RESEARCH NOTE

DETERMINING THE PROPER COMPRESSION ALGORITHM FOR BIOMEDICAL SIGNALS AND DESIGN OF AN OPTIMUM GRAPHIC SYSTEM TO DISPLAY THEM

A. Motamedi, H. Djahanshahi and H. Movahedian

Biomedical Engineering Laboratory
Amir-Kabir University of Technology
Tehran, Iran

Abstract In this paper the need for employing a data reduction algorithm in using digital graphic systems to display biomedical signals is firstly addressed and then, some such algorithms are compared from different points of view (such as complexity, real time feasibility, etc.). Subsequently, it is concluded that Turning Point algorithm can be a suitable one for real time implementation on a microprocessor-based graphic system. The remainder of the paper is devoted to a discussion of a Biomedical Signals-Display System using a Graphic Display Processor (GDP). This section includes a brief introduction of 9365 GDP, as well as some features of a Z 80- based ECG data display system employing this chip.

Key Words Compression Algorithm, Real-Time Display, Turning-Point Algorithm, Biomedical Signals, ECG Signals

چکیده در سیستمهای نمایش اطلاعات حیاتی، نمایش بلادرنگ و با کیفیت مناسب به طوری که اطلاعات موجود در سیگنال را در خود حفظ کند، از اهمیت بسیاری برخوردار است. در این مقاله ضمن بررسی آلگوریتمهای مختلف، آلکوریتم TURNING POINT جهت فشرده سازی سیگنال ECG انتخاب می شود. سخت افزار طراحی شده که از چیپ GDP ۹۳۶۵، استفاده می کند با به کارگیری آلگوریتم فوق به خوبی می تواند سیگنال ECG را به صورت بلادرنگ و با حفظ اطلاعات (فرکانس قطع بالا بیش از ۱۰۰ هرتز) روی صفحهٔ CRT ۵۱۲ × ۵۱۲ فقط نمایش دهد. با توان بوجود آمده در مدار طراحی شده ریزپردازهای ساده مانند Z -۸۰ نیز می توانند به راحتی سیگنالهای حیاتی و اطلاعات جنبی دیگر را در دو صحفه روی CRT نمایش دهد.

During the past years such diverse methods as bouncing-ball display, and non-fade displays (both z-modulation and D/A types) have been employed to display biomedical signals in medical equiement. Recently, however, graphic systems have attracted widespread attention, because of the advantages they present over other methods.

In graphic display methods used in computer systems, the screen is divided into minute randomly accessible, pixels, providing high quality complex color pictures.

A graphic system must be able to receive digital data and display these data in a real time mode on the monitor. Such data, may include biomedical signals and/or alpha-numeric data to be used by the physician. appropriate processing techniques are used to convert the biomedical signal to its simplest form and a high-quality easy-to-build graphic board is designed. The system presented here has been primarily designed for use in electrocardiography and ICU and CCU monitoring but can also be used, with minor alterations, for most other biomedical signals.

It has been shown [1] that most biomedical signals can be considered, for all practical purposes, to fall within the range of 100 Hz or below. Given a maximum frequency of

100 Hz, the sampling rate can be about 250 Hz (i.e. more than two-fold). In other words, 250 pixels per second are needed to display such a biomedical signal on the screen.

According to current standards, an ECG monitoring system should be capable of displaying a four-second-long ECG segment. Consequently, the monitor screen needs at least 1000 (= 4×250) pixels.

For a high-resoultion display of such a signal a 1024×1024 graphic card is needed which would in turn pose certain problems. Firstly, the cost of the high resolution monitor would be great and second, the board dynamic memory should be at least 1,048,576 bits or 128 K bytes making the hardware more complicated. The high quantity of graphic data causes another basic problem, i.e. the short time available for real-time signal processing and display. Below a CCIR standard monitor screen, is considered exhibiting 25 frames and 625 lines per second:

$25 \times 625 = 15{,}625$ Hz	Horizontal frequency
$1/15625 = 64$ ms	Line scanning time

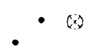
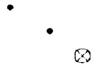
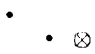
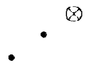
The effective time on the screen is somewhat less than 64 ms (approximately 52 ms). It follows that:

$52/1024 = 51$ ns	
$1/51$ ns $= 19.7$ MHz	Minimum dot frequency needed.

To minimize the above-mentioned problems, an attempt must be made to reduce the data as much as possible prior to graphic board design. This can be achieved through various means. In one experiment, the ECG sampling rate was reduced to half (i.e. from 250 to 125). The resulting signal, though acceptable, was of low quality. The second and preferable method, used here, is to sample the biomedical signal with the same frequency (250 Hz), followed by application of appropriate data reduction methods. Different methods are available for compression coding of ECG signals. To name a few, Huffman, delta coding [5], linear predictive coding [7], A Z TEC [3,5] CORTES [2,4] (a combination of TP and AZ TEC) and turning point (TP) method [4]. We have used the TP method which is the easiest and fastest ECG signal compression method to perform .

In the TP algorithm, the first sample is received and stored as the reference point (X_0). It is followed by the second and third samples (X_1 & X_2), creating a pattern which may assume one of eight forms shown in Table 1.

Table 1. The TP algorithm

$X_0 X_1 X_2$	pattern
	1
	2
	3
	4
	5
	6
	7
	8
	9

In each case one of the two points x_1 or x_2 (encircled in the table) is chosen and reserved as the reference point for the next step and the other point is discarded. Next, a second couple of samples is received, considered as the next x_1 and x_2 and the above-mentioned operations are repeated. Notice that in most cases the last point (i.e.x_2) is chosen whereas x_1 is chosen only in two instances, where it is a turning point.

Figure 1 summarizes Table 1.In the seven combinations in part a, the stored point and the reference point mimic the almost uniform change of the original pattern especially when the two points are connected with a

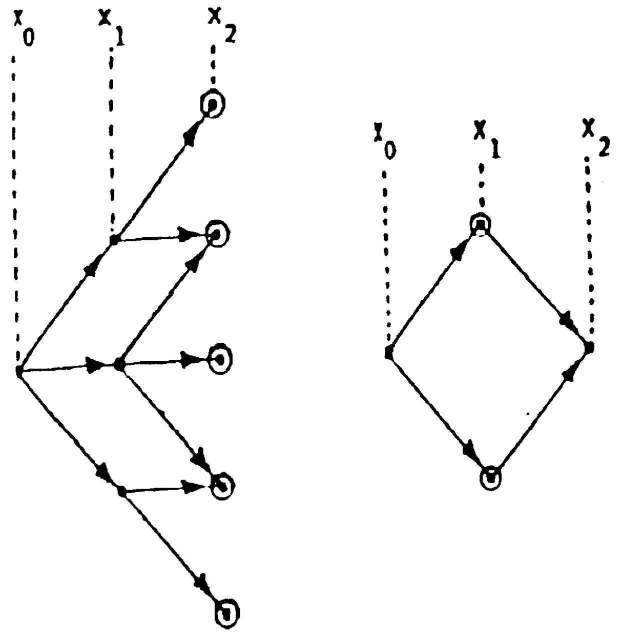


Figure 1. Creation of a pattern from the TP algorithm

straight line (i.e. using first-order interpolation instead of zero order), as is the case with our graphic system.

In the two combinations of part b, choosing x_1 as the stored point conserves the turning point or peak shape of the original pattern, an important prerequisite for the positive and negative peaks of the QRS complex. The turning-point position represents a change in the slope sign. This mathematical feature can be integrated into the software algorithm to determine the pattern:

$$(x_1 - x_0).(x_2 - x_1) < 0 \Rightarrow \text{save } x_1,\ x_0 \leftarrow x_1$$

$$(x_1 - x_0).(x_2 - x_1) \geq 0 \Rightarrow \text{save } x_2,\ x_0 \leftarrow x_2$$

The TP algorithm reduces the data to 50%, which equals half a reduction in the sampling rate. However, all the turning points (high-frequency peaks) sampled with the original sampling rate are reserved. In the presence of a turning point, a local distortion on the time axis will be introduced due to nonequal intervals between consecutive stored samples. The distortion, however, is minimal and not observable when a part of the large scale reconstructed ECG signal [4].

A frequently overlooked point, but one of great importance with the TP method, is the problems concerning the digital filters, their coefficients and other features [6]. First, the sequence of data compression and filtering subroutines assumes great importance. Any change in the sequence of these two software blocks would alter the overall frequency response.

This is because the TP algorithm performance is almost equal to halving the sampling frequency and so if the filter block is located after the compression block, the filter coefficients must be changed in order to obtain results similar to those achieved by compressing the filtered signal. On the other hand, halving the sampling frequency is not a precise model for the TP subroutine because of indeterminable (random) local time distortions introduced by turning points. Therefore, in order for each block to operate correctly, the sampled data must be first filtered and then compressed with a ratio of 2:1.

The merits of TP algorithm for compressing the ECG data in our microprocessor system are:

1- A reduction in the number of horizontal points in the four-second display to about a half (from about 1000 to about 500).

2- Halving of the RAM memory used for storing the past 32-second data from 8000 bytes to 4000 bytes.

3- A decrease in processing time (i.e. displaying, storage, serial transmission etc.), providing more free time for other processes.

4- Reduction of baud rate in the transmission of serial data from the bedside to the central station.

On the other hand, this reduction in the data volume makes it possible to use a 512×512 graphic board instead of a 1024×1024 one. As a result, both a reduction of up to a quarter in the dynamic memory of the graphic board and a considerable decrease in display time can be achieved. But still data-microprocessor will not be able to control the graphic board.

The rest of this paper is devoted to a discussion of graphic board design based on the previously-mentioned biomedical signal-display features and assuming a resolution of 512×512.

Discrete circuits could be a choice. Here, the simplicity of elements used-though an advantage-would necessitate an increase in their number, resulting in the complexity of the hardware.

The other choice is using chips especially designed to control the graphic boards. A number of different chips were studied and the EF 9365 was selected.

Using the right chips results in a reduction in the circuit complexity as well as improved speed and signal quality.

The vector-drawing capability of the EF 9365 causes a considerable increase in biomedical signal-display quality with little time consumption. This replaces interpolation procedures usually done by CPU software.

Internal character generator provides for extra pieces of information such as body temperature, heart rate, blood pressure, etc. to be easily shown on the screen together with the main signal. Generally speaking, the present chip makes it possible to display, in black and white or in color, any complex stationary of moving figure on the monitor.

In view of above points, a biomedical signal-display was designed, using a Z-80 microprocessor and a EF 9365 GDP (Figure 2).

The biomedical signal, after passing through sample & Hold and A/D at the rate of 250, Byte/Sec., is received by CPU, processed and sent to the graphic board at half rate for display. Here two CTCs are used to provide a 250^{Hz} sampling frequency as well as interrupt vectors for CPU which is programmed on the interrupt made No 2. Interrupt vectors produced by CTC can be used for heart rate and temperature measurements and in such diverse instances as electrode disconnection and emergency alarms.

In Figure 2 the graphic board is surrounded by a dashed line. It consists of eight 4164 dynamic memories exhibiting an overall memory of 64 Kbytes capable of producing two 512×512 parallel pages of which one is used for biomedical signal-display and the other is allocated to relevant alphanumerical characters.

Figure 3(a) presents ECG signal-dispaly based solely on processed samples. Vectors or interpolations are not used. Here, although the figure can be determined, the discontinuity especially in the QRS complex, reduces image quality. This defect, can be overcome by CPU extraroutines, but it would be impractical as it needs a considerable amount of time. Succesful interpolation and a perfectly continuous and normal ECG, can be obtained by employing the vector-drawing ability of EF 9365 with no loss of CPU time (Figure 3(b)).

Figure 4 presents the timing of the program by Z-80 to display an ECG signal. As shown in part a, normally, only 1.5 ms out of 4ms (sampling interval) is needed for data reception and display and the rest is available to CPU to be used for other procedures when necessay. Further improvement can be achieved through TP compression procedure as it can halve the display data. Consequently, the CPU time necessary for display will be 1.5 ms in one period, while only 0.15 ms in the next (Figure 4(b)). This means about 40% extra CPU free time.

Figure 5 is a photograph of the monitor screen. A vertical line is in continuous movement from the left side to the right side of the screen, erasing the previous signals and replacing them with new ones. Normally, four stationary ECG cycles are seen on the screen. A program, to be called on through the keyboard, can be prepared to make alterations in the time scale possible.

Due to GDP's high display speed, it is possible for the whole signal to continously move from left to right. In other words the new signal could enter the screen from the left side and the previous signal leave it from the right. But this requires screen memory shift which is more time- consuming.

In our system it is possible to store a 32-second interval in the memory to be later called upon through the keyboard. In the upper panel of Figure 5, the temperature is shown on the left and heart rate on the right. The normal heart rate range (upper and lower limits) is shown by small numbers beside the heart rate and can be set by the operator. One of

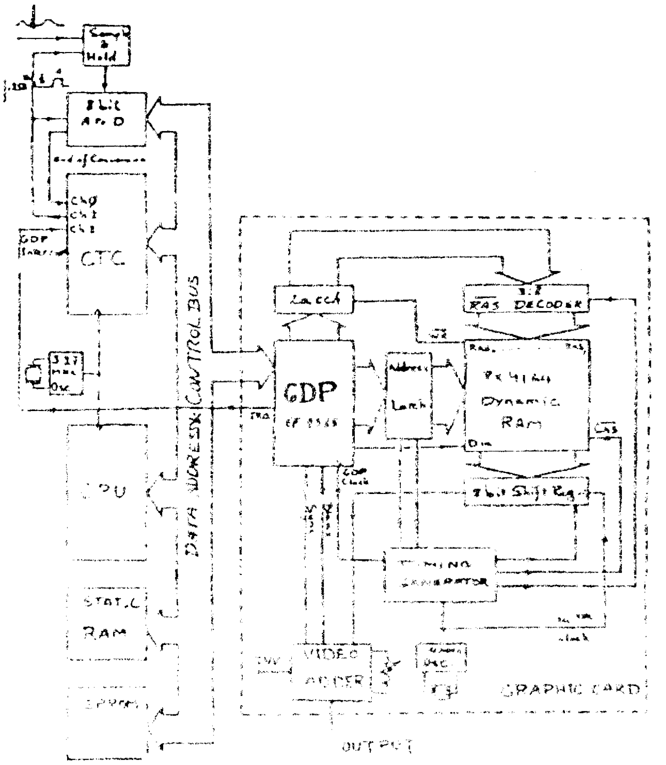


Figure 2. A biomedical signal-display

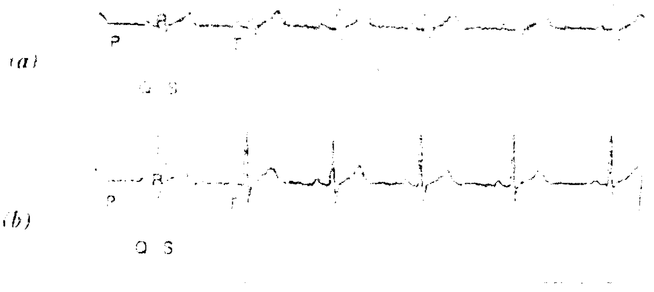


Figure 3. ECG signal display based only on processed samples

GDP capabilities used here is different alphanumeric sizes.

The system, in addition to ECG display, is capable of graphically displaying the phonocardiogram (PCG) as the second channel.

The band-width of PCG exceeds that of ECG, while the number of pixels remains unchanged. Consecutive TP algorithims, therefore, are employed to compress PCG signal samples resulting in a compression ratio of twice normal (i.e. CR= 4:1) though causing a negligibly-higher mean distortion which is commonly endurable for PCG signals.

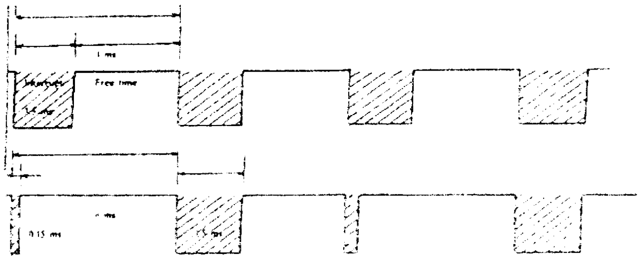


Figure 4. Display of an ECG signal

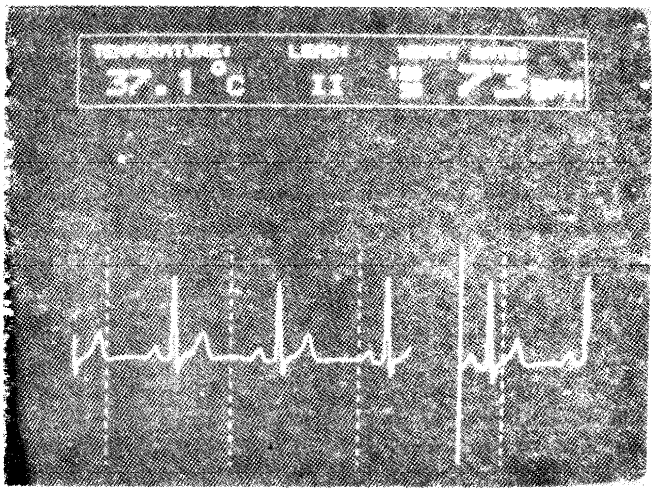


Figure 5. Photograph of the monitor screen

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