Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits and Systems, Dominican Republic, Nov.3-5, 2004

Localization of Maximum and Minimum Values of Electrocardiography Signals with High Level of Noise

Antonino Caralli[1], Adelmo Ortiz-Conde[2], Francisco García Sanchez[2]

[1]Universidad de Carabobo, Valencia 2001, Carabobo, Venezuela e-mail: acaralli@ieee.org.
[2]Laboratorio de Electrónica del Estado Sólido, Universidad Simón Bolívar,
Apdo 89000, Caracas 1080, Venezuela e-mail: {ortizc, fgarcia }@ieee.org

Abstract – **We present a method to localize electrocardiographic signals maximum and minima values with high level of noise. The method is based on integrations instead of differentiation in order to decrease the effects of the noise.**

I. Introduction

The localization of the maximum, P, R and T, and minimum values, Q and S, of electrocardiographic signals (ECG) is very important for medical diagnosis. For example, the expert can establish a diagnosis based on segment and interval duration. One of the most significant instances is the detection of the QRS complex. There exist several algorithms to determine the beginning and ending points of this complex. Presently, the most popular algorithms used for the localization of ECG peaks are based on: a) the amplitude and its first derivative [1-4], b) the first derivative only [1,5-6], c) the first and second derivatives [1,7-8], d) digital filters with differentiator [1,9-10]. Since ECG signals are usually affected by high level of noise, methods based on derivatives cannot be used to obtain the localization of the maximum and minimum values These previous methods are not completely satisfactory if the signal is not sufficiently free from artifacts such as noise and baseline variations. These artifacts are caused by, for example, patience movement, respiration, and changes in electrode impedance.

Some methods, based on pattern comparison [11-16], decrease noise at the expense of eliminating data. On the other hand, methods based on nonlinear transformations [16] are sensitive to noise because they include derivatives in their calculations.

We presented recently [17] a method that evaluates the location of the maximum value of a given function under the presence of high level of noise. This method, which is based on integrations instead of differentiation, was succesfully used to extract the threshold voltage in a MOSFET.

In the present article we have generalized our previous method in order to also extract the location of the two minima values. The method is applied to ECG signals with and without added noise. Because the method is based on integration rather than on differentiation, it decreases the effect of noise instead of increasing it.

II. Method

For the sake of completeness, we summarize here our previous method [17]. Let $y(x)$ be a continuous function with a maximum value at $x{=}x_{\max}$. Then the Content function is [18-20]:

$$C(x,y) \equiv \int_0^y x\,dy \tag{1}$$

which represents the area contained between the function and the vertical axis. Using integration by parts it can be rewritten as:

$$C(x,y) = xy - \int_0^x y\,dx \tag{2}$$

where the second term in the right-hand side of (2) is called the Co-Content [18].

Taking the derivative with respect to x of $C(x,y)$ in (2):

$$\frac{dC}{dx} \equiv y - x\,\frac{dy}{dx} - y = -\,x\,\frac{dy}{dx} \quad . \tag{3}$$

Equation (3) implies that the maximum of the Content function occurs at $x{=}x_{\max}$ because $dy/dx = 0$ at this point.

Taking the derivative with respect to y of $C(x,y)$ in (3):

$$\frac{dC}{dy} \equiv x \ . \tag{4}$$

A plot of the Content function versus y will present a maximum value at a peak for the corresponding values of $x{=}x_{\max}$. The slope of this plot yield to the value of x because of (4).

Although this method [17] was originally developed obtain the localization of the maximum value is also valid to obtain the minimum value because all the previous arguments remain valid.

III. Application to an ECG signal without added noise

Figure 1 presents the ECG signal (y) MIT-BIH 100 [21] versus the sample number (x) from 1700 to 2000. The so called complex QRS region is taking place in the region between 1805 to 1840 and is shown in a expanded scale in Fig. 2. The amplitude value at the point 1805 was selected as the reference (zero level) for convenience in the numerical calculations. This figure also presents the calculated Content function versus the sample number. We see in figure 2 that both, the ECG signal and the Content, present a maximum value at x_{max}=1826 and two minima at x_{min1}=1814 and x_{min2}=1832.

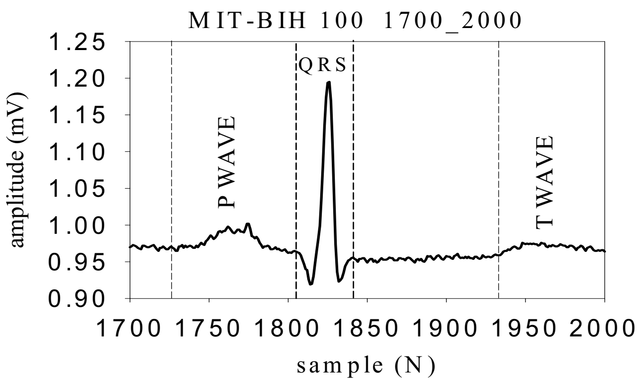

Fig. 1. ECG signal MIT-BIH 100 1700_2000 [21]. We can observe a low level of noise in this signal.

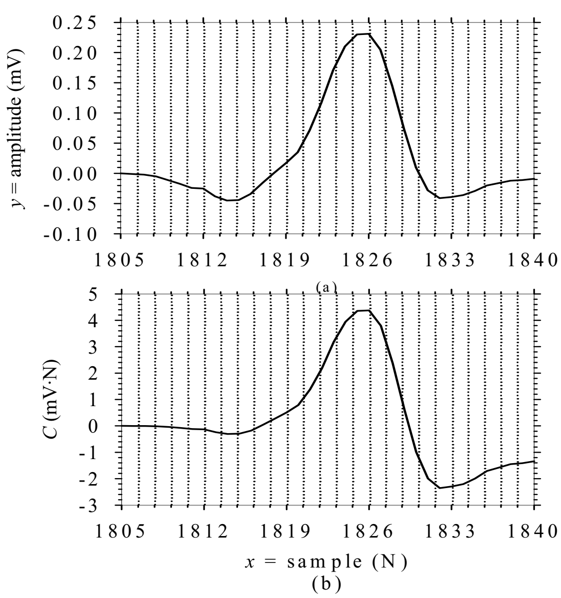

Fig. 2(a). ECG signal MIT-BIH 100 1805_1840 [15] showing the complex QRS region; and (b) Corresponding Content function versus the sample number (= x).

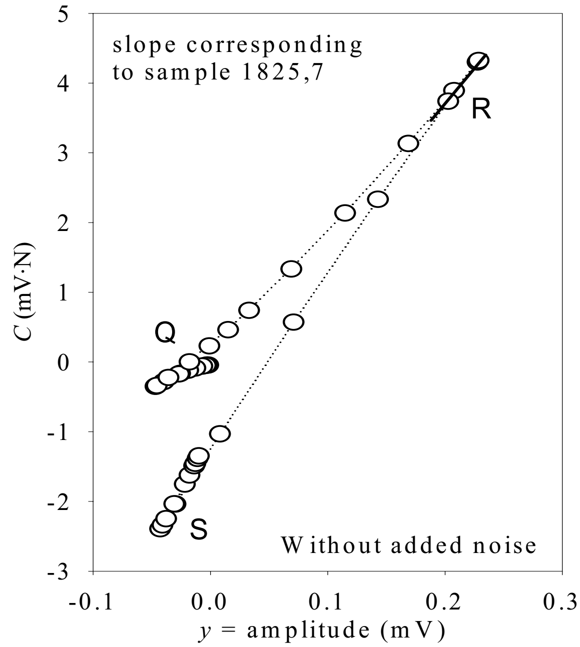

Fig. 3. Calculated Content function versus the amplitude value (y) for sample number from the sample 1809 at the 1840.. The slope of the straight line at the peaks gives the location of the the maximum.

Figure 3 illustrates the same calculated Content function versus the amplitude value (y). The slope of this plot gives the sample number (x) and evaluated at the three peaks yields to 1826, 1814 and 1832 which are the original values without added noise of x_{max}, x_{min1} and x_{min2}. Therefore, the method was able to extract the location of one maximum and two minima with high level of noise.

IV. Application to an ECG signal with added noise

In order to illustrate a particular case in which the location of the maximum and minimum values cannot be obtained directly, we add noise to the original ECG signal. The noise is generated using random numbers between -320 µV and +320 µV. Figure 4 (a) shows the ECG signal with added noise.

Figure 5 (a) presents the expanded region of the ECG signal with added noise. Figure 5 (b) shows the corresponding Content function versus the sample number. We see in this figure that the location of the maximum and two minima of both functions has been lost because of the noise.

Figure 6 illustrates the Content function versus the amplitude value (y) for the results presented in the previous figure. This plot presents three peaks and the corresponding slopes of these peaks yield 1825, 1813 and 1831 which are very close to the values x_{max}=1826 , x_{min1}=1814 , and x_{min2}=1832.

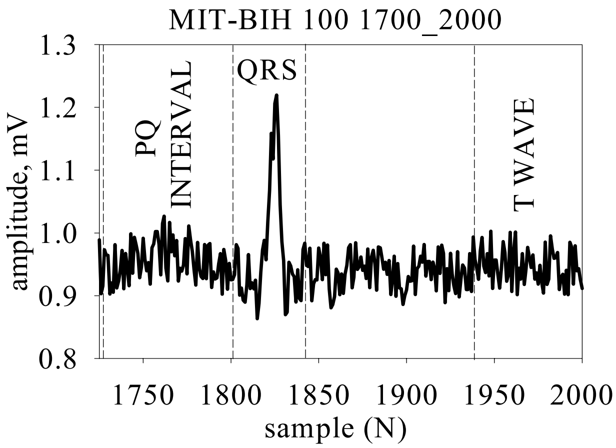

Fig. 4. ECG signal MIT-BIH 100 1700_2000 with added noise

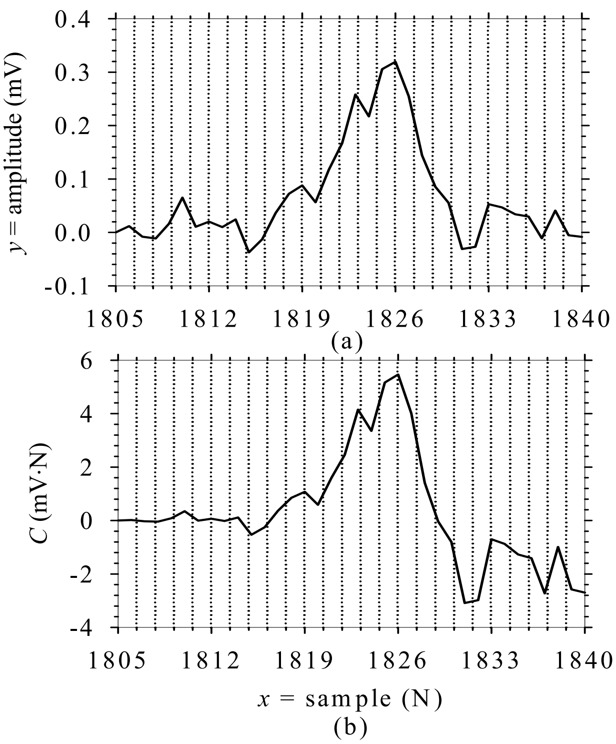

Fig. 5(a) ECG signal MIT-BIH 100 1805_1840, with added noise, [21] showing the complex QRS region; and (b) Corresponding Content function versus the sample number (= x).

V. Conclusions

We have extracted the location of the maximum and two minima values of electrocardiography signals with high level of noise. We have used a method based on integration instead of differentiation in order to decrease the effects of the noise. The present method is a generalization of our previous method [17] used to extract the threshold voltage in a MOSFET.

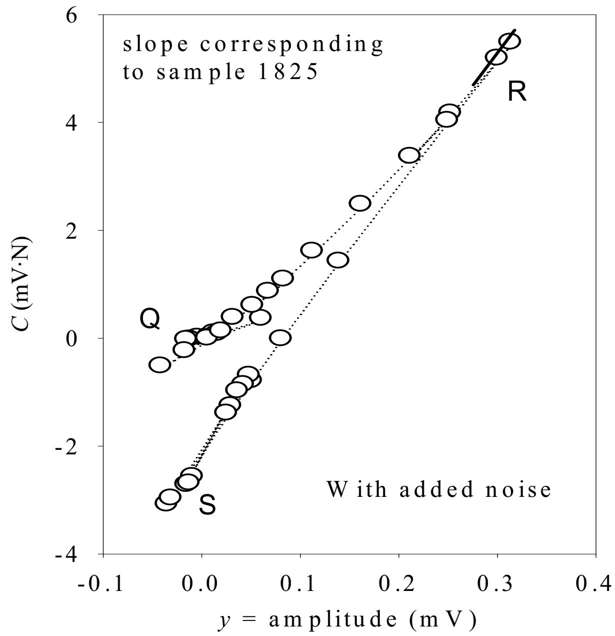

Fig. 6. Calculated Content function with added noise versus the amplitude value (y) for sample number from the sample 1809 at the 1840. The slope of the straight line at the peak gives the location of the maximum value without added noise.

References

[1] G.M Friesen, *et al.*, "A comparison of the Noise Sensitivity of Nine QRS Detection Algorithms", IEEE Transactions on Biomedical Engineering, Vol. 31, No. 1, pp. 85-98, Jan. 1990.

[2] P.M. Mahoudeaux et al., "Simple microprocessor-based system for on-line ECG analysis," Med. Biol. Eng. Comput., vol. 19, pp. 497-500,1981.

[3] J. Fraden and M. R. Neuman, "QRS wave detection," Med. Biol. Eng. Comput., vol. 18, pp. 125-132, 1980.

[4] D. Gustafson et al., "Automated VCG interpretation studies using signal analysis techniques," R-1044 Charles Stark Draper Lab., Cambridge, MA, 1977.

[5] A. Menrad et al., "Dual microprocessor system for cardiovascular data adquisition, processing and recording." in Proc. 1981 IEEE Int. Conf. Industrial Elect. Contr. Instrument., 1981. pp. 64 – 69.

[6] W. P. Holsinger et al., "A QRS preprocessor based on digital differentation," IEEE Trans. Biomed. Eng., vol. BME-18, pp. 212-217, 1971.

[7] R. A. Balda et al., "The HP ECG analysis program," Trends in Computer-Processed Electrocardiograms. J. H. vanBemnel and J. L. Willems, Eds. North Holland, 1977, pp. 197-205.

[8] M. L. Ahlstrom and W. J. Tompkins, "Automated high-spedd analysis of holter tapes with microcomputers," IEEE Trans. Biomed. Eng., vol. BME 30, pp. 651-657, Oct. 1983.

[9] P.Laguna, *et al.* , "Low-pass Differentiators for Biological Signals with Known Spectra: Application to ECG Signal Processing", IEEE Trans. Biomedical Eng. Vol. 37, No. 4, pp. 420-424.

[10] N.V. Thakor, J.G. Webster, and W.J. Tompkins, "Estimation of QRS Complex Power Spectra for Design of a QRS Filter", IEEE Transactions on Biomedical Engineering", Vol. 31, No. 11, pp. 702-706, November 1984.

[11] E. Vullings, J. García, and P. Laguna, "Waveform Detection in Holter ECG using Dynamic Time Warping", Comunicaciones del XV congreso anual de la sociedad española de ingeniería biomédica, pp. 313-316, Valencia, Spain., 1997.

[1] A. Koski and M. Juhola, “Segmentation of Digital Signals Based on Estimated Compression Ratio”, IEEE Transactions on Biomedical Engineering, Vol. 43, No. 9, pp. 928-938, September 1996.

[1] A. Koski, M. Juhola and M. Meriste, “Syntactic ecognition of ECG Signals by Attributed Finite Automata”, Pattern Recognition, Vol. 28, No. 12, pp. 1927-1940, 1995.

[2] P. Trahanias and E. Skordalakis, “Syntactic Pattern Recognition of the ECG”, IEEE Transactions on Pattern Analysis and Machine Inteligence”, Vol. 12, No. 7, pp. 648-656, July 1990.

[3] P. Trahanias and E.Skordalakis, “Bottom-up approach to the ECG patternrecognition problem”, Medical and Biological Engineering and Computing, pp. 221- 229, May 1989.

[4] S. Suppappola and Y. Sun, “Nonlinear transforms of ECG Signals for Digital QRS Detection: A Quantitative Analysis” , IEEE Transactions on Biomedical Engineering,Vol. 41, No. 4, pp. 397-400, April 1994.

[5] A.Ortiz-Conde, F.J. García Sánchez, A. Caralli D'Ambrosio, "A method to evaluate the location of the maximum value of a function with high level of noise" Solid-State Electronics, vol. 47, pp. 93-97, 2003.

[6] Chua L. O.,“Stationary principles and Potential functions for nonlinear networks”, Journal of the Franklin Institute, 1973, 296, pp. 91-114.

[7] García Sánchez F.J., Ortiz-Conde A., De Mercato G., and Liou, J.J., “Parameter extraction and signal processing using potential functions”, Universidad, Ciencia y Tecnología, 2000, 4, pp. 123-136.

[8] García Sánchez F.J., Ortiz-Conde A., De Mercato G., Liou, J.J., and RECHT, L., “Eliminating parasitic resistances in parameter extraction of semiconductor device models”, Proceedings of the (ICCDCS'95) First IEEE International Caracas Conference on Devices, Circuits. and Systems, 1995, Caracas, pp. 298-302.

[9] MIT-BIH Arrhythmia Database CD-ROM, 2nd. Ed., Harvard-MIT Division of Health Sciences andTechnology,Aug.1992.