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WATERSHED AND H_{MIN} VALUES OF MORTAR FRACTURE SURFACES : EXPERIMENTAL RESULTS

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ABSTRACT

This paper propose an investigation of the watershed method linked to a h_{min}-h_{max} method using a geodesic reconstruction with multimodale images having their values in the real space R. It leads to correct automatic segmented images. One gives also a method to automate the process. Example is given based on civil engineering materials (mortars) observed by confocal microscopy.

Key words : 3D image, feature extraction, watershed, h_{min}, mathematical morphology.

INTRODUCTION

Segmentation, registration, pattern recognition and many other image analysis domains need to extract from the studied objects, specific features and characteristics. Although it is easy for the human eye to recognize two parts of the same object or the same object oriented in different conditions, by automatic image analysis with actual means (computer sciences, mathematics) it is so difficult that we cannot reproduce the same calculation with another set of images. Parameters of algorithms are always different. Moreover the most part of the developed operators, like in mathematical morphology, work only on specific images and are not adapted to another class of objects.

The studied characteristics are not simple features but often a combination of several of them. So an image must be considered as several functions $v_i=f_i(x,y,z)$, where v_i is a given value for the characteristic f_i at the point (x,y,z) in the image. We are talking about multimodal images, and for each mode, f_i function can be extended in four dimensions in order to binarize it. $f_i^b(x,y,z,v) = \delta$ with f_i^b the binarized function of f_i, (x,y,z) being the coordinates of the point in 3D discret space, v a value in R domain, δ a boolean value, $(x,y,z) \in N^3$, $v \in R$, $\delta \in \{0,1\}$.

Thus, in this paper we have chosen to study, develop and apply morphological operators which are generalized and can be used with all type of image functions f_i^b in order to use the same segmentation algorithm with any f_i function image.

The investigation of multimodal images implies to manipulate a lot of data, as our image are in three dimensions with one value per mode. The number of modes is not limited. So one must select a set of data in our algorithm because complexity arises sometimes in O(n) or become worse in $O(n^2)$, (O corresponds to the execution time which is proportional to the quantity, or to the square of the data quantity). Moreover all these information are not necessarily to be utilized. This selection must be reproducible and geometrical invariant. Regarding the image function f_i, one easily notes that this function can have several minima, maxima and plateaus. Such extrema can be local or regional, the position of these extrema is detectable in a reproducible way and these loci are geometrical invariants : they do not change even if the objets are translated or rotated. As suggested by Beucher (1990), image function can be considered as a relief, (x,y,z) being the coordinates and the value v the altitude (in four dimensions). The set of these particular points (maxima and minima) are crest lines and beds of valleys.

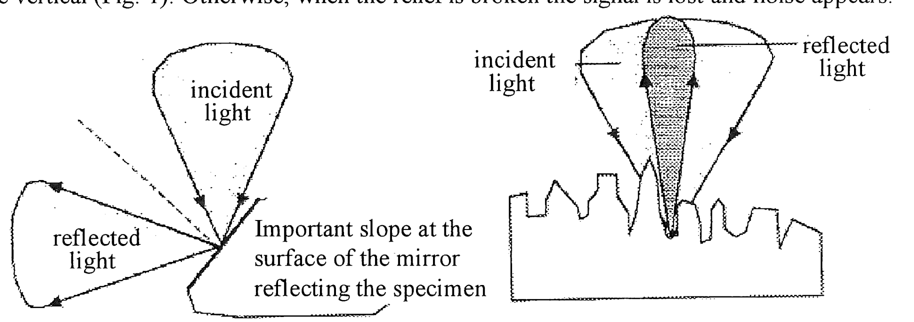
There are several ways to extract crest lines of an image function f_i. One has chosen to use a morphological operator, the watershed, because its construction and its properties are well-known. Its informatic implementation is easy, and its execution time is very short even for 3D images when an algorithm based on queues is used (Vincent, 1990). Watershed is a very good tool of segmentation, but it must lead to the right set of markers in order to avoid to generate over-segmentation or to extract multiple unused crest lines.

This over-segmentation is generated by the presence of peaks in the image function f_i. These peaks are sometimes due to their characteristics themselves, but in many time it can be generated by the noise which cannot always be reduced in a classical way.

In this paper, we propose to study the watershed combined with the h_{min}-h_{max} method (Grimaud, 1991) using geodesic reconstruction with multimodal images having their values in the real space R. It is also proposed a method to automate the process and to obtain a complete watershed despite of the noise or the chaotic image functions.

MATERIAL AND METHODS

To validate the proposed method on real cases, the rupture surface of a cement mortar has been chosen. Such images were obtained using a confocal microscope Zeiss LSM 310. Thanks to an optical scanning system and a pinhole placed behind the captor, the confocal microscope allows to observe the only part of the object in the focal plane scanned by the laser. Using a motorized platine, by a vertical scanning of the sample, a series of images can be obtained and the 3D images can be reconstructed. Because of the opacity of the material, the microscope is used in a reflective way : so images are uncomplete and present holes when portions of objects are vertical (Fig. 1). Otherwise, when the relief is broken the signal is lost and noise appears.



Reflection problem causing a local lost of signal — Lack of signal due to a large numerical opening and a broken relief

Fig. 1. Acquisition problems with confocal microscopy (Mathis and Coster, 1996).

In this work one considers the altitude image as an image when each point has a given altitude value (it corresponds to a pseudo 3D image). The 3D image can be reconstructed from this image, while the luminance image is given by the confocal microscope (Fig. 2 and 3).

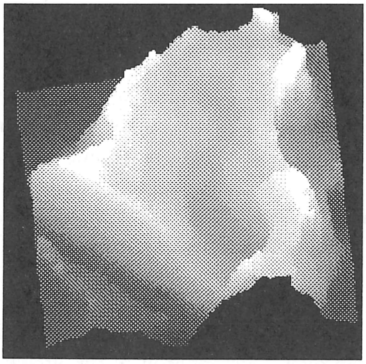


Fig. 2. Topography of a fracture surface of a mortar by confocal microscopy.

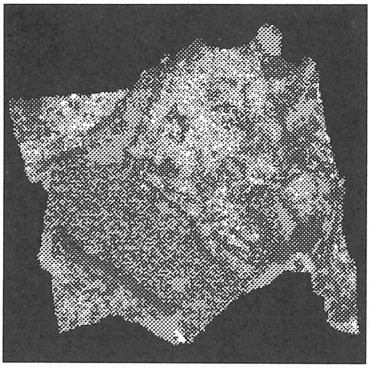


Fig. 3. Luminance image of a 3D surface corresponding to the image of the Fig. 2.

Thus, our images are uncomplete, with broken relief and noise. They are representative of classical images.
Our confocal images are not really in 3 dimensions, but in 2.5D, for each coordinate (x,y). One has only one point at the altitude z. But our algorithm is not limited with this type of images : one can have several noisy uncompleted 3D objects present in an image.
Let us talk about implementation. From the original image, other images can be calculated from altitude images, color images, curvature images (Durand et al., 1997; Lenoir, 1997). All the deduced images are different between them : some of them have values in N space, others in R with different ranges. Thus our developed operators can work even if the entry has real or integer values. To do this, we do not access directly to the point of the 3D matrix stored in the memory of the computer, but points are considered as objects. These objects are manipulated without knowing what they are exactly. When one needs to know the value of a point, one asks informatically the object representative of the point. This mode of programming is called oriented object programming. It decreases a little the speed of the process, but presents advantages to use generic and quite clear operators. Moreover, as a great number of data are manipulated, one cannot afford scanning the whole image all the time. So one must use neighbourhood information and treat only useful points. It is necessary not to forget that one has to process an image in R^3 (or N^3) and that only a part from these points of the R^3 space has to be processed. To increase the speed of the processing, a queue process is used (Vincent, 1990). One has to keep in mind that our image functions f_i are non-continuous. Using neighbourhood information, to jump from points to points in a sequential way may cause differences with the theoretical model based on continuous function.
Another point regarding with implementation problems is that these images are to be considered as 4D image functions with boolean values $f_i(x,y,z,v_i) \in \{0,1\}$. To work in 2D or, for simple cases, in 3D is generally classical. But the extension to higher spaces appears very difficult as new configurations can be added. A 4D topological study will be necessary for future works.
Having a library and programming environment of image treatment operators (Clouard et al., 1997) added by our generic objects, one are able to develop generic operators in order to

extract specific points.
Face up to the size of the data, specific points must be selected in the image. This selection must be easy, reproducible, generic, quick and correspond to a physical phenomena. Some points of the surface possess characteristics of unusual luminance or particular curvatures. These points correspond to minima, maxima, crest lines or beds of valleys in the image functions. It is therefore interesting to extract them in the image to better characterize the relief.
Analyzed images in mathematical morphology are often seen as topographic surfaces or mountainous relief (Beucher, 1990). In this representation, grey level of a pixel in a 2D image corresponds to the altitude : this idea can be extended to 3D images with real values instead of grey levels and thus define a 4D relief.
Different methods are usable (for example Thirion and Gourdon, 1992), but we propose an approach using mathematical morphology tools : h-min, h-max operators and a watershed method (Fig. 4), (Beucher, 1990). The watershed method uses a geodesic segmentation operator that reconstructs an image (markers) in another image (reference image). Markers are local minima of the reference image. The quality of the segmentation will greatly depend on these markers. Noise or artefacts presence provokes an over-segmentation of the image (Fig. 5).

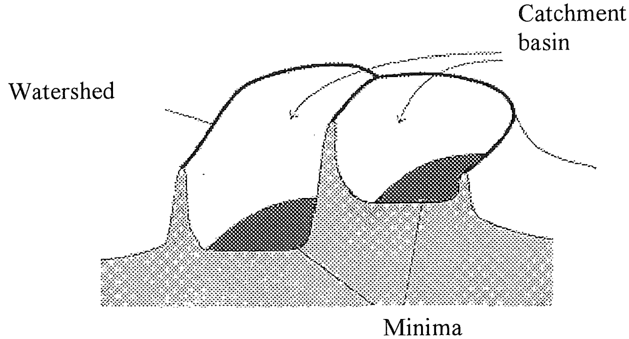


Fig. 4. Image considered as relief (Beucher, 1990).

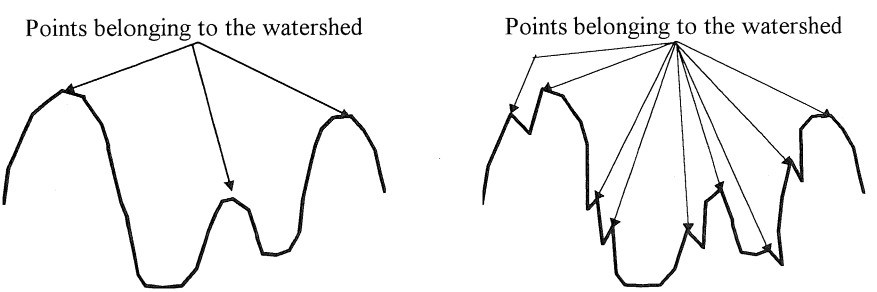


Fig. 5. Effect of a broken relief in the watershed.

The idea is to preserve as markers, minima of the image belonging to a valley with a depth

larger than a given height. The same process is applied on maxima.
To keep these markers, one first deletes valleys having small depth, and next remaining minima are markers. To suppress valleys, the h_{min} algorithm using a geodesic reconstruction (geodesic dilation) is used (Grimaud, 1991).
In mathematical morphology, geodesic dilation of a function f under a function g is defined, as proposed by Schmitt and Mattioli (1993), by :

$$D^{r}_{g\lambda}(f_{\lambda}) \qquad [1]$$

where r is the size of the dilation, and λ such as $f_\lambda = \{x, f(x) \geq \lambda$, (Fig. 6).

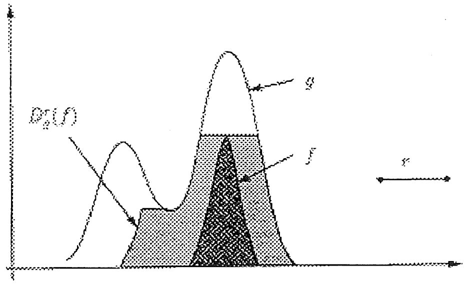


Fig. 6. Geodesic dilation of a function f under a function g (Schmitt and Mattioli, 1993).

The geodesic reconstruction is done with an infinite size dilation and g is the image function f translated by the value h, which corresponds to the minimum depth of valleys.
In a first step, one seeks for finding minima and maxima of the image. A local minimum (local maximum) is a point that does not possess neighbours with lower values (or with higher values). This research puts therefore the problem of the existence of plateaus in the image that can be regional minima, maxima, or neither one nor the other.
First, one seeks for local minima and local maxima. Among these points, one recovers points belonging to plateaus by using a « FIFO ordered queue » (First In, First Out) containing plateau points and a second queue containing the totality of neighbour points on the same plateau that the studied point.
These plateau points will be processed during the second step. From these queues, one verifies if these plateaus belong to extrema or not. In the case of a positive reply, points of the concerned plateau are added to the maxima or minima images.
The process for the geodesic reconstruction is simply described : i) one translates the image function f with a chosen value h (Fig. 7); ii) from the detected minima, one follows along the image function points until a local maxima is found or until one is above the translated function (f+h), (it is like an inundation initiated from minima and stopped when the valley is full or when one touches the (f+h) function (Fig. 8 and 9)). The process continues until the result function is stable (Fig. 10). Thus the final result is obtained (Fig. 11).

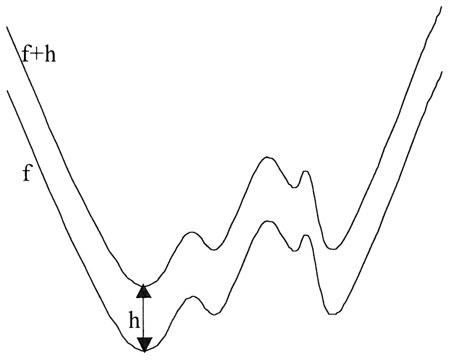


Fig. 7. Translation of image by h (f+h).

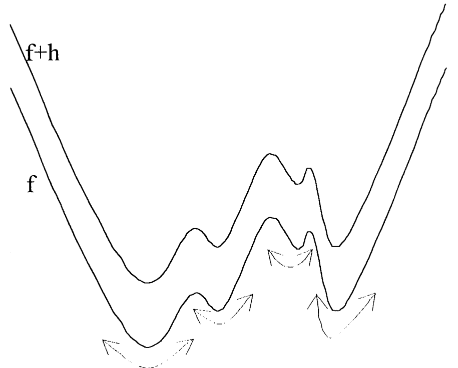


Fig. 8. Propagation around a minima.

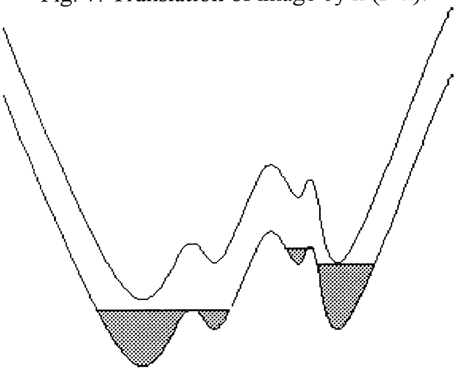


Fig. 9. First step, end of propagation.

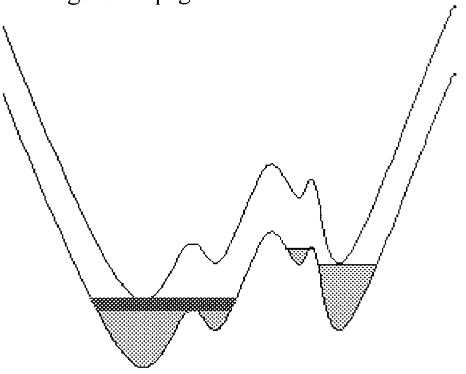


Fig. 10. Last step, no more modification.

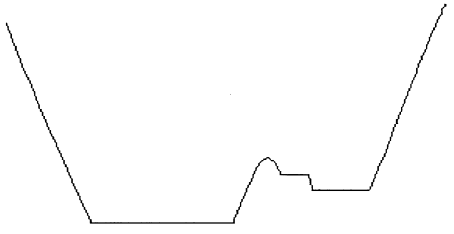


Fig. 11. Final result of the geodesic reconstruction.

With this reconstructed image function, one has only minima which belong to a « deep » valley. To facilitate the construction of the watershed, one selects only one minimum point in each catchment basin by eliminating the neighbour points from the list, because the majority of minima belongs to a plateau.

The extraction of crest lines was made by the watershed segmentation. Here again a queue process, similar to that proposed by Vincent and Soille (1991) is used. As markers the h_{min} markers are used and one gradually reconstructs catch basins by region growth. The watershed corresponds to the totality of the boundaries between the regions.

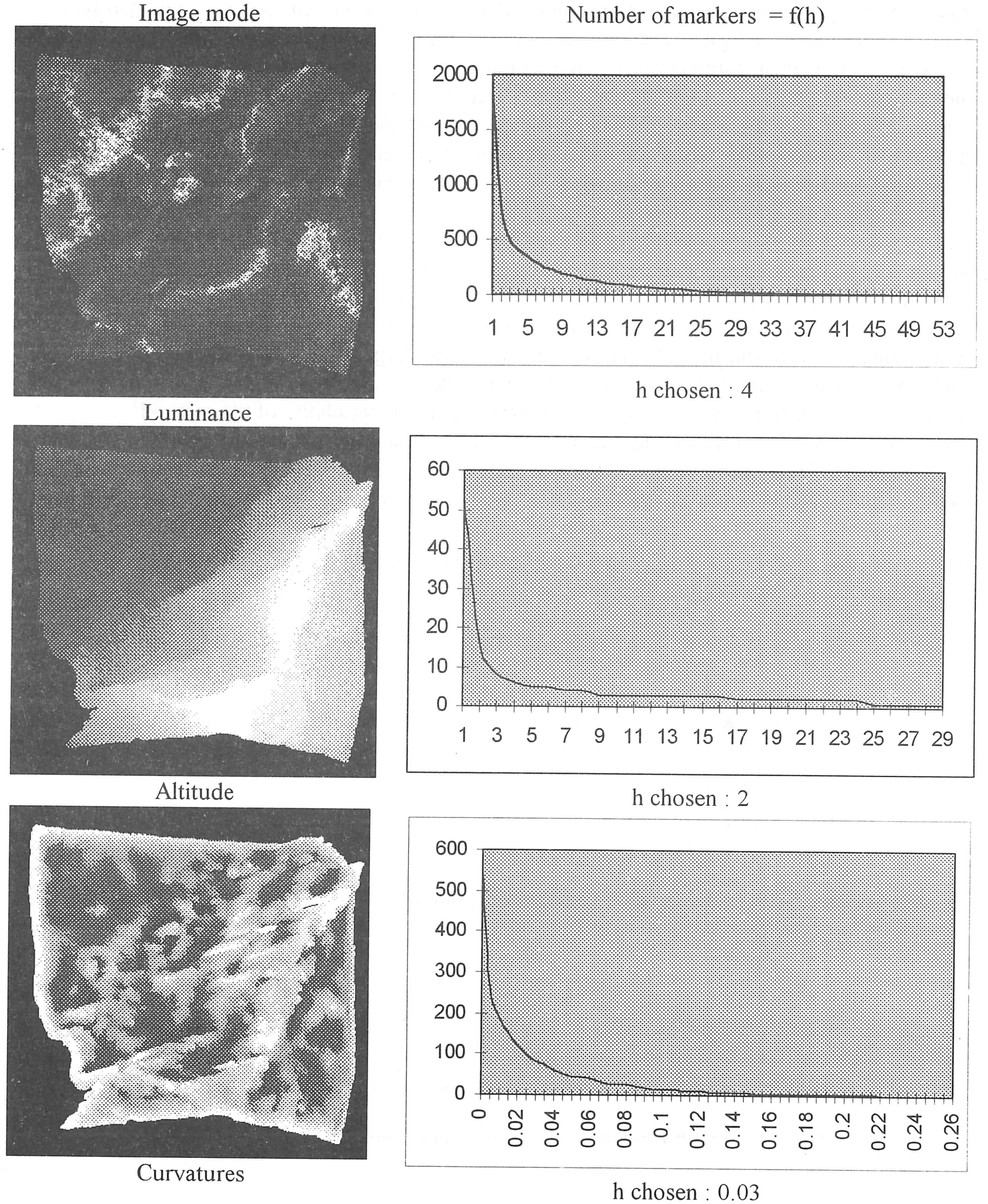


Fig. 12. Modes and h values : results concerning the luminance, altitude and curvatures in the case of an image of a mortar fracture surface (150x130x120, 55000 points). X axis : h; Y axis : number of markers for the chosen parameter.

RESULTS

Quite good quality watershed is then obtained using this described geodesic reconstruction. But, like for many morphological operations, the type of studied images must be known : there is no universal parameters for these operators and previous knowledge on images is necessary. So, a study for the right value of the depth of valley in the h_{min} process is needed.
First, in order to appreciate this phenomena, measurement of the number of minima is performed in an image when the minimum depth of valley increases. Our morphological operators are used on multimodal images. We do one geodesic reconstruction per mode with an increased h value (depth of valleys), (Fig. 12).
All these curves present the same feature : in the first part, a very important decrease, followed by one or several plateaus, and thereafter the curve tends to the number of objects in the scene. The first part allows to exclude small variations in the image function which parasite the construction of the watershed. Empirically, one decided to choose as h value, the point of the curve placed before the first plateau, to keep a safety margin. This method was improved on only five images, and the values obtained were nearly the same for a given mode (but unfortunately it is not a statistical result!). It shows only the feasibility of the method.
From these results, one can build watersheds and the following results are obtained (Fig. 14). The number of remaining points in the image is small, and one can attempt to intersect this multimodal watershed, but with the risk to have few points if different modes are not very correlated. These obtained watersheds are not thin, because catch basins are constructed by region growth and the watershed corresponds to the totality of the boundary points between the regions. In a last operation, one can thin them.

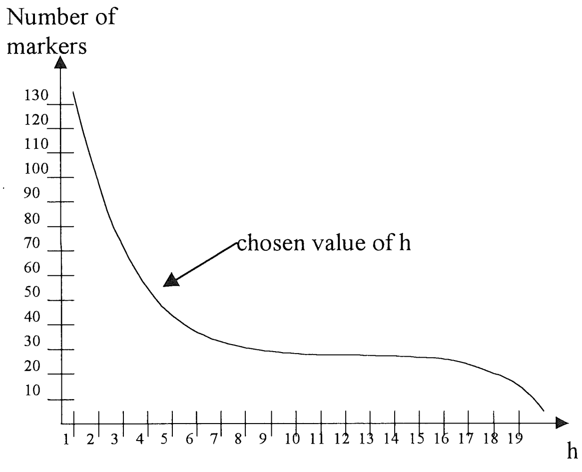
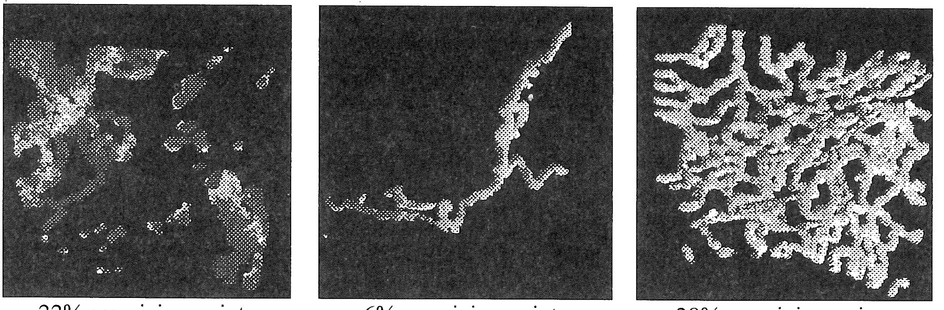


Fig. 13. Theoretical curve of the number of minima as function of h.



22% remaining points 6% remaining points 28% remaining points

Fig. 14. Watersheds of luminance, altitude and curvature images.

CONCLUSION

Using watershed to extract specific values in function image allows to obtain good results. Each of us know that the watershed is very sensitive to the noise or with broken relief in the function image. To avoid this problem, one can use a geodesic reconstruction to suppress unwished values affecting the process. Using the h_{min} method creates two problems. The first one is the determination of the h value without knowing the image, the second one is that one can afford to try all possible values. But this automatic determination is too long. So, knowing the behavior of the curve of the number of minima, one can model it and then from some calculated values, an approaching value of h can be determined. The process will be relatively fast (it needs only the first part of the curve) and entirely generic and automatic.

All these selected extracted features points can be used for several applications, when one needs to select points, because the set of data is too large. These points are geometrical invariants, and possess a physical meaning.

In our case, one needs to register 3D images. These images are noisy and can come from different acquisitions. To register them, one needs to extract features, calculating multimodal images. Then some characteristical points can be taken in order to find common points to register images.

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REFERENCES

Beucher S. Segmentation d'images et morphologie mathématique. Thèse de Docteur-Ingénieur, Ecole Nationale Supérieure des Mines de Paris, 1990.

Clouard R, Elmoataz A, Angot F. Pandore : une bibliothèque et un environnement de programmation d'opérateurs de traitement d'images. Pandore : library and programming environment of image treatment operators, ISMRA, GREYC, Internal Report, 1997.

Durand S, Lenoir A, Coster M, Revenu M, Chermant JL. Non planar surfaces, multimodal images and mathematical morphology. Acta Stereol 1997; **16** : 293-298.

Grimaud M. La géodésie numérique en morphologie mathématique. Thèse de Doctorat of the

Ecole Nationale Supérieure des Mines de Paris. 1991.

Lenoir A. Fast estimation of the mean curvature on the surface of a 3D discrete object, Proceeding of DGCI'97, Lecture Notes in Computer Science (to appear). 1997.

Mathis S, Coster M. Confocal microscopy study and corrosion process : the Al-(HF, HNO_3, HCl) system. Microsc Microanal Microstruct 1996; **7** : 527-532.

Schmitt M, Mattioli J. Morphologie Mathématique. Edition Masson, Paris, France. 1993.

Thirion JP, Gourdon A. The 3D marching lines algorithm and its application to crest lines extraction. INRIA Research Report, N° 1672 (1992).

Vincent L. Algorithmes morphologiques à base de files d'attente et de lacets, extension aux graphes mathématique. Thèse de Doctorat of the Ecole Nationale Supérieure des Mines de Paris. 1990.

Vincent L, Soille P. Watersheds in digital spaces : an efficient algorithm based on immersion simulations. IEEE Transaction on Pattern Analysis and Machine Intelligence 1991 ; **13**/6:583-598.

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