Research of Rectal Pressure Signal Preprocessing Based on Improved FastICA Algorithm

Peng Zan[1], Yankai Liu[1], Suqin Zhang[2], Chundong Zhang[1], Hua Wang[1], and Zhiyuan Gao[1(✉)]

[1] Shanghai Key Laboratory of Power Station Automation Technology, School of Mechatronics Engineering and Automation, Shanghai University, Shanghai, China
gaozhiyuan86@shu.edu.cn
[2] Naval Aeronautical University Qingdao Campus, Qingdao, China

Abstract. In view of some shortcomings of the existing rectal function diagnosis method, we propose that use the artificial anal sphincter system to collect the human rectal pressure signal, and then achieve the diagnosis of human rectal status through the rectal function diagnosis model. Since the collected signal is not pure rectal pressure signal, the single-dimensional pressure signal is extended to a multidimensional time series by phase space reconstruction. And then preprocessing of the reconstructed signal is carried out by the improved fifteenth order Newton iteration Fast ICA algorithm. The improved algorithm is simulated and the better separation effect is realized, proving the feasibility of the algorithm.

Keywords: Rectal pressure signal · FastICA · Signal preprocessing

1 Introduction

Fecal incontinence is that the anal sphincter loses control capacity of fecal and gas discharge, which is a common clinical disease. There are a variety of treatments for fecal incontinence, including conservative treatment represented by controlling diet, surgical treatment represented by colostomy, and other treatments between them [1, 2]. But they all have some deficiencies. So bionic artificial anal sphincter system that do not change the body's traditional defecation model came into being, which will greatly reduce the pain of patients with fecal incontinence [3].

At present, the diagnosis of rectal function are: digital rectal examination, proctoscopy, rectal pressure measurement, X-ray examination, CT, MRT and other methods [4]. However, there are more or less drawbacks. This article designs a new type of rectal function diagnosis model, which is characterized by the use of artificial anal sphincter system implanted in human body for intestinal pressure information in a real-time, sustained and convenient way. The one-dimensional signal is reconstructed into multidimensional by phase space reconstruction [5], and then the preprocessing of the signal is realized by using the improved FastICA. Finally, a series of further signal

M. Fei et al. (Eds.): LSMS/ICSEE 2017, Part I, CCIS 761, pp. 3–12, 2017.
DOI: 10.1007/978-981-10-6370-1_1

processing of the rectal pressure signal after pretreatment is used to realize the rectal function diagnosis. In addition, the effectiveness of the method is proved by simulation experiments.

2 The Principle of Rectal Pressure Signal Preprocessing

The rectal function diagnostic model relies on the platform of the artificial anal sphincter system and obtains rectal pressure information through the sensor located in the sensing bag around the rectum continuously. Since the signals we receive exist some Interference signals (breathing, muscle movement, noise, etc.) and various interference signals have independent sources. Therefore, this paper uses FastICA algorithm for rectal pressure signal pretreatment. For characteristic of the algorithm that the initial value is more sensitive, we adopt an improved fifteenth order convergence of the iterative algorithm [6]. FastICA algorithm requires multidimensional time series, but the signal measured is one-dimensional pressure signal. Thus, phase space reconstruction technology is adopted to rebuild the one-dimensional pressure signal to multi-dimensional. Rectal pressure signal preconditioning will lay the foundation for the realization of rectal function diagnostic model. The principle of rectal pressure signal preprocess is shown in Fig. 1.

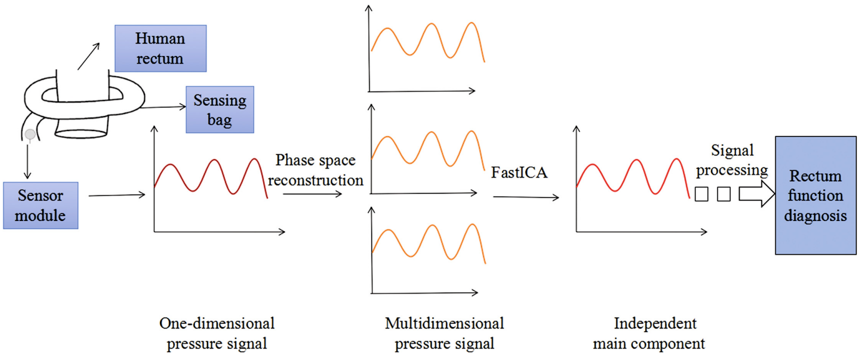

Fig. 1. The principle of rectal pressure signal preprocessing

3 Algorithm Analysis of Rectal Pressure Signal Preprocessing

3.1 Phase Space Reconstruction

Phase space reconstruction is a method proposed by Takens to construct the phase space structure of the original system by one-dimensional time series. The delay coordinate method is commonly used. The selection of time delay τ and embedding dimension m is very important. In this paper, the embedded dimension and time delay automatic algorithm is used to reconstruct the one-dimensional pressure sequence [7]. The principle is as follows:

(1) Set the pressure sequence as $X = \{xi(t)\}$, i = 1,2…N. Let $m = m_0$ and τ varies from small to large. Construct X as vectors $\{y_i\}$, i = 1,2…M, $y_i = (x_i, x_{i+1}\ldots x_{i+}(m-1)\tau)$,$M = N - (m-1)\tau$. Then Calculate the average amount of displacement:

$$s(\tau) = \frac{1}{M}\sum_{i=1}^{M}\sqrt{\sum_{j=1}^{m-1}\left(y_{i+j\tau} - y_i\right)^2} \tag{1}$$

Next it will be derivative of τ. When the value is close to 0, the value of $s(\tau)$ reaches the saturation.

Substitute the calculated τ into $\Gamma_{-\text{test}}$ to calculate the corresponding best m. Set $z = f(x_1, x_2\ldots x_m) + \gamma$. Give a value of m, and then reconstruct vectors space of X.

$$\varepsilon_i = \{x(i), x((i+1)\tau), \ldots x((i+m-1)\tau)\} \tag{2}$$

(2) Set $z_i = x((i+m)\tau)$, i = 1,2..M. Create M groups of input, output vector pairs. Find the neighbor vectors of p in the vector space. Calculate

$$\begin{cases} dx(h) = \dfrac{1}{p}\displaystyle\sum_{h=1}^{p}\frac{1}{M}\sum_{i=1}^{M}|\varepsilon(N(i,p)) - \varepsilon(i)|^2 \\ dz(h) = \dfrac{1}{p}\displaystyle\sum_{h=1}^{p}\frac{1}{2M}\sum_{i=1}^{M}[z(N(i,p)) - z(i)]^2 \end{cases} \tag{3}$$

Use linear interpolation $dz = Adx + \Gamma$ to estimate the approximate value of γ, Γ. Increase m, and then repeat (1). Calculate the corresponding the minimum value of the approximation of τ, γ, where m, τ is the optimal value.

3.2 FastICA Algorithm

FastICA algorithm is presented by Hyvärinen et al., University of Helsinki, Finland [8]. In this paper, an improved FastICA algorithm based on the largest negative entropy is used. For the shortcoming of basic Newton iteration Fast ICA algorithm that is more sensitive to the initial value, the improved algorithm takes the modified form of the Fifth - order Newton iteration with better convergence rate [6].

Before carrying out the FastICA, data needs to be removed mean and whited.

$$x = x' - E\{x'\} \tag{4}$$

$$E\{yy^T\} = I \tag{5}$$

The objective function of Fast ICA algorithm based on negative entropy is:

$$J(W) = \left[E\left\{G\left(W^T Z\right)\right\} - E\{G(V)\}\right]^2 \quad (6)$$

The algorithm estimates an independent component of the source signal by maximizing the objective function. And the maximum value of J (W) is obtained at the extreme point of E{G(W^TZ)}. According to the Lagrangian condition, the extreme value of E{G(W^TZ)} can be obtained by solving the following condition under the constraint condition of E{(W^TZ) ^{2}} = ‖ W ‖ ^{2} = 1:

$$E\left\{Zg\left(W^T Z\right)\right\} + \beta W = 0 \quad (7)$$

$\beta = E\left\{W_0^T Zg\left(W_0^T Z\right)\right\}$, W_0 is the initial value of W, and g (.) is the derivative of G (.).

The improved Newton iteration method is as follows:

$$\begin{cases} x_{n+1}^* = x_n - \frac{f(x_n)}{f'(x_n)} \\ z_n = x_n - \frac{2f(x_n)}{f'\left(x_{n+1}^*\right) + f'(x_n)} \\ y_n = z_n - \frac{f(z_n)}{f'\left(x_{n+1}^*\right)} \\ x_{n+1} = y_n - \frac{f(y_n)f'(y_n)}{f'^2(y_n) - f''(y_n)f(y_n)/2} \end{cases} \quad (8)$$

The improved iterative scheme is at least 15th order convergent, and the iterative efficiency is much larger than the Newton iteration method. Use the modified Newton iteration method to solve Eq. (7):

$$W_{k+1} = W_1 - \frac{\left[E\left\{Zg\left(W_1^T Z\right)\right\} + \beta W_1\right]\left[E\left\{g'\left(W_1^T Z\right)\right\} + \beta\right]}{\left[E\left\{g'\left(W_1^T Z\right)\right\} + \beta\right]^2 - \frac{\left[E\left\{g''\left(W_1^T Z\right)\right\}_1\right]\left[E\left\{Zg\left(W_1^T Z\right)\right\} + \beta W_1\right]}{2}} \quad (9)$$

Among them,

$$\begin{cases} W_1 = W_2 - \frac{E\left\{Zg\left(W_2^T Z\right)\right\} + \beta W_2}{E\left\{g'\left(W_3^T Z\right)\right\} + \beta} \\ W_2 = W - \frac{2\left[E\{Zg(W^T Z)\} + \beta W\right]}{\left[E\left\{g'\left(W_3^T Z\right)\right\} + \beta\right] + \left[E\{g'(W^T Z)\} + \beta\right]} \\ W_3 = W - \frac{E\{Zg(W^T Z)\} + \beta W}{E\{g'(W^T Z)\} + \beta} \end{cases} \quad (10)$$

4 Experimental and Simulation Analysis

In order to validate the improved FastICA method in this paper, simulation experiments are carried out. First, four common non-Gaussian signals are generated: sine wave, square wave, sawtooth wave, and a random noise. They are expressed as: sine wave

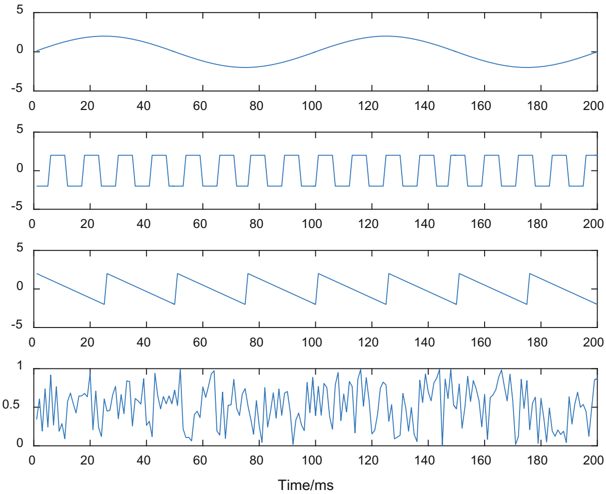

Fig. 2. Source signal waveform

signal s_1 = 2 * sin (0.02 * pi * n); square wave signal s_2 = 2 * square (100 * t, 50); sawtooth signal (1, –1, n); s_3 = 2 * [a, a, a, a, a, a, a, a]; random noise is s_4 = rand (1, N).The waveform of the source signal is shown in Fig. 2.

The sinusoidal signal is viewed as a valid signal, and the others are viewed as three kinds of interference signals. Mix the four signals into one-dimensional signals, as shown in Fig. 3. The mixing matrix is A = [0.7847 0.5379 0.0529 0.0891].

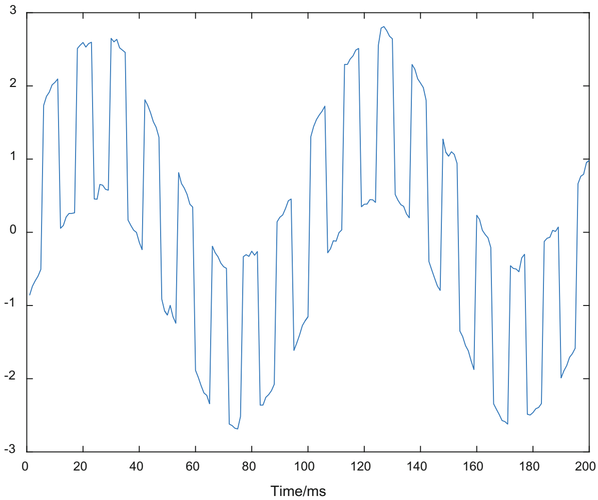

Fig. 3. One-dimensional mixed signal

The obtained one-dimensional mixed signal is phase-reconstructed to obtain the reconstructed 4-D signal as shown in Fig. 4.

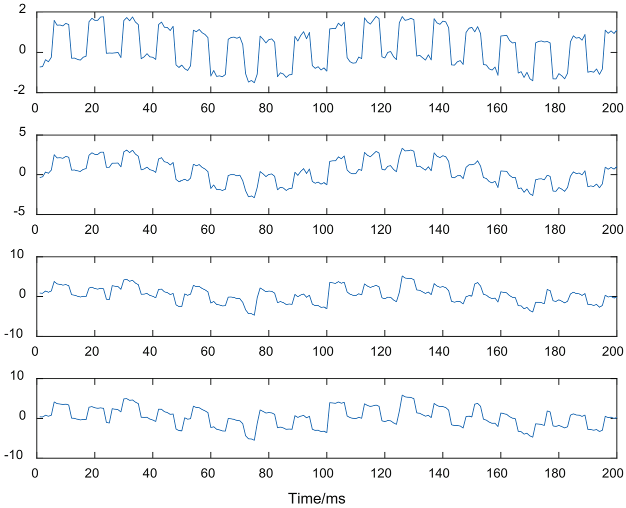

Fig. 4. Phase space reconstructed signal

Use the improved FastICA algorithm described above to obtain the Separation signal as shown in Fig. 5. As can be seen from the figure, the output of the classification of the waveform roughly unchanged, proving a better separation effect and achieving the desired purpose. The output order of the waveform of the components after the remolding changed and the amplitude and phase of each component changed contrast to the source signal. This is determined by the inherent characteristics of the ICA algorithm [6]. But we generally pay more attention to the waveform of the signal and the amplitude of the change doesn't affect our extraction and analysis.

The reconstructed signal is processed by using the basic FastICA algorithm to obtain the separation result as shown in Fig. 6. From Figs. 5 and 6, we can see that the two algorithms can separate the various components, and the separation effect is similar. Then, each algorithm is run five times under the condition that the initial vector is indefinite. The number of iterations and the running time of the two algorithms are compared and the results are shown in Table 1. It can be seen from the table that the improved FastICA algorithm has less iterations. The iterative stability is better and the running time has been reduced. It is proved that the improved algorithm is insensitive to the initial value and the effect is better.

And then the real human rectal pressure signal is used for the validation of the improved the FastICA algorithm. The data used in this paper is from the pressure data collected in tester whose gut is healthy by biological parameters telemetry capsule invented by Shanghai Jiao tong University [9]. Select the fragment of one of the signal sequences as shown in Fig. 7 as the mixed signal to be separated.

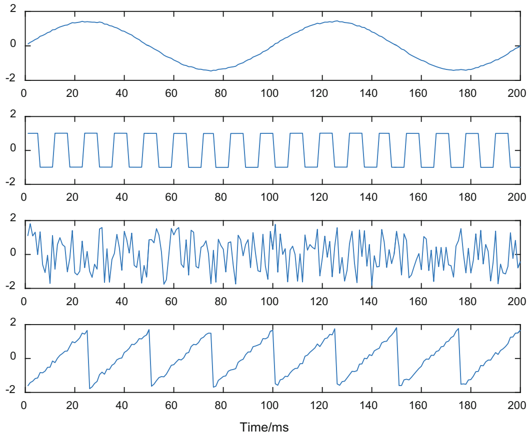

Fig. 5. Improved FastICA separation results

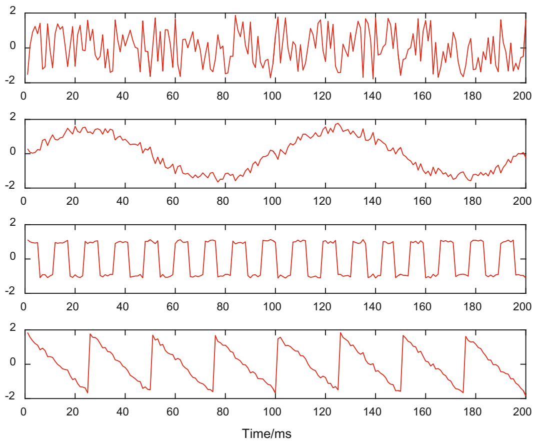

Fig. 6. Basic FastICA separation results

Table 1. Comparison of the number of iterations and run time of two algorithms

Number	Improved FastICA		Basic FastICA	
	Number of iterations	Run time	Number of iterations	Run time
1	152	0.817	714	1.646
2	134	0.834	384	0.957
3	167	0.822	217	0.867
4	179	0.834	206	0.805
5	157	0.818	482	0.943
Average value	157.8	0.825	400.6	1.0436

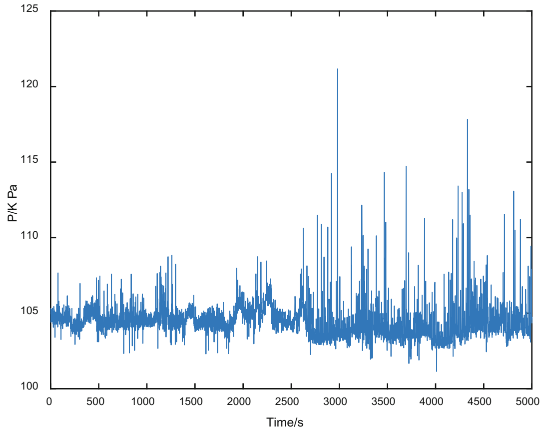

Fig. 7. Rectal mixed signal

According to the phase space reconstruction technique proposed above, the multidimensional pressure sequence reconstruction is carried out. Experiments show that $m = 3$, $\tau = 5$ are the optimal values, and the effect of reconstruction is the best. The reconstructed observation signal is shown in Fig. 8. The reconstructed multidimensional pressure sequence is separated by FastICA, and the results of the separation are shown in Fig. 9. It can be seen from the figure that the improved FastICA algorithm achieves the separation of the signal. The first component has the main trend and characteristics of the corresponding parent signal and it should be the pressure component caused by rectal contraction. The other two components should be abdominal muscle contraction, respiratory movement. The improved FastICA algorithm achieves the preconditioning of rectal pressure signals, laying the foundation for further online diagnosis of rectal function by further analysis and processing of pressure signals.

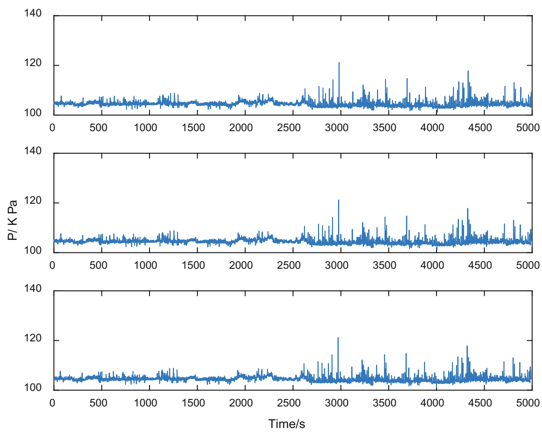

Fig. 8. The reconstructed observation signal

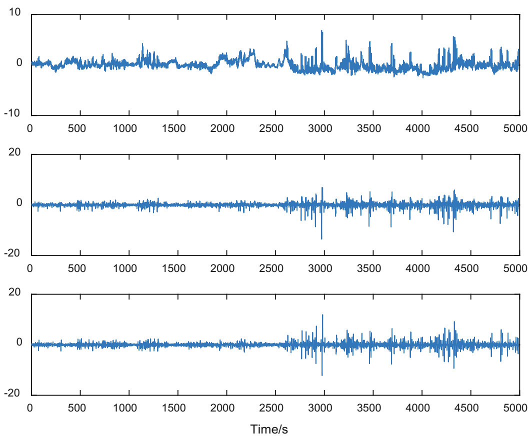

Fig. 9. Rectal pressure signal separation results

5 Conclusion

In order to achieve on-line, continuous detection of rectal function, using artificial anal sphincter system to collect the patient's rectal pressure signal for analysis is proposed. The adaptive pressure signal is reconstructed into multidimensional by phase space reconstruction technique, and then the improved FastICA algorithm is used to preprocess the signal. Finally, the simulations of the simulated data and real data are analyzed. The results show that the modified method can achieve the purpose of pretreatment, laying the foundation for the diagnosis of rectal function.

Acknowledgments. This work was supported by National Natural Science Foundation of China (No. 31570998)

References

1. Rezvan, A., Jakuswaldman, S., Abbas, M.A., et al.: Review of the diagnosis, management and treatment of fecal incontinence. Female Pelvic Med. Reconstr. Surg. **21**(1), 8–17 (2014)
2. Bochenska, K., Boller, A.M.: Fecal incontinence: epidemiology, impact, and treatment. Clin. Colon Rectal Surg. **29**(3), 264 (2016)
3. Fattorini, E., Brusa, T., Gingert, C., et al.: Artificial muscle devices: innovations and prospects for fecal incontinence treatment. Ann. Biomed. Eng. **44**(5), 1355–1369 (2016)
4. Saldana, R.N., Kaiser, A.M.: Fecal incontinence - challenges and solutions. World J. Gastroenterol. **23**(1), 11–24 (2017)
5. Song, J., Meng, D., Wang, Y.: Analysis of chaotic behavior based on phase space reconstruction methods. In: Sixth International Symposium on Computational Intelligence and Design, vol. 2, pp. 414–417. IEEE (2013)
6. Luo, W.J., Yuan, L.F., He, Y.G.: Improved fastICA algorithm based on fifteen-order Newton iteration. Comput. Eng. Appl. **52**(20), 108–113 (2016)

7. Otani, M., Jones, A.J.: Automated Embedding and the Creep Phenomenon in Chaotic Time Series (2001)
8. Huang, X.: An improved FastICA algorithm for blind signal separation and its application. In: International Conference on Image Analysis and Signal Processing, vol. 8556, pp. 1–4. IEEE (2013)
9. Li, Q.R., Yan, G.Z.: A non-invasive capsule and clinic experimentation for detecting the physiological parameters of gastrointestinal tract. Beijing Biomed. Eng. **27**(3), 281–285 (2008)