A 3D SNAKE APPROACH FOR EXTRACTING PLANS OF HERITAGE BUILDINGS

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Abstract

A comprehensive documentation of construction surveying is always desirable and, in the case of cultural heritage, imperative. Detailed layouts of heritage constructions help the understanding of the historical development of the building, however, drawing these plans is, usually, a manual process. In this paper, we present a new approach for obtaining accurate plans that include stone by stone drawings using 3D models. The proposed method overcomes the manual detection and drawing of features and individual stones. The approach works on 3D snakes (energy-minimizing active contour models) and on the detection of feature lines upon a surface curvature analysis. Our method can be applied to 3D meshes obtained with different techniques, but we have focused on 3D laser scanner techniques, which provide large amount of data quickly and accurately. Experimental results obtained on a romanesque church in Spain, are also given to illustrate the usefulness of the approach.

KEYWORDS: 3D surveying, Heritage documentation, laser scanning, 3D snake.

INTRODUCTION

Obtaining three-dimensional models of buildings, their environment and civil works in general is a matter of growing interest for documenting construction activities (El-Omari and Moselhi, 2007). The application of these models is known to be essential in a near future. But nowadays, the real usability of all these 3D data as source of documentation is not clear, since the graphical information managed by the construction professionals often continues to be bidimensional (mainly elevations, plan views and cross sections). So, new methods are being developed in order to extract useful information from the 3D data. The application of such information ranges from technical use in architecture and civil engineering, to multimedia divulgation. Recent advances in laser scanning technology, photogrammetric techniques and related 3D processing algorithms allow extracting huge amount of accurate measurements that reflect with great detail the complexity of relevant buildings.

In the present paper, an approach for accurate plan extraction from 3D models is presented. The main objective of the present work is to obtain detailed plans and layouts of constructions (more specifically, of cultural heritage buildings). These plans include stone-by-stone drawings, complete delineation of features and accurate cross sections. This method requires reduced human intervention and computational resources. The proposed procedure is primarily focussed on processing meshes from 3D laser scanner data, but could be applied to any kind of 3D mesh. Figure 1 shows part of the data acquisition process.

Figure 1: Data acquisition process (exterior and interior)

Feature lines are usually found using curvature analysis, as is outlined in the present paper. A more complex task consists in obtaining stone-by-stone plans, which is one of the main goals of this work. To this aim, 3D snakes are used in a novel way in order to maximise the information that can be extracted from 3D data. The algorithm is driven upon prior information about the building. In concrete, the generic structure of the snakes is adapted upon prior knowledge about the stones (dimensions, shape, colour). In this way, a directed search to suitably find the exact contour of the stones is carried out.

Some other specific tools developed to obtain elevation plans and cross sections of the building in a largely automated way, are also presented. These tools allow the results to be exported in dxf format, one of the most extended standards in architectonic delineation. Thus, a comprehensive documentation of the building is obtained. All these tools have been designed to be computationally efficient, so that they can deal with the great amount of data that must be processed.

The rest of the paper is organised as follows. Related and previous works are first discussed in Background Section. The 3D snake approach is presented in proposed Methodology Section. Feature line extraction and other specific tools are outlined in that same section. Achievements and some practical details are discussed in the experimental results section. Finally, critical thoughts and future trends are summarised in the conclusions section.

BACKGROUND

Obtaining 3D models

The use of laser scanners and photogrammetric techniques have eased the obtaining of 3D models. Processing these models to extract plans is a matter of growing interest. As mentioned above, the current paper is primarily focused on data obtained through laser scanning. Two main approaches are used for laser scanning in construction: time-of-flight and phase difference. Any of these acquisition technologies is assumed in this paper, since the presented procedures work in both cases. The point cloud obtained can then be filtered and processed to generate a polygonal model consisting of a triangle mesh that faithfully describes the original building. As an example, a shaded 3D model of the church measured in this work is shown in figure 2.

Figure 2: Different views of the generated 3D model of Santa Maria de Mave.

Finally, colour information can be added to the mesh using a texture mapping procedure or the colour information provided by the scanner.

3D Snakes

Energy-minimizing active contour models, commonly known as snakes, were originally proposed by Kass et al. (1988) and have been widely used for image segmentation and feature extraction. A snake is a dynamic curve that evolves iteratively, until a minimum of a specified energy function is reached.

In concrete, given a parameterisation of a snake $v(s) = (x(s), y(s))$, the evolution of the snake through time is controlled by minimizing its associated energy:

$$E_{snake}(v) = \int [E_{int}(v) + E_{ext}(v)]ds \qquad (1)$$

where internal energy of the snake (E_{int}) is related to the smoothness of the curve and external energy (E_{ext}) is related to the features of interest (Lee and Lee, 2002).

Several extensions of the original snake model have been investigated in image processing, like the one described by Cohen (1991). In this case an inflation force is added to make the contour grow in order to avoid local minima. This way, suggesting a good initial contour is not required, and selecting a small contour inside of the desired shape becomes suitable.

Active contour models have been extended to 3D meshes (Milroy et al. 1997). Some problems have to be solved for extending the snakes from 2D images to 3D mesh surfaces. First, the greater the connectivity of a 3D mesh is not regular, which is not the case in a 2D plane grid. Second, the internal energy terms must be defined in local surface tangent-planes. Third, the extra forces have to be calculated upon mesh features, instead of intensity image features. And finally, the snake must be restricted to lie on the mesh at the energy function minimum (Liu et al., 2006).

Snakes on triangular meshes have been used to detect features where a certain property, such as curvature, changes drastically, thus allowing the detection of sharp edges and peak vertices. In this work, the surface region surrounding the snake is parameterised, then the energy function is minimised and the motion of the snake in 2D is computed; finally, the snake is remapped back onto the 3D mesh. Other more recent research has also considered snakes for triangular meshes. In Jung and Kim (2004), snakes move step-by-step, from one mesh vertex to another, in order to avoid parameterisation artefacts. Moreover, snakes are given the ability to change their topology, thus allowing a given snake to split into multiple separate ones when appropriate. Based on this framework of parameterisation-free active contour models, a new representation and method for evolving snakes on triangular meshes is proposed in Bischoff et al. (2005). In this method, collision detection is enabled and topological controls such as snake merging and splitting is supported constraining the vertices of the snakes to move along mesh edges. However, as with all active contour models, the final snake is only locally optimal.

Feature lines

There are several techniques to extract feature lines on 3D models. Some of them are based on classification operators such as Hubeli and Gross (2001), other ones are based on curvature (Kobbelt et al., 2001), and others are based on principal component analysis (Gumhold et al., 2001). Our approach to feature line extraction is based on a curvature analysis of the 3D surface similar to Kobbelt et al. (2001), but using optimised algorithms from Ohtake et al. (2004) and Rusinkiewicz (2004).

PROPOSED METHODOLOGY

3D Snakes with prior information

The available prior information of the building is used to drive the algorithms. The major characteristics of the stones (size, shape, colour) are introduced into the generic snake formulation. The objective is to carry out a directed search to better find the exact contour of the stones.

Traditional process require the accurate selection of at least four points inside the target stone (obtaining a rectangle) or, usually, the selection of a significantly larger number of points if a more detailed draw is looked for. In contrast, selecting only one point inside the current stone is required by the proposed method. This way, a stone-by-stone plan drawing can be obtained readily, in a fast and easy way.

Some specific prior knowledge about the classes of the objects to digitise and their possible shapes has been introduced by Blacke and Isard (1998) into the definition of the active contours in 2D. In the present paper, this idea is generalised to 3D meshes and new terms of energy are introduced, as is discussed below.

Analogously to an image snake, a 3D geometric snake is represented by $v(s) = (x(s), y(s), z(s))$ and the corresponding functional becomes:

$$E_{snake}(v) = \int [E_{int}(v) + E_{mesh}(v)] ds \qquad (2)$$

The feature energy (E_{mesh}) is determined by the definition of the desired features. In our case, curvature changes are looked for in order to find crests and valleys in the mesh.

Moreover, some additional forces are included to the 3D snakes in order to detect robustly all the stones in the mesh. Specifically, we have introduced an angle energy favouring those vertexes in specified angles. So, for example if regular stones are looked for, 0º and 90º angles are used. If the stones of an arch are looked for, a 45º angle can be used. This energy must not be a very rigid requirement as we look for the exact contour of the stone and it can be oblique or irregular. Therefore a range of angles is allowed.

Furthermore, a colour related energy has been incorporated to the meshes when colour information is available. As a general rule, it can be established that an individual stone is homogeneously coloured, therefore this energy favours the edge detection based on checking the colour of the neighbourhood.

Finally, an energy based on the size of the stone is added. This is done by establishing a roughly minimum and maximum size through a new term of energy. The value of this term will be zero when the size of the snake lies between the specified minimum and maximum values. This energy term is similar to the inflation force described by Cohen (1991) but extended to meshes and adding upper and lower limits.

It is important to remember that the evolution of the snake is conditioned by the minimizing of all the different energies involved. In our method specific weights are assigned to every term in order to prioritise the importance of the different searched features.

The advantages of snakes are that implementations are typically very fast, and explicit models provide direct control over the snake. However, snakes suffer from some inconveniences: they are local in nature, and are prone to find local minima and thus, are highly dependent on the initial contour. It is well known that methods to optimise snakes using gradient descent are inherently local, as finding the global minimum is not guaranteed. With the added energies terms, these problems have been greatly reduced.

Crests and valleys

Very often, the documentation of construction works is still done by means of traditional 2D plans. But increasingly used three-dimensional data makes possible to have more detailed information about the works and buildings in question, as well as provide valuable parameters as distances, areas, volumes, earth movement, wall thickness and slopes. Using these 3D data is possible to obtain elevations and cross sections by intersecting the measured 3D models with the desired plane. Also, feature line detection allows extracting the most relevant information of the model while avoiding the handle of large amounts of information

The calculation of curvature gradients has been used to detect automatically these feature lines. The 3D meshes consist of a collection of indexed vertices, edges and faces. To evaluate the curvature of a vertex, his neighbourhood is checked. Specifically, the works of Rusinkiewicz (2004) have been considered. It has been assumed that the normal by vertex is the average of the normals at the adjacent triangles. Also, the tensor of curvature of each triangle is calculated as the directional derivative of the surface normal.

There are two possibilities for a comprehensive delineation: the crests, that define the outer boundary of profiles and the valleys, that define the innermost part (joints). Both of them help to visualise correctly the constructive details of the model. In our application crests and valleys are shown with different colours and are exported in different layers for easier interpretation. In both cases, a threshold may be chosen to better select the more representative lines. The obtaining of crests and valleys is completed using the formulae of Ohtake et al. (2004). The presence of both features is determined when the second order derivatives are equal to zero, which are calculated by approximation in finite differences. Finally, the nearby vertices are connected (crest or valley, as corresponds).

EXPERIMENTAL RESULTS

The results obtained on the Santa Maria de Mave, a romanesque church (Palencia, Spain) built between the years 1200 and 1208, are first shown and discussed. This church is one of the greatest jewels of the Spanish Monastic Romanesque. It has got three naves of three tranches each, cruise and triple header of semicircular apses. The style denotes a great influence burgundy in its original structure of ships side, with vaults of canyon of axis normal at the temple which was introduced by the Cistercians. The transept is occupied by the hemispherical dome on octagonal lantern.

Experiments have been carried out using a Leica HDS-3000 3D laser scanner (1800 points/sec, 360ºx270º field of view.), and a Canon PowerShot G6 digital camera (7.1 megapixel). InnovMetric PolyWorks v11 software has been used for building the initial 3D models from the measured points. The procedures presented in this paper have been implemented in C++ language. Performances have been tested in a 3 GHz, dual Intel Xeon computer under the Windows XP operating system.

A total amount of 31 3D scans (taken from a 20 m average distance, with 4 mm standard deviation; more 14 million points) and 135 photographs have been taken. Some additional results obtained from other churches are also presented.

The initial result of the process is a detailed colour 3D model of the building. 3D points are measured by the scanner (figure 1), then registered and filtered. Resulting points are meshed into triangles and the final colour model is shown in figure 2.

Both the inside and the outside of the church has been measured, and registered upon common points obtained through open doors and windows. The roof has not been measured since it was not required for the restoration work.

Feature lines can also be obtained upon a semiautomatic analysis of the surface curvature (Ohtake et al., 2004). An example is shown in figure 3.

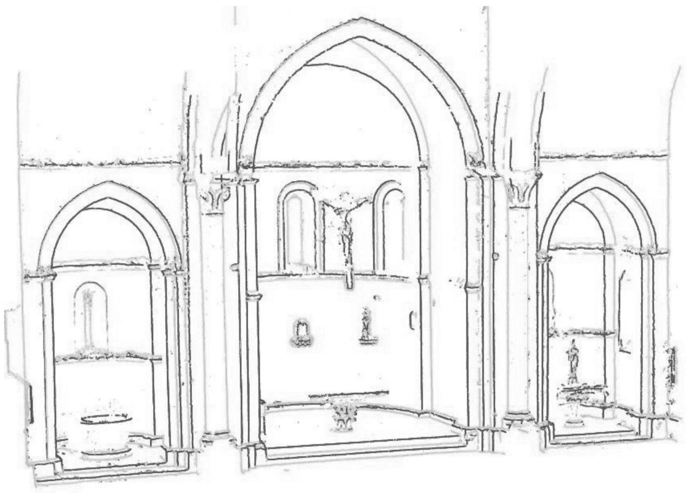

Figure 3: Crest (dark grey) and valleys (light grey) of the church's interior

Arbitrary sections can be obtained in a fully-automatic way. The result of intersecting the church model with a set of horizontal planes at two different heights is shown in figure 4. This result largely eases work such as plan drawing at different heights, and wall slope and thickness analysis.

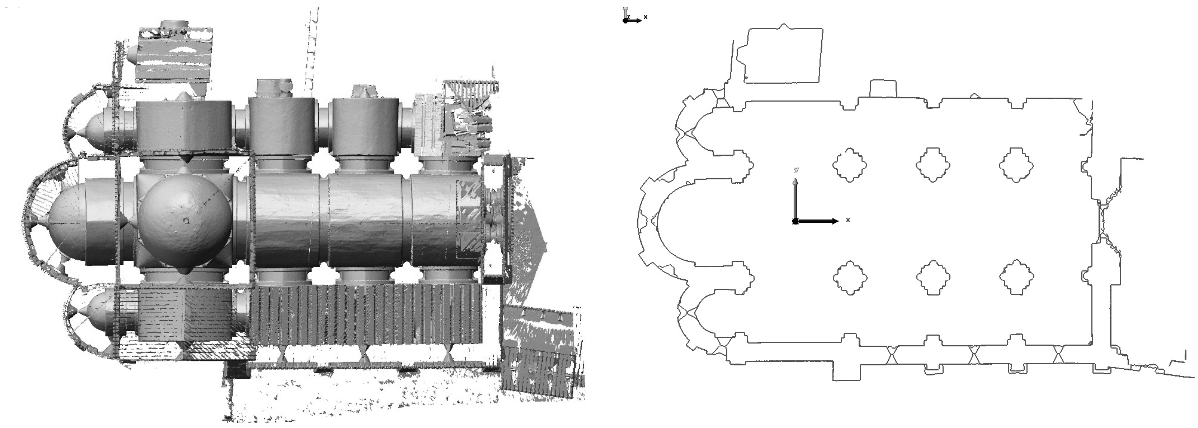

Figure 4: Plan view (left) and corresponding cross-section (right)

Some additional tools for manually drawing have been developed for completing or better defining areas where geometry is not sufficiently featured. Using these procedures, some AutoCad files are generated, where further retouching would still be possible.

3D snakes have been extracted to deliver a stone-by-stone plan of the church. In figure 5 some samples are presented, showing different kinds of stones (not just the typical ashlar) to demonstrate the validity of the approximation.

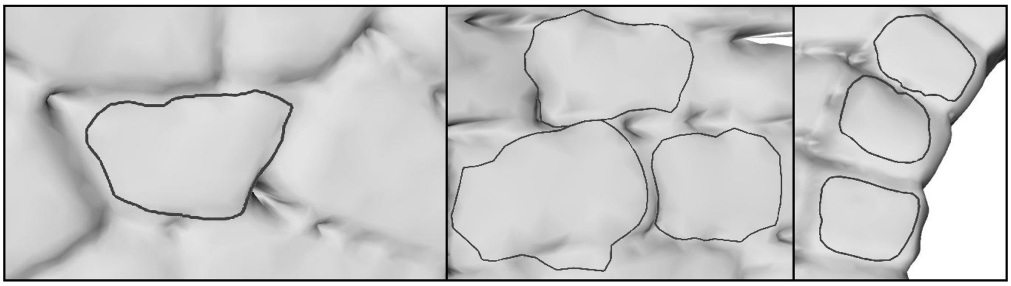

Figure 5: Samples of 3D Snakes applied to various stones' shapes

Orthophotos can also be readily obtained from coloured 3D models, by reprojecting them onto any arbitrary plane, towards a distant viewer. An example of north elevation of Santa Maria de Mave is shown in figure 6.

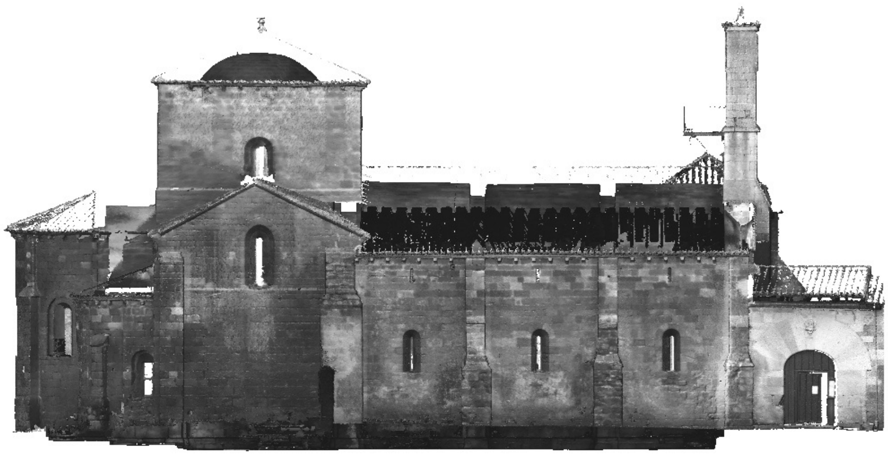

Figure 6: Ortophoto of North elevation of Santa Maria de Mave

CONCLUSIONS

The use of three-dimensional information in the construction sector is increasing and is becoming more important as it adds valuable information in cataloguing and documentation tasks.

A novel methodology has been presented, extending previous works on image snakes to 3D snakes and adding new terms in order to improve the stone delineation. The main idea of this approach is to apply 3D snakes to stone-by-stone plan extraction, using prior known information about stones, in form of additional energy terms. This new 3D snake formulation enable robust and precise extraction of stone contours.

Generic algorithms to extract feature lines are well known in the related bibliography but not so known about specific tools of construction documentation, as the ones presented in this paper. A method has been also presented.

Also, a briefly discussion of 3D model obtaining has been outlined, focusing on laser scanner.

A number of tools can operate on the obtained information, such as the automatic detection of large-curvature points. Furthermore, orthophotos may be readily obtained, which offer a significant help to architects and engineers in construction documentation.

Resulting 3D textured models allow detailed documentation of works and buildings to be obtained, along with valuable parameters such as distances, areas, volumes, earth movements, wall thickness and slopes. Also, feature lines, orthophotos and sections can be readily obtained.

All the developments of the presented methodology have been applied in a real documentation work conducted in Santa Maria de Mave church. The tools have been used satisfactorily by construction professionals of Santa Maria La Real Foundation under a big project related to cultural heritage buildings restoration in the north of Spain. The tests carried out have proved that more accurate and detailed plans can be achieved in a faster way with the proposed approach than traditional delineation techniques.

The presented approach is a work still in progress and some tools must be improved in order to increase their usefulness. With the current method, it is enough to select one point inside of the searched stone, but it would be desirable to automatically find these seed points. One possibility under development is just to mark the limits of a wall and the algorithms will try to find suitable seed points. Finally it would be desirable to improve the robustness of the approach with noisy 3D data.

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