A Compression Algorithm in Wireless Sensor Networks of Bearing Monitoring
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Abstract: The energy consumption of wireless sensor networks (WSNs) is always an important problem in the application of wireless sensor networks. This paper proposes a data compression algorithm to reduce amount of data and energy consumption during the data transmission process in the on-line WSNs-based bearing monitoring system. The proposed compression algorithm is based on lifting wavelets, Zerotree coding and Hoffman coding. Among of that, 5/3 lifting wavelets is used for dividing data into different frequency bands to extract signal characteristics. Zerotree coding is applied to calculate the dynamic thresholds to retain the attribute data. The attribute data are then encoded by Hoffman coding to further enhance the compression ratio. In order to validate the algorithm, simulation is carried out by using Matlab. The result of simulation shows that the proposed algorithm is very suitable for the compression of bearing monitoring data. The algorithm has been successfully used in on-line WSNs-based bearing monitoring system, in which TI DSP TMS320F2812 is used to realize the algorithm.

1. Introduction
Over the past decades, the system of on-line rolling bearing monitoring is based on wired network. But in actual work environments, wired monitoring would increase the cost of system and bring some practical engineering problems. Such as the layout of the signal wires, the wiring is difficult to carry in actual environment. And usually wired signal transmission constraints the communication of monitoring system with unstable device composition. For example, the wired system can’t be applied in on-board bearing monitoring of freight train because there are no signal connection and electric connection between sections. Beside wired connection will increase the cost of the lines and maintenance. Therefore, we want to find a solution to realize the bearing monitoring in some special situations in which vibration data are transmitted using the wireless mode⁹,¹².

In view of the requirement of the acquisition accuracy and transmission quality of monitoring system, we select ZIGBEE technology to establish a wireless sensor network to achieve on-line monitoring. Through setting up sensor monitoring node for each bearing, the vibration data of bearing are collected in node and then sent to base station. But because of the great energy consumption and large amount of vibration data in networks, we must compress data to reduce the pressure of network transmission.

Generally, the compression algorithms such as Distribute source coding¹³ and Hoffman coding in WSNs mainly compress the data on the basis of ensuring the data integrity. But for the vibration data transmission, traditional compression algorithm can’t achieve the expected purpose. And this paper mainly proposes a data compression algorithm for vibration data transmission in wireless sensor network. We utilize the Zerotree algorithm (EZW¹¹) to process one-dimensional vibration data and combine the existing lifting algorithm with it. In the process of compression we apply the lifting wavelets and Zerotree coding to filter the vibration data. Lifting wavelets acts as an adaptive filtering
window and Zerotree coding plays a role to select dynamic threshold. Through improving zerotree coding algorithm, we successfully combine Zerotree and lifting wavelet. This algorithm effectively increases the compression ratio with a suitable distortion rate. In order to adapt data transmission in wireless sensor networks, we add Hoffman coding to the algorithm. It further raises the compression ratio. For that the proposed algorithm is more suitable for the application of WSNs-based bearing monitoring.

2. Algorithm Design
Vibration signals contain a large amount of data, and one node data can easily make the network transmission saturated. Since the lossless compression algorithm is difficult to achieve a high compression ratio, Lossy compression algorithm is chosen. Lossy compression algorithm mainly captures signal features, and plays a role of filter to remove unimportant information and noise.

2.1. Lifting Wavelets
5/3 lifting wavelets has the traditional features of wavelet. It is a fast wavelet algorithm based on Mallet wavelet and has multi-resolution and self-adaptivity\(^\text{[3]}\). The 5/3 lifting algorithm is gradually built from lazy wavelet. The computing process includes three steps: split, predict and update. The split divides data into odd and even columns\(^\text{[8]}\). The predict uses the even column to forecast the odd column, and the prediction errors is the high frequency components from the transformation process. The update gets the low frequency components through using the prediction errors to update the even column\(^\text{[2,6]}\).

5/3 lifting wavelet algorithm doesn’t depend on Fourier transform, so the algorithm is much suitable for data processing by circuit and programme.

The algorithm equations as follows:

\[
\begin{align*}
c(n+1) &= x(n+1) - [x(n) + x(n+2)] \times 2^{-1} \\
d(n) &= x(n) + [c(n-1) + x(n+1) + 2] \times 4^{-1}
\end{align*}
\]

Equation 1. is the prediction equation. Column \(x\) is original column. Column \(c\) stands for prediction errors and is used for update the even column. Equation 2. is the update equation. Column \(d\) is the result of update. The whole process can be comfortably implemented in computer simulation and embedded device.

2.2. Zerotree coding
The embedded zerotree coding as an image compression algorithm has extensive use. Here the main purpose we use is to solve the problem that how to extend the application of the algorithm to compress vibration data.

In general Zerotree coding links closely with discrete wavelet. As a discrete wavelet the lifting algorithm divides the data into different subband in frequency domain. Owing to wavelet coefficients of each subband the Zerotree algorithm calculates the different threshold to filter the unimportant data to retain attribute signal. The process can be seen in figure 1.
The number of cycle of the process above is determined by the number of the lifting wavelet transform layers. We divide the wavelet coefficients into three classifications, zero roots, subtree of zero roots, important value\cite{1}. While a coefficient is less than threshold of the layer and in the first half section of coefficient column, we could classify it as zero root or subtree of zero roots. And the judgment of the two classes depends on the type of parent tree\cite{4}. If the coefficient is in later half section, we classify it as unimportant value. Finishing the coding of this layer, we need to select the first half of the column as the next layer processing to duplicate the work. Through the type judgment of coefficients, the data with the signal characteristic are preserved\cite{7}.

Through the process of the Zerotree, the unimportant signal components are basically filtered. The compression ratio changes simultaneously with threshold. Through combination of the two algorithms, the signal is compressed effectively. In the subsequent process of decompression we apply this characteristic data to carry out lifting wavelet reconstruction for restoring the signal\cite{5}.

2.3. Hoffman coding

Usually the Hoffman coding is embedded in Zerotree algorithm. It can help the Zerotree algorithm further improving compression ratio without increasing distortion rate. And especially in WSNs application, the encoded data greatly improve the transmission efficiency and reduce the error rate.

Before the coding process, we need to construct quantizers to quantify these data. And the quantizers are all set according to the threshold of each layer\cite{10}. Quantization makes the distributed data to be centralized in each layer. And then Hoffman coding algorithm could statistic the probability of the data and arranges the quantized data according to the corresponding probability. We use short code to replace the data of high probability, and long code to small probability. In accordance with the criteria we can execute the Hoffman coding part\cite{11}. In the process, there are two tables generated, one is code table, the other is data sheet. The both are needed to be sent in WSNs because of the requirement of decoding in receiver.

2.4. Overview of algorithm

The compression algorithm discussed in this paper mainly includes the three algorithms mentioned above. The flow chart of the whole process is shown in figure 2.

**Figure 1.** One layer of Zerotree algorithm process
Four types of the output data, code table, data sheet, thresholds and data location, are all necessary information for decoding and decompression. In sending process, the data of the four types are matched with different frame to ensure the independence and reliability of data transmission.

3. Algorithm simulation

We use a set of vibration data which contains 2048 points to simulate the algorithm process. First we filter the signal using a bandpass filter in order to compare decompressed result with original signal. The whole process contains filtering, compression, encoding, decoding and decompression.

Figure 3 is the signal waveform and its spectrum.

The filtered data are sent to execute lifting wavelet decomposition, and embedded by the Zerotree algorithm and quantization. Hoffman coding algorithm produces two tables, a code table and a data sheet.

| Value | Code  |
|-------|-------|
| -3802.85 | [1,1,1,1,1,0,1,0] |
| -3002.25 | [1,1,1,1,1,0,1,1] |
| 3002.25 | [1,1,1,1,1,0,0,0] |
| 250.1875 | [1,1,1,1,1,0,0,1] |
| -2601.95 | [1,1,0,0,0,1,0] |

-2201.65 [1,1,1,1,1,0]
-500.375 [1,1,0,0,1]
1801.35 [1,1,0,1,1]
500.375 [1,1,1,0,0]
-1801.35 [1,1,1,0,1]
Table 1. Code table

Table 1 is the code table of Hoffman algorithm. The left column is the data after the quantization, and the right is the code value. The data are listed from small to large of probability, and the corresponding codes are arranged from long to short. Through the table, the floating-point type data are converted into binary data. It greatly improves the transmission efficiency of WSNs.

Figure 4 is the time waveform and frequency spectrum of decompressed data.

In the simulation above, the algorithm compression ratio is 7.5. Therefore in regard to the problem of ratio selection, we need to analyze the relationship between signal distortion and compression ratio.

\[
TFE_{ss}(\omega) = -20 \log(P_{ss}(\omega) \cdot P_{ss}(\omega)^{-1})
\]

The \( P_{ss}(\omega) \) is the cross-power spectrum of the original signal and the decompression signal. And \( P_{ss}(\omega) \) is autopower spectrum. It represents that there are no frequency information lost in this
frequency if the TFE is equal to zero. The more the value of TFE deviating from zero, the more the information loses in compression process.

Though the definition, we calculate the two spectrums of the simulation data. Figure 5 is the curve about autopower spectrum of the original signal and cross-power spectrum of the original signal and the decompressed signal in compression ratio of 7.5.

![Figure 5. Autopower spectrum of the original signal and cross-power spectrum of the original signal and the decompressed signal](image)

Then, we draw the curve of TFE using the data obtained above. Figure 6 is the TFE curve. We could see in the frequency band of 3000Hz to 6000Hz, where are some points deviating from zero far relatively. It is inevitable that some information are lost in the process of compression. Overall, the basic features of the signal are preserved. The frequency spectrum after decompression ensures the needs of our analysis.

![Figure 6. TFE indicator curve](image)

The curve of the TFE above is at the compression ratio of 6.9. In the algorithm simulation, we could change the compression ratio through changing the compression threshold. In the simulation, the relationship between compression ratio and distortion is a significant characteristic of compression algorithm. We calculate the mean square value of TFE, and draw the curve of the relationship between the two parameters.

Figure 7 is the compression ratio-distortion curve. The longitudinal coordinates correspond to compression ratio and abscissa to mean square value of TFE. The mean square value of TFE reflects
the extent of distortion in different compression ratio. Therefore, we can get the relationship between compression ratio and distortion as an important reference in analysis of algorithm in experiment.

![Figure 7. Ratio-distortion curve](image)

4. Algorithm application

In the actual experiment, we apply the TI DSP2812 to execute the work of compression and coding. Meanwhile we use PC to establish a host computer to implement decoding and decompression.

DSP as a part of monitoring node is responsible for signal acquisition, compression and coding. Figure 8 is the PCB test board. ADC interface is used to receive the vibration data from acceleration transducer. The obtained data are sent to DSP to execute the compression. Because of huge amount of data we need to add an external RAM to store data. And then the processed data could be wireless transmitted through the interface linked to RF (radiofrequency) module.

![Figure 8. PCB test board](image)

We add formats to distinguish various types of compressed data in transmission process. With the successful transplantation of algorithm of decoding and decompression to host computer, the restored vibration signal can be analyzed in host computer.

The frame can be seen in Table 2.
Start Frame and End Frame are used to indicate the start and end of data transmission. Data type distinguishes and marks the four type data after Hoffman coding. Serial number of sensor is used to distinguish data from different measuring point. And parity bit checks the data. From it the different type of compressed data is coupled with different frame format to send.

In the whole process of experiment, the amount of data in RF module drops proportional to compression ratio. So, according to the requirements of signal distortion and environment requirements, we can change the compression ratio to meet the actual demands.

5. Conclusion
In the wireless monitoring system, the efficiency of transmission and energy consumption has been more and more eventful. Therefore, we propose the compression algorithm applied vibration data transmission in WSNs-based bearing monitoring. Through the process of simulation, we calculate the parameters and verify the feasibility of the algorithm. From the analysis of the simulation results, the compression ratio and distortion ratio both can reach our requirements simultaneously. And in the actual experiment, the transmission data drops significantly and the energy consumption deceases a lot. The signal distortion is still an important issue. Forasmuch improving the quality and efficiency of compression is the aim of our research in the future.

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