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An Efficient VLSI Implementation of Lossless ECG Encoder Design

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Abstract: ***An efficient VLSI implementation of a lossless electrocardiogram encoding circuit is designed for remote monitoring service. To reduce the wireless transmission power and the amount of storage data, an efficient lossless encoding algorithm had been built for the ECG signal compression. This algorithm consists of an adaptive predictor and a two-stage entropy encoder. The VLSI architecture of this work has the core area of 20308um² and synthesized by a 180nm CMOS process. It can be operated at 100 MHz processing rate by consuming 1280uW. The data compression ratio is approximately 30.***

Keywords: ECG, entropy coding, adaptive predictor, lossless data compression.

1. Introduction

ECG (electrocardiogram) is a test that measures the electrical activity of the heart. The heart is a muscular organ that beats in rhythm to pump the blood through the body. In an ECG test, the electrical impulses are generated while the heart beatings are recorded. The extensive use of digital electrocardiogram (ECG) produces large amounts of data. Since it is often necessary to store or transmit ECG records, efficient compression techniques are important to reduce transmission time or required storage capacity. Especially critical are long duration (24 or even 48 hours) Holter exams. The data generated in such cases can surpass 1G bytes. These Holter devices must present good storage capacity, in addition to reduced dimensions and low power dissipation in order to be comfortably carried by patients. These facts show the importance of using some data compression method that preserves the essential characteristics of the original signals.

In recent years several ECG compression methods have been discussed and average compression ratios (CR) ranging approximately from 2:1 up to 50:1 have been reported [6], [7], [8].

In the work [1], a low-complexity lossless data encoder for a wireless body sensor network had been proposed, in the work [3] present high-compression-rate ECG**,** These algorithms have the benefit of high compression rate. However, these algorithms are lossy compression algorithms and therefore do not allow perfect reconstruction of the original signal from its compressed representation. Arnavut [4] proposed a high performance compression algorithm based on the Burrows-Wheeler transform and MTF coding, Chua and Fang [5] proposed an efficient lossless data compressor based on Golomb-Rice coding, these designs provided efficient VLSI architectures but it is not easy to implement into VLSI circuits.

2. Lossless ECG Encoding Algorithm

This algorithm consists of an adaptive trending predictor and a two-stage entropy encoder. The adaptive trending prediction is used to improve the coding efficiency of the two-stage entropy coding. The details of these two parts are described below.

2.1. Adaptive trending prediction

Predictive coding is lossless compression technique which allows a compact representation of data by encoding the error between the data itself and information “predicted” from past observations. The prediction techniques build an estimate x'(n) for a given sample x(n) of the signal by using past samples x(n-1),x(n-2),x(n-3),,,,. The sample x(n) is substituted by the prediction difference, PD = x(n)-x'(n).

The biomedical signals are fairly slow and these are predictable distribution in nature. Hence we can use the prediction methodology to improve the performance of the encoding algorithm.

To improve the performance of prediction, a second order prediction method based on slope prediction along with the first order prediction methodology based on linear prediction which was used to forecast the present value of the biomedical signals by passing two values [1]. As shown in the Figure 1[a], the present value x (n) can be obtained by passing two values of x(n-1) and x(n-2) with the relationship diff-1 is equal to diff-2.
[a] diff-1=diff-2 [b] diff-1=2*(diff-2)-(diff-3)

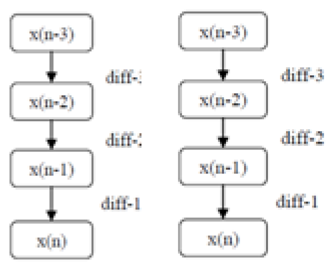

Figure 1: First order and second order prediction

As shown in the Figure 1[b], the present value x(n) can be obtained by passing three successive samples x(n-1), x(n-2) and x(n-3) with the relationship diff-1 is equal to two times of diff-2 minus diff-3.
From this adaptive trending prediction methodology, it is possible to improve the accuracy of prediction. Here, the prediction strategy will be adaptively selected from either first order or second order based on the trend in the signals.

The compression and decompression scheme consists of predictor, substractor and entropy encoder and is shown in Figure 2[a] and [b].

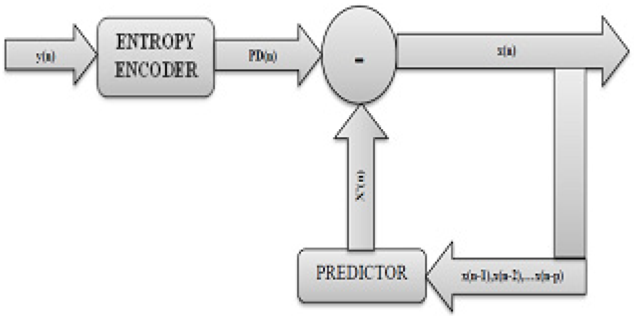

Figure 2[a]: Data compression scheme

Consider the *x(n)* signal, which has been coded up to sample *n-1*, and let *x(n-1)*, *x(n-2)*... *x(n-p)* be the *p*-values of the signal up to that moment. Estimation of the signal is predicted using the prediction rule from previous samples. The predictor represents a queue in which previous samples are stored and each sample is multiplied by its coefficient and when summarized, they create the predicted value.

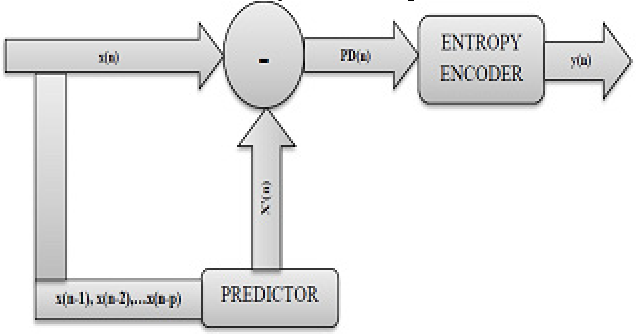

Figure 2[b]: Data decompression scheme

2.2. Dual stage entropy encoding

The Huffman's coding algorithm generates codes from a set of symbols probabilities [ ]. But this coding is based on Huffman coding tree which has the feature that one branch should be added to represent a new VLC code for each different value. The coding tree would grow significantly if the input values vary a large range. It is difficult to develop a low-cost and high-performance VLSI chip which has a block circuit with a huge depth of tree. For this reason, a novel two-stage entropy coding technique has been developed.

The prediction difference (PD) values which most often appear are encoded by the first arithmetic coding table as shown in Fig. 2. The first arithmetic coding table has the range of −3 to +3 and one extending code for indicating out of range. If the prediction difference values are over the range of the first Huffman table, the prediction difference value will be modified from diff_1 to diff_1-diff_2 and then check the absolute value of diff_1-diff_2 is less or greater than 20. If the absolute value is less than 20, the value of diff_1-diff_2 would be encoded by the second arithmetic coding table. Otherwise, if the absolute value is greater than 20, the value of diff_1-diff_2 would be directly sent by 12-bit without Huffman encoding. By composing the adaptive trending prediction and two-stage entropy coding techniques, the compression rate of MIT-BIH Arrhythmia data reaches up to an average value of 30%.

3. VLSI architecture

The lossless ECG encoder consists of two parts including an adaptive trending predictor and a two-stage entropy encoder. Figure 3[a] [b] shows the architecture of the proposed lossless ECG encoder. The details of the adaptive trending predictor and a two-stage entropy encoder are described below

3.1. Adaptive trending predictor

This consists of five registers, one adder, four substractors, one shifter, and one multiplexer. Four of the five registers are used to store the input values of x(n), x(n − 1), x(n − 2), and x(n − 3), and the other one is used to store the value of prediction difference. The register PD(n) is also a pipeline register for improving the performance of the proposed encoder design. The values of diff_2 and diff_3 can be obtained by two substractors. The value of 2*diff_2- diff _3 can be calculated by a shifter and a substractor with the obtained values of diff_2 and diff_3. The predicted value of diff_1 can be selected adaptively from the values of diff_2 and 2*diff_2-diff _3 according to the trend of the signal. Finally, the value of the prediction difference can be produced for entropy coding.

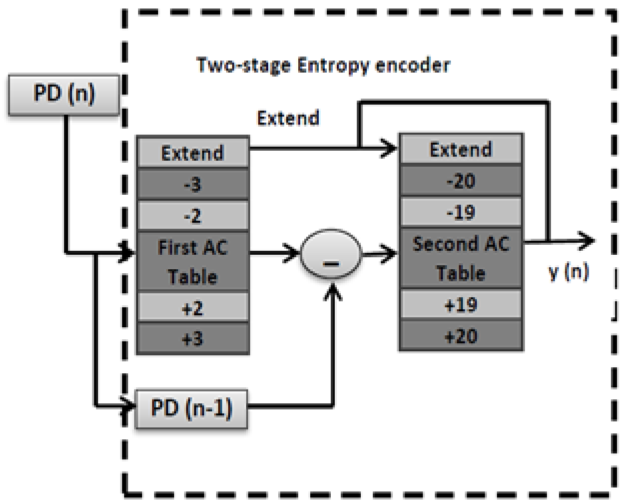

Figure 3[a]: Adaptive Trending Predictor

3.2. Two-stage entropy encoder

This consists of two Arithmetic coding tables, one register, and one substractor. The two Arithmetic coding tables were implemented by the architecture of look-up tables. The two-stage encoder receives the input signal PD from the predictor and then sends it to the first Arithmetic coding table for entropy encoding. If the value of PD is in the range of −3 to 3, the value of PD would be encoded by the first

Arithmetic coding table and the encoded data would be sent to output directly. Otherwise, if the PD value is out of range in the first table, an extending code would be produced and the value of PD (n)-PD (n−1) would be sent to the second Arithmetic coding table for entropy coding. The results of these two tables have 3bit codes and 6-bit code respectively. Finally, the arithmetic encoded data will be collected and sent to output for transmission.

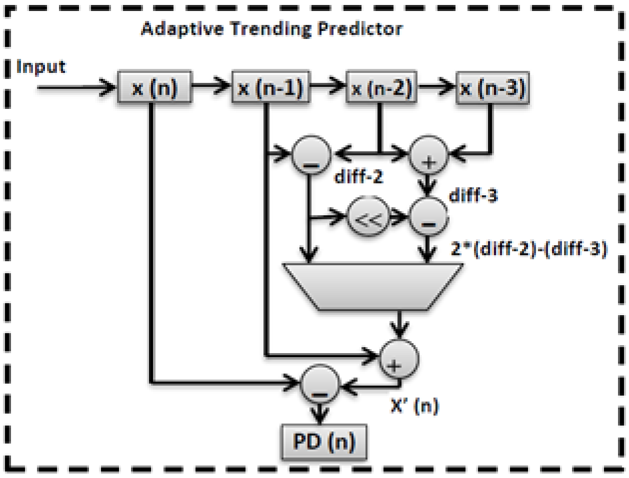

Figure 3[b]: Two Stage Entropy encoder

4. Results and Discussions

To be able to analyse the performance of the proposed ECG lossless compression algorithm, the MIT-BIH Arrhythmia Database was used as test patterns. After encoding by the proposed lossless compression algorithm, the average compression rate of all patterns in the MIT-BIH Arrhythmia Database is 30%.It was implemented by Verilog code, simulated by the ncverilog tool, and synthesised by Encounter(R) RTL Compiler. the chip area is **20308**μm2. The power consumption of this design is **1280uW** operating at 100 MHz

The compressor was designed for ECG compression, and tested with ECG records from MIT-BIH Arrhythmia Database. However, it could be used to compress various other one-dimensional signals similar to ECG (less than 12 bits per sample and high inter-sample correlation). This includes many biological signals, such as electroencephalogram and blood pressure signals, and those typically registered in multi-modal records such as polysomnograms.

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