Diagnosis system of sleep apnea based on wearable sensor

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Abstract. Sleep Apnea Syndrome (SAS) is a serious threat to the life and health of patients. In this paper, a breathing coil is used as a flexible sensor, and a breathing signal conditioning circuit is designed to collect breathing signals. At the same time, an algorithm for determining the incidence of apnea is designed. First, all the maximum points in the respiratory signal and the corresponding extreme positions are found; then the cubic spline interpolation function is used to fit the upper and lower values of the maximum and the minimum envelope, and find the average value of the upper and lower envelopes; finally, the peak or trough point by searching for the local minimum or local maximum in the average envelope was found, and then further segmented calculations was performed. The test results show that the misjudgment range between the number of sleep apneas recorded by the simulation experiment and the number of sleep apneas obtained by the algorithm is between -2 and 3 times. The designed system terminal equipment is accurate, comfortable to wear, can be monitored for a long time. And is suitable for family daily sleep monitoring.

1. Introduction
Sleep apnea syndrome is a common sleep disease that can induce a variety of diseases such as high blood pressure, diabetes, coronary heart disease. It seriously threatens the life of patients and requires timely treatment [1,2]. At present, the most authoritative diagnostic method for detecting SAS is PSG, which can not only diagnose the incidence of SAS, but also quantitatively analyze the sleep structure of patients [3]. However, the PSG test takes a long time and the test cost is expensive. The instrument has poor wearing comfort.

Based on the analysis of research status at home and abroad, it can be seen that although the existing algorithms for detecting sleep apnea syndrome have achieved good results, they often have some shortcomings, and most of the research is in the field of offline research. The application effect is poor [4]. With in-depth research in related fields such as biomedicine and embedded development, the development of a wearable, low cost, comfortable, accurate detection and high signal stability sleep apnea detection system has certain research significance and commercial value.

This paper combines respiratory signals to detect the incidence of SAS. The system uses a smart chest strap to record breathing data during sleep, and then analyzes the signal characteristics on the host computer to diagnose the incidence of SAS.

2. Respiration signal acquisition and conditioning
The acquisition method used in this paper is piezoelectric pneumography, and the piezoelectric material is PVDF piezoelectric film [5,6]. PVDF piezoelectric film is very suitable for long-term sleep monitoring systems. It has the following advantages [7,8]: wide frequency response, large dynamic range, high sensitivity of force-to-electricity conversion. This system embeds the PVDF piezoelectric...
film into the elastic chest strap of the wearable terminal to form a breathing coil, and realizes the front-end collection of human breathing signals through the breathing coil. The physical diagram of the breathing coil is shown in Figure 1. Human breathing forces the piezoelectric film and produces periodic deformation with the breathing rhythm. The amount of charge generated by the piezoelectric film also changes. By extracting the surface charge of the piezoelectric film, converting it into voltage, and then undergoing signal conditioning After that, the breathing signal can be obtained.

![Figure 1. Physical picture of breathing coil.](image)

The signal collected by the breathing coil is relatively weak, the frequency is 0.1~1Hz, and it is easily interfered by various noises [9], and even the output effective signal of the sensor is lower than the equivalent noise of the circuit, so the breathing signal needs to be conditioning. Including the original signal amplifying, filtering, lifting, etc., the flow diagram of the breathing signal conditioning circuit is shown in Figure 2.

![Figure 2. Block diagram of the flow of breathing signal conditioning circuit.](image)

3. The Algorithm for Judgment of SAS Incidence Based on Respiratory Signal

3.1 Respiration signal preprocessing based on cubic spline interpolation algorithm

The cubic spline interpolation function needs to construct a piecewise function according to a given function table, and the constructed function curve needs to pass through a given point, and it must have continuous first and second derivatives.

For the number set \( \{x_i\} \) with \( n+1 \) given points, set a node on the interval \( [a, b] \) and divide it into:

\[
a = x_0 < x_1 < \cdots < x_n = b
\]

If the function \( S(x) \in C^2[a, b] \), in each cell \( [x_j, x_{j+1}] \) is a cubic polynomial, where \( a = x_0 < x_1 < \cdots < x_n = b \) is Given a node, and the given function value on node \( x_j \):

\[
y_j = f(x_j)(j = 0, 1, \cdots, n)
\]

At the same time, the cubic spline function \( S(x) \) of the node set satisfies the interpolation condition:

\[
S(x_j) = y_j(j = 0, 1, \cdots, n)
\]
Then call this \( S(x) \) the cubic spline interpolation function.

Because \( S(x) \) is a polynomial with degree less than three in each interval, there are four unknown coefficients, and \( S(x) \) will be divided into \( n \) segments, so there are \( 4n \) unknown coefficients, but the conditions of interpolation and splines Only \( 4n-2 \) will be provided, so the two missing conditions need to be given by the boundary conditions. Usually these two conditions should be provided for the state of the interpolation function at the two endpoints \( a \) and \( b \) according to the actual situation. There are three types of boundary conditions for interpolation polynomials:

The first boundary condition is obtained by taking the first derivative of the interval endpoints.

\[
S'(x_0) = m_0 = f'(x_0) \quad (4)
\]

\[
S'(x_n) = m_n = f'(x_n) \quad (5)
\]

The second boundary condition is obtained by taking the second derivative of the interval endpoints.

\[
S''(x_0) = \alpha_0 = f''(x_0) \quad (6)
\]

\[
S''(x_n) = \alpha_n = f''(x_n) \quad (7)
\]

Among them, when the second derivative value of the endpoint is always 0, it is called a natural boundary condition.

\[
S''(x_0) = \alpha_0 = 0 \quad (8)
\]

\[
S''(x_n) = \alpha_n = 0 \quad (9)
\]

The periodic boundary condition is obtained by the function value or derivative value at the end of the interval satisfying the periodic condition. At this time, \( f(x) \) is a function with \( b-a \) as the period.

\[
S(x_0 + 0) = S(x_0 - 0) \quad (10)
\]

\[
S'(x_0 + 0) = S'(x_0 - 0) \quad (11)
\]

\[
S''(x_0 + 0) = S''(x_0 - 0) \quad (12)
\]

The cubic spline difference used by the algorithm selects the natural boundary condition in the second boundary condition.

### 3.2 Disease severity judgment algorithm

The main idea of the SAS disease severity judgment algorithm proposed in this paper is: for the collected respiratory signals, first, extract the effective signal according to the waveform, and perform further filtering processing on the basis of the hardware filter circuit to find all the effective signals. The maximum and minimum points and the corresponding extreme positions; then, use cubic spline interpolation function to fit the upper and lower envelopes of the maximum and minimum values, and find the average of the upper and lower envelopes. The peak or trough of the breathing signal after fitting is more obvious; finally, the waveform method is used for the average envelope of the signal to find the peak or trough point by finding the local minimum or local maximum position in the average envelope, and then perform further segment calculations. The detailed steps of the algorithm are:

1. For the saved breathing signal waveform \( b(t) \), first use the find function to find the maximum point \( b_{\text{max}} \) and extreme point in the waveform.

2. Use the interpret function to perform cubic spline interpolation function interpolation for the maximum and minimum points respectively; The component type uses the natural boundary conditions of csape, and the ppval function fits the signal envelopes \( Z_1(t) \), \( Z_2(t) \).

3. Calculate \( M(t) = (Z_1(t) + Z_2(t))/2 \), which is the average envelope.

4. Find the local maximum position of the envelope through the findpeak function, and find the peak value (ie the maximum value) of \( M(t) \), And determine the time position \( Y(t) \) corresponding to the wave crest.

The time interval between two adjacent peak points, that is, \( Y(i+1)-Y(i) \), if the difference is within the set time range, the peak value can be regarded as a valid peak. In addition, during sleep, the maximum breathing rate of a normal person does not exceed 25 breaths/min. Therefore, if the time interval between a certain peak and two adjacent peaks is less than 2.4s, that is, \( Y(i+1)- Y(i)<2.4 \), at
this time the wave is regarded as an interference wave and eliminated. If the time interval between two effective respiratory peaks exceeds 10 seconds, that is, $Y(i+1)-Y(i)>10$, it is considered that a sleep apnea has occurred. If $2.4<Y(i+1)-Y(i)\leq10$, then each complete effective peak can be regarded as a normal breath. Finally, the number of sleep apneas is used to determine the severity of sleep apnea syndrome.

4. Test results and analysis

In order to achieve the overall test of the system, this paper selected 5 males and 5 females, a total of 10 volunteers for relevant experiments. The subjects were all adults and did not suffer from any respiratory or heart diseases. Randomly selected respiratory signal segments in normal state and sleep apnea state, the results of the original respiratory signal after three times of spline preprocessing and the effect of peak positioning are shown in Fig. 3 and 4. It can be seen from the waveform that there will be small crests or troughs at part of the peaks and most troughs of the signal, that is, the phenomenon of pseudo crests (valleys).

![Figure 3. Respiration preconditioning and wave crest positioning diagram under normal conditions.](image)

Through comparison, it can be found that the algorithm has better peak positioning effect under normal conditions, but in sleep apnea state, although the number of sleep apneas can be more accurately determined on the waveform, it will appear the phenomenon of pseudo peak, which leads to a certain deviation of the respiratory rate.

After the peak location test, the next step is to further test the incidence algorithm. The test data also uses the respiratory data collected in the above simulation experiment. After processing and calculating the data, the number of sleep apnea and respiratory rate can be obtained. The error between the number of sleep apneas recorded by the simulation experiment and the number of sleep apneas obtained by the algorithm is small, and the misjudgment range is between -2 and 3 times, which has little effect on the judgment of the severity of the disease. So the simulated data can be used for test
5. Conclusion
This article is based on the respiratory signal to realize the judgment of the incidence of sleep apnea syndrome. The wearable terminal part of the system collects breathing signals through a breathing coil made of a polyvinylidene fluoride piezoelectric film, and designs a breathing signal conditioning circuit to realize the wearability of the equipment and improve the comfort. At the same time, an algorithm for the incidence of sleep apnea syndrome is designed. The algorithm first preprocesses the respiratory signal through cubic spline interpolation, then extracts the respiratory rate and obtains the number of sleep apneas, and then makes a simple judgment of the incidence based on clinical diagnostic criteria. Finally, the accuracy of the designed system is verified through experiments. The test results show that the wearable terminal can accurately and effectively collect breathing signals, and the error range of the number of sleep apneas of the disease degree algorithm is between -2 and 3 times, which can meet the needs of sleep apnea syndrome detection and disease severity judgment. However, the processing accuracy of the algorithm needs to be improved, and there are still individual peaks in the processed waveform. In addition, due to time and actual conditions, the simulation examples used in this article are few, and a large number of clinical cases are needed for verification.

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