Visual Realism in 3D Serious Games for Learning: A Case Study

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Abstract. Serious gaming has been proven to be an enjoyable tool to transfer particular knowledge or skills to target players. In educational context, serious games offer a powerful and effective approach to teaching, learning and skill development for all ages. Realism is one of the considerable factors which motivates players to accomplish their goals in a serious game. In this paper we present the elements and the process of visual realism design for 3D serious gaming, extended with a case study in LISSA (LIfe Support Simulation Application), a serious game designed to teach and learn cardiopulmonary resuscitation (CPR). LISSA exploits video game technology to link computer-based case simulations with e-learning functionalities in a single framework. An evaluation of visual realism with regard to photorealism and camera viewpoint is presented.

1 Introduction

A serious game is defined as a game with specific intention such as education, training, treatment, skill enhancement, widely used in many areas including military, health care, business management, or social science. Digital based serious games started appearing in the early 1970s for educational purpose [1]. Up to this date, a series of significant improvements to real-time hardware and software techniques realized new possibilities for computer generated images, animations and graphics for gaming.

With regard to *Dale′s cone of learning*, learning by simulating the real experience is an active learning process through which the learner could obtain 90% of what they participate within the simulation [2]. To simulate the real experience, the level of realism is always considered. Researchers in many areas consider game design, with regard to aesthetic context, as a key element in developing successful games [3] [4]. Game players tend to value good graphics, animation and sound. These factors provide sensory proof of the reality of a game, supporting and enhancing the impact of the whole game experience. Rhyne et al. [5] suggests that the higher the level of reality or fantasy is, the more entertaining a game becomes. And in doing so, graphics and scenario play the key roles. A realistic scenario keeps the player intrigued, thereby, increasing their satisfaction. Sound effects also help to establish the ambience or atmosphere of a game by increasing realism. Developing and deploying a serious game, with regard to the realism, have to take into account both the cutting edge technology and players perception.

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In this paper, we present a case study of visual realism design in our 3D serious game for cardiopulmonary resuscitation (CPR) learning, LISSA (LIfe Support Simulation Application). LISSA provides a 3D computer simulation of emergency scenarios where a patient needs CPR application. A comparison of different visual elements, namely photo-realism against non photo-realism and different camera viewpoints are evaluated.

2 Background

Realism in computer-simulated environments is considered as a "Virtual Reality" (VR), a term referring to the simulation of physical presence in places in the real world, as well as in imaginary worlds. Most current serious games for learning provide primarily visual experiences. In this section, we first explain the basic steps to create 3D virtual objects including modelling, texturing and lighting. Next, the literature review on the degree of realism related to player perception is presented. Finally, visual realism for serious games is explained.

2.1 3D Production for Gaming

In practice, several techniques are used in creating 3D graphics. The traditional process of creating 3D graphics for games can be divided into five basic phases (see Figure 1) which are modelling, texturing, lighting, animation and rendering, described in more details in the following.

Fig. 1. Example of; (a) Modeling, (b) Texturing, (c) Lighting and (d) Rendered image.

Geometric modelling is the process of forming the shape of an object. Basically, a 3D model is formed of points called vertices connected by polygons that define its shape. Polygons may contain arbitrary number of vertices, however, the most common method is to build triangle meshes. The overall integrity of the model and its suitability to use in animations depend on the structure of the polygons. Games are real-time rendering systems, producing dozens of frames in each second. Thus, 3D models particularly suited for games must contain a reasonably small number of polygons, also known as *low poly* model. The number of polygons and objects which can appear in a scene and can still be rendered at an acceptable performance, has to be carefully calculated and tested in order to maintain the smoothness while playing.

The second step of 3D production is *texturing* or *texture mapping*, a method to apply (map) the texture of surfaces to the 3D geometry produced by the previous phase. Every vertex in a polygon is assigned a texture coordinate (which in the 2D case is also known as a UV coordinate, the axes of the 2D texture) either via explicit assignment or by procedural definition. Image sampling locations are then interpolated across the face of a polygon to produce a visual result that seems to have more richness in colors than could otherwise be achieved with a limited number of polygons. Computer graphics techniques detailed above have been designed to make objects appear to contain more polygons than they actually do.

The third phase is *lighting* or *illumination*, which is usually created by a game engine. Upon rendering a scene, a number of different lighting techniques will be used to make the rendering look more realistic. For this matter, a number of different types of light sources exist to provide customization for the shading of objects. For example ambient lighting, directional lighting, point lighting, spotlight lighting, area lighting and volumetric lighting. Since the lighting calculation for games is processor-intensive, some of the lighting components such as area lights are not available at runtime processing but may be applied using off-line created light-maps during the texturing step.

Fourth is *animation* which refers to the temporal description of an object, i.e., how it moves and deforms over time. Popular methods include key-framing, inverse kinematics, motion capture and physical simulations, these techniques are often used in combination. Game engines also facilitate some turnkey solutions for animation such as animation retargeting, data-driven controllers (with motion capture system) etc. which reduce some repetitive animation tasks.

Finally, *rendering* is the process to convert the complete model of the 3D virtual world into a 2D image either by simulating light transport to get photo-realistic images, or by applying some kind of non-photorealistic style such as cartoon-shade or painting style. Obviously for games, the rendering step has to be performed at real-time rates.

2.2 Visual Realism in Games

Many researchers concur that player perception can be influenced by visual realism [7], [6]. Visual realism is distinguished by the term ”Visual Fidelity” which refers to the degree to which visual features in the virtual environment conform to visual features in the real environment [8], [9]. In order to convince the player that the virtual environment is real, the scene presented should faithfully model the expected actual environment. A highly accurate, fully modelled, interactive environment is thus seen as “virtually real”. Visual realism has five basic building blocks: *geometry (or form), surface, illumination, animation (including physics) and viewpoint*, each component can be created from realistic to abstract. For example, geometry is formed by points, lines, curves, or surfaces in the modelling step as described in Section 2.1. To model an object for games, the form can have real proportions or distorted depending on the game concept.

Despite its importance, the role of viewpoint and perspective is one of the least studied elements of realism and therefore, we give more focus on this topic in our work. Rob Pepperell discusses in [10] the problem of how to depict the relative indistinctness of peripheral vision as compared with central vision, and the appearance of our bodies in our field of view. He argues that first person view — intended to simulate viewing the scene through our own eyes — may be less realistic due to the lack of ability to see our body, comparing to other, outer viewpoints.

Since a game is an interactive virtual environment, careful definition of level of realism and the interactive qualities of the virtual environment are required. Interface or interaction fidelity refers to the degree to which the simulator technology (visual and motor) is perceived by a human participant to simulate the operational equipment and the actual real world task situation. In the following, we present our case study of the visual production of LISSA and the experiment on user perception focusing on visual realism.

3 Life Support Simulation Application (LISSA)

LISSA is a serious game designed to teach and learn CPR in complete compliance with The European Resuscitation Council (ERC) CPR guidelines, 2010 [11]. LISSA has been designed as an e-learning environment with all the actions turning around a CPR scenario that reproduces with 3D realism an emergency situation that requires CPR procedures. LISSA supports two types of users, instructors and learners. Instructors prepare the CPR scenario and present it to the learner as a test or problem. The learner solves the problem applying the CPR procedures in a game mode. LISSA evaluates the actions and assigns a final score. All of the learner's actions are registered in a central data base allowing instructors to consult them in order to track the learning process. Instructors then can use this information to recommend new scenarios and problems.

3.1 Visual Realism within LISSA

The visual realism of LISSA is considered during all production process from modelling to rendering with respect to the five elements of visual realism presented in Section 2.2. Starting with the modelling, a low polygon model with real proportions is specified. The proportions defined in character modelling of LISSA are the ones of an average person, generally seven and a half heads tall (including the head) which is the proportion of humanoid form. A true proportion is required in order to maintain the real kinetic and human factors during the emergency scenario.

In order to run as smooth as possible, minimizing the geometry, decreasing the number of polygons and texture distortion of all 3D models are needed. Within LISSA, the number of polygons are first limited by the game engine we used, Unity3D, allowing up to 60,000 polygons per object. Polygons of LISSA objects are between 5,000 to 30,000 depending on their structure. To ensure real-time interaction and preserve visual realism we created scenes where the number of polygons for a single scene, including characters, equipments and environment, was between 40,000 and 200,000. To minimize the number of polygons, modelers needed to maintain the visual realism as similar as a high-polygon model. The reduction of polygons was performed until the modeler found a reasonable compromise between visual quality and performance for real-time interactive use where usability is more important than visual perfection.

Figure 2 (a) and (b) present examples of a low polygon and a high polygon model, respectively, representing the same character within LISSA; the same texture, depicted in Figure 2 (c), was applied to both models. We can see that the results as presented in Figure 2 (d) and (e) look completely identical even though the number of polygons are very different (3,996 for the low polygon model and 251,120 for the high polygon

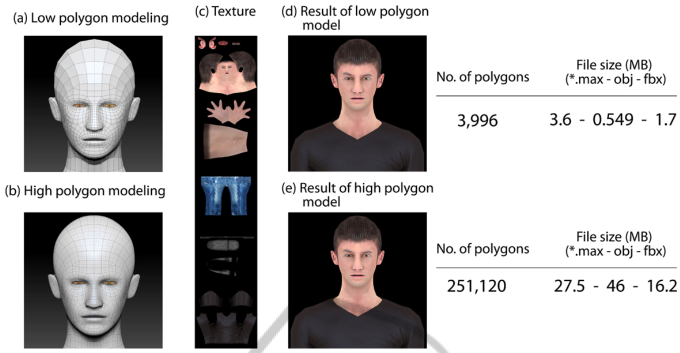

Fig. 2. Difference between low-polygon model and high polygon model.

model). In addition, some techniques were used in order to control the number of polygons in a rendered scene such as if an object is normally viewed only from a few sides or if the object is mostly flat, then it can be approximated by a textured polygon rather than by a full geometrical model. Furthermore, some unimportant and hidden objects were identified, simplified and completely eliminated.

To overcome the limitations of per-vertex surfaces, which require a high-level of tessellation to achieve smooth look, we use a set of bit-mapped images (multi-texturing) which contains color information and is usually projected onto the triangles of a mesh. When creating a character model, the high polygon model is first scrubbed in order to keep the details of folds and wrinkles on clothes then the topology is changed by turning the sculpted object into a low poly mesh. The details within the high poly model are unwrapped and turned to a realistic texture. Most of the texture maps used within LISSA are JPG format which can be lossy compressed. On the other hand to represent the transparent objects we use TIF format since alpha channel is supported in this format. Figure 3 shows an example of multi-texturing for a character in our game.

Fig. 3. Example of texture map of a character in the LISSA game.

To illuminate the scenes and the objects we used the basic lighting functionalities of Unity3D game engine [12] such as directional lights and spot lights. Textures we used were also embedded ("baked") with indirect illumination such as ambient occlusion, caustic (refractive, reflective) effects, and also post-processed (adjust saturation and contrast). These baked textures present how light appears to reflect from the model's

Fig. 4. Example of high precision animation while two objects have touched.

surface. In this way different off-line computed illumination effects such as shading and shadows can appear on texture maps, see Figure 3 for an example.

Since LISSA is defined as a serious game for learning, the posture and movement of characters have to be in the correct way. During the animation process, the main step that needs to be considered carefully is when two animated components have touched or collided as overlapping has to be avoided. For example as in Figure 4, when the helper′s hands are touching or holding a part of the patient′s body, the hands of the helper have to be positioned properly and with high precision in order to avoid unrealistic intersections. Another consideration is that an adaptive learning system such as LISSA should allow instructors to select the main actors in the game. When the characters are changed, some characteristics such as height, body size are also changing, while the position of touching needs to be exactly the same.

Finally, the render viewpoint needs to be considered. To maintain LISSA visual realism, 1st and 3rd person viewpoints are considered. The comparison of player perception has been evaluated, results are presented in Section 4.2.

4 Evaluation

In order to optimize the visual realism of LISSA, a visual perception survey has been done. The objectives of the survey are; i) comparison between photorealistic (PR) and non-photorealistic (NPR) rendering; ii) comparison between 1st and 3rd person viewpoint and iii) user perception survey on LISSA′s visual realism with predetermined rendering style (PR) and viewpoint (3rd person). Before doing the survey, the NPR style applied in the test was pre-selected by LISSA's developer team. Figure 5 shows examples of NPR rendering for pre-selection. The selection is based on the preference of team members. Finally, Figure 5 (h) has been chosen to compare with PR scene.

4.1 Method

The evaluation was based on a questionnaire, participants were gathered from 22 layperson volunteers. The same protocol was followed with each experiment. First, the participant completed the pre-experiment questionnaire. Second, the participant was told the goal of the experiment. Third, the participant was given the chance to practice playing the game in the demo mode with each user interface, (1) PR with 1st viewpoint (2) PR

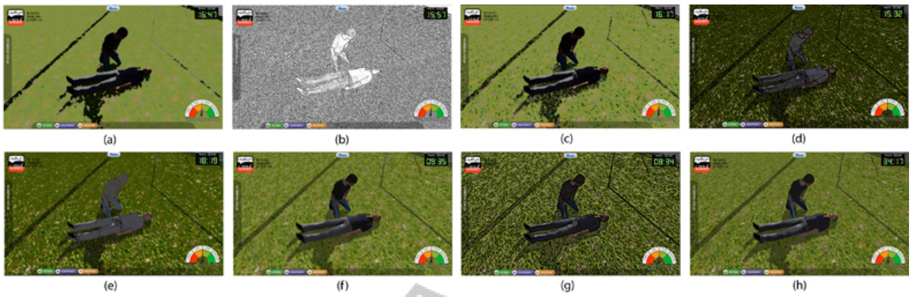

Fig. 5. Examples of NPR rendering for pre-selection.

with 3rd viewpoint (3) NPR with 1st viewpoint and (4) NPR with 3rd viewpoint (in randomized order), for no more than three minutes. Fourth, the participant played the game with pre-determined user interfaces, on a pre-determined level. Finally, the participant answered the interface experience questionnaire related to the user interfaces.

The questionnaire had two main parts. First part was a pre-experiment questionnaire, which gathered the participant's characteristics including gender (male/female), handedness (right / left / ambidextrous) and age (from <20 to >60 years old). The participants were also asked to rate their expertise with computers and games by selecting the frequency of using a computer and playing a computer game (from <1 to >20 hours per week). The second part was an interface experience questionnaire. In this part, three groups of questions (with 16 questions in total) were asked. The first group was a comparison between PR and NPR rendering, allowing a third, neutral answer denoting no user preference, see Figure 6 for details. The second group intended to compare 1st and 3rd person viewpoint, questions are shown in Figure 7. As in the first group, three options were provided. In the last group, the participants were asked to rate how much they agree about different statements related to the visual realism of LISSA, using a 5-point Likert scale [13]: strongly disagree, disagree, neutral, agree and strongly agree.

4.2 Results

The results of the survey are presented in Table 1, 2, 3, 4 and Figure 8 which are characteristics of the sampling; comparison results of "photorealism (PR)" and "non-photorealism (NPR)"; comparison results of "1st" and "3rd" person viewpoint; visual realism results of LISSA with predetermined rendering (PR and 3rd person camera viewpoint); and an evaluation of average results (in red) with error polylines of standard deviation (green and blue), respectively.

The results show that willingness of learning can be enhanced by visual realism. Photo-realistic (PR) rendering and 3rd person viewpoint was well rated. In terms of the type of rendering (PR) and viewpoint (3rd person), participants had positive feeling with the degree of visual realism, enjoyment, ease of use, comfortability while playing game. Participants also agreed in that the intended actions were accurately carried out on the screen when using LISSA′s interface. In the learning context, participants felt that when learning with LISSA, their CPR performance could be improved significantly.

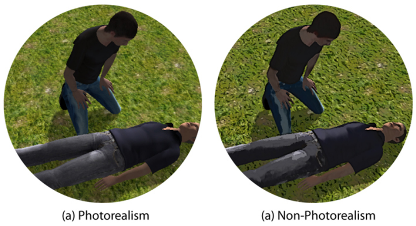

Fig. 6. Comparison of PR and NPR in LISSA.

Fig. 7. Comparison of 1st and 3rd person viewpoint for different actions.

Table 1. Characteristics of sample for the questionnaire.

Issue	Details
Gender	8 men, 14 women
Handedness	19 right, 1 left and 2 ambidextrous
Age (years old)	20 (21-40) and 2 (41-60)
Frequency of computer using (hour per week)	4 (1-10H) and 18 (>20H)
Frequency of playing game (hour per week)	4 (no), 6 (<1H), 8 (1-10H), 1 (11-20H) and 3 (>20H)

Table 2. Comparison results of "photorealism (PR)" and "non-photorealism (NPR)".

Questions	-1	$\mu \pm \sigma$	1
Q1. Which one was easier to understand?	NPR	1.0 ± 0.2	PR
Q2. Which one was more attractive?	NPR	1.0 ± 0.0	PR
Q3. Which one motivated you to learn more?	NPR	1.0 ± 0.0	PR
Q4. In overall, which one satisfied you more?	NPR	1.0 ± 0.0	PR
Q5. Which one is more appropriate with LISSA?	NPR	1.0 ± 0.0	PR

Table 3. Comparison results of "1st" and "3rd" person viewpoint.

Questions	-1	$\mu \pm \sigma$	1
Q6. Which viewpoint made you feel more real?	1st	0.6 ± 0.8	3rd
Q7. Which viewpoint was more comfortable to use?	1st	0.9 ± 0.4	3rd
Q8. For overall satisfaction, which one satisfy you more?	1st	0.8 ± 0.6	3rd
Q9. Which one is more appropriate with LISSA?	1st	0.8 ± 0.6	3rd

5 Discussion and Conclusions

In this paper we presented the process of optimizing visual realism within our serious games for cardiopulmonary resuscitation learning, LIfe Support Simulation Application (LISSA). Five visual realism components, form, surface, illumination, animation and

Table 4. Visual realism results of LISSA.

Questions	1	$\mu \pm \sigma$	5
Q10. Visual realism enhance the willingness of learning	Strongly Disagree	4.5 ± 0.5	Strongly Agree
Q11. The degree of visual realism in LISSA is high enough	Strongly Disagree	3.8 ± 0.6	Strongly Agree
Q12. Using this interface was enjoyable	Strongly Disagree	3.8 ± 0.7	Strongly Agree
Q13. Learning this interface was easy	Strongly Disagree	3.7 ± 1.0	Strongly Agree
Q14. This interface was comfortable to use	Strongly Disagree	3.7 ± 0.6	Strongly Agree
Q15. My intended actions were accurately carried out on screen when using this interface	Strongly Disagree	3.7 ± 0.9	Strongly Agree
Q16. I feel like more practice time with this interface would have made a significant difference to my performance	Strongly Disagree	4.2 ± 0.5	Strongly Agree

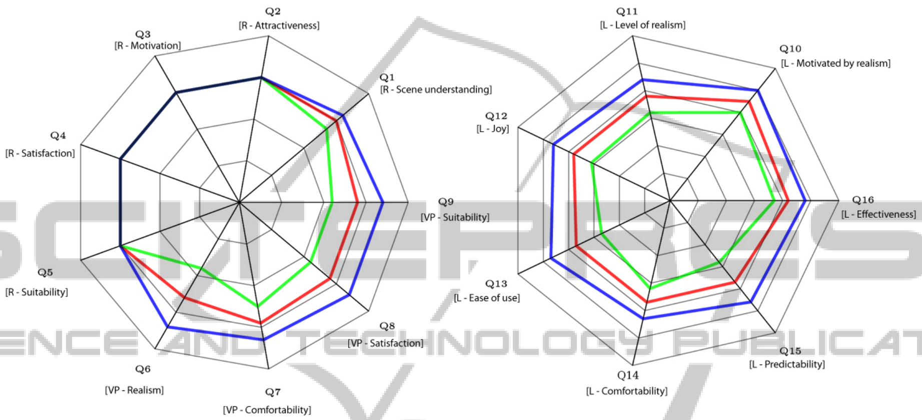

Fig. 8. Evaluation of average results (in red); error polylines (green and blue) at one standard deviation. *R, VP* and *L* denote questions related to rendering mode, view point and the effectiveness of LISSA, respectively.

camera viewpoint have been proposed and used during the game production procedure. Additionally, all objects and characters have been maintained with the real proportion and movement. The basic illumination provided by Unity3d game engine has been used in addition to the indirect illumination such as ambient occlusion which was embedded into the texture maps. Two of the five components including surface rendering (PR, NPR) and camera viewpoint (1st , 3rd viewpoint) were evaluated by 22 laypeople.

The evaluation results show that photo-realistic rendering with 3rd person viewpoint are well rated and participants feel positive with the visual realism of LISSA. These confirm both that realism plays a key role in teaching by simulation applications, as well as the observations made by Pepperell [10] about the difficulties of the realistic depiction of peripheral vision in first person view including the limited visibility of the viewers body. As future work, comparative evaluations with other systems are required and we also would like to investigate another types of realism, including functional and physical realism, as well as the further possibilities of visual realism that effects each step of learning process.

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