervention of multiple medical operators with the need of a high skill in managing and prioritizing patient assistance procedures. The enactment of such a scenario requires a vast amount of free ground, several electronic patients and actors together with trainees. Electronic mannequins are quite expensive since their cost ranges from 20 to 80k \$. Only a few medical schools and the military can afford such expenses. Therefore, simulations involving the use of an electronic mannequin are usually enacted in emergency room environment or in simple non-hospital environment, and they use a single electronic patient.

A computer-based simulation can also improve the trainee environmental awareness without any risk for the simulation participants, and medical operators can be confronted with situations involving many risks both for the patient and for themselves. These situations and the actual actions to be performed can be simulated realistically not only at no cost but also without any risk for the trainees. An example is a basic life support (BLS) scenario in an apartment of a burning building where simulation participants need to take care of their team safety before assisting the patient, requesting, if needed, firemen support.

This paper is organized as follows. First, in Sect. 2, the major related works regarding systems and “serious games” for training and rehabilitation are presented. Section 3 describes the use cases and the main scenario. Section 4 is dedicated to system architecture, navigation metaphor, user interaction with implementation details. Section 5 shows prototype assessment, heuristics used for user tests, the evaluation process and discussion of the results. Lastly, some conclusions are drawn, and future works are discussed.

2 Related work

The literature in the field of medical training systems reveals, in recent years, an orientation towards the design

of high configurable prototypes [3–6]. These systems are difficult to implement and maintain due to the fact that medical procedures are becoming everyday more complicated. On the other hand, very specialized systems [8, 9] have been designed that are not adaptable and flexible enough to be deployed in different scenarios. Furthermore, for the most part, the majority of interfaces of these systems are not fully immersive and intuitive. Even if they exploit different tools for interaction such as haptic sensors, cameras and markers, they could benefit a lot from natural interaction techniques.

The Cybermed framework [4] is a system for medical training via computer network. It has advanced features for configuring some aspects of the simulation such as the number of users, the gestures to manipulate the objects, the type of devices (mouse or haptic systems), the choice of the actors for remote mentoring and distance learning (tutor or participants), though it does not really allow an exhaustive characterization of the situation or the definition of complex medical procedures. SOFA [5], ViMet [6] and GiPSi [7] frameworks instead are open-source projects which feature a high level of modularity and rely on the capability of a multi-model representation of simulation models (deformable models, collision models, instruments) exposing appropriate APIs.

Although they easily allow to simulate a scenario, say a laparoscopy, they neither provide a real natural and immersive interface nor they go beyond enabling the system to respond to punctual *stimuli* (e.g. in the laparoscopy use case, deformation of the liver and collision with the ribs). Spring [8] is a more specific mouse-based desktop framework for real-time surgical simulations, which provides a basic configurability of patient-specific anatomy. Laerdal MicroSim [9] is a non-immersive simulation system that presents to trainees pre-hospital, in-hospital and military scenarios. As can be seen in Fig. 1, in the pre-hospital scenario, the user can interact with the patient through a simple 2D interface and has a static view of the scene. Recent studies [10, 11] instead have proved the benefits of game dynamics to boost the adoption of simple computer-based virtual patients by groups of students for training sessions in the medical field.

Regarding more immersive solutions, Honey et al. have created a virtual environment in second life for haemorrhage management [12]; Cowan et al. [13] have developed a system for the inter-professional education (IPE) for critical care providers where an immersive 3D situation is accessed across the network in a ‘multi-player online’ environment, allowing trainees to participate, as avatars, from remote locations. Sliney et al. [15] propose a system, named JDoc, which uses realistic situations to train junior doctors in dealing with the frenzy of a first-aid hospital. Immersivity and realism are one of the key points for users

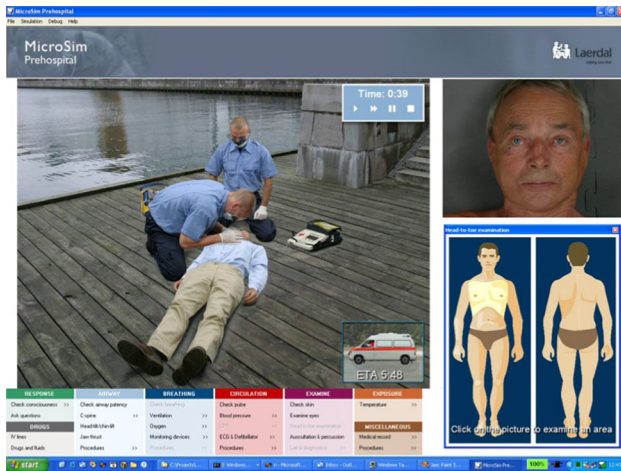


Fig. 1 Laerdal MicroSim pre-hospital scenario

engagement in the development of training systems. This is confirmed by Buttussi et al. [14] who obtained encouraging results evaluating a 3D serious game as a support tool for medicine students.

Natural interaction is definitely the other key factor that can be a plus in medical training systems. Several so-called natural interfaces featuring natural interaction systems have been used in medical rehabilitation, although sparsely, leveraging different technologies (e.g. Nintendo Wii, PlayStation EyeToy), as part of physical therapy. Haptic sensors are commonly used in rehabilitation to ease the interaction with the systems [16, 17]. Markers and accelerometers/gyroscopes provided by the Nintendo Wii have been used to get information about scene orientation and objects positioning in order to improve systems responsiveness [18]. These solutions, despite being easy to implement, have the disadvantage to be not really natural, forcing users to wear or to hold different devices with their hands in order to interact with the system [19].

As regards Kinect-enabled systems, they are commonly used in rehabilitation. Lange et al. [20], for example, have developed a Kinect-based game 'JewelMine' that consists of a set of balance training exercises to stimulate the players to reach out of their base of support. This kind of software takes advantage of the situation realism and the naturalness allowed by the Kinect sensor in gestures tracking. This is relevant especially to encourage physical exercise but is not very common in medical operators training systems. LISSA [21] is a Kinect-based system developed to train specific skills in cardiopulmonary resuscitation (CPR). This system is one of the first medical training softwares exploiting motion tracking but, compared to EMERGENZA, LISSA is more skill-oriented rather than procedure-oriented.

A comparison of solutions adopted by previous works and by EMERGENZA is available in Table 1.

Taking into account all these issues, EMERGENZA, a system that developed in the RIMSI project for the simulation and training of medical and para-medical personnel in emergency medicine, is proposed. The prototype aims at reproducing pre-hospital scenarios with critical environmental situations in a reconfigurable way. It was decided to portray this kind of scenarios since they are the most expensive and difficult to reproduce in simulation facilities. The system is composed by a scenario editor for the instructors and a simulator. Users are able to navigate a virtual realistic environment as both first and third person character controllers. To improve the immersivity of the system, a gesture-driven interface based on the KinectTM has been developed.

3 Use cases and scenarios

Medical simulation systems can have different goals such as training communication between members of a team, situational awareness and personal skills. Testing skills require precise measurement or human evaluation of procedures. In these drills, a few millimetres of error may result in a critical outcome for the patient as in the case of a surgical operation. Furthermore, it is really difficult to obtain an effective virtual simulation for personal skill training, while, for intra team members communication and situational awareness, there is the need of generating a sufficient complexity in the scenario. For example, while assisting a paediatric patient, parents may interfere in the procedure, though at the same time they are probably the only and most accurate source of information on the patient's history and the cause of his/her condition. To improve medical operators' communication skills, it is also important to be able to repeat simulations. Simulations may be repeated with the same parameters or with slight variations. This kind of simulation is usually performed with the use of expensive electronic patients or mannequins that have to be remotely controlled by instructors, impacting heavily on staff costs. McIntosh et al. [22] have analysed the economics of simulation centres in a 2006 article. Results showed that the overall set-up cost for facilities and equipment was \$876,485, fixed costs per year amounted at a total of \$361,425, while variable costs for session training and teaching totalled \$311 per course hour. The savings derived from the adoption of the EMERGENZA system cannot be precisely quantified but it would certainly relieve the expenses for equipment, simulation scenarios setup, courses and teaching staff.

Of course the use of a virtual environment may decrease the realism of the simulation, since it would be complicated

Table 1 Solutions adopted by the different serious games for medicine and by EMERGENZA

	Cybermed	SOFA	ViMet	GiPSi	Honey et al.	Cowan et al.	Spring	JDoc	Microsim	Buttussi et al.	LISSA	EMERGENZA
3D graphic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mouse and keyboard	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓
Haptic interaction	✓		✓	✓								
Gesture interaction											✓	✓
Immersive env.				✓	✓	✓	✓	✓		✓	✓	✓

**Fig. 2** Two of the available characters: a doctor and his assistant. The doctor acts as a playing character while the assistant as a NPC

to deliver the tactile information that a physical mannequin can, and it offers substantial advantages: it both allows to decrease the cost of the simulation and to increase the simulation complexity. A first point is to vary the environmental conditions so to force environmental awareness in the trainees. A second point is to increase the amount of patients in need of assistance with no cost at all. Moreover, the use of non-playing characters (NPC), in any number, can greatly improve the communication complexity and realism of the simulation.

According to these needs, the EMERGENZA game is composed of a simulator and a scenario editor that allows instructors to mix different sources of complexity in the emergency procedure scenario. The virtual world is therefore reconfigurable, and the same environment can generate several different situations. It is possible to employ NPCs. NPCs can have different roles: they may be relatives, friends of the patient or simple bystanders, and they can also be members of the medical team performing the procedure. In both cases, they are employed to deliver information to the player. As a special case, an NPC can

**Fig. 3** Animation of player securing the environment before patient assistance

serve to augment the sensory input of the experience. As an example, although smell generators exist [23] and can be relatively affordable, an NPC can be exploited to provide information on the environment such claiming she is smelling smoke or other odours that may indicate danger.

In the following, one of the possible scenarios that EMERGENZA can simulate is presented: Basic life support and defibrillation (BLS/D) procedure in a house with a gas leak. In this scenario, a player (the doctor) and an NPC (the assistant) are used. Two of the available models are shown in Fig. 2.

This scenario depicts a typical BLS/D procedure with the added risk of a gas leak. The gas smell and the possible leak are reported by the assistant. The player has to decide how to confront this situation, he/she could ask for help, leave the house or locate the gas source. The player can navigate in the virtual rooms to check the environment safety. If the player decides to locate the gas source and block the leak, then he/she can proceed to the BLS/D. An animation of the player removing the source of danger, in

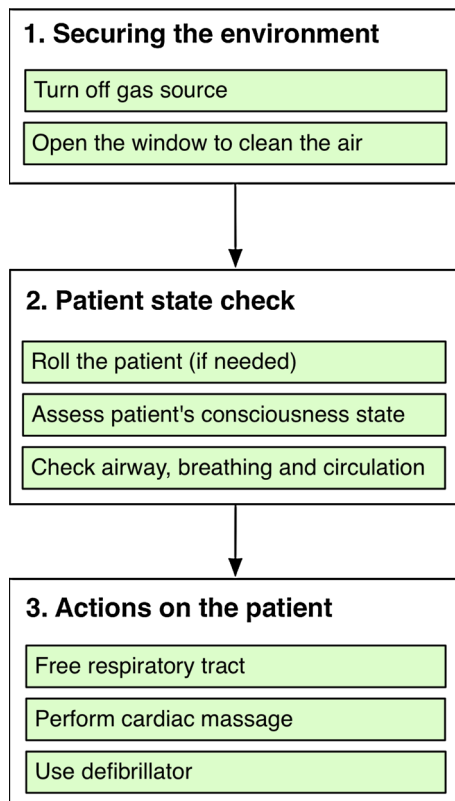


Fig. 4 Correct sequence of the simulated BLS/D scenario

this case the gas leak, is used to signal that the procedure can start safely, as shown in Fig. 3. Moreover, in order to correctly perform the procedure, there is a need to interact with these objects, the environment and the patient.

Errors are reported by the medical assistant with audio and textual feedback. Timers are used in order to assess the player's performance and to consider the need of different procedures. To finalize the procedure, the player has to carry out certain actions in a specific order as shown in Fig. 4. After securing the environment opening the window, he/she has to take care of the patient, grab the proper tools and activate them in the correct way. As an example, if a defibrillator is needed, the player has to catch it, turn it on and wait until it is completely charged before activating it. The simulation ends successfully if the player completes the procedure correctly or unsuccessfully if he/she commits too many errors or delays in taking decisions. Some of these actions are shown in Fig. 5.

4 The system

The logical architecture of the system is shown in Fig. 6. The proposed system is composed by an immersive 3D

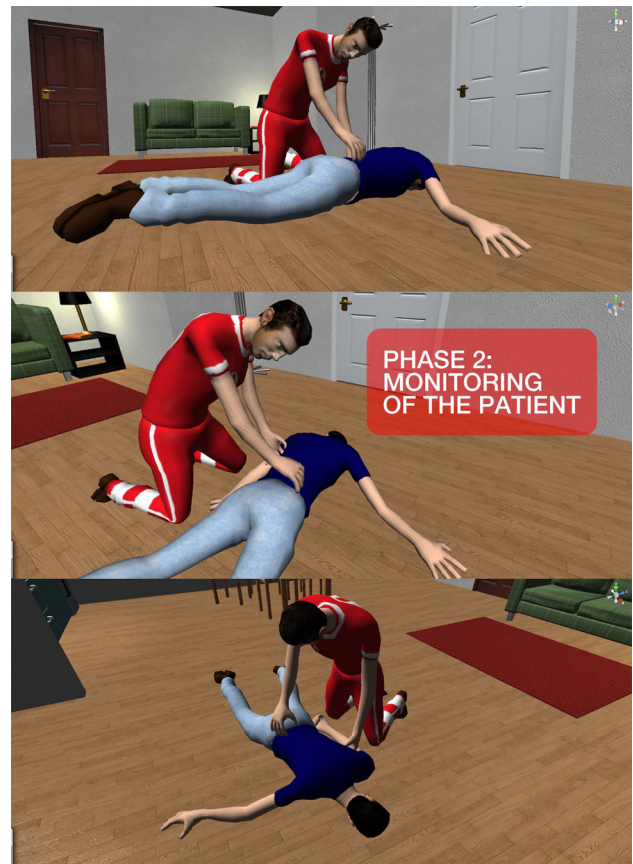


Fig. 5 Animation of player monitoring the patient

virtual environment that allows user interaction through body gestures. Gestures are tracked using a Microsoft Kinect™ sensor and recognized by a dedicated software module. Furthermore, the system is composed by a configuration tool that enables medical teachers to change training session parameters. Simulation sessions can be recorded in order to be replayed in the debriefing stage of the training. In the remainder of this chapter, all the components of the system are described in detail.

4.1 Navigation and virtual environment

For virtual environments and natural interfaces to be effective, it is essential that the scenarios are very realistic [24]. By scenery, the places, the events and also the virtual humans involved in a particular situation are designated. The environment has been designed with realistic features, for example a house has furniture, lights and house appliance. Some sample screenshots of this environment are shown in Fig. 7.

Avatars should also be able to give realistic feedback, express emotions and react to natural stimuli. In many medical simulation centres where, currently, simulator

Fig. 6 Logical architecture of the overall system

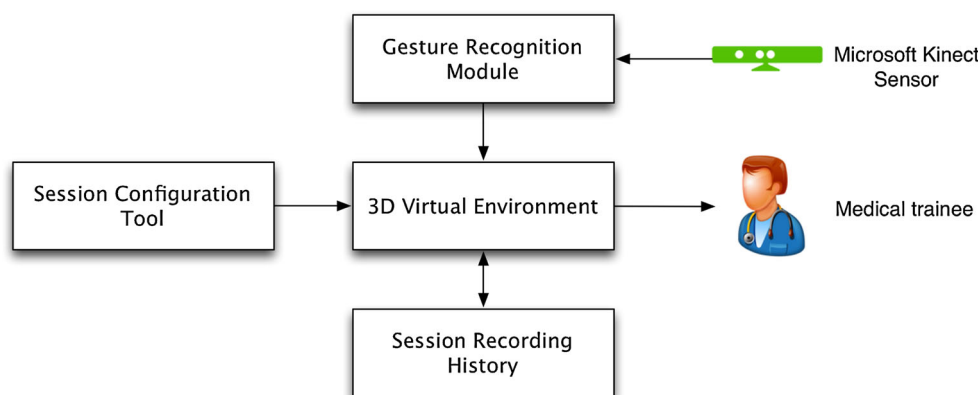


Fig. 7 A sample scene from the simulation prototype

systems provided with mechanical patients are used, the trainee's task is to carry out some emergency actions on a patient whose vital signs are in the meantime monitored and controlled by training doctors present in another room. The trainees have the possibility to evaluate these values through a vital sign monitor. Their behaviours influence the responses and the reactions of the patient, guided interactively by trainers. Mannequins can be very realistic though, as mentioned above, laboratories equipped with high and low fidelity medical mannequins are expensive to build and to maintain.

The proposed system is a free-roam game. A free-roam game is a game where there is no predefined order in which actions need to be taken in order to obtain accomplishments. This is obviously a means of improving realism since, as in real life, a user may decide to assist a patient before another or patrol the environment to assess its safety before beginning the assistance of patients. Although some actions need to be taken in order, as an example if multiple patients are present in the scene the more severely injured should be assisted first, a wrong decision in this case may not necessarily lead to a patient death. Timers are used in order to assess the player performance and to indicate the need of different procedures.

Table 2 Associations between gestures and character actions

Gesture	Body pose	Actions
Take/ Grab	One of the hands moves in front of the body (on Z axes)	The character grabs objects in front of him/her, opens/closes handles
Rotate	The rotation of the torso is evaluated using x, y values of users' shoulders	The camera rotates in order to explore the scene
Walk-in-place	Sequences of x,y values of legs' joints are evaluated to check several phases of the walk	The character moves along the direction he/she is facing
Bend	Sequences of decreasing y values of chest and knees	The character bends on his/her knees to examine the patient
Point	User's hand in front of the body,x,y values are normalized with respect to the user's position	A cursor is visualized in order to allow multiple choices

The virtual environment is based on the Unity3D [25] game engine, and it runs on any recent hardware. Scenes and models have been created with Maya.

4.2 Gesture recognition module

The navigation in the EMERGENZA virtual environment is made possible by a gesture-driven Kinect™ interface, through which user behaviours are evaluated in order to interact with the scenario.

Simple or complex gestures can be recognized with the use of a depth camera and a skeletal tracking system [26]. Based on information extracted from the depth and RGB cameras, the Microsoft Kinect™ APIs tracks the position and orientation parameters of all the joints of the skeleton model in real time. For every gesture that users can perform in the simulator, we defined a simple finite state machine (FSM), and the relative FSM recognizer has been



Fig. 8 Avatars performing actions based on user's gestures. In the bottom picture, a virtual menu with multiple options is shown

implemented. In general, gesture recognition relies only on some specific body part, so for every gesture only significant skeleton joints are considered. Defined gestures can be found in Table 2, along with details about considered skeleton joints and actions performed by the virtual character.

Gestures have been defined according to the requirements of the simulation context. Since the training sessions consist of applying the correct procedures and not of learning the semantics of predefined gestures, users can interact in the virtual environment as they would do in real life. Simple actions and behaviours can be easily translated in natural body gestures or poses. As an example, the rotation of the torso causes a rotation of the character and a change in the point of view, while the action of bending is used to approach the patient and check his condition.

However, not every phase of the medical procedure can be associated with natural gestures. When the trainee has to face a choice between different options, virtual menus appear to allow the player to choose the action to perform. Figure 8 shows some phases of the interaction.

4.2.1 Hand pose recognition

At the time of the EMERGENZA prototype implementation, the only limitation of the standard Kinect™ SDK was the lack of a hand pose recognition algorithm. The recognition of the hand pose allows a system to recognize on/off actions such as activating, grabbing or manipulating an object in the 3D world. This limitation was often handled with the use of persistence, i.e. a user must keep his/her arm still for a not so short amount of time (3 s) while aiming at some sensitive area in order to interact with it.

So it was proposed to employ an improvement to this system based on a robust hand pose classifier developed [27]. The proposed system is trained on a large dataset (30k+) of hands in closed and open status recorded at several distances, from eight subjects of different genders wearing various clothings. This vision module improves the responsiveness of the interface and, detecting the state of the hands of all players, enables the activation and manipulation of 3D objects. See Fig. 9 for an example of the detector output.

As an example, in the reanimation scenario, the player could grab the electrodes one at a time or with both hands by simply pointing at them and closing the hand(s) and place them on the patient body by opening his/her hand(s).

In the vision module, hands are localized and segmented with the aid of a skeletal tracker. Hands are represented with a regular grid of 5 Speeded Up Robust Features (SURF) [28] descriptors. SURF are local features typically used to compactly and robustly represent image patches. SURF features are also fast by design since they employ integral images and box filters to compute image gradients.

This feature is fed to a nonlinear support vector machine classifier with a RBF kernel [29] that predicts the state of the hand. This module has a very low overhead in terms of computation, in fact as can be seen in Fig. 10 a detection can be obtained in less than a frame, although this detection can be noisy. To improve the system robustness, the classifier is cascaded with a temporal Kalman filter [30] that outputs a smooth estimate of the hand state. The filter acts as a temporal smoothing. The filter in this system is parametrized by the measurement error σ . The σ parameter can be varied obtaining a trade-off between responsiveness and robustness of the system.

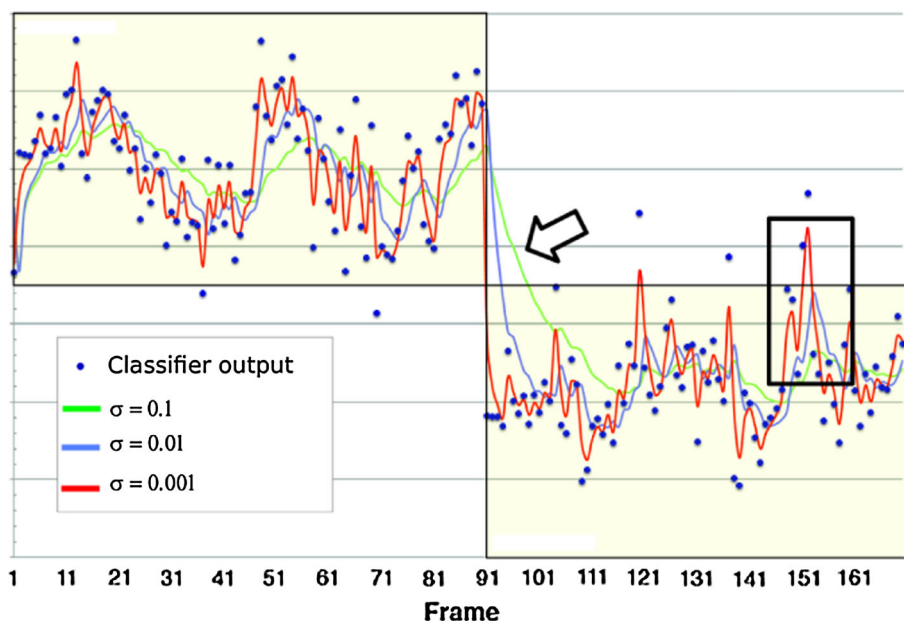
Tests were performed, training the system on a dataset² of eight subjects and testing on sequences of a held out subject. Without the temporal smoothing, 96.34 % accuracy was obtained, applying the temporal smoothing the result improved by more than 2 % raising the accuracy to 98.95 %. As seen in Fig. 10, there is a trade-off between accuracy and responsivity; thus, tuning the system to be less responsive, it is possible to raise the accuracy further.

² <http://www.micc.unifi.it/vim/datasets/hand-pose/>.

Fig. 9 Hand status detection: *square* (open hand), *circle* (closed hand)



Fig. 10 Filtered and unfiltered detections with different Kalman filter measurement errors



The Kalman filter consistently reduces detection errors. It was observed that the SVM output is noisy and the Kalman filter performs a temporal smoothing that slightly reduces the system reactivity but bring the reliability (in our tests) close to 100 %.

4.3 Session configuration tool

In order to allow the instructor to change some aspects of the simulated scenario, a tool was developed to configure the training session. Through the use of this tool (shown in Fig. 11), trainers can change several parameters of the configuration. The tool allows trainers to place the patient in different positions in the environment, to vary the environment itself and to add to each scenario several additional threats for the safety of patients and medical operators. Furthermore, it is possible to insert various patients conditions, like his pose and state of consciousness, and different responses to therapies that require consistent standardized procedures. In this way, the system can be useful even for multiple session, in order to assess trainee's behaviours in several situations.

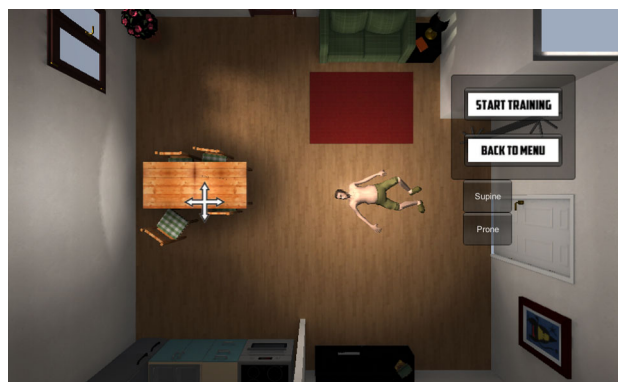


Fig. 11 Session configuration tool

5 Evaluation

5.1 Prototype assessment and debriefing

Trainees performance is assessed in the EMERGENZA system in two ways: (1) through game dynamics and (2) in a debriefing stage with instructors. During gameplay, the

player is given continuous feedback from the system on the effectiveness of his/her actions using several audio visual and textual indicators (errors reported by the medical assistant, time elapsed, visual feedback to actions). However, even a successful game can benefit from a debriefing in order to understand whether the actions taken in the environment and the interactions with the patient have been performed in a safe and correct way.

In a real training session scenario, the so-called debriefing usually follows the interactive simulation. During the debriefing, the trainers and the team of trainees discuss actions and mistakes often with the aid of a video record of the whole session: this is the stage where trainees learn more. The traditional classrooms or debriefing for learning have a teacher-centred approach, because trainees involved in the interaction session are not able to ‘see’ themselves and their errors. Moreover, in training sessions mediated by mannequins, users undergo behaviours and reactions. In natural interaction systems instead, individual responsibility, represented by the avatar or character in the game, and self-assessment are more relevant. In this sense, EMERGENZA uses a learner-centred teaching approach: the trainee is the user himself, through interaction, to guide the learning process resulting in a better procedures memorability. Furthermore, as a general rule, it should be noted that, as shown by Villeneuve et al., digital natives prefer the use of technology in learning [31].

The use of a completely virtual simulation also allows to produce digital logs of all the events occurring during the procedure. The game logs not only contain patient vital signs and symptoms but also the exact position and the posture of all players. With these data, it is possible to literally playback the whole simulation, switching the point of view and analysing in detail the behaviour of all the participants.

In the field of medical training, debriefing in simulation is considered as important as the simulation itself [32]. In this respect, EMERGENZA not only allows the simulation of otherwise too expensive or dangerous situations but also greatly improves this following phase of the training.

5.2 Heuristic evaluation of the virtual environment (VE)

According to [33], there are four main ways to evaluate a user interface: (1) formally by some analysis technique, (2) automatically by a computerized procedure, (3) empirically by experiments with test users and (4) heuristically by simply looking at the interface and passing judgement according to one’s own opinion. Inspection-based methods generally use guidelines or checklists as criteria to point out usability problems, although deciding which guidelines

are applicable to particular problems usually becomes more difficult as the number of guidelines grows. On the other hand, heuristic evaluation methods are quicker to use since they employ a limited set of design principles or heuristics. Since heuristic evaluation is quick, it is a cost-effective method and traps a high proportion of usability problems with 4-5 trained evaluators [34]. The heuristics used in the present study are derived from Nielsen’s work and from previous results about virtual environment design principles [35]. Starting from the heuristics proposed by Sutcliffe, a subset of heuristics that suited to the nature of our virtual environment was selected. In particular, emphasis was given to heuristics for evaluating the interaction intuitiveness and system immersivity. The following heuristics were chosen:

- H1 *Natural engagement* Interaction should approach the user’s expectation of interaction in the real world as far as possible. Ideally, the user should be unaware that the reality is virtual.
- H2 *Compatibility with the user’s task and domain* The VE and behaviour of objects should correspond as closely as possible to the user’s expectation of real-world objects.
- H3 *Natural expression of action* The representation of the self/presence in the VE should allow the user to act and explore in a natural manner and not restrict normal physical actions.
- H4 *Realistic feedback* The effect of the user’s actions on virtual world objects should be immediately visible and conform to the laws of physics and the user’s perceptual expectations.
- H5 *Faithful viewpoints* The visual representation of the virtual world should map to the user’s normal perception, and the viewpoint change by body movement should be rendered without delay.
- H6 *Sense of presence* The user’s perception of engagement and being in a real world should be as natural as possible.

Ten evaluators (6 of them researchers in the field of interactive systems and 4 medical operators in the field of emergency medicine) were asked to interact with the virtual environment. Evaluators were instructed how to interact with the system, and the task they were supposed to accomplish was described to them. In particular, the correct medical BLS procedure was explained and they were asked to perform it in the virtual environment. Eventually, evaluators were asked to fill a questionnaire based on the proposed heuristics. The questionnaire consisted of 10 declarative statements, each one of those related to one of the heuristics. Evaluators rated these statements using a 5-point Likert scale, from 1 (strongly

Table 3 Results of the heuristic evaluation questionnaire. Rating is expressed on a 5-point scale

Statement	Rating
H1a The interactions with the environment were natural	3.6
H1b The gestures which controlled movement through the environment were natural	3.9
H2 The behaviour of the objects in the virtual environment was close to my expectation	3.6
H3a User's representation in the VE acts naturally	3
H3b User's representation in the VE matches my body movements	4.1
H4a The effects of user's actions on virtual world objects are immediately visible	3.4
H4b Virtual world objects conform to the laws of physics and the user's perceptual expectations	4.1
H5 Avatars are designed to convey user's viewpoint and activity	4.1
H6a I was sufficiently involved in the VE experience	4.3
H6b I was concentrated on the assigned tasks rather than on the mechanisms used to perform those tasks or activities	3.1

disagree) to 5 (strongly agree). Average results of the heuristic evaluation for each statement are reported in Table 3.

The results show that the users were highly engaged in the virtual reality experience (H3b, H5, H6a), even if there are still some issues related to gesture understanding and tasks accomplishment due probably to the prototypal state of the system (H2, H3a).

6 Conclusion

The EMERGENZA prototype is part of the so-called serious games technologies for the improvement of skills and knowledge in medicine. Serious games provide an interactive environment where students and teachers are represented by avatars. Currently, most of the simulated training sessions in medicine occur in real environments such as laboratories, though more realistic digital simulations that facilitate learning in a safe environment can be implemented through emerging technologies such as tracking and VR environments.

EMERGENZA features a 3D virtual environment, high-resolution graphics and natural interaction interfaces to improve the effectiveness of the training of medical personnel in emergency situations. It provides an immersive and intelligent digital environment which can respond to natural gestures and actions of more team members in a simulated situation of emergency. The system has been developed to improve the learning methods currently in use and to solve some common issues.

Simulation in medicine has really improved in both fidelity and validity, though there are still several issues that justify skepticism in its adoption in the training process. Nonetheless, several schools of medicine all around the world are integrating simulations in doctor training and even offer certifications for simulation centres [36]. The main reason of delay in the adoption is related to the cost of personnel, equipment and programs that can be mitigated with the creation of large structures that promote the collaboration between different hospital units.

In this context, the proposed prototype is extremely valuable. In fact, it can reduce the cost of simulation replacing expensive structures and devices with virtual worlds. Moreover, a system is proposed that enables the simulation of dangerous and extreme scenarios enriching the training of junior doctors. Furthermore, compared to simulations with mannequins, the system allows:

1. to have an intelligent system that responds automatically to user actions,
2. to receive continuous audiovisual feedbacks,
3. to simulate an immersive environment such as that with the use of mannequins, but at a lower cost, enhancing learnability and memorability of procedures,
4. to be corrected on the fly and have system feedback in real time (the debriefing phase assumes instead a period of time between the wrong action and the correction).

The use of the session configuration tool enables trainers to define complex and varied situations to keep their trainees always focused on the environment, patient condition and bystanders. The whole standard procedure can thus be learned as a complex interaction of medics, bystanders and patients in the environment.

Interactive sessions with EMERGENZA can also be recorded and used as training materials. In this way, a large database can be build quickly to evaluate errors and the most common difficulties of trainees. These data, in addition to increasing the effectiveness of training, can be useful to assess how well these simulation environments work and how they can be improved.

6.1 Future work

Regarding future work, an interactive prototype is currently under development for the proper execution of the Surgical Safety Checklist (Fig. 12) procedure that must precede every surgical operation as proposed by the World Health Organization [37].

Practicing few individual critical steps defined by the checklist that medical operators have to carry out 'before induction of anaesthesia', 'before skin incision' and 'before

World Health Organization			SURGICAL SAFETY CHECKLIST (FIRST EDITION)		
Before induction of anaesthesia		Before skin incision	Before patient leaves operating room		
SIGN IN		TIME OUT		SIGN OUT	
<input type="checkbox"/> PATIENT HAS CONFIRMED <ul style="list-style-type: none"> • IDENTITY • SITE • PROCEDURE • CONSENT 		<input type="checkbox"/> CONFIRM ALL TEAM MEMBERS HAVE INTRODUCED THEMSELVES BY NAME AND ROLE		NURSE VERBALLY CONFIRMS WITH THE TEAM:	
<input type="checkbox"/> SITE MARKED/NOT APPLICABLE		<input type="checkbox"/> SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE VERBALLY CONFIRM <ul style="list-style-type: none"> • PATIENT • SITE • PROCEDURE 		<input type="checkbox"/> THE NAME OF THE PROCEDURE RECORDED	
<input type="checkbox"/> ANAESTHESIA SAFETY CHECK COMPLETED		ANTICIPATED CRITICAL EVENTS		<input type="checkbox"/> THAT INSTRUMENT, SPONGE AND NEEDLE COUNTS ARE CORRECT (OR NOT APPLICABLE)	
<input type="checkbox"/> PULSE OXIMETER ON PATIENT AND FUNCTIONING		<input type="checkbox"/> SURGEON REVIEWS: WHAT ARE THE CRITICAL OR UNEXPECTED STEPS, OPERATIVE DURATION, ANTICIPATED BLOOD LOSS?		<input type="checkbox"/> HOW THE SPECIMEN IS LABELLED (INCLUDING PATIENT NAME)	
DOES PATIENT HAVE A:		<input type="checkbox"/> ANAESTHESIA TEAM REVIEWS: ARE THERE ANY PATIENT-SPECIFIC CONCERNS?		<input type="checkbox"/> WHETHER THERE ARE ANY EQUIPMENT PROBLEMS TO BE ADDRESSED	
KNOWN ALLERGY?		<input type="checkbox"/> NURSING TEAM REVIEWS: HAS STERILITY (INCLUDING INDICATOR RESULTS) BEEN CONFIRMED? ARE THERE EQUIPMENT ISSUES OR ANY CONCERNS?		<input type="checkbox"/> SURGEON, ANAESTHESIA PROFESSIONAL AND NURSE REVIEW THE KEY CONCERNS FOR RECOVERY AND MANAGEMENT OF THIS PATIENT	
<input type="checkbox"/> NO		HAS ANTIBIOTIC PROPHYLAXIS BEEN GIVEN WITHIN THE LAST 60 MINUTES?			
<input type="checkbox"/> YES		<input type="checkbox"/> YES			
DIFFICULT AIRWAY/ASPIRATION RISK?		<input type="checkbox"/> NOT APPLICABLE			
<input type="checkbox"/> NO		IS ESSENTIAL IMAGING DISPLAYED?			
<input type="checkbox"/> YES, AND EQUIPMENT/ASSISTANCE AVAILABLE		<input type="checkbox"/> YES			
RISK OF >500ML BLOOD LOSS (7ML/KG IN CHILDREN)?		<input type="checkbox"/> NOT APPLICABLE			
<input type="checkbox"/> NO					
<input type="checkbox"/> YES, AND ADEQUATE INTRAVENOUS ACCESS AND FLUIDS PLANNED					

Fig. 12 First edition of the surgical safety checklist by World Health Organization

patient leaves operating room' can minimize the most common and avoidable risks that endanger the outcome of a surgical operation.

Each expected action in the checklist will be translated into a series of gestures and activities that the virtual system will be able to recognize and register. In particular, a multi-user scenario with three actors (surgeon, anaesthesia professional and nurse) and, for each step of the procedure, the actions that each actor has to perform have been identified. This scenario too has been designed as a 'serious game': there will be a maximum time for operators in order to complete the procedure, and for each item of the checklist, actors will have to raise their arm to decide who should carry out the specific action.

Compared to the BLS scenario, in which the user has to explore the virtual space, this second scenario is more static. The focus is on the training and the improvement of communication skills between the actors and the respect of roles and tasks. Users are expected to interact via voice (using the Microsoft Kinect™ SDK speech recognition engine) and gestures. This second scenario will allow the trainers to observe the dynamics of dialogue between the trainees (sessions will be registered for the debriefing phase) and the trainees to familiarize naturally with the procedure.

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