Characterization of the 3-D information of Calyptogena shells

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ABSTRACT

We propose in this paper an application of multiresolution analysis techniques to extract information contained in the growth increments of a bivalve mollusk called: *Calyptogena*. The first stage consists in extracting a range image of the mollusk's shell using a 3-D scanner. Applying a multiresolution analysis enables us to localize precisely those growth increments by preserving relevant details. Moreover, interesting spatial and frequency properties of the multiresolution analysis underline information contained on the shell. Intra-individual variation and inter-individual variations are compared to assume some conclusions as for the ontogenetic evolution of the animal such as periodicities, which can be later related to certain regular changes in its environment.

Keywords: 3-D scanning, wavelet transform, multiresolution analysis, characterization of growth increments

1. INTRODUCTION

The development of 3-D digitalization techniques makes it possible to restore increasingly complex forms within the framework, for instance the design of an industrial product. In this case, the 3-D points cloud is a basis for a 3-D mesh in order to reconstruct a parametric surface model to be compared to the original conception model. The other way is to consider the 3-D points as a range image to be analyzed with 2-D methods. We choose this solution to study *Calyptogena*, a deep sea bivalve mollusk living (approximately at 3000 meters) in the vicinity of hydrothermal sources. More or less regularly spaced growth lines appear on their shell resulting from fluctuations of the accretion rate of the shell during the animal's development. By performing a multiresolution analysis on the range image, we are looking for a relevant biological signal. An additional algorithm is performed to improve the detail signal. The next section describes the range image acquisition, section 3 briefly introduces the principle of multiresolution analysis. The employed algorithm and the necessity of extracting a sub-image are explained in section 4.

2. RANGE IMAGE ACQUISITION

The acquisition of the shell's range image is performed with a three dimensional scanner (Replica 500 from 3-D Scanners) made up of three parts: a three axes travelling gantry, a single line laser projector and an acquisition system of the points. The acquisition of images is carried out by triangulation of the projection of the laser beam on the object using two CCD cameras. The volume of work permitted by this scanner is $500mm$ in X, $500mm$ in Y and $275mm$ in Z with a minimal measurement step of $50\mu m$ in X and Y. Displacement along the Z axis can be automatically adjusted in order to optimize the focusing of the laser line on the object thus guaranteeing a measuring accuracy of $20\mu m$. The head of the 3-D Scanner is shown in Figure 1.

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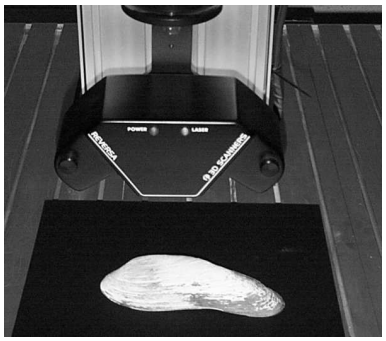

Figure 1. Head of the 3-D Scanner

Our studied specimens have a length going from 100 to 200mm, the valve shown in Figure 1 is approximately 180mm in length and 70mm in width. The acquisition gives a range image where the gray level indicates the heigth of the shell. The images are processed to reduce noise's spikes with a median filter and to interpolate some voids. Indeed, points that can't be acquired are considered as voids by the scanner.

3. MULTIRESOLUTION ANALYSIS PRINCIPLE

For the ten last years, the wavelets and multiresolution analysis have known an important development. Nowadays, image analysis could not occur without such a tool, concerning various fields from images compression (new JPEG 2000 format) to the 3-D mesh grids simplification[1](image synthesis). This part briefly describes the multiresolution analysis diagram and the algorithm used.

3.1. Analysis scheme

A multiresolution analysis[2,3] is defined as a family of vector subspaces fit into each other in such a way that the transition from one subspace to another is the result of a scale change. These subspaces are called subspaces of approximation at the scale $j(j \in \mathbb{Z})$ and check the following properties:

$$... \subset V_1 \subset V_0 \subset V_{-1} \subset ... \subset V_{j+1} \subset V_j \subset ... \tag{1}$$

$$\overline{\bigcup_{j\in\mathbb{Z}}} \mathcal{L}^2(\mathbb{R}) \tag{2}$$

$$\overline{\bigcap_{j\in\mathbb{Z}}} \{0\} \tag{3}$$

The dyadic multiresolution analysis leads to:

$$\forall j \in \mathbb{Z}, \text{if } f(x) \in V_j \Leftrightarrow f(2^{-1}x) \in V_{j+1} \tag{4}$$

It means that the subspace V_{j+1} contains signals two times coarser than the subspace V_j. Another property of the analysis scheme is the stability by translation:

$$\forall j \in \mathbb{Z}, \text{if } f(x) \in V_j \Leftrightarrow f(x-k) \in V_j \tag{5}$$

There is a function φ, called scaling function, that generates an orthonormal basis of V_j, by dilatation and translation. This analysis is enhanced by any subspaces called detail subspaces W_j:

$$V_{j-1} = V_j \oplus W_j \tag{6}$$

$$\mathcal{L}^2(\mathbb{R}) = \bigoplus_{j\in\mathbb{Z}} W_j \tag{7}$$

$$\forall j \in \mathbb{Z}, \text{if } k \neq j \text{ then } W_j \perp W_k \tag{8}$$

There is also a function ψ called wavelet function which generates an orthonormal basis of W_j by dilation and translation. Multiresolution analysis enables to project a function at different scales of approximation and conserving the details lost.

3.2. The Mallat's algorithm

Rather than projecting a function on different subspaces, this algorithm leads to apply directly any filters to calculate successive approximations and details. $\varphi(x)$ is a function of V_0. As $V_0 \subset V_{-1}$, it is possible to project $\varphi(x)$ on V_{-1}. The coefficients of this projection give a numerical sequence $h[n]$ considered as the impulse response of a numerical filter. In the same way, $\psi(x)$ is a function of W_0 and since $W_0 \subset V_{-1}$, it is possible to project $\psi(x)$ on V_{-1}. The coefficients of this projection give a numerical sequence $g[n]$ also considered as the impulse response of a numerical filter.

Let's call a_n^j the projection coefficients of f on the approximation subspaces and d_n^j the projection of f on the detail subspaces. Mallat[4] demonstrates that:

$$a_n^j = \sum_l \tilde{h}[2n-l]a_l^{j-1} \tag{9}$$

$$d_n^j = \sum_l \tilde{g}[2n-l]a_l^{j-1} \tag{10}$$

$$\text{where } \tilde{h}[n] = h[-n] \text{ and } \tilde{g}[n] = g[-n]$$

Thus, to calculate the approximation and detail coefficients at successive scales, the signal is convolved by some numerical filters and is downsampled by a factor of 2. Conversely, the multiresolution analysis has properties of reconstruction: starting from all the detail coefficients and all approximation coefficients, we can rebuild until obtaining the original approximation. This process is called reconstruction, or synthesis. The multiresolution analysis can be extended to the 2-D by a tensor-product of two 1-D subspaces. The Figure 2 shows that separable analysis leads the image to be decomposed by four sub-images: one image of approximation and three detail images (horizontal, vertical and diagonal detail coefficients).

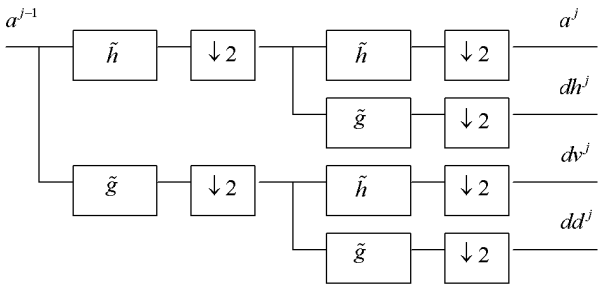

Figure 2. One step decomposition of Mallat's algorithm

4. APPLICATION TO *CALYPTOGENA* ANALYSIS

4.1. Principle

The process used was developed by Diou et al.[5] for the study of shells living in fresh water. Firstly, a multiresolution analysis is performed to compute detail and approximation coefficients at different scales. Secondly, the reconstruction is done with only the detail coefficients corresponding to the explored scale (see Figure 3).

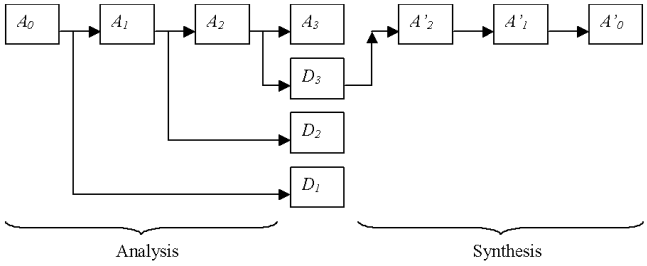

Figure 3. Principle of detail image

Therefore, the result gives an image where the details are advantaged without the approximation of the shell's shape. Moreover, thanks to its properties of time-frequency localization, the multiresolution analysis brings interesting information on period and localization of growth increments.

4.2. Selection of a suitable sub-image

The study carried out by Diou et al.[5] concerned fresh water bivalves, and gave reliable results. In that case it was easy to compare periodicities with biological cycles of growth increments since the biological parameters of the studied species were accessible. The study of *Calyptogena*'s growth increments is not so easy for several reasons. First, these mollusks are living at great depths (more than 2000 meters) and it is impossible to breed them and to access their biological parameters. Second, it was shown that the growth increments may record both biological variations and the fluctuations of the hydrothermal sources, from which we have only little knowledge concerning their possible periodicity[6] . Third, the geometry of the shells prevents us to perform a reliable analysis without following the growth direction given by the growth lines. Consequently, we had to apply additional treatments to obtain suitable results.

The range image is first filtered by a multiresolution thresholding.[2,7] After having decomposed the image by the discrete wavelet analysis, the detail coefficients are threshold to keep the more significant coefficients. Indeed, it is proved that the signal to noise ratio is higher on the highest coefficients. The detail image is then reconstructed as shown previously in Figure 3.

During the multiresolution analysis and the synthesis, we used the "Symlet" basis introduced by I.Daubechie.[8] This basis has good properties: orthogonal, compact support and nearly symmetric. Nevertheless, because of the shell's shape and the use of discrete wavelet transform which is obtained by a tensor-product, the smoothness along the increments isn't seen. The discrete wavelet transform suffers from poor directionality because coefficients reveal only three spatial orientation: horizontal, vertical and diagonal.

To overcome this difficulty a sub image is extracted from the original one to get the growth increments approximately in a same direction. However, the selection has to respect biological criteria. Indeed, the growth directions of *Calyptogena* are going from the hook (start point of shell's growth and articulation of the two valves) to the palleal edge (external edge of the shell), as shown in Figure 4.

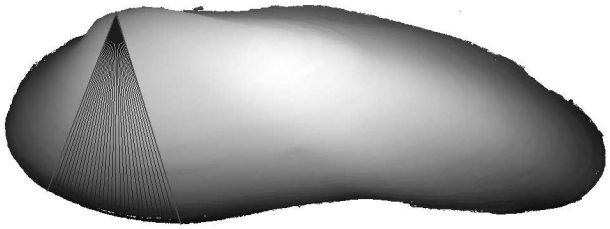

Figure 4. Example of different directions

Growth lines look orthogonal to the direction of growth from the hook to the edge. Therefore, a band is extracted from that direction minimizing the criteria: $c(\theta) = \hat{\sigma}_{col}/\hat{\sigma}_{lig}$, where $\hat{\sigma}_{col}$ and $\hat{\sigma}_{lig}$ are respectively the mean of the standard deviation along the columns and the rows of the detail image. The more increments are parallel to the columns and the more they are important from a line to another, the smaller the criteria is. Even if, in that case, the vertical details are the most relevant, horizontal and vertical details are kept in order to restore the increments' curvature. The criteria is computed on the detail image with an angular range: Figure 5 shows results from the computation, the sub-image is a band selected at 92 degrees.

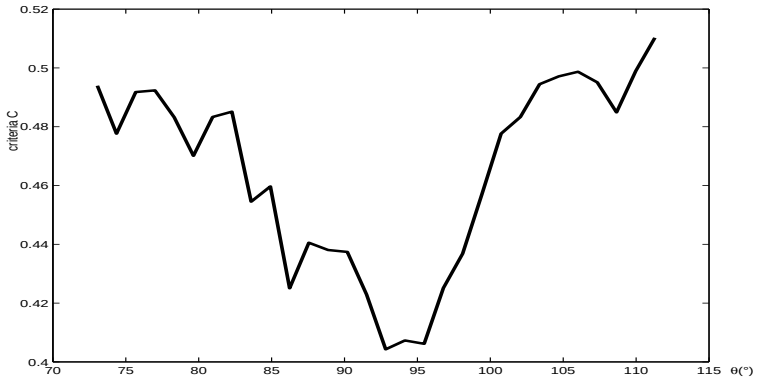

Figure 5. Evolution of the selection criteria c

4.3. Results

The previous method is applied to a sample of valves collected by the submersible "Nautile" along the internal wall of the subduction zone which borders the Central America and South America coast during two oceanographic cruises: "Nautimate" off the West coast of Mexico and "Andinaut" off Peru.

First, the algorithm is applied on the shells to obtain a suitable sub-image as shown in Figure 6. The biologist selects the hook, the upper and lower angle to determine the range of calculation. Then, sub-images are automatically extracted from the hook to the palleal edge and criteria is computed to select the suitable sub-image.

Figure 6. Extracted sub-image

The Multiresolution analysis is then performed to obtain a detail sub-image which highlights growth increments (Figure 7). The reconstruction is made with detail coefficients from scales 4 and 5.

Figure 7. Detail sub-image

Then, a spectral analysis is carried out on each detail sub-image to emphasize periodicities contained in the increments series. It reveals characteristic frequencies due to periodic fluctuations of the animal's environment. Figure 8 recapitulates the results obtained on two individuals from the Mexican mission.

	NM09CII5 (valve 1)	NM09CII5 (valve 2)	NM09CII4 (valve 2)
Best angle θ	92.8	91.4	96.7
Hook-Palleal edge distance	$5.99cm$	$6.28cm$	$4.85cm$
Principal peak period	$2.9mm$	$2.9mm$	$2.8mm$

Figure 8. Summary of the characteristics of *Calyptogena*

We can assume that the same periodic signal is contained on the both valves (*Calyptogena* NM09CII5). Another specimen (*Calyptogena* NM09CII4) reveals the same period of its growth increments. Information contained on these two specimen show a periodicity of environment fluctuations.

5. CONCLUSION

The multiresolution analysis is adapted to characterize the growth increments of *Calyptogena* for several reasons. First of all, by preserving only the relevant details, the detail image doesn't take care of the whole curve of the shell. In addition, space-frequency properties of the wavelet transform enable to both localize increments and study periodicity information. Nevertheless, because of the shells' geometry and the low amplitude of the growth increments, we had to overcome these problems. Firstly, we take advantage of the multiresolution analysis to reduce noise of images by applying a multiscale thresholding. Secondly, an algorithm is performed to select the best direction to extract a sub-image. This one is then analyzed to characterize growth increments of *Calyptogena*. A spectral analysis is performed on the final sub-image to highlight periodicities. Hence, the same frequency peak was present on both valves of an animal, showing the biological information contained in growth increments. Moreover, this same frequency was found from another specimen originating in the same site. The growth increments from the two animals record the same fluctuation.

Future work will consist in improving our multiresolution analysis using nonseparable wavelet bases and in applying this algorithm on numerous specimens to test the connection of the signal to biological processes or to external fluctuations of the environment.

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