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Java implementation of low pass Butterworth filter for biomedical applications

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***Abstract*— Signal Processing have become an integral part of biomedical devices. In most of the cases, hardware filters are used for the removal of noise in the input signal which often lead to an increased power consumption. This problem can be rectified by implementing hardware filters in java. In this paper, low pass Butterworth filter is implemented in java by analysing ECG samples.**

***Keywords*— ECG, Butterworth filter**

I. INTRODUCTION

Digital signal processing is a very significant tool in the field of biomedical engineering. Biomedical signal analysis has a lot of applications in advanced diagnosis patient monitoring and recovery. ECG, being one of the most important biomedical applications, keeps track of cardiac activity and also helps in the diagnosis of cardiac abnormalities.

Diagnosis, being a very important part, is supposed to be performed accurately. However, the ECG signal corrupted by noise leads to wrong diagnosis and various real time problems associated with the signal. But on the other hand, using hardware filters give rise to power wastage and additional expenses. Software filters, being compatible, convenient and inexpensive, can be considered as the best alternative for hardware filters.

II. JAVA IMPLEMENTATION

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A. Butterworth filter

As a result of various researches conducted, it was observed that Butterworth low pass filter helps to obtain a requisite frequency response plot for ECG noise removal. The importance of Butterworth filter lies in the fact that its frequency response is maximally flat with no ripples.

A low pass filter with a cut off frequency normalised to one radian per second will have a frequency response (gain) which is given by the equation

$$G(\omega) = \frac{1}{\sqrt{1+\omega^{2n}}},$$

This gives a frequency response of a low pass Butterworth filter of angular frequency ω and order n.

The frequency response of an n^{th} order Butterworth low pass filter with a cut-off frequency ω_c , angular frequency ω, transfer function H(s) and DC gain (gain at zero frequency) G_o is:

$$G^2(\omega) = |H(j\omega)|^2 = \frac{{G_0}^2}{1+\left(\frac{j\omega}{j\omega_c}\right)^{2n}}$$

B. ECG database

ECG signal processing require an authenticated dataset. One of the sources which provides standard ECG database is MIT-BIH Arrhythmia Database [1]. The database contains raw data with inclusive additive noise. The database also includes data of different abnormalities like atrial fibrillation, ventricular disorder and Cardiac death.

Another set of data is extracted using an IC called AD8232 from a healthy person. However, the data has additive noise due to powerline interference.

C. Java implementation

Java implementation of Butterworth filter algorithm can be subdivided into three steps:

Step I – Function declaration

Declaring a function with return type void and four arguments which are:

First Coefficient matrix of the filter which is a double array of order 3 (a [ ]), where the standard array is extracted from an excel file in csv format stored in the same directory

Second Coefficient matrix of the filter which is a double array of order 3 (b [ ]), where the standard array is extracted from an excel file in csv format stored in the same directory

The input double array (N [ ]) which is the ECG database saved as an excel file in csv format.

Filtered data which is a double array (p [ ]) of the same order as that of input array.

Step II - Generating two reference matrices

Two reference matrices were generated which were similar to coefficient matrices a[ ] and b[ ]. These matrices were named as b_a[ ] and b_b[ ].The output matrix p[ ] is generated using these two reference matrices.

Step III - Algorithm implementation

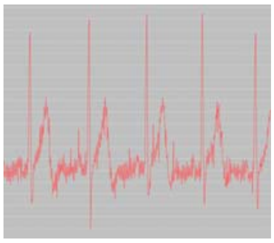
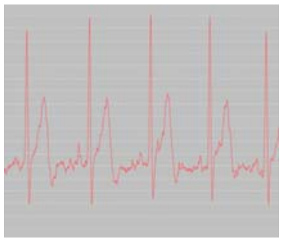
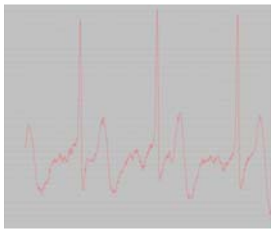
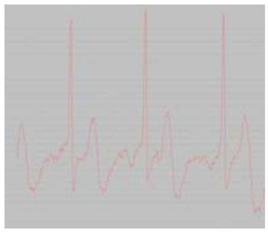
The filtered data is generated with the help of four nested loops.

```
public class filter2 {
        void fil(final double a[], final double b[], final double N[], double p[])
  {
          double b_b[]=new double[3];
          double b_a[]=new double[3];
          int k;
          double dbuffer[]=new double[3];
          int j;
          for (k = 0; k < 3; k++) {
            b_b[k] = b[k];
            b_a[k] = a[k];
          }
            for (k = 0; k < 3; k++) {
              b_b[k] /= a[0];
            }

            for (k = 0; k < 2; k++) {
              b_a[k + 1] /= a[0];
            }

            b_a[0] = 1.0;


          for (k = 0; k < 2; k++) {
            dbuffer[k + 1] = 0.0;
          }

          for (j = 0; j < 2000; j++) {
            for (k = 0; k < 2; k++) {
              dbuffer[k] = dbuffer[k + 1];
            }

            dbuffer[2] = 0.0;
            for (k = 0; k < 3; k++) {
              dbuffer[k] += N[j] * b_b[k];
            }

            for (k = 0; k < 2; k++) {
              dbuffer[k + 1] -= dbuffer[0] * b_a[k + 1];
            }

            p[j] = dbuffer[0];
          }
      }
  }
```

III. Experimental Results

Three distinct series of data (as mentioned in ECG database) have been analysed to assess the performance of the filter and to evaluate the implemented algorithm. Each set of data was stored in an excel file in CSV format. Respective CSV files were read and the data was stored as a double array. The java code was compiled with each sets of data and corresponding graphs were plotted. The graphs plotted in eclipse are given in Table I.

TABLE I
ANALYSIS OF THREE DIFFERENT DATA SETS WITH THE ALGORITHM

Data	Unfiltered Data	Filtered Data
Extracted from Front end ECG IC AD8232		
MIT Arrythmia Database		
Motion Artefacts		

From the above table, it is observed that in the first set of data, all the high frequency noise has been removed by the Butterworth filter which is clear from the graph. In the second and third sets of data, the input samples are extracted using a more sophisticated IC and hence contains lesser amount of additive noise. However, filtering is performed in those graphs also.

IV. Conclusions

After implementing the Butterworth filter using the java code and observing its performance by testing it on different sets on input data, it is observed that Java implementation of Butterworth filter had significantly reduced high frequency noise in the input data. As discussed earlier, this helps in lowering costs as well as in better diagnosis in biomedical field.

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