Mixing Virtual and Real scenes in the site of ancient Pompeii

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Abstract

This paper presents 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 behaviors in an immersive, fully mobile Augmented Reality environment. The main goal is to push the limits of current Augmented Reality (AR) and virtual storytelling technologies and exploring the processes of mixed narrative design of fictional spaces (e.g. frescos-paintings) where visitors can experience a high degree of realistic immersion. Based on a captured/real-time video sequence of the real scene in a video-see-through HMD setup, these scenes are enhanced by the seamless accurate real-time registration and 3D rendering of realistic complete simulations of virtual flora and fauna (virtual humans and plants) in a real-time storytelling scenario based environment. Thus the visitor of the ancient site is presented with an immersive and innovative multi-sensory interactive trip to the past.

Keywords

Virtual Humans, Augmented-Mixed Reality, Computer Animation, Component-based Framework, Real-time Camera Tracking, Virtual Storytelling

Introduction

Since antiquity, images were used as records of both events-lifestyles, as well as decorations. The possibility of reviving them adds 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 personalized, interactive experience and visualization of the description of it. 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 [2]. Mixing such aesthetic ambiences with mobile virtual life augmentations in real-time and adding dramatic tension, can develop these narrative patterns into an exciting new edutainment medium.

Therefore, this paper proposes a 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 (Figure 1). 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, this work aims to position itself between the extremes of real life and Virtual Reality, in the spectrum of "Mixed Reality"[3] and especially Augmented Reality (AR), in which views of the real world are combined in some proportion with specific graphic enhancements or augmentations.

In the following sections the technologies for mobile virtual human simulation on augmented heritage will be described after and introduction to the current state-of-the-art in AR simulations. The aim of this work is that 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 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 is 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 (Figure 2). Thus in the Results section, latest results are presented together with thorough descriptions of our VR/AR middleware framework as well as key fundamental research aspects in real-time AR virtual fauna and flora simulation.

Related Work

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 [4] 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 [5]. 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.

Augmented Reality is currently an active research topic as well as a high potential commercial application target as can be seen from the numerous papers as well as latest patents[6] [7] in the field (approximately 150). As researchers continue to improve the tracking, display and mobile processing components of MR systems, the seamless integration of virtual and sensory information may become not merely possible but commonplace. Many observers [8] have suggested that one of the many potential applications of augmented and mixed realities will emerge as the “killer app”- a use so compelling that it would result in mass adoption of the technology. However, the topic of integrated virtual human simulation in augmented reality is not explicitly covered yet in the current bibliography or the latest patents list.

A growing number of projects are currently based on AR integrated platforms, exploring a variety of applications in different domains such as medical [9], cultural heritage [10] [11], training and maintenance [12] [13] and games [14]. Special focus has recently been applied to system design and architecture in order to provide the various AR enabling technologies a framework [15] for proper collaboration and interplay. Azuma [16] 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.

AR component-based Framework

Our AR platform is based on the VHD++ [17] 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. The framework has borrowed extensive know-how from previous platforms such as [18]. The key innovation is focused in the area of component-based framework that allows the plug-and-play of different heterogeneous technologies such as: Real-time character rendering in AR, real-time camera tracking, facial simulation and speech, body animation with skinning, 3D sound, cloth simulation and behavioral scripting of actions. To meet the hardware requirements of this aim, a single DELL P4 M50 Mobile Workstation was used, with a Quadro 4 500 GL NVIDIA graphics card, a firewire Unibrain Camera for fast image acquisition in a video-see-through TekGear monoscopic HMD setup, for advanced immersive simulation. Our previous efforts were based on a client-server distributed model based on 2 mobile workstations. To achieve the requirement of 'true mobility', a single mobile workstation is used in our current demonstrations, after improvements in the streaming image capturing and introduction of hyper-threading in the platform code.

Real-time Markerless Camera Tracking

Several commercial tracking solutions are currently available that are suitable to augmented reality applications. These are however mostly based on intrusive tracking technologies such as magnetic tracking, outside-in optical tracking and ultrasound tracking. While being successful in well-controlled studio conditions, these solutions are not applicable to cultural heritage applications for several reasons. Cultural heritage sites are not allowed to be modified in any way, which often means no fixed power output points, no tracking technology of any type may be mounted and no fiducial markers may be applied at all. Thus real-time markerless camera tracking is perfectly suited to this environment since it's in accordance with all the above limitations on scene modification.

Real-time markerless camera tracking presents two main problems though, namely the absence of easily recognisable markers and a demand for high-speed computation. Markerless tracking requires accurate tracking to be done with only natural features present, often with sharply varying light sources, shadows, motion blur and occlusions. Performing this tracking in real-time necessitates the use of algorithms specially adapted to fast operation, and thus disqualifies many algorithms that are perfectly suitable in offline applications.

We based our system on the approach that the integrated camera tracker [19], depicted in Figure 12, should be able to self-initialize anywhere within the tracking environment without any intervention from the user as well as recover immediately in case of degenerate tracking (i.e. looking out of the designated area). In effect this means that instead of calculating *relative* changes in rotation and translation, we calculate *absolute* rotation and translation for every frame. This has the advantage of avoiding the problem of drift, and also ensures instant recovery after tracking was lost due to excessive motion blur or occlusion.

To facilitate this solution it was necessary to adopt a two-stage system, the first being training and the second the real-time operation. Training consists of recording a few seconds of movie of the relevant scene. This information is processed by the tracker setup software, which analyses the scene and produces a database of key features and structure for the scene. This training process only has to be performed once by the animators, after which the database can be used time and again. Real-time operation uses this database to instantly position the camera from a single frame and do so reliably and quickly. This enables us to instantly recover from any occlusion or motion blur.

Careful attention was given to algorithm design and implementation in order to ensure an efficient tracking system running at high frame rates. The system takes advantage of multiprocessor systems as well as the new HyperThreading technology on Pentium processors to achieve a higher frame rate. The tracking system is currently running between 14 and 30 frames per second on a dual-processor 3.02 Ghz Pentium 4 pc. The variation in frame rate is due to a dynamic level-of-detail controller within the tracking system that spends more time analyzing featureless difficult-to-solve areas and less time on easy areas. This ensures that we always get the optimal quality vs speed ratio.

Research in Real-time Cloth simulation

There is still a gap between the time expensive techniques 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 wherever it is possible.

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 behavior at different level are necessary [20]. 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.

Thus for the creation of clothes we use our in-house software. The garment designer is assisted in drawing 2D patterns - the shape of the patterns are defined as they were built at this time as demonstrated in Figure 3 - and defining seaming lines on the borders of the garment patterns, referring to the polygon edges that are to be joined during the garment construction process. The patterns are then tessellated into a triangular mesh and are placed around the 3D virtual body. Next, the initial shape of the garment is computed through a collision response. The shape of the body model guides the surface of the cloth as a result of the collision response (Steps illustrated in Figure 4).

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 [21] 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 (shown in Figure 5):

a) Layer 1: "Stretch clothes" - Garment regions that stick to the body with a constant offset. In this case, the cloth follows exactly the movement of the underlying skin surface.

b) Layer 2: "Loose clothes" - Garment regions that move within a certain distance to the body surface are placed in another category. The best examples are shirtsleeves.

The assumption in this case is that the cloth surface always collides with the same skin surface and its movement is mainly perpendicular to the body surface.

c) Layer 3: “Floating cloth" - Garment regions that flow around the body. The movement of the cloth does not follow exactly the movement of the body. Collisions are not predictable; for a long skirt, for instance, the left side of the skirt may collide with the right leg during animation.

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:

a) 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.

b) 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 modeled 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 kinematical correction is applied on the position and the velocity.

Real-time Facial emotion expression and Speech animation

Face Modeling

a) One methodology consists in using 3D modeling software like 3DSMax or Maya that can be used to create facial mesh models and precise specifications of geometry, mesh resolution, and textures (Figure 6).

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.

b) The *photo cloning* methodologies developed by Lee et al [22] 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 (Figure 7), certain morph targets are designed using 3D modeling 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 parameterized 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" [23].

b) Parameterized mesh deformation algorithm: A parameterized 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 [24]. 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 artifact-less animation, with or without any expressions.

A new approach for co-articulation and expression blending has been developed for speech animation [24]. 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 (Figure 8). 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.

Real time plant simulation

The added value of virtual flora presence in a virtual environment is obvious: as nature surrounds us in the real world then so it should be in virtual world. Not only do virtual plants bring a sense of life, but they also carry strong aesthetic, dramaturgical and cultural meanings. This stated, plants bring a non-negligible contribution in our AR system to the three identified key factors in simulation: immersion, imagination and interaction. To fulfill these requirements, we have enabled support in the AR platform of the outcome of the Bionatics [25] plug-in, which has focused its efforts on providing the following features:

- botanically and visually correct vegetation with state-of-the-art real-time technology;
- species developed according to the spatial and historical contexts;
- animated plants;
- means for interaction capabilities during runtime simulation.

More details on the Bionatics [25] functional solutions for each one of the cited aspects are covered in [26]. Figure 9 shows an extract from the integrated plant simulations.

Experiments & Results

Heritage AR Storytelling using virtual life simulation

In order to further continue AR tests in our labs of our scenario of the ‘thermopolium’ (tavern) of Vetutius Placidus and the augmentation with virtual life, a real ‘maquette’ was constructed in order to resemble the actual Pompeii site that we visited for our first on site tests. This allowed us to do extra fine tuning and improvement of our simulation and framework, without having to visit the actual site numerous times. We’ve developed a system using a single mobile workstation capable of rendering two different AR storytelling scenarios yielding a performance of ~8 frames per second. Each one featuring two virtual humans with complete real-time body, speech, facial expression, cloth simulation, real-time camera tracking and plant [25] simulation. The results from the two AR demos are shown in Figure 10.

For the synchronization, scripting and scenario specification, the actions of the virtual humans were specified based on python scripts applied as a top layer on the actual framework components [17] which automatically expose their functionality in python. Figure 11 is an excerpt of the python script between the dialogue of Vetutius and Celer.

Conclusions and future work

With the current result of our AR Framework we are able to manage real-time augmented reality full virtual character simulations (body, face and clothes) in cultural heritage environments through a markerless AR tracking system. However, there is still a lot of space for improvement. The 'illumination' registration between the real and the virtual scene is currently been addressed with the introduction of High Dynamic Range Image Based Lighting for virtual character simulations in AR. Also the performance of the real-time camera tracker is also been upgraded to yield higher frame rates. Finally ongoing work is continuing in the integration of real-time hair simulation and dynamic level-of-details in the AR framework for improved realism and overall rendering performance.

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Figure 1Revival of ancient life in Pompeii

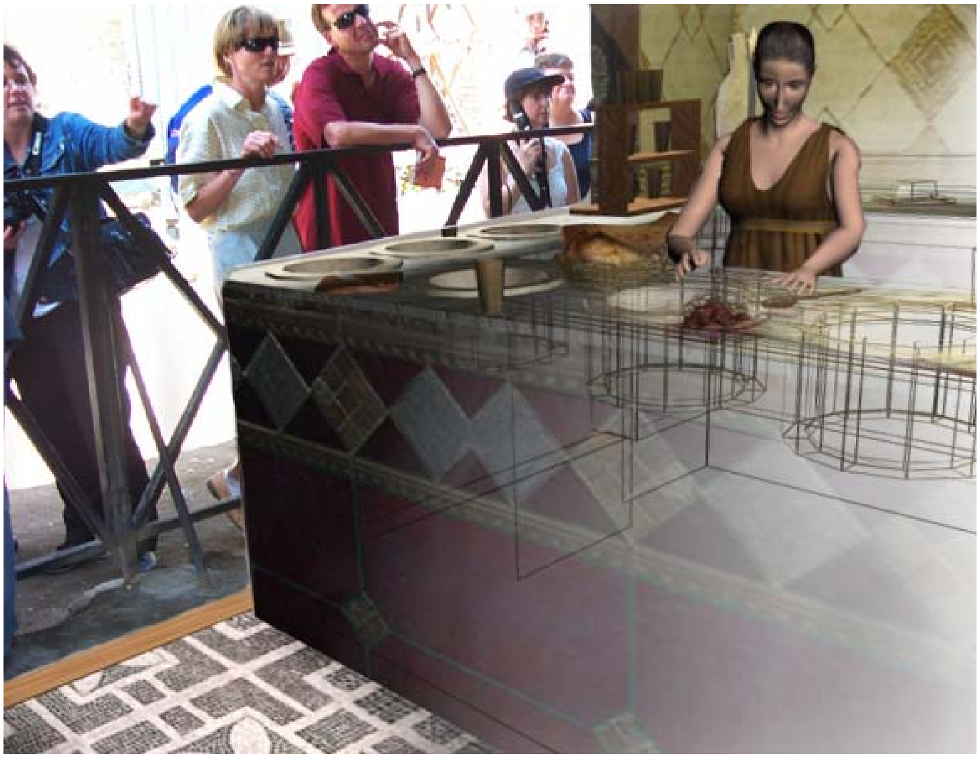

Figure 2 Virtual character Augmented Reality Concept

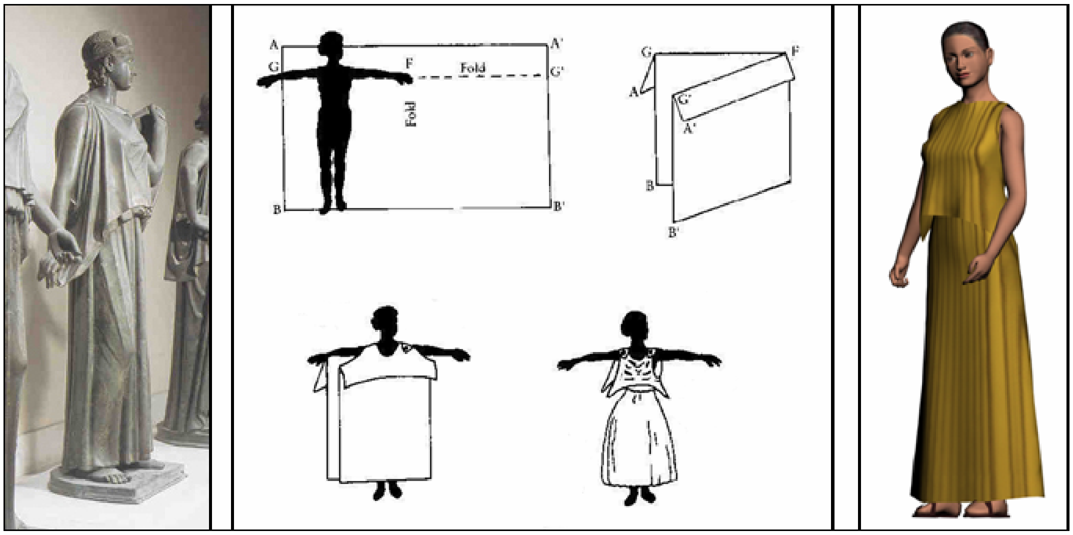

Figure 3 Virtual Garment based on a real ancient dress

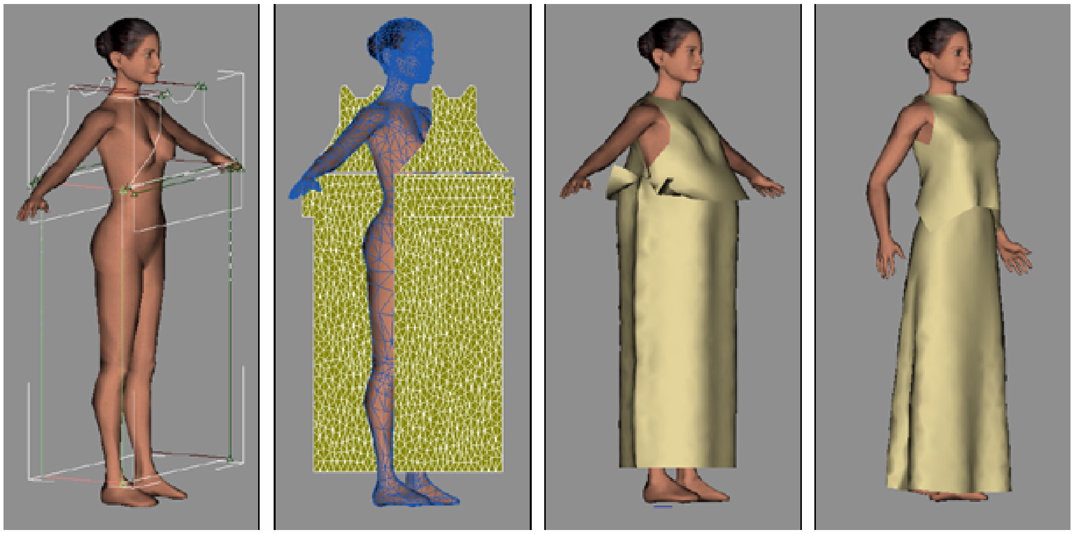

Figure 4 Creation of an ancient virtual garment

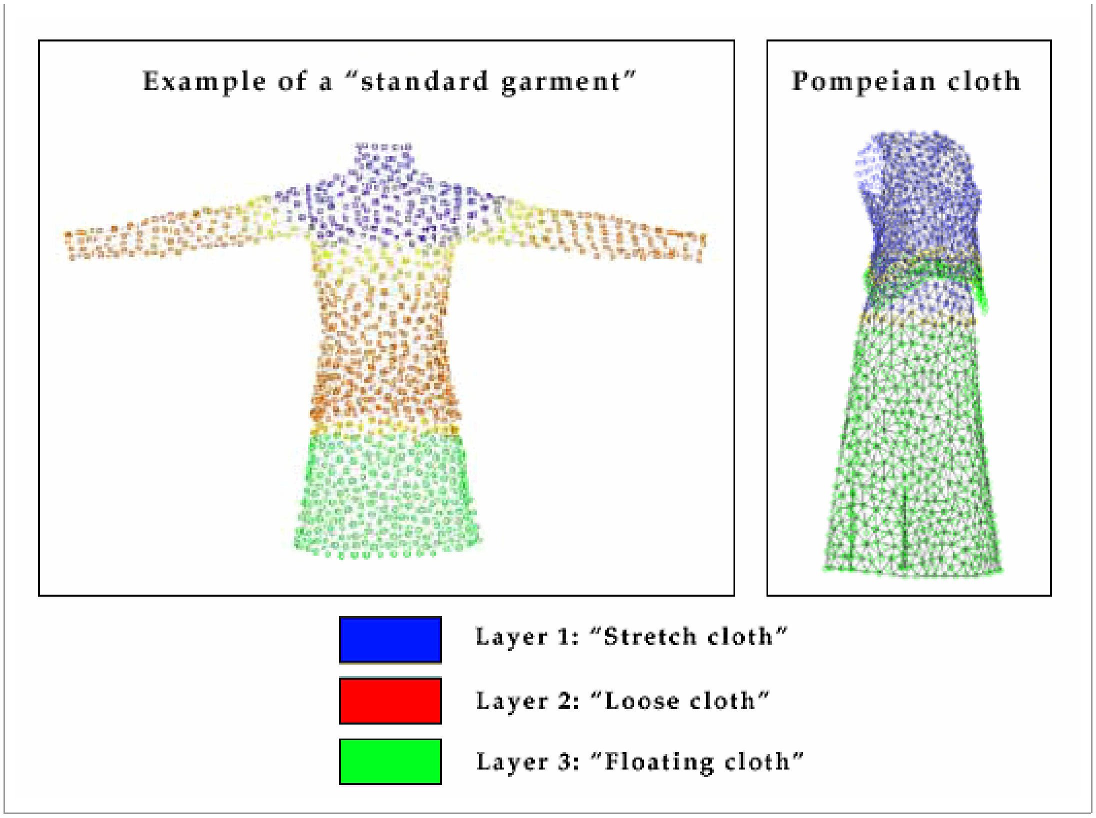

Figure 5 Layers in segmentation of garments

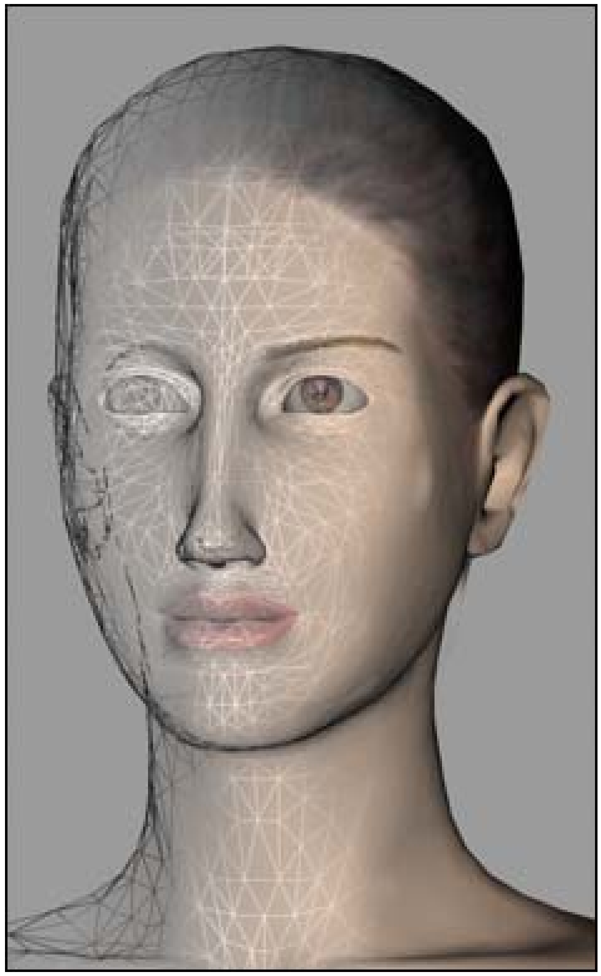

Figure 6 3D facial mesh model

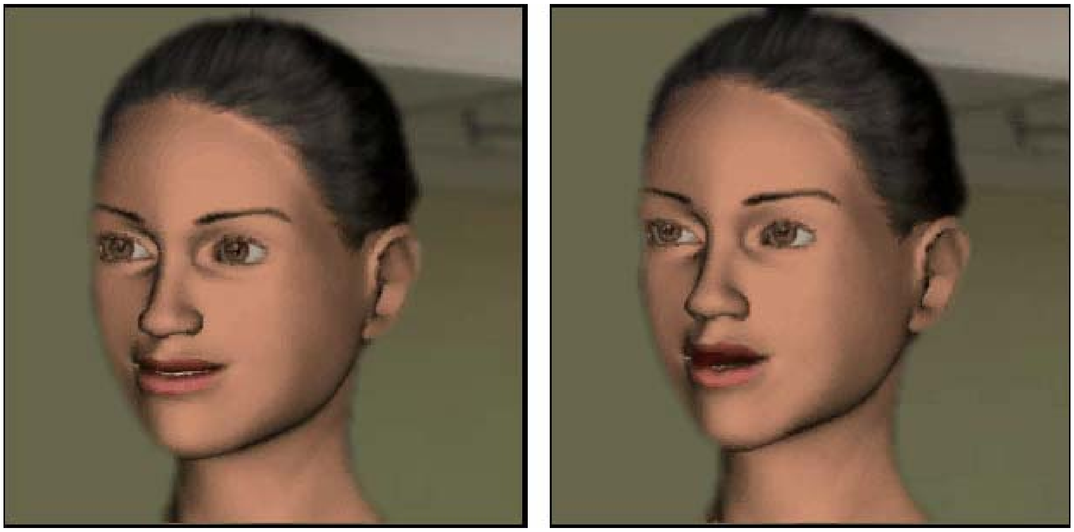

Figure 7 Facial Animation using morph targets

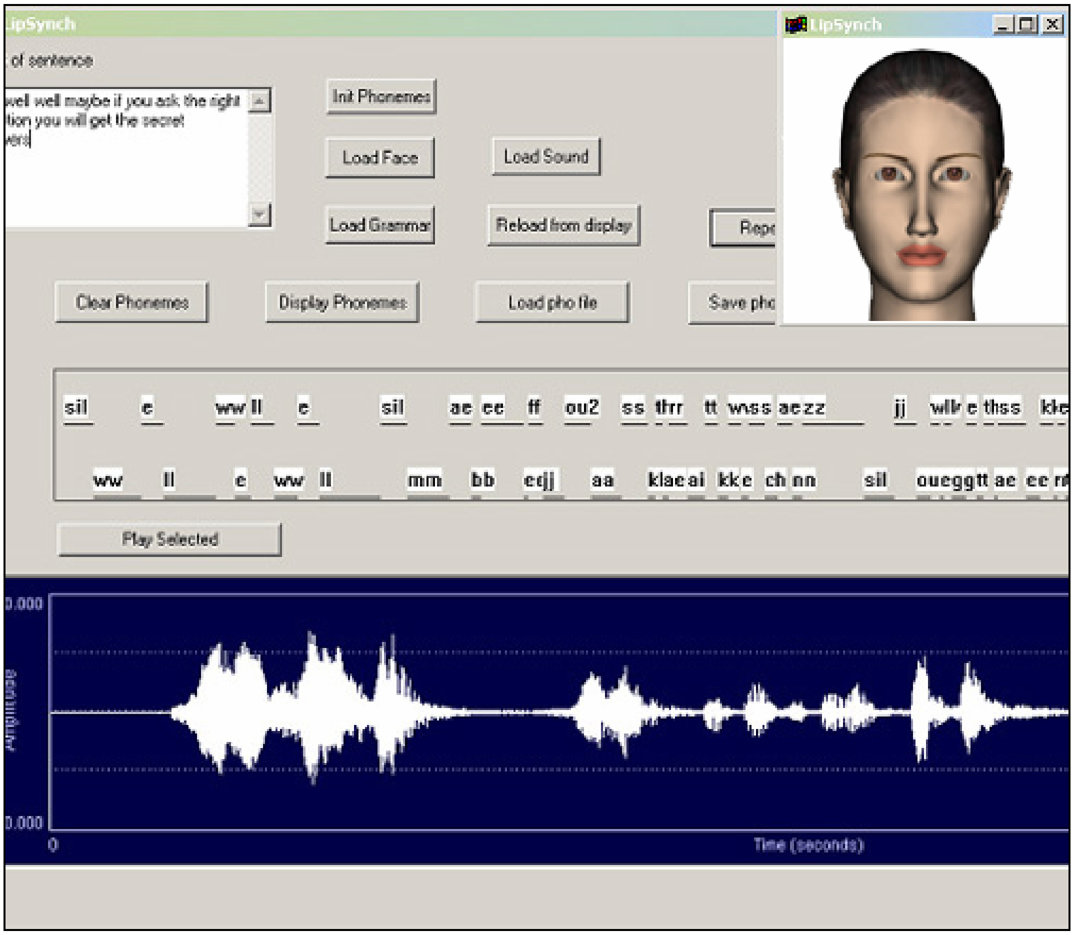

Figure 8 Speech Animation General Tool

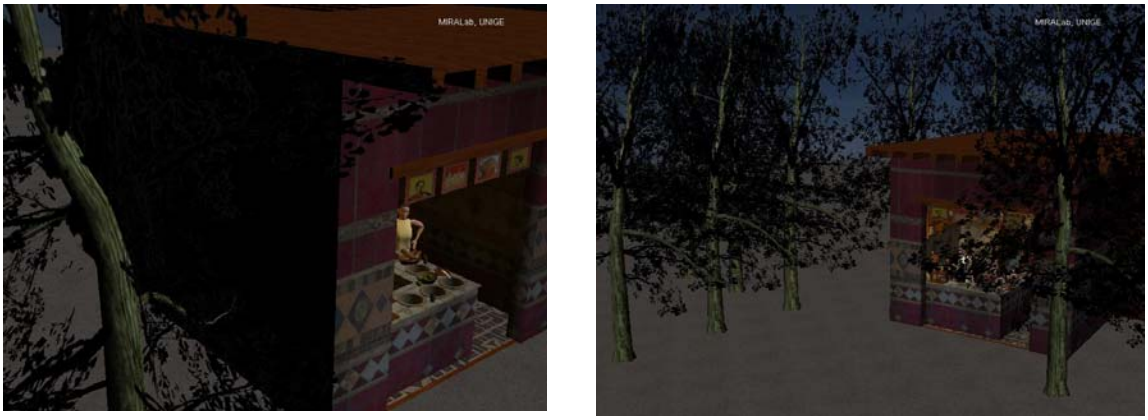

Figure 9 Real-time plant simulation

The mobile workstation with the USB webcam augmenting the real 'maquette'

The Pompeian 'thermopolium'

1st AR scenario with occlusion support

2nd AR scenario with plant simulation

Figure 10 AR demonstration Results

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#Vetutius & Celer Scenario dialogue example
```

```
#Celer says I'm thirsty
hagentService.kfSetGlobalTranslationMode("Celer",'celer1a',"KEYFRAME_RELATIVE_MODE")
hagentService.kfSetGlobalRotationMode("Celer",'celer1a',"KEYFRAME_RELATIVE_MODE")
hagentService.activateAction("Celer",'celer1a',0.0)
voiceService.activateAction("Celer",'CelerSpeech.celer1',1.0)
hagentService.kfSetGlobalTranslationMode("Vetutius",'vetutius1a',"KEYFRAME_ABSOLUTE_MODE")
hagentService.kfSetGlobalRotationMode("Vetutius",'vetutius1a',"KEYFRAME_ABSOLUTE_MODE")
hagentService.activateAction("Vetutius",'vetutius1a',0.0)

bRun=True
while (bRun==True):
  if (hagentService.kfHasReachedEndOfSequence("Celer",'celer1a')) and (hagentService.kfHasReachedEndOfSequence("Vetutius",'vetutius1a')):
    hagentService.stopAction("Celer",'celer1a')
    hagentService.stopAction("Vetutius",'vetutius1a')
    bRun=False
  vhdYIELD

#Vetutius answers I'm coming ... My slogan is (2 voices)
hagentService.kfSetGlobalTranslationMode("Vetutius",'vetutius1b',"KEYFRAME_ABSOLUTE_MODE")
hagentService.kfSetGlobalRotationMode("Vetutius",'vetutius1b',"KEYFRAME_ABSOLUTE_MODE")
hagentService.activateAction("Vetutius",'vetutius1b',0.0)
voiceService.activateAction("Vetutius",'VetutiusSpeech.vetutius1',1.0)
hagentService.kfSetGlobalTranslationMode("Celer",'celer1b',"KEYFRAME_RELATIVE_MODE")
hagentService.kfSetGlobalRotationMode("Celer",'celer1b',"KEYFRAME_RELATIVE_MODE")
hagentService.activateAction("Celer",'celer1b',0.0)
vRun=True
while(vRun==True):
  if(voiceService.hasActiveActionEnded("Vetutius",'VetutiusSpeech.vetutius1')==True):
    vRun=False
voiceService.activateAction("Vetutius",'VetutiusSpeech.vetutius2',1.0)

bRun=True
while (bRun==True):
  if (hagentService.kfHasReachedEndOfSequence("Vetutius",'vetutius1b')) and (hagentService.kfHasReachedEndOfSequence("Celer",'celer1b')):
    hagentService.stopAction("Vetutius",'vetutius1b')
    hagentService.stopAction("Celer",'celer1b')
    bRun=False
  vhdYIELD
```

Figure 11 Python dialogue script scenario example

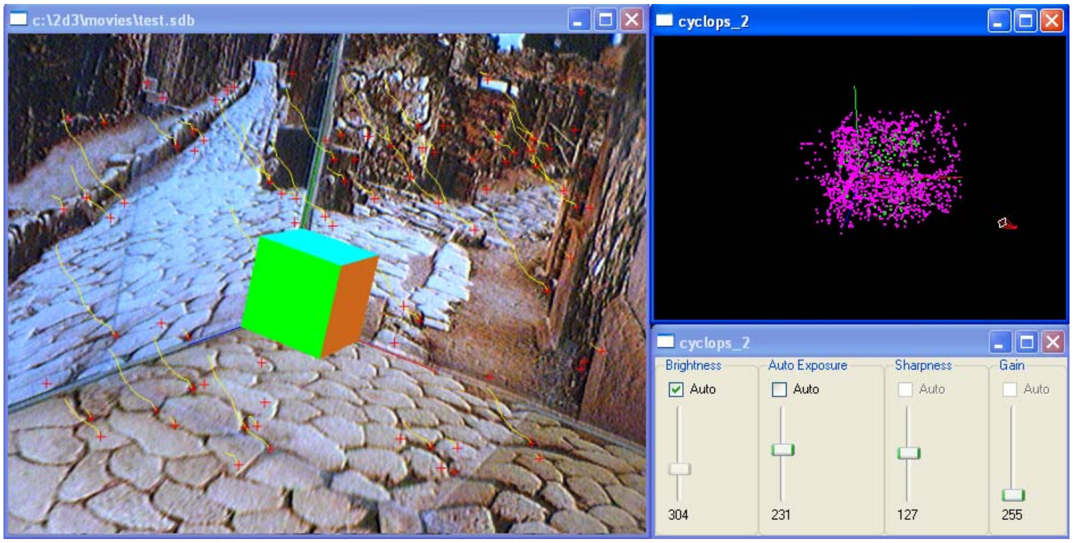

Figure 12 Real-time markerless camera tracking