Sawing of Logs in Virtual Trees Using 3D Intersection Algorithms

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Abstract

This work is issued from researches developed in the Programme of Plant Modelling Programme (AMAP) at Cirad: modelling, simulation and visualisation of trees. The goal is to extract and to visualise sawed boards from virtual trees, which are produced by the software AMAP. The initial geometric description of the trees have to be adapted to the sawing: the branches are not "correctly" connected to the trunk. So, in collaboration with the laboratory LMC, two approaches have been developed. The first one uses 2D-image techniques while in the second one, a new description of the surfaces is developed with some 3-D intersections algorithms to solve the problem of connections. It uses Bézier surfaces and geometrical connection techniques.

1 Introduction

In conjunction with Inra and in relation with the national and international scientific community, the Programme of Plant Modelling (AMAP) (Atelier de Modélisation de l'Architecture des Plantes) is a laboratory from Cirad. It designs and develops the necessary methods for measuring, analysing and simulating the architecture, functioning, growth and production of plants, crops and plant stands, be they annual or perennial, tropical or temperate. Its research involves a wide range of expertise-biology, botany, ecology, applied mathematics, information technology and combining these fields is a major scientific and technical challenge for modern agronomy and forestry. The methods and tools developed by the program are made available to researchers and to students working with its teams. They are also diffused in software form.

Why this work ? - The research of alternative for a new forestry is to reduce the cost, to concentrate the consummation of specimen better selected and to improve the growth of trees. We wait of this a better quality of wood in harmony with the demands of the joinery and the industry of furniture. This objective can be divided into three parts :

- Production of a pertinent model of growth.
- Production of models of wood property for the users.
- Finally creation of a tool of decision for the sylviculture.

Here, we are concerned with the second part, e.g. modelling of the internal structure of wood and sawing simulation of boards in virtual trees.

2 Modelling Plant Growth and Architecture

Beside the improvement of classical empirical growth and yield models, elaborated from classical agronomic and forestry field experiments and permanent, most recent developments in plant growth modelling are based on a morphogenetic approach [1].

2.1 Biological Concepts

A tree has a tri-dimensional structure. The elementary structure used in the description of the plant's aerial architecture is the plant axis, otherwise known as the stem or branch. It is made up of a stem or axis carrying leaves and ending in an embryonic part, the apical meristem, at it tip. The leaves are inserted into the stem at the nodes and are positioned along the axis according to the geometrical rules of phyllotaxy. The part of the stem situated between two consecutive nodes is the internode. The growth in length of a plant axis is made up of two phases: fabrication of the internodes in the meristem (apical growth), and then growth after a variable amount of time (internodale growth). The part of the stem that is put in place during a lengthening period is called growth unit (G.U.). The pith is the central part of the stem, it generates the new growth units years after years. In our modelling we are not only interested by the primary growth (creation of new G.U.) of a tree but also by the secondary (creation of new ring). We remember that the summer and winter woods are the part of rings generated in summer and winter. The winter wood is darker than the summer wood, distinguishing the circumvolution of wood (Fig.1).

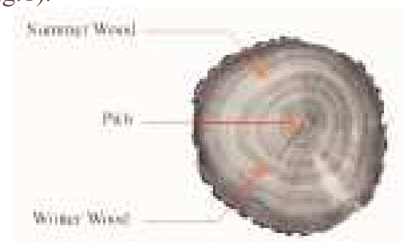

Fig. 1. Radial section of a trunk.

The growth of a stem (or branch) is divided into several parts. The summer wood growths and covers the wood existing, from the spring to the summer, and after a layer of wood more dense, the winter wood, will cover the layer of summer wood. So the growth is made by juxtaposition of layer of new woods (Fig.2).

Fig. 2. Secondary growth model of the tree.

2.2 Morphogenetic plant growth models

The morphogenetic modelling approach aims at generating 3-D virtual plants which are faithful to botany. It results in growth simulators which describe the architectural development according to the genetic programme of the plant, in a given biophysical environment (stand density, site quality, *etc.*). This approach articulates two complementary parts: (*i*) the elaboration of mathematical models based on botanical knowledge and experimental measurements; (*ii*) the computer simulation of plant development based on these mathematical models.

Here, we are interested in the architecture of the plants and with the processes which ensure its operation. This approach is privileged in the work of the Program of Plant Modelling of CIRAD (laboratory AMAP). It is based on the qualitative knowledge brought by the school of Hallé and Oldeman in architecture and on the quantitative methods developed at the point with AMAP. These methods are based on the description of the buds dynamics (growth, death, ramification) by stochastic processes [2], [3]. The simulation software resulting from these theories makes it possible to build realistic models of plants in which topology (relationship between the entities constituting the plant) and the geometry (size of these entities) are simulated according to the parameters of the model, themselves estimated from the experimental data catches on the plants. These models allows to visualize in 3D the architecture of the plants (Fig.3, left) and also the internal structure of the trunk (Fig.3, right) [4].

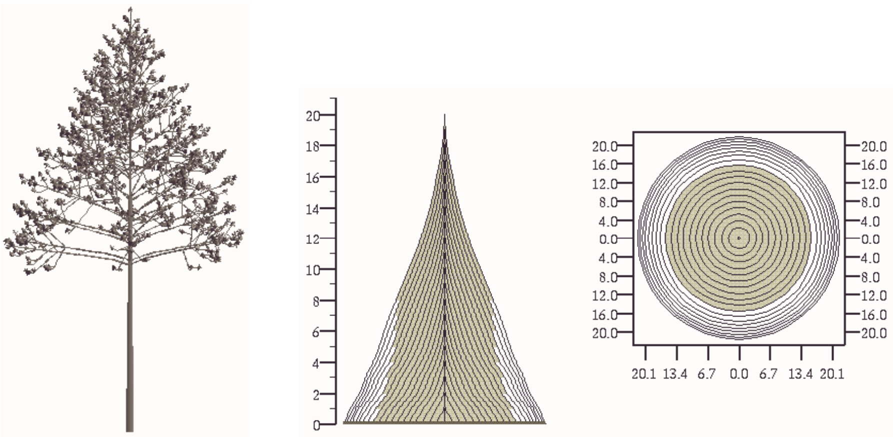

Fig. 3. Growth simulation of a tree (left) ; Longitudinal section and radial section to the trunk basis (right).

3 Sawing Simulation: 3D-Intersection Methodology.

3.1 Objectives and Strategies

In our modelling we assume that there are no sleeping bud and that each G.U. is composed by only one internode. Our goal is to saw boards in virtual trees generated by AMAP simulation software. A first approach has been made by C. Dailly in 1996 [5] and used in virtual forests [6]. He was able to saw board from a trunk without ramification, e.g. without branches . And we have to remember that we wish to observe the nodes from branches on the boards ! But this surfacic approach is not adapted to solve the ramification's problem. The description of the stem and branches involves cylinders and cones which are not connected together.

Their intersection with a plane (the board) will produce a lot of segment curves which have to be continuously connected. Furthermore many hidden parts of these sections have to be removed. This connection problem is the heart of this work. Of course, one should not forget that this connection problem has to be treated in 3 dimensions as shown in figure 4, right . Furthermore we have to take in account that the geometric model must be able to fit data issued from measures. See for example the figure 5. Clearly, these one can only be roughly approximated by circles. Thus, from now, we have at least two solutions. The first one is to improve the surfacic approach in order to take in account ramifications and the data. The second one is to find a new approach and so to change the model.

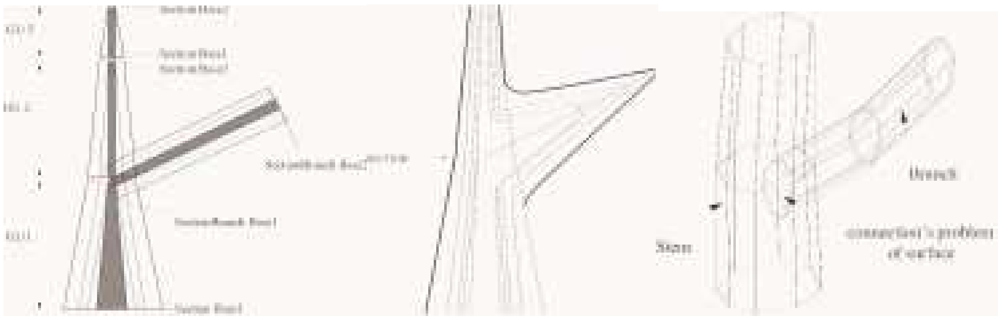

Fig. 4. Connection of a branch with the stem.

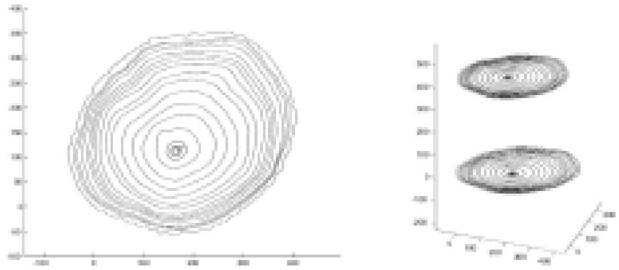

Fig. 5. Radial sections in a trunk from a measured tree.

In fact, we have tried these two ways. Each of them needs to consider the geometric modelling of the internal structure of the tree and then the problem of the sawing of the board, which appears as an intersection 3D problem.

Surfacic approach - In the following of the AMAP simulation software, the surfacic approach appears quite natural. The first step is to define a geometric continuous 3D model, i.e., to connect internodes, stems and branches at each level in the 3D space. Clearly, these connections requires other surfaces than cones and cylinders. Thus, we have to choose appropriate surfaces in such a way that we are able to connect them. Finally, we have to develop algorithms to intersect these connected surfaces with planes to get sawed board.

Implicit approach - An other approach is to use the hierarchical topological model of the tree with an implicit radial definition of the different ring of wood. Connection is then carried out during the stage of intersection in a graphic way with the help of blending functions. This 2D approach is clearly less intricate than the previous one, but do not provides an analytic definition of the tree and of the sawed boards.

3.2 The surfacic approach

As previously said, we need here specific surfaces. We use here tensor product bicubic Bézier surfaces. These one are defined by a geometric polyedral structure which allow to connect them in a natural way [7] (Fig.6). Each section is approximate by four or eight cubic Bézier curves which are C_1 connected. An other cubic Bézier curve is used to describe the axis, so that we can model rings of each internodes with 4 or 8 Bézier surfaces.

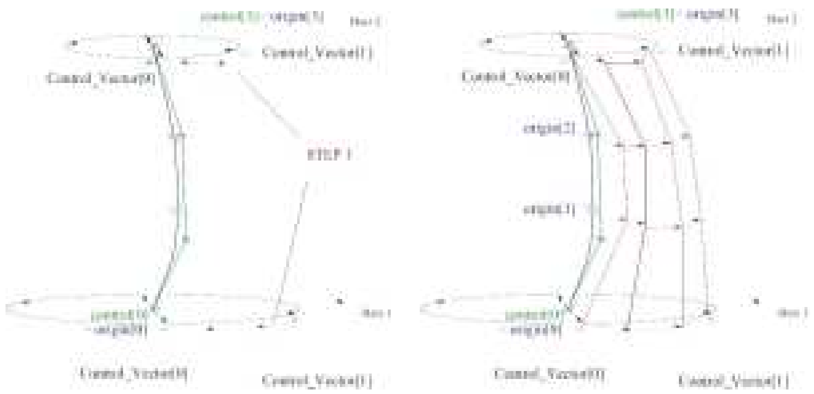

Fig. 6. Tensor product Bézier surfaces.

Connections with branches (which are modelled in the same way) are carried out by modifying the control vectors. So, this surfacic approach provides an 3D geometric model for the tree (Fig.7).

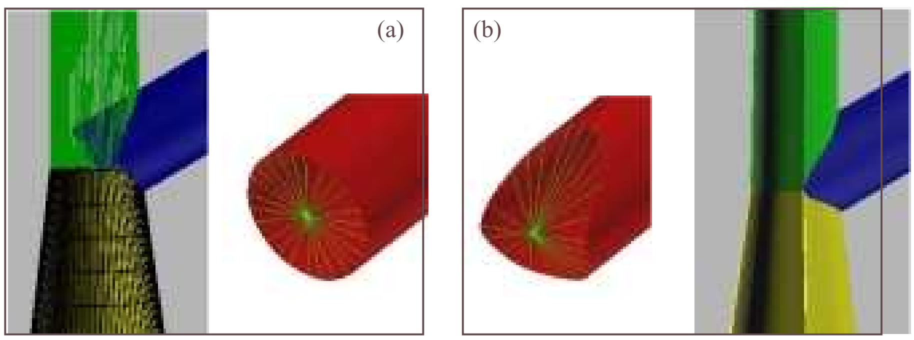

Fig. 7. Surfacic model and Bézier connection: before connection (a) and after connection (b).

The procedure of intersection is then treated by means of subdivision's algorithm and convex hull property of these Bézier surfaces. It does not raise strong difficulties and produce the desired continuous curves from which we deduce the sawing board [8], [9].

3.3 The implicit approach

To saw a board means, in fact, to cut a tree by a plane. In fact it is a question of creating an image of pixels. Thus for each point, it is enough to find the colour of the point which is the colour of the ring in which it is. If it is at the exterior of the tree then its colour has is the external colour. The difficulty comes owing to the fact that when there are branches, a point can belong to two rings of different colours. The colour of the point will be then that of the oldest ring i.e., of the oldest period.

Each year l ($l = 0, 1, \ldots$), we have two periods of growth which we distinguish: the period $k = 2l+1$ of summer wood and the period $k = 2l+2$ of winter wood. The period $k = 0$ corresponds to the formation of the pith. Thus, during the first year ($l = 0$),we have three periods.

We denote by W_k the totality of the wood produced in the tree (stem and branches) during the period k, i.e., W_k is the union of all the growth units of the period k. This wood W_k is supposed to be 3D-continuous, of the same density and so, of the same colour. Now, let $g_k\,[i]$ be a growth unit of the period k and $g_{k-1}[i]$ the growth unit of the period k-1 in the same internode i. We define each growth unit $g_k\,[i]$ by mean of an implicit function $F_k\,[i]$. Since, $g_k\,[i]$cover $g_{k-1}[i]$, a point M of the the 3D-space belongs to the growth unit $g_k\,[i]$ if

$$F_k\,[i]\,(M) \;\geq\; 0 \quad \text{and} \quad F_{k-1}\,[i]\,(M) < 0 \qquad (1)$$

The definition of these functions $F_k\,[i]$, which we denote by F in the following, leads to an implicit radial model for the tree. An internode is limited by two planes P_1 and P_2 which are parallel. In these planes, two sections S_1 and S_2 define a growth unit by linear interpolation (Fig.8). These sections are starred polygons. Let O_1 and O_2 be the barycentres of the pith's sections in each of these planes. Furthermore, we consider an euclidean system of coordinates (u, v, w) such that (u, v) is parallel to the planes P_i.

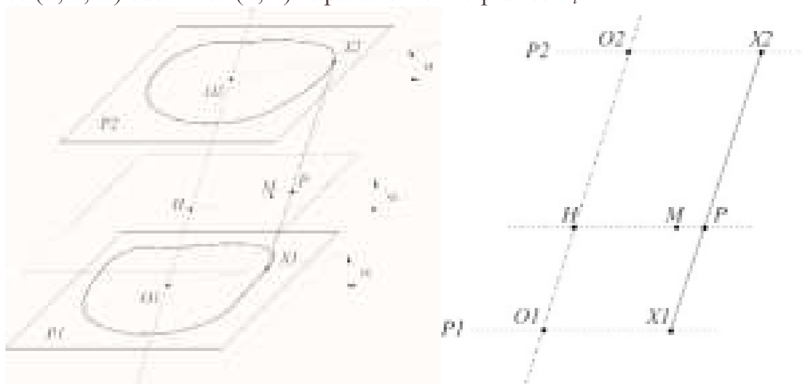

Fig. 8. Implicit radial model for the tree.

Given a point M, we consider the plane Π, parallel to (u, v) and containing the point M. This plane intersects in H the axis $(O_1 O_2)$ and we denote by r the distance $r = | H M |$, and by r_{max} the distance $| H P |$ as shown in the figure 8. For this growth unit, the function F is defined in the following way :

$$t = \frac{\overline{O_1 H}}{O_1 O_2} \quad \text{and} \quad F(M) = \begin{cases} -\infty & \text{if } t \notin [0,1] \\ r_{\max} - r & \text{else} \end{cases} \tag{2}$$

Now, thanks to these implicit functions, we are able to determine each growth unit which contains a given point. Nevertheless, this method leads to acute connections between the stem and the branches. In order to get smooth connections we introduce a notion of neighbourhood in the functions F.

Precisely, for each internode of the stem and the branches we consider a (smoothing) parameter of neighbourhood $\alpha > 0$. Then, for a point M which does not belong to the growth unit $g_k [i]$, but such that $-\alpha_i < F_k [i] (M) < 0$, we increment a quantity $\nu(M)$, called *neighbourhood of M* in the following way

$$\nu (M) := \nu (M) + \frac{(\alpha_i + F_k[i](M))^2}{\alpha_i^2} \tag{3}$$

Thus, if at the end of the analysis of all growth units of the period k, the neighbourhood of M is greater than 1, the point M is said to be in W_k . So, the point M belongs to the period k. We thus obtain elliptic connections.

4 First Results

This implicit approach has been successfully used on a virtual tree generated by AMAP. So, the figure 9 shows us some surfaces which are the results of the intersection between the rings inside the tree and a virtual plan of sawing. And the figure 10 represents the simulation of a sawed board in the same virtual tree. You can remark the representation of the nodes on the board surface. These nodes result from the position of the branches along the trunk and their connection to the trunk pith.

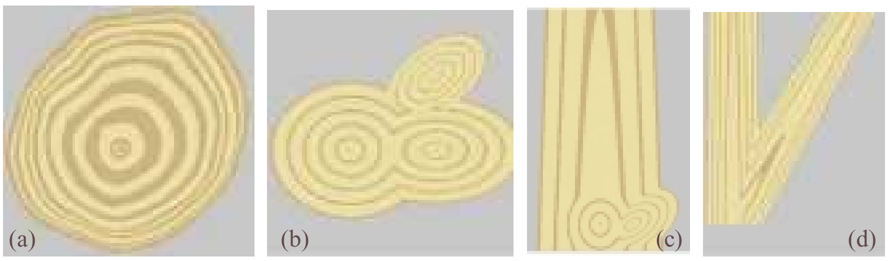

Fig. 9. Different planes Π (Fig.8): radial sections (a, b) and longitudinal sections (c,d) .

Fig. 10. Simulation of a sawed board using the implicit method.

To finish, the figure 11 shows us the simulation of sawed board and beam. In this case, the data has been measured from real tree. The "Wood Quality Research Team" from Inra experiments a new method allowing 3D measurements of the geometry of a standing mature tree to be closely linked to the spatial distribution of internal wood properties. The accuracy of the geometrical information is assessed from repeated measurements performed on 10 mature poplar trees. For this first test, the description of the branches has been ignored. So no node can be seen on the sawed board and beam.

Fig. 11. Board and beam sawing using the implicit method: real data for the internal structure of the tree (poplar).

5 Conclusion and Perspectives

Clearly, the two methods have strong differences. The surfacic one provides a three dimensional model for the tree and an analytic definition for the sawed boards. That is not the case with the implicit model. So the surfacic approach allow further analysis and computation on the model. Nevertheless, this approach is really too much complicated for our purpose.

The implicit method seems quite suitable for the modelling of the trees. Furthermore, it allows the development of algorithms to compute pixel images of the sawed boards. So we decided to go on with this approach and improve it to take in account other kinds of connections, data fitting, sleeping bud, dead branches,...

References

[1] F. Houllier, P. Reffye (de). “Relationships between tree architecture, stem structure and wood quality : a modelling approach.” Communication to : "*Workshop Biological Improvement of Wood Properties"*, Hook, Sweden, June 13-17, pp.92-93, 1994.

[2] D. Barthélémy, F. Blaise, T. Fourcaud, E. Nicolini. « Modélisation et simulation de l'architecture des arbres : bilan et perspectives. » *Rev. For. Fr.*, XLVII, N° hors Série, pp.71-96, 1995.

[3] P. Reffye (de), F. Houllier, F. Blaise. « Modelling plant growth and architecture: some recent advances and applications to agronomy and forestry. » *Acta Horticulturae*, vol.456, pp.105-116, 1998.

[4] Blaise F., Barczi J.F., Jaeger M., Dinouard P., Reffye P. de,. Simulation of the growth of plants - Modeling of metamorphosis and spatial interactions in the architecture and development of plants. *In*: Cyberworlds, Kunii T.L., Luciani A. Eds., Tokyo (JAP), Springer, pp.81-109, 1998.

[5] Dailly C. Modélisation géométrique de la structure interne du bois. Application : découpe de planches et déroulage. Rapport de stage EERIE Nîmes, 39 p., 1996.

[6] F. Blaise, P. Reffye (de), F. Houllier. “Sawing logs in virtual trees.”*In* : G. Nepveu (Ed.) : IUFRO WP S5.01.04 Second Workshop, *Connection between silviculture and wood quality through modelling approaches and simulation softwares* (Berg-en-Dal, South Africa, 26-30/08/96), pp.203-212, 1997.

[7] G. Farin. Courbes et surfaces pour la CGAO. Masson, 1992.

[8] B. Bieth. 3D-intersection algorithms to cut boards from virtual trees. Technical Report. LMC-LIAMA, 2000.

[9] M. Razandrazaka.:Modelisation of the Internal Structure of a Tree. Technical Report. LMC-LIAMA, 2001.

[10] J. Bloomenthal, B. Wyvill. “Interactive Techniques for Implicit Modeling.” Computer Graphics, Symposium on Interactive 3D Graphics, 1990.