Reliable Classification Of Brachiopods Through Curvature Scale Space And Level-Set Method

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***Abstract*- Brachiopods have a lateral outline which is quite important in systematic studies. It is often assessed by a qualitative evaluation and linear measurements, which are not clear enough and precise for describing the shape of the shell and its changes. In this work we shed light on a new approach based on digital image processing of these species. Our approach includes two steps. The first is to determine the contour of the species from their 2D images using the implicit active contours (Level set). The second step is to use the CSS (Curvature Scale Spaces) to index curves. This new mathematical model reported here presents a suitable morphologic descriptor which allows us to: (1) express a rigorous morphologic quantitative assessment; (2) emphasize the various differences between different shapes.**

Keywords- Brachiopods, Image, Active Contour, Level-Set, CSS.

I. Introduction

The analysis is the quantification of the organization's morphology which forms an important aspect in the paleontological studies. On the one hand, they make it possible to understand the biodiversity in its morphological dimension. On the other hand, they highlight the morphological transformations undergone during the biological evolution. Historically, the form was encircled by a purely descriptive approach based on the qualitative evaluations of the morphological change starting from simple images. This approach was replaced gradually by the biometric methods having leads to the populated design of the fossil species. The variables used in such methods are linear dimensions, angles, surfaces and ratio or combination of dimensions. But, these biometric descriptors are insufficiently informative since they give only one approximate quantitative representation of the form and its changes. An alternative approach of the quantitative description of morphology is the multivariate analysis based on the methods of the analysis of the form classified in two categories: the geometrical morphometry and analysis of contour. The first based on the location of points homologous on the organizations and the quantification with their morphological differences (Bookstein77), (Bookstein85), (Bookstein91). The second is called analysis contour subdivided in two classes:

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analyzed by Eigenshape defined initially by (Lohman83) its basic principle is to calculate the average shape of a population. This technique consists in applying the algorithm of (Zahn and Roskies72) to produce pairs of coordinates to regular intervals around a contour beginning to one some homologous point available, and to use the tangent angle of Bookstein. This method raises many difficulties of interpretation.

- Analysis of Fourier which consists in approaching the form by a goniometrical function defined by a sum of terms of sine and cosine. This function is broken up into a series of amplitude of harmonics and phases or into a series of coefficient of Fourier being useful like variables for the quantitative analyses. The first application of such a method for the morphological study of the fossils is that of (Kaesler and Waters72). Since, many applications succeeded but this method is valid right for the forms regular (convex external format), indeed when morphologies become complex, it is not more possible to use such descriptors see (Bachnou99).

We present in this work a new method for classification of fossil the species known as Brachiopods. This method comprises two stages: The first is the detection of the external contour of the Brachiopod starting from their image 2D by one of the techniques of active contour, and more precisely the technique of the whole of level (Level-Sets), the latter is based on the equation of wave propagation of the face, whose deformation depends on the geometry of the structure. This technique was developed by Osher and Sethian in (Osher and Sethian88) and was used for the segmentation of image which constitutes a great step in the treatment and the interpretation of the images. The second stage is the characterization of contour by the descriptor CSS (Curvature Scale Space) which has undeniable advantages of invariance, compactness, effectiveness and stability.

This article is organized in the following way: In the first part we approached the concept of active contours and more precisely the model of active contours based areas. We thus defined the functional calculus of energy to be minimized. The minimization of energy by the method of the level lines (Level-Set) is treated in the second section, after having made a recall on this method. In the third part we implemented the point on the setting of the descriptor CSS. We tested this method on real images of the fossils, this model gives results which are very satisfactory and encouraging ones, in terms of quality of image and the possibility to answer a request.

II. THE MODEL OF ENERGY

The segmentation of image is an operation of picture treatment that has as an objective to reassemble pixels between them according to of the meadow-definite criteria. Pixels are regrouped thus in regions, that constitute a paving or a partition of the picture. It can be for example about separating objects of the bottom. If the number of classes is equal to two. The segmentation is a primordial stage in treatment of picture. To this day, it exists numerous methods of segmentation, that one few citers:

1) Active contours based contours
2) Active contours based regions

The first method using the active contours is based contours exclusively (Kass et al.88). It doesn't permit a spatial information utilization intern and external to the contour. The method based region permits to introduce the global terms characterizing regions. It is therefore this method that we decided to use here. In the two cases, the active contour method consists in choosing a functional to minimize to make evolve a contour. Let's take the example of the segmentation of a picture in two regions Ω_{in} : the region containing objects to segment and Ω_{out} , the region of the bottom. The interfacing between these two regions is noted $C=\partial\Omega_{in}$. The two regions form a partition of the image, one has therefore $\Omega_{in}\cup\Omega_{out}\cup C=\Omega_{I}$. Who is the domain of the image and $\Omega_{in}\cap\Omega_{out}=\varnothing$. One can introduce a functional then general to minimize for the partition of a picture in two regions:

$$E(\Omega_{in},\Omega_{out},C)=\int_{\Omega_{in}} k_{in}(x,\Omega_{in})dx+\int_{\Omega_{out}} k_{out}(x,\Omega_{out})dx + \int_{C} k_b(x)da$$

In this criterion, k_{in} designate the descriptor of objects to segment, k_{out} the descriptor of the region of the bottom and k_b the descriptor of the contour. In our study we considered descriptors proposed by Chan and Vese in (Chan and Vese2001) for the segmentation of a image in two regions in addition terms of regularization of Munford and Shah (Munford and Shah89). So we introduce the energy function:

$$E(C,c_1,c_2)=\mu Length(C)+\nu\, Area(inside(C)) + \lambda_1\int_{inside(C)}\left|u_0(x,y)-c_1\right|^2 dxdy + \lambda_2\int_{outside(C)}\left|u_0(x,y)-c_2\right|^2 dxdy$$

Where u_0 is the image and $\mu\geq 0,\ \nu\geq 0,\ \lambda_1>0,\ \lambda_2>0$ are fixed parameters. So our goal is to find C, c_1 , c_2 such that $E(C,\ c_1,\ c_2)$ is minimized.

III. LEVEL SET METHOD

A. Definition

The method level-set is an analytic work setting working on the geometric evolution of objects. Instead of to use a representation classic Lagrangienne to describe geometries, the method level-set described them through a scalar function ϕ , in the formalism of level set, the curve, C is not parametric, but implicitly definite by the bay of a superior dimension function ϕ :

$$\phi:\ \begin{array}{l}\Omega\subset N^2\rightarrow\Re\\ (x,y)\ \rightarrow\phi(x,y)\end{array}$$

The contour to one instant t is defined then by the curve of level zero of the function ϕ to this instant.

The main advantage of this method is the ability to automatically manage the change of topology of the curve evolution. Curve C can be divided into two or three curves, conversely several curves can merge and become a single curve.

Another advantage is that geometric properties of the curve are easily determined from a particular level set of the surface. For example, the normal vector for any point on the curve C is given by:

$$N=\frac{\nabla\phi}{|\nabla\phi|}\quad (1)$$

And the curvature K is obtained from the divergence of the gradient of the unit normal vector to the front:

$$K=div(\frac{\nabla\phi}{|\nabla\phi|})\quad (2)$$

Finally, another advantage is that we are able to evolve curves in dimensions higher than two. The above formulae can be easily extended to deal with higher dimensions. This is useful in propagating a curve to segment volume data.

B. Equation Of Evolution

It has been shown in (Sethian99) that $C(t)$) evolves according to equation $\frac{\partial C((x,y),t)}{\partial t}=F.N$ then the implicit representation respects the equation: $\frac{\partial\phi((x,y),t)}{\partial t}=F.\left|\nabla\phi((x,y),t)\right|$

Where de set $\{(x,y),\ \phi_0(x,y)=0\}$ defines the initial contour, and F is the speed of propagation. Function level set initial is gotten by the utilization of the distance signed to curve initial:

$$\phi_0 = \begin{cases} -d((x,y),C_0)\ if\,(x,y)\in \text{ inside(C)} \\ +d((x,y),C_0)\ if\,(x,y)\in \text{ ouside(C)} \end{cases} \quad (3)$$

C. Level-Set Reformulation Of The Model

For the level set formulation of the variation active contour model, we replace the unknown variable C by the unknown variable, and using the Heaviside function H, and the one dimensional Dirac measure defined respectively by:

$$H(z)=\begin{cases}1, \text{ if } z\geq 0\\ 0, \text{ if } z<0\end{cases} \qquad \delta=\frac{d}{dz}H(z)$$

In order to compute the associated Euler- lagrange equation for unknown function φ, our numerical simulations involve regularized version of H and δ, denoted here by H_ε and δ_ε, as $\varepsilon\to 0$. In this paper, we approximate the regularization of Heaviside by:

$$H_\varepsilon=\frac{1}{2}+\frac{1}{\pi}\ \arctan(\frac{z}{\varepsilon}) \quad \text{and} \quad \delta_\varepsilon=\frac{dH_\varepsilon}{dz}$$

We express the terms in the energy E in the following way:

$$\begin{aligned} E(C,c_1,c_2) &= \mu\int_\Omega \delta_\varepsilon(\phi(x,y))\left|\nabla\phi(x,y)\right|dxdy \\ &+\nu\int_\Omega H_\varepsilon(\phi(x,y))dxdy \\ &+\lambda_1\int_\Omega \left|u_0(x,y)-c_1\right|^2(1-H_\varepsilon(\phi(x,y)))dxdy \\ &+\lambda_2\int_\Omega \left|u_0(x,y)-c_2\right|^2)H_\varepsilon(\phi(x,y)dxdy \end{aligned}$$

The constants c_1, c_2 are the averages of u_0 in $\phi<0$ and $\phi\geq 0$ respectively. So they are easily computed as:

$$c_1(\phi)=\frac{\int_\Omega u_0(x,y)(1-H_\varepsilon(\phi(x,y)))dxdy}{\int_\Omega (1-H_\varepsilon(\phi(x,y)))dxdy} \quad (4)$$

$$c_2(\phi)=\frac{\int_\Omega u_0(x,y)H_\varepsilon(\phi(x,y))dxdy}{\int_\Omega H_\varepsilon(\phi(x,y))dxdy} \quad (5)$$

Minimizing $E(C)$ with respect to ϕ fields the following Euler- Lagrange equation for ϕ, parameterize the descent direction by time, t>0. Equation in $\phi(t,x,y)$ with $\phi(0,x,y)=\phi_0(x,y)$ is :

$$\begin{cases} \dfrac{\partial\phi}{\partial t}=\dfrac{dH_\varepsilon}{dz}(\phi)[\ \ \mu div\left(\dfrac{\nabla\phi}{|\nabla\phi|}\right)-\nu-\lambda_1(u_0-c_1)^2 \\ \qquad\qquad +\lambda_2(u_0-c_2)^2\ \ ] \\ \dfrac{dH_\varepsilon}{dz}(\phi)\dfrac{\partial\phi}{\partial n}=0\ \ if\ \ t>0\ \ and\ \ (x,y)\in\partial\Omega \\ \phi(0,x,y)=\phi_0(x,y)\ \ \ if\ \ (x,y)\in\Omega \end{cases} \quad (6)$$

We suggest the following approximating schemes:

$$\frac{\phi^{n+1}{}_{i,j}-\phi^n{}_{i,j}}{\Delta t}=\frac{dH_\varepsilon}{dz}(\phi^n{}_{i,j})\left[\mu K(\phi^n)-\nu-\lambda_1(u_{0,i,j}-c_1(\phi^n))^2 +\lambda_2(u_{0,i,j}-c_2(\phi^n))^2\right] \quad (7)$$

Finally, the principal steps of the algorithm are:

Choose epsilon

Initialize ϕ^0 by ϕ_0 , n=0

Repeat until $\int_\Omega(\phi^{n+1}(x,y)-\phi^n(x,y))^2dxdy<epsilon$

Compute $c_1(\phi^n)$ and $c_2(\phi^n)$ by (4) and (5)

Compute curvature term $K(\phi^n)$ by (2)

Compute ϕ^{n+1} by (7)

End

IV. APPLICATION

To study the performance of the Level-Set method, we apply the algorithm developed to detect the outer contour of the Brachiopod from their two-dimensional images. The

Fig.1. Initial Image

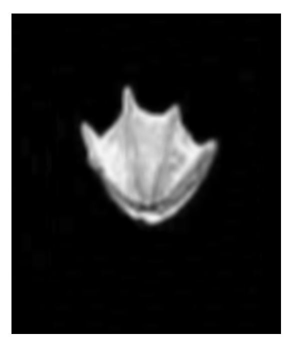

Fig.2. Filtred Image

image to segment contains several regions, so it is necessary to go through a preprocessing to adapt the image model of energy used here. For that reason we applied to the original image a medium filter.

After the filtering operation, we apply the image to the Level-Set method described above in order to extract the outer contour of the brachiopod. The initial contour used in our case is a circle containing the object as shown in Figure (3):

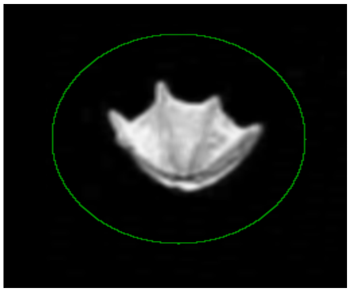

Fig.3. Initial contour

Figures (4) and (5) are two intermediate steps, and figure (6) gives the results obtained by the method of Level-Set. We can easily notice that the contour of the initial curve is perfectly shaped in the form of the outer contour of brachiopod.

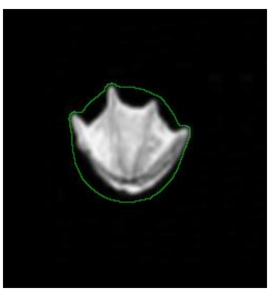

Fig.4. Intermediate step

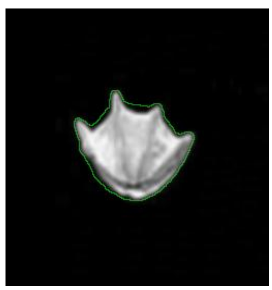

Fig.5. Intermediate step

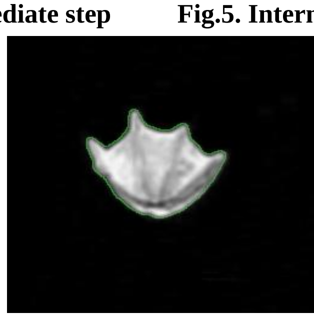

Fig.6. Segmentation by Level-Set

V. CLASSIFICATION OF BRACHIOPOD

Once the contour of the Brachiopod is determined we think of as characterizing a specific descriptor. Note that if the shape is convex Fourier analysis gives a stunning result, which is to approximate the shape by a trigonometric function defined by a sum of terms of sinus and cosines. This function is decomposed into a series of Fourier coefficients used as variables for quantitative analysis. By cons, if the shape is concave, as if here we chose the handle CSS (Curvature Scale Space) to index the shapes.

The CSS descriptor was originally proposed by Mokhtarian in (Mokhtarian92) and selected for the MPEG-7. Its basic principle is based on the description of a concave curve and its subsequent filtering in order to monitor these concavities. The role of filtering is to smooth the curve and thus gradually eliminating its ventricles. The shape of the brachiopod is described by a closed curve representing the contour. Each item is identified by its curvilinear abscissa on this standard curve $C = \{x(u),\ y(u);\ u \in [0,1]\}$.

The function C then undergoes filtering by a Gaussian kernel and it looked for points of inflection of the curve to characterize their shape. These inflection points are obtained when the curvature at different scales is equal to 0.

With

$$k(u,\sigma) = \frac{X_u(u,\sigma)Y_{uu}(u,\sigma) - X_{uu}(u,\sigma)Y_u(u,\sigma)}{(X_u(u,\sigma)^2 + Y_u(u,\sigma)^2)^2}$$

Where

$$X(u,\sigma) = x(u) * g(u,\sigma) \text{ and}$$

$$Y(u,\sigma) = y(u) * g(u,\sigma)$$

According to the properties of convolution, the derivatives of every component can be calculated easily:

$$X_u(u,\sigma) = x(u) * g_u(u,\sigma)$$

and

$$Y_u(u,\sigma) = y(u) * g_u(u,\sigma)$$

$g(u,\sigma)$ is a Gaussian kernel of with σ.

These turning points are used to iteratively build an image (image called CSS) by stacking successive layers of points where each layer represents the inflection points found in a number of filters given. So the CSS image is obtained, the horizontal axis, the curvilinear abscissa and ordinate, the number of filters. Figure (7) shows the CSS image obtained to describe the contour of brachiopods.

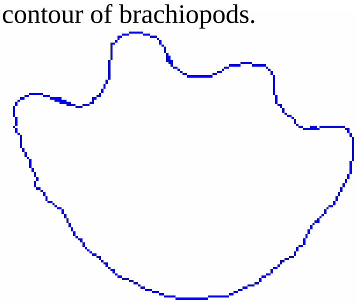

Fig.7. Contour

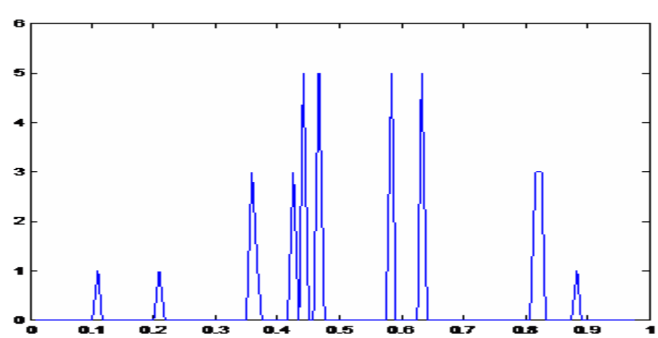

Fig.8. CSS image

Each peak represents a concave contour. The curvilinear abscissa ensures invariance in translation and scale. The rotational invariance is also guaranteed by a lateral shift of the peaks in the CSS image. Small peaks obtained in the CSS image correspond to the noise in the contour.

VI. Conclusion

In this work, we could determine the external contour of the Brachiopods with the help of the level set techniques which seem more powerful than the other techniques used previously in (Sasaki91), (Crampton92), (Renaud el al.96), (Bachnou99).

When with the classification of these species, we adopted the technique based on the CSS which makes it possible to define a descriptor of these species which have a non-convex form, the thing which was impossible by Fourier's analysis.

VII. References

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