A pattern assessment of attractors structured by acceleration plethysmogram time series data

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1. Introduction

Drawing various media attention for years, it is understood that health is one of the most intriguing phenomena for humans. Even the simple word health is equivocal, varying in meaning from a narrow sense, as an antonym of disease , to a wider sense of health that represents a comfortable physical, spiritual and social environment.

Development of modern medical science has enriched our knowledge of disease. For that reason, health in its narrow sense of meaning has been strongly tied to conventional science; it continues to advance. On the other hand, now that the importance of preventive medicine has been recognized, humans have come to require the health in its wider sense. Nevertheless, modern medicine used to be a science by which a partial disease state in a human s body was diagnosed elementally and reductionistically as disease. Therefore, a wider sense of disease will engender increasing demand for general condition assessment because there is no medical information that assesses general conditions of organisms.

In such a context, recently, attention to traditional Chinese medical science (Chinese medicine) has been increasing. Chinese medicine has a chiropractic view, a unique way of grasping an organism, according to which disease is viewed not as local but as a part of the whole during diagnosis and treatment. Such is their theoretical base. Chinese medicine uses sphygmoscopy: it is considered to yield essential information that collectively reflects the state of the general body. Systematically analyzed information obtained from a pulse is used as an objective indicator for observing a disease state.

It is possible that a pulse wave should include information that is useful to assess the general body state. Nevertheless, partly because the trend of arguing against oriental medicines is that they lack scientific authority, what is called a western scientific quest for the essence of sphygmoscopy has not been developed.

Our study has specifically addressed scientifically classifying information from a pulse wave. In addition, we have tried classification assessment of disease state so far by applying nonlinear chaotic analysis to acceleration plethysmogram time series data. [1] The present study examines a new analytical method to supplement information that is missed by the recurrence plot method. We report on this new method as we have used it in conventional research.

2. Recurrence plot method in acceleration plethysmogram.

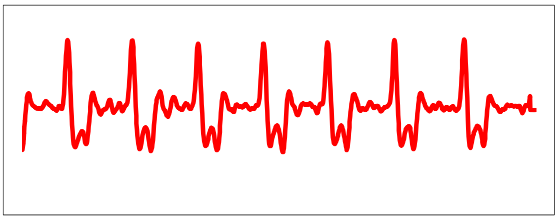
Acceleration plethysmogram time series data, as our analytical object, were collected by Salus APG, a built-in measurement and analysis system, which was developed through our preceding research activities. [2] In this system, the volume shift of a pulse on a fingertip is obtained by sensing the shift of infrared light absorbance with an infrared light transmission sensor. The acceleration plethysmogram is obtained as subject data by quadratically differentiating the picked-up fingertip volume plethysmogram. In our research, we A/D transformed the finger-tip volume plethysmogram with a sampling frequency of 1000 Hz, input it into computer, processed it with digital filter and discrete differentiation, and then thinned it out into 200 Hz, which is the form in which it is used for data.

In the preceding studies, we made the following applications:

1. Each sample of acceleration plethysmogram data for 6 s (1200 point) is normalized into the section [-1, +1].
2. The time delay coordinate system is structured using normalized data (embed dimension 2, delay time 1).
3. For the time delay coordinate system, the recurrence plot image (the distance between two points is calculated by Euclidean distance, bimodal with threshold value e=0.40) is drawn to obtain the rate of dotted white points in the entire plot (white rate for recurrence plot: RP_dw).

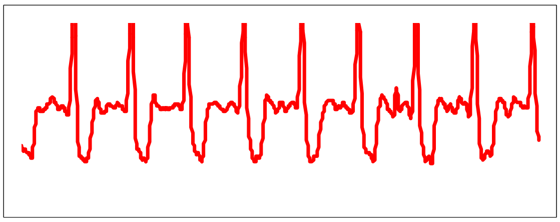
A certain result was obtained by adopting the RP_dw obtained here as an index for quantitative health estimation and attempting to classify data into a control group and a disease state group.

On the other hand, examples also exist in which the expected analytical results were not obtained in our previous research. Figure 1 shows acceleration plethysmograms obtained from two subjects. Whereas both chaotic analytical index values, TPM_ave and RP_dw, are not significantly different, seeing wave patterns, subject (B) s C wave declines in comparison with subject (A) s. It is suspected that the descent of C wave may be organically and functionally caused by vascular sclerosis. Therefore, it is desirable to identify these two wave patterns.



Subject (A)

PR=78, TPM_ave=0.103, RP_dw=0.504



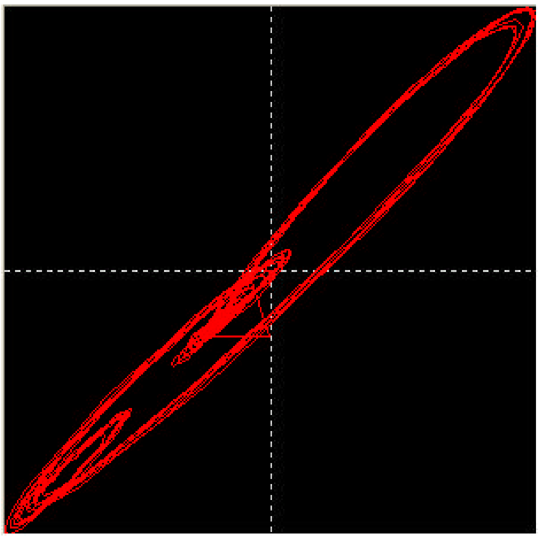
Subject (B)

PR=90, TPM_ave=0.100, RP_dw=0.517

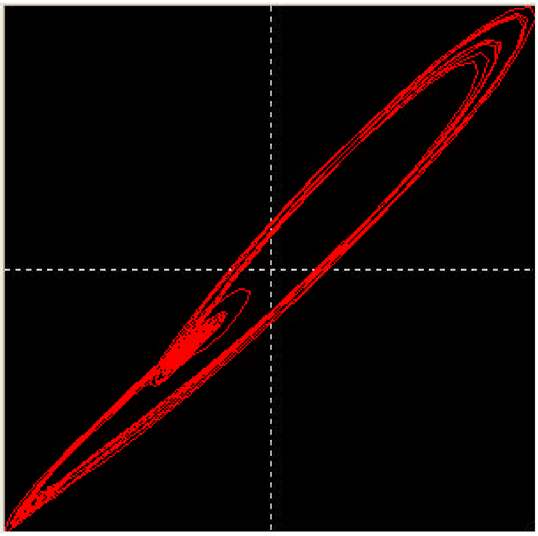
Figure 1 : Cases that could not be classified.

As in the above example, chaotic analysis is essentially an analytical method that can express a difference. Figure 2 shows the attractor, illustrating the time delay coordinate system constructed by the embed parameter setup of dimensionality 2 and time delay 1 from the two acceleration plethysmograms shown in Figure 1. There is a marked difference between the orbits: especially, a spiral orbit seen at the upper left part of subject (A) s attractor is not evident in subject (B) s.

In addition to the case mentioned above, the following case exists: the unsteadiness of pulse wave can be medically determined, but cannot be represented by RP_dw in the case where the state of circulation is unstable because of arrhythmia. Conversely, even if blood vessels are aged by arterial sclerosis and RP_dw consequently shows an abnormal value, blood flow and health sense itself may appear to be clinically stable when they are measured.



Subject (A)



Subject (B)

Figure 2 : Attractor (dimension 2, delay time 1)

Any of these cases can be classified by the degree of stability in nonlinear analysis. In addition, because the recurrence plot method is originally a method to visualize the correlation among all the points on the time delay coordinate system, it has high ability to represent the instability that time series data have. However, RP_dw, even if showing the relative distance between coordinate systems, has yet to be an index reflecting such a visually elaborate correlation as plot patterns, which recurrence plot method should originally provide.

Therefore, we aim at examining an analytical method by which to have a more accurate grasp of the stability degree of attractor and at improving its classification function.

3. Distribution of distances between points on the time delay coordinate system

As described above, the recurrence plot figure represents the distance between two points on the time delay coordinate system as a concentration distribution figure. If we develop such an analytical method to quantitatively express the distribution pattern, we should be able to express the information brought about by recurrence plot method with more accuracy. An experiment using texture analytical method and a method assuming KS entropy have been suggested as a preceding study of recurrence plot s pattern analysis. [3] We presumed that the histogram is generated by the distance between two points that are represented by each point of recurrence plot. We also presumed that its configuration should provide a distribution pattern.

The algorithm for making the histogram is the following:

1. Data of acceleration plethysmograms for 6 s are normalized to structure a time delay coordinate system. To date, the process is identical to that of conventional analytical methods that we have used before.
2. For the time delay coordinate system, the Euclidean distance between two points of each vector combination is calculated to produce distribution figures with section threshold e=0.01 and to generate a histogram.

Because the data of acceleration plethysmograms are normalized, the combination of two points whose distance is the largest is (-1, -1) (1, 1). Therefore, the Euclidean distance of the two points is:

$$0 \le d \le 2\sqrt{2} \cong 2.828$$

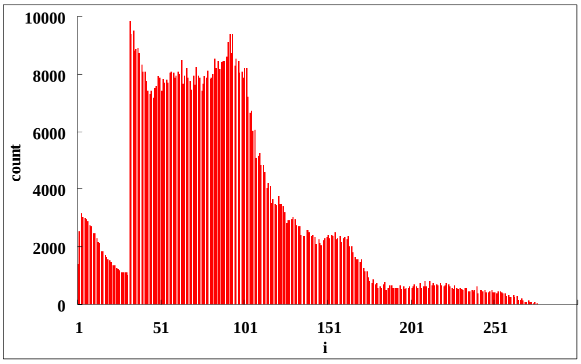
Therefore, the distribution figure, X(i), is defined in this formula:

$$X(i) = count\_if((i-1)*\varepsilon \le d \le i*\varepsilon)$$
$$(1 \le i \le 283)$$

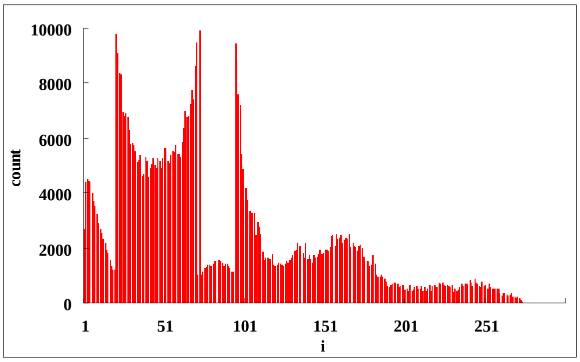
On the basis of this algorithm, with two cases of acceleration plethysmograms in Figure 1, a histogram is made to resemble that in Figure 3.

In subject (A) s acceleration plethysmograms, because the component waves of A, B, and C have sharp inclining and declining trends, the attractor has a small spiral orbit. Therefore, the statistic of Euclidean distance between each point shows scattered distance distributions, which are reflected in the histogram.

On the other hand, in the subject (B) s acceleration plethysmograms, the C wave declines and B, C, and D waves are united into one component wave, thereby simplifying the attractor. Therefore, the histogram has a shape with several peaks because the coordinate systems that produce the attractor are dispersed around two points: one is near and the other is far.



Subject (A)



Subject (B)

Figure 3 : The histogram of between-each-point distance

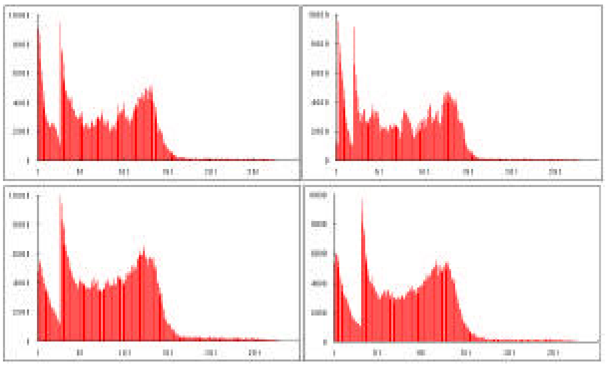
4. Application of the between-each-point distance histogram to acceleration plethysmograms in different modes

Figure 4 shows a histogram of the distances between points estimated from acceleration plethysmograms of four healthy high-school students and four subjects who tended to have a poor blood circulation. The histograms shapes are altogether different from those of the subjects in Figure 3, though healthy; blood flow reflects the slight aging.

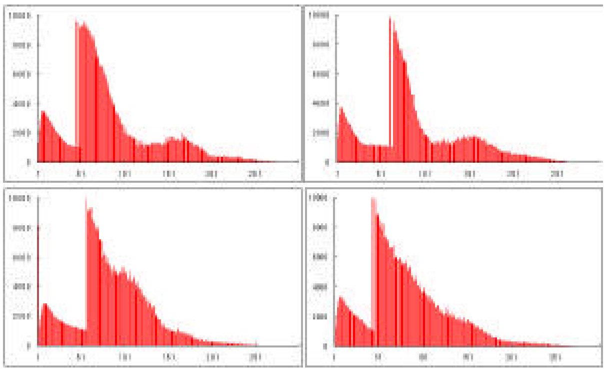
In healthy acceleration plethysmograms are typical of high-school students, whereas A and B waves, which systolic component waves, have sufficient amplitude, the reflection waves are smaller from the C wave on and have orbits near the base line. Then, with the attractor orbit, points are converged around the center of the orbit. Consequently, the combinations of points for which the separation distance is shorter increase. The histogram shows that phenomenon as a peak.

Regarding subjects tending to have a poor blood circulation, the wave pattern is unstable and the stable section near the base line is short compared with healthy or slightly aged acceleration plethysmograms. This fact suggests that the amplitude of the systolic component of A or B wave is small. Therefore, the waves from C wave become relatively larger. Consequently, the coordinate system structuring attractor is dispersed. Therefore, the distribution is also dispersed with the distance between each point.

In this way, it is possible to observe structural patterns in spectra by drawing the histogram as statistical information of the between-each-point distance estimated from the constructed time delay coordinate system.



Healthy high-school students



Subjects who are suspected of having poor blood circulation

Figure 4 : Histograms from different subjects

It is suggested that this method for observing structural patterns can be another explanation of chaos from a different aspect from the previously used conventional methods, including trajectory parallel measure (TPM) to index the orbiting disorder, or the draw white rate for Recurrence Plot (RP_dw) to index the rate of stability in comparison to the whole extent of analysis.

5. Conclusion

This study examined a new analytical method to obtain pattern information of a time delay coordinate system. This is the first study to examine it. Producing a histogram from distances between respective points on the time delay coordinate system, we confirmed that characteristics of the distance distribution of coordinate system can be observed in a spectrum. Partly because in sphygmoscopy, the shape of each wave pattern and the sequence regularity are originally grasped. Very importantly, we can estimate this structural pattern in acceleration plethysmograms chaotic analysis. In addition, even in analyzing other signals than acceleration plethysmograms, it is useful that we can research the structure pattern of a time delay coordinate system.

Some obstacles to development exist. First, although this study described only that we can visually confirm the construction pattern by making a histogram, we did not mention it concretely or index it numerically. At present, even if we advance the study anticipating that spectrum analysis of histogram should engender numeric expression of the result, we have not yet obtained a remarkable result.

In addition, this method did not always clearly classify arrhythmia in the direction of the time axis, such as tachycardia and bradycardia. The instability in the direction of the time axis can be verified by looking at the wave pattern of plethysmograms or measuring the pulse rate and its dispersion. Nevertheless, from the viewpoint of pattern information, it should be classified to be put to practical use. We view this as one items to be examined in future studies.

In this study, which advances research that specifically addresses pattern classification, we first tried analyzing the recurrence plot image s pattern using pattern epistemology and image epistemology. Furthermore, we attempted to express the complexity of patterns by observing the degree of compressibility of the recurrence plot image; we received only the results reported here. We must examine other analytical methods that better reflect the pattern of a time delay coordinate system.

[Reference]

[1] Chaos-based Quantitative Health Evaluation and Disease State Estimation by Acceleration Plethysmogram , Tadashi Iokibe etc, Journal of Japan Society for Fuzzy Theory and Intelligent Informatics (Vol.15 No.5), pp.565-576

[2] Salus APG New Item for Health and Chaos -, Mitsuyuki Amata etc, The Journal of Advanced Community Medicine, Vol 1(2003), pp.16-21

[3] Quantifying Recurrence Plots by Texture Analysis , Tohru Ikeguchi etc, Technical Report of IEICE (Vol.95 No.505 (NLP95-101)), pp.23-30