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A Reliable Wireless Monitoring of Periodic Vital Signals using a Novel Joint Source-Channel Coding

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***Abstract*— This paper proposes a joint source-channel coding technology to transmit periodic vital information such as an electrocardiogram (ECG). It shows the iterative decoding method using a correlation value which can be obtained from ECG periodicity as Side-Information. The improvement is shown when bit strings are transmitted with different encoding rates. Because the proposed method has an error correcting system and makes a code processing decrease, some miniaturization and energy-saving can be expected of the equipment. Finally, the effectiveness of the proposed method is shown by comparisons with Differential Pulse Code Modulation, which is a typical compression method of ECG, and with the no coding method.**

I. Introduction

The wireless communication technology of vital information has been studied to achieve "Ubiquitous medical health care" which can provide a service anytime and anywhere. Wireless monitoring of patient vital signs is expected to reduce both the workload of medical staff and the constraints of patients. In such a wireless monitoring system, the transmitter attached to the patient should be small and operate with low power-consumption for easy use. This demands development of energy-efficient processing of both source coding, which compresses vital signals, and channel coding, which uses redundant bits to make the wireless transmission reliable.

In this paper, we propose a joint source-channel coding for periodical vital signs such as ECG and pulse waveform. This coding method uses a correlation of periodical vital signals in the time domain to successfully compress the signals.

Using such a correlation, the digitized vital signals are compressed by simply discarding a part of them. By introducing a channel coding such as Turbo codes or LDPC codes, the decoder recovers the discarded part through iterative decoding using the correlation of the original vital signals and the transmitted part, which probably includes erroneous bits. These strong channel codings provide performance close to the Shannon limit. In this decoding procedure, the correlation is used as side-information. This type of coding has been paid attention to in video coding [1,2] and joint coding for sensor networks [3] The theoretical background has been established by Slepian-Wolf theory or Wyner-Ziv theory. There is also previous research about a wireless ECG monitor that can use the communication channel effectively by detecting an abnormal state of health. However, this method does not include channel coding [4].

In this paper, we demonstrate a joint source-channel coding for ECG waveforms. The performance evaluation is given in terms of accuracy of the coding through the wireless channel by computer simulations. In the next section, a joint source-channel coding for ECG waveforms is illustrated. A performance evaluation is given in Section III. Finally, conclusions of this paper are addressed.

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II. Joint Source-Channel Coding for Periodic Vital Signs

In this paper, we focus on a wireless transmission of ECG waveform. ECG is a periodic wave, which means that it has a time correlation [5]. We propose a coding method using such a correlation in the time domain. Fig.1 shows an example of ECG waveforms.

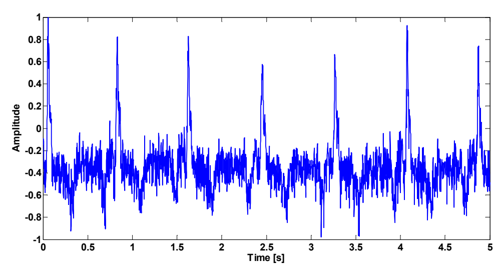


Fig.1. An example of ECG waveforms before passing through a filter

The definition of a coding parameter is shown below. The ECG is first digitized by passing through an analog-digital converter, and then encoded by following a source coding method. Here, the digitized ECG data is encoded by each set of N bits which forms one packet. Information bits $\mathbf{m}_j$ are shown by

$$\mathbf{m}_j = \{m_{j,1}, m_{j,2}, \cdots, m_{j,N}\}, (j = 1, \cdots, K) \quad (1)$$

where K is all numbers of packets to be transmitted to send one codeword. The correlated parameter σ_{ij} which provides side-information for the decoder is given by

$$\sigma_{ij} = \sigma_{ji} = \frac{\|XOR(m_i, m_j)\|}{N} \quad (2)$$

where XOR ($\mathbf{m}_i$, $\mathbf{m}_j$) means the exclusive-or between $\mathbf{m}_i$ and $\mathbf{m}_j$. $\|\mathbf{x}\|$ stands for taking Hamming weight of $\mathbf{x}$ [3].

The ECG waveform in Fig.1 has a periodic state. This state can be thought of as a good health condition. This ECG cycle time is 0.8[s]. Fig.2 shows the relationship between the transmitting packet length and the correlated parameter σ_{ij}. The correlation characteristic becomes strongest when the packet length is 0.8[s]. In other words, if packet length is the same as the ECG cycle time, the correlation between packets is strongest.

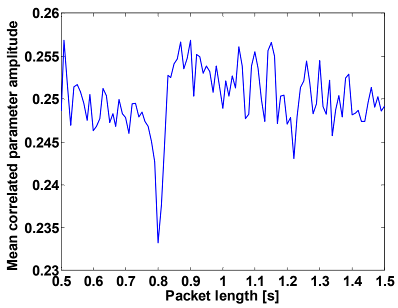


Fig.2. The ECG relationship between packet length and correlation parameter σ_{ij}.

A. Encoder

Fig.3 shows the proposed encoder. After quantizing, ECG data is encoded. The encoder is a Recursive Systematic Convolutional turbo encoder which has the restraint length of 3 and encoding rate R_c = 1/3. π is an interleaver. The turbo encoded packet becomes R_c = 1/2 by the puncturing processing. BPSK is modulated after the RCS encoder is passed and its packet transmits. The first packet transmits the encoded packet of R_c = 1/2. From the second packet, the information bits are deleted from the encoded packet. By this operation, the encoding rate R_c can become 1 because the transmission packet size becomes equal with the length of information bits. Therefore, the length of redundancy bits becomes shorter by this coding method even if channel encoded processing is conducted. This encoding method is called “using packet correlation method”.

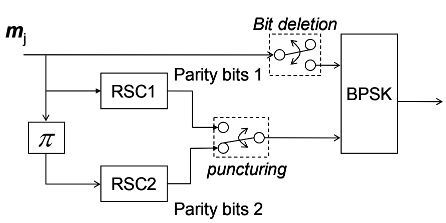


Fig.3. Encoder

B. Decoder

ECG has time correlativity. Fig.4 shows the decoder. This decoder is composed by the iterative decoder which uses the soft likelihood value by the Log-MAP algorithm. π^{-1} is a deinterleaver. First, the obtained information bits μ_1(“1”or”0”) by the first packet are preserved. Next, the tentative information bits $\boldsymbol{y_j}$ using the correlation value σ are given by (3) from the second packet onwards.

$$y_j = \mu_1 \cdot (1-\sigma) \quad (3)$$

Received parity bits $\boldsymbol{P'}_j$ are multiplied by α. These parity bits $\boldsymbol{P}_j$ are given by

$$P_j = \alpha \cdot P'_j \quad (4)$$

The discarded information bits are restored by passing the iteration decoder the tentative turbo packet which is composed of $\boldsymbol{y_j}$ and $\boldsymbol{P_j}$.

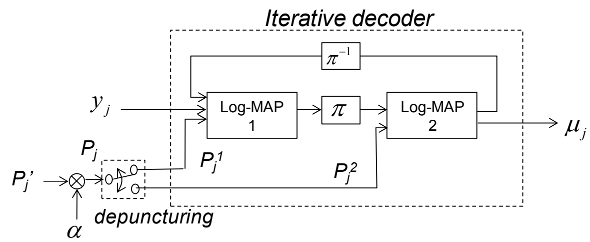
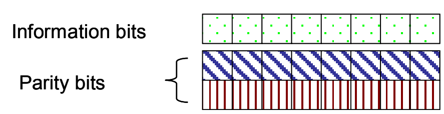


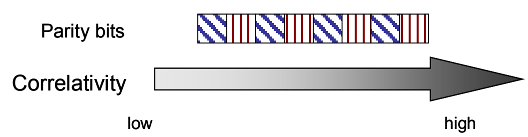
Fig.4. Decoder

C. Correlativity Effect of Each Bit

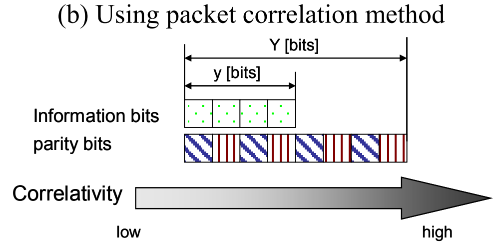
Fig.5 shows an example of a transmission packet in the proposed method.



(a) Turbo coding packet with encoding rate 1/3



(b) Using packet correlation method



(c) Using packet and bit correlation method

Fig.5. Transmission packet (from the second packet onwards)

The highest bit of the quantized data strings suggests that the correlativity is the strongest. On the other hand, the lower bits’ correlativity becomes weaker than the higher bits. Therefore, these bits are not restorable in the proposed decoder. The transmission packet can be decided by using the bit correlativity effect as well as using the packet correlation method. The transmission packet from the second packet onwards in the packet correlation method has only the parity bits as shown in Fig.5(b). In this manuscript, we propose the method of adding the information bit corresponding to y parity bits on the lower correlativity bits as shown in Fig.5(c). This encoding method is called “using packet and bit correlation method”. In decoding, tentative bit strings from (y+1) to Y bits are first given by expressions (3) and (4). Next, the received bit string from 1 to y bits is carried to the decoder .The information bits are restored by this processing.

III. EVALUATION METHOD

The proposed joint source-channel coding is evaluated by computer simulation. Two kinds of ECG are used to evaluate the error margin of the decoded wave. The small amplitude range waveform is called "Es ECG", and the big amplitude range waveform is called "Eb ECG". The ECG wave downloaded from "http://www.logis-pro.com/math_power_ecg.html" is used. Table 1 shows the simulation parameter. On the receiver, the correlated parameter σ_{ij} is a fixed value statistically obtained beforehand. The quantized processing range is from -1 to 1. Number of Quantization bit and Sampling frequency are typical values in ECG management. Packet length is the duration for the correlation to reach the maximum.

Table1 Simulation parameters

	Es ECG	Eb ECG
Amplitude range	0.9 - 1.0	-1.0 - 1.0
Path	AWGN	
Eb/N0	5 [dB]	
Number of Quantization bit : Y	10	
Sampling frequency	1 [kHz]	
Weight value : α	2	
Packet length	0.8 [s]	
Correlation value : σ	0.25	
Number of decoder iterations	15	

IV. SIMULATION RESULTS AND DISCUSSIONS

Fig.6 shows the decoded ECG waveform of the second packet using the packet correlation method. Fig.7 shows the iterative decoder performance difference of Es and Eb ECG. When the amplitude range is small like Es ECG, its decoded wave has no wave deterioration. As the number of decoder iterations increases, the bit error rate (BER) is improved, and an errorless decoded ECG wave is obtained at the seventh iteration.

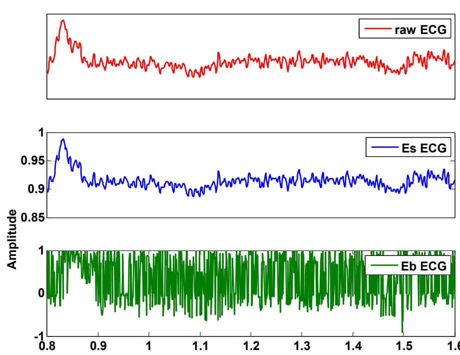


Fig.6. Decoded ECG waveform of the second packet using the packet correlation method

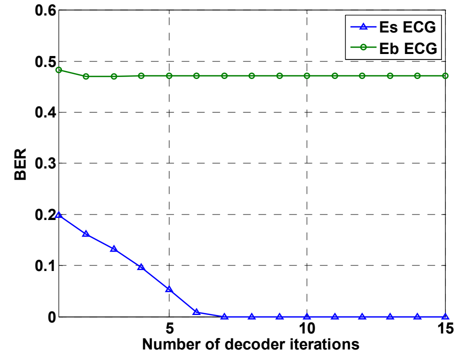


Fig.7. BER performance difference of Es and Eb ECG in decoding the second packet

On the other hand, when the amplitude range is big, like Eb ECG, its wave can not be correctly decoded, and BER performance becomes worse than for Es ECG.

The factors of these phenomena are shown below. The Es ECG and Eb ECG quantized amplitude ranges are shown in Table 2. In Es ECG, which was able to be transmitted without wave deterioration, its quantized amplitude range is small. From this amplitude range, the correlativity between its packets becomes very strong. On the other hand, in Eb ECG which cannot obtain a correctly decoded waveform, the correlativity between its packets will become much weaker than Es ECG because its range is bigger. Therefore, it can be judged that the proposed method using the packet correlation can not use Eb ECG correlation characteristics well.

Table2 Quantized Es and Eb amplitude value

	Es ECG	Eb ECG
Max	1023	1023
Min	958	0
Range	65	1023

Next, the decoded waveforms using the packet and bit correlation method are shown in Fig.8. Fig.9 shows the iterative decoder performance difference using the packet correlation method and using the packet and bit correlation method with Eb ECG.

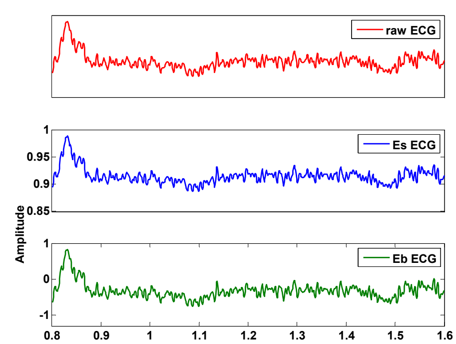


Fig.8. Decoded ECG waveform of the second packet using the packet and bit correlation method

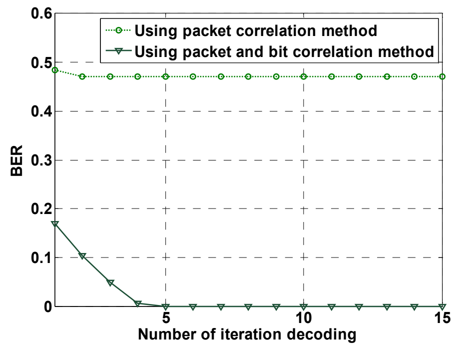


Fig.9. Eb ECG BER performance of the second packet in two different coding methods

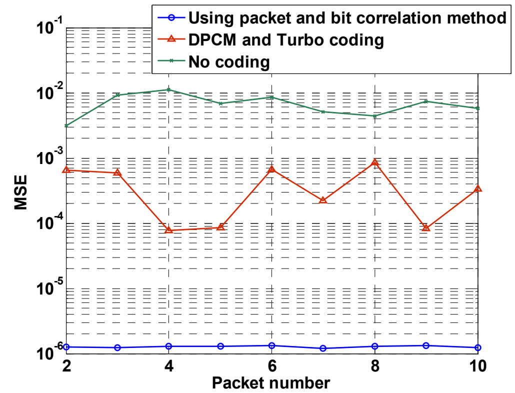


Fig.10. MSE values of three methods

Even if the transmission packet is Eb ECG, the decoded waveform can be obtained without wave deterioration by using both packet and bit correlation method. When the transmission packet which deleted all the information bits is used, BER cannot be improved by the iterative decoder. On the other hand, when the transmission packet with bit correlativity is used, BER can be improved, and BER become zero at the fifth iteration. Therefore, it can be stated that the proposed method which accompanies lower correlativity bits with information bits is an effective method.

V. Comparison between Proposal and Other Methods

In this chapter, the proposed method is compared with other coding methods by Mean Square Error (MSE) evaluation. The following three methods are compared.

1. Proposed method using packet and bit correlation
2. DPCM and Turbo coding
3. No coding (only BPSK modulation)

In the proposed method, there were 14 bits in one specimen datum. This is the sum of four supplementary information bits and 10 parity bits. For impartial comparison, the number of bits for the other methods also assumed 14 bits. In DPCM, which is a typical compression method of ECG transmission, and the Turbo coding method, the number of quantization bits is 7, and the encoding rate is R_c = 1/2. In the no coding method, the number of quantization bits is 14, and transmission occurs after BPSK modulation. This simulation parameter is the Eb parameter from Table 1. Fig.10 shows the MSE values between raw wave and decoded wave of the three above-mentioned methods, each transmitting 10 packets. MSE values of the proposed method are the lowest of the three methods. In the DPCM and Turbo coding methods, MSE values are higher than in the proposed method because the number of quantization bits is lower than that of the proposed method. The no coding method is more dominant than the proposed method because its number of quantization bits is higher. However, its MSE value is the highest of the three methods because bit errors were caused by the channel. From this comparison of the three methods, the effectiveness of the proposed method can be confirmed.

VI. Conclusion

In this paper, the wireless monitoring of ECG waveforms, which are assumed to have periodicity, and the joint source-channel coding which uses correlation information obtained from its periodicity, is proposed. This method can accept miniaturization and energy-saving because it has an error correcting system that decreases code processing. However, deterioration is occasionally caused in this coding method using only packet correlation because its correlativity between packets changes with the ECG amplitude range. Therefore, this paper also applies bit correlativity to the proposed method. Moreover, the proposed method is evaluated by MSE value. The proposed method has effective error correction and has a lower MSE value than the DPCM and Turbo methods. The effectiveness of the proposed method can be confirmed from these results.

In the future, this method will be able to judge abnormal health states because it can identify vital failures using ECG periodicity.

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