SFB 603 "Model-Based Analysis and Visualization of Complex Scenes and Sensor Data" and

Graduate Research Center "3-D Image Analysis and Synthesis"

in cooperation with
IEEE Signal Processing Society

and
Gesellschaft für Informatik GI (FG 1.0.4, FG 4.1.2)

B. Girod, H. Niemann, H.-P. Seidel (Eds.)

Vision Modeling and Visualization '99

Proceedings
November 17-19, 1999
Erlangen, Germany

infix

B. Girod, H. Niemann, H.-P. Seidel (Eds.)

Vision, Modeling, and Visualisation '99

Proceedings
November 17–19, 1999
Erlangen (Germany)

infix

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

Vision Modeling and Visualization '99 : proceedings ;
November 17–19, 1999, Erlangen (Germany) / [VMV '99. SFB 603
"Model-Based Analysis of Complex Scenes and Sensor Data" and
Graduate Research Center "3D Image Analysis and Synthesis" in
cooperation with IEEE Signal Processing Society and Gesellschaft für
Informatik GI (FG 1.0.4, FG 4.1.2). B Girod ... (ed.)]. – Sankt
Augustin : Infix, 1999
ISBN 3-89601-015-8

Cover Design: Art und Media, Bonn
Printing and Binding: Hundt Druck GmbH, Köln
Printed in Germany

ISBN 3-89601-015-8

Preface

Vision and visualization are complementary fields that are rapidly coming together. Modeling of scene and object geometry, photometry, and statistical properties are essential in both areas individually, but especially for the convergence into a new, unified field of image analysis and synthesis. The declining cost of processors, memory, and sensors continues to expand the scope of viable applications. New system solutions are in reach by combining state-of-the-art techniques from research areas that were traditionally separate. The thorough scientific treatment of the underlying principles, for example the limitations of sensors, the reliability, accuracy, and complexity of image processing algorithms, or the fidelity of interactive visualization schemes, is the prerequisite for such advanced systems.

The Erlangen Workshop '99 Vision, Modeling, and Visualization is the fourth in a series of annual meetings organized by the Graduate Research Center "3-D Image Analysis and Synthesis". The first two meetings were held in Erlangen, the previous meeting was held in Alpbach, Austria. In 1999, the meeting is for the first time jointly organized with the new Center of Excellence SFB 603 "Model-based Analysis and Visualization of Complex Scenes and Sensor Data" at the University of Erlangen-Nuremberg. The Graduate Research Center, supported by the Deutsche Forschungsgemeinschaft (German Science Foundation) since January 1996, comprises a program of collaborative doctoral research and advanced studies with special emphasis on problems of 3D image aquisition, computer vision, 3D computer graphics, and selected applications ranging from medicine to manufacturing. The SFB 603, funded by the Deutsche Forschungsgemeinschaft since January 1998, complements this activity through 12 long-term collaborative research projects.

Both Graduate Research Center and SFB 603 cooperate with many laboratories and research groups both nationally and internationally. The more than 50 papers in these Proceedings present an excellent cross-section through the current ongoing research in their area of scientific endeavour. Contributions were solicited in a Call for Papers that was distributed with the help of the Gesellschaft für Informatik (German Computer Science Society), FG 1.04 and FA 4.1.2, and the IMDSP Technical Committee of the IEEE Signal Processing Society. Each submission was anonymously reviewed by at least two members of the Technical Program Committee. The accepted papers are organized in seven sessions for oral presentation: Imaging and Calibration, Multiview Processing, Motion and Tracking, Recognition and Localization, Representation and Processing of Geometry Data, Rendering and Visualization, and, last but not least, Medical Applications. In addition, we are happy that five internationally renowned experts have accepted our invitation to present keynote speeches:

- Prof. Edward H. Adelson, Massachusetts Institute of Technology, Cambridge, MA, USA
- Prof. Luc Van Gool, Katholieke Universiteit Leuven, Belgium
- Prof. Markus Gross, ETH Zurich, Switzerland
- Dr. Hans Steinbichler, Steinbichler Optotechnik GmbH, Neubeuern, Germany
- Prof. Demetri Terzopoulos, University of Toronto, Canada

The meeting itself was organized by members of the SFB 603 and the Graduate Research Center. G. Greiner and C. Karadag managed the finances. D. Paulus took charge of publicity, K. Hormann of these proceedings. M. Teschner assisted in organizing the reviews and the technical program. R. Rabenstein managed local arrangements, including the traditional social event at Schloß Atzelsberg. Without their many hours, the meeting and this book would not have been possible. The Fraunhofer-Institute for Integrated Circuits again hosted this meeting free of charge, their generous hospitality is gratefully acknowledged.

Erlangen, November 1999

B. Girod, H. Niemann, H.-P. Seidel

General Chair

Heinrich Niemann

Technical Program Chair

Bernd Girod
Matthias Teschner

Publicity

Dietrich Paulus

Publications

Kai Hormann

Local Arrangements

Rudolf Rabenstein

Finances

Thomas Ertl
Günther Greiner

Technical Program Committee

Kiyoharu Aizawa, Japan
Nicholas Ayache, France
Subhasis Chaudhuri, India
Rama Chellappa, USA
Gershon Elber, Israel
Aggelos K. Katsaggelos, USA
Erwin Keeve, USA
Jelena Kovačević, USA
Murat Kunt, Switzerland
Inald Lagendijk, Netherlands
Henri Maitre, France
Roberto Manduchi, USA
Bärbel Mertsching, Germany
Heinrich Müller, Germany
Jörn Ostermann, USA
Nikola Pavešić, Slovenia
Alex P. Pentland, USA
Frits Post, Netherlands
Jerry L. Prince, USA
Bernd Radig, Germany
Gerhard Sagerer, Germany
Hans-Peter Seidel, Germany
Michael Strintzis, Greece
Thomas Strothotte, Germany
Murat Tekalp, USA
Roland Wilson, UK
Avideh Zakhor, USA

Contents

Deformation Modelling of Irregular Objects

S. Di Bona[1], O. Salvetti[1], L. Lutzemberger[2], A. Carini[1], S. Di Pierro[1]

[1]Institute for Information Processing
Italian National Research Council (IEI-CNR)
Via S. Maria 46 - 56126 Pisa (Italy)
Email: dibona - salvetti@iei.pi.cnr.it

[2]Dept. of Neuroscience
Institute of Neurosurgery, Univ. of Pisa
Via Roma 67 - 56126 Pisa (Italy)

Abstract

A main aspect in Image Synthesis is that of "Virtual Environment" (VE), that is the ability of realistic modelling of interacting objects. VE studies have found a natural implementation in Medical Imaging (MI).

MI applications have shown the need of modelling human tissues and organs, not only from a geometrical point of view (shape, aspect) but also from a physical point of view (soft tissue, rigid bodies, viscoelasticity). This has led to the definition of "deformable objects", described both in terms of morphologic and physical features.

This paper presents a model able to complete the morphologic description of complex anatomical structures, reconstructed from volumetric data sets (MR, CT, etc.), with mechanical properties. This model, implemented in AVS/Express^{TM}, represents a simulator able to perform both a realistic modelling of the evolution of intracranial expansive lesions (haematoma, cancer, haemorrhage) and an evaluation of the influence on the surrounding encephalon anatomical districts.

1 Introduction

Deformable models based on "virtual springs" can be used to describe the physical behaviour of real objects. Spring-based models differ each other for the disposition of the springs, usually organised to build meshes suitable to fit the geometry of the system to be modelled. In our case, the expansive characteristic of a lesion can be modelled by a radial distribution of the springs starting at the origin of the anomaly itself.

With respect to the anatomic cranial-encephalic 'system', the main aspects of the macroscopic behaviour of expansive phenomena are:

- the structure of the encephalon soft tissues
- the mechanical configuration of the 'system'
- the internal idrostatic interactions

Modelling of encephalon soft tissues is a biomechanical problem. Biosolid soft tissues have an intermediate behaviour between liquid and solid-elastic materials (*viscoelastic materials*). Such a dynamic behaviour can be formalised by means of differential equations depending on the particular model adopted. Maxwell, Voigt and Kelvin are the most known models [1]: their mathematical formulations are based on a *constituent equation* which represents the *Stress-Strain* relation of a generic tissue under dynamic solicitation. In Voigt, for instance, such relation is given by $F = k \cdot u + \eta \cdot \frac{\partial u}{\partial t}$, where F is the force applied, k is an elasticity constant, u is the elongation and η is a viscosity coefficient;

the other models lead to similar formulas. k and η depend on the tissue and can be experimentally defined by an *Uniaxial-Loading* test [2, 3]. By discretising the expansive phenomenon progression, soft tissues can be modelled as springs, since the dynamic aspect of the phenomenon itself has no influence.

Other aspects are the structure of the skull-encephalon and the biotissue architecture. In order to observe the action of a growing lesion, it is convenient to distribute the deforming isotropic pressure along a certain number of *force lines*. These lines are traced from the origin of the expansive mass up to the skull [4, 5].

When the force lines cross the encephalon tissues, the pressure transmitted is unidirectional while the tissue resistance cannot be modelled as a series of springs, one for each tissue involved in the deforming process. In fact, such a spring composition implies that the pressure transmitted by the first spring is unchanged with respect to the pressure received. This is not true in our case since the encephalon tissues react with distributed resistances whose force vectors have different directions and only the resultant vector has the same module and opposite direction of the deforming pressure. For this reason a "pressure dispersion corrector" is then introduced.

One more aspect to be considered is the presence of a liquid fluid inside the structure. The fluid container, that is the sub-aracnoidal space and the ventricular system, cannot be considered hermetically closed: in that case, in fact, the growing intracranial lesion would cause a high increment in the fluid pressure. In the reality this happens only in pathologies with an advanced evolution state.

In more detail, the fluid reacts to the expansive mass in the same way as the compensation tissues, which, relaxing, allow the fluid itself to flow down. For this reason, the liquid can be modelled employing identical springs as those used to model the compensation tissues.

2 Deformable Model Definition

The skull is the natural boundary of our deformable system. The iso-density volumes of real structures in tomographic scans of the head correspond to morpho-functional regions whose behaviour must be simulated in our virtual model. Owing to the iso-density of these regions, the corresponding geometry in the model can be assigned to springs with identical elasticity parameters, where the elasticity values are strictly related to the grey values of the digital images.

The geometric virtual model is composed of the following elements:

- a container volume which represents the skull and can not be deformed
- a certain number of internal volumes which depend on the granularity of the reality simulation

In the following, a simplified 2D geometric model is used, where the encephalon morpho-functional regions are represented by sections of pseudo-spherical surfaces.

3 Mechanic Characterisation

From point C (figure 1), which is the deforming pressure origin, r force vectors are radially disposed on a generic section plane belonging on the 3D scan examined, with a constant increment angle, up to the known boundary (represented by the skull); r states the resolution degree for the final deformation.

The pencil of lines represents a force field starting at the origin of the expansive lesion and ending on the skull. The intersection points between the force lines and the boundaries of the objects located inside the geometric context considered, define the "control points" C_i used to control the deforming simulation process. Each force vector, defined by two adjacent control points, represents a spring that describes the behaviour of the corresponding tissues. A generic "virtual spring" ɜ Model Def-

l boundary of our de-
so-density volumes of
ɔgraphic scans of the
ɔho-functional regions
e simulated in our vir-
ıe iso-density of these
ling geometry in the
o springs with identi-
ɜ, where the elasticity
ed to the grey values

model is composed of

which represents the
e deformed
of internal volumes
he granularity of the

nplified 2D geometric
ɜ encephalon morpho-
presented by sections
ıces.

Characterisa-

which is the deform-
ɜe vectors are radially
ection plane belong-
ined, with a constant
the known boundary
l); r states the reso-
l deformation.
presents a force field
the expansive lesion
l. The intersection
lines and the bound-
ated inside the geo-
l, define the "control
l the deforming sim-
force vector, defined
points, represents a
behaviour of the cor-
ıeric "virtual spring"

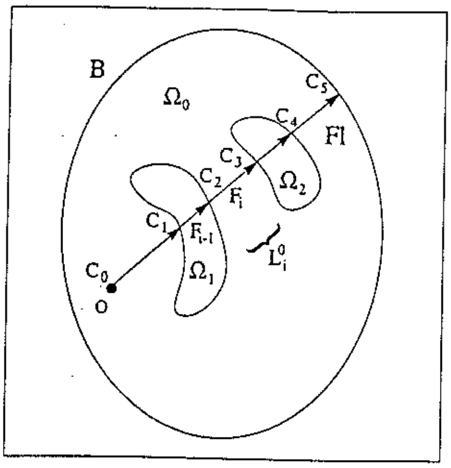


Figure 1: The Deformable Model - B: known boundary, Ω_i: homogeneous space, F_i: force vector, Fl: force line, $C0 \equiv O$: origin of the deforming agent, C_i: control point, L_i^0: relax length of the spring i

i is characterised by the following parameters, related to the region to be modelled:

- relax length L_i^0 (where i is the iso-density region which the spring corresponds to)
- elastic constant k_i (proportional to the region density δ_i)
- the minimum force λ_i^{min} able to compress the spring
- the maximum threshold p_i^{max} of compression of the spring
- the minimum coefficient of pressure transmission ξ_i^{min}, that is the non critical value that simulates the force dispersion between two adjacent tissues (experimentally or statistically determined)

In order to determine the displacement vectors which control the global deformation, the application point, the direction, the verse and the module should be fixed. The last one is defined by the Euclidean distance between two positions of the same control point in two different system states. The other values depend on the force line (figure 2).

The formalisation of the deformation vectors' modules, allows the mechanical characterisation of the geometric model.

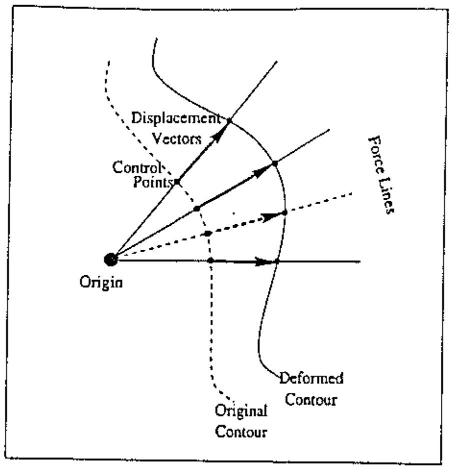


Figure 2: Example of deformation vector

4 Virtual Environment interaction

At the step t_j, with $j > 0$, if the pressure force, identically distributed along the r directions, is not zero, the pressure transmitted to each spring of the force line is computed. For each spring, the computation is based on the specific parameters and on the pressure transmitted by the preceding spring. The global compression obtained is subtracted to the springs relax lengths and the result gives the deformation amount of the tissues against the rigid limit of the geometric context (the skull).

The control points set at step t_0 and t_i represent the control set of the *Radial Base Function* (RBF) and the *B-Spline* approaches used to deform the original scene [5, 4].

The approach has been tested on real images pairs of the same patient, representing both healthy and pathologic situations. The healthy images have been taken either before the expansive lesion appearance or subsequently the surgical lesion removal, after the intracranial structure had assumed again its the original geometry (relaxing time).

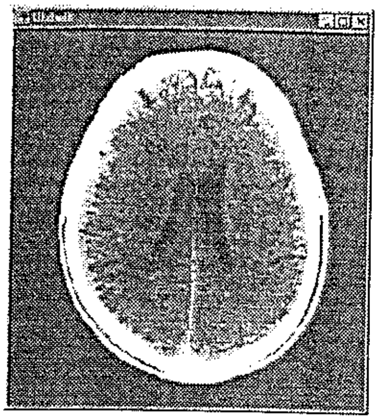


Figure 3: Example of MRI of the brain: healthy situation

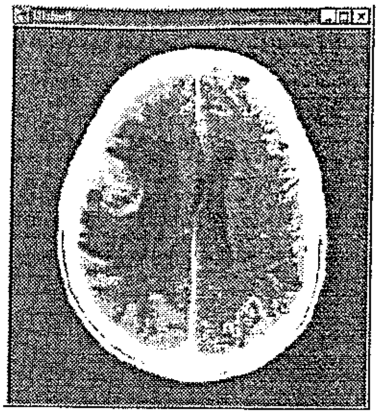


Figure 4: Example of MRI of the brain: pathologic situation

5 The Simulator

The deformable model has been implemented on AVS/Express, in order to simulate the expansive phenomenon at 2D level (CT or MR). Images with 256 grey levels have been considered. The applications implement dedicated algorithms for the simulation of the encephalon objects deformations; such algorithms perform their computation on the basis of the specific resistance of each tissue to the radial force field. Figures 3 ÷ 8 show a simulation example; figure 3, which has been used to simulate the growing process, shows a section of a healthy encephalon, while figure 4, used to evaluate the results, shows the homologous pathologic slice of the same patient. Firstly the system extracts the contours of the main anathomical regions of the healthy image (figure 5); then, the origin point and the module of an expansive force is specified. Figure 6 and figure 7 show the simulation result by using the RBF and the B-Spline deformation approaches respectively. Figure 8 shows a comparison between the contours extracted from the result of the B-Spline approach and the pathologic image.

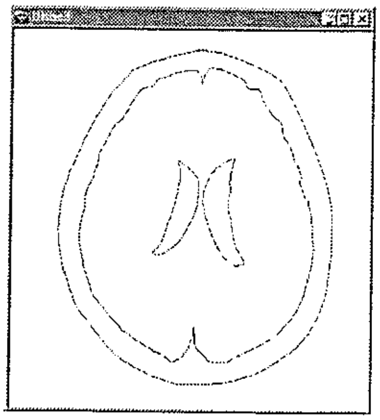


Figure 5: Contours of the healthy image

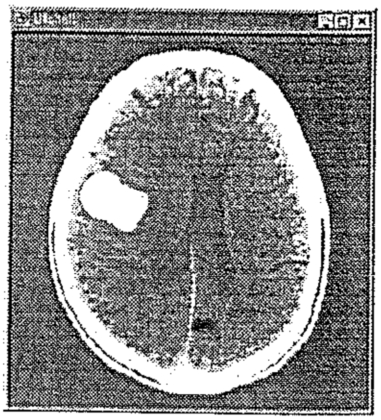
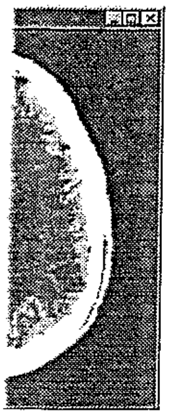
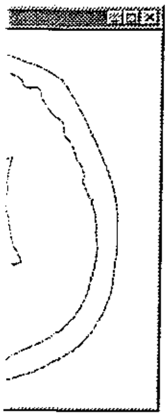


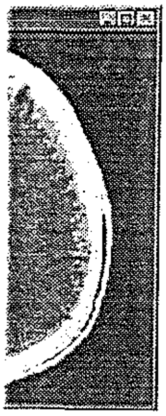
Figure 6: Simulation result with the Radial Base Function approach



ɿIRI of the brain:



he healthy image



ılt with the Radial

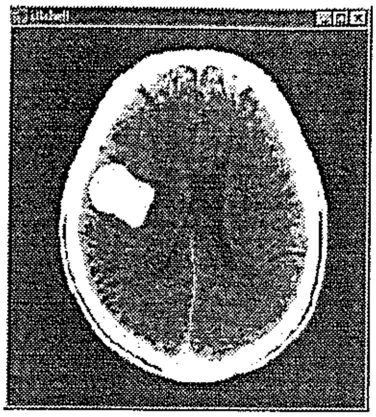


Figure 7: Simulation result with the B-Spline Function approach

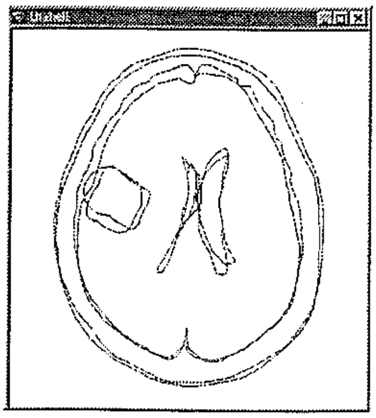


Figure 8: Contour comparison between the healthy image and the B-Spline approach result

6 Conclusions

In this paper a physical and geometrical model has been proposed able to determine the structural variation of the cranial-encephalon system and simulate the behaviour of the endocranial tissues under a defrmation force field. Methodologies and techniques for the anatomical tissue analysis and the pathologic deforming process evaluation have been studied and developed. At last, the approach has been tested on real complex cases, considering both the healthy and the pathological situations of a same patient: starting from the healthy slice, a growing intracranial lesion has been simulated, using both a B-Spline and a RBF approach, and the results have been compared with the pathological slice.

A future extension of the model introduced, is a full 3D simulation of intracranial expansive lesions and the possibility to analyse and characterise more different deforming agents in the same geometric context. Furthermore, optimisation methods can be introduced in order to reduce the simulation complexity and the computational time.

References

[1] D. De Rossi, R. Fumero, Bioingegneria degli Organi Artificiali, *Contributi del IX Convegno Annuale del Gruppo Nazionale di Bioingegneria del CNR*, Bressanone, Bologna Ed, Pàtron, 1-4 Ottobre, 1990.

[2] Y.-C. Fung, N. Perrone, Stess-Strain-History of Soft Tissues in Simple Elongation, *Biomechanics: Its Foundations and Objectives*, Anliker M. ed., Prentice Hall, 1972

[3] Y.-C. Fung, Biomechanics: mechanical properties of living tissues, 2nd Edition, Springer, New York, 1993.

[4] L. Lutzemberger, O. Salvetti, Deforming Process Simulation of Brain Structures, In *Proc. CAR '96*, Paris, June 28-29, 1996, pp. 805-810.

[5] L. Lutzemberger, O. Salvetti, C. Di Sacco, Deformation Analysis of Tree-Dimensional Morphometric Structures, In *Proc. IEEE Int. Conf. on Image Processing*, Santa Barbara, CA, USA, 24-26 October, 1997.