INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team MIRAGES

Object Manipulation in Image Sequences for Augmented Reality and Special Effects

Rocquencourt

THEME COG

2004

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1. Team

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Tung Le Than [INRIA scholarship, until 31/10/2005]
Chee Kwang Quah [NTU Scholarship]

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2. Overall Objectives

2.1. presentation

The MIRAGES project research activity is concentrated on the manipulation of 3D objects in images sequences and its application domain is oriented towards new services (related to those 3D objects) which will appear in future communication networks. Research activity is carried out in two directions:

2.1.1. First Research activity: 3D Analysis of image sequences

We are interested in the determination of properties such as structure, mouvement and photometry of 3D objects in image sequences. Our approach differs from traditional methods as we mainly look for feedback model-based methods to guide the analysis. The main problems we are handling are:

- 3D object tracking in image sequences when the geometry of the object is known but its movement has to be determined. Both rigid, articulated and deformable objects are considered: particularly human body and face tracking.
- Automatic and semi-automatic object model renormalization: starting from a generic model of an object(for example a human body or a face) and an image sequence, this task has to construct the specific model which will be used for tracking in image sequences (see above)
- Interactive, semi-automatic and automatic camera calibration: Here, we use 3D object models (very often, generic models) which are used as calibration tools, in order to perform calibration. Calibration is necessary for 3D model renormalization
- Inverse rendering (Computer Graphics denomination corresponding to photometric analysis in Computer Vision): We dispose of input images of a scene and of a 3D model of this scene. The aim is to compute the photometry of the part of the scene available on those images in such a way that the digital synthesis of the scene model corresponds faithfully to the input images. The main application of this specific research is oriented towards the creation of advanced tools for audio-visual productions (advertising, films,...)

Collaboration is carried out with Mikros (a french post-production company) on the RIAM VIP3D contract which started in 2001. With VIP3D, we tackle human body tracking and specially facing tracking for 3D rotoscopy in post-production. Golf-STREAM contract started in June 2002 in collaboration with the french Symah Vision production company. The task is to study complete human body tracking and more specifically professional golfers from image sequences in order to allow them to improve their technique and also enrich journalists comments for television broadcasts of professional golf tournements. We hope to extend this work to other types of applications such as video-surveillance, tele-conferencing, video games, while mixing real and synthetic images.

2.1.2. Second Research Activity: 3D Garment Simulation

The second research direction is the creation and deformation of soft objects, particularly non linear and hysteretic ones. Presently, our research activity is limited to the 3D simulation of garments. In this research area, we are mainly studying:

- The control of the mechanical properties of soft 2D structures (like textile materials) modelled by mass/spring systems.
- The automatic construction of garments from 2D patterns around a human body modelled as an articulated mechanical system.

Potential applications are the realistic synthesis of 3D garments on 3D numerical mannequins applied to future e-commerce of garments for the textile industry. This problem was studied within the framework of an EUREKA contract (COMEDIA) where the main contractant was Lectra Systemes.

3. Scientific Foundations

3.1. Augmented reality for TV productions: 3D human tracking

Keywords: *3D human modeling*, *3D tracking*, *anthropometry*.

Participants: Philippe Gérard, Christian Roure, Chee Kwang Quah, André Gagalowicz.

A 3D model-based approach is applied to human body tracking for production and post-production applications.

We are currently developping a 3D tracking system using video cameras able to produce outdoor motion capture without the use of markers. A standard 3D human body and anthropometric measurements give a very first result of morphology adaptation. Then, further body adjustments are made using images. After positioning the puppet on the first frame, the texture is learnt and a tracker has to retrieve the position of the puppet automatically in the rest of the image sequence.

3.2. Realistic face reconstruction and 3D face tracking

Keywords: *3D Face Modeling from Images*, *3D Face Tracking*, *Deformable Models*, *Model-Based modeling*.

Participants: Richard Roussel, André Gagalowicz.

3D reconstruction of a realistic face model is one of the greatest challenges in the field of audio-visual post-production and special effects generation. Previously manual, tracking is more and more automated. We are working on faces, which are one of the most difficult entities to track, because of their slight deformations. In order to perform a high quality tracking, we developed a technique to model a 3D mesh of face from a set of images taken from a video sequence. This model, first constructed in a neutral expression, will be animated for tracking purposes.

3.3. 3D garment simulation

Keywords: *constraints*, *mass-spring systems*, *numerical integration*, *spatial coherence*.

Participants: Hatem Charfi, Jeremy Denise, Le Than Tung, Corpet Pascal, André Gagalowicz.

3.3.1. Mechanical modeling of textile materials

Usual geometric modeling is not sufficient to simulate cloth: an in-depth knowledge of fabrics behaviour is required. Relations between stress and strain have to be delt with, that are not defined by ordinary differential equations. Since analytical solutions are not available, numerical models are used; we have chosen mass-spring systems.

These models have to be fed with correct parameters. The Kawabata Evaluation System is the de-facto industry standard for fabrics measurements (limited to warp/weft textile materials): it operates typical deformations upon cloth samples and evaluates the resulting stress, which is provided as digital data.

3.3.2. Dynamic cloth simulation

Once a numerical model of cloth is stated, our goal is to compute its evolution with respect to time; it relies on the integration of the fondamental equation of dynamics. Several families of algorithms exist, adequations to the underlying problem of which vary, both in terms of stability and computation time.

Handling contact phenomenon between pieces of cloth, and the characters that wear cloth is the other big challenge: large amount of data have to be processed to accurately detect possible collisions, and a realistic model has to be used once an actual collision has been detected.

4. Software

4.1. Emilion

Emilion is the cloth simulation system that was developed by J. Denise during his Ph.D.

This software computes the evolution along time of a set of garments that are represented by mass-spring systems. Both explicit and implicit integration schemes are available. Hysteretic behaviour is taken into account in order to reach a high degree of realism. Contact and inverse kinematics are introduced through the constraints handling method initiated by Baraff [1]. An attractive feature is the spatial partitioning scheme that makes collision detection a low-cost task, even with large scenes (less than 15 % computation time in typical simulations).

Emilion was written in C++ and makes heavy use of Generic Programming concepts (which most famous incarnation is the Standard Template Library [2]). Tcl [3] was chosen as its scripting language to ease both its feeding with external data and the simulation of Kawabata [4] experiments.

An extended version was developed by D. Reversat to allow draping on animated characters.

5. New Results

5.1. 3D Human tracking

During the first year of Golf-Stream, an interactive tool to adjust a 3D squeleton and reconstruct a 3D skin envelope from images has been successfully achieved (see: figures 1, 2 and article [3])

The 3D tracking algorithm should give tracking results visible soon.

5.2. Realistic face reconstruction and 3D face tracking

5.2.1. Realistic face reconstruction

Our realistic face reconstruction requires only a small set of uncalibrated images showing the same face under different points of view, and the use of a generic model, that is deformed in two steps. In the first step, the deformation of the generic model is performed using 38 characteristic points that are related to the face anatomy. An iterative technique involving camera calibration and 3D computation of the face characteristic points is performed to find the real 3D locations of each point on the specific face. A Radial Basis Function

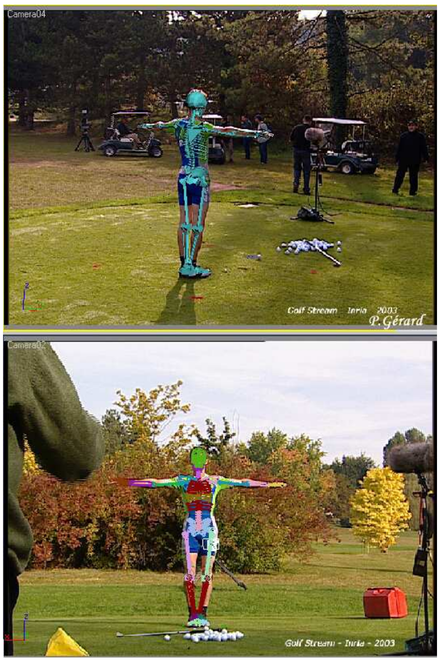

Figure 1. Squeleton adjusment using several views

Figure 2. Skin reconstruction using several views

(RBF) technique propagates the deformations resulting from the displacement of the characteristic points on every vertex of the 3D model. In the second step, the silhouettes of the 3D face model are, in turn, matched to those of the real face, on images. The additional control of the silhouette curves gives much more information that allows more faithful reconstruction of faces. The technique has been applied very successfully to many different human faces. (see fig. 3), even with very caricatural faces.

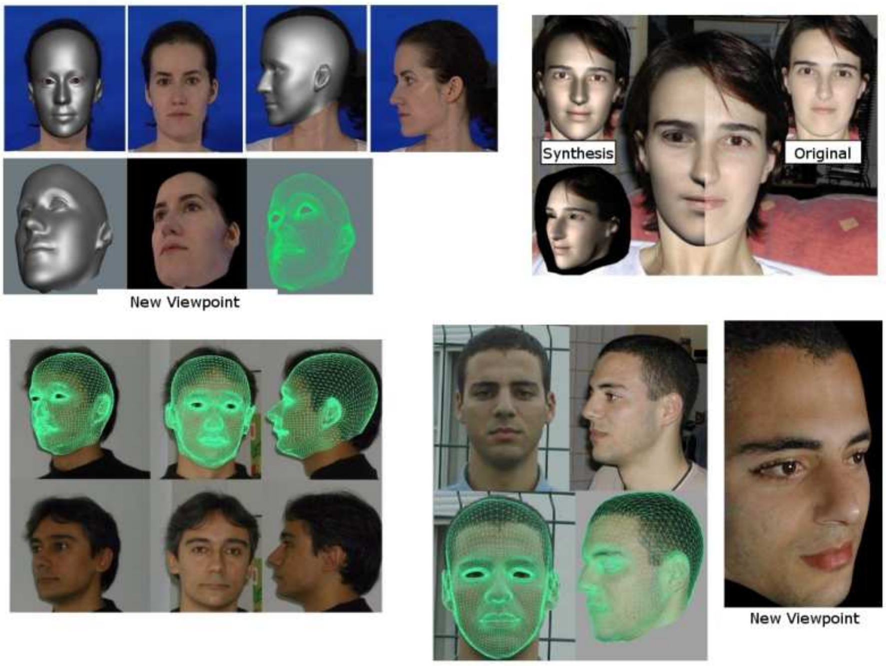

Figure 3. Some results using our technique.

5.2.2. Validation of the reconstruction technique

The validation of the method has been carried out with the use of a synthetic face, the 3D geometry of which was available. 3 images (from 4 used) of this synthetic face are shown in figure 4. The initial error (in cm) between the generic model and the real one to construct is displayed on figure 5.a . White corresponds to the maximum error and dark to zero for the various vertices of the model to construct. In figure 5.b, we see the new error when the control of our 38 feature points has been used. In figure 5.c, the control of one silhouette is added. In figure 5.d, two silhouettes are controlled and in figure 5.e, all (4) silhouettes are used to control the deformation. It is easy to see the continuous improvement of the method. The average error (in cm also) is also displayed beneath each error image. It is 0,837 cm initially and is reduced to 0,278 cm for a face that is roughly 25 cm large. We had similar types of errors for all the examples tried with the use of only four silhouettes. The final reconstruction error is of the order of 1/100 which is roughly the precision reached by conventional laser systems. This proves that this new type of reconstruction is faithfull, quick and does not require any hardware except a cheap camera.

5.2.3. Facial Tracking

Given the specific 3D model built in the previous section, we can now use it to track the face of the reconstructed person in a movie. In fact, we're using an analysis / synthesis loop in order to determine the exact position and rotation of the 3D textured mesh over a image (see figure 6 and 7).

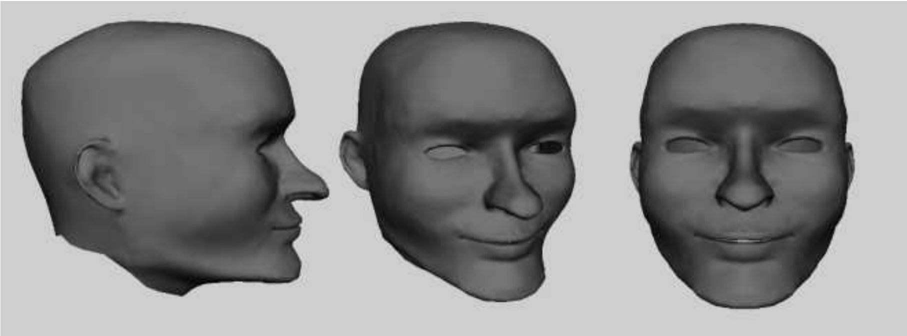

Figure 4. The 3D model used to validate our method.

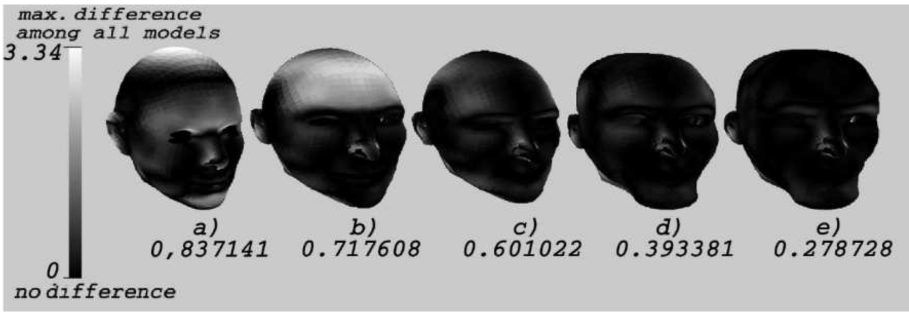

Figure 5. Reconstruction error between the 3D model, and the generated one.

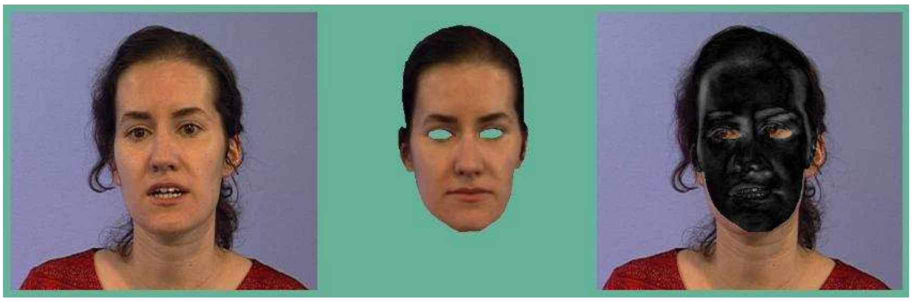

Figure 6. A bad position and rotation of the 3D textured mesh (in the center image) over the original image (the left one) gives a big matching error, in the right image.

Figure 7. A good position, and facial expression give us a very low matching error, in the right picture.

In order to improve the face tracking, we have developed a muscle model, allowing us to deform the face as muscles do. We learnt how each muscle was deforming the skin, and the eyes. We saw that each action of the face (smiling, rising the eyebrows, etc.) comes from a combination of several muscles. Our muscle model is a hierarchical model with, at the highest level, a set of 14 behaviors (rise the upper/lower lip, close the left/right eye, etc.). The tracking algorithm has to consider each behavior as a degree of freedom of the system, in order to find the best vector, in the behavior space, to represent the face. This algorithm minimizes the pixel-matching error between two images. The first image is the original image, in which we want the tracker to work, and the second is a rendering of the textured model, according to a particular face vector, translation and rotation. The method searches the translation and rotation of the 3D model and, in a the behavior space, the best vector that makes the smallest difference between the original image, and the synthetic image. When done, we have found not only the face position and rotation, but also the facial expression. Some results are given in figure 8.

Figure 8. Two snapshots of our tracking, in a talking sequance, on the left, and in a smiling sequence.

5.3. Study of fabrics

5.3.1. Virtual cloth pre-positioning:2D Model Mapping

We introduce a method based upon geometry to prepare the pre-positioning. Our idea is to dress a standard human model and then the garment will be mapped on the real model.

We build a 2D silhouette (Figure 9a) and extract the feature points (ex. neck, shoulder, waist...) from the real 3D human model, and then the figure is sub-divided into regions corresponding to the standard silhouette (Figure 9b). A region-region mapping is then determined to move the garment from the standard to the specific silhouette.

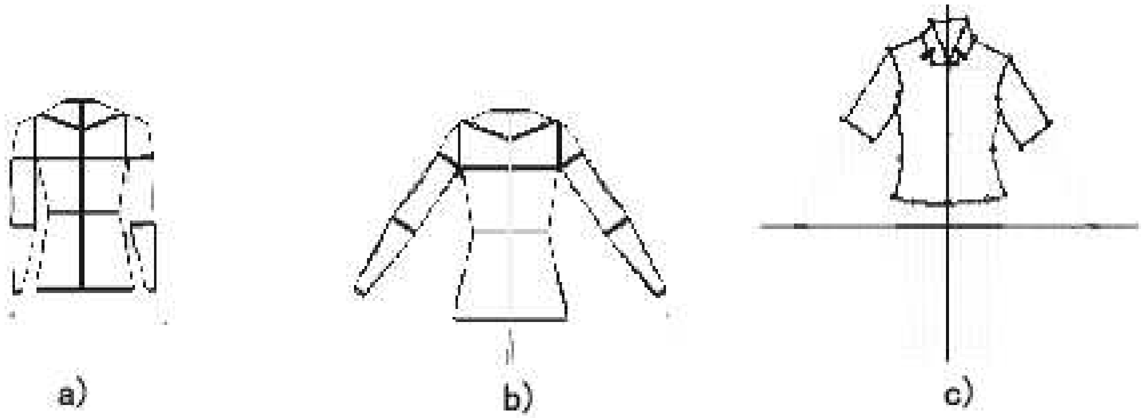

Figure 9. a - Real silhouette; b - Standard silhouette; c - Figurine manipulation

2D silhouette (front and back) provided by a producer are used as key element in our method (Figure 9c). They are placed over the 2D standard figure and they can be edited to match the real figure. A sewing information between the 2D pattern themselves is provided by the user in the figure. At the end, an assignment between the garment patterns and the points in the silhouette is required to start the pre-positioning.

5.3.2. Virtual cloth pre-positioning: 2D garment manipulation

Figure 10a presents a real garment imported using DXF file; 2D patterns may contain some holes. The 2D patterns can be cut in several pieces to eliminate these holes, and each part doesn't contain any hole. Or the problem can be resolved by simply adjusting two virtual sewing lines from the hole to the garment bound. The line direction is selected by the user (Figure 10b).

To simplify the manipulation, the imported patterns need to be sewed together. This action is done by the user, who specifies the sewing information and how the garments look like at the end.

5.3.3. Analysis of viscous dissipation

Cloth simulation is a major research orientation in Mirages project. Thus, a cloth simulator was developed within the team.

However, this simulator does not make it possible to model precisely the effects of energy damping which can be generated either by friction between moving cloth and air, or by friction between the warp and the weft threads of fabric.

Energy damping is an important phenomenon in order to model garment simulation in a realistic way.

An experiment was carried out in collaboration with ATTITUDE-STUDIO using a MOCAP system in order to measure precisely the energy damping during the movement of fabric.

The experiment performed in collaboration with ATTITUDE-STUDIO consists in dropping a piece of fabric in free fall and measuring its trajectory using a motion capture system (MOCAP) (see figure (13) for the setup). The viscous parameters are then obtained by the adjustment of the simulated trajectory of this fabric computed by our simulator, to the real trajectory.

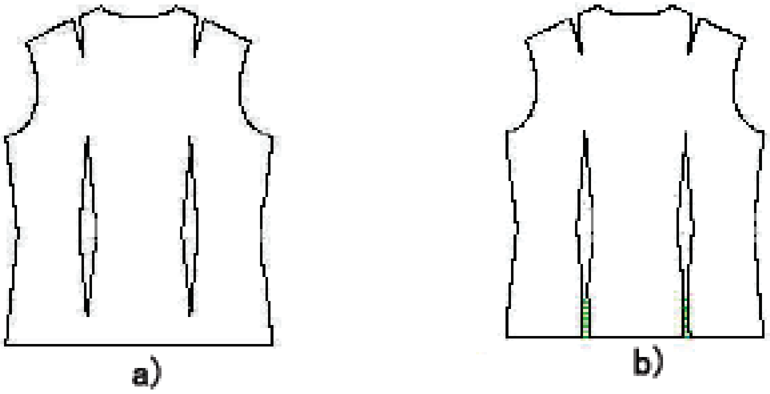

Figure 10. The real garment and the virtual sewing lines.

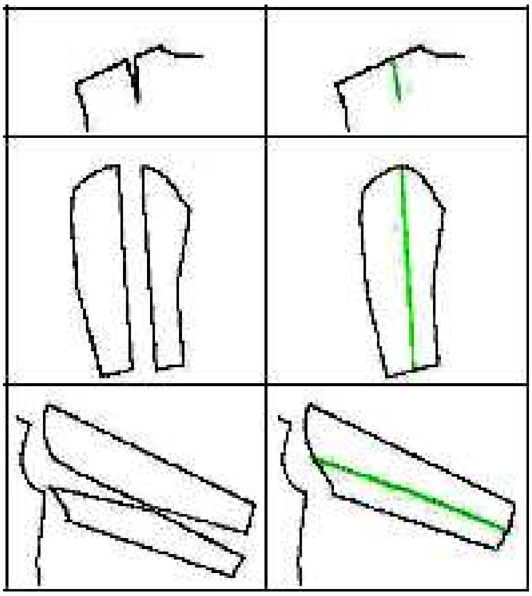

Figure 11. Virtual garment sewing.

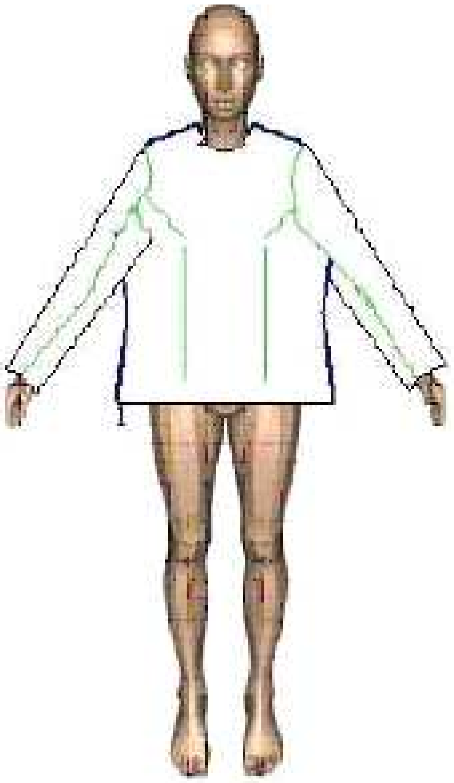

Figure 12. A jacket and its 2D patterns after the manipulation.

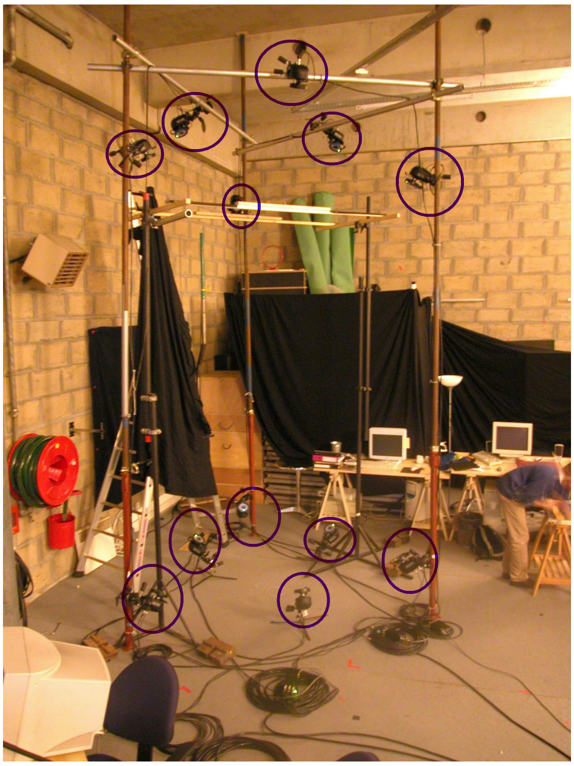

Figure 13. 12 cameras of the Motion Capture System (MOCAP)

A sample of 50cm by 50cm of fabric (woven in warp/weft) is cut.
Reflective round markers are stuck on both sides of the fabric in order to form a regular grid.
Then, the fabric is thrown in a free fall and the MOCAP system starts recording the successive positions of the markers (see figure (14)).

Figure 14. A sample of fabric with reflective markers

The damping model used is linear and called a Rayleigh model.Its parameters were always determined in an empirical manner.
Our work gives the possiblity to compute experimentally these parameters and to measure their numerical and visual contribution for the simulation.
In figure (15), the yellow fabric is the real trajectory and the green is the simulated one.
It is clear that the real trajectory and the simulated one are very close which validates our approach.

5.3.4. Collision processing within an animated environment

5.3.4.1. Input:

The geometry of the garment environment is assumed to be, for each frames. We need a way to estimate the garment position for the whole simulation time interval. We have assumed that a linear interpolation would be a good approximation. We can also compute each mass speed at each time step.

Rather than trying to take into account the textile thickness (a minimal distance between environement and cloth) during the detection stage as we do for self-collision, we decided to add the thickness to the environment geometry for all key frames, and then to interpolate between those thickened positions. As the ratio between time step and frame duration is quite important (about 100), computing time spent for this operation is insignificant.

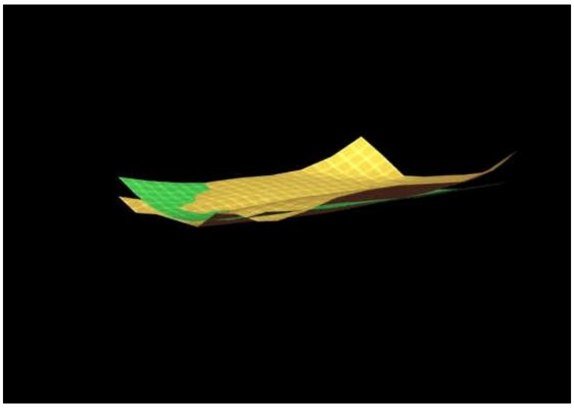

Figure 15. Comparaison of real and simulated trajectory

5.3.4.2. Detection:

Collision between a cloth mass P and an external facet $f = ABC$ can occur only when mass P reaches the facet plane f:

$$\left(\overrightarrow{AB(t)} \wedge \overrightarrow{AC(t)}\right) \cdot \overrightarrow{AP(t)} = 0 \tag{1}$$

During the time step between t and $t + \Delta t$, we can assume a linear movement for each mass and we obtain a 3^{rd} degree equation in t. Then we check for each t_i solution if $P(t_i)$ is inside the triangle.

Assuming we have a well-oriented environment, we can remove here "going away collisions": those who decrease the distance defined by (1) i.e those such that the derivative of (1) is negative.

Collision detection leads to a constraint creation, linking P to f.

5.3.4.3. Processing of the constraint:

At the beginning of each step, we **already know** exactly the cloth position at the end of the step. We can thus constrain the linked particle positions in order not to collide. This constraint can be applied on the speed.

The constraint is only on one direction : the facet normal at the end of the current step. Indeed, if we constrain that P will be above f at the end of the step, then all positions in a plane parallel with f with be valid, regarding the collision.

If we suppose the distance between P and F must not change during the time step, we obtain :

$$\begin{aligned} d_{before} &= AP(t) \cdot N(t) \\ &= (P - A) \cdot N(t) \\ d_{after} &= AP(t + \Delta t) \cdot N(t + \Delta t) \\ &= (P + \Delta t \cdot v_P - A - \Delta t \cdot v_A) \cdot N(t + \Delta t) \end{aligned} \tag{2}$$

writing $v_P = z \cdot N(t + \Delta t)$ and $d_{after} = d_{before}$, we obtain :

$$\begin{aligned} (P - A) \cdot N(t) &= (P - A) \cdot N(t + \Delta t) + \Delta t \cdot z - \Delta t \cdot v_A \cdot N(t + \Delta t) \\ z &= (A - P) \cdot \frac{N(t+\Delta t) - N(t)}{\Delta t} + v_A \cdot N(t + \Delta t) \end{aligned}$$

If we constrain P to move along $\overrightarrow{d} = N(t + \Delta t)$ of z, we insure that there are no collisions.

5.3.4.4. Simulation:

A model for modeling hysteretic behaviour of cloth was proposed in [2]. Attempts were then made to include contact friction effects. Several approaches to improve both stability and computation time were investigated as well.

Our spatial partitioning scheme drastically reduces collision detection computation time. Geometrical properties of the simulated scene were investigated; conditions were established so a linear complexity (in terms of geometric primitives) could be achieved.

6. Contracts and Grants with Industry

6.1. Golf-Stream

Participants: Philippe Gérard, Eric Nowak, Tung Le Than, Wei Du, André Gagalowicz.

The Golf-Stream project of the Riam (Research and Innovation in Audiovisual and Multimedia) network is interested in movement capture on a real life character. This is a complex problem that we are solving by adjoining INRIA's skills with those of the Symah Vision production house. PGA (professional Golfer association) and FFG (French Federation of Golf) are part of that project in order to drive the golf analysis.

MIRAGES develops a tool that makes it possible to capture actual movements of a golfer on site. In an initial stage, static images of the player are shot from different angles and are used to reconstruct his or her skeleton and body envelope. The virtual character is then superimposed live over the player in action and adjusts itself by learning. It can determine body movements (pelvis rotation, arms position, etc.) as well as the position of the player's center of gravity and direction imposed to the ball with great precision. This method does not require the use of sensors placed on the athlete's body! We needed one night of computations. However to obtain a result on a sequence, we optimized the software to be much faster and usable by TV crews. Standard video cameras are able to provide up to fifty measures per second. It is thus possible to broadcast a slow-motion sequence showing the superimposed skeleton of the player with added visualization tools that support live comments on such and such aspect of the shot, barely a few minutes after the shot. This product should be available for TV broadcasts about nine months from now.

Golf-Stream is now under the MIRAGES Coordination and got a positive review from the Industry Ministry, in November 2003.

6.2. VIP3D

Participants: Richard Roussel, André Gagalowicz.

This contract is an application of our research for post-production and is conducted in collaboration with MIKROS IMAGE. This contract follows two european MULTIMEDIA ESPRIT contracts : NEMESIS I and NEMESIS II where the target was to produce commercial software for the 3D rotoscopy of rigid objects. This software is now available under the name of FROGPLUS. In VIP 3D, we generalize the former technique to the case of deformable objects. Practically, we reduced research activity to the study of human face tracking for 3D rotoscopy.

6.3. Attitude Studio Partnership

Participants: Hatem Charfi, David Reversat, André Gagalowicz.

This contract is an application of our research on 3D garment simulation. The idea was to put together ATTITUDE STUDIO expertise on the design of realistic human avatars, and the expertise of MIRAGES on 3D garment simulation in order to produce a realistic avatar (EVE SOLAL) wearing realistic garments. A two-years research position was proposed to David Reversat by INRIA to work for this application.

Attitude Studio's computer graphists provided us with a 200 frames animation of their own virtual "star" : Eve Solal. This allowed us to perform our first test with dynamic environment on our simulator and thus to improve and validate it. Then we prepared several videos of Eve with different clothes that where submitted to Attitude's computer graphists opinion.

During the partership, David Reversat spent one week at Attitude Studio to transfer the MIRAGES software, EMILION (see section 4). This software was integrated to their internal environment. David Reversat also modified EMILION, originally developed under Unix, so that it could be run under Windows with visual C++.

During summer, we worked in parallel on the case of a gown. Objectives were many : simulator validation, comparison with other commercial software that professionals use to work with, comparative measurement of computing time for the same complexity.

Figure 16. Eve with a dress

7. Other Grants and Activities

7.1. International collaborations

- Collaboration with XID Technologies, a company located in Singapore. André Gagalowicz is scientific advisor for the company.
- A new collaboration with NUS (National University of Singapore) has been initiated.

7.2. Invitation of foreign researchers

- Professor Robert Laganière from the University of Ottawa was invited the 28th of April 2004.
- Quah Chee Kwang from NTU is invited from the 1st of November 2004 until the end of March 2005.
- Patrick Callet from Ecole Centrale Paris on the 2nd of November.
- Akhiro Sugimoto from the CRL of Hitachi on the 19th of August 2004.
- Tsuyoshi Minakawa from SRL of Hitachi on the 14th of September 2004.
- Laise Guay, CTO of MVM, Montréal, Canada on the 28th of October 2004.

Figure 17. Eve with a pant

Figure 18. Eve with a shirt

Figure 19. Eve with a shirt and a pant

8. Dissemination

8.1. Animation of the scientific community

- André Gagalowicz was scientific advisor at the ESIEA Recherche.
- André Gagalowicz was scientific advisor at the INSA Lyon Scientific Committee.
- André Gagalowicz was scientific advisor at the University of Bordeaux I Scientific Committee.
- André Gagalowicz was member of the scientific advisory board of "Machine, Graphics and Vision", "Computer Graphics and Geometry" journals as well as of the LCPC journal.
- André Gagalowicz was scientific advisor of X&D Technologies, Singapour.
- André Gagalowicz was invited by the Senat to Tremplin Industries meeting and is invited to present Mirages activities at the Senat in 2005.
- André Gagalowicz was a member of the scientific committee at the defense of Franck Perbet PhD at Inria Rhones Alpes on the 26th of February.
- André Gagalowicz presented the Mirages Research during the Hitachi visit at Inria on the 3rd of May and on the 19th November, and during the chineese delegation visit on the 14th and 15th of December.

8.2. Conference program committees and revue in signal processing

André Gagalowicz was a member of the conference program committees of:

- ICCV' 2004 conference in Warsaw, Poland.
- IVCNZ' 2004 conference in New Zealand.
- GRAPHICON 2004 conference in Moscow, RUSSIA
- WSCG' 2004 conference in Pszen, Czech Republic.

8.3. Teaching

André Gagalowicz has taught Computer Vision in the DESS on images of the University of Bordeaux III.

Hatem Charfi has taught Java Programming in the first year undergraduate courses (DEUG MASS) at the university Paris 9 Dauphine..

8.4. Participation to seminars, conferences and invitations

- A.Gagalowicz has presented an invited conference at ICCVG' 2004 in Warsaw, Poland.
- A.Gagalowicz has presented an invited conference at Imagina 2004, Monte Carlo, Monaco.
- A.Gagalowicz has presented an invited conference at ISS'04 in Cannes,France.
- A.Gagalowicz has presented an invited conference CVMP'2004, in London, Great Britain.
- Presentation of Golf-Stream by P.Gerard to RIAM Days in Rennes
- Hatem Charfi went to the EuroGraphics 2004 conference.
- P.Gerard went to the Laval Virtual 2004.

9. Bibliography

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