VLSI Implementation of Lossless ECG Compression Algorithm Using Adaptive Trending Prediction

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Abstract -*ECG (electrocardiogram) is a test that measures the electrical activity of the heart. In this paper, an efficient and low power VLSI implementation of compression algorithm has been presented in this concept. To improve the execution, the proposed VLSI design uses bit shifting operations as a replacement for different arithmetic operations. Firstly, ECG compression algorithm comprises two parts: An Adaptive linear prediction technique and Content-Adaptive Golomb -Rice code. Further this project is enhanced by Adaptive trending prediction technique. Predictive coding is a 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 the past three samples from the data.*

Key Words: ECG(electrocardiogram), VLSI, Golomb Rice code, Adaptive linear prediction, Adaptive trending prediction.

1.INTRODUCTION

In an ECG test, the electrical impulses are generated while the heart beatings are recorded. The extensive use of digital electrocardiogram (ECG) generates the data in large amounts. As it is necessary to store and transmit ECG records, efficient compression techniques are used.By using efficient compression techniques transmission time and required storage capacity are reduced.In recent years several ECG compression techniques have been implemented and average compression ratios (CR) ranging approximately from 2:1 up to 50:1 have been reported [7], [8], [9].

In recent years, Cardiovascular disease (CVD) has been the major cause of death worldwide and is reported as roughly 31% of all global deaths [1].Using electrocardiogram (ECG) signals, cardiovascular disease and many other diseases are diagnosed. ECG signal is a biomedical signal which contains information regarding the condition of the heart and it is the most common screening tool which is used for curing cardiac diseases. In a 24-hour ECG signal monitoring system, the monitoring system will be producing a huge amount of data.

To understand the amount of data generated during ECG monitoring process, following two different frequencies can be taken as examples. Normally at the sampling frequency of 125 Hz, 7.5 KB of ECG data is generated for the duration of 1 minute per sensor. If the sampling rate is 500 HZ then it will generate 45 KB of data per minute for one sensor [2]. So, to store this vast data, a solution is required to reduce the data of ECG signal. As a solution, ECG compression is performed in such a case to save the storage space.ECG signal has various components such as waves, segments and intervals. A typical ECG signal is shown in Fig. 1 [2].Long-term ECG recording is often carried out with patients admitted with cardiac problems. ECG can also be recorded continuously for 24-48 hours using monitors for mobile patients [3]. Thus, a large amount of data is gathered using continuous ECG monitoring systems over such period of time. In order to trim the amount of data, a real-time data compression algorithm which can preserve storage space is necessary.

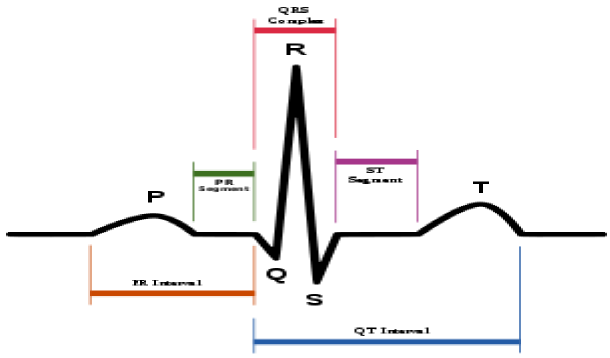

Fig. 1. A Typical ECG Signal

Many types of research on VLSI implementation of lossless ECG compression has been carried down in the past. Chen et al. [3] has conferred a mixed signal VLSI design of ECG compression which admit a smart analog-to-digital converter (ADC) and lossless ECG compression is performed on the basis of trend forecasting and entropy coding. Although this design is intended for low power applications yet its power consumption is quite high which makes such design unsuitable for present low power devices. Another VLSI implementation of ECG compression has been proposed by Zou et al [4], which uses wavelet transform and Run-Length Encoding (RLE).But the drawback of the design is that the working frequency required is quite high which makes it unsuitable to be used in real-time ECG data compression. The sampling frequency of ECG devices is in range of a few

100Hz to 1000 Hz [5], [6]. So, the design proposed by [4] is useful in the cases where ECG data has been already recorded in some storage and then compression is performed. Yazicioglu et al. [10] has presented an ASIC for compression of ECG signals using ADC yet its power consumption is 30 µW.

In this paper,VLSI implementation of Lossless ECG compression algorithm has been proposed developed on the work of Tsung-Han and Muhammad[8] which introduces an ECG compression algorithm comprising of Adaptive trending prediction technique as prediction part and Golomb Rice code as entropy coding part.

The organization of this paper is as follows. Section II provides an overview of the proposed ECG lossless compression technique. VLSI implementation is discussed in section III, section IV includes results and discussions for VLSI implementation. The conclusion is provided in section V.

II. Related work

The main processing parts involved in ECG data compression are error prediction and data coding. The block diagram of the algorithm is shown in Fig. 2. The prediction error value, e(n), can be calculated as (1)

$$e(n) = x(n) - \hat{x}(n) \quad (1)$$

where $\hat{x}(n)$ is the prediction value, and x(n) is the value of current sample data in ECG data at time n. This prediction error value is utilized in Golomb code.

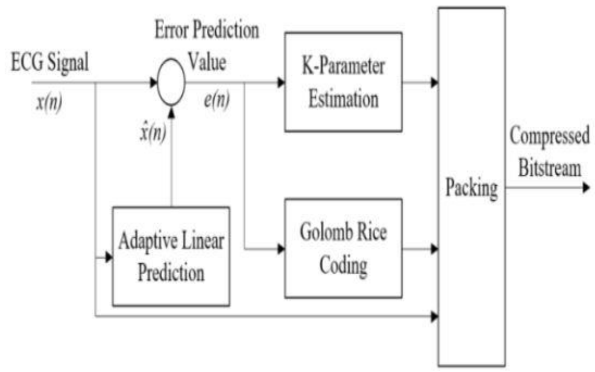

Fig.2: Block diagram of the lossless ECG compression algorithm

Adaptive linear prediction is based on forward samples in order to reduce the redundancy with original data and is able to improve predictive accuracy and to enhance the compression rate. For entropy coding part, a content-adaptive Golomb-rice code(GRC) with a window size has been proposed to compress ECG data. Thus the main aim of this work is low power design while using the minimum number of gates.

A. Adaptive Linear Prediction

ECG signal having numerous regions with exact amplitude variations, such as QRS, P, and T wave regions, as shown in Fig. 1, which may result in a higher prediction error during prediction error estimation phase. In [11], an adaptive linear predictor technique is proposed to improve the prediction error by keeping its value minimum.

Previous four samples are used to estimate the prediction value, which has been shown in fig. 3. The value of the four parameters i.e. 'D1_2', 'D1_3', 'D2_3', and 'D3_4' is calculated through the following equations;

$$D1\_2\ (n) = x\ (n-1) - x\ (n-2) \quad (2)$$

$$D1\_3\ (n) = x\ (n-1) - x\ (n-3) \quad (3)$$

$$D2\_3\ (n) = x\ (n-2) - x\ (n-3) \quad (4)$$

$$D3\_4\ (n) = x\ (n-3) - x\ (n-4) \quad (5)$$

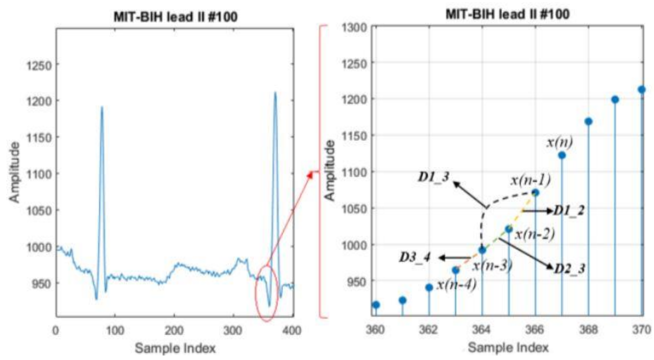

Fig.3.Relation between previous four samples

Taking the characteristics of the ECG signal into consideration, the simple differential predictors with coefficients are used. Due to low complexity computation and good performance in estimating the prediction value, the following three differential predictors have been selected in algorithm development as shown in (6), (7) and (8). A detailed discussion on the derivation of the equations (2) to (8) can be found in [11].

$$P1: \hat{x}\ (n) = x\ (n-1) \quad (6)$$

$$P2: \hat{x}\ (n) = 2x\ (n-1) - x\ (n-2) \quad (7)$$

$$P3: \hat{x}\ (n) = 3x\ (n-1) - 3x\ (n-2) + x\ (n-3) \quad (8)$$

B. Lossless Data Compression Technique

Entropy coding is an important coding technique in data compression, which involves frequently occurring patterns or values are presented with few binary bits and rarely occurring ones are presented with many binary bits. Built on the work of [12], the reference software implementation uses a low-complexity entropy encoder i.e. Golomb–Rice code [11].

C. Content-Adaptive Golomb-Rice code

Golomb coding is a data compression scheme based upon entropy encoding and is best for alphabets with a geometric distribution. The Golomb-Rice code comprises of two parts: quotient and remainder, which are represented by

$$\begin{cases} quotient : \left\lfloor \dfrac{M[n]}{2^k} \right\rfloor ; & encode\ with\ unary\ code \\ remainder : M[n] \bmod 2^k ; & encode\ with\ binary\ code \end{cases} \tag{9}$$

where k represents the number of bits for the remainder, and M[n] is a positive integer. M[n] is achieved by transformation of a prediction error, which may be a negative value, into a positive number. This function can be described by

$$M[n] = \begin{cases} 2e, & e \geq 0 \\ 2|e|-1, & e < 0 \end{cases} \tag{10}$$

where e is the prediction error value. In algorithm development, a window is used to calculate the distribution of prediction errors [11]. The distribution of prediction error of each window is applied to determinate the k parameter. The size of the window is determined using the QRS segment in the ECG signal.

D. Data Packing Format

In the decoding process, to reconstruct the original signal, the encoded output stream contains the first sample of ECG data of 11-bits and the k parameter with 3-bits for each window and prediction error which is encoded by Golomb-Rice code. The output bit stream is illustrated in Fig. 3.

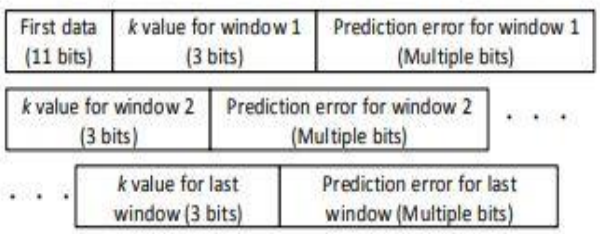

Fig.3.Encoded bitstream format

III. Proposed Methodology

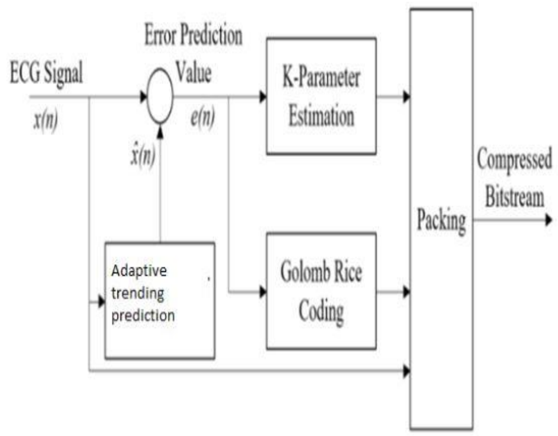

Fig.4.Block diagram

A. 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)

This consists of 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 accumulation 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 acquired 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.

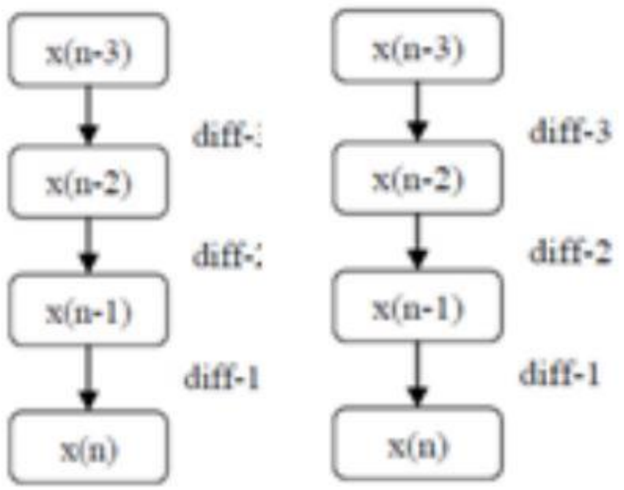

Fig.5.First and second order prediction

As shown in the above Figure, 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 main Figure.

B. Content-Adaptive Golomb-Rice code

Golomb rice coding is the most complex and computation intense part in the whole compression algorithm. And due to continuous data processing, the hardware design is designed to keep minimum delay for data processing in Golomb Rice coding. Moreover, area saving techniques were implemented so that the chip area does not get big.

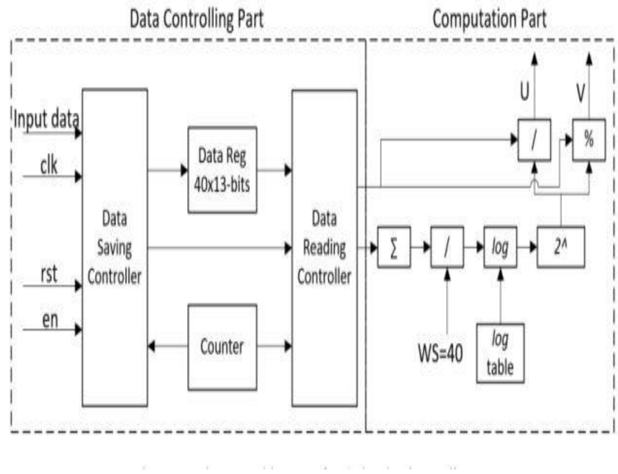

Fig.6.Hardware architecture for Golomb Rice coding

Figure 6 shows the hardware architecture design for Golomb Rice coding module. Input data is post-processed data of the error predictor module. Data is processed for one complete window so there is a 40x13-bits register to save one window's values. When new window's values are arriving then previous window's values are processed to find the value of U and V, where U and V represent quotient and remainder respectively. So, in general, this module's architecture can be divided into two parts; data controlling part and computation part as shown in Fig. 8. In the computation part, operations have been divided into different clock cycles to reduce the processing delay. Instead of using the built-in operators of division or power, bit shifting has been used to perform the multiplication, power, mod and division operations. By using this bit tweaking, the design is able to benefit from the reduction of a number of gates and power consumption. For example, division and multiplication of a number by two have been performed by shifting the value to right and left by 1 bit respectively.

Moreover, division is performed after the summation of the values of one window, the range of values will be between 1 to 127. So, the log values of these values have been stored in a log table, which is accessed whenever a log operation is required in the design. A single counter is being used to control data reading and saving to reduce resources usage. Moreover, sharing of the single counter for both controllers leads to less activity as compared to using two counters which results in saving switching power.

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C. Packaging

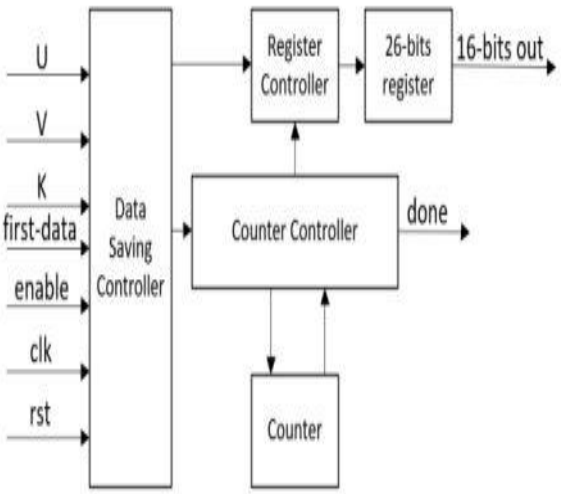

Fig.7.The hardware architecture for packaging module.

Packaging module includes two controllers which are responsible for data saving in a temporary 26-bits register as well as sending 16-bits of output data when 16 or more than 16 bits have been stored in the temporary register. The hardware architecture for packaging module is shown in Fig. 7.

IV. RESULTS & DISCUSSION

Parameter	Adaptive Linear Prediction	Adaptive Trending Prediction
Gate count	1032	356
Power consumption	0.126	0.115
Time (ns)	2.188	1.796

Table -1: Comparison between the systems with adaptive linear prediction and adaptive trending prediction techniques.

The above table shows the results of the system with adaptive linear prediction and adaptive trending prediction techniques respectively. The parameters like gate count, power consumption and time required are analysed. The system using adaptive trending prediction is having a gate count of 356,the power consumed is 0.115 and time required is 1.796ns but whereas the system with adaptive linear prediction technique is having a gate count of 1032,power consumed is 0.126 and the time required is 2.188ns.

V. CONCLUSION

This work represents a low power VLSI Implementation of the lossless ECG compression algorithm. The proposed method has been tested for MIT-BIH arrhytmia database and exhibits reduced complexity with high compression performance as compared to other reported methods.The parameters like gate count, power consumption, time are taken into consideration for analysing the behaviour of the system.The results obtained shows that the performance of the system using Adaptive trending prediction is better than the system with the Adaptive linear prediction.

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