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APPLICATION OF SKELETONIZATION ON GEOPHYSICAL IMAGES

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Abstract: Skeletonization has been a part of morphological image processing for a wide variety of applications. The skeleton is important for object representation in different topics, such as image retrieval and computer graphics, character/pattern recognition and analysis of biomedical images. The purpose of the present work is to apply a sequential skeletonization algorithm on geophysical images, resulting from shallow depth mapping of archaeological sites. The accurate identification of curvilinear structures in geophysical images plays an important role in geophysical interpretation and the detection of subsurface structures. Experimental results on real data show that skeletonization comprises an important tool in image interpretation.

Keywords: Image analysis, sequential algorithm, filtering, magnetic images

1. Introduction

The interpretation of linear features in geophysical imagery resulting from mapping of archaeological sites is of considerable importance since they can correspond to underlying relics and architectural structures. Practical decisions are often made based on the images of the subsurface obtained through the inversion of the original geophysical data. The accurate representation and interpretation of the linear features is mainly a function of the spatial resolution of the images, the sampling of the measurements and the interpolation algorithms, the signal to noise level of the data, the prior information regarding the expected targets and the ability to model the measured quantities appropriately.

The necessity of designing skeletonization algorithms dates back to the early years of computer technology, in the 1950s. It was realised that in some applications (such as character recognition), it is sufficient to consider a reduced amount of information instead of the whole image, which is usually in the form of a line-drawing. The basic idea was to "peel" the original picture by iteratively removing certain contour points. This procedure is the so-called skeletonization process, through which a line-like shape (the skeleton) is created in order to ease the execution of any further analysis and processing of the images. The skeleton contains less information to process and it enhances shape analysis analysis procedures. Today, skeletonization is applied in a very wide range of topics such as the analysis of blood cells or chromosome shapes in medical science or the identification of signatures and fingerprints.

In morphology (Serra, 1982, 1988), the most commonly used algorithms are the parallel ones (Vincent, 1990, 1991; Couprie, 2006). Their principle is based on the modification of the value of the current pixel p of an input image (n-dimensional array of pixels) according to the values of the pixels in a given neighborhood of p. The new value of p is then written in an output image different from the current one, so that the order in which pixels are scanned has no influence on the result. Further scannings can then be performed, until a given criterion is fulfilled (e.g., a certain number of scannings is achieved, or stability is reached). These algorithms are conceptually very easy in their implementation and they are well suited to specialized hardware systems. On the other hand, they usually require a large number of complete image scannings, so that their interest on classical architectures-like workstations or personal computers-remains limited, due to prohibitive computation time. This is particularly true when complex transformations like watershed or skeletons are considered.

For this reason, another family of algorithms was introduced in 1966 the so-called sequential or recursive algorithms (Rosenfeld and Pfaltz, 1966; Lay, 1987) aiming towards the reduction of the number of image scannings required to compute a given transformation. Like parallel ones, sequential algorithms do not require sophisticated data structures or scanning techniques. They differ from parallel algorithms in that they use well-defined scanning orders (usually video or anti-video) and that the new value of the current pixel p, determined from the values of the pixels in its neighbourhood, is exported in the image being processed. So, the value of an already scanned pixel may have an influence on the value of the subsequent scanned pixel.

This study tries to document the approach of skeletonization on geophysical images and their contribution to the interpretation of the features that are contained in them. The particular technique was applied on real magnetic data obtained from high resolution (0.5m or 1m) measurements of the vertical magnetic gradient employing a Geoscan FM36 fluxgate gradiometer. For our experiments we used a Core 2 Duo laptop at 1.5 GHz. The computational complexity of the proposed scheme is O(N•M), where N denotes the number of pixels in the given image and M the number of filters. A typical processing time for the execution of the proposed scheme is about 15 seconds for a typical image of 0.25 MP (500 x 500) and 24 filters.

2. Methodology

Prior the application of skeletonization the geophysical images were smoothed using a wavelet decomposition and a step filter convolution, in order to reduce noise levels and enhance the curvilinear structures to be detected.

Different types of zero mean filters can be used for curvilinear structures enhancement. The proposed step filter models a line of specific orientation and width. Figure 1 illustrates the proposed step filter model of 45^o orientation, which has been used for curvilinear structures enhancement. Let *F(a,w)* be a zero mean filter of orientation angle a and width w. The filter was constrained to be zero mean and to have total energy equal to 1, so that it would yield zero response on constant structures and the responses of different angles and widths would be comparable, respectively.

The preliminary goal of skeletonization is to classify I_m pixels into three classes C_1, C_2 and C_3 with label numbers 1, 2 and 3, respectively:

C_1: The pixels that (surely) belong to curvilinear structures.

C_2: The pixels that they are uncertain if they belong to curvilinear structures.

C_3: The pixels that (surely) do not belong to curvilinear structures.

The proposed classification is inspired by hysterisis thresholding technique (Canny, 1986). Hysterisis thresholding has been successfully used on edge detection problem (Canny edge detector). The edge detection process serves to simplify the analysis of images by drastically reducing the amount of data to be processed, while at the same time preserving useful information about object boundaries. According to hysterisis thresholding, two thresholds T_l (low), T_h (high) are used for initial classification (three classes). A pixel is detected if it is either greater than T_h (or greater than T_l and connected to a pixel that is greater than T_h). The advantage of this type of thresholding is that it allows the abstention of some connected point groups (Kermad and Chehdi, 2002).

In the proposed scheme, the thresholds T_l and T_h are automatically estimated. Let Med to denote the median value of I_m. Then, T_l is given by the mean value of I_m pixels that have a value lower than Med, whereas T_h is given by the mean value of I_m pixels that have a value higher than Med. Let B_i be the image of initial pixel classification into classes C_1, C_2 and C_3. Let $I_m(p)$ and m to denote the value of image I_m on pixel p and the median value of 9 pixel-neighborhood of pixel p in I_m, respectively.

Then, if $I_m(p) \geq T_h$ and $I_m(p) > m$, p is classified to C_1, since its value is very high comparing with the image ($I_m(p) \geq T_h$) and with its neighborhood ($I_m(p) > m$). If $I_m(p) \geq T_h$ or ($I_m(p) > T_l$ and $I_m(p) > m$), p is classified to C_2 class. If the pixel value is high compared with the image, but it is not high enough compared with its neighborhood or reversely, then it is labeled to an unknown class. Otherwise, p is classified to C_3 class.

Finally, a region growing based method is executed providing the final pixel labeling into classes C_1 and C_3. So, the goal of this method is to classify the pixels of class C_2. Let B_f be the image of final pixel classification into classes C_1 and C_3. According to the method, the pixels of C_2 class are classified to C_1 if they are connected to a pixel of C_1, otherwise they are classified to C_3 class.

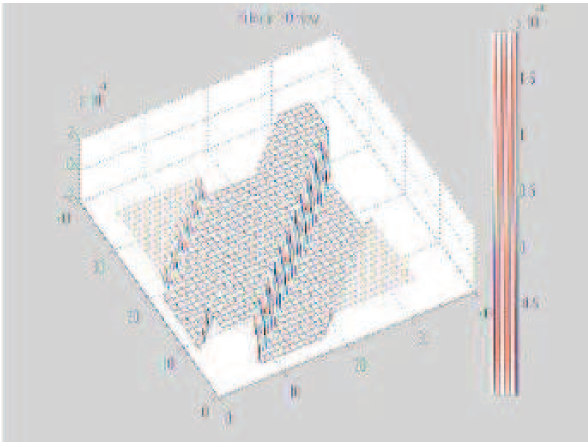

Fig.1. A sample of the step filter used for signal enhancement of the geophysical signals.

Thin curvilinear structure detection (B_t) is provided if we change the rule of classification to class C_2 removing the case of $I_m(p) \geq T_h$.

Figure 2 illustrates the results skeletonization, using as input the geophysical image of Figure 1(a). I_m response using polynomial filters is shown in Figure 2(b). The initial and the final pixel labeling results are illustrated in Figure 2(c) and (d), respectively. The white, gray and black pixels correspond to classes C_1, C_2 and C_3, respectively. Finally, Figure 2 (e) indicates the outcome of the thin curvilinear structure detection, projected on the original image Figure 1(a), with colour lines. The colour of the lines is related to the curvilinear structure enhancement image I_m (red for high values and blue for low values). The method sufficiently recognizes all curvilinear structures under various orientations and scales.

3. Results and Discussion

A lot of algorithms have been developed and implemented during the past ten years to find the skeletons of different images. It is very difficult to measure the "goodness" of such a method quantitatively. The analytical comparison of the methods is very sophisticated, since they are based on different models. That is the reason why the skeletonizations are compared according to the results they produce in the practice. There are papers about the technical parameters of these algorithms (like computation speed, memory requirement, etc.) and there are observations based on the resulting skeletons produced by the various algorithms. A possible way to classify the algorithms is to examine if the resulting skeletons meet the following (natural) conditions (Fazekas and Hajdu, 1996):

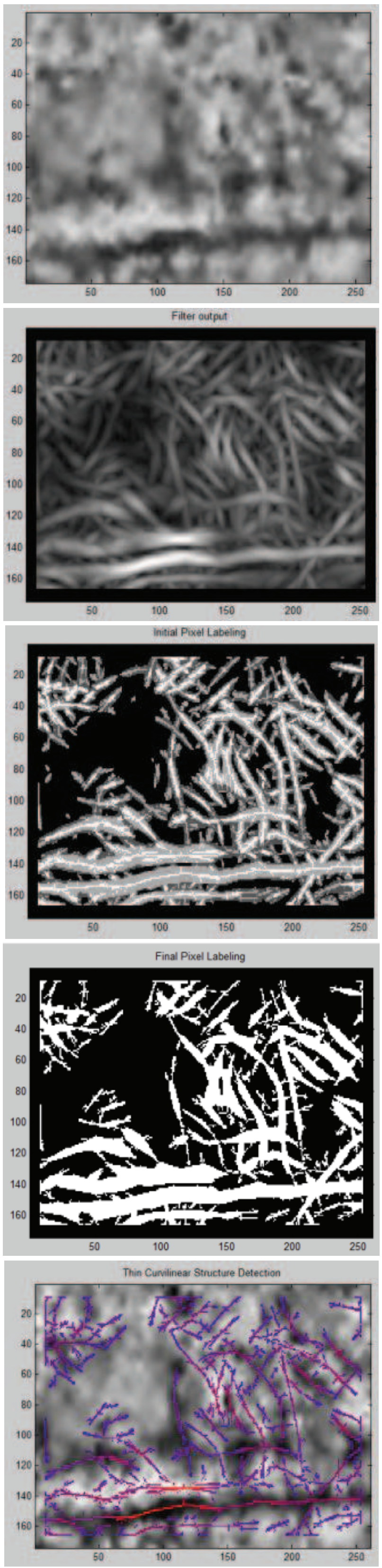

Fig. 2. Results of pixel labelling. (up, α) original image; (b) I_m, curvilinear structure enhancement; (c) B_i , initial pixel labelling; (d) B_f, final pixel labelling; (down, e) B_t, thin curvilinear structure detection.

1. The skeleton should accurately reflect the shape of the original image.

2. The topological properties (homotopy) of the object and the background should be preserved.

3. The thickness of the skeleton should be one pixel.

4. The skeletonization should preserve symmetry.

5. The skeletonization process should be immune to noise.

Figures 3, 4 and 5 illustrate results of the proposed method for different geophysical images. The processing of the particular images was carried out using 2 different widths and twelve different orientations (15^{o} angle step), resulting good curvilinear structure enhancement in any of the above orientations.

In the example of Figure 3 (a), the given geophysical image resulting by measurements of the vertical magnetic gradient above a roman structure in Sikyon, is mainly prevailed by linear subsurface structures, well detected (Fig. 3b, c, d) using the pre-mentioned algorithm. The example of Figure 4 (a) was selected, in order to demonstrate the efficiency of the presented algorithm in detecting curvilinear structures. The relics of a church (Byzantine Basilica) prevail in this image. The shape (Fig. 4b, c, d) of the church is well specified after the application of skeletonization. Secondary structures around the church, weakly observed in the original image, are also detected after the application of skeletonization.

Figure 5 (a) shows the original image of the vertical magnetic gradient acquired above a Roman-Byzantine complex in Nikopolis. The shape of the subsurface linear and curvilinear structures is more complex in this image. The efficiency of the applied algorithm is also proved by the results of Figures 5 (b), (c), (d).

The most significant factor constraining the matching of skeletons is the skeleton's sensitivity to an object's boundary deformation; little noise or a variation of the boundary often generates redundant skeleton branches that may seriously disturb the topology of the skeleton's graph. This is also observed in the presented examples. However, the stability of the algorithm is also connected to the data quality. Well preserved subsurface structures producing a strong magnetic response within a relative low noise background,

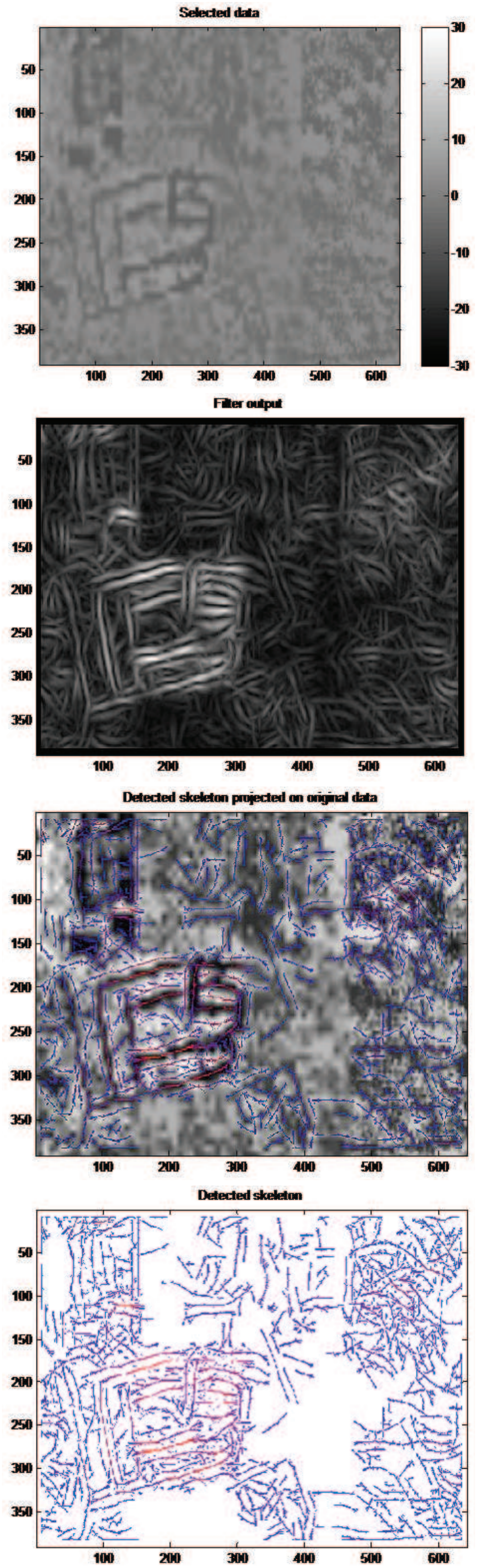

Fig. 3. Results of the proposed method on magnetic data acquired above a Roman structure in Sikyon (area A). (up, a) Original image (units in nT/m); (b) Linear structure enhancement; (c) Thin linear structure detection; (down, d) The skeleton of the studied area.

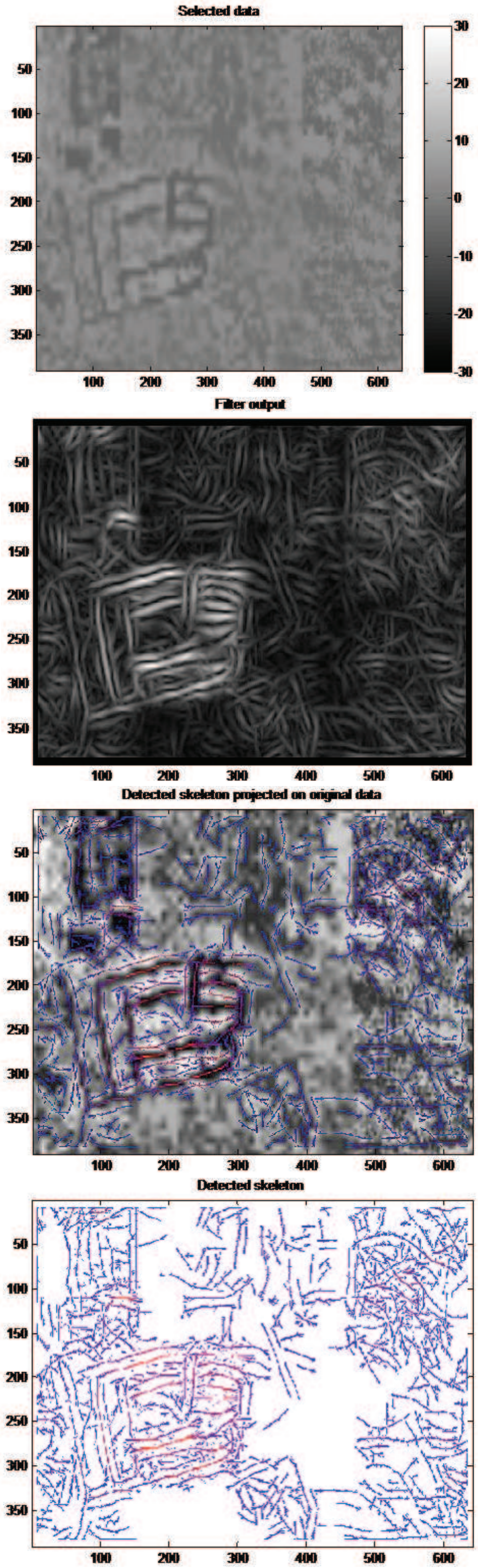

Fig. 4. Results of the proposed method on magnetic data acquired above a Byzantine Basilica church in Sikyon (area B); (up, a) Original image (units in nT/m); (b) Curvilinear structure enhancement; (c) Thin curvilinear structure detection; (down, d) The skeleton of the studied area.

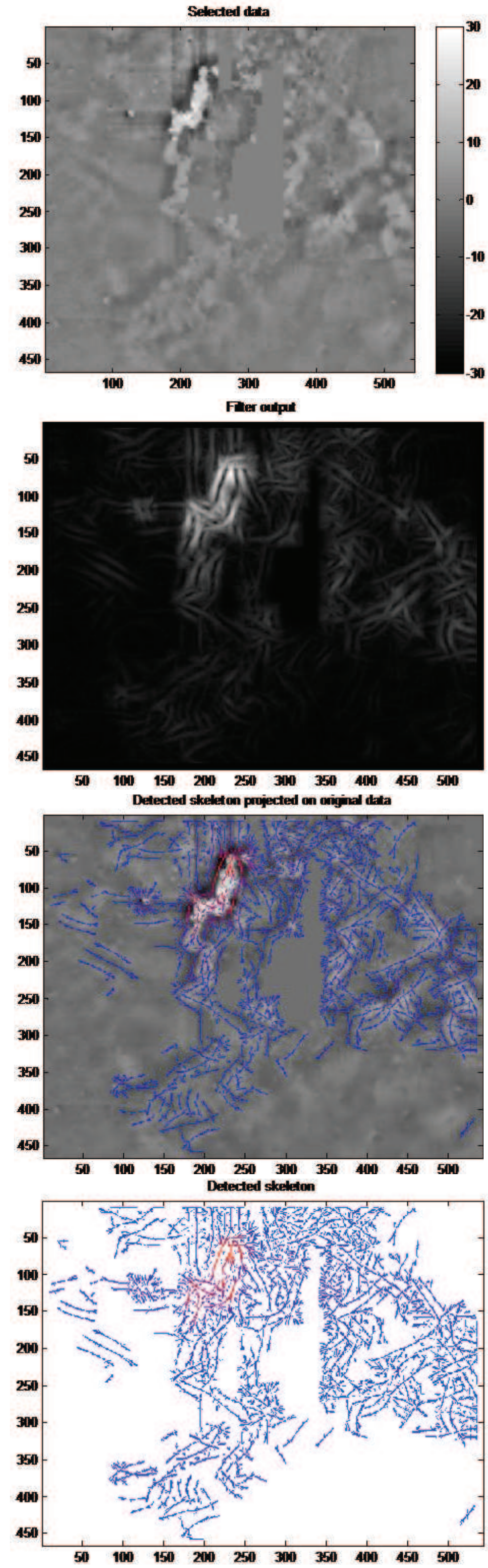

Fig. 5. Results of the proposed method on magnetic data acquired above a Roman-Byzantine complex (probably paths) in Nikopolis. (up, a) Original image (units in nT/m); (b) Linear and curvilinear structure enhancement; (c) Thin linear and curvilinear structure detection; (down, d) The skeleton of the studied area.

4. Conclusions

In this paper a fast, effective method for the enhancement of curvilinear patterns of geophysical images is proposed. The algorithm efficiently combines a rotation and scale invariant filter providing a detection of subsurface curvilinear structures. The proposed method has been applied to recognize patterns in archaeological sites which may be correlated to architectural relics. Experimental results with real geophysical images indicated the reliable performance of the proposed scheme.

As future work we plan to overcome skeleton's instability of boundary deformation by applying skeleton pruning (i.e., eliminating redundant skeleton branches).

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