LIFEPLUS:
Revival of life in ancient Pompeii

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Abstract. In this paper we present our work on the LIFEPLUS project which proposes an innovative 3D reconstruction of ancient frescos-paintings through the real-time revival of their fauna and flora, featuring groups of virtual animated characters with artificial life dramaturgical behaviours, in an immersive AR environment. The goal of LIFEPLUS is to push the limits of current Augmented Reality (AR) technologies, exploring the processes of narrative design of fictional spaces (e.g. frescos-paintings) where visitors can experience a high degree of realistic interactive immersion. Based on a captured/real-time video of a real scene, the project is oriented in enhancing these scenes by allowing the possibility to render realistic 3D simulations of virtual flora and fauna (humans, animals and plants) in real-time. Although initially targeted at Cultural Heritage Centres, the paradigm is by no means limited to such subjects, but encompasses all types of future Location-Based Entertainments, E-visitor Attractions as well as on-set visualisations for the TV/movie industry. In this paper we provide an overview of the project and the technologies being employed and finally we present early results based on the ongoing research.

1. Introduction

1.1 Problem to be solved

Since antiquity, images were used as records of both events-lifestyles, as well as decorations. The possibility of reviving them will add a new dimension in understanding our past. However, the recreation of historic environments for serious study, education and entertainment is not new [1] although the methods for achieving the objectives have evolved considerably over time. Before the days of widespread books and printing, story tellers would conjure up visions of events and places, providing their listeners with an impression of realities (often augmented realities) elsewhere in time and space. Theatre, fine art and cinema have added to the richness of the explicit visual experience available to the viewer. They have made the interpretations of history more accessible to the general public, but at the same time narrowing the individual's scope for personalised, interactive experience and visualisation of the description of it.

Therefore, for the application of technology to heritage to become a viable historical recreation tool, a combination of technological, economic and creative challenges must be overcome. Potentially a Virtual Reality-based heritage experience gives the visitor the opportunity to feel they are present at significant places and times in the past and use a variety of senses to experience what it would have felt like to be there. However, a review of the range of projects on the internet described as Virtual Heritage [2], shows numerous examples of virtual environments build as reconstructions of historic sites but sterile and devoid of population. Engaging characters that are needed in an interactive experience are now slowly coming into focus with recent EU funded IST projects (Charismatic [3]). The main reason for their slow adoption is due to a) the incapability of current VR rendering technology for realistic, entertaining, interactive and engaging synthetic characters and b) lack of interesting interaction paradigms for character-based installations. Historical frescos are a unique arrangement of "mise-en-scene" elements that enhance the user experience by creating a set of compelling narrative patterns, alas however in a static, two-dimensional way. The word "narrative" refers to a set of events happening during a certain period of time and providing aesthetic, dramaturgical and emotional elements, objects and attitudes [4]. Mixing such aesthetic ambiences with virtual augmentations and adding dramatic tension, can develop these narrative patterns into an exciting new edutainment medium.

Therefore, LIFEPLUS proposes new development for the innovative revival of life in ancient frescos-paintings in ancient Pompeii and creation of narrative spaces. The revival is based on real scenes captured on live video sequences augmented with real-time autonomous groups of 3D virtual fauna and flora. The metaphor, which inspires the project approach, is oriented to make the "transportation in fictional and historical spaces", as depicted by frescos-paintings, as realistic, immersive and interactive as possible. For that purpose, LIFEPLUS aims to position itself between the extremes of real life and Virtual Reality, in the spectrum of "Mixed Reality"[5] and especially Augmented Reality (AR), in which views of the real world are combined in some proportion with specific graphic enhancements or augmentations. Apart for Virtual Heritage, LIFEPLUS addresses the following emerging market needs:

a) Tourism and Education-Entertainment (Edutainment). Novel operational paradigms (immersive AR virtual life) for edutainment experiences are preconditions for economic viability for all types of future Cultural and memory Institutions, Location-Based Entertainments and E-visitor Attractions.
b) On set visualization & Virtual Studio: Film studios currently shoot films expecting to add in computer generated (CG) effects such as backgrounds, dinosaurs or CG characters later. Directors would benefit from the ability to see in real time or very soon afterwards an overlay of real and planned CG elements to decide whether the composition is acceptable. Broadcasters are also currently seeking to expand the use of virtual life in live broadcasts (e.g. Ananova [6]).

The project (that commenced on 1st March 2002) is defining new models-tools and affordable solutions for 3D virtual life simulations in AR environments with emphasis on two real-time commercialised end-products with project case study the ancient city of Pompeii: a) a mobile AR on-site guide based on immersive wearable computing b) a middleware architecture of self-contained SDKs and APIs. Innovative research extends the state of the art of technologies developed in IST and other research projects for: a) Real-time camera tracking in unknown environments b) Immersive on-site guides based on mobile-AR units c) Introduction of virtual humans in mixed reality environments and synthesize a new real-time framework that will allow virtual fauna and flora to enhance real environments in AR for, a new breed of innovative edutainment experiences.

Two case study applications on virtual heritage are being developed and demonstrated in the middle and end of the project. Historical world-class frescos-paintings are 'brought to life', through lively 3D animated revival of their content, superimposed on their real environment. Thus the ancient characters of the frescos-paintings (including humans, animals and plants) will be revived and simulated in real-time in 3D, exhibiting in a new innovative manner their unique aesthetic, dramaturgical and emotional elements. The whole experience will be presented to the user on-site during his/her visit, through an immersive, mobile Augmented Reality-based Guide featuring wearable computing and multi-modal interaction.

Early results of the first case study will be presented later in this paper together with thorough descriptions of our VR/AR middleware framework as well as key fundamental research aspects in virtual fauna and flora simulation.

1.2 Quantified Objectives

The goal of LIFEPLUS is to *push the limits of current Augmented Reality (AR) technologies*, exploring the processes of narrative design of fictional spaces (e.g. frescos-paintings) where users can experience a high degree of realistic interactive immersion. Based on a captured/real-time video of a real scene, the project is oriented in enhancing these scenes by allowing the possibility to render realistic 3D simulations of virtual flora and fauna (humans, animals and plants) in real-time. According to its key mobile AR technology, visitors are provided with a see-through Head-Mounted-Display (HMD), earphone and mobile computing equipment. A tracking system determines their location within the site and audio-visual information is presented to them in context with their exploration, superimposed on their current view of the site. LIFEPLUS extends that system and provides key new technologies to render lively, real-time animations and simulations of ancient virtual life (3D human groups, animals and plants). In greater detail LIFEPLUS quantified specific objectives are:

a) *Real-time "realistic" virtual life*. With the advent of virtual human actors such as the ones in the recent CG movie "Final Fantasy: The Spirits Within"[7], the race for heightened reality is prominent and such impressive results highlighted the fact. Even in the area of real-time 3D CG the pursuing for hyperrealism is driven by hardware and algorithmic research, development as well as the viewers expectations set by the film industry. That involves a) Hair simulation b) Cloth animation c) Skin rendering and interactive programmable shading d) Plant simulation e) Artificial life methods for behavioural animation of virtual characters f) Multi-resolution scalable graphics for dynamic Levels Of Detail g) Realistic facial emotion expression.

b) *Automatic Real-time Camera Tracking*. In order to mix 3D computer graphics (CG) with footage of the real world, the CG camera needs to be matched to the actual camera that took the footage. This process ensures that the computer graphics elements match the perspective and movement of the real objects in the real camera shot. Camera tracking, as this technique is called, has been so far performed off-line and mostly involves manual editing work. Fundamental research extends the state of the art for camera tracking in unknown environments in real-time, for an interactive, immersive compelling historical recreation. The approach is based on the only available in the market automated offline AR camera tracking software, which is provided by the industrial leader 2D3™ [8].

c) *Design of successful character based installations*. In order for the overall installation to be successful, it must let people read the intentionality of the characters. New variety of ways to conceive such installations based on the latest research from Blumberg et al [9] are being carried out, lead by the industrial expert noDna [10]. A clear challenge at present is that there is no established paradigm for what an AR immersive virtual heritage experience involving groups of virtual life simulation should look like. This impacts not only on the quality of the experience but also on the technological implementation and on commercial issues such as visitor throughput. New synergies between various disciplines (performing arts, AR technologies, marketing strategies) need to conceptualise characters in a way so that creators can generate AR installations that enable participants to read the desires, beliefs and actions of the virtual characters.

d) *Middleware architectural interoperable components* according to ISTAG [11] and not a monolithic 'black-box solution'. Relations and possible synergy with other projects (STAR, ARVIKA, ARCHEOGUIDE) are also being further explored.

e) *New AR product markets*. To open a wide range of applications where Virtual humans, animals and plants will be merged into a real-time in a real scene, such as a) new breed of highly valued edutainment experiences and presentation methods for the education/entertainment and tourism industry b) pre-visualisation of special effects/ human animation in the movie industry c) many more practical and high potential applications foreseeable in fields such as maintenance, medical visualisation, guidance and information, e-learning, virtual prototyping etc.

f) *Analysis of existing and future standards*. These involve from Web3D (VRML), H-ANIM, X3D and MPEG to mobile telecommunication standards in order to specify the format to generate, store, retrieve and transmit the LIFEPLUS virtual life scenes. As far as it concerns the H-Anim (Humanoid Animation) Specification, this will be considered as a template to be adopted for Virtual Flora and Virtual Animal specification of articulated skeletons for their later simulation (animation-deformation).

3. LIFEPLUS Real-Time System Architecture

3.1. Hardware Requirements Overview

In this section we present an overview of the main functional requirements of the LIFEPLUS system proposal followed by the short overview of the hardware components that will be necessary to meet them.

- Mobility:
    - The overall hardware unit must be highly mobile
    - Its weight should be limited
    - It must be easy to use
    - It must have low power consumption and run on batteries
- Responsiveness:
    - The overall tracking, rendering and AR image composing times must be kept under certain limits in order to assure quality of immersive experience (~200ms)
- Performance:
    - The system must be able to deliver certain number of frames per second (not less than 10fps)
- Robustness:
    - System AR mode boot and run phases should be easy to initialise and robust in operation in order to assure possibly unconstrained interaction of the visitor with the site.
- Camera:
    - head mounted
    - reasonable resolution (~800x600),
    - FireWire for the best digital quality and high transmission bandwidth (limiting lags)
    - Monoscopic video see-through AR allowing to avoid critical problems with composing of synthetic and real images
- DGPS and Digital Compass:

    - On-site localization of the visitor
    - Optional support for vision based real camera tracking
- HMD display:
    - Light, compact and low cost
- Two mobile workstations:
    - Separation and parallelization of the main two heavyweight system tasks: real-time camera tracking and real-time 3D rendering (the ideal solution would be double processor mobile workstation)
    - 3D image rendering workstation must feature state of the art Graphics Processing Unit (GPU) which will allow for real-time generation of VR images of high quality

3.2 Software Architecture and Content Components Overview

The overall LIFEPLUS system architecture is designed based on the VHD++ real-time development framework being a proprietary middleware solution of both MIRAlab and VRlab laboratories. VHD++ is a highly flexible and extendible real-time framework supporting component based development of interactive audio-visual simulation applications in the domain of AR and VR with particular focus on virtual character simulation technologies. C++ has been chosen as the main implementation language. The most important features and functionalities of the VHD++ framework as seen from these different perspectives are: a)support for real-time audio-visual applications, b)extendible spectrum of technologies, c)middleware portability, extendibility and scalability, e)runtime flexibility: XML based system and content configuration f) complexity curbing: multiple design patterns improve clarity and abstraction levels simplify description of problems g) fundamental components and pluggable components hide implementation level details allowing to work on required abstraction level simplifying implementation constructs h) large scale code reuse: *fundamental components* and readymade components encapsulating heterogeneous technologies.

The LIFEPLUS system architecture is designed around two VHD++ runtime engines being active software elements running on two separate portable computers. Each of the runtime engines power supplies a set of pluggable VHD++ services that provide to the system encapsulation of required application level technologies. This kind of architecture allows for separation of computationally heavy real-time tracking and synthetic image rendering tasks.

As shown on Fig. 1, the TRACK runtime engine features relatively light weight services taking care of DGPS based on-site positioning of the visitor and providing her/him with additionally multimedia information related to the current position at the site being visited. Those services play the mayor role in the phase of sight-seeing of the actuall site. Once the visitor reaches the point of interest where the AR simulation is possible then DGPS services become secondary and play a supportive role for the computationally heavy weight real-time, vision based camera tracking service that calculates and sends subsequent camera matrices to the VR/AR runtime engine.

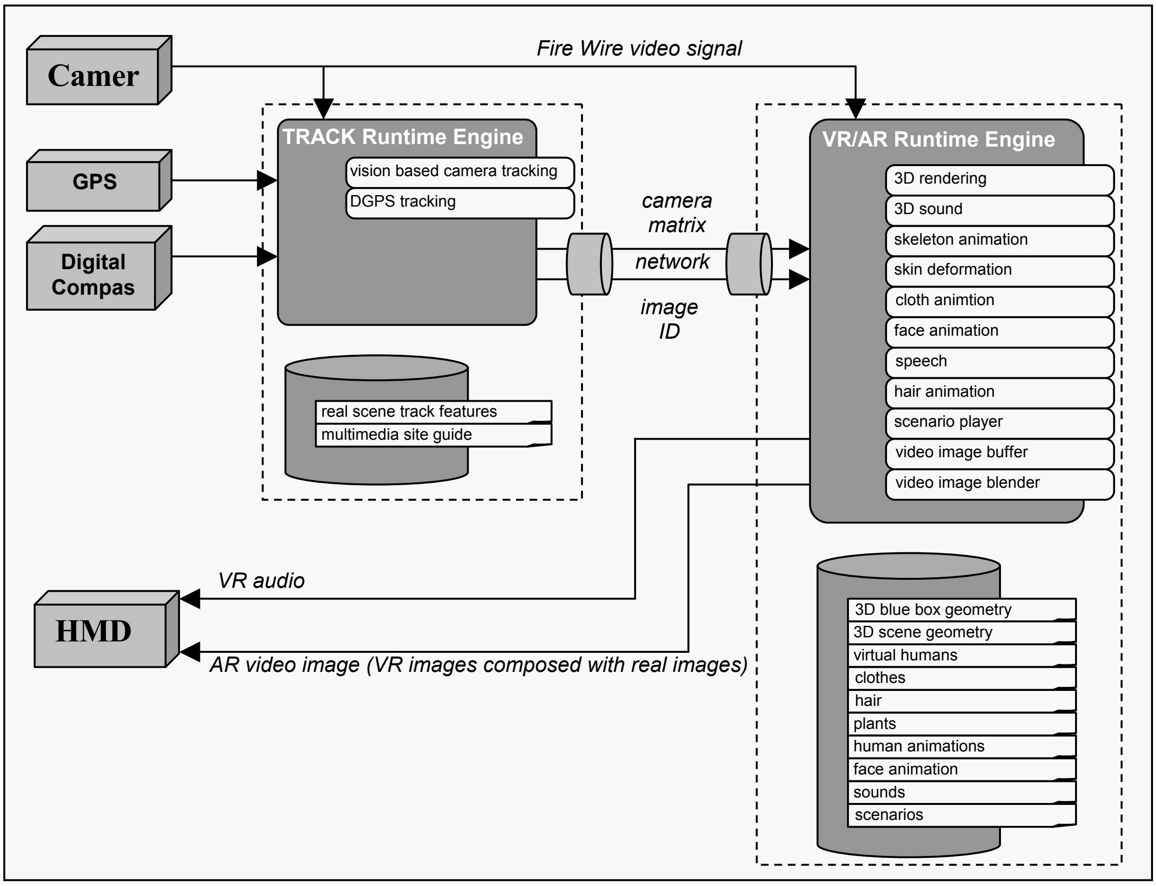

Fig. 1. LIFEPLUS Mobile System Architecture and Content Database

The VR/AR runtime engine features multiple services encapsulating required VR simulation technologies supporting real-time generation of realistic synthetic 3D images and sound effects according to camera matrices obtained from the tracking side. Here we find as well services that are responsible for real image buffering and composition with the synthetic image.

One of the main advantages of this architecture is clear separation of heavyweight tasks that can be in this way performed in parallel. While VR/AR runtime engine is rendering a new frame the TRACK runtime engine can already start calculations for the next frame so that when the VR/AR side is finished it will have already next camera matrix for which to render the next frame. More detailed overview of the data flow issues affecting overall system responsiveness and performance issues is presented in the next section.

3.3. System in Operation

The LIFEPLUS mobile system is required to operate in *two main modes*. The first one is designed to support the visitor of the site with location based multimedia information facilitating sight-seeing of the area by provision of both practical and historical information in form of text, images, short movies overlaid on the head mounted display. In this “sight-seeing” operational mode mainly DGPS technology is used to track relatively coarsely current position of the visitor in the area. Once the visitor reaches the spot where the AR simulation is possible (s)he is informed about it and allowed to enter into AR simulation mode.

In AR simulation mode, the visitor is exposed to the VR simulation scenario blended into the real imagery of the site. The visitor is able to walk around and look around some spatially limited space usually naturally constrained by the walls of a particular site. In this mode DGPS technology plays secondary role supporting real-time, vision based, computationally heavyweight camera tracking module that is designed to deliver precise camera matrix values per each simulation frame in order to allow for generation of respective 3D synthetic images and blending them with the real camera ones.

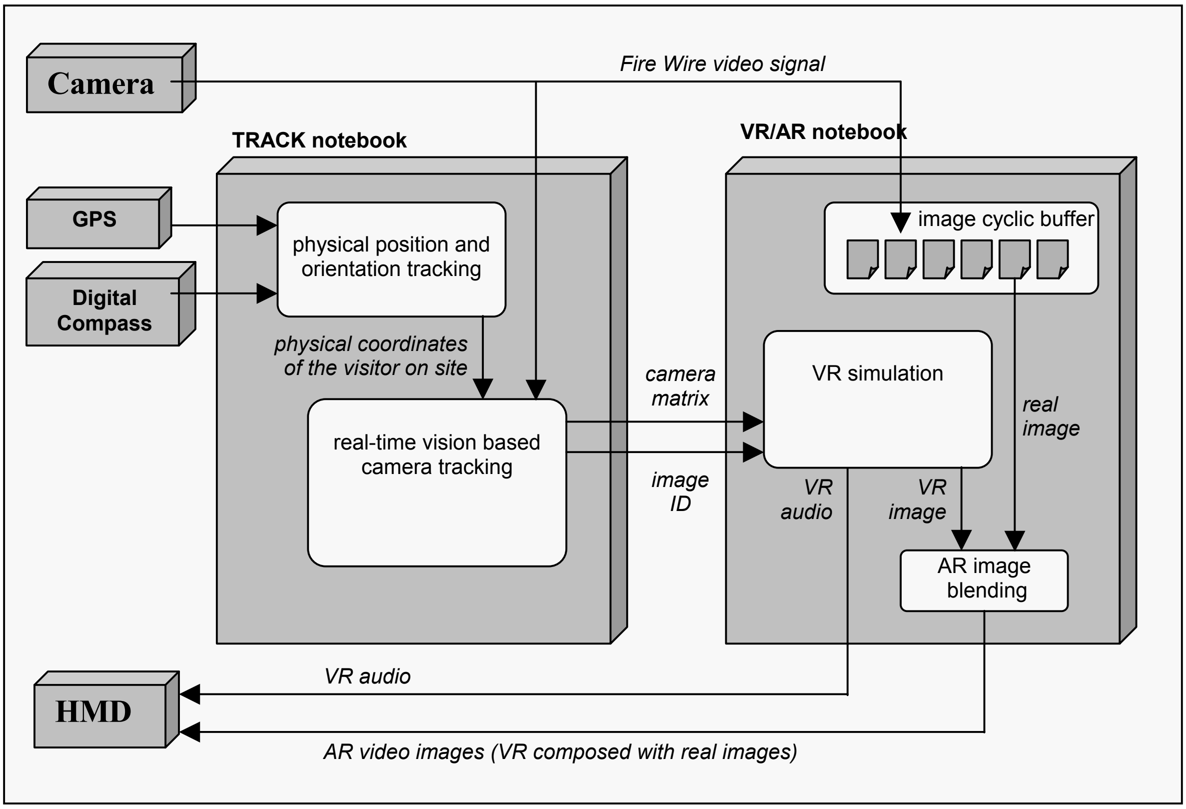

Fig. 2. LIFEPLUS Mobile System Data Flow

Schematic overview of the data flow in LIFEPLUS system is presented in Fig.2. High quality FireWire digital video signal carrying both image and frame ID information is split to two portable computers running respectively TRACK and VR/AR runtime engines. For each frame real-time, vision based tracking module, optionally supported by directional data from DGPS calculates real camera matrix and sends it together with the received FireWire frame's ID to the VR/AR side. As the real camera tracking costs certain time the VR/AR side needs to buffer vide images obtained from the FireWire together with their respective Ids. Once the real camera matrix is ready for a real image stored in the cyclic buffer the VR simulation module generates respective 3D synthetic image that is then blended with the real image and sent to the HMD by AR image blending module. It is important to note that VR simulation module is responsible not only for 3D image generation but as well for generation of proper 3D sound effects accompanying the simulated scenario.

3. Fundamental Research in Virtual Fauna and Flora Simulation

3.1 Real-time Cloth simulation

There is still a gap between the time expensive techniques (Figure 3) that bring simulation accuracy and duplication of actual fabric mechanical parameters, and efficient techniques that are able to manage complex animated garments with simplified mechanical models. In order to define realistic cloth simulation systems that are able to simulate complex garments realistically while keeping a reasonable computation time, a deeper study of the cloth model and the identification of its movement behaviour at different level are necessary [12]. This study should not intend to integrate yet more precisely the parameters measured for given fabric materials, but rather focus on the real-time constraints for the simulation and the visual cloth motion features to which the observer is sensitive. A new simulation model has been implemented that avoids heavy calculation of collision detection and particle system wherever it is possible.

Figure 3: Virtual Human Clothing

One of the most challenging research areas in this context is in developing a robust methodology on simulating clothes in real-time performance. We have developed a novel approach exploiting the merits of geometric deformations and predetermined conditions between the cloth and the body model. When observing a garment worn on a moving character, we noticed that the movement of the garment could be classified into several categories depending on how the garment is laid on the body surface and whether it sticks or flows on it. For instance, a tightly worn trouser will mainly follow the movement of the legs while a skirt will flow around the legs. The first part of the study was to identify all the possible categories:

a) Clothes that stick to the body with a constant offset. In this case, the cloth will follow exactly the movement of the underlying skin surface.
b) Clothes that flow around the body: the movement of the cloth does not follow exactly the movement of the body. In case of a long skirt, the left side of the skirt can collide the right legs.
c) Clothes that move within a certain distance to the body surface will be put into another category. The best example is the sleeves of a shirt. The assumption in this case is that the cloth surface always collides the same skin surface and its movement is mainly perpendicular to the body surface.

The idea behind the proposed method is to avoid heavy calculation of collision detection wherever it is not necessary. Using a versatile physical-based method for the whole garment implies huge calculation because of the dimension of the particle system and the number of polygons for collision detection. The main interest of our approach is to pre-process the target cloth model and segment the cloth in order to define the parts where we trade the simulation quality for real-time performance. Simulations that simply calculate all potentially colliding vertices may generate a highly realistic movement, with no guaranteed frame time. Following is a description of the methods that are employed for real-time clothing:

Geometric deformation

A simple geometric deformation is employed for clothes that stick to the body as they are deformed the same way as the underlying skin. No collision detection is required; the method will keep a constant offset between the cloth and the underlying skin.

Hybrid deformation

For the clothes that sweep on the body, a hybrid deformation is applied considering the fact that the movement will mainly be sweeping, and not complex movements such as draping, buckling, or wrinkle resilience. With the assumption of its perpendicular movement to the skin surface, each cloth vertex is modelled as a particle freely moving inside a sphere following the equation of rigid body motion. The spheres are attached to the skin and follow its movements rigidly. In case the particle leaves the spheres, a kinematic correction is applied on the position and the velocity.

3.2 Real-time Facial emotion expression and Speech animation

Face Modelling

Using 3D modelling software: A 3D modelling software like 3DSMax, or Maya can be used to create facial mesh models and precise specifications of geometry, mesh resolution, and textures. The disadvantage of this method is that it needs time and artistic expertise. Further, additional information regarding the topology has to be generated in order to animate the model. The result is superior as compared to simple to use techniques.

Photo cloning: The methodologies developed by Lee et al [13] use two photographs of a person to generate a 3D model. Since the methods use a generic 3D model, the animation information is built-in, and thus the photo-cloned model is directly animatable. Also, the method is simpler to use with interactive tools developed and hence very useful when a variety of models have to be created quickly. The models are not as superior in looks as the "hand designed" models, as there is hardly any control over the texture and resolution. It is possible to combine these two techniques to create new face models. Thus, a database of models is created using the images from the fresco involving human faces. A dedicated tool is provided in order to add new face models to this database using simple operations like interactive texture mapping with every new image. In order to animate these models easily, MPEG-4 compatible models have been developed.

Real-time Facial Emotion Animation

Given a facial mesh, there are various ways to animate it, depending upon the application, the available tools and the desired performance:

a) Animation using "morph targets": In this method, certain morph targets are designed using 3D modelling software like 3DS Max and Maya. These morph targets are static expressions like smile and sadness and visemes corresponding to the essential phoneme shapes. The animators design these targets precisely and beautifully. Whole mesh information for each of these targets is stored, unlike the parameterised approach discussed below. Though it allows creation of precise and aesthetic animations, it results into a lot of data to be used for animation. Another drawback of this technique is that this work has to be done for every model in use, as morph targets are mesh dependant and cannot be applied to any other mesh. The desired animation is then extracted using interpolation of the entire mesh for these morph targets. We use MPEG-4 Facial Animation Tables to realize such "morph targets"[14].

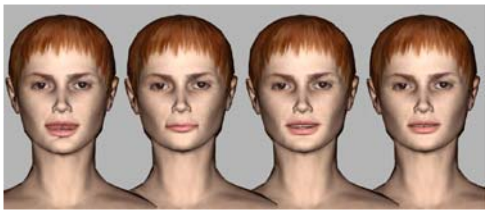

Figure 4. Facial Animation using morph targets

b) Parameterised mesh deformation algorithm: A parameterised facial model is animated by a set of parameters that control the deformation. The deformation algorithm generally then can be applied to any generalized facial mesh, compatible for the deformation method. The deformation method depends on the set of parameters used. In this technique also, morph targets are defined, but they are stored in terms of parameters and not the entire mesh. Thus, data storage space required is less, and the parameters are usable on any models. We use such MPEG-4 facial Animation Parameters for facial animation. A simple high-level API, compatible with the graphics platform chosen, has been developed so that the models developed above can be easily animated using the MPEG-4 parameters. This API enables easy integration of the facial animation with the VR-AR platform.

Real-time Realistic Speech Animation

Speech animation involves design of visemes, extraction of phonemes from speech, application of co-articulation for smooth animation and finally appropriate mesh deformation in synchronization with speech signal. Furthermore, it is also an interesting problem to mix expressions with speech. In the current approach, various shape envelopes are defined for different static expressions and visemes (visual counterpart of phoneme). E.g., phonemes are used with triangular envelopes and the expressions are used with an “attack-sustain-decay-release” type of envelope. A weighted sum of corresponding parameters results into a smooth and artefact-less animation, with or without any expressions [14]. A new approach for co-articulation and expression blending has been developed for speech animation. This involves study of phonetic structures enabling more natural mouth shapes. A database of such mouth shapes (bi-visemes or tri-visemes) has been designed for real-time speech animation. For expression blending, a statistical study of a variety of facial expressions has been performed. Not only a database of expressions has been created, but also the dedicated tools for applying a high-level design of such expressions quickly, and for mixing them with visemes in a natural way.

4. Case Study: Early Mixed Realities simulations in ancient Pompeii

Our early results (the project started 1st March 2002) span across the frame of non-real-time mixed realities simulations to real-time VR interactive experiences. In greater detail, we have tested our methodologies-plug-ins, SDKs and platform in the following 3 example scene simulations featuring behavioured virtual Pompeian characters. In Figure 5, the screenshots depict part of our test rendered sequences, where virtual clothes, hair, speech, body and facial animation are tested using 3DSMax and MIRALab dedicated virtual human plug-ins.

Figure 5: At the Pompeian bakery in non-real-time VR

In Figure 6, screenshots of the real-time simulation based on our framework platform VHD++ are shown, where real-time scene fly-through, virtual body and facial animation are illustrated.

Figure 6: At the Pompeian Bakery in Real-time VR

In Figure 7, the 2D3[8] Boujou™ software was used to perform offline camera tracking and then the mixed reality simulations of virtual life were performed. Thus the virtual humans were correctly ‘registered’ with the ‘real scenes’ from the various ‘real’ video sequences using 3DSMax and the dedicated MIRALab plug-ins. The screenshots are excerpts from the complete simulation sequences.

Figure 7: Mixed Reality offline simulations in various Pompeian residences

5. Future Work

LIFEPLUS future work can be grouped into the following directions:

a) Complete Software middleware components addressing the needs for a multi-layered AR architecture of self-contained SDKs and APIs to enable interoperability, inter-working, openness and integration of applications and services across platforms demanding Augmented Reality, Virtual Life and Virtual Environments.

b) An integrated, complete platform for a Mobile On-Site AR Guide for new user interaction modes for accessing and presenting audiovisual AR information and navigation in a new user-friendly, intuitive, enhanced reality way.

c) Innovative-intelligent Services for conceiving and providing commercially viable business models for the new cultural economy of institutions. That involves the methodologies and practices of setting up LIFEPLUS sites, AR digitisation of their content, delivery channels addressing to the changing meanings of culture etc.

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