



Research Article

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The physiological characteristics research of human gait based on wavelet multi-scale entropy analysis

Yixin Wu

School of Exercise Human Science, Shenyang Sport University, Shenyang, China

ABSTRACT

The walk-run sport is a movement that is very easy to implement and can help protect health and mental wellbeing. This article focuses on the gait biometrics characteristics in the process of walking, by studying the biometrics characteristics of the gait to provide data basis for the movement guidance and clinical therapy. Human gait is a biometric characteristics, with difficult to disguise, little affected by environment and other unique advantages. Along with the development of physiological signal analysis techniques, this paper studies the gait of eight different study objects in the walk-run movement course, and uses wavelet multi-scale entropy analysis method. Research shows that the mean values in the axial direction of 8 study objects' peak values are larger and all concentrated between 3.0-3.6, with little individual differences; Conducts feature points information analysis of the two states of three study objects, the peak position overall moves in the low-frequency section in the non-normal state, the total entropy value increases in the Y axial direction and decreases in the Z axial direction. Through this theoretical explanation and the data statistical results, this research method can well solve the needs of motion analysis and medical data.

Key words: Wavelet entropy, human physiology, physiological signals, gait characteristics

INTRODUCTION

The analysis and processing of physiological signal is a research field of great significance in modern biomedical engineering. The gait characteristic represents a lot of information the rest and exercise state of human body, which belongs to specific category in physiological signals. Gait is a biometric characteristic, without the effect of the distance, non-invasive, difficult to disguise, little affected by environment and other unique features, which has received insider's attention in recent years. Gait is the attitude collectivity of people in the walking process. The body's physiological function will impact human gait on different degrees, that is the human health condition and physiological characteristics can be represented by gait [1,2]. The most important mechanical feature of gait is the acceleration. Through the analysis of acceleration the characteristics of gait can be drawn in order to realize quantitative analysis of human motion through these features.

The advanced algorithms commonly used by data mining and processing of gait signal includes time domain analysis, frequency domain analysis, time-frequency analysis and nonlinear analysis, etc., mathematical tools we need to use has Fourier transform, wavelet transform, Chaos and genotyping analysis, nonlinear prediction and data mining techniques [3,4]. This article analyzes the gait acceleration of human body based on a wavelet multi-scale entropy method; this method has a better applicability and accuracy in gait analysis [5,6].

The theoretical knowledge for gait analysis and wavelet multi-scale entropy analysis is constantly improving; the field of application has also been updated. In the near future, the development of these two fields must be accompanied by the development of computer skills and get a broader development; many people have made efforts for the studies of gait analysis, and make a certain contribution for the development of this field. On the basis of

previous work this paper uses wavelet multi-scale entropy analysis method to study gait, in order to provide a theoretical basis and data reference for the quantitative analysis of walk-run motion and clinical analysis of medical.

The principles and methods of wavelet multi-scale entropy analysis

Wavelet analysis is extensively applied in signal processing, image generation, bio-engineering, and artificial intelligence. This analysis method is a method different from time-frequency analysis, but a time-frequency localization analysis method that window size is fixed, its shape can change, and the time window and frequency window can both change. The low-frequency part has a higher frequency resolution and a lower time resolution, the high frequency part has a higher time resolution and a lower frequency resolution, which is known as "Math microscope." Wavelet entropy is developed by Osvaldo. A etc. on the basis of the wavelet decomposition and reconstruction theory. Compared to the conventional entropy analysis based on the Fourier transform power spectrum; as its amplitude and energy is independent of signal, wavelet entropy contains new information [7].

Multi-scale entropy analysis method is a method to describe the irregularity degree of the time series at different time scales based on sample entropy. Multi-scale entropy includes the scale factor, embedding dimension and threshold three parameters.

Suppose a discrete time series have L points in total, conduct coarse-breakpoint transform on the sequence in order to obtain new time sequence s , the coarse-breakpoint transform is in the formula (1) as follows:

$$y_j^{(\tau)} = \frac{1}{\tau} \sum_{i=(j-1)\tau+1}^{j\tau} x(i) \quad (1)$$

In Formula (1) τ means the scaling factor, the length of each coarse - breakpoint time sequence is L/τ , when the scale is $\tau = 1$, the coarse - breakpoint time sequence is the original time sequence, and the schematic diagram of scale transformation is shown in Figure 1:

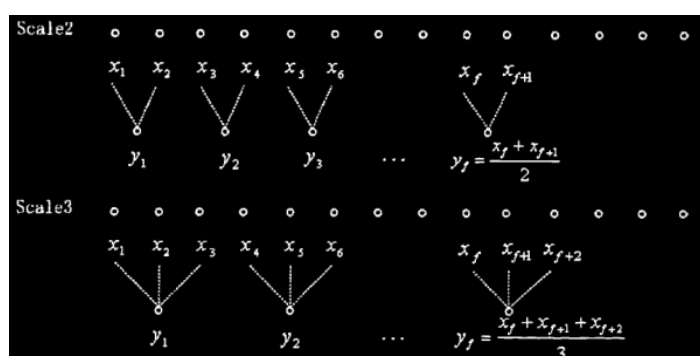


Figure 1: Schematic diagram of scaling variation

The length of the time sequence obtained according to scale change of τ is $N = \frac{L}{\tau}$, form a group of m -dimensional vector $Y^{(\tau)}(1) \cdots Y^{(\tau)}(N - m + 1)$ in consecutive serial, the expression of the i th dimension is shown in formula (2)

$$Y^{(\tau)}(i) = [y^{(\tau)}(i), y^{(\tau)}(i + 1), \dots, y^{(\tau)}(i + m - 1)], i = 1, 2, \dots, N - m + 1 \quad (2)$$

Provide $d[Y^{(\tau)}(i), Y^{(\tau)}(j)]$ equals scale factor τ , then the representing method of the absolute maximum distance between the vector $Y^{(\tau)}(i)$ and the corresponding element of vector $Y^{(\tau)}(j)$ is in the formula (3),

$$d[Y^{(\tau)}(i), Y^{(\tau)}(j)] = \max [|y^{(\tau)}(i + k) - y^{(\tau)}(j + k)|] \quad (3)$$

For a given threshold value r , for each value of $i \leq N - m + 1$, the ratio of the number of $d[Y^{(\tau)}(i), Y^{(\tau)}(j)]$ less than r and the total distance number $N - m$ associated with this number is denoted by $C_i^{\tau, m}(r)$, its calculation form is the formula (4):

$$C_i^{\tau, m}(r) = \frac{1}{N - m} \{ [d[Y^{(\tau)}(i), Y^{(\tau)}(j)] < r] \} \quad (4)$$

In Formula (4) $C_i^{\tau, m}(r)$ represents the time scale τ , take $Y(i)$ as the center, when the embedding dimension is m and the threshold value is r , the probability of the distance $d[Y^{(\tau)}(i), Y^{(\tau)}(j)]$ between the rest vector $Y^{(\tau)}(j)$ and $Y^{(\tau)}(i)$ less than r represents the association degree of all $Y^{(\tau)}(j) (i \neq j)$ and $Y^{(\tau)}(i)$.

Averaging all the points, the solution method is in the formula (5) below:

$$C^{\tau, m}(i) = (N - m + 1)^{-1} \sum_{i=1}^{N - m + 1} C_i^{\tau, m}(r) \quad (5)$$

In Formula (5) $C_i^{\tau, m}(r)$ represents the average degree of autocorrelation of the time series $y(i)$.

If increase the dimension to $m + 1$, τ can be obtained, the $C_i^{\tau, m}(r)$ under the dimensions $m + 1$, the average value $C_i^{\tau, m+1}(r)$ is obtained; in theory, the sample entropy of this time sequence under scale of τ is defined in the formula (6):

$$\text{SampEn}(m, r) = \lim_{N \rightarrow \infty} - \ln \left[\frac{C^{\tau, m+1}(r)}{C^{\tau, m}(r)} \right] \quad (6)$$

In Formula (6) the value of SampEn is related to m, r , and generally take $m = 2, r = 0.1 - 0.2\text{SD}$, SD represents the standard deviation of the raw data.

When the number value N of the original data is finite, based on the above steps the sequence length N can be drawn, the estimated value of the sample entropy in scale of τ is shown in the formula (7):

$$\text{SampEn}(\tau, m, r) = - \ln \left[\frac{C^{\tau, m+1}(r)}{C^{\tau, m}(r)} \right] \quad (7)$$

Multi-scale entropy is defined as the collection of sample entropy in a number of scales, so multi-scale entropy is in the formula (8) below:

$$\text{MSE} = \left\{ \tau \left[\text{SampEn}(\tau, m, r) = - \ln \left[\frac{C^{\tau, m+1}(r)}{C^{\tau, m}(r)} \right] \right] \right\} \quad (8)$$

There is no rule on the single scale level of the time series determined by sample entropy; the lower the sample entropy value is, the higher the sequence self-similarity is; the larger the sample entropy is, the more complex the sequence is. If we merely adopt the sample entropy rather than using multi-scale analysis, only means comparison and analysis of physiological time series in scale of 1, which cannot distinguish well. If using the multi-scale analysis, when the scale becomes larger, the sample entropy of these three kinds of sequences can get a good distinction. Thus multi-scale entropy analysis has more advantages than merely using sample entropy analysis.

Data empirical analysis**The data statistics of peak feature point**

Multi-scale entropy graph has a peak value under some specific scale. Extract the amplitude and location information of these peaks to evaluate its reproducibility, take it as the extracted feature value in order to reflect the specificity of the accelerated information entropy in the body walking process. Table 1 shows acceleration signal information of the five study objects in the three axis of three-dimensional coordinate system.

Table 1: The data statistics of peak feature point

Axes	Characteristic point	Experimental subject	Position average	Position variance	Range average	Range variance
X axis	The first peak	A	33.33	1.00	3.34	0.092
		B	32.33	1.32	3.48	0.061
		C	36.75	1.50	3.25	0.028
		D	38.01	1.73	3.59	0.099
		E	34.00	1.73	3.64	0.040
	The second peak	A	53.33	1.32	3.59	0.041
		B	47.33	1.32	3.57	0.044
		C	57.01	0.50	3.59	0.046
		D	60.00	0.50	3.64	0.039
		E	48.00	0.50	3.64	0.061
	The third peak	A	78.67	2.50	3.57	0.045
		B	82.67	4.00	3.57	0.063
		C	89.25	1.50	3.61	0.067
		D	90.00	0.50	3.69	0.037
		E	83.00	1.73	3.62	0.029
Y axis	The first peak	A	25.67	1.58	3.36	0.067
		B	43.67	4.00	3.56	0.023
		C	17.25	1.50	3.43	0.124
		D	18.00	0.50	3.34	0.024
		E	13.00	1.73	3.11	0.031
	The second peak	A	45.00	3.67	3.18	0.083
		B	101.00	3.00	3.51	0.083
		C	48.00	2.45	3.50	0.054
		D	52.00	1.73	3.54	0.034
		E	43.00	1.73	3.21	0.084
	The third peak	A	133.33	7.66	3.37	0.122
		B	158.00	3.35	3.53	0.041
		C	119.25	10.78	3.37	0.193
		D	92.00	1.73	3.12	0.076
		E	106.00	3.46	3.23	0.042
Z axis	The first peak	A	32.33	2.00	3.53	0.069
		B	13.00	1.50	3.36	0.091
		C	18.75	1.50	3.32	0.506
		D	20.00	1.73	3.52	0.038
		E	21.00	0.50	3.25	0.576
	The second peak	A	51.33	1.00	3.57	0.053
		B	43.33	3.39	3.48	0.053
		C	43.50	3.87	3.47	0.088
		D	46.00	1.73	3.46	0.128
		E	40.00	1.73	3.63	0.136
	The third peak	A	80.33	2.50	3.56	0.041
		B	85.33	1.58	3.51	0.051
		C	94.50	1.73	3.00	0.234
		D	97.00	1.73	3.17	0.087
		E	88.00	1.73	3.12	0.095

As shown in Table 1, the average magnitude of all axes is relatively close, substantially concentrated in between 3.0-3.6. There are small differences between individuals, there are many overlapping range of all amplitude values. If the amplitude alone cannot be resolved to get a clear analysis, but meanwhile the location mean and variance of another indicator's peak point can more dispersedly and clearly project the distribution condition.

The data comparison of normal and abnormal gait characteristic point

In order to verify the gait feature point information based on wavelet multi-scale entropy analysis, this paper conducts the data comparison and analysis of normal and abnormal gait characteristic point for the three study objects, the data statistical results is shown in Table 2:

Table 2: The data statistics list of two gait feature points

Object of study	Status	Peak 1	Peak 2	Peak 3	Total entropy
F	X Normal	36.75	57.00	89.25	108.33
	X Improper	33.01	106.51	175.26	111.23
	Y Normal	17.25	48.00	119.25	117.52
	Y Improper	52.51	99.00	175.50	76.00
	Z Normal	18.75	43.51	94.50	102.66
	Z Improper	26.25	97.49	165.76	120.21
G	X Normal	38.00	60.00	90.00	119.81
	X Improper	49.00	119.00	155.00	119.27
	Y Normal	18.00	52.00	92.00	102.52
	Y Improper	52.00	105.00	148.00	96.08
	Z Normal	20.00	46.00	97.00	108.35
	Z Improper	21.00	55.00	152.00	123.82
H	X Normal	34.00	48.00	83.00	108.02
	X Improper	56.00	95.00	157.00	108.81
	Y Normal	13.00	43.00	106.00	101.73
	Y Improper	16.00	92.00	158.00	80.51
	Z Normal	21.00	40.00	88.00	94.57
	Z Improper	31.00	91.00	126.00	116.96

As shown in Table 2, the peak position of non-normal state moves to the low frequency overall, in the range of 150-170 scales there appears a new peak, thus the frequency distribution of acceleration in non-normal state becomes low, so it contains more low frequency information; By comparing the total entropy of the three experiment objects, the total entropy of the Z-axis direction is increased than the normal state, indicating that the collected acceleration data has orderly decreased, most likely caused by left-right asymmetry of the test case, resulting disordered waveform, so that the entropy increases. In the Y-axis direction, the total entropy significantly reduced than the normal state, the regulation of action balancing is different from normal. In order to maintain balance oscillation amplitude and frequency need to be controlled, man-made swing around makes it orderly, so the total entropy decreases.

CONCLUSION

In this paper, it studies the gait of eight different study objects in the walk-run course, uses the wavelet multi-scale entropy analysis method, this paper first describes the mathematical model and calculation principles of the wavelet entropy, and then discusses the several characteristics of the traditional entropy analysis method, and finally through data statistics studies the peak points' characteristic of eight study objects; the mean values in the axial direction of 8 study objects' peak values are larger and all concentrated between 3.0-3.6, with small individual difference, by the statistics in table 1, better results can be drawn, followed by feature points information analysis in the two states of three study objects; the peak position overall moves in the low-frequency section in the non-normal state, the total entropy value increases in the Y axial direction and decreases in the Z axial direction, the changes of total entropy value can infer the cause of abnormal state. In this paper, the gait research based on wavelet multi-scale entropy analysis can obtain the body's physical state conditions by studying human gait information, which can make a scientific guide for the study of sport, can also provide data base for the medical industry.

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