DESIGN OF A "REALISTIC" WEB3D SIMULATOR FOR BIOMEDICAL E-LEARNING PURPOSE: 3DWEBEPL

Sandro Moos, Stefano Tornincasa, Enrico Vezzetti, Mariagrazia Violante, Antonio Zompì

Dipartimento di Sistemi di Produzione ed Economia dell'Azienda

Politecnico di Torino - Italy

sandro.moos@polito.it, *stefano.tornincasa@polito.it*, *enrico.vezzetti@polito.it*, *mariagrazia.violante@polito.it*, *antonio.zompi@polito.it*

Abstract

Simulation has become one of the most powerful tools for supporting product development, for forecasting the behaviour of different processes typologies, but is becoming, thanks to the significant advantages given by virtual reality technology, also a powerful tool for supporting new training methodologies. Many sectors have started to introduce simulation contents in the conventional e-learning platforms in order to provide to the user those experimental aspects that normally e-learning is not able to provide. Also the medical context could obtain significant benefits from the introduction of a virtual reality platform if the simulator is able to synthesize real life events. So in order to provide a tool for supporting with efficacy the medical training process, it is necessary to have a virtual reality platform that provide a "realistic" scenario. In order to reach this aim it is necessary to find a common language for codifying in computer science specifications, those medical features that are significant from the physicians point of view and that describe what is "realistic" for the scenario. In order to fulfil this aspect this paper, introducing the Quality Function Deployment (QFD) methodology, wants to create a "meta-framework" between the medical features and the computer science ones, for providing the guide-lines supporting the virtual reality simulator design and development process.

Keywords: Virtual Reality, Quality Function Deployment, e-Learning

1. INTRODUCTION

Vocational and Educational training has been always one of the most important key point for improvement of the social and economical asset. For this reason during the past years many efforts have been done in order to provide always more complete methodologies and tools for supporting this process, trying to increase the competencies portfolio of as many people as possible. Starting from the engineering context, till arriving to biology, one of the key factor for an efficient training process has been demonstrated to be the practical experience. All these sectors in fact need a strong presence of laboratories in order to provide to the student a certain level of manual expertise, together with an experimental validation of the competencies that has matured during the theoretical lessons. For this reason simulation, technique to replace or amplify real experiences with guided experiences, often immersive in nature, that evoke or replicate substantial aspects of the real world in a fully interactive fashion [1], has been verified to be one of the most powerful tool to support the training process. Focusing in particular the attention on the medicine field, simulation-based learning has been used in the field of anaesthesiology for more than 20 years and is gaining popularity in the training of medical students, residents, clinical educators, nurses, and pre-hospital personnel. This educational methodology ranges from the most basic patient mannequins to high-fidelity patient models and computer-screen simulation to a virtual reality experience. Partial task trainers such as cardiopulmonary resuscitation mannequins and intubations heads have long been used for training of simple procedures, such as intubations or central venous line placement. More sophisticated mannequins, such as high-fidelity patient simulators, have computer-programmed physiological responses to certain interventions and administered medications. These high-fidelity models have recently been used for clinical and procedural education, competency and professional assessments, quality improvement exercises in individual training sessions, and disaster preparedness exercises [2]. Computer-based simulation is also extensively used, the most common of which are multimedia presentations created to supplement traditional didactics with movies, photographs, and audio files that are available via specialized software or over the Internet. Benefits of Internet interactions include the possibility of online live discussions and immediate updates [3]. Computer program simulators provide a 1-dimensional clinical scenario via a desktop computer complete with multiple choice responses in which the learner can choose an intervention and observe the patient response. This type of simulation is based on learned facts and their application in a focused clinical situation in response to specific questions. These types of computer simulations are very affordable, requiring only a computer and, in certain cases, Internet access. Many programs can be accessed online for no charge. Instructor-driven simulators are intermediate-fidelity mannequins (or mannequin body parts) in which the learner may experience interaction in a limited fashion dependent on the input programmed by the instructor. Next step is represented by Virtual Reality, that is the term used to describe an advanced human-computer interaction in which the learner can interact with a computer-generated environment that simulates the physical world [4]. Four categories of this simulation modality were first described by Voelter and Kraemer in 1995: desktop, immersive, pseudo, and inverse. A fifth category known as augmented reality has also been described, in which the virtual world is superimposed upon the actual reality by means of a see-through head mounted display so that the learner experiences both simultaneously [5]. Augmented reality is currently being used in maxillofacial surgical training. Desktop virtual reality is similar to computer program simulation, in which the learner can observe and manage a scenario on the screen, but has no further integration in the virtual world. Immersive virtual reality occurs when the learner is physically located in a simulator surrounded by realistic visual and auditory display, as in modern flight simulators used in the aviation industry. With pseudo virtual reality, the learner can control the animation and observe the outcomes, but has no further interaction, such as a 3-dimensional anatomic model that can be rotated on the computer screen but is not palpable. Inverse virtual reality integrates the computer into the physical world of the user. High-fidelity simulation is ideal for developing teamwork and communication skills. Although still in the early stages of evolution, emergency medicine as a specialty has had some limited experience with the use of simulation in the development of formal curricula for emergency medicine residents. But in order to guarantee that the virtual reality simulation tool could be able to support the physician during the training process it is necessary to make a certain attention to its “realism”. Unfortunately the “realism” criteria, that normally is confused only with photo-realism, is more difficult to formalise because it is difficult to codify in computer science parameters the suggestions normally provided by the physicians. For this reason this paper wants to propose a “meta-framework” for codifying the physician specifications (user needs) in the technical specifications (degrees of freedom) of the virtual reality tool, developing the guidelines for supporting a virtual reality manikin simulator.

2. VIRTUAL MANIKIN DESIGN METHODOLOGY

For the emergency medicine “realism”, means that the image has to provide the same visual information as the scene. Information here means knowledge about the meaningful properties of objects in a scene, such as their shapes, sizes, positions, motions and materials, that allows an observer to make reliable visual judgments and to perform useful visual tasks. Realism is defined in terms of the fidelity of the information the image provides. The generic requirement for fidelity can be, for example, decomposed, in medical field, into fidelity in patient appearance, symptoms presentation, and patient response to treatment. As explained in the previous paragraph in order to succeed in the design and development of a “realistic” virtual manikin simulator, able to support efficiently and with enough efficacy the emergency medicine training process, it is necessary to involve in the virtual model design process a formalisation methodology able to synthesize the real needs of this specific training process, involving the emergency medicine physicians. In order to fulfil this aim, it has been decided to employ the Quality Function Deployment (QFD) [6,7,8]

2.1. The physicians specifications: user needs

The first step of the QFD method is based on the identification of the users needs, that in this specific application are represented by those features that the virtual manikin should provide in order to be considered useful for disaster medicine training process. This information has been collected through a series of interviews made on a sample of emergency medicine physicians. At the beginning, the interviewer has left to the interviewed persons the possibility to freely explain which needs they consider to be the most important for simulating, with the virtual manikin, an injury without having to answer to specific questions. The “Raw Data” collected have then been managed in order to better express customer needs (“Reworded Data”), and to show possible similarities between the information given by different customers, thanks to the use of Hierarchical Cluster Analysis. When working on the reworded data, interviewed persons have been asked to express a relative importance for every different need on a scale from 0 to 10. Thanks to this relative importance value (*di*), expressed with respect to every need, it has been possible to create an organized “importance list” (Tab.1).

Table 1: Training needs list and importance

Disaster Medicine Training Needs	**Aggregated Needs**	**Relative importance d_i**
The manikin should represent different injury levels	To provide modularity an flexibility to the virtual manikin simulator	23%
The manikin should show and combine different pathologies		
The manikin should show breathing with different speeds and movements		
The manikin should show the age of the person	To provide photorealistic features to the virtual manikin simulator	15%
The manikin should show the sex and the provenience of the person		
The manikin should show color pale		
The manikin should show bleeding from face or other body parts		
The manikin should show eyes opening with different configurations	To provide configurable animations and interactions to the virtual manikin simulator	28%
The manikin should allow the inspection of the pupils dimensions providing different configurations		
The manikin should allow the inspection of verbal response providing different configurations		
The manikin should allow the inspection of motor response with different configurations		
The manikin should allow the inspection of motor function providing different configurations		
The manikin should allow the inspection of eyes verifying the pupils dimension with light interaction, providing some different configurations		
The manikin would be integrated with health parameters (blood pressure, …)	To provide a powerful, simple and flexible interface	23%
The virtual manikin should be user friendly		
The manikin could be employed for a collaborative exercise		
The use of the virtual manikin should not ask significant and expensive IT investments		
The manikin should be interactive providing to the student the opportunity to select the right medical procedure in time		

2.2. Virtual Manikin simulator technical specifications

The second step of the QFD method consists in the definition of the possible virtual manikin simulator measurable specifications. The problems on “realism” of the virtual human, could be divided into three key parts: manikin model, animation, and virtual simulation platform (simulator interface).

2.2.1 Virtual Manikin model

In order to create the structure of virtual manikin it is possible to focus the attention on four different strategies: stick figure models, surface models, volume models, and multi-layered models. Systems using stick figure models consist of a hierarchical set of rigid segments (limbs) connected at joints. These models are called articulated bodies and may be more or less complex, depending on the number of limbs and joints involved. Each joint can have up to three degrees of freedom (DOF) and the model can be more or less complex, reaching more than 200 DOFs as the real human skeleton. Surface models were proposed as an improvement to the stick models. A new layer, which represents human skin, was introduced in addition to the skeleton layer . Therefore, this model is based on two layers: a skeleton, which is the backbone of the character animation and a skin, which is a geometric envelop of the skeleton layer. The deformations in the skin layer are governed by the motion of the skeleton layer. This model can be examined under three topics: points and lines (the simplest surface model), polygons, and curved surface patches (Bezier, Hermite, bi-cubic, B-spline and Beta-spline). Surface deformation controlling across joints represents the big problem with the surface method. In volume models, simple volumetric primitives like ellipsoids, spheres and cylinders are used to construct the shape of the body. Recently, multi-layered models to represent human figures have been developed. In this approach, normally a skeleton is used to support intermediate layers that simulate the body volume (bones, muscles, fat tissues and so on) and the skin layer. Complex motions are easily created using the advantage of additively building an animation in different layers. These additional layers are used to improve the realism of the model. Where visual fidelity is one of the most important aspect to fulfil, it is better to employ a combination of techniques including muscle simulation, that can achieve the best realism in the mesh deformation. The attachment of mesh geometry to the underlying skeleton rig is called 'skinning' and this can be understood as a function mapping of the skeleton parameters to a deformation field. One of the common skinning methods in interactive systems is known by the following nomenclatures: sub-space deformation (SSD), smooth skinning, linear blend skinning and enveloping. The process followed by this technique is to assign influence joints and blend weights to each vertex of the character. Transforming the vertex by a weighted combination of the joints local coordinate frames completes skin computation. Leaving aside the specific technology employed, it is possible to characterize the manikin model for this specific purpose, thanks to the following list of technical specifications:

- **Level of details**: represents the detailed features that compose the human body and the medical pathology
- **Dimension:** represents the dimension of the virtual manikin and consequently also the dimension of the file
- **Geometric Primitives:** represents the different possible geometries it is possible to employ in order to create the virtual manikin model
- **Rendering Typology:** represents the visualization technology that is employed in order to provide a photorealistic appearance to the virtual manikin
- **Texture Typology:** represents the technology that is employed for integrating images over the three-dimensional shapes, in order to provide a more photorealistic appearance to the model maintaining a low file dimension
- **Model shape control:** represents the modifiers that will be employed for animating the model providing a dynamical behavior to the manikin

2.2.2 Virtual Manikin animation

The second part of the problem, human motion simulation, is also a complex task. It is very difficult to take into account all the interactions with the environment involved in a simple movement. Kinematics studies the geometric properties of the motion of the objects independently by the forces that cause the motion. Forward and inverse kinematics are the two main categories of kinematic animation. The essential concept of forward kinematic animation is that the positions of particular parts of the model at a specified time are calculated from the position and orientation of the object, together with any information on the joints of an articulated model. Inverse kinematic animation refers to a process utilized to calculate the required articulation of a series of limbs or joints, such that the end of the limb ends up in a particular location. In contrast to forward kinematic animation, where each movement for each component must be planned, only the starting and ending locations of the limb are necessary. Morph target animation (or per-vertex animation) is a method that is sometimes used as an alternative to skeletal animation. Morph target animation is stored as a series of vertex positions. In each key frame of the animation, the vertices are moved to a different position. This method allows more control over the movements because the virtual manikin simulator could define the individual positions of the vertices within a keyframe, rather than being constrained by skeletons. This can be useful for animating cloth, skin, and facial expressions because it can be difficult to conform those things to the bones that are required for skeletal animation. Vertex animation is usually a lot more time-consuming than skeletal animation because every vertex position would have to be calculated. A more complex, but more realistic approach is based on dynamics. The motion of a human body is governed by forces and torques applied to limbs. Two problems may be considered: the direct- dynamics problem and the inverse-dynamics problem. Leaving aside the specific technology employed, it is possible to characterize the animation strategies for the training specific purpose, thanks to the following list of technical specifications:

- **Multimedia**: represents the typology of audio effects that integrate the movement of the virtual model
- **Frame per seconds:** represents the correlation between the manikin movement and the time
- **Level of detail:** represents the accuracy of the movements of the virtual manikin
- **Cameras number and location:** represents cameras (view point) number and locations
- **Lights number and locations:** represents lights number and locations
- **Features deformation rules:** represents the rules that could be followed in order to control the model dynamic (Cinematic, Dynamic, …)

2.2.3 Virtual Manikin platform

The third part of this problem is correlated with the virtual reality platform that could be employed in order to finalize the simulator. Web3D represents the technology that involves 3D on the Web and could be employed for training purpose, together with traditional e-learning platforms. Leaving aside the specific technology employed, it is possible to characterize the WEB3D technology for this specific purpose, thanks to the following list of technical specifications:

- **Customization:** represents the possibility to create simple interfaces that allow different possible simulations
- **Interoperability:** represents the possibility to integrate different models and animations, operate over different operative systems (Mac, Unix, Windows, …) and to be integrated in virtual collaborative environment (VCE)

2.2.4 The correlation matrix

Once having defined the user needs and the technical specifications, it is necessary to identify which correlation level exists between technical specifications and user needs. Hence, it is essential to understand which technical specifications can better fit customer needs. These tables have been evaluated by several independent virtual reality platform designers, who have been in charged of suggesting the level of correlation $r_{i,j}$ existing between technical specifications and user needs, by employing three different values (5 – 3 – 1). By managing the collected data, it has then been possible to define an average correlation matrix (Tab.2). The final step of the QFD approach consists in the evaluation of the absolute importance level w_j, which is to be found inside the technical specifications, and the relative level w^*_j. This evaluation is essential in order to focus the attention on the most significant technical specifications that represent an IT codification of the Physician suggestions. Moreover, this evaluation allows the design of a set of tests based on costumer needs. This final information can be obtained by following the **Independent Scoring Method**, that is a combination of the correlation $r_{i,j}$, the user needs, the technical specifications and the relative importance of the specific user needs d_i:

$$w_j = \sum_{i=1}^{n} d_i \cdot r_{i,j} \qquad (1)$$

where n = user needs number and m = technical specification number

$$w^*_j = \frac{w_j}{\sum_{j=1}^{m} w_j} \qquad (2)$$

Table 2: Correlation Matrix

Correlation Level r_{ij}	Modelling Level of details	Modeling Geometric Primitives
Modularity and Flexibility		3
Photorealistic Features	5	5
Configurable Animations and interactions	3	5
Powerful, simple and cheap simulator platform		
Relative Importance w_i^*	7%	12%

Correlation Level r_{ij}	Modeling Model Dimension	Modelling Rendering Typology
Modularity and Flexibility		3
Photorealistic Features	1	3
Configurable Animations and interactions		1
Powerful, simple and cheap simulator platform	1	
Relative Importance w_i^*	1%	5%

Correlation Level r_{ij}	Modelling Texture Typology	Modelling Model Shape Control
Modularity and Flexibility	3	3
Photorealistic Features	3	3
Configurable Animations and interactions	1	5
Powerful, simple and cheap simulator platform		
Relative Importance w_i^*	5%	11%

Correlation Level r_{ij}	Animation Multimedia	Animation Frame for seconds
Modularity and Flexibility		1
Photorealistic Features		5
Configurable Animations and interactions		5
Powerful, simple and cheap simulator platform	5	
Relative Importance w_i^*	4%	10%

Correlation Level r_{ij}	Animation Level of details	Animation cameras numbers and locations
Modularity and Flexibility	1	3
Photorealistic Features	5	
Configurable Animations and interactions	5	1
Powerful, simple and cheap simulator platform		
Relative Importance w_i^*	10%	4%

Correlation Level r_{ij}	Animation Lights number and locations	Animation Model features deformation rules
Modularity and Flexibility	3	3
Photorealistic Features	1	1
Configurable Animations and interactions	1	5
Powerful, simple and cheap simulator platform		
Relative Importance w_i^*	4%	10%

Correlation Level r_{ij}	Platform Interoperability	Platform Costumisation
Modularity and Flexibility	5	5
Photorealistic Features		
Configurable Animations and interactions	3	5
Powerful, simple and cheap simulator platform	3	5
Relative Importance w_i^*	8%	10%

3. VIRTUAL MANIKIN EXPERIMENTAL PHASE

Looking at the results obtained by the QFD strategy, it is possible to see that the most significant aspects that represent the guidelines for virtual manikin design and development are: **the model Geometric Primitives, the model shape control, the animation frames for seconds, the animation level of detail, the animation model features deformation rules and**

the platform customisation. These virtual reality parameters represents those computer science specifications that could fulfil the medical needs explained by the emergency physicians interviewed, for defining the meaning of “realistic simulation”. The presence of the geometric primitives, that is correlated with the model shape control, as is visible in the QFD roof, underlines this aspect. The geometric primitives become important in order to provide a sufficient number of control (modifiers) for managing the animation with high attention. The attention to animation is increased looking to the significance of the parameters animation level of detail, frames for seconds and model features deformation rules. Looking at all these data, it is possible to understand that it is necessary to empathise the symptoms presentation providing a significant investment in the animation design.

3.1 Virtual Manikin modeling approach

In order to guarantee a more structured implementation of the virtual simulator, the manikin structure has been described with the help of the Product Breakdown Structure (PbS). Considering the significant importance of the animation features and its correlation with the modelling techniques employed, the PBS scheme has been used also for correlating body elements and animation technologies (Morphing, Vertex animation, …). In order to fulfil to the specification that have been underlined by the just explained approach and looking at the possible available solutions, the virtual manikin model has been created following the anatomical structure of the muscles. This first choice has been implemented because of the problems that occur using other more commercial solutions as the joint skeleton skinning. So, once defined the key features of the model, it has been composed with a skin mesh and a skeleton. Once the skin has been properly attached to the skeleton, transformation of the bone automatically derives transformation of the skin mesh. Then considering that the skeleton is composed by limbs and joints, it is possible to set at most three kinds of position angles: flexing, pivot and twisting. The flexing is a rotation of the limb which is influenced by the joint and cause the motion of all limbs linked to this joint. This flexing is made relatively to the joint point and a flexing axis which has to be defined. The pivot makes rotate the flexing axis around the limb which is influenced by the joint. The twisting causes a torsion of the limb which is influenced by the joint. The direction of the twisting axis has been found similarly to the direction of the pivot. In order to provide the features of realistic animation, underlined by the QFD scheme, the manikin model has been integrated with anatomic concepts and motion observations for providing the best joint position and a faithful representation of anatomical breathing (Fig.1).

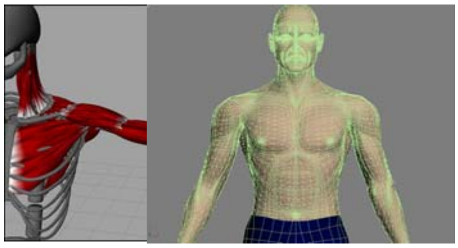
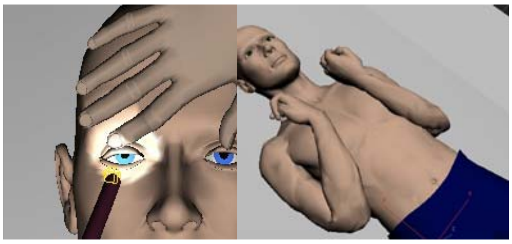


Figure 1: Shape design strategy steps

Then the manikin body has been modelled following the real anatomical structure of the muscles. The skeleton is constituted by ideal lines that correspond to the axes of ideal cylinders that contain the mesh cross-sections

3.2 Virtual Manikin animation approach and virtual platform implementation

In order to fulfil the QFD results and to provide an animation usable on WEB3D platform the human limbs and torso have been deformed by manipulating the cross-section contours, thus transforming a complicated 3-D operation into a 2-D operation which is more intuitive and easy to control. During inspiration (inhaling), the external intercostals muscles contract, lifting the ribs up and out, and the diaphragm contracts, drawing it down. During expiration (exhaling), these processes are reversed and the natural elasticity of the lungs returns them to their normal volume. At rest, we breath 15-18 times a minute. In more vigorous expiration, the internal intercostals muscles draw the ribs down and inward and the wall of the abdomen contracts pushing the stomach and liver upward. Interval depends on normal breathing, accelerate breathing rhythm, pneumo-thorax. The specific motion of real creatures depends on their intricate musculoskeletal structure. Determining exact muscle forces that would make the animation look realistic is extremely difficult. In addition, with dynamics methods each animation frame depends on the previous frame (and consequently on all other preceding frames). The smallest change of dynamic properties of any single frame drastically affects all consecutive frames, resulting in lack of controllability. Space-time constraints can addresses the need for both realism and controllability of character motion. In the space-time framework it is necessary to specify pose constraints that must be satisfied by the resulting motion sequence (e.g. the character pose at the beginning and end of the animation). In addition to these constraints, it is also specified an objective function that is a performance or style metric of such as total power consumption of all of the character's muscles. By these information, a set of possible configuration trajectories has been determined during the T-second. From the movement trajectory study, the middle positions key points for the realistic animation have been identified. So the key frames have been defined. Once defined the virtual manikin model and its animation strategy the virtual simulator has been implemented with the use of the WEB3D technology. In relation with the suggestions provided by the QFD results and in relation with the technological specifications that the different WEB3D technologies have shown, the virtual reality simulator has been implemented with the use of CULT3D solution, that represent the best solution compared with the technical specifications requested.



4. CONCLUSIONS

Thanks to the use of the QFD it has been possible to codify in term of computer science specifications (IT) the emergency medicine "realism". On the contrary of what normally is implemented in computer graphic (photorealism) the creation of an aesthetical detailed manikin is absolutely useless for the emergency medicine training purpose. The modelling level of detail represents only a key factor for supporting a detailed animation, in which every movement is correctly designed as for a real body. Only with the presence of a sufficient number of modifiers it will be possible to design a consistent animation as the QFD has underlined. Thanks to the positive results obtained it is possible to think to the application of this methodology not only to other medical contexts but also to other fields where computer science culture is not so close.

5. REFERENCES

[1] Gaba DM., 2004, "*The future vision of simulation in health care*", Qual Saf Health Care; Vol.13, pp. 2-10.

[2] Issenberg SB., McGaghie WC., Hart IR., 1999, *"Simulation technology for health care professional skills training and assessment*" JAMA, Vol. 282, pp. 86 - 126.

[3] Vozenilek J., Huff JS., Reznek M., 2004, "*See one, do one, teach one: advanced technology in medical education*", Acad Emerg Med, Vol. 11,pp. 1149-1154.

[4] Reznek M, Harter P, Krummel T. *Virtual reality and simulation: training the future emergency physician*. Acad Emerg Med 2002;9:78287.

[5] McLaughlin SA, Bond WF, Promes S. *The status of human simulation training in emergency medicine residency programs*. Simul Healthc 2006;1:18221.

[6]Kogure M., Akao Y., (1983)," *Quality Function Deployment and Cwqc Japan*" Qualità Progress, n.16, pp. 25-29.

[7] Almannai B., Greenough R., Kayasdasdas J., *A decision support tool based on QFD and FMEA for the selection of manufacturing automation technologies*, Robotics and Computer-Integrated Manufacturing, Volume 24, Issue 4, August 2008, Pages 501-507

[8] Kwong C.K., Chen Y., Bai H., Chan D.S.K., *A methodology of determining aggregated importance of engineering characteristics in QFD,* Computers & Industrial Engineering, Volume 53, Issue 4, November 2007, Pages 667-679

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