Digital Filter Design for Classifying Coconut Ages using Blackman FIR and Elliptic IIR Filters

Diana Rahmawati, Haryanto, Fahrus Sakariya
Electrical Engineering Department, University of Trunojoyo Madura, Bangkalan, Indonesia
diana.rahmawati@trunojoyo.ac.id, haryanto@trunojoyo.ac.id, fahrussakariya@gmail.com

Heri Setiawan
Electrical Weapon System, Indonesian Army Polytechnic, Malang, Indonesia
diana.rahmawati@trunojoyo.ac.id, haryanto@trunojoyo.ac.id, fahrussakariya@gmail.com

Abstract. Tapping a coconut fruit is one of conventional ways that requires specialty in determining the ages of the fruit. The frequency of these taps can be used as a reference to determine the ages of coconut. This study aims to make an automatic device to determine coconut ages using digital filter based on the tapping frequency. The filter could screen the received signals in order to produce clear tapping sounds, or without noises. Two filter types namely Blackman Finite Impulse Response (FIR) and Elliptic Infinite Impulse Response (IIR) were used to reveal the filter’s length and order. MATLAB software was used in the filter testing to compare the responses of the two filters used. Results depicted that Elliptical IIR was better that Blackman FIR, of which the Elliptical IIR produced less noises and better frequency responses.

Keywords. Digital filter, Blackman FIR type, Elliptic IIR type, MATLAB, coconut ages

1. Introduction
People usually use coconut tapping method to classify its ages and determine the ages regarding their experience and judgment. The coconut age classification includes young, medium, and old coconut. Previous study found that the coconuts age could be determined from different parameters covering young coconut with the coconut weight of 3.7 ± 0.7 kg with an average frequency of 79 ± 14 Hz. The medium coconut was weighing 3.2 ± 0.3 kg with a frequency of 107 ± 10 Hz. Meanwhile, the old coconut weighted 1.4 ± 0.2 kg with a frequency of 150 ± 15 Hz [1]. The study showed that there was indeed an influence of ages on the weight and tapping frequency of coconuts. In general, the older the coconut, the greater the frequency produced. Moreover, the lighter the weight of the coconut fruit was due to the condition of the volume of water and the thickness of the meat on the coconut [1].
Thus, an automation tool is designed to determine the classification of coconut ages, which can be carried out without bringing in those called experts, the ones who knew the conventional ways of defining coconut ages. The aim of designing the tool is to facilitate traders in classifying the coconut ages. The making of this tool utilizes the frequency produced from the knocks or the taps over the coconut fruit using Arduino Due microcontroller. The measurement of the frequency values can be measured using a MAX9814 sound sensor which has a high sensitivity level to infrared sound. Before entering the microcontroller, this signal must be filtered so that there are no unwanted sound signals or noises [2], [3], [4], [5].

This study designed a digital filter that fits within the coconut age classification system to minimize noises in the acoustic frequency sound produced by coconut tapping. The filters used covered digital bandpass with Blackman FIR type and Elliptic IIR type, of which both filter types were compared between one another. The variables investigated involved filter length and order. Filter testing was conducted by comparing the frequency responses of the two filters using MATLAB software. Filters with a frequency response that contained less noises would be selected as the best filter used to assist classify coconut ages.

2. Reviews of Literatures

2.1. Coconut Ages

In determining the coconut ages, coconut sellers usually do knocking or tapping on the surface of the fruit and rely on their instincts to determine the age categories. This is evidenced from previous studies that there were distinguishing elements in the form of acoustic frequency, weight, and volume of coconut water depending on the ages of the fruit. In their research, the researchers conducted a series of experiments in the form of weighing several coconuts and recording tap sounds on the surface of the coconut fruit. The Spectra PLUS-DT software was employed to analyze and find out the frequency values of the sound after identification so that the maturity level of young coconut could be weighted of 3.7 ± 0.7 kg with an average frequency of 79 ± 14 Hz. The medium ones had a weight of 3.2 ± 0.3 kg with a frequency of 107 ± 10 Hz, while the old coconut had a weight of 1.4 ± 0.2 kg with a frequency of 150 ± 15 Hz. The results occurred due to differences in water volume and thickness of coconut fruit [1].

2.2. Digital Filter

The types of frequency filters for digital signals used are almost similar to analog signals such as lowpass, bandpass, highpass, and bandstop [6], [8]. FIR filter is a type of digital filter whose filter length is limited, in other words, the filter length is determined by a mathematical calculation approach. The FIR filter types tend to be stable and have linear phase responses [7], [8]. The equations of input, output, and filter transfer functions are formulated as follows [7].

\[ y[n] = \sum_{k=0}^{N-1} h[k] x[n-k] \] (1)
\[ H[z] = \sum_{k=0}^{N-1} h[k] z^{-k} \] (2)

Notes:

\[ y[n] \] : Output filter
\[ h[k] \] : FIR filter impulse response coefficients
\[ x[n] \] : The digital input that will enter the filter
\[ k \] : Variables in arrays that show k-filter coefficients with k = 0,1,2,3 ... N-1
\[ n \] : Variables that show the n\textsuperscript{th} output and input
\[ N \] : Filter length
\[ H[z] \] : Filter system transfer function from the result of transformation h [n].

The equation used in finding the bandpass filter coefficients with the Blackman type using windowing method drawn as follows:

\[ h[n] = h_{k}[n] \] (3)
where $h[n]$ is the filter coefficient with $n = -(N-1/2) - (N-1)$, $hD[n]$ is the ideal filter impulse response function, and $w[n]$ is a window filter function.

$$hD[n] = 2f_d \left( \frac{\sin \left( \frac{n\pi}{D/2} \right)}{n\pi/2} \right) - 2f_1 \left( \frac{\sin \left( \frac{n\pi}{D/2} \right)}{n\pi/2} \right)$$

with $\omega=2\pi f$ if $n\neq0$, and if $n=0$ so the following formula applied:

$$hD[n] = 2(f_d - f_1)$$

The function of the Blackman FIR window filter is formulated in the following equation:

$$w[n] = 0.42 + 0.5 + 0.08 \cos \left( \frac{2\pi n}{N-1} \right)$$

With

$$N > \frac{5.5}{\Delta f}$$

(7)

$$f_L = \frac{f_c}{f_T}$$

(8)

$$\Delta f = \frac{f_{bt}}{f_{c}^2}$$

(9)

$$f_L^{'s} = f_L + \frac{\Delta f}{2}$$

(10)

with $N$ is the filter length coefficient, $f_c$ is the normalization value of the cutoff frequency, $f_p$ is the passband limit frequency, $F_T$ is the digital signal sampling frequency, $f_{bt}$ is the transition width frequency, $\Delta f$ is the normalization value of the filter transition width, and $f_{c}^{n}$ is a change in the normalization value of the cutoff frequency.

In general, IIR filters could be modeled with the following equation [7], [9].

$$y[n] = \sum_{k=0}^{N} h[k]x[n-k]$$

(11)

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

(12)

$$H[z] = \frac{\sum_{k=0}^{N} b_k z^{-k}}{1 + \sum_{k=1}^{M} a_k z^{-k}}$$

(13)

which can be factored as,

$$H[z] = \frac{N(z-z_0)(z-z_2)\cdots(z-z_{2k})}{(z-p_1)(z-p_2)\cdots(z-p_{2M})}$$

(15)

3. Methodology

In making a digital filter a series of tests was conducted to produce a good filter signed with a frequency response form on a stable and accurate system [9]. Experiments of making digital filters were performed by comparing the results of the digital signal frequency response results from the designs that had been made [10], [11]. The first filter used Blackman FIR digital filter and the second type of Elliptic IIR. The designed filter specifications had a passband frequency between 60-300 Hz with a 50 and 320 Hz stopband frequency because the conventional recording devices had a frequency range of 65 Hz - 165 Hz, stopband attenuation of 40 dB, and passband ripple of 0.1 dB [1]. Filters used as a design filter to process digital signals from coconut fruit tapping later were the one that had the best frequency response system values and a high efficiency level. [12], [13], [14].

4. Result and Discussion

4.1. Digital Filter Testing

In designing a digital filter, the values of its constituent variables were carried out so that they can later be used in system programs [15]. The filter was designed in the form of two filters namely Blackman type digital bandpass filter and Elliptic IIR type. The variable investigated in the form of filter length, and order, which were revealed by utilizing filter equations described following on the basis of theory [9], [10], [11]. Whereas, the filter testing was conducted by comparing the two filters based on the goodness of the frequency response created from the graphic using MATLAB software.
as an aid for interfaces and a note for the filter efficiency by looking at the filter length and the number of coefficients created from the results using the equation [16].

The process of finding the constituent variables could be drawn as follows:

Known from the specifications, the filter had:

\[
\begin{align*}
F_{p1} &= 60 \text{ Hz}, \quad F_{p2} = 300 \text{ Hz}, \\
F_{s1} &= 50 \text{ Hz}, \quad F_{s2} = 320 \text{ Hz}, \\
A_s &= 40 \text{ dB}, \quad A_p = 0.1 \text{ dB}.
\end{align*}
\]

The first step was to find the value of the sampling frequency where the frequency of coconuts from young to old had a frequency of 65-1665 Hz so that the specifications were specified in the design and had a maximum frequency of 350 Hz. So, the value of the sampling frequency of the sound signals of coconut fruit and digital filters to meet the engineer version of Nyquist criteria was equal to:

\[
F_T \geq 2.2 \times f_{\text{max}}
\]

\[
F_T \geq 2.2 \times 350 = 700 \text{ Hz}
\]

So, it was decided that the sampling frequency was 1000 Hz.

**Blackman FIR Filter:**

Cut-off normalization frequency:

\[
\begin{align*}
\frac{f_{c1}}{F_T} &= \frac{60}{1000} = 0.06, \quad \frac{f_{c2}}{F_T} = \frac{300}{1000} = 0.3
\end{align*}
\]

Filter length:

\[
N > \frac{5.5}{\Delta f} = 5.5 \times 0.015 = 366.66 \approx 367
\]

If \( N \) was an even number then \( N = N + 1 \). If it was an odd number then \( N = N \). So, \( N = 367 \). The filter length was 367 so the number of causal filter coefficients was defined at \( 0 \leq n \leq N-1 \) or \( 0 \leq n \leq 366 \). Whereas for undefined non-causal filters started at \( -N-1 \leq n \leq N-1 \) or \( -183 \leq n \leq 183 \). So that the Blackman FIR bandpass filter coefficients were described as follows, of where the calculation below was the first 10 values of 367 filter coefficient data "\( h[n] \)".

\[
\begin{align*}
h_{e}[0] &= 0.51, \quad h[1] = 0.1946, \quad h_{e}[2] = -0.2028, \quad h_{e}[3] = 0.1383, \quad h[3] = -0.1382 \\
h_{e}[4] &= 0.0019, \quad h[5] = -0.0781, \quad h_{e}[6] = -0.0926, \quad h[7] = 0.0035, \quad h[8] = -0.0092, \quad h[9] = -0.0408
\end{align*}
\]

4.2. **Elliptic IIR Filter**

\[
n \geq \left[ \frac{1}{1 - \frac{1}{\sqrt{1 - \frac{4}{N}}} \right] = 6.1189 \quad n \approx 7,
\]

So, according to the equation above the Elliptic digital bandpass IIR filter used was a 7th order type filter because \( n = 7 \) [17].

The results of the equation \( y[n] \) above was an Elliptic IIR bandpass digital filter output equation that met the requirements. Where, the filter coefficients were multiplier variables of input \( x[k] \) and output \( y[nk] \) so that it could be assumed that the multiplier variable \( x[nk] \) was \( bk \) (numerator) and the multiplier variable \( y[nk] \) was \( ak \) (denominator) with \( k = 0,1,2, \ldots, 14 \) for \( bk \) and \( k = 1,2,3, \ldots, 14 \) for \( ak \) [17], [19].

Moreover, the last was to compare the system frequency responses by entering filter coefficient values in numerator and denominators array variables, then used as an equation of the function transfer value \( z \) with program commands in MATLAB software [19], [20]. Then, the frequency response was graphed with the plot command in the software. As a note, for the FIR filter the denominator value was 1 and the numerator was the coefficient value \( h[n] \), while for the filter IIR the numerator was \( ak \) and the denominator was \( bk \).
Fig. 1. Frequency response of Blackman digital FIR causal bandpass filter with a defined coefficient at $0 \leq k \leq N - 1$ (Source: Simulation)

Fig. 2. The frequency response of the Blackman digital FIR bandpass filter with a defined coefficient at $-(N - 1)/2 \leq k \leq (N - 1)/2$ (Source: Simulation)

Fig. 3. Response of 7th order Elliptic IIR digital bandpass filter frequency (Source: Simulation)

From the simulation results, it was decided that the filter used was Elliptic IIR bandpass filter. This filter was selected because it had a better frequency response than the Blackman FIR did [18], [20]. In addition, there were fewer order that made the system process more efficient [20]. Moreover, the next study needed to be carried out regarding the implementation and direct testing of the IIR filter design results in the processing of tapping sound signals of the coconut fruit.

5. Conclusion
The simulation results show that the Elliptic IIR frequency is better than the Blackman FIR digital causal filter frequency response due to less order and noise generated. Therefore, this study recommends to use Elliptic FIR filter type to help classify coconut ages, so that the conventional ways could be left. This idea is indeed relevant to prepare the effective working performance in industrial era 4.0
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