Tracking-based baseline restoration circuit for acquisition of bio signals

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Most bio signal waveforms have a baseline that may drift over a large range compared to the excursion of the signal component. A circuit is developed, based on the amplitude tracking technique, for fast estimation and removal of the baseline drift, for effective use of the input dynamic range of the signal acquisition setup.

Introduction: Bio signal waveforms generally consist of a signal component, related to the physiological phenomenon of interest, superimposed on a baseline with an offset. This offset may drift over a range much larger than the excursion of the signal component. The baseline may be changing with time owing to body movement and motion artefacts, or owing to offset drift in the analogue signal conditioning circuit. Digital-signal-processing-based methods have been used for correction of baseline drift, but these can be used only after the digitisation of the signal. To make effective use of the input dynamic range of the signal acquisition setup, the baseline should be restored, at least partly, by removing the offset drift before digitisation of the signal. Generally, the spectra of the drift are overlapped with that of the signal, making it difficult to restore the baseline drift by highpass filtering the signal. In this Letter, we present a fast baseline restoration circuit, developed as a part of instrumentation for impedance cardiography, which may be used for acquisition of several bio signals.

Impedance cardiography is a non-invasive technique, based on sensing the variation in electrical impedance across the thorax, caused by change in the blood volume during the cardiac cycle, for monitoring stroke volume and obtaining diagnostic information on cardiovascular functioning [1–6]. The impedance change caused by cardiovascular activity is about 1–2% of basal impedance [2, 4]. Sensing of this variation is confounded by variation in the thoracic impedance caused primarily by change in the dimension of the thoracic cage and/or skin-to-electrode impedance. These respiratory and motion artefacts have large amplitudes as compared to the impedance variation owing to cardiovascular activity, and can cause a large baseline drift.

Several circuits for automated balancing of offset drift have been reported, including a self-balancing system [7] and a successive approximation register (SAR) based method [2, 8]. The self-balancing system requires up to 2n cycles for an n-bit digital-to-analogue (D/A) converter depending on the value of the offset. The SAR technique requires n clock cycles for a baseline balancing using n-bit SAR. The signal is not usable during the drift correction interval, and hence this time interval should be short and correction should not take place too frequently. In the circuit presented here, tracking has been used, for estimation and removal of the baseline drift, and this requires only one clock cycle. This technique has been implemented using a microcontroller and a D/A converter.

Circuit description: The block diagram for the tracking based baseline restoration is shown in Fig. 1. The up/down counter and a D/A converter are used to track the baseline drift in the input signal, and the estimated drift $V_D$ is subtracted from the input to give the drift balanced amplified output $V_C$. Two thresholds $V_{s1}$, $V_{s2}$ are selected corresponding to the desired range of the signal or the input range of the signal acquisition. Whenever the output crosses the threshold range in either direction, a new estimation of the drift is carried out in the up/down counter depending on the direction of the drift, and the value is output to the D/A converter. The baseline drift correction is done in one clock pulse. One quantisation step of the D/A converter after amplification is set to half of the output threshold range. Hence, after crossing of the threshold in either direction, the signal is brought back in the middle of the two thresholds. The relationship between input voltage $V_i$ and the output voltage $V_C$ along with the correction voltage $V_I$ is shown in Fig. 2, for increasing input (Fig. 2a) and decreasing input (Fig. 2b). Drift cancellation has a hysteresis, and the actual output depends on the direction of input change.

Fig. 2 Input-output relationship

- a Increasing input
- b Decreasing input

Fig. 3 Circuit diagram of microcontroller-based implementation

The circuit of the microcontroller-based implementation is shown in Fig. 3. The circuit uses quad op amp TL084 as U1, 20-pin microcontroller AT89C2051 as U2, and 12-bit serial D/A converter TLV5618A as U3, used as 8-bit D/A converter by masking four LSBs. This circuit has been developed for baseline drift removal in an impedance cardiograph with ±5 V supply. Op amp U1A is used as a summer for the input voltage $V_i$, the reference voltage $V_r$, and the correction voltage $V_c$. The output is given as

$$V_o = A_1 V_{im} - A_2 (V_x - A_1 V_{m}/A_3)$$

where $A_1 = (R_2[R_1 + R_3])/(1 + R_2/R_3)$, $A_2 = (R_1/R_2)(1 + R_3/R_2)$, and $A_3 = R_2/R_4$.

Op amps U1B and U1C are used as comparators for comparing the output $V_C$ with the threshold voltages $V_{s1}$ and $V_{s2}$, which are set using a resistive divider. The port pins P1.2 and P1.3 of microcontroller U2 are used to scan threshold detector outputs. The tracking up/down counter of Fig. 2 is realised using software inside the microcontroller. The count...
value is written as a correction byte to the D/A converter, interfaced serially to the microcontroller via a serial peripheral interface (SPI), for varying its output over 0–4.2 V in 256 steps.

The input consists of the actual signal \( V_s \) superimposed on the baseline drift \( V_d \). The input signal range is mapped to the output voltage, and hence the gain for the input signal is selected as \( A_s = \frac{(V_d - V_b)(V_{max} - V_{min})}{V_s} \). If the summer output \( V_s \) goes below the lower threshold \( V_t1 \), the up/down counter is decremented, and the D/A converter output \( V_s \) gets decreased by one step. Similarly, if \( V_s \) goes above the upper threshold \( V_t2 \), \( V_s \) is increased by one step. Thus the correction voltage \( V_c \) is given as

\[
V_c(t_n + 1) = V_c(t_n) + \Delta V_c, \quad V_c(t_n) > V_{t2} \\
V_c(t_n) - \Delta V_c, \quad V_c(t_n) < V_{t1} \\
V_c(t_n), \quad \text{otherwise}
\]

For \( N \) steps in the D/A converter, the step voltage is \( \Delta V_c = \frac{V_{max} - V_{min}}{N} \). The gain for the correction voltage is \( A_s = \frac{0.5(V_d - V_b)}{\Delta V_c} \). If the output \( V_s \) is within the range \([V_{t1}, V_{t2}]\), both the comparator outputs are low, the counter in the counter is not changed and the correction voltage remains constant.

**Results:** The component values shown in Fig. 3 were selected for threshold voltages of \( \pm 3 \) V, \( V_s = 4.2 \) V, signal gain \( A_s = 45 \), correction voltage gain \( A_c = 180 \), and reference voltage gain \( A_r = 90 \). The time for restoring the drift is less than 1 ms. An example of drift cancellation by the implemented circuit is shown in Fig. 4. The input consists of a 40 mV (p–p) impedance cardiogram waveform, with fundamental frequency of 1.2 Hz, superimposed on a slowly varying baseline drift, with a slope of 40 mV/s. The output waveform shows that the baseline is restored when the signal after amplification crosses the threshold range in either direction.

**Conclusions:** A tracking-based circuit for fast restoration of baseline by cancelling offset drift has been presented. Although the circuit has been developed for impedance cardiography, it can be used for acquisition of other bio signals with large drift or abrupt baseline shift. This circuit is independent of the processor to which the signal acquisition unit is interfaced and can be used in setups with real time as well as offline processing. In the present implementation, tracking of the baseline is initiated by the output going out of the defined range. Alternatively, the microcontroller can be programmed to carry out the tracking for drift cancellation at periodic intervals, which may be appropriate for certain applications.

© The Institution of Engineering and Technology 2007
25 October 2006
Electronics Letters online no: 20073152
doi: 10.1049/el:20073152
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