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# IIR digital filter design for powerline noise cancellation of ECG signal using arduino platform

**Akif Rahmatillah*** **and Ataulkarim**

Department of Biomedical Engineering, UniversitasAirlangga, Kampus C Mulyorejo, Surabaya, Indonesia, 60286

*Corresponding email address: akif-r@fst.unair.ac.id

**Abstract**. Powerline noise has been one of significant noises of Electrocardiogram (ECG) signal measurement. This noise is characterized by a sinusoidal signal which has 50 Hz of noise and 0.3 mV of maximum amplitude. This paper describes the design of IIR Notch filter design to reject a 50 Hz power line noise. IIR filter coefficients were calculated using pole placement method with three variations of band stop cut off frequencies of (49-51)Hz, (48 - 52)Hz, and (47 - 53)Hz. The algorithm and coefficients of filter were embedded to Arduino DUE (ARM 32 bit microcontroller). IIR notch filter designed has been able to reject power line noise with average square of error value of 0.225 on (49-51) Hz filter design and 0.2831 on (48 - 52)Hz filter design.

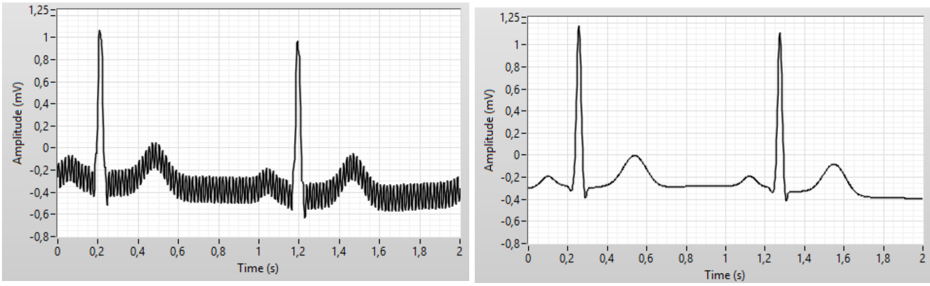
## 1. Introduction

ECG signal is a signal which indicates electrical activity of heart. It has been used in cardiovascular condition assessment [1]. On the frequency domain, its signal can be represented from 0,05 Hz to 150 Hz [2,12]. As a typical of bio potential signal, ECG signal can be interfered by noises. There are many interferences or noise sources on ECG signal measurement such as friction of an electrode with body (motion artifact), instrumentation noise, respiration movements, and power line noise. Interference is classified based on their frequency content [3]. The most significant interference of ECG signal measurement is at 50 Hz / 60 Hz power line noise [4, 12]. This noise can make an ECG signal difficult to be interpreted [11], and this is caused by a change in ECG signal shape as shown in Figure 1. For that reason, a filter which is able to reject a single frequency component of noise is needed. This refers to Notch Filter which can be applied using analog electronics circuit or digital filter design. However, analog filters have some disadvantages such as nonlinear phase shift of input-output filter signal and cut-off frequency which make it difficult to be applied due to its limitation of resistors and capacitors value and sensitivity of electronics circuit to temperature. Digital Filters can apply a precise value of cut - off frequency, and it is not sensitive to temperature or other environmental conditions [5].

IIR filter design is one of digital filter algorithm which applies linear time-invariant properties of filter system. A notch filter for Electromyography (EMG) signal has been used in IIR filter algorithm [6]. Coefficients of IIR filter can be calculated with many methods such as Pole Zero Placement method which has been used to calculate coefficients of IIR filter to be stable [7]. IIR filter design also has the ability to reduce the transient response of notch filter [10]. This method is applied to eliminate noises of ECG signal [5].

On the other hand, a computational platform to apply IIR filter algorithm is needed. An Arduino platform has been used to apply FIR digital filter [13]. Arduino DUE is one of low cost computational platforms based on 32-bit ARM Microcontroller with 12-bit resolution of ADC and 13 kHz frequency sampling [8]. Although it is a "low-cost platform", it can be used as a hardware platform of IIR notch filter design for ECG referring to a resolution of ADC.

This study proposes a design of IIR notch filter algorithm, and the algorithm is applied to Arduino DUE platform.




(a) (b)

**Figure 1.** (a) ECG Signal with 50 Hz Powerline Noise. (b) ECG Signal with 50 Hz Powerline Noise.

## 2. Background

IIR filter algorithm is characterized by recursive equation as shown in (1) in which $h[k]$ is filter impulsive response that it has an infinite value, and $b_k$ and $a_k$ are filter coefficients, while $x[n]$ and $y[n]$ are input and output filter.

$$y[n] = \sum_{k=0}^{\infty} h[k]x[n-k] = \sum_{k=0}^{N} b_k x[n-k] - \sum_{k=1}^{M} a_k y[n-k] \tag{1}$$

In Z domain, IIR filter transfer function is represented as in (2)

$$H(z) = \frac{b_0 + b_1 z^{-1} + \ldots + b_N z^{-N}}{1 + a_1 z^{-1} + \ldots + a_M z^{-N}} = \frac{\sum_{k=0}^{N} b_k z^{-k}}{1 + \sum_{k=1}^{M} a_k z^{-k}} \tag{2}$$

Therefore, it can be factorized as shown in (3)

$$H(z) = \frac{K(z-z_1)(z-z_2)\ldots(z-z_N)}{(z-p_1)(z-p_2)\ldots(z-p_N)} \tag{3}$$

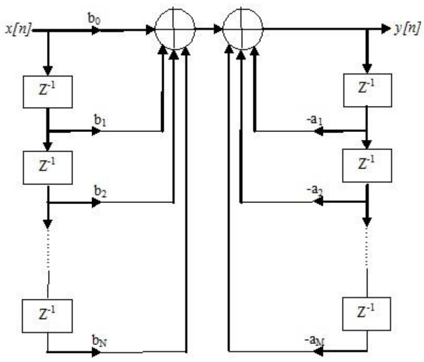



**Figure 2.** IIR Filter Data Flow Diagram.

Inwhich $z_1, z_2, ..., z_N$ are zeros, and $p_1, p_2, ..., p_M$ are poles of $H(z)$. The poles of $H(z)$ should contain the unit circle (i.e., $|z| = 1$) of which the filter is stable in the sense of Bounded Input - Bounded Output Stability. Thus, IIR filter may not be stable if a pole is outside of unit circle. On the other hand, IIR filter is recursive. There is a feedback as shown in (1) that the coefficients of IIR filter are less than those of FIR filter. An Application of IIR filter is a computation algorithm which can be represented with data flow diagram as shown inFigure2.

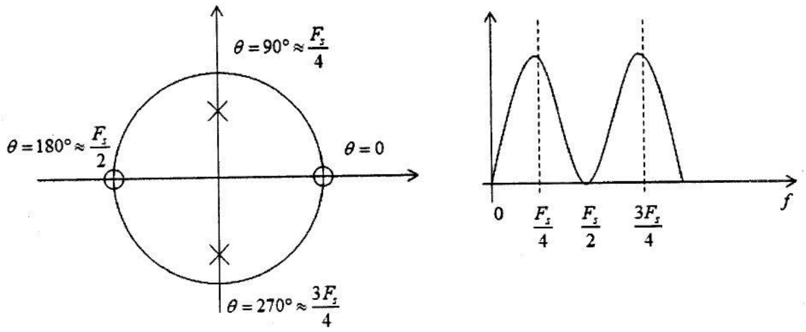



**Figure 3.** Figure with short caption (caption centred)[9].

Poles and Zeros Placement Method was used to calculate coefficients of notch filters. This method uses a property of poles and zeros position on Z domain. A frequency response of IIR filter value will be 0 on zeros position s and $\infty$on poles positions as shown in Figure 3. In this method, there is a relationship between an angle (placement position of zeros and poles) and frequency [5]. The relationship is simple and follows linear comparison. Angle positions of poles and zeros can be calculated using (4)

$$\theta = \frac{f}{f_s} \times 360^o \tag{4}$$

In which $f$ is stopband designed for frequency of filter, $f_s$ is sampling frequency, and $\theta$ is angular position of poles and zeros. A radius of poles and zeros to the center of unit circles (r) is calculated using (5) in which $BW$ is bandwidth of passband filter.

$$r = 1 - \left(\frac{BW}{f_s}\right)\pi \tag{5}$$

Notch filter is one of typical band stop filter with narrow stop band. Its common use is to reject a powerline noisewhich has a single frequency component to reject. Figure 4 shows the illustrationoffrequency response of notch filter in which $\omega_c$ is a frequency which is rejected.

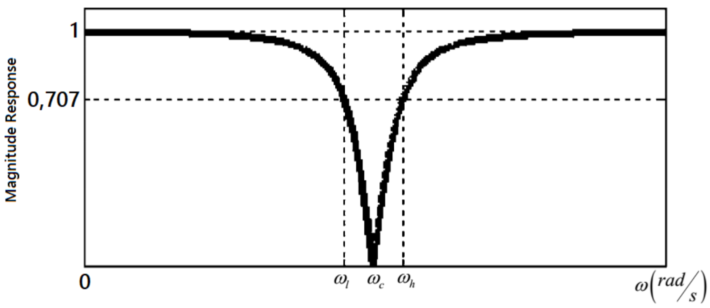



**Figure 4.** Frequency Response of Notch Filter.

## 3. Filter specification and design

For attenuating 50 Hz powerline noise, three variations of bandwidth rejection of notch filter were applied; they are 49 - 51, 48 – 52, and 47 - 53 Hz. Each variation had 50 Hz to be the center of stopband filter or the Q point. Using (4) and (5), filter coefficients were calculated and produced a transfer function of each design, and a sampling frequency has been designed at 200 Hz.

For 49 - 51 Hz bandwidth rejection is obtained that *BW* is 2 Hz. Using (4) and (5), angle position of $\theta$ is ±90° and *r* is 0,9686. Transfer function and difference equation of filter for this specification is shown in (6) and (7). Coefficients of filter are $b_0 = 1, b_1 = 0, b_2 = 1, a_1 = 0,$ and $a_2 = 0,9382$. The poles - zeros placement result and bode diagram response of filter are shown in figure 5.

$$H(z) = \frac{1+z^{-2}}{1+0,9382z^{-2}} \tag{6}$$

$$y[n] = x[n] + x[n-2] - 0,9382y[n-2] \tag{7}$$

The second variation is 48 - 52 Hz which had 4 Hz of *BW*, ±90° for $\theta$ , and 0,9732 for *r*. Then, transfer function and difference equation of filter for this specification isshown in (8) and (9). Coefficients of filter are $b_0 = 1, b_1 = 0, b_2 = 1, a_1 = 0$ and $a_2 = 0,8783$. The poles - zeros placement result and bode diagram response of filter are shown in figure 6.

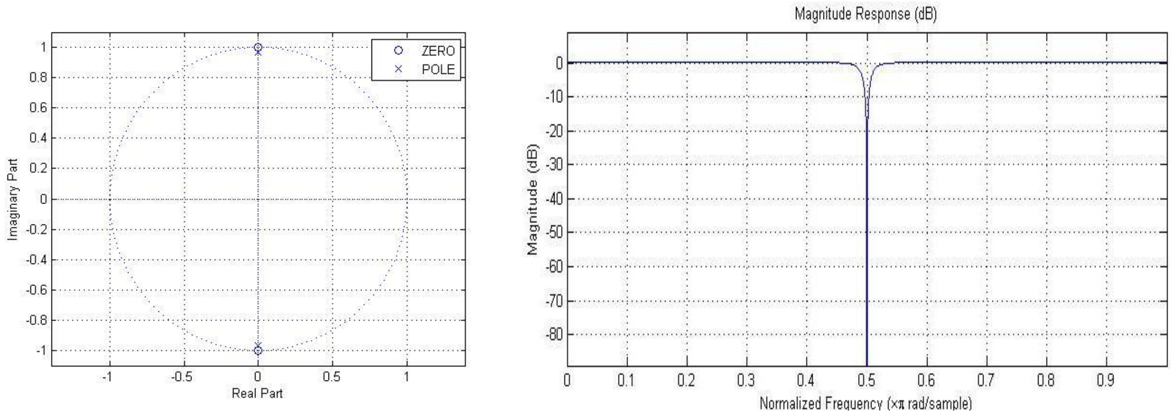
$$H(z) = \frac{1+z^{-2}}{1+0,8783z^{-2}} \tag{8}$$

$$y[n] = x[n] + x[n-2] - 0,8783y[n-2] \tag{9}$$

The second variation is 47 - 53 Hz which had 6 Hz of *BW*, ±90°for $\theta$ , and 0,9058 for *r*. Than transfer function and difference equation of filter for this specification are shown in (10) and (11). Coefficients of filter are $b_0 = 1, b_1 = 0, b_2 = 1, a_1 = 0$ and $a_2 = 0,8204$. The poles - zeros placement result and bode diagram response of filterare shown in figure 7.

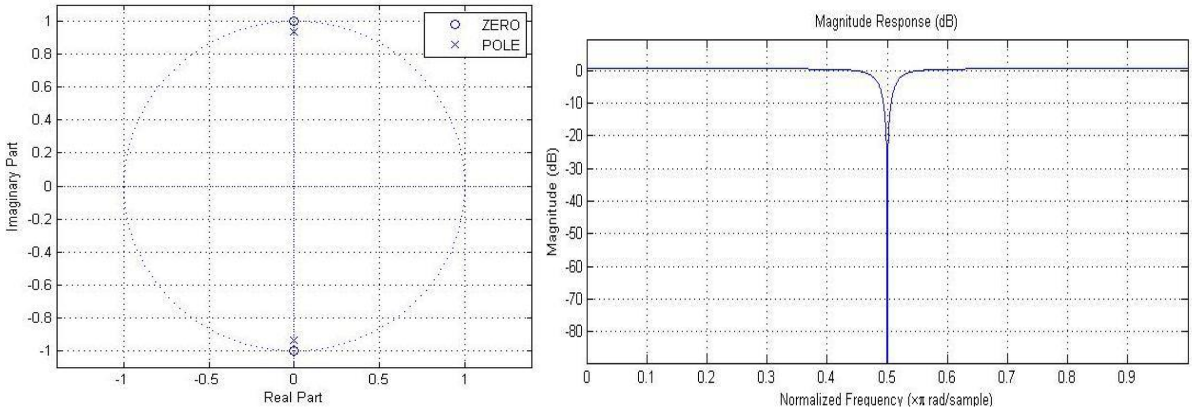
$$H(z) = \frac{1+z^{-2}}{1+0,8204z^{-2}} \tag{10}$$

$$y[n] = x[n] + x[n-2] - 0,8204y[n-2] \tag{11}$$



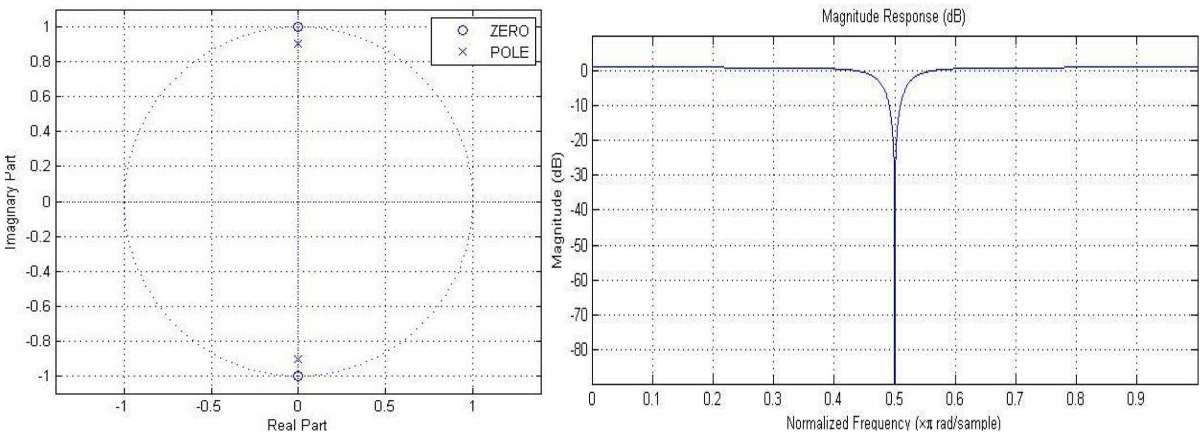

(a) (b)

**Figure 5.** Notch Filter Design Result for Bandwidth rejection 49 - 51 Hz (a) Poles - Zeros Placement, and (b) Bode Diagram of Magnitude Response




(a) (b)

**Figure 6.** Notch Filter Design Result for Bandwidth rejection 48 - 52 Hz (a) Poles - Zeros Placement, and (b) Bode Diagram of Magnitude Response




(a) (b)

**Figure 7.** Notch Filter Design Result for Bandwidth rejection 47 - 53 Hz (a) Poles - Zeros Placement, and (b) Bode Diagram of Magnitude Response

Each variation produced a second order filter. It happened because the poles - zeros placement method always placed two poles and zeros for every filter design.

## 4. Experimental result

To evaluate notch filter design, experimental setup was developed. LabVIEW 2013 Biomedical Toolkit was used to generate ECG simulated signal with powerline noise. The specification of power line noise was 50 Hz and 0,3 mV amplitude of noise signal. Noising ECG simulated signal generated on analog output of NI MyDAQ. Analog input of Arduino DUE which had been embedded on IIR Filter program received and filtered the signal. Denoised ECG signal was sent to Personal Computer to displaydenoised signal using serial communication. The experimental setup is shown on figure 8. Equation (7), (9), and (11) are represented by IIR Filter program written in C language and compiled by Arduino IDE 1.5.2.The program was written on Appendix.

The fourier transform of ECG signal before and after filtering is shown in Figure 9 (a) and (b), 10 (a) and (b), and 11(a) and (b). Notch filter on Arduino DUE had rejected the 50 Hz signal component which was power line noise signal. It was indicated by the amplitude of filter output signal which was zero on 50 Hz. Furthermore,the quality of ECG signal after filtering was measured with Root Mean

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Square Error value. Error value was obtained by comparing signal after filtered to ECG to ideal signal shown in Figure 1(b). Table 1describes RMS values of each variation design of IIR Notch filters.

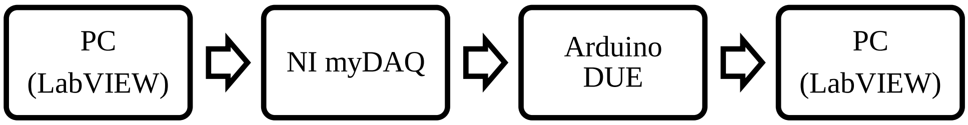
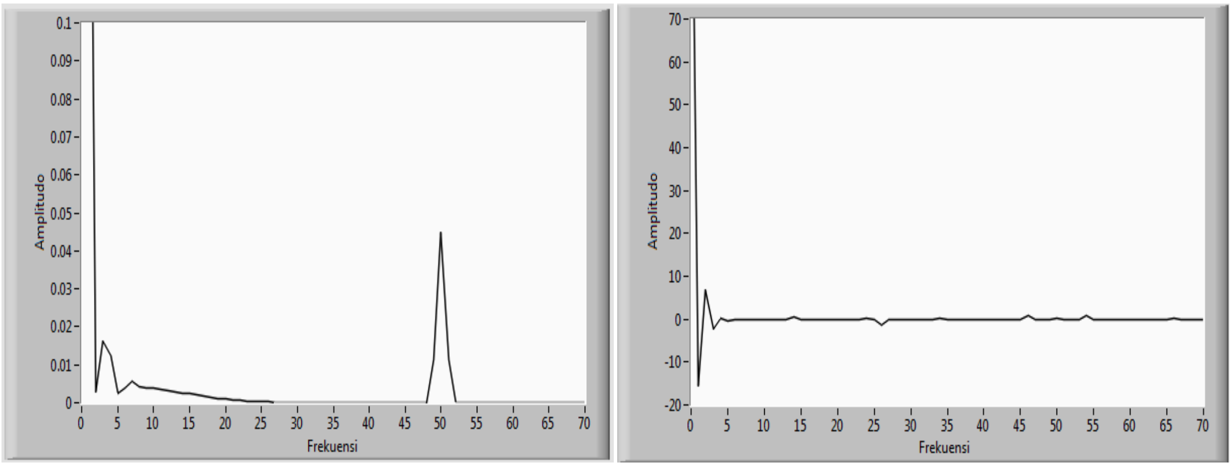
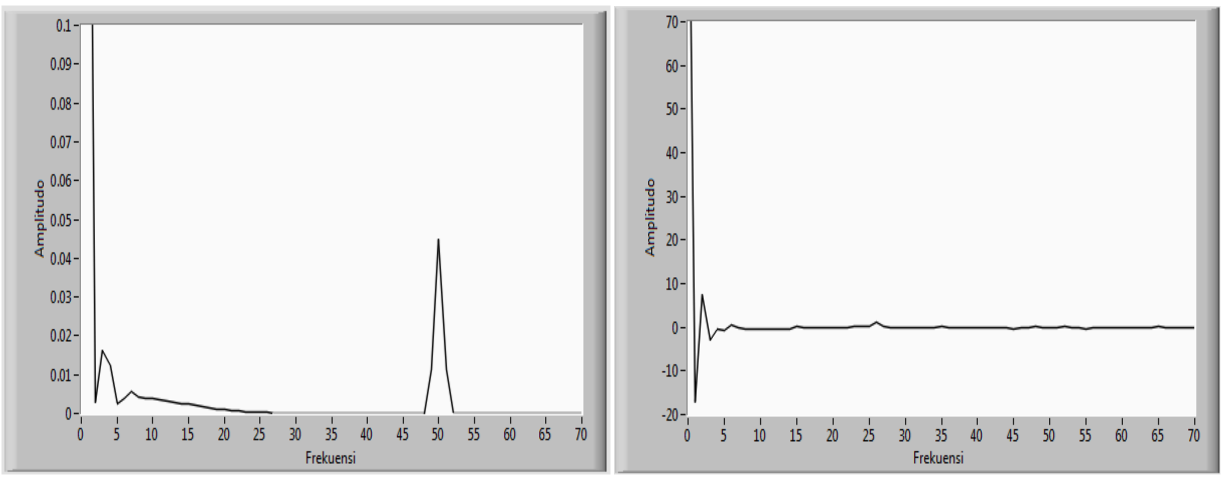



**Figure 8.** Experimental Set-Up.



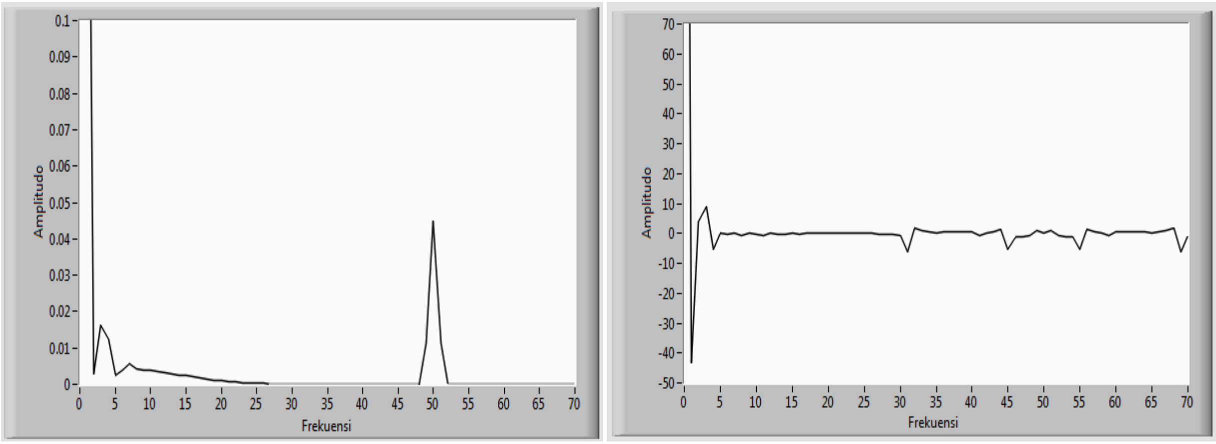

(a) (b)

**Figure 9.** IIR Filter Performance for Bandwidth Rejection 49 - 50 Hz (a) Before Filtering, and (b) After Filtering




(a) (b)

**Figure 10.** Notch Filter Design Result for Bandwidth rejection 48 - 52 Hz (a) Poles - Zeros Placement. (b) Bode Diagram of Magnitude Response.




(a) (b)

**Figure 11.** Notch Filter Design Result for Bandwidth rejection 47 - 53 Hz (a) Poles - Zeros Placement, and (b) Bode Diagram of Magnitude Response

## 5. Discussion

Design of IIR Notch filter using poles-zeros placement method was depended on bandwidth specification applied. From Figure 5 to Figure7, the width of a bandwidth correlated withpoles position. A narrow bandwidth made poles tend to keep away from thecenter of unit circler and vice versa. Then, a narrow bandwidth of notch filter gave perfect filtering only at 50 Hz (see Figure 9(b)). It can be compared with Figure 10(b) that the FFT result from after signal filtering gave ripplesat 30-70 Hz.

**Table 1.** RMSE Values of IIR Notch Filter for 50Hz Frequency Rejection

| Bandwidth | RMSE Value |
|---|---|
| 49 - 51 Hz | 0.254 |
| 48 - 52 Hz | 0.2831 |
| 47 - 53 Hz | 1.5609 |

From table 1 it is shown a narrow bandwidth gave the filter betterqualitythan that of wide bandwidth. It is shown by RMSE value that the narrower bandwidth of notch filter is, the smaller the RMSE value. Small value of RMSE shown afterECG signal filtering was more like ECG signal without noise. Then, an Arduino DUE platform can be used as a hardware platform of Digital Signal Processing especially for IIR Notch filter design. This hardware platform can be embedded on IIR filter algorithm to perform filtering without any obstacle.

It can be concluded that IIR Notch filter whose coefficients calculated by poles-zeros placement method and applied to Arduino DUE platform was able to reject a 50 Hz powerline noise of ECG signal.

## 6. Appendix

IIR Notch Filter Program in C language and applied toArduino DUE Platform

```
float b0= ; //IIR Filter Coeficients
float b1= ;
float b2= ;
```

```
float a1= ;
float a2= ;
float x=0;//signal variable declaration
float x1=0.0;
float x2=0.0;
float y=0.0;
floatyl =0.0;
float y2=0.0;
intdatain[10000];//ECG data initialization
intdataout[10000];
int i=0;
void setup() {
//  analogReadResolution(12);
Serial.begin(9600);
}
void loop() {
while (i<20000)
{
datain[i]=analogRead(0);
  x=datain[i];
  y=b0*x + b1*x1 + b2*x2 - a1*yl - a2*y2 - a3*y3;
  y2=yl;
yl=y;
x2=x1;
x1=x;
dataout[i] = y;
Serial.println(dataout[i]);
  i=i+1;
}
}
```

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