



INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team MIRAGES

*Object Manipulation in Image Sequences
for Augmented Reality and Special Effects*

Paris - Rocquencourt

THEME COG

Activity
R *eport*

2008

Table of contents

| | |
|---|----------|
| 1. Team | 1 |
| 2. Overall Objectives | 1 |
| 2.1.1. First Research Activity: 3D Analysis of Image Sequences | 2 |
| 2.1.2. Second Research Activity: 3D Garment Simulation | 2 |
| 2.1.3. Third Research Activity: 3D cities modeling and reconstruction | 2 |
| 3. Scientific Foundations | 3 |
| 3.1. Realistic Face Reconstruction and 3D Face Tracking | 3 |
| 3.2. Augmented Reality for TV Productions: 3D Human Body Tracking | 3 |
| 3.3. 3D Garment Simulation | 3 |
| 3.3.1. Mechanical Modeling of Textile Materials | 3 |
| 3.3.2. Dynamic Garment Simulation | 4 |
| 3.4. 3D cities reconstruction | 4 |
| 4. Software | 5 |
| 5. New Results | 5 |
| 5.1. Realistic Face Reconstruction and 3D Face Tracking | 5 |
| 5.1.1. Tracking algorithm | 5 |
| 5.1.2. Face animation | 6 |
| 5.2. Human body reconstruction | 11 |
| 5.2.1. Introduction | 11 |
| 5.2.2. Former Modeling System | 11 |
| 5.2.3. Refinement of the reconstructed Model | 12 |
| 5.2.3.1. Smooth filter | 12 |
| 5.2.3.2. Slice filter | 12 |
| 5.2.3.3. Neighbor triangular normals filter | 14 |
| 5.2.4. Texture Mapping | 14 |
| 5.2.4.1. View Point Independent Method | 14 |
| 5.2.4.2. Cylinder Unwrapping Method | 14 |
| 5.2.5. Skinning | 16 |
| 5.2.6. Conclusion | 16 |
| 5.3. Garment Simulation | 17 |
| 5.3.1. Development of a virtual try-on system | 17 |
| 5.3.1.1. Tailor interactive tool | 18 |
| 5.3.1.2. 3D Interaction tool | 19 |
| 5.3.2. Meshless Virtual Cloth System: New Progress and Results | 20 |
| 5.3.2.1. Experimental Results | 20 |
| 5.3.2.2. Discussion | 21 |
| 5.3.3. New buckling Model for Cloth Simulation | 23 |
| 5.3.3.1. Experimental Results | 23 |
| 5.3.3.2. Conclusion | 24 |
| 5.3.4. Reconstruction of a human body from scanned data | 26 |
| 5.3.4.1. Adjusting the number of slices | 26 |
| 5.3.4.2. Fitting each slice | 26 |
| 5.3.4.3. Fitting problematic slices using B-splines | 27 |
| 5.3.4.4. Results and future work | 28 |
| 5.4. 3D cities reconstruction | 29 |
| 5.4.1. Presentation | 29 |
| 5.4.1.1. Role and contributions | 29 |
| 5.4.1.2. Coordination and technical direction | 29 |

| | | |
|------------|---|-----------|
| 5.4.1.2.1. | The restructuring and organization of research and developments tackling this problematic: | 31 |
| 5.4.1.2.2. | The definition of work package interfaces: | 31 |
| 5.4.1.2.3. | Inter-relation with all connected work packages: | 31 |
| 5.4.1.2.4. | Technical and financial reporting to project's coordinator and funders: | 31 |
| 5.4.2. | Data importation and visualization under Sketchup | 31 |
| 5.4.2.1. | Sub level | 31 |
| 5.4.2.2. | Technical interface | 31 |
| 5.4.2.3. | Ruby wrapping | 31 |
| 5.4.2.3.1. | The definition and encoding of an architecture grammar model under a dependency graph paradigm: | 32 |
| 5.4.2.3.2. | The implementation of different facade subdivision schemes based on image analysis: | 32 |
| 5.4.3. | 3D Facade Structure Parameterizations Based on Similarity Detection from a Single Image | 32 |
| 5.4.3.1. | Facade Structure Parameterizations based on Similarity Detection | 32 |
| 5.4.3.2. | Similarity Measure — Gradient-Weighted Mutual Information | 33 |
| 5.4.3.3. | Rough-Fine Template-Based Similarity Detection | 33 |
| 5.4.3.4. | Architectural Element Analysis | 34 |
| 5.4.3.5. | Rules Extraction | 34 |
| 5.4.3.6. | Optimization of the Facade Subdivision | 36 |
| 5.4.3.7. | Experimental Results | 36 |
| 5.4.3.8. | Conclusions | 37 |
| 5.4.4. | 3D modeling of Parisian Buildings | 37 |
| 5.4.4.1. | Data Importation and Manipulation | 39 |
| 5.4.4.2. | Haussmannian Facades Characterization | 39 |
| 5.4.4.3. | Haussmannian Building Facade Image Analysis and Synthesis | 40 |
| 5.4.4.4. | Computer Graphics Architecture Grammar Modeling | 40 |
| 5.4.4.5. | Conclusion | 41 |
| 5.5. | Non Verbal expression modeling and control | 41 |
| 5.5.1. | Greta, a real-time ECA system | 41 |
| 5.5.2. | Listener Model | 42 |
| 5.5.3. | Projects elaboration | 44 |
| 5.5.3.1. | European project | 44 |
| 5.5.3.2. | National projects | 44 |
| 6. | Contracts and Grants with Industry | 44 |
| 6.1. | AXIATEC | 44 |
| 6.2. | TERRA NUMERICA | 44 |
| 6.3. | Simulvet | 44 |
| 7. | Other Grants and Activities | 45 |
| 8. | Dissemination | 45 |
| 8.1. | Animation of the Scientific Community | 45 |
| 8.2. | Teaching | 45 |
| 8.3. | Conference Program Committees and Revue in Computer Vision and/or Computer Graphics | 45 |
| 8.4. | Participation to seminars, conferences and invitations | 46 |
| 9. | Bibliography | 47 |

1. Team

Research Scientist

André Gagalowicz [Team Leader, Research Director (DR) INRIA, HdR]

Technical Staff

Catherine Pélachaud [Technical Staff, Professor, delegation up to October 2008]

Cédric Guiard [Technical Staff, INRIA, since 2008]

Tung Le Thanh [Technical Staff, INRIA, since Mars 2008]

Yujun Chen [Technical Staff, INRIA, since 2008]

Weiran Yuan [Technical Staff, INRIA, since 2008]

PhD Student

Daria Kalinkina [INRIA scholarship]

Thibault Luginbuhl [INRIA scholarship]

Chun Liu [INRIA scholarship]

Zheng Wang [Tianjin University, China, up to October 2008]

Tung Le Thanh [INRIA scholarship, January-March 2008]

Bevacqua Elisabetta [Paris VIII scholarship, 2008]

Elchafai Nicolas [France Telecom scholarship, 2008]

Bernard Jean [Paris VIII scholarship, 2008]

Hyniewska Sylvia [Paris VIII and U. of Geneva scholarship, 2008]

Post-Doctoral Fellow

Peters Christopher [Paris VIII scholarship, 2008]

Niewiadomski Radoslaw [Paris VIII scholarship, 2008]

Hong Ping Yan [Researcher Inria, until end of July to 2008]

Visiting Scientist

Patrick Horain [INT, since May 2008, HdR]

David Gomez Jauregui [PhD, INT scholarship, since May 2008]

Manoj Rajagopal [PhD, INT scholarship, since October 2008]

Administrative Assistant

Nathalie Gaudechoux [Administrative Assistant, INRIA]

Other

Emilia Lombardo [since 2007, INRIA intership]

2. Overall Objectives

2.1. Overall Objectives

The MIRAGES project research activity is oriented towards the development of model-based approaches with feedback. It is the way that MIRAGES has chosen to develop Computer Vision/Computer Graphics collaboration techniques since 1984 when this approach was chosen by the members of the project. Its activity is concentrated on the manipulation of 3D objects in image sequences with an application domain oriented towards new services (related to those 3D objects) which will appear in future communication networks as well as new products for objects customization. Our research activity is carried out in three directions:

2.1.1. First Research Activity: 3D Analysis of Image Sequences

We are interested in the determination of properties such as structure, movement and photometry of 3D objects (especially human beings) 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.
- Interactive, semi-automatic and automatic camera calibration: Here, we use 3D object models (very often, generic models) as calibration tools, in order to perform calibration. Calibration is necessary for 3D model specification.
- Automatic and semi-automatic object model specification: starting from a generic model of an object (for example a human body or a face) and an image sequence, this task consists in constructing the specific model which will be used for tracking in image sequences (see above).

Collaboration is carried out with AXIATEC (a french company interested in products customization) on face modelling and animation. The Golf-STREAM contract (RIAM funding) started in june 2002 in collaboration with the french Symah Vision production company. The task was to study complete human body 3D tracking and more specifically professional golfers from image sequences in order to allow them to improve their technique and also enrich journalists comments on television broadcasts of professional golf tournaments. This task was not entirely accomplished during the period of the contract but we are continuing this research with our own funding. 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, or using meshless approaches.
- 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. We put a great effort to build a strong consortium in order to submit a proposal to the ANR. We finally obtained an important funding source for this application.

2.1.3. Third Research Activity: 3D cities modeling and reconstruction

This research direction is new and related to an activity in the TERRA NUMERICA French competitiveness network coordinated by Thalès. The aim of this research is to produce a 3D representation from Ile De France from aerial photos (produced by IGN) and from videos and 3D scans obtained from cars sensing facades from the ground. The activity of Mirages consists in using an analysis/synthesis approach to replace the raw data obtained from our partners as well as building and vegetation models in order to replace raw data by compact 3D representations suitable for new services.

"TERRA NUMERICA" is a federated project of the French competitive cluster "Cap Digital" focused on Digital Content Creation. TERRA NUMERICA has been labeled on February, 2006 and is funded by the French Ministry of Industry and the territorial institutions of the Ile-de-France area. Dedicated to the modeling and visualization of large urban areas, this collaborative project gathers 17 industrial and academic partners under the governance of Thales for an overall budget of 15M euros. Planned over a 3 years period, this project started on January 2007. Within this project, the Mirage team is responsible for the coordination and technical direction of technological developments targeting the 3D reconstruction of geo-specific buildings : Work Package WP3.1.4 also gathering TRIMBLE, IGN, THALES, ENSMP-CMM, ENST.

The modeling of large urban areas drains significant stakes both from an economical (development of new geo-localized services targeting mass and business markets segments in the field of city planning, territory management, tourism, security/defense simulations) and societal (control of numerical heritage) perspectives. Yet, focusing on buildings, the definition of the realistic visual representations implied in such numerical model predominantly comes down to several man years of labor when dealing with large-scale reconstruction area. The work package 3.1.4 of TERRA NUMERICA aims to develop and integrate new technologies fulfilling this problematic. Based on the analysis of various acquisitions and on the formalization of architectural a priori, these developments are intended to automate and gain in productivity in the reconstruction process while certifying the compliancy and fidelity of a 3D representation both at the geometric and semantic level.

3. Scientific Foundations

3.1. Realistic Face Reconstruction and 3D Face Tracking

Keywords: *3D face modeling from images, 3D face tracking, deformable models, model-based modeling.*

Participants: Daria Kalinkina, André Galalowicz.

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

3.2. Augmented Reality for TV Productions: 3D Human Body Tracking

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

Participants: Zheng Wang, Chee Kwang Quah, André Galalowicz.

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

We are currently developing a 3D tracking system using video cameras able to produce outdoor motion capture without the use of markers. A generic 3D human body is used as input. Then, 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.

3.3. 3D Garment Simulation

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

Participants: Yujun Chen, Weiran Yuan, Tung Le Thanh, André Galalowicz.

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 dealt 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 provides digital data. Our textile models are now able to simulate precisely Kawabata curves of real textile for tension, shear and bending.

3.3.2. Dynamic Garment Simulation

Once a numerical model of cloth is stated, we have to produce complete garments. The technique we use directly comes from the textile industry. We use the same 2D patterns as those really manipulated by garment designers. This incorporates sewing information. We have to construct the garment automatically from this data. It appears to be a very complex problem, not solved in the literature (and even almost never tackled !). our goal is then to compute the evolution of this complete mass/spring system with respect to time; it relies on the integration of the fundamental equation of dynamics. Several families of algorithms exist, adequation to the underlying problem of which vary both in terms of stability and computation time. Checking the validity of our approach is also a very strong challenge that we began to undertake.

Handling contact phenomenon between pieces of cloth, and the characters that wear them is the other big challenge: large amounts 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.

3.4. 3D cities reconstruction

Participants: Cédric Guiard, Chun Liu, Emilia Lombardo, Hong-Ping Yan, André Gagalowicz.

Cities are of multi-dimensions, high functional and visual complexity. They are the concentration of history, culture, economy, and ecology, etc. Therefore, modelling and visualizing 3D cities with visual reality using computers covers various disciplines and is a real challenge to researchers in different research domains. The potential applications for creating 3D cities range from research and educational purposes like urban planning and global navigation to entertainment like tourism and 3D computer games. Buildings, as one of the main objects in cities, differ from one another in many aspects like motif, style, dimensions, etc. Facades can to a great extent reflect most aspects of one building. Therefore, our research will mainly focus on 3D facade reconstruction based on multi-source information (including aerial images, ground images, architectural knowledge, etc.). Our goal is to create a real time 3D facade reconstruction system with a user friendly interface. Three major challenges will be tackled:

- our system will face not only expert users but also non-expert users so, **we have to concieve a user friendly interface**. Is there a way to let all of our future users express their idea in 3D? This is a demanding task to provide our various potential users with easy-to-use interface that require no/not much learning while keeping the high quality results.
- real-time and realism are two critical factors for 3D object modeling and visualization. Here, architectural knowledge, like floor height and width should be adopted in order to get plausible results, and meanwhile considering the application of our system, memory consuming and time consuming should be reduced.
- robustness is another important factor in facade reconstruction from multi-source information. Since the quality and complexity of the input information cannot perfectly meet our requirements (usually there are heavy image noise, measurement errors, small irregular elements, etc.), how to get stable and precise reconstruction result will be a tough nut to crack.

Ranging from the generation of typical buildings appearance -considered to populate the environment- to the accurate reconstruction of existing ones -regarding specific fidelity and precision constraints-, the production of 3D buildings representation draws a bridge between Computer Graphics and Computer Vision approaches. Techniques in Computer Graphics are interested in large-scale modeling making use of procedural schemes. Introduced in the 70's [69] as a formal approach to architectural design, Shape Grammars have recently evolved to extend their derivation mechanisms ([67], [76], [63], [65]). Shape grammars can be complemented by cellular textures [61] and generative mesh modeling to generate facade ornaments. Meanwhile; these techniques do not allow to count for precise similarity constraints to a real environment.

Conversely, there is a wide spectrum of strategies for urban reconstruction in Computer Vision. Depending on considered input data : single image [66], ground-based facade images ([52], [74]), interactive editing using aerial images [68], aerial images combined with ground-based panorama images [73], ground-based laser scans combined with aerial images or airborne laser scans [55], [56], these systems still resort to semi-automatic and notorious fragile methods having quite difficulties to extract the structural characterization of the considered constructions.

All these different acquisitions types (geo-referenced through the help of the numerical cadaster) are considered and accessible in the scope of the TERRA NUMERICA project. In this context, our scientific objective is to establish a virtuous loop linking image-based analysis techniques to model-based building characterization through the introduction of an innovative reconstruction scheme counting for the simultaneous registration of planimetric, 2D photo and 3D scans acquisitions. This approach is foreseen to couple the respective advantages carried by these techniques while making up for their weakness in order to:

- Enlarge the space of the buildings representation that can be instantiated considering a procedural paradigm;
- Support an interactive parametrization and automate the reconstruction process;
- Integrate precision and fidelity constraints in Data correspondence as a mean to incrementally qualify and enrich the Model;
- Improve structural and semantic characterization under a hierarchical scheme.

4. Software

4.1. Software

Emilion is the cloth simulation system that was developed first by J. Denise during his Ph.D. Then, it was extended by D. Reversat to allow draping on animated characters (See [54]). An automatic pre-positioning technique by T. Le Thanh and A. Gagalowicz (See [70] [8]) was recently added. Thanks to these new results garment simulation becomes really affordable. In order to improve the realism of the simulation, we are now adding buckling effects which should produce nicer folds.

This software computes the evolution along time of garments that are represented by mass-spring systems. Both explicit and implicit integration schemes are available. Hysteretic behavior 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. 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 STL, the Standard Template Library). Tcl was chosen as its scripting language to ease both its feeding with external data and the simulation of Kawabata experiments.

5. New Results

5.1. Realistic Face Reconstruction and 3D Face Tracking

5.1.1. Tracking algorithm

Participants: Kalinkina Daria, Andre Gagalowicz.

Our 3D face tracking approach is based upon analysis/synthesis collaboration and uses a textured polygonal 3D model as a tool to detect face position and expression in each frame of the sequence by minimizing the mean-square error between the generated synthetic image of the face and the real one. Since the performance of tracking (precision and stability of detection) relies heavily on the precision of the 3D model used, before starting to track we adapt our deformable generic 3D model to the person in the video. To do the adaptation we use one or more images of the person taken from different views. The matching is performed in two steps: the first step consists of the adaptation of the certain predefined characteristic points which is done in parallel with the per-view camera calibration; the second one consists of the adaptation of the contours in all the views. At the initialization step of tracking the specific 3D model should be positioned interactively on the first image of the sequence in order to acquire texture; after that the tracking process is fully automatic.

For each frame of the video sequence our algorithm searches for an optimal set of the system parameters

$$\sigma = (t, r, \lambda)^T,$$

where

$$t = (t_x, t_y, t_z)^T$$

and

$$r = (r_x, r_y, r_z)^T$$

are the global head translation and rotation vectors respectively and λ is the vector of parameters that control facial expression, by using an iterative minimization tool. The error function is represented by the per-pixel difference between the current video frame image and the textured projection of the 3D model which has been updated with respect to the new values of the parameter vector σ . Per-pixel difference is computed only for those pixels that are covered by the textured model projection and is represented by the Euclidean norm on the RGB components of the image. In order to avoid getting trapped in local minimum we use the simulated annealing minimization algorithm. Due to the large total number of parameters to optimize we split them into several independent groups and perform minimization over each group separately. These groups are:

- rigid tracking (translation and rotation), which is performed in the first instance;
- expression tracking - mouth part (lips, jaw);
- expression tracking - eyes part (eyelids, eyeballs, eye squint);
- expression tracking - eyebrows part;
- expression tracking - nose, tongue (optional). For groups related to the expressions the error is computed only from the sub-image that represents the part of the face in question. The global tracking scheme is shown in Figure 1.

5.1.2. Face animation

In order to be able to track expressions we've developed three different animation systems.

The first animation system is based upon facial muscle structure, muscles being represented as Bezier curves attached to the mesh vertices. The shape of each of these curves is controlled by four parameters: two control points and two tangent vectors. By changing these parameters one deforms the curve and thus adjusts the underlying vertices positions, this deformation being propagated over the whole mesh using radial basis functions. The animation itself is performed through a higher-level parameters - the so-called "expression units". Each unit controls deformation of one or several curves at a time and corresponds to specific facial expression subparts such as lower lip up/down, mouth corners up/down e.t.c. Figure 2 shows the example of activation of several expression units (represented by sliders) to form a smile.

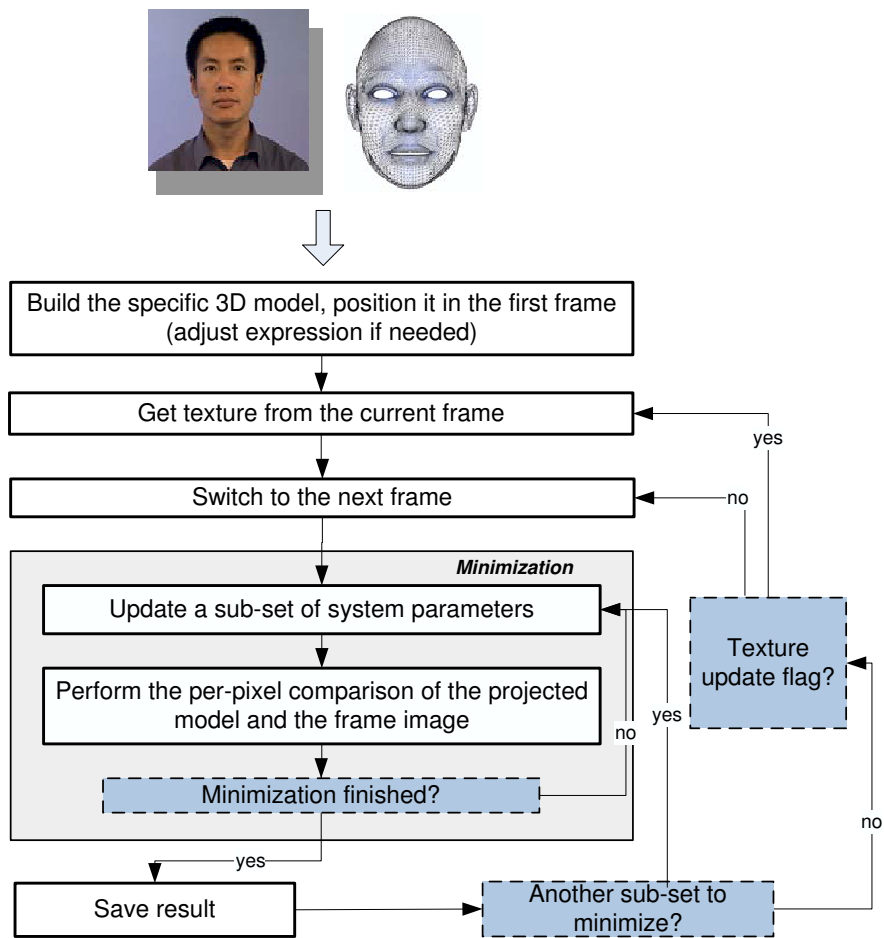


Figure 1. Global tracking framework

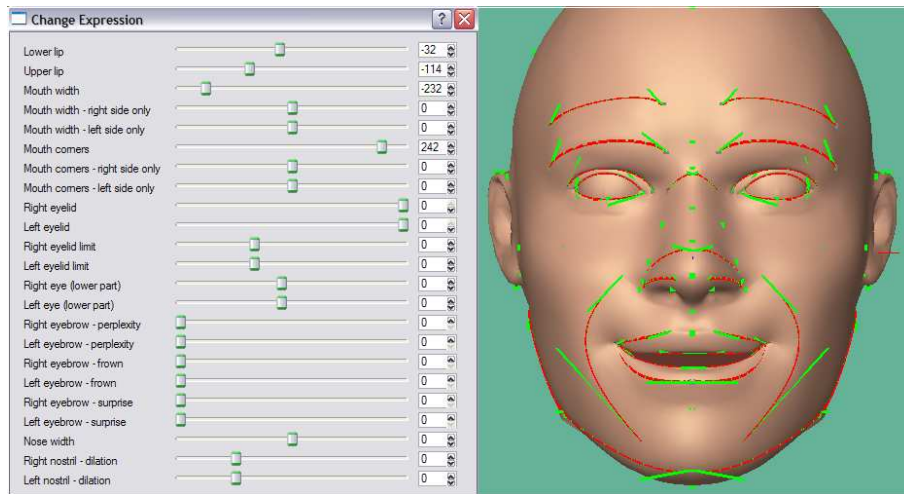
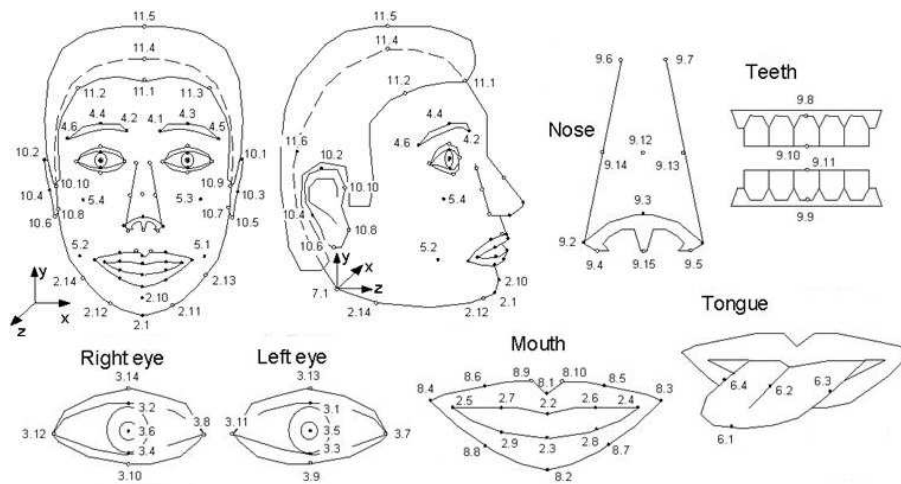


Figure 2. Example of expression units

The second animation system implemented within our tracking framework is based upon the facial animation parameters specified by MPEG-4 standard. In MPEG-4, standard facial animation is defined by two types of parameters [5]: a set of Facial Definition Parameters (FDPs) that reflects the geometry of the 3D model (see Figure 3), and 68 Facial Animation Parameters (FAPs) that specify the animation part and are closely related to muscle action. At the same time MPEG-4 only defines the action related to each FAP (see examples in Figure 3) leaving to the users its interpretation in terms of actual deformation of the 3D mesh.

As a basis of our implementation of the MPEG-4 facial animation system we've adopted the one that is used for animating the virtual conversational agent "Greta" created by the team of prof. Catherine Pelachaud. This gives us two advantages: firstly it allows to refine our tracking algorithm by validating it on synthesized Greta-animated video sequences and secondly - to do the retargeting of any facial expression from a rich hierarchical semantic library. In order to comply with the Greta's MPEG-4 implementation we've constrained the action of each FAP by splitting the surface of our generic model into 68 semantic zones, each FAP affecting only a specified sub-set of them. The region of influence of each FAP within this sub-set is in its turn defined as an ellipsoid centered at the control point (FDP) corresponding to this FAP. In Greta, the sizes of ellipsoids were represented by fixed values which didn't allow any transfer of Greta's animation mechanism to the facial models of other dimensions/geometry because the visual effect of the animation of a FAP greatly depends on the dimensions of its region of influence with respect to the 3D model. Since our goal was to build an animation system that would work for any kind of faces, we've created geometrical dependencies for all the ellipsoids radii, so that the system could adapt automatically to any face geometry given as an input, thus making it applicable to any kinds of faces produced on basis of our generic face model. At the same time our system should provide the same effects on the Greta model reconstructed from our generic 3D face, as it does on real Greta.

Although MPEG-4 parameterization is potentially capable of reproducing a rich palette of realistic expressions and as a consequence allows to perform expression tracking with more precision in comparison with our muscle-based method, it has several significant drawbacks which makes it difficult to use FAPs directly as parameters for tracking. Firstly it gives too many parameters to minimize - especially in the mouth region where animation is controlled by a total of 28 FAPs! - that would lead to huge computing time and would make minimization more sensitive to local minimum traps. Secondly it doesn't provide any global constraints for the FDP's displacements: all of them cause only local deformations and are completely independent which means



| # | FAP name | FAP description | Motion | FDP |
|-----|-----------------------|---|--------|-----|
| ... | | | | |
| 8 | <u>lower_t_lip_lm</u> | Vertical displacement of midpoint between left corner and middle of top inner lip | down | 2.6 |
| 9 | <u>lower_t_lip_rm</u> | Vertical displacement of midpoint between right corner and middle of top inner lip | down | 2.7 |
| 10 | <u>raise_b_lip_lm</u> | Vertical displacement of midpoint between left corner and middle of bottom inner lip | up | 2.8 |
| 11 | <u>raise_b_lip_rm</u> | Vertical displacement of midpoint between right corner and middle of bottom inner lip | up | 2.9 |
| ... | | | | |

Figure 3. FDPs and FAPs specified in MPEG-4

that a minimization tool will waste a lot of time on searching the optimum in the aggregate of irrelevant facial expressions. At last, the deformation function being generalized doesn't take into account particular properties of the mesh geometry and thus is capable of producing unrealistic expressions. On the other hand muscle-based method produces a better control of the mesh surface providing smoother deformations but is less precise and very slow because of the RBF interpolation. We've decided to combine both methods in a hierarchical way leaving the highly parameterized MPEG-4 face animation mechanism as a basis of our animation system but restraining FDPs displacements by our muscle curves. Further if necessary the refinement can be done using the FAPs directly. The scheme of the combined tracking algorithm is presented in Figure 4.

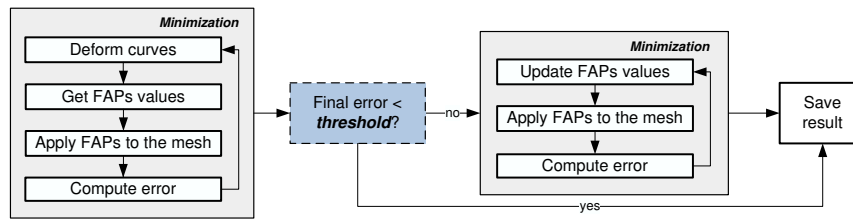


Figure 4. New tracking scheme

Being very precise and stable our algorithm is however far from real-time requiring computational time of around 1,8 minutes per frame due to multiple cycles of minimization for a single image each containing 300-400 iterations. This time however can be reduced to 1 minute by transmitting a part of the computation to the GPU. Indeed if we look closely at the operations performed at each iteration (see Figure 5) we'll see that the most "expensive" one from the computational point of view is reading back the image with the textured projection from the GPU memory for comparison with the frame image. So the idea was to perform this operation directly on the GPU by using GPGPU reduction algorithm and to transfer only the error value. Masking of the negligible pixels is done through the alpha-component and all the GPU-computation is implemented using pixel shaders.

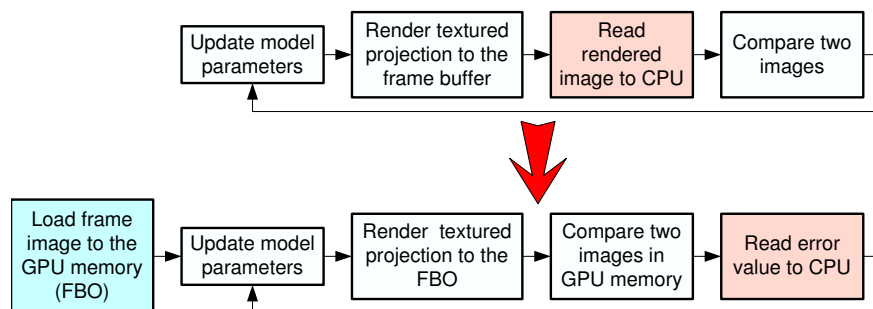


Figure 5. GPU acceleration scheme

Finally we've implemented several interface issues adding among other things tracking result playback option. Also we've completed our generic face model by adding eyes, teeth and tongue to it.

5.2. Human body reconstruction

Participants: Zheng Wang, Andre Galalowicz.

5.2.1. Introduction

A system that constructs a three dimensional human model using two dimensional images taken from multiple view-points is presented. This system improves our former modeling work by including three filters, stable texture mapping and skeleton animation. Results indicate that our system is able to construct a high quality human model which provides a solid foundation for future motion tracking system.

5.2.2. Former Modeling System

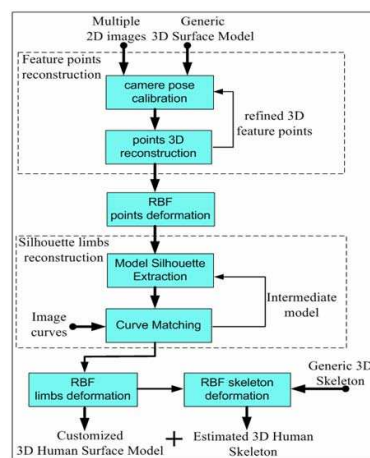


Figure 6. block diagram for former modeling system

The former modeling system was built to produce a specific model via deforming a generic one. The inputs to the system are:

- 2D images from different views.
- generic model and it's 32 selected surface characteristic points.
- feature point matches in the image views and 3D human model vertices.

The output of the system are:

- Camera calibration parameters of the different views.
- Customized 3D surface model with regular surface that will overlay nicely onto the images of the subject's silhouette limb in all views.
- estimated position and reconstruction of the specific skeleton of the subject.

The block diagram of the former modeling system is shown in Figure 6. The whole process includes four main off-line stages.

- Camera calibration and reconstruction of model feature points.
- Deformation of a generic model by using RBF function and feature points.
- Refinement of model via silhouette limbs deformation.
- Skeleton estimation

5.2.2.1. Existing problems

The former system enables us to obtain a global surface geometry of the human subject. However, some local distortions occur on the geometry surface because of the non perfect camera calibration, as shown in Figure 7.

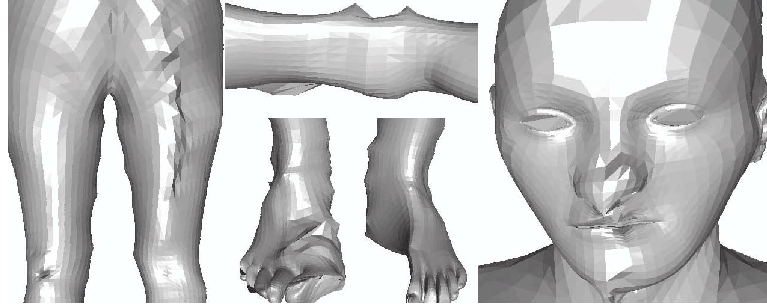


Figure 7. local distortions of the mannequin

To solve these problems, we analysed the distortions and classified them into three categories which are vertical bulge, large-scale and small-scale twists. We designed a filter to solve each problem: they are smooth filter, slice filter and neighbor triangular normals filter.

5.2.3. Refinement of the reconstructed Model

5.2.3.1. Smooth filter

Some noticeable vertical bulges can be spotted on the arm surface in Figure 7. We want to eliminate the bulges and meanwhile preserve the correct body features as much as possible. The following shows the implement action of the smooth filter. A vertex of the specific geometry is denoted as $P(x, y, z)$, $Q_i(x, y, z)$ are neighbor vertices of P . Let

$$P'(x, y, z) = \frac{1}{N} \sum_{i=1}^N Q_i(x, y, z)$$

Let D be the distance from P to P' , if D is greater than a threshold ρ whose value is set to the mean value of D , then replace P with P' . The smoothed result is shown in Figure 8.

5.2.3.2. Slice filter

A very serious distortion can be detected on the feet of the specific model. To fix it, we designed a slice filter and implemented it by using following procedure:

- Segment whole body into several parts including head, neck, arms, legs and bust. Then the axis of every part is estimated. This step is achieved using PCA method.
- Along the axis, each part is cut into many slices via computing the intersection of the geometry and the cutting planes which are orthogonal to the axis. The slice numbers on the generic model and specific model are equal. Figure 9 shows one slice on every part.
- Overlap every pair of slices and compare the variation of the distance between the two borders. A slice will be marked as "bad" if the maximum distance between the two border is greater than a threshold whose value is related to the mean distance of one pair slice.
- After all the bad slices are detected, a scaled copy is done from generic model to specific model.

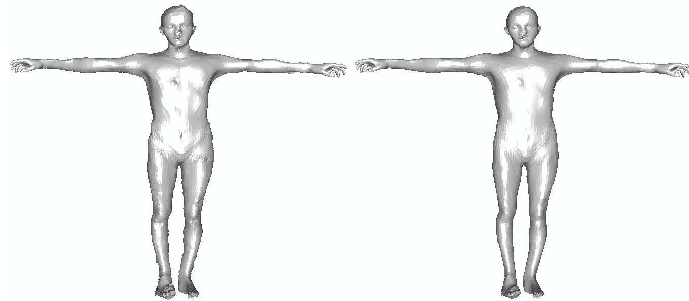


Figure 8. Left: before smoothing; Right: after smoothing

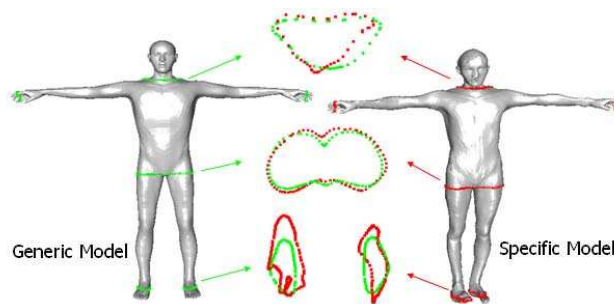


Figure 9. one slice on every part

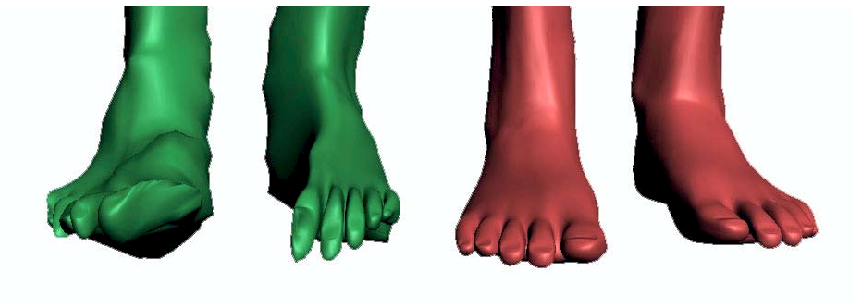


Figure 10. result of using slice filter

Figure 10 shows the result after using slice filter.

5.2.3.3. Neighbor triangular normals filter

Some small area distortions are hard to be detected and corrected by using the two filters introduced above. For example a face with a twisted nose and a defective mouse even if the remaining is normal. To solve this problem a neighbor triangle normal filter denoted as NTNF is presented here. To use NTNF a precondition must be that on small matched areas the generic and the specific geometry are similar and fortunately it is the case for most human body parts. To each vertex P on the generic and its equivalent on the specific model, we compute the angle difference between the normals of the matched triangles attached to P and its equivalent. If the maximum angle is greater than a threshold, than P will be denoted a suspicious vertex. After checking all the vertices on the specific model, we obtain several suspicious vertex groups and their corresponding vertex groups of the generic model. According to a chosen bounding box of each pair of vertex groups, a scaled replacement is performed from the generic model to the specific one in order to suppress those suspicious vertex groups. After one pass of this replacement, we can reiterate the process on remaining suspicious vertex groups. Figure 11 shows the effect on the face after using NTNF.

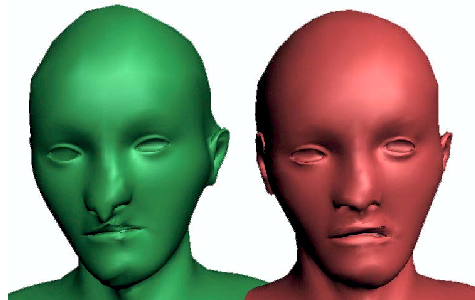


Figure 11. result of using NTNF

5.2.4. Texture Mapping

In order to perform a model-based 3D tracking of a human body movement with feedback it is fundamental to dispose of a precise textured model of the person. Due to illumination variations, it is difficult to obtain a consistent one which is really necessary for a good tracker performance. We have been investigating two kinds of texture mapping methods.

5.2.4.1. View Point Independent Method

Because for almost each patch on the reconstructed model, its texture can be obtained from several views. The idea is to select the best view. We adopt the view point independent algorithm to solve this problem. The principle of this algorithm is the following: a view will be regarded as the best one if the angle between the camera viewing direction and the normal of the patch is maximum. Figure 12 shows the texture mapping results by using this method with 6 images.

5.2.4.2. Cylinder Unwrapping Method

From Figure 12 we observed that the texture is not continuous because the illuminations in the 6 images are very different. To deal with this problem we are designing a cylindrical unwrapping method. It is implemented in the following way:

- Estimate first the 3D vertical axis of the specific model centered around the inertia center of the body volume.
- Construct the vertical cutting plane containing the camera focal center and this axis.



Figure 12. Texture mapping via view point independent method

- Slice vertically the specific model with 2 vertical planes, one to the left of the cutting plane and the other one to the right side of this cutting plane. These planes are indexed by the angles $-\text{teta1}$ and $+\text{teta2}$ (they may be equal or not). This defines an angular portion of the 3D human body (see Figure 13).
- We sample the interval $[-\text{teta1}, +\text{teta2}]$ with $N1$ values, and the body total height by $N2$ values and build a $N1 \times N2$ images containing the color of the point corresponding to its height $N2$ and its angle $N1$ on the 3D body.
- We perform the same operation for the next view in order to cover the complete $[0, 360]$ interval and chose each teta1 and teta2 value such taht the corresponding $[\text{height}, \text{teta}]$ images overlap and finally perform a linear angular interpolation between neighboring images. Figure 13 shows a 2D $[\text{height}, \text{teta}]$ image corresponding to the left part of the Figure. The full $[0, 360]$ blending of the images is shown in Figure 12.
- Finally we perform the texture mapping using the former image. The final result is shown in Figure 13.

This work is still underway as we have to detect occlusions and adapt the technique (using multi-layer visibility considerations) in order to use multiple $[\text{height}, \text{teta}]$ images for the same view. Occluded parts of one view will be textured by the other views and angular interpolation will be run on these multiple images in parallel.



Figure 13. Synthesized Texture

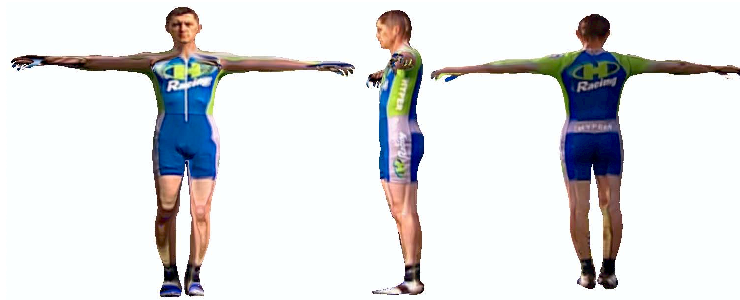


Figure 14. Texture mapping with Synthesized Texture

5.2.5. Skinning

For our future work on 3D human body tracking, the skinning is implemented via adopting a vertex blending algorithm [60]. A specific skeleton is obtained after deforming the generic skeleton with RBF. The weighting parameters used for connecting the skin to the skeleton can be set in 3DS Max and exported into a XML files. Figure 15 shows the result of skinning of one arm. However, this skin deformation technique sometimes produces non-natural results. For future work, dual quaternion algorithm [58] will be adopted to obtain better skinning results.



Figure 15. Skinning

5.2.6. Conclusion

A new technique for modeling a 3D human body of a particular person based on a limited set of images acquired from different viewpoints with wide baseline has been introduced. First, characteristic points clicked both on a generic model and on these images are required. Then we establish an initial model by using a camera calibration/feature-point reconstruction loop and interpolating the sparse reconstructed points using RBF. The initial model is refined by using a silhouette outline adaption which consists in matching the projection of silhouette edges of the initial model with the image limbs. To obtain a higher quality model, three filters are implemented to eliminate different defects distributed on the mesh. Finally the model is texture-mapped by using a novel method which synthesizes images used for reconstruction to yield an integrated texture with continuous illumination changes. Furthermore, a vertex blending skinning is implemented as the foundation for future motion tracking.

In the future, we are planning to improve the quality of texture mapping via automatically adapting slice angle according to silhouette of 3D model and incorporating occlusion considerations. Then we will use this customized model to track the target subject.

5.3. Garment Simulation

Garment simulation seems to be a completely different research domain which has nothing to do with the other activities of MIRAGES. In fact, they are intimately related. As it has been said previously, human body modeling and tracking are the core of our research activity. Usually, people that we have to track are dressed, so that what we have to track is more a garment than a human body itself. As we use model-based approaches, we need to have a garment model at our disposal. As it is a very complex domain, it became a research domain in itself in MIRAGES. Research on cloth animation and computer generated garments is a field of major interest among both Computer Graphics and Textile research communities. The most common approach is to model cloth objects using mass-spring systems and to resolve Newton's equation governing the system motion using implicit integration methods. Unfortunately, results usually lack of realism. So the main effort carried out was to improve realism which is both necessary for its use in the textile industry as well as for a precise 3D human body tracking.

5.3.1. Development of a virtual try-on system

Participants: Le Thanh Tung, André Galalowicz.

With the quick evolution of computer graphics hardware nowadays, a garment simulation process can be realized within a short time. Efficient cooperation between cloth manufacturing industry and computer graphics has become possible. A major interesting research is dedicated to the realization of a 'virtual fitting room', where techniques and technologies for virtual garment management, cloth assembly, try-on evaluation and buying have to be developed. The goal is to reduce cloth manufacturing and stock costs by using internet facilities. We want to cover the whole process leading to this technology.

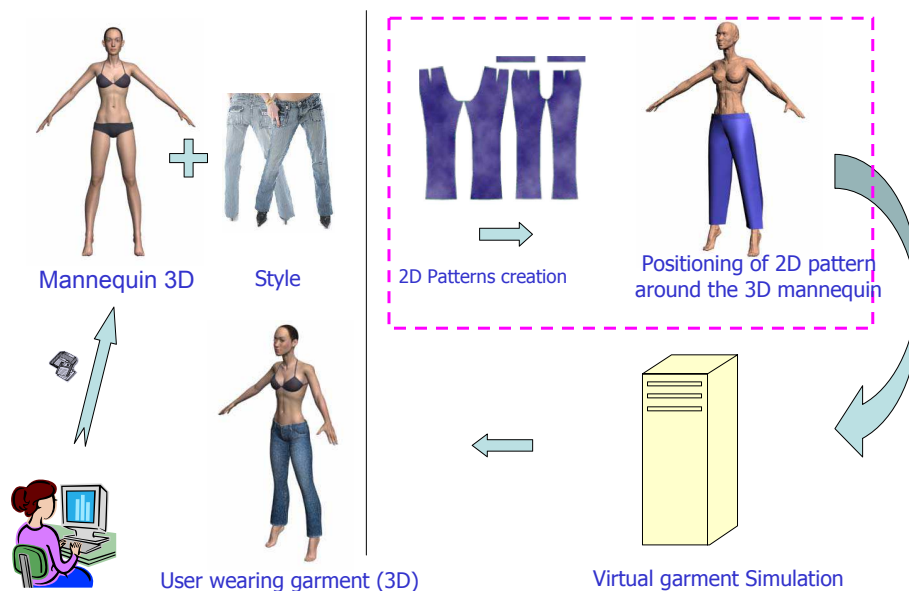


Figure 16. Scenario of a virtual garment try-on system

In Figure 16, we propose a natural computer-based scenario to try virtual clothes. This scenario does not require any complex 3D interaction of the user. The first step is to enter user's 3D geometry to the system. Such data can be obtained from actual 3D sensors. The only problem is that these sensors usually do not furnish REGULAR 3D surfaces (mainly due to the presence of holes) but regular surfaces are necessary to run 3D garment simulations. User's size measurements will be extracted automatically from this data and this information will be used to generate garment 2D patterns adapted to the user's body. The next step for the user will be to select a garment type and style from a data base furnished by the retailer, than choose a material. He will have then to see himself in 3D wearing the garment he chose.

Our work is intended to be a complete virtual try-on system. The whole process from the design over the tailoring to the try-on and customization of virtual garments shall be supported by 2D interaction tool and 3D automatic simulation techniques. The specificity of this technique is that no interaction (except simple clicks) is required from the user.

5.3.1.1. Tailor interactive tool

We provided a set of basic functions in our 2D interaction tool. This tool allows tailors to import 2D pattern from industrial textile software. Tailors can also edit/delete the redundant patterns if needs.

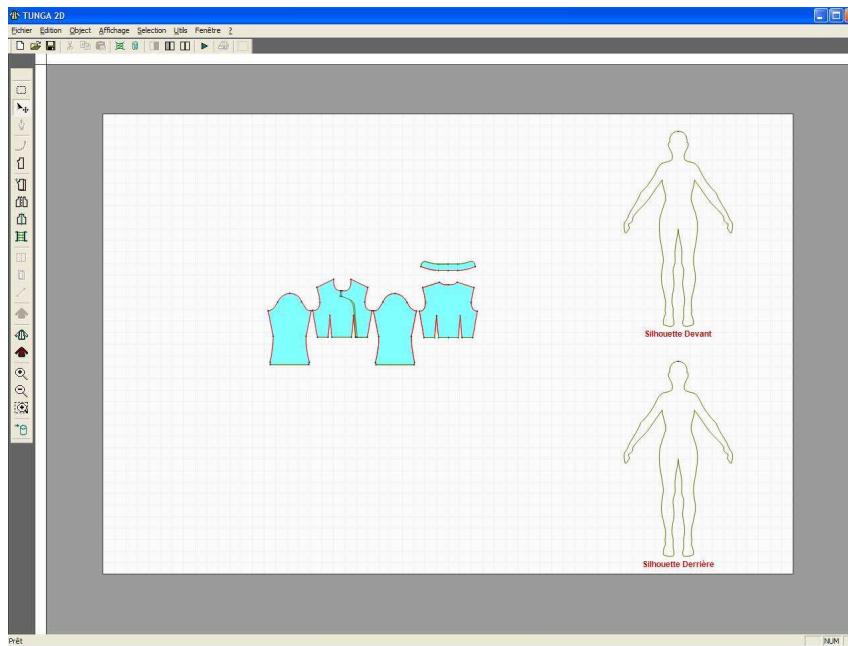


Figure 17. Tailor Interaction Tool Interface.

Implementing the 2D tool is a time consuming task because we aim to use the output data coming from various CAD/CAM textile software. Even through they use the same DXF format (Data eXchange Format), garments definition can vary from system to system.

Currently, our system supports the Nurb/Bezier/Polyline definition of 2D patterns curves. After a standardization phase, every garment is presented in Bezier form with control knots. This presentation allows editing or even creating a new garment easily.

We are currently implementing basic tailor tools like drawing pens, scissors, measurement tools for designing the patterns and figurines. Sewing information and even material parameters were also implemented providing

an easy work environment for tailors. However, the current 2D interaction tool does not support multi-layers garments that need to be incorporated in the near future. But we are lack of any mechanical friction parameters between different materials if such simulation has to be realized.

5.3.1.2. 3D Interaction tool

We provide to the end-user an interaction tool that combines a Web panel interface, a pre-positioning automatic module and a cloth simulation engine. Figure 18 presents the interface of our 3D interaction tool installed in an end-user's computer. This tool allows the user to select a garment and the materials used to design it by clicking on simple icons and see HIMSELF/HERSELF in 3D wearing the garment corresponding the user's size and choice.

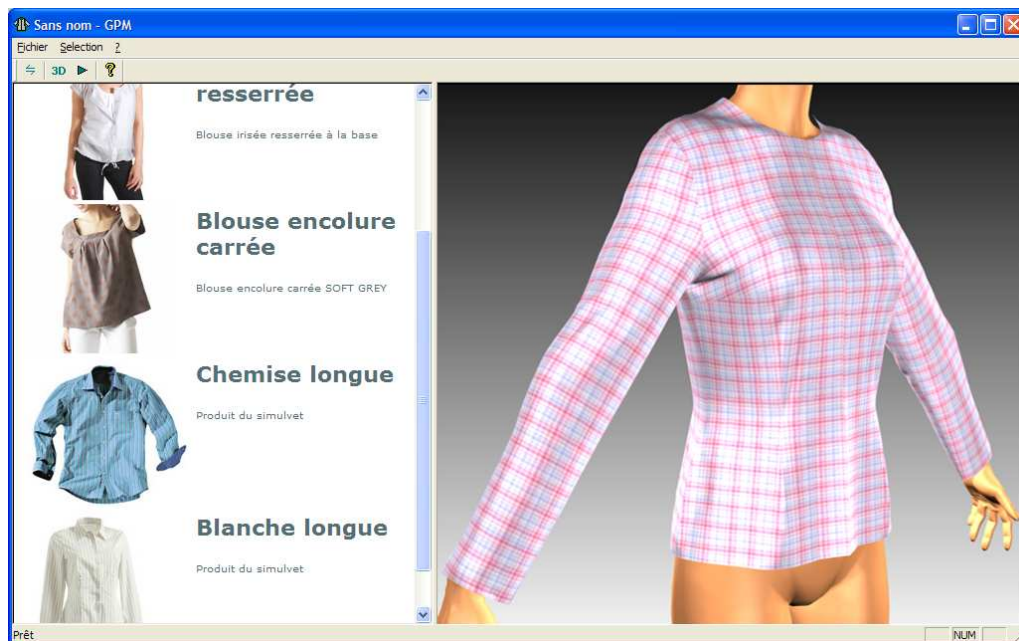


Figure 18. 3D Interaction Tools Interface. The garment icons are shown in the left panel. Once the user clicks on an icon, its virtual garment will be shown in the right panel.

- In the first step the user has to enter his own 3D digital shape (+texture). This data can be obtained is from a body scanner or simply from a customizable body modeling tool.
- Next, the user clicks on an icon of a garment he would like to buy. Through this simple click, the 2D patterns corresponding to the chosen garment will be fetched from a database server installed in the seller's site.
- Finally, he clicks on the icon corresponding to the material (color and type) he selects for his garment. Another, more informative type of interaction consists of the furniture by the seller of o booklet of samples of the material that are available for the garment production. The client will be able to touch it and transmit the code written on it to the system. When doing so, the client will, once again, call other databases; one containing the digital image of the chosen material, the other one will contain the Kawabata characteristic curves (tension, shear and flexion) which will be used to design the mechanical non linear and hysteretic mass/spring model of the chosen material.

An important topic of future research will be the implementation of techniques for speeding up the simulation engine; GPU computing is a good choice since robust graphics cards are highly developed and this technology became very popular today.

5.3.2. Meshless Virtual Cloth System: New Progress and Results

Participants: Weiran Yuan, Yujun Chen, André Gagalowicz.

Cloth simulation has become a very popular research topic in recent years in computer animation and textile industry domain.

Till now, mass-spring methods are the traditional models for cloth simulation. However this new meshless method has advantages that the mass-spring methods do not have. The mass-spring approach has the advantage of easy implementation and low computation. But it has the natural drawbacks related to non-continuum configuration. For instance, the material cannot be simulated consistently and the results depend on the mesh resolution; the spring parameters do not reflect well the physical behaviour of textile. In the textile industry realistic cloth behavior is required. A possibility relies on the use of continuum mechanics such as finite element methods or meshless methods, to solve the problem. By continuum methods, material behavior can be reproduced accurately, independently of discretization.

In the activity report of project MIRAGES of 2007, we have introduced Meshless methods to solve cloth simulation problems and we gained more progress and new results in 2008. The proposed Meshless method simulates cloth with Kirchhoff-Love (KL) thin shell theory. The special features of cloth require the use of a thin shell approach which brings several problems to traditional meshless methods. For instance, cloth has different stiffness both in plane and bending directions. In most of cloth simulation approaches, the treatments of bending models is done by an angular expression which is not accurate. This means that realistic material parameters and resolution independence cannot be expected. However, our method can provide both accuracy and continuum representation. The discretization is based upon a meshless method, which means that the discretization is independent of the geometric subdivision into finite elements. The requirements of consistency are met by the use of a polynomial basis of quadratic or higher order.

Another advantage of meshless models with KL theory is that the parametric coordinates are fixed during the dynamic simulation, due to the fact that the relative position of neighbor nodes on the background of the cloth surface will not change unless the cloth topology is changed (e.g. tearing cloth). As general meshless methods without KL model (i.e. without parametric space) use the global Euclidian space as background coordinate system, they don't have fixed background coordinates when displacement exists. The fixed parametric coordinates of KL model speeds up the search of local neighbors of nodes and simplifies the 3 dimensional problem to be solved to a 2 dimensional one.

When large deformations are involved, nonlinear equations make the simulations costly. The finite strain, known as geometrical nonlinearity, is closely linked to the invariance of the measure under rotations. We use co-rotational formulation to attach the parameterized local coordinate system of nodes. In addition, we compute the rotation field by an efficient iteration scheme. This allows us to use stable co-rotated strains.

The collision problem is a difficult problem for the meshless method, since the model has not the explicit connections and triangles. It makes the traditional collision detection invalid. We propose a detection method based upon the moment matrix from shape functions. The shape functions construct the meshless approximation and provide a natural indicator to track the surface. The detection method presented in this paper can detect a contact region using a simple criterion.

5.3.2.1. Experimental Results

In this section we present our experimental results on our meshless cloth simulator. In our algorithm, since the shape function is computed in the parameterized surface Λ , $\mathbf{R}(\xi^1, \xi^2)$ and $\mathbf{P}(\xi^1, \xi^2)$ and \mathbf{G} for a point is constant. So we store them in order to accelerate the whole computation process. When computing the neighbors id of x in the sub-domain Ω_s , the searching computation can be processed only once in the initialization. These conditions are due to the fact that the parameterized space and surface Λ are constant.

We have fixed this material parameters, such as the elasticity coefficient (Young's modulus) $E= 10000\text{N/m}$ and Poisson's ratio $\nu = 0.3$. The real parameters in continuum mechanics present the behavior of material constantly and directly, but they are hard to be obtained experimentally. Cloth has nonlinear characteristics. Solutions by Kawabata evaluation system (KES), obtained by a group of standard equipments which measure the physical parameters of the textile, have already been developed for mass-spring methods. KES includes 16 parameters, containing stretching, shear, bending, compression and friction aspects of the textile. These parameters reflect the physical character of the specific textile. Therefore, with these KES parameters we can get deep understanding of the textile behavior and make the animation more realistic. KES parameters will be considered in our meshless cloth simulation system in our future work, in order to obtain more physical behaviors. Presently, the Poisson's ratio cannot be obtained from KES. The relationship between Poisson's ratio and KES parameters should be constructed in order to give a more physical basis to our approach.

In the first example, we simulate a cylindrical sleeve constrained by a twisting force. Cylindrical sleeves are often used in cloth simulation research as they allow to test the validity for buckling and folds of the simulator. Cylindrical sleeves are also the basic elements of virtual garments and available results can prove potential capabilities for virtual try-on. Figure 19 shows the original computational nodes with the local coordinates drawn in each node, and the thicker sampling points for rendering. In Figure 20, the folds are clearly reproduced and the process of twisting produces realistic behaviors as observed with the real fabrics. The realistic shapes of meshless cloth simulation results are obtained because we use continuum physics and consistent way to model cloth. Sampling and rendering of meshless surfaces can take advantage of the research achievements in point based graphics.

Another experiment is the cloth dropping on a pole. Figure 21 shows the dynamic behavior of the results. Figure 22 shows a cylindrical cloth without sewing which is hanging on its middle line. The examples below show small buckles and wrinkles produced by the simulator.

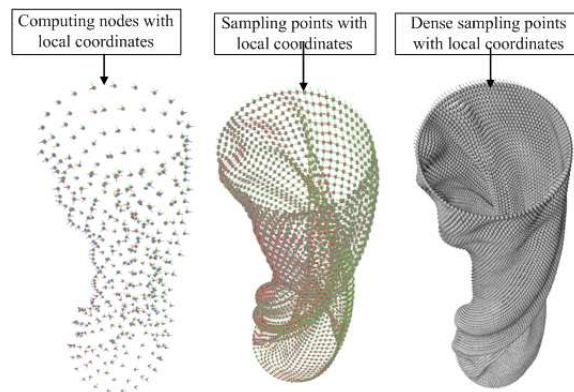


Figure 19. Computing nodes and sampling points

5.3.2.2. Discussion

A meshless cloth simulation method is developed combining the KL thin shell representation. The system is solved with collision handling. Meshless methods are usually computationally costly but as a continuum method, it has a more smooth interpolation field and a natural mechanical behavior. Nevertheless, the computing cost was reduced by the fact that KL model reduces a 3 dimensional cloth to a 2 dimensional parametric space.

We have to mention that although meshless methods present many positive aspects on cloth simulation compared to mass-spring methods, a major difference with the mass-spring method is that it needs to overcome

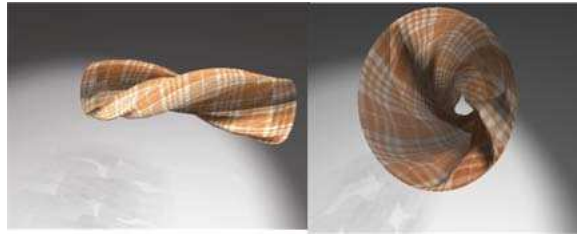


Figure 20. Results of cylindrical sleeves with twisting forces

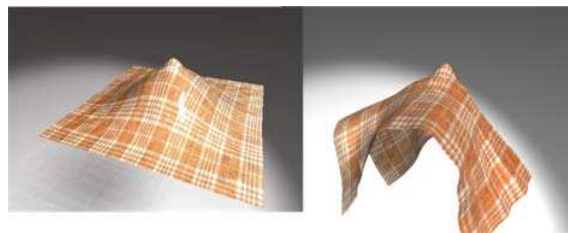


Figure 21. Results of a cloth dropping on a pole

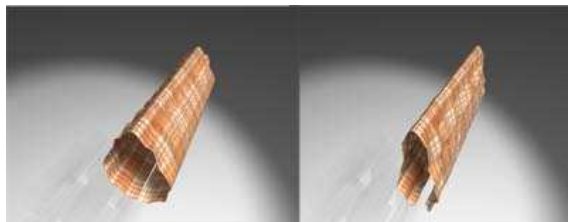


Figure 22. Results of a cylindrical cloth draping on its middle line

the large deformation problem using co-rotational formula. While non-continuum methods as mass-spring methods have a natural property to treat large deformations because they measure strains by the state of springs instead of the difference of current configuration and reference configuration in continuum mechanics.

The proposed meshless method for virtual cloth simulation has theoretical fundamentals with the thin shell theory and meshless solving, at the same time the experimental results proves that this method can produce natural cloth simulation.

5.3.3. *New buckling Model for Cloth Simulation*

Participants: Yujun Chen, Weiran Yuan, André Gagalowicz.

Buckling phenomenon exists broadly in the daily life for thin materials such as clothes and shells. Research on buckling is one of the most important and difficult topics in mechanics, fabric mechanics and garment simulation area.

Mechanics research points out that buckling is generated when an object cannot stand compressing forces and changes from an unbalanced status to the equilibrium one. As for cloth material, when a compression force is added to the object, at first cloth can stand the force and keep the same shape, but after a critical moment cloth comes to an unstable state creating a huge shape change. Cloth simulation would not look natural without buckling effects. However, the existing research in mechanics is focusing on the accurate mathematical solving for the buckling effect which cannot be directly applied to cloth simulation; at the same time, in cloth animation domain, most of the methods for buckling are based on geometrical hypotheses. For example, Choi presented a post buckling model based on the hypothesis of post-buckling shape in every spring of the cloth model. Philippe Decaudin [53] studied the procedure of the compression of a cylindric cloth and generated buckling effect using a diamond geometrical hypothesis. Both of the existing methods generate buckling effects from a predefined shape instead of from the dynamic rules of the cloth simulation system, which makes the simulation being far from reality. Therefore, it is critical to develop a physically-based buckling model combined with the cloth simulation procedure to generate fast and realistic buckling effect.

In our work, a model with a steady physical Koiter's imperfection sensitivity theory foundation is implemented which fits the cloth simulation. Simulation uses a mass spring method to model physically cloth by solving the equation of dynamics based upon Kawabata evaluation system parameters. The buckling disturbance is applied to the system when it is not under the equilibrium state. The disturbance distance is computed on the most compressed spring. The buckling effect is generated by dynamic simulation which makes it more realistic than the existing methods.

5.3.3.1. *Experimental Results*

This report proposes two typical experiments in the buckling research area to examine our method. One is the cylinder compression model which is difficult for buckling. It contains two sub-experiments one the with model one and without model one. Another experiment is the standard model for buckling: a planar cloth with in-plane compression force. The purpose of these two experiments is the following: firstly during the compression process global buckling will inevitably come out together with a complex collision phenomenon. Secondly, the procedure of cylinder compression is very similar to the sleeve movement in garments. Therefore if the cylinder buckling experiment can achieve good results, the application to the virtual human dressing system would also get realistic effects. Work on planar cloth with in-plane compression force is the standard way to verify buckling effects, since without buckling operation, cloth simulation system will come to a numerical unstable state during the in-plane force action.

In our experiment, a spring length is $0.005m$ and the number of the masses is 20×20 for the planar cloth and 20×40 for the cylinder model. The time step and parameters are inputted by a tcl interface file. In this case the time step is $0.001s$ in order to get stable results.

(1) Cylinder compression experiment: In this experiment the cylinder is modelled by a $10cm \times 20cm$ rectangle cloth. At the initial state, there is no external force on the cylinder, then a vertical force is applied to the cloth using a displacement constrain implementation. At each time step, we check if there are compressed tensile springs. If it is the case, we process the most compressed one by displacing it so that its new deformation

disappears and we iterate until all compressed springs disappeared. Then we move to the next time step by applying a new in-plane displacement to the cloth. Figure 23 shows the evolution of buckling. Figure 24 presents our results compared to the mechanics engineering result with accurate computing.

(2) In plane pressing cloth experiment: this experiment uses a $10\text{cm} \times 10\text{cm}$ cloth. This cloth is lying on a big plane model in order to counteract gravity. The initial state of the cloth is static, then one border of the cloth is pushed while the opposite border is fixed. We proceed as with the cylinder. Figure 25 is the comparison of our method with the famous approach of Ko and Choi¹ performing a pure geometric post-buckling control. Figure 26 is the result of the 3D body model in order to illustrate the validity to the 3D garment simulation.

In order to make the comparison of our buckling model, three compared models are adopted.

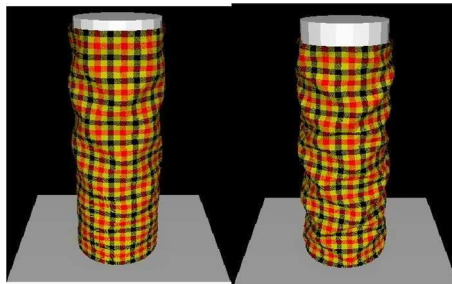


Figure 23. Cylinder cloth buckling -state1, state2

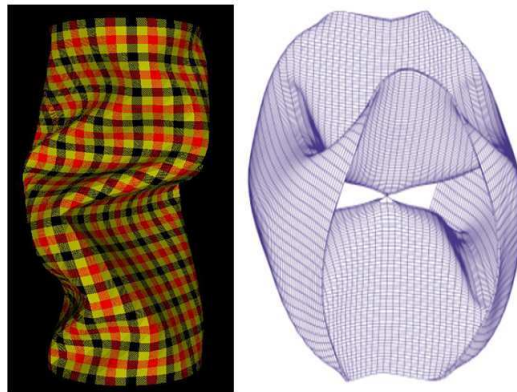


Figure 24. Comparison: result from the mechanic simulation of cylinder shell with a force applied in the middle of cloth

5.3.3.2. Conclusion

This paper presents a new cloth buckling simulation technique. The buckling constrain is applied by adding a disturbance to the system and the implicit method is used to solve the dynamical system. This method can

¹Choi-Ko02

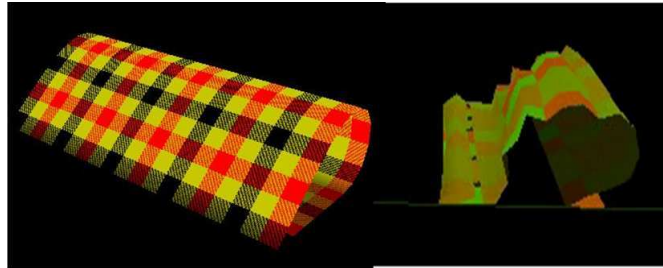


Figure 25. Comparison: buckling method with our approach (left) with the post buckling procedure from Ko and Choi² (right)



Figure 26. Buckling results on a virtual garment

easily be combined to the existing cloth simulation system and applied to the virtual dressing system. The experimental results prove the validity of this method and show that this method can generate more natural buckling effects.

5.3.4. Reconstruction of a human body from scanned data

Participants: Thibault Luginbühl, Andre Galalowicz.

In this work, we tackle the problem of reconstructing a complete model of a human body from scanned data. Most of the time data are noisy, contain holes in the parts that the beam of the scanner cannot reach and, in our case, some parts of the body are missing completely (feet) or partially.

Our data comes from a 3D scanner using structured light called SYMCAD and produced by a French company: Telmat. The technique developed here is designed specifically for this scanner. Telmat is our partner in SimulVET, an ANR funded project for virtual try-on applications. Different types of output are available from the scanner: the point clouds (one for the front view and one for the back view), segmented surfaces (one triangulated surface for each member in each view) and a segmented model where in each member the points are organized in slices, one slice per centimeter. Segmentation was computed on 2D images, using a matching procedure between 2D pixels and 3D points. The segmentation distinguishes 5 parts: left and right leg, left and right arm and torso. The sliced model is composed of 5 independent closed meshes, curves have been fitted to each segmented surface to link points from the two views and to form a single mesh of each member.

We developed a fitting technique on this segmented model. Our textile application needs a single regular mesh without holes to work correctly. So we built a generic model with the following properties:

1. It is a single mesh of the complete human body.
2. It has a regular topology for our application.
3. It is segmented (left and right feet, legs, hands and arms, torso and head), a specific color was manually assigned to every point of each member.
4. Arms, legs and torso are organized in slices like the data coming from the scanner.

5.3.4.1. Adjusting the number of slices

A first step is to establish a correspondence between the slices of the generic model and the slices of the data. According to the size and the proportions of a specific person we may need to add or remove some slices. Therefore two functions were created: *addSlice* and *removeSlice*. Both of them rely on a third one: *buildFacesBetweenSlices*. The principle to make a triangulation between two slices is to link each point on one of them to the closest ones on the other and then build the complete triangles.

Adding and removing slices is done so that the generic model remains smooth in the parts that are modified. The number of slices to add/remove is computed automatically using informations provided by the scanner such as the height, the position of the crotch etc. .

5.3.4.2. Fitting each slice

After the previous adjustments we have almost everywhere a 1 by 1 correspondence between the slices on the model and the slices of the data. The only slices that have still an important difference are the ones linking the shoulders to the torso, those slices will be treated differently from the following method.

For all the other slices we start by aligning the center of the curve of the generic model to the center of the curve of the data. Then, for each point of the slice of the generic model, we consider the ray starting from the center and going through the point. We move the point to the intersection of the ray and the curve on the data (see Figure 27).

However, this approach can't be used for the slices where the arms and the torso are involved. As the meshes are closed in the data, some points are inside the curve and that there are overlapping parts between the torso and the arms. Furthermore, the segmentation is not precise enough because a large part of the torso is in the arm member. This, added to the fact that such slices do not correspond to a cylindrical shape and therefore don't have a usable center for our approach, makes it clear that we need to find another way.

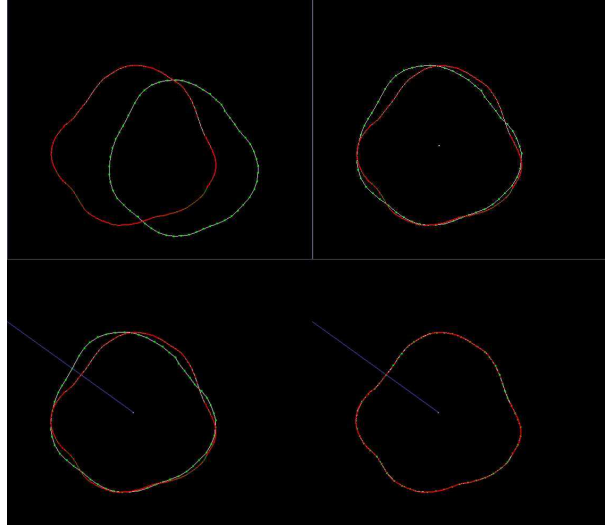


Figure 27. This picture shows the different steps of the fitting. The points of the data are in red and those of the model are in green. Top-left, the curves in their initial position, top-right the bounding boxes were fitted, bottom, we draw a ray starting from the center going through a point of the generic model, we move each point to its intersection with the data.

5.3.4.3. Fitting problematic slices using B-splines

In order to find a solution for the slices where arms and torso are joining, we propose the use of B-splines. Our idea is to fit a B-spline function to the 2D points, and use the parametric equation to move the points of the generic model.

First we need to fit a B-spline to the data points. Lower and upper envelopes of the slice are computed using the CGAL library. The two envelopes are linked to get a complete envelope of the slice with points organized counter-clockwise. Let m be the number of points of this envelope. We set the closest point to the axis $x = 0$ with highest y coordinate as the origin of the curve. For each point $A_i, 0 \leq i \leq m - 1$ on the envelope, we compute its chordal distance d_i defined by : $d_0 = 0$ and for $1 \leq i \leq m - 1, d_i = d_{i-1} + \|A_i - A_{i-1}\|$ (it is a first order approximation of the curvilinear abscissa). We define $d_m = d_{m-1} + \|A_{m-1} - A_0\|$ and we finally divide all the values by d_m to have a parametric representation in $[0, 1]$.

Then, we compute a least-square approximation B-spline function. We choose a degree d and a number of control points n . We build a periodic knot vector because we want to represent a closed curve. The curve will be defined by :

$$t_k = \frac{k - d}{n - d}, \quad 0 \leq k \leq n + d, \quad \text{and} \quad C(t) = \sum_{k=0}^{n-1} B_{k,d}(t)P_k$$

where $P_k, 0 \leq k \leq n - 1$ are the control points to be found and $B_{k,d}$ is the k -th basis B-spline function of degree d

Using all the points of the envelope, we get a linear system,

$$\begin{pmatrix} B_{0,d}(d_0) & B_{1,d}(d_0) & \dots & B_{n-1,d}(d_0) \\ \vdots & \vdots & \ddots & \vdots \\ B_{0,d}(d_{m-1}) & B_{1,d}(d_{m-1}) & \dots & B_{n-1,d}(d_{m-1}) \end{pmatrix} \begin{pmatrix} P_0 \\ \vdots \\ P_{n-1} \end{pmatrix} = \begin{pmatrix} A_0 \\ \vdots \\ A_{m-1} \end{pmatrix}$$

We use third degree B-splines. For this degree we found that choosing n between 30 and 40 is enough to get a good approximation of all curves of the human body in our examples. We are in the case where $m > n$, because the envelopes contain at least more than 100 points. So we choose the pseudo-inverse solution of the system.

With it we get the control points of the fitted B-spline. Now we have to move the points of the generic model. We consider the same kind of parametrization that we use for the envelope for the curve of the generic model (between 0 and 1 and with the origin at $x = 0$ with maximum z value). We build it the same way as explained. We evaluate the fitted B-spline to all parameters of the points of the generic model and move them to the found value.

5.3.4.4. Results and future work

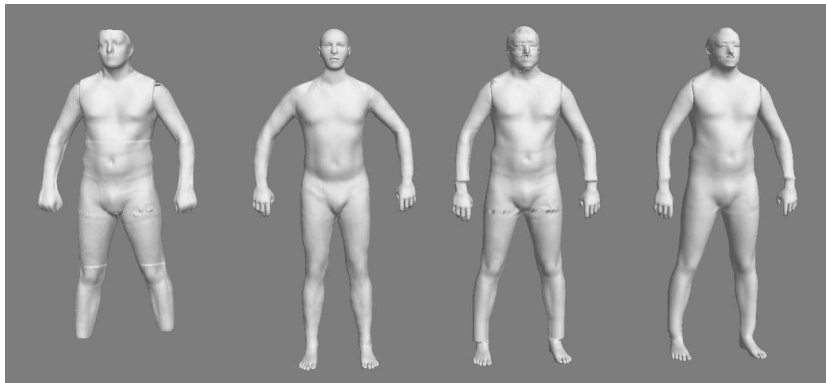


Figure 28. From left to right: data from the scanner, the generic model, model after fitting, model after Laplacian smoothing.

Once the slices are fitted, some parts of the generic model are translated in order to be aligned with the new positions (feet and hands). We took the hands of the generic model because data is too imprecise to make a correct fitting of this part. Figure 28 shows the results on a scanned person without using B-splines. Since the last curves of each limb in the data are often used to close the meshes, they contain some non reliable points as we see in the third model in Figure 28, at the link between the legs and the torso. To solve this problem we put all the points of these curves at the middle position between their upper and lower neighbors.

Figure 29 shows the result around the shoulders of the 3D model with the use of B-splines, the approach gives promising results, there is no more self intersection as with the previous method. However we still have to find a solution when there is an asymmetry (for example when an arm is higher than the other we may have curve where right arm and torso meet but not left arm and torso or vice versa).

The main problems we have to deal with now are the head and the links with parts taken from the generic model (links between legs and feet or arms and hands for example). Work is still in progress. For these parts, we will use more 3D information instead of 2D curves only, relations between a set of consecutive curves can be explored to improve regularity. Comparison with the original point cloud can also be used to refine the result after this step.



Figure 29. Difference between the case where we don't use B-splines to fit the curves (left) and the result when B-splines are used with $d = 3$ $n = 35$ (right).

Several filtering techniques have also been developed in our team by Zheng Wang. These techniques may be useful to treat difficult parts like the linking regions between parts fitted to the data and parts taken completely from the generic model.

Finally, after the full geometry is recovered, the next step is to get texture information from the pictures taken in the scanner. A first attempt has been done: for each point of the generic model we set its color to the color of the closest point of the data. Figure 30 shows that it's a good start, but we have to find a way to fill the texture in the parts where it is not available in the data.

5.4. 3D cities reconstruction

5.4.1. Presentation

5.4.1.1. Role and contributions

As it is a new activity, and this activity is important within the TERRA NUMERICA competitiveness network, we start by describing the organisation of our activity within this project.

The role of Mirage is twofold. In one hand, Mirages is responsible for the coordination and technical management of the overall work package. In the other hand, Mirages actively contributed to the research and developments handled in WP3.1.4-3.

The work package **WP3.1.4** covers the development of three complementary approaches:

WP3.1.4-1 Reconstruction from facades acquisitions : TRIMBLE

WP3.1.4-2 Reconstruction from aerial imagery : IGN

WP3.1.4-3 Reconstruction coupling terrestrial and aerial acquisitions relying on the definition, exploitation and enrichment of an architectural model : INRIA, THALES, ENSMP-CMM, ENST

These works share common interfaces and consider similar assumptions regarding architecture typologies/components characterized for the reconstruction process **WP3.1.4-0**. These developments are integrated and delivered to the consortium as modeling tools of the production platform. All results undergo a comparative analysis in the scope of **WP3.1.4-4**.

5.4.1.2. Coordination and technical direction

The coordination and technical direction started in January 2008. Achieved works cover:

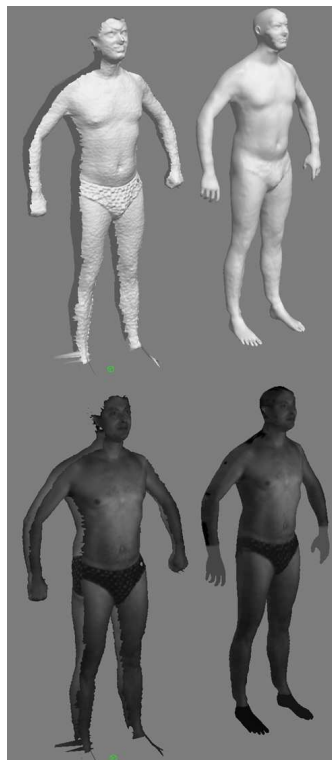


Figure 30. In the upper part we see the original data and the reconstructed data without texture, in the lower part the exact same model with texture.

5.4.1.2.1. The restructuring and organization of research and developments tackling this problematic:

formalizes the different deliverables and explicits the milestones associated to the different approaches developed in this work package. Through UML components diagram decomposition and planning breakdown, this document acts as a general specification and design regulating the development and integration of these different works.

5.4.1.2.2. The definition of work package interfaces:

explicits the structure, file format and metrics associated to the interfaces, this document draws concrete assumptions and constraints on considered input acquisitions and derived representations.

5.4.1.2.3. Inter-relation with all connected work packages:

because of its central position and objectives in the project architecture, a particular attention has been paid to control planning and technical interdependencies regarding data acquisitions, filtering and registration as well as guarantying the exploitation of delivered results to the production platform. We also contributed to the system architecture and demonstrator's scenarios definition.

5.4.1.2.4. Technical and financial reporting to project's coordinator and funders:

as work package coordinator, Mirage is in charge to synthesize and present achieved progress and to draw management's reports for the consortium. Technical workshops and periodic progress meeting have been established among the WP's partners.

5.4.2. Data importation and visualization under Sketchup

Research and technical developments were initiated in September 2007 by anticipation. Works achieved during the last period concern the characterization of Parisian architectural typologies. Starting with the prevalent haussmannian style, this study has enabled to draw the hierarchical decomposition, visual references, metrics and relationships of architecture components underlying the analysis and synthesis of this particular buildings class. It also concerns the collaborative development of a tool supporting the interactive reconstruction of buildings instances as architecture grammar rules: the particular contribution of Mirages to this development concerned first the importation and report of data acquisitions as a mean to support the modeling process.

5.4.2.1. Sub level

In order to realize the 3D buildings reconstruction for the TERRA NUMERICA project, it was necessary to define at first the data structure needed for this reconstruction. My main work, together with my colleague Roger Liu, was to allow data importation and visualization within SketchUp. SketchUp is the main development platform used in this project. Considering that SketchUp does not support native import of most data type involved in TERRA NUMERICA, we had to determine a C++ data structure which was then wrapped into Ruby language. As Ruby can be interpretable under SketchUp, data importation and visualization becomes possible.

5.4.2.2. Technical interface

To achieve the data importation and visualization under Sketchup, we had to define a technical interface necessary to manipulate 3D reconstruction input and output data. The considered data is: Geo-referenced : GeoTiff (2D), kml (3D) No-geo-referenced : Ply (3D), Shape (2D), Colada (3D)

My main work, together with Roger Liu, was to define and implements in C++ a technical interface that allows us to work with all this different data types.

5.4.2.3. Ruby wrapping

Ruby Native is an open source library that makes it easy to use your C++ classes inside Ruby. It does this by wrapping your C++ objects inside a ruby object. As SketchUp does not support native C++ code, this library allows us to use our technical interface (implemented in C++) inside SketchUp. On this part of the project, I was in charge of implementing the Ruby wrapping of all the C++ classes previously defined

These two tasks allowed importation and visualization of all the data involved in 3D building reconstruction.

5.4.2.3.1. The definition and encoding of an architecture grammar model under a dependency graph paradigm:

traditionally the evaluation of CGA grammar follows a rule-based production scheme leading to a sequential and static procedural derivation. We have proposed to encode architectural operators as nodes and to embed and drive their evaluation through a dependency graph in order to support an interactive and dynamic definition of a model architecture. Currently in development, we expect that this scheme will also enable to derive and enrich an architectural model through the analysis of dependency graphs characterizing different buildings instances.

5.4.2.3.2. The implementation of different facade subdivision schemes based on image analysis:

we have developed two approaches enabling to extract and to encode facade structures in a hierarchical way. Both inferred design are encoded as grammar rules. The first method make use of the Gradient-based Mutual Information and significantly improves the registration quality regarding conventional measures. The second technique is based on analysis of edge and colorimetric histogram derived from a rectified facade image. In both cases, similarity and features detection follows a rough-fine template-based scheme which reduces computation time while increasing the robustness of the whole process. Extracted grammar rules draw a compact and semantically meaningful characterization of the building structure that can be considered to support the design of other instances of the same typology.

5.4.3. *3D Facade Structure Parameterizations Based on Similarity Detection from a Single Image*

Cities are of multi-dimensions, and high functional and visual complexity. They are the concentration of history, culture, economy, and ecology, etc. Modeling and visualizing 3D city using computers covers various disciplines and is a real challenge to all the researchers in different research domains. The potential applications for creating 3D cities range from research and educational purposes like urban planning and global navigation to entertainment like tourism and 3D computer games.

Up to now, there is much work in procedural architectural modeling, and Pascal Muller, et al. did a lot of work in this domain. Currently, we are firstly trying to implement the algorithms proposed by Muller in the SIGGRAPH07 paper "Image-based procedural modeling of facades". In this paper, a 3D façade model with high visual quality and the related shape grammar rules are derived from single rectified façade image. The basic philosophy of Muller's work is to mimic the procedural modeling pipeline from computer graphics to subdivide a facade texture in a top-down image analysis manner into meaningful elements such as floor, tiles, windows, and doors based on architectural knowledge. The authors introduce mutual information to extract the irreducible facade which consists of all the basic elements existing in the original facade image. From the hierarchical subdivision of the facade image, a set of shape grammar rules, which can be somehow modified to generate different facades from the original one, could be automatically derived.

As one of the main man-made objects in cities, buildings on the one hand differ from one another in many aspects like motif, style, dimensions, etc., and on the other hand resemble each other in the symmetric and regular shapes(parallelism and orthogonality), the repetition hierarchical structures. A typical example is windows, many of which are usually identical and parameterizable shapes. They are commonly organized in logical hierarchies in a facade. So, all identical windows can then be represented by a single window symbol instead of a variable number of symbols, and the whole complex facade can be described with a few parametric symbols in a logical hierarchical way. Buildings can be decomposed into roof and facades, and facades into floors composed of tiles (walls, windows and doors) and ornaments. Our work will mainly focus on 3D facade modeling based on similarity detection from a single image.

5.4.3.1. *Facade Structure Parameterizations based on Similarity Detection*

As mentioned above, at different scales, facade components refines in repetitive structures such as windows and doors within a tile; therefore, in order to simplify the description of facade structure, we consider template as a mean to model construction elements sharing similar shape and dimension. In order to characterize these templates, we adopt a similarity measure — Gradient-weighted Mutual Information to detect the repetitive structures hidden in a facade image. Our method will work in four steps: 1) repetitive structure detection;

2) element parameterization; 3) rule extraction; 4) optimization of facade subdivision. The input is a single rectified image from ground-based imagery, and the output is a reconstructed 2D facade image and a set of shape grammar rules which can be reusable to thereby create a large variety of facades.

5.4.3.2. Similarity Measure — Gradient-Weighted Mutual Information

Mutual Information(MI) is an accurate measure for rigid and affine mono- and multi-modality image registration. This measure is defined by the joint distribution $P(I, J)$ of two random variables I and J and their marginal distributions $P(I)$, $P(J)$ (See Equation 1).

$$MI(I, J) = \sum_{I, J} P(I, J) \log_2 \frac{P(I, J)}{P(I)P(J)} \quad (1)$$

Unlike measures based on correlation of grey values or differences of grey values, MI does not assume a linear relationship between the grey values in the images. However, this measure lacks spatial information, which may lead to local maxima in some cases, for example, when the images are of low resolution, when the images contain little information, or when there is only a small region of overlap. GMI extends MI measures to spatial information in images by multiplying the MI with the spatial similarity measure. For pair of corresponding pixels i, j in two images I_i and I_j , we have the formula (Equation 2) to define the similarity between their spatial information:

$$f(i, j) = \frac{2(\Delta_i \cdot \Delta_j)(\|\Delta_i \times \Delta_j\|)}{(\|\Delta_i\| \|\Delta_j\|)^2} \quad (2)$$

Here, Δ_i and Δ_j are the gradients at pixels i and j , $\Delta_i \cdot \Delta_j$ is their scalar production, $\Delta_i \times \Delta_j$ the vector production, and $\|\Delta_i\|$ the module of Δ_i . Note that the value of $f(i, j)$ varies in the range $[0, 1]$ with the direction similarity of the two gradients Δ_i and Δ_j , and if they are of similar direction, $f(i, j)$ approaches to 1. GMI thus takes function 2 into conventional MI as a measure of spatial strength of an image in a given direction. Based on Equation 1 and 2, GMI can be expressed as following:

$$GMI(I, J) = MI(I, J)f(I, J) \quad (3)$$

5.4.3.3. Rough-Fine Template-Based Similarity Detection

Pure GMI-based similarity detection is quite time-consuming. In order to build a template library and meanwhile to speed up our method, we adopt edge profile (see Figure 31) and rough-fine template-based scheme under the right-handed coordinate system originating from the left-bottom of the facade with x axis parallel to and y axis perpendicular to the ground baseline of the facade. Here, a template is such a geometric and semantic model that represents a class of architectural structures with same or similar geometric shape and same architectural function.

Considering that the ground floors of commercial buildings always lack similarity with the other floors due to wall covering and vitrified decoration, we first tackle vertical similarity detection by analyzing the similarity among different facade floors. Depicting the vertical similarity detection as illustration, we use vertical edge profile (in y axis direction) to get N initial estimates of horizontal slitting lines $y(x)$ at the mid-positions y_i of two adjacent valleys in the vertical edge profile, i.e. $y(x) = y_i$ (see Figure 31). If there is no valley locating at the top and/or bottom margin(s) of the image, we add the top and/or bottom margin(s) as the first and/or last slitting line(s), which means that y_0 is always equal to 0 and y_N always the total height of the whole facade.

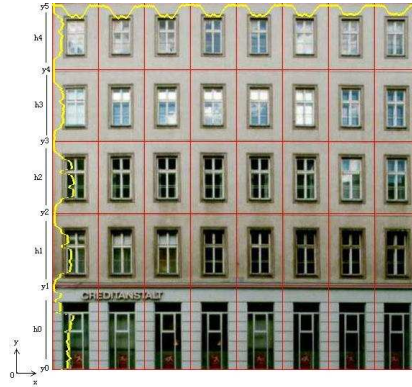


Figure 31. Left: Edge profile in yellow and splitting lines in red.

According to the assumptions about the considered architectural typologies, the floor height h is variable in an interval $[2.5\text{m}, 5.5\text{m}]$, so the facade can be decomposed into a set of floors with heights $h_i \in [2.5\text{m}, 5.5\text{m}]$. Each floor is given an ID, i.e. an integer i starting from 0. In another words, 0 corresponds to the ground floor, i the i -th floor. In order to generalize our method and meanwhile simplify our grammar rules, we now run a pick-out process — Rough-Fine Template-based Similarity Detection to build a floor template library without repetitive floor structures inside. Each template candidate is named with the combination of the template function type and an ID number. For example, $floor_i$ represents a floor template with ID number i . Each template is parameterized with its ID i , width w_i , and height h_i , in the form of $floor(i, w_i, h_i)$. Initially, regard all the floor structures as floor template candidates.

We exhaust all possible similar template candidates in the vertical direction. Now, similarity detection is performed in the horizontal direction separately on the floor templates derived from the vertical analysis. This stage successfully achieves the characterization of the basic architectural elements structuring the facade (See Figure 32 Middle). Through this process of similarity detection, a parametric floor and tile template library is generated, and each individual facade region(tile and floor. See Figure 32 Right) is parameterized with its position, i.e., the coordinate of its top-left corner (x_{ij}, y_{ij}) in the facade, and related template ID. In the next step, we will detail the tile(window, door) structure.

Our method is intuitive and meanwhile effective for reconstructing rectangle-shaped windows and doors. But, in fact, there are a lot of buildings with other different and complicated window and door structures other than rectangle, therefore in the cases when the geometric shapes of windows and doors are complex, the extracted outer rectangle is just the outline of the whole shape. We need further to perform edge detection in the region to get the inner structures. Here, Canny detector is employed to approach the accurate shape structure.

5.4.3.4. Architectural Element Analysis

Up to now, we have already subdivided facade structure into floors and further tiles, and obtained floor and tile template library in Section 5.4.3.3 on page 5.4.3.3. At this stage, we will get the interior structures of the tiles. We first obtain the edge profile projection of the tile template (Figure 33 Left). Based on this profile and the window/door frame width, we could detail the tile template structure (Figure 33 Right). Since we have already parameterized each individual tile with its template ID, we can match the tile with its template. Considering the influence of image noise and image distortion, we utilize the local(tile) and global(floor in horizontal direction and parcel in vertical direction) edge profile projection to slightly tune the positions of the mapped structures.

5.4.3.5. Rules Extraction

Since the previous procedures are hierarchical and semantic, which share the same features with shape grammar rules, it is easy to extract the shape-grammar rules through these analyses. As mentioned above,



Figure 32. Left: Original image with global edge profile in yellow. Middle: Tile templates. Right: Subdivision based on edge profile and GMI (splitting lines in red).



Figure 33. Left: Tile edge profile in yellow. Right: Extracted window structure in blue.

grammar rules is very flexible and could help our method realize its potential in various applications. Therefore, our system draws a complete rule set that describes the segmented facade from the subdivision process. The extracted rule set can be applied to different dimensional facades with different styles, or as an initial state for reconstructed facade optimization.



```
#grammar rules of facade (from top to bottom):
#number of floors: 5
#number of floor types: 3
1: facade=Subdiv(Y, 1, 3, 1){floor0|floor1|floor2}
2: floor0=floor(0, 512, 94)Repeat(XS, 64){'tile0.obj'}
3: floor1=floor(0, 512, 100)Repeat(XS, 64){'tile1.obj'}
4: floor2=floor(0, 512, 118)Repeat(XS, 64){'tile2.obj'}
```

Figure 34. Left: Original image (512*512). Right: An example of our rule file extracted from the test image on the left.

Figure 34 (Right) shows an example of the grammar rules extracted from Figure 34 (Left). As shown in the example rule file, comments lines begin with the symbol #, and four rules with a rule ID number 1, 2, 3, 4 at the beginning are inferred from the test image. The first rule is the *Subdiv* operation, which means along y axis, the facade in the test image is divided into 1 floor0 (one kind of floor structure) with floor height 94-pixel, 3 floor1 with floor height 100-pixel and 1 floor3 with floor height 118-pixel. Here, | is used to separate symbol between different architectural patterns/structures, and all the values are defined under the xoy right-hand coordinate system originated from the left-bottom of the test image. The left 3 rules are the *Repeat* operations. For example, Rule2 tells us that floor0 is composed of tile0 which is of 64-pixel width and is repeated 8 times in x direction. The symbol between ' and ' represents a terminal shape stored in shape library. One rule is ended by a terminal symbol even though the object indicated by this symbol can be further decomposed into other components. In such a way, we can control the level of detail of the reconstructed structure. In order to describe similar while not symmetry structures, we exploit *Translation* operator $\mathbf{T}(\mathbf{dx}, \mathbf{dy}, \mathbf{dz})$ in front of a structure, for example $\mathbf{T}(\mathbf{dx}, \mathbf{dy}, \mathbf{dz})\{\text{tile0.obj}\}$, to translate this structure from the current position (x_0, y_0, z_0) to the desired position (x_0+dx, y_0+dy, z_0+dz) . Considering generalization and extension of our method, we provide *Insert* operator $\mathbf{I}(\text{objectname})$ to insert particular object represented by the parameter *objectname* somewhere, *Scale* operator $\mathbf{S}(\mathbf{a}, \mathbf{b}, \mathbf{c})$ to scale an object with factors a , b and c separately in x , y and z direction, and *Rotate* operator $\mathbf{R}(x, y, z, \theta)$ to rotate an object with angle θ around the axis OP , $P(x, y, z)$. For now, we didn't introduce the depth information into the rules, i.e., all the z values are equal to 0, which can be done later after our subdivision results are optimized.

5.4.3.6. Optimization of the Facade Subdivision

From the extracted rules and without the support of a depth information, we can derive a 2D reconstruction of the facade image. Due to distortions in the original image and errors produced during facade subdivision, the reconstructed 2D image differs from the original image to some degree. In order to optimize the subdivision results, we project the reconstructed 2D image I_r back to the original one I_o , and get a difference image $I_\Delta = I_o - I_r$. This difference image is considered to locally adjust the rule parameters, namely, the vertical and horizontal offset of the splitting lines and the center positions of the terminal shapes (windows, doors, etc..). This optimization loop breaks when all the position errors are under 2 pixels.

5.4.3.7. Experimental Results

We implemented our system in C++ using a PC with Intel(R) Core(TM) dual-CPU, T7200, 2GHZ, and different facade images from buildings at Paris were chosen to test our method. The average running time of the whole system for a 512*512 image is about 1 minute.

For comparison with the conventional MI-based method, Figure 35 shows an original image (Left, 396*480) with tree in front of the building, and the subdivision results by using our method (Middle) and the conventional MI-based method (Right). The results in Figure 35 demonstrate that our method is insensitive to image noise, and more robust and accurate than the conventional MI-based method. Figure 36 shows an original image (Left) with the resolution of 512*512, the reconstructed result before optimization (Middle) and the reconstructed result after optimization (Right). Obviously, after the optimization process, the windows are more accurately located.

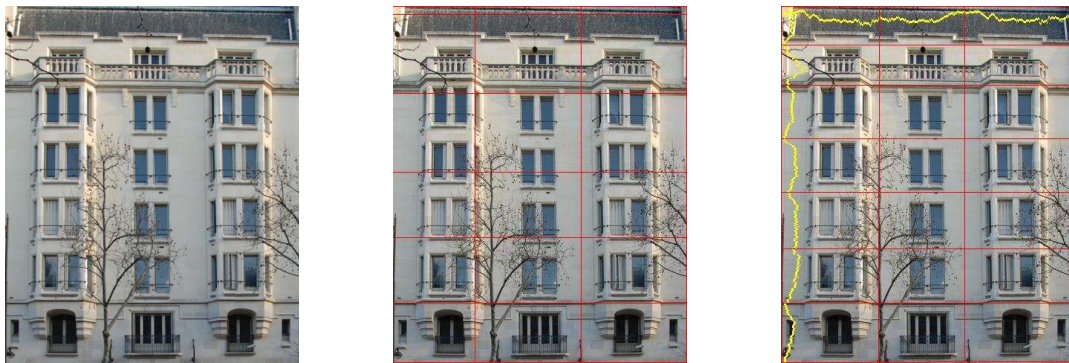


Figure 35. Left: Original image with strong noise. Middle: Subdivision result using conventional MI-based method [66]. Right: Subdivision result using our method.

5.4.3.8. Conclusions

Our method is a variant of [66] targeting facade reconstruction based on a single rectified image. Sharing a similar strategy, we introduce a rough-fine template-based similarity detection scheme making use of Gradient-weighted Mutual Information to increase the robustness and accuracy of the reconstruction process and to extend its applicability considering less regular architecture style and degraded image assumption. This proposal also contributes to improve the efficiency and to speed up the whole system. By providing a feedback of the reconstructed 2D image to the original one, we close the loop between the facade subdivision analysis and the representation issued from the rule sets parametrization. This optimization process can improve the reconstruction accuracy and meanwhile lessen the risk of misregistration.

This image-based subdivision technique results in sets of grammar rules which form plausible estimates and variability constraints to consider the facade reconstruction under a model-based paradigm. Future works will also introduce depth information and consider coupled 2D-3D registration to automate the 3D facade reconstruction.

These results also illustrate the interest of an analysis by synthesis loop to refine the facade subdivision paving the way to the forthcoming model-based optimization.

5.4.4. 3D modeling of Parisian Buildings

Two main topics in this project are facade recognition and procedural building model reconstruction, to be short, building analysis and synthesis. A good start of facade recognition is Pascal Müller's SIGGRAPH07 paper of "Image-based Procedural Modeling of Facades", where the facades with high degrees of symmetry in post modern style, are analyzed and modeled. In the context of Parisian facades, mostly Haussmannian



Figure 36. Left: Original image. Middle: Reconstructed 2D facade image before optimization. Right: Reconstructed 2D facade image after optimization.

Facades, however, we do not have this tiling symmetry, but a rigid typology. By utilizing the different image profiles including hue and edge profiles, it is possible to split the facade into floors and tiles in a semantic way and deduce a set of architectural rules of facade typology description for facade reconstruction. The second topic deals with building reconstruction. In this topic, procedural modeling techniques have been proved to be more efficient comparing to manual creation of 3D building contents. Necessarily, the concepts and principles of this technique, known as Computer Graphics Architecture Grammar, have been studied extensively. According to that, a simplified 2D version has been implemented and the fully functional 3D version implementation is undergoing. Then, based on a set of grammar rules, a building facades could be reconstructed quickly and efficiently. Moreover, by re-examining the edge difference between the original and the reconstructed images, the grammar description could be modified to better match the original one. In this way, we are introducing a feedback loop of facade analysis and synthesis.



Figure 37. Reconstructed Parisian Urban Environment

On top of that, in the framework of TERRA NUMERICA collaboration, MIRAGES is responsible for data importation and exportation as planned. Thus a software package is delivered to all partners, hosting various

type of data in 2D and 3D, in an integrated platform of SketchUp and Maya. And the package is in the form of C++ SDK and bounded to Ruby and Python scripting languages.

Above all, many progress have been made in the project towards image-based and model-based 3D building reconstruction. Current analysis and methods could help establish a good base to achieve the final goal, reconstructing Parisian urban environment, efficiently and gracefully.

5.4.4.1. Data Importation and Manipulation

As there are many data from many sources and in various formats, it is required that a common platform should be developed for all partners. Considering that, SketchUp is chosen as the main platform and C++ is the principle language to be used among all developers. Besides, Maya and other 3D modelers are also considered. In order to be more flexible and practical, the data package is planned to be wrapped in Ruby and Python scripting languages.

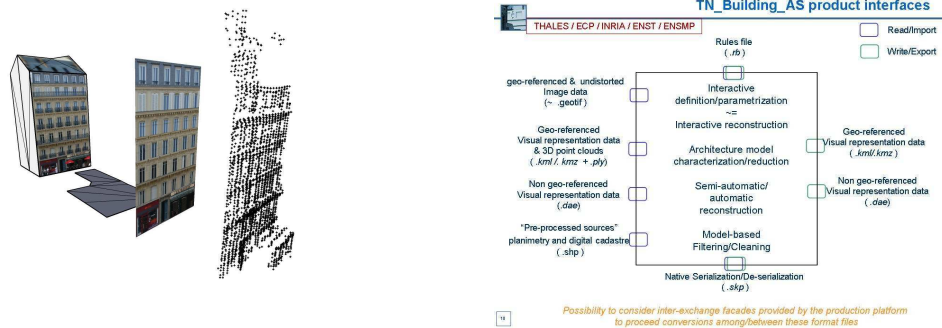


Figure 38. Data Importation and Exportation Package

Within this platform, almost all kinds of data could be imported and manipulated in a seamless and integrated way. Various data classes for 1D signal, 2D images and 3D polygons are implemented in the data package to incorporate different data. In the one dimensional domain, several frequent filtering and indexing operations are integrated. For two dimensional data as images, common image processing algorithms and image operations are implemented. Also three dimensional data in various formats, including Google KML/KMZ, COLLADA, wavefront OBJ, Autodesk 3DS, and Stanford PLY, could be imported into one unique central format for segmentation, profiling and many other tasks.

5.4.4.2. Haussmannian Facades Characterization

Paris owns a vast of building styles and maintains a charming harmony in terms of urban perspective, rhythm and coherence. Almost all styles could be found in Paris, including Roman-ism, Renaissance, Baroque, Neo Classic, Art Nouveau, Eclectic and Haussmannian, Art Deco, Modern, Post Modern and many many more. However, two buildings in different styles may share the same typology and it is the typology that prevails as we investigated. In this regard, we would attach the facade typologies to the characterization of parts buildings rather than styles. More precisely, the Haussmannian facade typology is of interest as it is of the most common in Paris.

On one hand, it could be seen that less colorimetric variations appear in a typical Haussamannian facade. Colors limited to beige, gray, blue, white and red could form into a minimal palette for various architectural elements like roofs, joineries, dimension stones, window glasses, window blinders, etc. Hence, by properly utilizing color information, a facade image could be divided into several functional and semantic layers, which is quite interesting for facade image analysis.

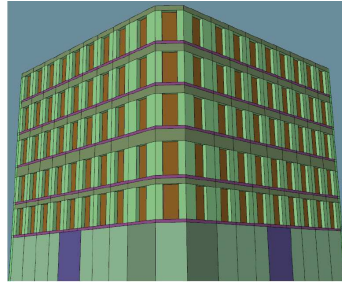


Figure 39. Haussmannian Facade Typology

On the other hand, according to building regulations and conventions, the building dimensions are somehow fixed in a common manner. Typically building height and roof pitch are fixed according to the street width. Also other dimensions could be consistently repeated as floor height, window aperture width, room span and etc. Particularly, a typical Haussmannian Facade consists of 5 or 6 floors including the ground floor, usually used for shops, and attics in the mansard roof, and residence floors. The floor height may keep the same or decreases with a certain amount successively. Without any doubt, this architectural consistency could also offer floor separation information for analyzing the facade elements.

In brief, based on our colorimetric and dimension analysis, we may obtain several architectural knowledge and deduce a procedure to analyze or synthesize the facade or even the building model in 3D.

5.4.4.3. Haussmannian Building Facade Image Analysis and Synthesis

Our facade image analysis starts from Pascal MTeller's SIGGRAPH 2007 paper about facade analysis for post modern buildings with a strong repetition of window tiles in a tiling manner. In that paper, the correlation information called mutual information is computed to get the basic repetition tissue (window tile) and repetition recipe horizontally and vertically.

As we move to Haussmannian building, such symmetries partially exists or does not exist at all. In consequence, we have to concentrate on edge information and several profile information including hue profile. As there are few color patterns and variations in the Haussmannian buildings, we could use hue information to achieve the horizontal and vertical separations. Afterwards those separation lines could be verified in the edge image. By doing that globally we could split the facade image into floors and then to window tiles. Then local refinement could help defining the edges for window frames, lintels, transoms and etc. In this way, we could segment the facade image and deduce a description of the facade hierarchically.

After the analysis, we have information of the facade hierarchy, size, location and texture of each architectural elements identified. Next, by reversing the order of analysis and composing architectural elements in 2D or 3D, the facade could be synthesized. In general, we have extracted the building facade structures and architectural grammars in terms of semantics (architectural elements) and syntax (composition rhythm).

5.4.4.4. Computer Graphics Architecture Grammar Modeling

Besides the facade analysis and synthesis, our another objective is to construct the building model in 3D, considering the real 3D scan data. Notably, Computer Graphics Architecture Grammar, known as CGA grammar is widely used in building modeling in a procedural and efficient way. We have made some studies in this grammar and tried to make some improvements on that. A similar grammar software package is under development and also we are investigating the possibility of exploring more information from the 3D scans like window depth and ornament projection depth.

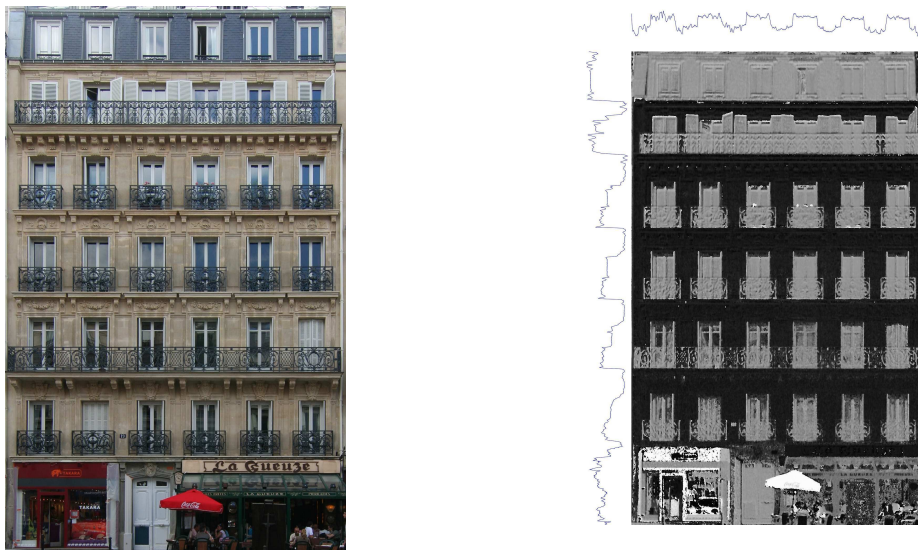


Figure 40. Haussmannian Facade Hue Profile Analysis

5.4.4.5. Conclusion

In conclusion, regarding to our goal of Parisian urban environment Reconstruction, several achievements have been made, including a detailed facade characterization analysis, a data package hosting all types of data, and then facade image analysis and synthesis towards fully 3D reconstruction. We are now looking forward to image based and model based 3D building model reconstruction.

5.5. Non Verbal expression modeling and control

Catherine Pelachaud and her students were in delegation in the Mirages project from January to October 2008. During this period, they helped us understand and develop a part of their expertise on the modeling of non verbal expressions that we are interested to use in both face and human body tracking when they were in delegation in the MIRAGES team they pursued two lines of research: the development of a real-time system for an Embodied Conversational Agent and the model of feedback behaviors. Catherine also worked on the writing of several project proposals. She have participated to these proposals as INRIA. But since she joined CNRS in October 2008, she had the authorization to transfer the accepted projects to her new laboratory.

5.5.1. Greta, a real-time ECA system

We have transformed our agent system, Greta, into a SAIBA-compliant system working in real-time. SAIBA [72] is an international research initiative whose main aim is to define a standard framework for the generation of virtual agent behaviour. It defines a number of levels of abstraction (see Figure 41), from the computation of the agent's communicative intention, to behaviour planning and realization.

The **Intent Planning** module decides the agent's current goals, emotional state and beliefs, and encodes them into the Function Markup Language (FML) [50]. To convey the agent's communicative intentions, the **Behavior Planning** module schedules a number of communicative signals (e.g., speech, facial expressions, gestures) which are encoded with the Behavior Markup Language (BML). It specifies the verbal and nonverbal behaviours of ECAs [72]. Finally the task of the third element of the SAIBA framework, **Behavior Realization**, is to realize the behaviours scheduled by the Behavior Planning. It receives input in the BML format and it generates the animation.

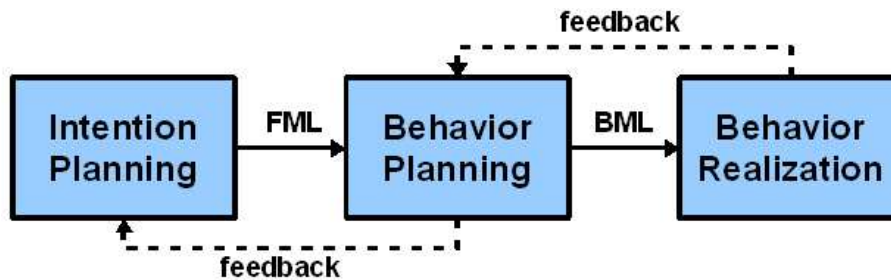


Figure 41. Saiba framework [72]

While BML is in a pretty final specification stage, FML is still at its early age. We have developed our own version, FML-APML. It is an XML-based markup language for representing the agent's communicative intention and the text to be uttered by the agent. The communicative intentions of the agent correspond to what the agent aims to communicate to the user: its emotional states, beliefs and goals. It originates from the APML language [51] which uses Isabella Poggi's theory of communicative acts.

Figure 42 illustrates the architecture of our agent. The Behavior Planner receives as input the agent's communicative intention encoded in FML-APML and generates as output a set of BML signals. These signals are sent to the Behavior Realizer that generates the agent animation following the MPEG-4 standard. Finally, the animation is played by the Player. Our architecture has also a Listener Intention Planner, that belongs to the SAIBA Intention Planner module. Such a planner is able to generate in real-time the agent behaviour while in the role of the listener.

All modules in the architecture are synchronized by a Central Clock and communicate with each other through a whiteboard. For this purpose we use the Psyclone messaging system [71] which allows modules and applications to interact together, even if they are running on separate machines connected through TCP/IP. The system has a very low latency time and is suitable for real-time applications.

5.5.2. Listener Model

The Listener Intent Planner module is in charge of the computation of the agent's behaviors while being a listener when conversing with a user. This component encompasses three modules called reactive backchannel, cognitive backchannel, and mimicry. Research has shown that there is a strong correlation between backchannel signals and the verbal and nonverbal behaviors performed by the speaker [75], [62]. Models have been elaborated that predict when a backchannel signal can be triggered based on a statistical analysis of the speaker's behaviors [75], [62], [64]. We use a similar approach and have fixed some probabilistic rules to prompt a backchannel signal when our system recognizes certain speaker's behaviors; for example, a head nod or a variation in the pitch of the user's voice will trigger a backchannel with a certain probability. Probabilities are set based on studies from the literature [75], [62]. The reactive backchannel module takes care of this predictive model. On the other hand, the cognitive backchannel module computes when and which backchannel should be displayed using information about the agent's beliefs toward the speaker's speech. We use Heylen's taxonomy of communicative functions of backchannels [57]: accept/refuse, agree/disagree, believe/disbelieve, understand/don't understand, etc. From a previous study [57] we have elaborated a lexicon of backchannels based on perceptive studies. The cognitive module selects which signals to display from the lexicon depending on the agent's reaction towards the speaker's speech. The third module is the mimicry module. When fully engaged in an interaction, mimicry of behaviors between interactants may happen [59]. This module determines when and which signals would mimic the agent. So far we are considering solely speaker's head movement in

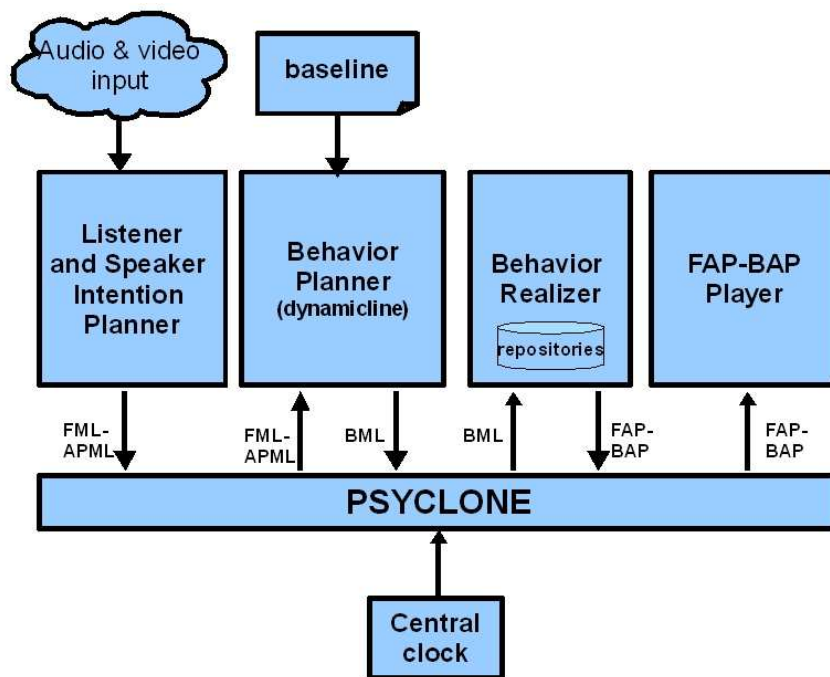


Figure 42. Architecture of the system

the signals to mimic. A selection algorithm determines which backchannels to display among all the potential signals that are outputted by three modules.

5.5.3. Projects elaboration

5.5.3.1. European project

I participated to the writing of several EU project proposals. One project has been accepted. Social Signal Processing Network, SSPNet, is a network of excellence running for 5 years starting February 2009. The goal of the SSPNet is to establish a virtual distributed institute for research on Social Signal Processing (SSP), i.e. on conceptual modelling, detection, interpretation, and synthesis of social signals. This project has been transferred to CNRS.

5.5.3.2. National projects

Two proposals have been retained. The project Geste et Voix pour une Lecture Expressive, GV-LEx, aims to endow a humanoid robot with reading capacity. The robot should be able to read in a pleasant and expressive manner. Its voice and gestures should not be monotonous and repetitive. They should be expressive. The project Complex Emotions in Communication, Interaction, and Language, CECIL, takes place within the domain of affective computing. the project CECIL will define (and disambiguate the definition of) some set of emotions, and incorporate them into the reasoning processes of an embodied conversational agent (ECA). It will endow the agent with the capabilities to express its emotions by means of different modalities including facial expressions, gestures, and language. Both of these projects have been transferred to CNRS.

6. Contracts and Grants with Industry

6.1. AXIATEC

Participants: Daria Kalinkina, André Gagalowicz.

This contract deals with the "cheap" realistic 3D modeling of human faces from a small set of images (even from only one picture) whatever the position of the face on the images. This research is conducted with the collaboration of AXIATEC, a small company interested in customization products. This research is an extension of the former work done within the framework of the VIP3D project. We still have to implement the case of one image, add eyes, teeth, tongue and hair to the faces reconstructed before. Realism of the model is not sufficient to recognize the human person for the moment, so we are going to investigate more refined interaction tools to reach realism.

6.2. TERRA NUMERICA

Since the beginning of 2007, Mirages is a member of a new competitiveness network funded by the French Government. The coordinator of this project is Thalès. The aim of this network is to produce a full 3D version of a tool similar to Google-Earth. Mirages is the coordinator of the most important workpackage of this network. Its role is to use an analysis/synthesis approach in order to produce a compact 3D representation of a part of Ile De France from building and vegetation models and from geo-referenced raw input data (images and 3D scans) obtained from other partners of the consortium.

6.3. Simulvet

Participants: Tung Le Thanh, Yujune Chen, Weiran Yuan, Thibault Luginbuhl, André Gagalowicz.

MIRAGES recently got an important funding from the ANR (French Research Funding Agency) through the RNTL programme. The aim of this project is to design, a first prototype of a virtual try-on system which will allow any person to buy garments through Internet. The client will have the possibility to choose the type and style of garment and the kind of the textile material and to see himself/herself in 3D wearing the chosen garment. This raises very difficult and fascinating scientific problems that we will have to solve. This project is coordinated by Telmat (a company building 3D scanners for human persons), La Redoute (the biggest garment distributor in France) will bring its expertise in the contacts and interfaces with the clients, Nadine Corrado will serve as the expert on garment design. Nadine Corrado is a Fashion Creator; we collaborate on the validation of our 3D simulation of garments software. She is a potential end-user and also brought us a lot of information about garment conception. We are presently testing the 2D pre-positioning software which has to be connected with her design software. LMPT (university laboratory specialized in the mechanics of textile) will furnish physical data for the garment simulator developed by MIRAGES.

7. Other Grants and Activities

7.1. International Collaborations

- Collaboration with XID Technologies, a company located in Singapore. André Gagalowicz is a scientific advisor for the company.
- Collaboration with NTU (Nanyang Technological University) in Singapore has been initiated. A PHD student Quah Chee Kwang is supervised by both A. Gagalowicz from MIRAGES and Seah Hock Soon from NTU. this collaboration expands after the signature of a collaboration framework between the French Ministry of Foreign affairs and Singapore (Merlion contract).

8. Dissemination

8.1. Animation of the Scientific Community

- André Gagalowicz was a scientific advisor at the INSA Lyon Scientific Committee.
- André Gagalowicz was a member of the scientific advisory board of "Machine, Graphics and Vision" journal
- André Gagalowicz was a member of the scientific advisory board of "Computer Graphics and Geometry" journal,
- André Gagalowicz was a member of the scientific advisory board of the LCPC journal.
- André Gagalowicz was a scientific advisor of XID Technologies, Singapore.

8.2. Teaching

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

8.3. Conference Program Committees and Revue in Computer Vision and/or Computer Graphics

André Gagalowicz is the chairman of MIRAGE 2009 international conference specialized in computer vision/computer graphics collaboration techniques.

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

- Edutainment 2008, Nanjing, China.
- GraphiCon 2008 Conference, Moscow, Russia.
- ICCVG 2008, Warsaw, Poland.
- IVCNZ 2008, Christchurch, New-Zeland.

8.4. Participation to seminars, conferences and invitations

Catherine Pelachaud has been teaching Emotional Machines, HCSNet, 6h, Sydney December 2008.

André Gagalowicz was invited by NTU in Singapore from October 26 to November 5 in the framework of the MERLION collaboration between France and Singapore.

André Gagalowicz has presented an invited talk or paper at:

- Journées AUM/AFM 2008, “Contrôle du comportement mécanique de tissus tissés pour la simulation de vêtements”, Mulhouse, 27-29 August.
- Edutainment 2008, “Towards a Virtual Try-on Technology”, Nanjing, China, 24-26 June.
- Microsoft Asia, “Collaboration between computer vision/computer graphics and applications”, Beijing, China, 23 June.
- ICCVG 2008, “3-D representation of large cities”, 10-12 November.
- André Gagalowicz was invited by Prof. Anderson, Provost of NTU to join an international delegation to propose research orientation of the new IMI Institute started at NTU, Singapore, 29/04-02/05.
- Participated to ICCV 2008, Marseille, France, 13-17 October.

Catherine Pelachaud has presented an invited talk or paper at:

- HCSNet workshop on Embodied Interaction, Sydney, December 2008.
- MLMI, Machine Learning and Multimodal Interfaces, Utrecht, September 2008.
- Journée Nationale Culture Numérique : un domaine encore en émergence, Cherbourg, July 2008.
- Game Developer Conference, GDC’08, La Defense, June, 2008.
- CogSci’08, Moscou, Juin 2008.
- Conférence jointe JEP/TALN 2008, **Journées d’Etude sur la Parole / Traitement Automatique de la Langue Naturelle**, Avignon, Juin 2008.

Catherine Pelachaud has participated to invited seminars at:

- Journée “Interactions Personnes / Systèmes Robotiques”, GDR Rob, GT5, Université Paris6, July 2008.
- University of Luxembourg, Campus Kirchberg, invitée par Patrice Caire, January 2008
- Université de Cergy Pontoise, invitée par Philippe Gaussier, February 2008
- Université de Toulouse II, invitée par Michèle Guidetti, March 2008
- Université de Paris VI, Laboratoire ISIR, invitée par Mohamed Chetouani, November 2008.

André Gagalowicz has participated to invited seminars at:

- ENST, “Workshop on Gesture and Images”, 25 March.

9. Bibliography

Major publications by the team in recent years

- [1] A. GAGALOWICZ, W. PHILIPS (editors). *Computer Analysis of Images and Patterns*, ISBN 978-3-540-28969-2, vol. 3691, LNCS of Springer Verlag, 2005.
- [2] A. GAGALOWICZ, W. PHILIPS (editors). *Computer Vision/Computer Graphics Collaboration Techniques and Applications*, ISBN 978-3-540-71456-9, vol. 4418, LNCS of Springer Verlag, 2007.
- [3] S. BOIVIN, A. GAGALOWICZ. *Image-Based Rendering of Diffuse, Specular and Glossy Surfaces from a Single Image*, in "ACM Siggraph, Los Angeles, CA, USA", August 2001, p. 107–116.
- [4] H. CHARFI, A. GAGALOWICZ, R. BRUN. *Determination of Fabric Viscosity Parameters Using Iterative Minimization*, in "Computer Analysis of Images and Patterns", ISBN 978-3-540-28969-2, vol. 3691, LNCS of Springer Verlag, 2005, p. 789–798, http://dx.doi.org/10.1007/11556121_97.
- [5] D. KALINKINA, A. GAGALOWICZ, R. ROUSSEL. *3D Reconstruction of a Human Face from Images Using Morphological Adaptation*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", ISBN 978-3-540-71456-9, vol. 4418, LNCS of Springer Verlag, 2007, p. 212–224.
- [6] T. LE THANH, A. GAGALOWICZ. *Virtual Garment pre-positioning*, in "Computer Analysis of Images and Patterns", ISBN 978-3-540-28969-2, vol. 3691, LNCS of Springer Verlag, 2005, p. 837–845, http://dx.doi.org/10.1007/11556121_103.
- [7] T. LE THANH, A. GAGALOWICZ. *Fast Virtual Cloth Energy Minimization*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", ISBN 978-3-540-71456-9, vol. 4418, LNCS of Springer Verlag, 2007, p. 139–149.
- [8] T. LE THANH, A. GAGALOWICZ. *Hierarchical Multi-Resolution Model for Fast Energy Minimization of Virtual Cloth*, in "Proceedings of VISAPP 2007", 2007, p. 453–458.
- [9] M. MATHIEU, C. QUAH, A. GAGALOWICZ. *Modeling 3D Humans from Uncalibrated Wide Baseline Views*, in "SAE Digital Human Modeling Conference", Award of "Substantial contribution to the Technical Program of SAE Digital Human Modeling, 2006.
- [10] C. K. QUAH, A. GAGALOWICZ, R. ROUSSEL, H. S. SEAH. *3D Modeling of Humans with Skeleton from Uncalibrated Wide Baseline Views*, in "Computer Analysis of Images and Patterns", ISBN 978-3-540-28969-2, vol. 3691, LNCS of Springer Verlag, 2005, p. 379–389.
- [11] R. ROUSSEL, A. GAGALOWICZ. *A Hierarchical Face Behavior Model for a 3D Face Tracking Without Markers*, in "Computer Analysis of Images and Patterns", ISBN 978-3-540-28969-2, vol. 3691, LNCS of Springer Verlag, 2005, p. 854–861.

Year Publications

Doctoral Dissertations and Habilitation Theses

- [12] Y. CHEN. *Research on physically based soft object simulation and animation*, Ph. D. Thesis, Tsinghua University, 2008.
- [13] C. K. QUAH. *Model-based 3D markerless human motion capture*, Ph. D. Thesis, NTU, september 2008.
- [14] W. YUAN. *Meshless Based Computer Animation and High Performance Solution Method (in chinese)*, Ph. D. Thesis, Peking University, China, 2008.

Articles in International Peer-Reviewed Journal

- [15] G. CARIDAKIS, A. RAOUZAIYOU, E. BEVACQUA, M. MANCINI, K. KARPOUZIS, L. MALATESTA, C. PELACHAUD. *Virtual agent multimodal mimicry of humans*, in "Language Resources and Evaluation, special issue on "Multimodal Corpora For Modelling Human Multimodal Behavior"", Eds J.-C. Martin, P. Paggio, P. Kühnlein, R. Stiefelhagen, F. Pianesi, 2008.
- [16] N. E. CHAFAI, C. PELACHAUD, D. PELÉ. *A case study of gesture expressivity breaks*, in "Language Resources and Evaluation, special issue on "Multimodal Corpora For Modelling Human Multimodal Behavior"", Eds J.-C. Martin, P. Paggio, P. Kühnlein, R. Stiefelhagen and F. Pianesi, 2008.
- [17] C. PELACHAUD. *Studies on Gesture Expressivity for a Virtual Agent*, in "Speech Communication, special issue in honor of Björn Granstrom and Rolf Carlson", to appear, 2008.
- [18] W. YUAN, Y. CHEN, K. LIU, A. GAGALOWICZ. *Application of Meshless Local Petrov-Galerkin (MLPG) Method in Cloth Simulation*, in "CMES: Computer Modeling in Engineering & Sciences (Journal)", vol. 35, n^o 2, 2008, p. 133–156.

International Peer-Reviewed Conference/Proceedings

- [19] P. BAGGIA, F. BURKHARDT, J. MARTIN, C. PELACHAUD, C. PETER, B. SCHULLER, I. WILSON, E. ZOVATO. *Elements of an EmotionML 1.0. W3C Final Incubator Group Report*, in "World Wide Web Consortium", M. SCHRÖDER (editor), November 2008.
- [20] E. BEVACQUA, M. MANCINI, C. PELACHAUD. *A listening agent exhibiting variable behaviour*, in "Intelligent Virtual Agents, IVA'08, Tokyo", September 2008.
- [21] Y. CHEN, J. WANG. *Deformation Framework based on Meshless Method and Adaptive Volumetric Points Generation*, in "International 3D-TV Conference (The True Vision capture, transmission and display of 3D Video)", 2008.
- [22] Y. CHEN, W. YUAN, A. GAGALOWICZ. *Deformation Framework based on Meshless Method and Adaptive*, in "Mirage 09 Computer Vision/Computer Graphics Collaboration Techniques and Applications", accepted, 2008.
- [23] G. GEORG, M. CAVAZZA, C. PELACHAUD. *Visualizing the Importance of Medical Recommendations with Conversational Agents*, in "Intelligent Virtual Agents, IVA'08, Tokyo", September 2008, p. 380–393.
- [24] G. GEORG, C. PELACHAUD, M. CAVAZZA. *Emotional Reading of Medical Texts Using Conversational Agents*, in "Seventh International Joint Conference on Autonomous Agents and Multi-Agent Systems, AAMAS'08, Estoril Portugal", May 2008, p. 1285–1288.

- [25] D. HEYLEN, S. KOPP, S. MARSELLA, C. PELACHAUD, H. VILHJÁLMSSON. *The Next Step Towards a Functional Markup Language*, in "Intelligent Virtual Agents, IVA'08, Tokyo", September 2008.
- [26] T. LE THANH, A. GAGALOWICZ. *From Interactive Positioning to Automatic Try On of Virtual Cloth*, in "Proceedings of Mirage 2009", accepted, 2009.
- [27] T. LUGINBÜHL, P. GUERLAIN, A. GAGALOWICZ. *A Model-Based Approach for Human Body Reconstruction from 3D Scanned Data*, in "Proceedings of Mirage 2009", accepted, 2009.
- [28] M. MANCINI, R. NIEWIADOMSKI, E. BEVACQUA, C. PELACHAUD. *Greta: a SAIBA compliant ECA system*, in "Workshop on Animated Conversational Agents (WACA'08), Paris, France", 2008.
- [29] M. MANCINI, C. PELACHAUD. *Distinctiveness in multimodal behaviors*, in "Seventh International Joint Conference on Autonomous Agents and Multi-Agent Systems, AAMAS'08, Estoril Portugal", 8 pages, May 2008.
- [30] M. MANCINI, C. PELACHAUD. *The FML - APLM language*, in "The First FML workshop, AAMAS'08, Estoril, Portugal", May 2008.
- [31] R. NIEWIADOMSKI, M. OCHS, C. PELACHAUD. *Expressions of empathy in ECAs*, in "Intelligent Virtual Agents, IVA'08, Tokyo", 8 pp., September 2008.
- [32] M. OCHS, C. PELACHAUD, D. SADEK. *An Empathic Virtual Dialog Agent to Improve Human-Machine Interaction*, in "Seventh International Joint Conference on Autonomous Agents and Multi-Agent Systems, AAMAS'08, Estoril Portugal", 8 pages, May 2008.
- [33] M. SCHRÖDER, R. COWIE, D. HEYLEN, M. PANTIC, C. PELACHAUD, B. SCHULLER. *Towards responsive Sensitive Artificial Listeners*, in "Fourth International Workshop on Human-Computer Conversation, Bellagio, Italy", 2008.
- [34] M. SCHRÖDER, I. WILSON, W. JARROLD, D. EVANS, C. PELACHAUD, E. ZOVATO, K. KARPOUZIS. *What is most important for an Emotion Markup Language?*, in "Proc. Third Workshop Emotion and Computing, KI 2008, Kaiserslautern, Germany", 2008.
- [35] Z. WANG, A. GAGALOWICZ, M. SUN. *Low-cost multi-images based 3D human body modeling*, in "Proceedings of Mirage 2009", accepted, 2009.
- [36] H. YAN, C. LIU, A. GAGALOWICZ, C. GUIARD. *Facade Structure Parameterizations Based on Similarity Detection from a Single Image*, in "MIRAGE'2009", accepted.
- [37] W. YUAN, Y. CHEN, A. GAGALOWICZ, K. LIU. *Application of Meshless Local Petrov-Galerkin (MLPG) Method in Cloth Simulation (abstract)*, in "ICCES Meshless Methods '08, Suzhou, China", October 2008.
- [38] W. YUAN, Y. CHEN, A. GAGALOWICZ. *Meshless Virtual Cloth*, in "Mirage 2009, INRIA Rocquencourt, France", accepted, May 2009.

Workshops without Proceedings

- [39] E. BEVACQUA, M. MANCINI, C. PELACHAUD. *Exploring behavioural styles in human-ECA interaction*, in "Speech and Face to Face Communication, Grenoble, France", 2008.

Scientific Books (or Scientific Book chapters)

- [40] Y. CHEN, W. YUAN, A. GAGALOWICZ. *Deformation Framework based on Meshless Method and Adaptive*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", LNCS of Springer Verlag, 2009.
- [41] G. CHOLLET, A. ESPOSITO, A. GENTES, W. KARAM, P. HORAIN, C. PELACHAUD, P. PERROT, D. PETROVSKA-DELACRETAZ, D. ZHOU, L. ZOUARI. *Multimodal Human Machine Interactions*, in "Virtual and Augmented Reality", Springer, 2008.
- [42] T. LE THANH, A. GAGALOWICZ. *From Interactive Positioning to Automatic Try On of Virtual Cloth*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", 2009.
- [43] T. LUGINBÜHL, P. GUERLAIN, A. GAGALOWICZ. *A Model-Based Approach for Human Body Reconstruction from 3D Scanned Data*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", LNCS of Springer Verlag, 2009.
- [44] I. POGGI, R. NIEWIADOMSKI, C. PELACHAUD. *Facial Deception in Humans and ECAs*, in "Modeling Communication with Robots and Virtual Humans", Springer series Lecture Notes in Computer Science (LNCS), subseries Lecture Notes in Artificial Intelligence (LNAI), vol. 4930, Springer-Verlag, Berlin, 2008.
- [45] Z. WANG, A. GAGALOWICZ, M. SUN. *Low-cost multi-images based 3D human body modeling*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", LNCS of Springer Verlag, 2009.
- [46] H. YAN, C. LIU, A. GAGALOWICZ, C. GUIARD. *Facade Structure Parameterizations Based on Similarity Detection from a Single Image*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", LNCS of Springer Verlag, 2009.
- [47] W. YUAN, Y. CHEN, A. GAGALOWICZ. *Meshless Virtual Cloth*, in "Computer Vision/Computer Graphics Collaboration Techniques and Applications", LNCS of Springer Verlag, 2009.

Research Reports

- [48] C. GUIARD. *TD - WP3.1.4 - Interfaces*, Technical Paper, Terra Numerica contract, Technical report, INRIA, 2008.
- [49] C. GUIARD. *TD - WP3.1.4 - Technologies de reconstruction de bâti géo-spécifique*, Technical Paper, Terra Numerica contract, Technical report, INRIA, 2008.

Other Publications

- [50] D. HEYLEN, S. KOPP, S. MARSELLA, C. PELACHAUD, H. VILHJÁLMSOHN. *Why Conversational Agents do what they do? Functional Representations for Generating Conversational Agent Behavior The First Functional Markup Language Workshop*, The Seventh International Conference on Autonomous Agents and Multiagent Systems Estoril, Portugal, 2008.

References in notes

- [51] B. D. CAROLIS, C. PELACHAUD, I. POGGI, M. STEEDMAN. *APML, a Mark-up Language for Believable Behavior Generation*, in "Lifelike Characters. Tools, Affective Functions and Applications", H. PRENDINGER, M. ISHIZUKA (editors), Springer, 2004.
- [52] P. DEBEVEC, C. TAYLOR, J. MALIK. *Modeling and rendering architecture from photographs: a hybrid geometry and image-based approach*, in "Proceedings of ACM SIGGRAPH 1996", ACM Press, H. Rushmeier, Ed., 1996, p. 11–20.
- [53] P. DECAUDIN, D. JULIUS, J. WITHER, L. BOISSIEUX, A. SHEFFER, M.-P. CANI. *Virtual Garments: A Fully Geometric Approach for Clothing Design*, in "Computer Graphics Forum (Eurographics'06 proc.)", vol. 25, 2006, p. 625–634.
- [54] J. DENISE, D. REVERSAT, A. GAGALOWICZ. *Modeling of the Hysteretic Behaviour of Fabrics*, in "Proceedings of Mirage 2003 (Computer Vision / Computer Graphics Collaboration for Model-based Imaging, Rendering, image Analysis and Graphical special Effects)", INRIA Rocquencourt, France, March, 10-12 2003.
- [55] C. FRUH, A. ZARKHOR. *3D model generation for cities using aerial photographs and ground level laser scans*, in "CVPR, IEEE Computer Society", 2001, p. 31–38.
- [56] C. FRUH, A. ZARKHOR. *Constructing 3D city models by merging ground-based and airborne views*, in "Computer Graphics and Applications", 2003, p. 52–61.
- [57] D. HEYLEN, E. BEVACQUA, M. TELLIER, C. PELACHAUD. *Searching for Prototypical Facial Feedback Signals*, in "IVA07, Paris, France", 2007, p. 147–153.
- [58] L. KAVAN, S. COLLINS, J. ZARA, C. O'SULLIVAN. *Geometric Skinning with Approximate Dual Quaternion Blending*, in "ACM Transaction on Graphics", vol. 27, n^o 4, 2008.
- [59] J. LAKIN, V. JEFFERIS, C. CHENG, T. CHARTRAND. *Chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry*, in "Nonverbal Behavior", vol. 27, n^o 3, 2003, p. 145–162.
- [60] J. LANDER. *Graphic content: skin them bones: game programming for the web generation*, 02-14 2006.
- [61] J. LEGAKIS, J. DORSEY, S. GORTLER. *Feature-based cellular texturing for architectural models*, in "Proceedings of ACM SIGGRAPH 2001", ACM Press, E. Fiume, Ed., 2001, p. 309–316.
- [62] R. MAATMAN, J. GRATCH, S. MARSELLA. *Natural Behavior of a Listening Agent*, in "LECTURE NOTES IN COMPUTER SCIENCE", vol. 3661, 2005, 25.
- [63] J.-E. MARVIE, J. PERRET, K. BOUATCHOUK. *The FL-system : a functional L-system for procedural geometric modeling*, in "The Visual Computer", 2005, p. 329–339.
- [64] L.-P. MORENCY, I. DE KOK, J. GRATCH. *Predicting Listener Backchannels: A Probabilistic Multimodel Approach*, in "8th International Conference on Intelligent Virtual Agents, Tokyo, Japan", september 2008, <http://people.ict.usc.edu/~gratch/papers/predict-iva08.pdf>.

- [65] P. MÜLLER, P. WONKA, S. HAEGLER, A. ULMER, L. V. GOOL. *Procedural modeling of buildings*, in "Proceedings of ACM SIGGRAPH 2006 / ACM Transactions on Graphics", vol. 25, ACM Press, New York, NY, USA, 2006, p. 614–623.
- [66] O. MÜLLER, G. ZENG, P. WONKA, L. V. GOOL. *Image-based procedural modeling of façades*, in "Proceedings of ACM SIGGRAPH 2007 / ACM Transactions on Graphics", ACM Press, vol 26, n°3, 2007.
- [67] Y. PARISH, P. MÜLLER. *Procedural modeling of cities*, in "Proceedings of ACM SIGGRAPH 2001", ACM Press, E. Fiume Ed., 2001, p. 301–308.
- [68] W. RIBARSKY, T. WASILEWSKI, N. FAUST. *From urban terrain models to visible cities*, in "IEEE Computer Graphics and Applications, 22, 4", 2002, p. 231–238.
- [69] G. STINY. *Pictorial and formal aspects of shape and shape grammars*, Birkhauser Verlag, Basel 1975.
- [70] T. L. THANH, A. GAGALOWICZ. *Virtual Garment pre-positioning*, in "CAIP", 2005, p. 837–845, http://dx.doi.org/10.1007/11556121_103.
- [71] K. R. THÓRISSON, T. LIST, C. PENNOCK, J. DIPIRRO. *Whiteboards: Scheduling Blackboards for Semantic Routing of Messages & Streams*, in "AAAI-05 Workshop on Modular Construction of Human-Like Intelligence", 2005, p. 8–15.
- [72] H. VILHJÁLMSOON, N. CANTELMO, J. CASSELL, N. E. CHAFAI, M. KIPP, S. KOPP, M. MANCINI, S. MARSELLA, A. N. MARSHALL, C. PELACHAUD, Z. RUTTKAY, K. R. THÓRISSON, H. VAN WELBERGEN, R. J. VAN DER WERF. *The Behavior Markup Language: Recent Developments and Challenges.*, in "IVA", C. PELACHAUD, J.-C. MARTIN, E. ANDRÉ, G. CHOLLET, K. KARPOUZIS, D. PELÉ (editors), Lecture Notes in Computer Science, vol. 4722, Springer, 2007, p. 99–111.
- [73] L. Y. WANG, U. NEUMANN. *Large-scale urban modeling by combining ground level panoramic and aerial imagery*, in "3DPVT06", 2006.
- [74] X. WANG, S. TOTARO, F. TAILLANDIER, A. HANSON, S. TELLER. *Recovering facade texture and microstructure from real-world images*, in "Proceedings of ISPR Symposium on Photogrammetric Computer Vision", 2002, p. 381–386.
- [75] N. WARD, W. TSUKAHARA. *Prosodic features which cue back-channel responses in English and Japanese*, in "Journal of Pragmatics", vol. 23, 2000, p. 1177–1207.
- [76] P. WONKA, M. ZIMMER, F. SILLION, W. RIBARSKY. *Instant architecture*, in "ACM Transactions on Graphics 22", 2003, p. 669–677.