Virtual Worlds and Augmented Reality in Cultural Heritage Applications

Nadia Magnenat-Thalmann
MIRALab, University of Geneva, Geneva, Switzerland

George Papagiannakis,
MIRALab, University of Geneva, Geneva, Switzerland

ABSTRACT: we describe a complete methodology for real-time integrated mixed reality systems that feature realistic complete simulations of animated virtual human actors (clothes, body, skin, face) who augment real environments and re-enact staged storytelling dramas. Although initially targeted at Cultural Heritage Sites, the paradigm is by no means limited to such subjects. The abandonment of traditional concepts of static cultural artifacts or rigid geometrical and textual augmentations with interactive, augmented historical character-based event representations in a mobile and wearable setup, is the main contribution of the described work as well as the proposed extensions to AR Enabling technologies: a VR/AR character simulation kernel framework with character to object interaction, a markerless camera tracker specialized for non-invasive geometrical registration on heritage sites and an NPR mixed reality illumination model for an alternative modal reality. We demonstrate a real-time case study on the actual site of ancient Pompeii.

1 INTRODUCTION

Mixed Realities (Milgram & Kishino 1994) and their concept of cyber-real space interplay invoke such interactive digital narratives that promote new patterns of understanding. However, the "narrative” part, which refers to a set of events happening during a certain period of time and providing aesthetic, dramaturgical and emotional elements, objects and attitudes (Nandi & Marichal 2000, Tamura et al 2001) is still an early topic of research. Mixing such aesthetic ambiences with virtual character augmentations (Cavazza et al 2003) and adding dramatic tension has developed very recently these narrative patterns into an exciting new edutainment medium (Lindt 2003). Since recently, AR Systems had various difficulties to manage such a time-travel in a fully interactive manner, due to hardware & software complexities in AR ‘Enabling Technologies’ (Azuma et al 2001). Generally the setup of such systems was only operational in specific places (indoors-outdoors) or with specific objects which were used for training purposes rendering them not easily applicable in different sites. Furthermore, almost none of these systems feature full real-time virtual human simulation. With our approach, based on an efficient real-time tracking system, which require only a small pre-recorded sequence as a database, we can setup the AR experience with animated virtual humans anywhere, quickly. With the interplay of a modern real-time framework for integrated interactive virtual character simulation, we can enhance the experience with full virtual character simulations. Even if the environmental conditions are drastically altered, thus causing problems for the real-time camera tracker, we can re-train the camera tracker to allow it to continue its operation.

The proposed set of algorithms and methodologies aim to extend the “AR Enabling Technologies” in order to further support real-time, mobile, dramaturgical and behavioured Mixed Reality simulations, as opposed to static annotations or rigid geometrical objects. Fig. 1 depicts fully simulated virtual humans (skin, clothes, face, body) augmenting a cultural heritage site.

1.1 OVERVIEW

As a preprocessing stage, our real-time markerless camera tracker system is being trained on the scene that is aimed to act as the mixed Reality stage for the Virtual actors. During real-time mobile operation and having already prepared the VR content for the virtual play, our system allows the user to be immersed fully in the augmented scene and for the first time witness storytelling experiences enacted by realistic virtual humans in mixed reality worlds. The minimal technical skills and hardware configuration required to use the system, which is based on portable wearable devices, allow for easy setup in various indoors and outdoors feature rich locations. Thus in Section 2 of this work we review the previous work performed in the main areas of “AR Enabling technologies”, such as camera tracking and illumination as well as the extensions that we propose: complete VR character simulation framework with character to object interactions as well as a new illumination model for MR. In Section 3 we present such a framework which is mandatory in order to handle the exponential complexity of virtual character drama, that traditional rendering-centric AR systems cannot anymore handle. A new illumination model and NPR method is presented in Section 4, in order to explore the redefinition of the MR mediation by stylizing it to create a ‘dreamy’ artistic and painterly reality. Finally in section 5 we present our two case studies in a controlled environment as well as on the site of ancient Pompeii and we epitomize with the discussion and conclusions sections 6 and 7 respectively.

Fig. 1. Example of mixed reality animated characters acting a storytelling drama on the site of ancient Pompeii (view from the mobile AR-life system i-glasses)

2 RELATED WORK

On AR integrated platforms, a number of projects are currently exploring a variety of applications in different domains such as medical (ART 2004), cultural heritage (Stricker et al 2001**Error! Reference source not found.**, Papagiannakis et al 2005, training and maintenance (Wohlgemuth & Triebfürst 2000) and games (Thomas et al 2000). Special focus has recently been applied to system design and architecture in order to provide the various AR enabling technologies a framework (Gamma et al 1994) for proper collaboration and interplay. Azuma (Azuma et al 2001) describes an extensive bibliography on current state-of-the-art AR systems & frameworks. However, few of these systems take the modern approach that a realistic mixed reality application, rich in AR virtual character experiences, should be based on a complete VR Framework (featuring game-engine like components) with the addition of the “AR enabling Technologies” like a) Real-time Camera Tracking b) AR Displays and interfaces c) Registration and Calibration. Virtual characters were also used in the MR-Project (Tamura et al 2001) where a complete VR/AR framework for Mixed Reality applications had been created. Apart from the custom tracking/rendering modules a specialized video and see-through HMD has been devised. However, none of the aforementioned AR systems can achieve to date, realistic, complete virtual human simulation in AR featuring skeletal animation, skin deformation, facial-speech and clothes simulation. For realizing the dynamic notions of character based Augmented Heritage, the above features are a prerequisite.

Camera tracking methods can be broadly divided into outside-in and inside-out approaches, depending on whether the sensing device is located on the tracked object, or multiple sensing devices surround the tracked object. Technologies used to perform the tracking include mechanical (Roberts 2005), magnetic (Ascension 2005), optical (Vicon 2005), inertial (Intersence 2005), ultrasound or hybrids (Fozlin et al 1998) of these. Due to the sensitive nature of the environment our tracking system had to function in, namely the ancient ruins of Pompei, we opted to develop an inside-out optical system without the need for fiducial markers. Visual through-the-lens tracking is a widely researched topic and several papers have been published investigating different methods of achieving this goal. A software library has also been released called ARToolKit (ARToolkit 2005) which is widely used in the Augmented Reality community. This relies on large fiducials placed throughout the scene which are identified by the system and used to perform pose estimation. Davison & Kita 2001 has published several papers based on Simultaneous Localization and Mapping (SLAM), a very promising real-time probabilistic visual method of tracking. Another popular approach is that reported by Vachetti et al 2005, which is based on a prior scene model with real-time line and texture matching. The visual fiducial method commercialised by Radamec (Thomas et al 1997) has proven to be very accurate but has the disadvantage of requiring severe scene modifications and extensive setup. Our real-time markerless tracking method has been already described in (Papagiannakis et al 2005).

GPU hardware methods in Mediated and Mixed Reality have been recently explored by (Fung et al 2002, Fung et al 2004). Their application remains exclusively in Reality or Virtuality spectrum of the Mediated Reality space, as the focus is on applying image processing visual filters on real scenes using desktop PCs and multiple GPUs or pure NPR techniques on the virtual only augmentations. Our approach projects both real (video stream) and virtual parts (3D models) in a common space and applies the NPR shader in that common space. Ansari 2004 has also exploited the application of GPU shader image processing programs in real-time video sequences.

3 MR FRAMEWORK COMPONENTS FOR CHARACTER SIMULATION

3.1 *AR-Life System design*

Our AR-Life system is based on the VHD++ (Ponder et al 2003), component-based framework engine developed by VRLAB-EPFL and MIRALab-UNIGE which allows quick prototyping of VR-AR applications featuring integrated real-time virtual character simulation technologies, depicted in Fig. 2. The framework has borrowed extensive know-how from previous platforms such as presented by Sannier et al 1999. The key innovation is focused in the area of component-based framework that allows the plug-and-play of different heterogeneous human simulation technologies such as: Real-time character rendering in AR (supporting real-virtual occlusions), real-time camera tracking, facial simulation and speech, body animation with skinning, 3D sound, cloth simulation and behavioral scripting of actions.

The integrated to the AR framework tracking component is based on a two-stage approach. Firstly the system uses a recorded sequence of the operating environment in order to train the recognition module. The recognition module contains a database with invariant feature descriptors for the entire scene. The runtime module then recognizes features in scenes by comparing them to entries in its scene database. By combining many of these recognized features it calculates the location of the camera and thus the user position and orientation in the operating environment. The main design principle was to maximize the flexibility while keeping excellent real-time performance. The different components may be grouped into the two following main categories:

- System kernel components responsible for the interactive real-time simulation initialization and execution.
- Interaction components driving external VR devices and providing various GUIs allowing for interactive scenario authoring, triggering and control.

Finally the content to be created and used by the system was specified, which may be classified into the two following main categories: a) Static and b) Dynamic content building blocks such as models of the 3D scenes, virtual humans, objects, animations, behaviors, speech, sounds, python scripts, etc.

3.2 *MR framework operation for character simulation*

The software architecture is composed of multiple software components called services, as their responsibilities are clearly defined. They have to take care of rendering of 3D simulation scenes and sound, processing inputs from the external VR devices, animation of the 3D models and in particular complex animation of virtual human models including skeleton animation and respective skin and cloth deformation. They are also responsible for maintenance of the consistent simulation and interactive scenario state that can be modified with python scripts at runtime. To keep good performance, the system utilized four threads. One thread is used to manage the updates of all the services that we need to compute, such as human animation, cloth simulation or voice (sound) management. A second thread is used for the 3D renderer, who obtains information from the current scenegraph about the objects that must be drawn as well as the image received from the camera. It will change the model view matrix accordingly to the value provide by the tracker. The third thread has the responsibility of capturing and tracking images. The last thread is the python interpreter, which allows us to create scripts for manipulating our application at the system level, such as generating behaviors for the human actions (key-frame animation, voice, navigation).

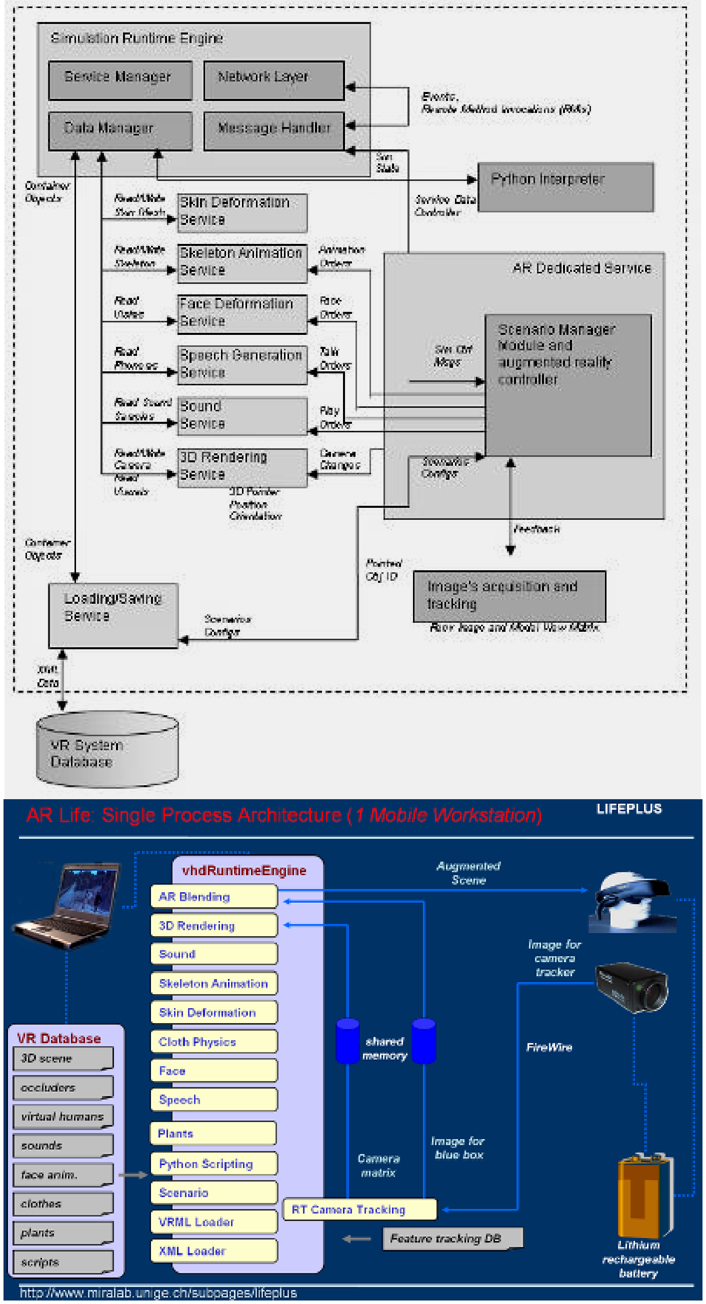

Fig. 2 VHD++ AR Framework Overview

The AR system presented in Fig. 2 features immersive real-time interactive simulation supplied with proper information in course of the simulation. That is why content components are much diversified and thus their development is extremely laborious process involving long and complex data processing pipelines, multiple recording technologies, various design tools and custom made software. The various 3D models to be included in the virtual environments like virtual human or auxiliary objects have to be created manually by 3D designers. The creation of virtual humans require to record motion captured data for realistic skeletal animations as well as a database of real gestures for facial animations. Sound environments, including voice acting, need to be recorded in advance based on the story-board. For each particular scenario, dedicated system configuration data specifying system operational parameters, parameters of the physical environment and parameters of the VR devices used have to be defined as well as scripts defining atomic behaviors of simulation elements, in particular virtual humans. These scripts can modify any data in use by the current simulation in real-time. This allows us to continue running the simulation whilst some modifications are performed.

3.3 *MR registration and staging*

Employing a markerless camera tracking solution for registering the CG camera according to the real one, is an added value advantage since it eliminates the use of external tracking devices or avoids polluting the real scene with the use of known fiducial markers. However, the issue that arises is how to geometrically calibrate the camera and define the scene fiducial origin in world coordinates. Especially as our MR scenes have animated virtual characters, initial character staging, scaling and orientation is a crucial factor in order to determine correct initial, life-sized, believable geometrical registration. In the pipeline described in section 4, boujou allows for an initial scene origin to be defined offline on a tracked scene feature. This feature though is not sufficient as for a number of characters and a storytelling scenario, designers would like to interactively direct, stage and adjust the action in real-time, according to their dramaturgical interest. Therefore we propose a simple algorithm for determining the storytelling scene origin and orientation, harnessing the features of the underlying OpenGL scenegraph renderer camera metaphor and world node coordinates as depicted in Fig. 3. We allow for interactive manipulation of the scene camera as well as separate scene global repositioning and scaling according to the standard OpenGL formulas for ModelView and Projection matrices: The ModelView and Projection matrices are used to set up the virtual camera metaphor and are provided in real-time for each tracked frame, by the underlying camera tracker (Papagiannakis et al 2005). Thus for interactive authoring-staging in the MR scene, two more controls are supplied: a) A single vector is mapped via keyboard contols on the translation part of the camera so that the camera can be furthermore tweaked within the tracked frame and b) A single 4x4 translation matrix is mapped as a virtual trackball metaphor, so that a designer can interactively stage the “Main Scene” scenegraph node that contains all the virtual augmentation. Since the basic renderer of the VHD++ framework is based on OpenScenegraph, all individual elements can have their transformation matrix modified. However, for the MR real-time authoring stage, it is important that the whole staged experience can be initially positioned according to the real scene so that the camera tracking module can subsequently register it accordingly with the real scene.

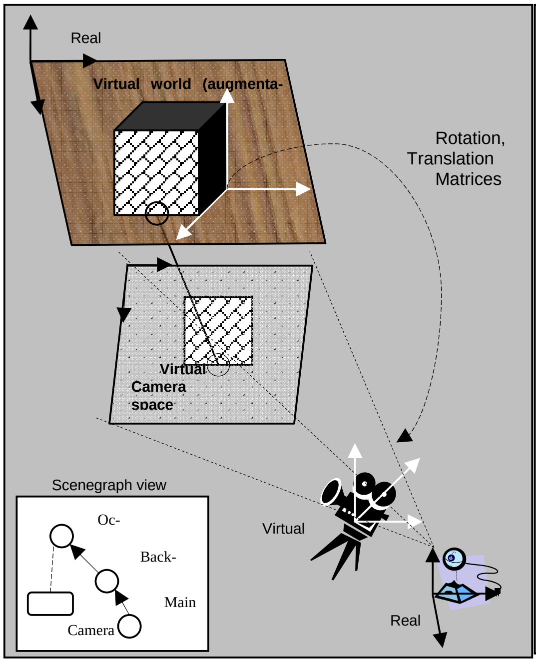

Fig. 3. Camera Coordinate Systems in MR

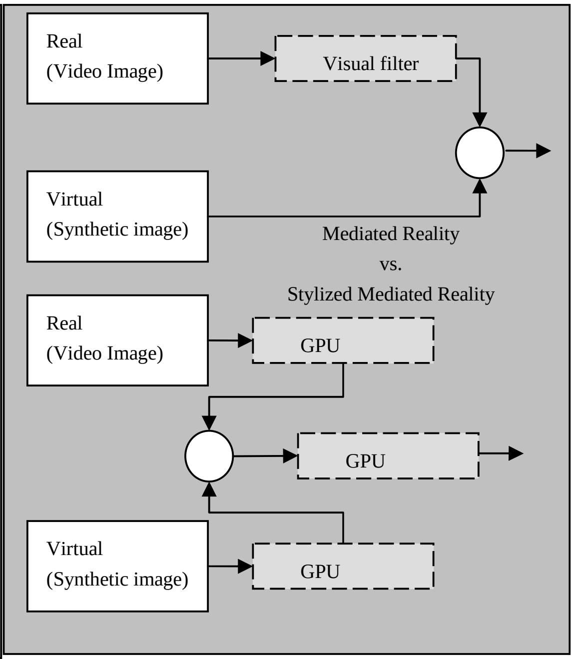

Fig. 4 Stylized Mediated Reality Extension (The "Visual filter" **Error! Reference source not found.** refers to the process that mediates the visual reality and that may insert virtual objects into the visual stream)

For the final geometrical registration, the following algorithm was employed, according to Fig. 2 and Fig. 4 to modify the scenegraph virtual parts as shown in Fig. 3:

1. Retrieve the camera image
2. Run the feature tracker on this image
3. Extract ModelView and Projection camera matrices
4. modify the combined camera matrix according to user authoring scaling/position controls (mapped virtual trackball mouse metaphor operation)
5. apply the combined/adjusted camera matrix to scenegraph renderer
6. move Occluder geometries as root nodes in the scenegraph with GL-DEPTH test set to OFF
7. set the background image acquired from the camera in a 2D projected screen textured quad (thus since background image applied as a texture it is hardware accelerated and independent of window resolution, as hardware extension for non power of 2 textures was employed)
8. modify the Main Scene root node according to user preference for further global positioning and scaling
9. execute draw threads on the whole scenegraph

Thus with the above simple and fast algorithm we were able to both stage our fiducial MR characters and scene Occluders without any performance drop in frame rate.

4 MR ILLUMINATION GPU BASED MODEL

In Mann & Fung 1998, a “Visual Filter” on top of the R (real-actual) scene is defined as a reality mediator. In Fung et al 2002, various ‘Reality Mediators’ are described such as thermal sensor vision, or a diminished mediator who acts by removing parts of the image of the real environment. In this work (Fig. 4) we propose to apply such Visual Filters independently on both the R and V parts of the mediated reality spectrum, as well as to their joined common image space, in the forms of GPU shader programs.

In the following list the main steps of the algorithm are defined:

1. Mediate the Virtual component with an IBL shader
2. Mediate the Real component with an image space processing shader

3. Transform and register both virtual and real in a common image space by a “Render to Texture” operation

4. Further mediate the combined integrated common image space with a stroke-based NPR shader

As is depicted in Fig. 4, the framework for Stylized Mediated Reality is open allowing any number of GPU shaders to be applied at each stage albeit in the expense of multiple rendering passes. However, as currently one shader is applied at each stage, the overall result is a single pass shader visual filter mediation. Our approach creates the Stylized Mediated Reality spectrum by altering both individual and common Reality, Virtuality components by an application of shader based IBL (Beeson and Bjorke 2004) and stroke-based pointillistic NPR effect (Buchin and Walther 2004) to dynamic virtual characters lighted by captured real world illumination.

4.1 *Virtual character and Video Stream Mediation using Shader-based Hatching*

Hatching is a common non-photorealistic rendering NPR (Strothotte & Schlechtweg 2002) technique in which a series of strokes are combined into textures. These stroke compositions can convey the surface tone and form through stroke orientation, the surface material trough stroke arrangement and style and the surface illumination through stroke density. In our approach we are based on the method described by (Buchin and Walther 2004) for employing pixel shaders in our hatching scheme and altering each stroke color using a pointillistic style, as depicted in Fig. 5:

$$\text{Pixel Value} = \prod_{i} \left(\begin{cases} y_i & if\ x_i \geq I \\ 1 & otherwise \end{cases} \right) \text{ where } y_i \text{ is the stroke color}$$

Fig. 5 Real-time Hatching NPR Rendering of a single video frame

However, our innovation stems from the fact that since the stroke shader is applied in a Stylized Mediated Reality manner in the last common image based of the combined Real Video Image and Virtual Synthetic Image components, we avoid the typical problems of hatching such as uniform screen width of stroke textures that lead to incoherent rendering when applied to animated structures. Also a further difference on our approach is that all lookups on the stroke texture are performed in the pixel shader since we apply them on the final common space of Real-Virtual (the rendered to texture quad), which was too costly in performance for (Buchin and Walther 2004). Thus we proposed a very fast and scalable rendering technique for Mixed Reality that allows for special Non Photorealistic Rendering which is applied as in our project one of the aims was to reconstruct the life in frescos of Pompeii. Hence creating an artistic ‘pointillistic’ effect we stylize Reality into a new medium of interplay between real and virtual.

5 CASE STUDIES AND RESULTS

To meet the hardware requirements of this aim, a single Alienware P4 3.20 GHz Area-51 Mobile Workstation was used, with a GeforceFX5600Go NVIDIA graphics card, an IEEE1394 Unibrain Camera (Unibrain 2005) for fast image acquisition in a video-see-through i-glasses SVGAPro (i-glasses 2005) monoscopic HMD setup, for advanced immersive simulation. Our previous efforts were based on a client-server distributed model, based on 2 mobile workstations as at the beginning of our project a single laptop could not suffice in simulating in real-time such a complex MR application. To achieve the requirement of ‘true mobility’, a single mobile workstation (**Error! Reference source not found.**) is used currently in our final demonstrations. That was rendered possible only after the recent advances on the hardware side (processor, GPU) of mobile workstations and on our further software/algorithmic improvements (sections 3, 4, 6), in the streaming image capturing and introduction of hyper-threading and GPU calculations of the MR renderer. In all our case studies we employed 5 fully simulated virtual humans **Error! Reference source not found.**, 20 smart interactive objects for them, 1 python script, 1 occluder geometry and in the case of the 'lab maquette' the 3D geometry of part of the thermopolium. The case studies statistics utilizing the above hardware configuration boil down to 20fps for the camera tracker and 17fps for the main MR simulation for the 'lab maquette' trial and 13fps and 12 fps respectively for the Pompeii trial.

5.1 *Controlled environment setup trial*

In order to validate that our integrated AR framework for virtual character simulation operates in different environments, we have tested the system directly in the ruins of Pompeii. However, in order to further continue AR tests in a controlled lab environment, a real paper 'maquette' was constructed in order to resemble the actual Pompeii site that we visited for our first on site tests. This allowed us for extra fine tuning and improvement of our simulation and framework, without having to visit numerous times the actual site. Fig. 6 (right) depicts an example of augmenting the real 'maquette'.

5.2 *Pompeii and the thermopolium of Vetutius Placidus trial*

With the help of the Superintendence of Pompeii (Archaeological Superintendence of Pompeii 2004), who provided us with all necessary archaeological and historical information, we have selected the 'thermopolium' (tavern) of Vetutius Placidus and we contacted our experiments there. The results are depicted in the following Fig. 6, Fig. 7 where the technologies employed for simulating and authoring our virtual humans where already described in (Papagiannakis et al 2005).

Fig. 6 (left). The Real Pompeian 'thermopolium' that was augmented with virtual animated virtual characters. In this figure the scene is set-up for camera tracking preprocessing; consequently the laptop is put in the backpack for the run phase. (right) Lab 'maquette' controlled AR tests. For optimum flexibility and tests the camera is detached from the HMD and moved freely within the 'tracked area' augmenting it with virtual characters (laptop monitor)

Fig. 7. The Mobile AR-Life simulator system on the actual site of Pompeii

6 DISCUSSION AND FUTURE WORK

From the end-user point of view, the benefits of the described approach are significant. He/she can view a superposition of the real world with a virtual scene representing fully simulated living characters in real-time. As we are able to occlude with real objects the virtual augmentations, we can therefore enforce the sensation of presence by generating believable behaviors and interaction between the real and virtual objects. However, someone could argue that no 'parthenogenesis'in the Mixed reality algorithmic field is exhibited by this study; our premise is that, as shown in Section 2, fully simulated (animated and deformed in real-time) virtual human actors have not yet appeared so far in real-time Augmented Reality providing a complete, mobile-wearable, integrated methodology that can be re-applied on multiple AR contexts with a markerless tracked camera in real-time. Our key contribution has been into providing an exciting integrated methodology-application for AR with incremental research and extensions in the 'AR Enabling technologies' (Azuma et al 2001). Finally, there are a number of issues that need to be further improved as future work. For example the illumination registration issue is still not yet addressed which will help for rendering more realistic the MR experience and we are currently experimenting with HDRI. The real-time camera tracking performance can be further improved as well as the training process to be further shortened. Currently if the lighting conditions on the real scene are altered, the system has to be retrained and a new database to be generated. In the virtual human simulation domain, an important aspect that we will be addressing in the future is interactivity between the real users and virtual actors.

7 CONCLUSION

Nowadays, when laymen visit some cultural heritage site, generally, they cannot fully grasp the ancient vibrant life that used to be integrated in the present ancient ruins. This is particularly true with ruins such as the ancient city of Pompeii, where we would like to observe and understand the behaviors and social patterns of living people from ancient Roman times, superimposed in the natural environment of the city. With the extensions to "AR Enabling techonogies" and algorithms that we propose for camera tracking, virtual object interaction and NPR illumination coupled under a complete real-time framework for character simulation, we aim provide new dramaturgical notions for Mixed Reality. Such notions could extend further research in MR and develop it as an exciting edutainment medium.

8 ACKNOWLEDGMENTS

The authors wish to thank Sebastian Schertenleib for his support with the VHD++ framework and Marlene Arevalo and Nedjma Cadi for their design work. The work presented has been supported by the EU IST FP6 programme, in frame of the EU IST ENACTIVE project.

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