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Segmentation of Echocardiogram Image Sequence with Scale-Rate as the Measurement of Local Signal Complexity

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Abstract: - The scale-rate of digital signals is proposed as a novel feature of local signal complexity. It is proved experimentally that the scale-rate value has direct relationship with the signal's local changing rate. The scale-rate is applied in automatic echocardiogram analysis as a feature of gray-scale variation for image sequence segmentation. The experimental results show that the proposed method is effective and has promising application in automatic echocardiogram analysis.

Key-Words: - Scale-rate, echocardiogram analysis, medical image processing, local complexity, image segmentation

1 Introduction

Medical image processing has become much important in diagnosis with the development of medical imaging and computer technique. Huge amounts of medical images are obtained by X-ray radiography, CT and MRI. Moreover, not only static medical images but also dynamic image sequences can be acquired. A typical case is echocardiogram. The examination with echocardiography is non-invasive and can be performed easily and safely. Echocardiography enables the visualization of the beating heart with its internal structures. However, in most cases the qualitative and quantitative anatomical and functional parameters are assessed artificially. Therefore, the automatic processing of echocardiogram image attracts much attention of the researchers in this field.

For medical image processing, feature extraction is an important basis, such as edge detection, corner detection, texture analysis, etc. Based on these features the medical images can be segmented into areas of different properties. Moreover, some specific features of medical images can help distinguish between normal tissues and those with pathological changes. The specific features include the area, perimeter and shape factor of cells, which are obtained based on the common image features of grey-scale, edge and texture [1].

In recent years, complexity becomes a new feature of systems and signals, which is being intensively studied [2,3]. Fractal dimension reflects the complexity of an fractal object's structure, which has been applied in image processing [4,5]. However, fractal dimension is defined for fractal geometric objects while signal data usually do not satisfy the strict definition of fractal. Currently, there is no standard definition of image complexity [3]. Many researches are being carried out on complexity measurement of signals and images. In this paper, the scale-rate of digital signals is proposed to extract local complexity feature, which is based on the change of signal measurement on different observing scales. A new segmentation method of echocardiogram image sequence is proposed based on the scale-rate. The experimental results show that the scale-rate is an important feature of local signal complexity and is effective for echocardiogram image segmentation.

2 The Scale-Rate of Digital Signals

The fractal dimension is a measurement of the complexity for fractal objects. However, fractal dimension is defined for fractal objects. In practice, the signal data usually do not satisfy the strict definition of fractal dimension. In this paper, a new feature of complexity named scale-rate is proposed, which is inspired by the scaling property of signal measurements. The scale-rate is a local feature and can represent local complexity of digital signals.

2.1 The Box-counting Dimension

The box-counting dimension is a widely used concept of fractal dimension in practice, which is defined as follows[4]:

$$\dim_B F = \lim_{\delta \to 0^+} \frac{\log N_\delta(F)}{-\log \delta} \quad (1)$$

where F is a non-empty bounded set in $\boldsymbol{R}^n$. $N_\delta(F)$ is the minimum number of the sets covering F and their radii are no larger than δ. In practice, $N_\delta(F)$ can be obtained by dividing the space into boxes of width δ and counting the number of the boxes that F occupies. According to the data group $(-\log \delta_i, \log N_{\delta_i}(F))$, the slope of the line is estimated as the box-counting dimension by the least-squares linear regression[4]. The estimation of the box-counting dimension is shown as Fig. 1.

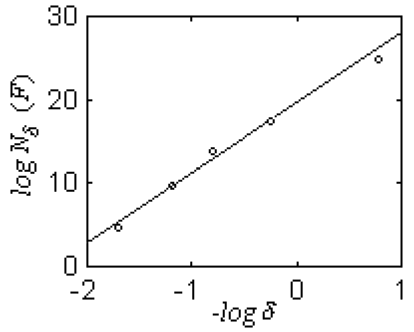

Fig. 1. The estimation of the box-counting dimension with the least-squares linear regression

2.2 The Definition of Scale-Rate

In the estimation of the box-counting dimension, $N_\delta(F)$ can be regarded as a measurement of F on the observing scale δ, i.e. the number of boxes that F occupies. The box-counting dimension reflects the changing rate of the measurement with the changing scale.

In the multi-scale representation of F, the smaller the observing scale, the more the details. If an object has more complex structure than the others, when the observing scale decreases, more complex details appears and its measurement can increase faster than the simpler ones.

Therefore, it is indicated that the changing rate of measurement with observing scale reflects the complexity of objects, which inspires the presentation of scale-rate.

2.2.1 Multi-scale Representation of Digital Signals

The multi-scale representation of digital signals should be defined in order to obtain the measurement of a signal under a certain observing scale. For a digital signal $g(k)$ of finite length, the representation of $g(k)$ under discrete scale δ is defined as follows:

$$g_\delta(l) = \max_{l\times\delta \le k < (l+1)\times\delta} \{g(k)\},\ l = 0,1,2...,L_\delta - 1 \quad (2)$$

where $g_\delta(l)$ is the representation of $g(k)$ under the scale δ. L_δ is the signal length of $g_\delta(l)$. For simplicity, it is assumed that $g(k)$ has non-negative values since signals such as images have non-negative values. According to the definition of $g_\delta(l)$, it is obvious that when δ =1, $g_\delta(l) = g(l)$. An example of multi-scale representation of a digital signal on different observing scales is shown as Fig. 2.

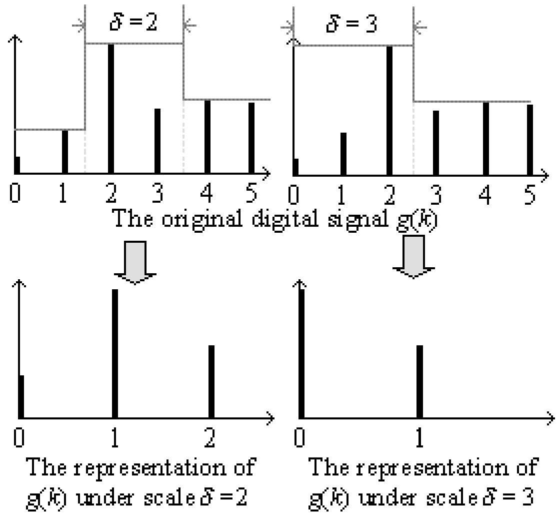

Fig. 2 The multi-scale representation of $g(k)$

2.2.2 The definition of Scale-rate Based on Multi-scale Representation of Digital Signals

On the analogy of the box-counting dimension estimation, the measurement of digital signal $g(k)$ under scale δ is defined as the sum of the signal values of $g(k)$:

$$M[g_\delta] = \sum_{l=0}^{L_\delta - 1} g_\delta(l) \quad (3)$$

where g_δ is the representation of $g(k)$ under discrete scale δ. L_δ is the signal length of $g_\delta(l)$.

Based on the multi-scale representation of digital signals with finite length, the scale-rate is defined as the changing rate of the signal measurement with the changing scale. The calculation of scale-rate is as follows. For a discrete scale set $\{\delta_i, i=1,2...M\}$, the data group $\{(\delta_i, M[g_{\delta i}]), i=1,2...M\}$ can be obtained. The slope of the line is estimated as the scale-rate value by the least-square linear regression according to the data group. For digital signals of finite length, the flowchart of the scale-rate calculation is shown as Fig. 3.

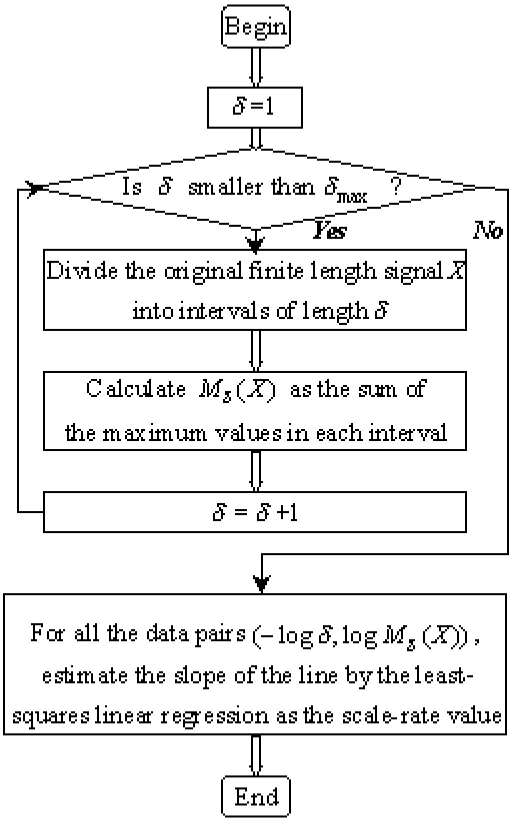

Fig. 3 The flow-chart of scale-rate calculation

2.2.3 The Relationship between Scale-rate and the Signal's Changing Rate

The relationship between the scale-rate value and signal's changing rate is investigated experimentally. The test signals are linear functions whose length is 12. The signal values increase with increasing time *t*. The signal changing speed is represented by Δ, which is the difference of signal values between adjacent time coordinates. In the experiment, the value of Δ is increased from 0 to 20, and the corresponding scale-rate values are calculated. The test signal series with increasing value of Δ is shown as Fig. 4. According to the data obtained in the experiment, the relationship between the scale-rate value and Δ is shown as Fig. 5, where the *x* coordinate represents the value of Δ and the *y* coordinate represents the corresponding scale-rate value. Fig. 5 indicates that the scale-rate value has a direct relationship with the signal's changing rate.

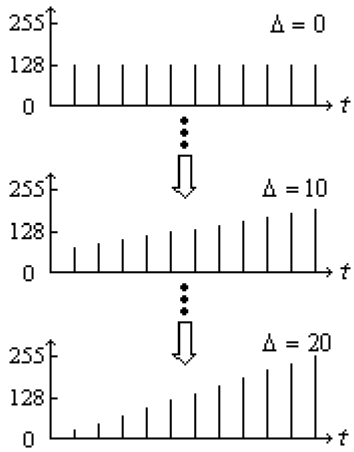

Fig. 4 The test signal series with increasing Δ

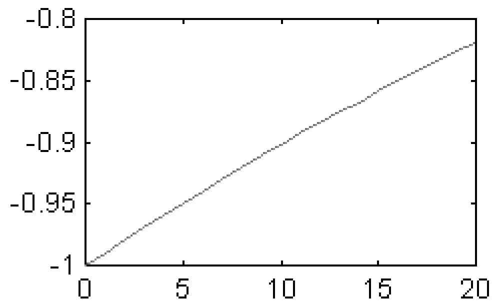

Fig. 5 The relationship between scale-rate values and the signal's changing rate

3 Segmentation of Echocardiogram Image Sequence with Scale-Rate

The image sequence of echocardiogram records the complex motion of the beating heart. It is difficult to accurately segment different parts of the heart in a single image. Because of the difference between physical and biological composition and structure of cavity and muscles, the time-varying property of grey-scale values is different between muscles and cavities in echocardiogram. In this paper, the scale-rate is applied in the segmentation of echocardiogram image sequence.

The image sequence of echocardiogram can be regarded as a three dimensional discrete signal. Each point in a frame has *x*-coordinate, *y*-coordinate and *t*-coordinate. The scale-rate value along the time axis is estimated for each point to reflect the time-varying property of grey-scale values at that point. In the experiments, the scale-rate values are estimated with adjacent 6 frames along the time coordinate axis to reflect the local time-varying property of grey-scale at each point. The result of segmentation can reflect the different parts of the heart, which may provide information for further diagnosis and automatic analysis.

Fig. 6 is the first frame of a certain echocardiogram. The scale-rate distribution of the image sequence is shown as Fig. 7. The threshold of scale-rate values is 0.05 for segmentation. The result of segmentation is shown as Fig. 8. According to an echocardiogram model shown as Fig. 9, the main part of the heart is contained in a sector area. Therefore, the segmentation of the main part of the heart area is shown as Fig. 10, which is obtained after denoising and removing irrelevant small areas. In Fig. 10, the black parts in the sector area indicate the areas of the atrium and the ventricle. According to Fig. 10, the different parts of the heart in the original image are shown as Fig. 11.

Fig. 6. The first frame

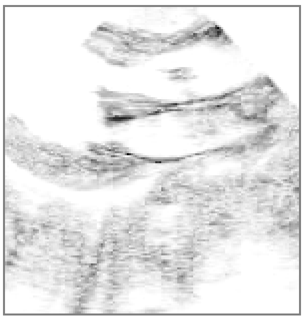

Fig. 7. The scale-rate distribution of the image sequence

Fig. 8. The result of segmentation

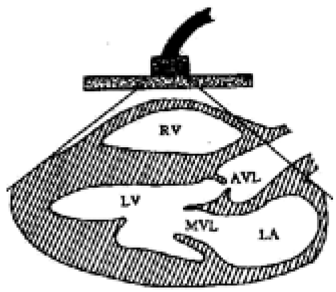

Fig. 9. Different parts of the echocardiogram

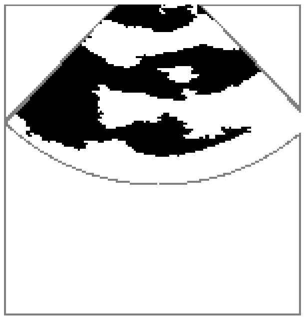

Fig. 10. The segmentation of the heart area

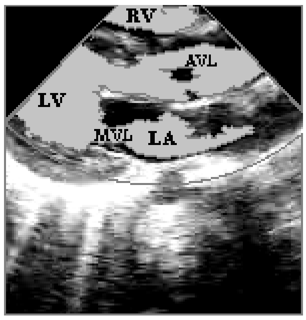

Fig. 11. Different parts of the heart in the original image

4 Conclusion

In this paper, the scale-rate is proposed to extract local complexity feature based on multi-scale representation of digital signals. The scale-rate is experimentally proved to have direct relationship with the local changing rate of digital signals. A new method is presented for automatic segmentation of echocardiogram image sequence based on the scale-rate. The experimental results show that the proposed method is effective and has promising application in automatic echocardiogram analysis. Further research will be focused on the application of scale-rate in other medical image processing tasks. In future work, the property of the scale-rate will also be investigated theoretically and experimentally.

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