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Performance of IIR and FIR Filters using MATLAB Simulation

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Abstract. Digital filters are similar to analogue filters in that they can remove unwanted noise from the original signal. Digital filters are mainly divided into two types based on the impulse response of the filter. They are Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters. This paper seeks to acquire a thorough understanding of the simulation between IIR and FIR filters. FIR filters are so named because the response is fixed to zero at specified intervals, unlike the IIR filter, which operates with indefinite periods. As filters can be used in different applications, they can be used to condition a time domain signal through attenuating undesirable frequency content.

Keywords: Finite Impulse Response, Infinite Impulse Response, Digital filters, Analogue filters.

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1. Introduction

Digital filters are similar to analogue filters in that they can remove the unwanted noise from the original signal. The behavior of the linear digital filters can be represented mathematically verbatim as [1]:

$$y(n) = \sum_{k=0}^{N-1} h(k) - x(n-k) \tag{1}$$

Where *h(k), k=0,1,....N-1* are the filter coefficients. x(n) is the filter input, and y(n) is the filter output. This process is equivalent to the convolution of the input signal with the impulse response of the filter. Digital filters can be classified based on their function [1-2], so the filter might be used as low pass filter, high pass filter, band-pass filter, or band-stop filter [2-3]. Filters can be used in different applications. So, they can be used to condition a time domain signal by attenuating undesirable frequency content. They can also be used as anti-Aliasing Filters to remove signal content that cannot be properly digitised before Analog-to-Digital conversion. Another application is to use it as a Noise Removal, to remove unwanted high frequency noise from a signal [4-5].

Digital filters are mainly divided into two types [6]: FIR and IIR filters, based on the impulse response of the filter. They can also be categorised based on their function [1-7]: low pass, high pass, band pass or bandstop filters. FIR and IIR can do the job for the four functions but with different configurations. A general structure of FIR filter is depicted in Figure 1.

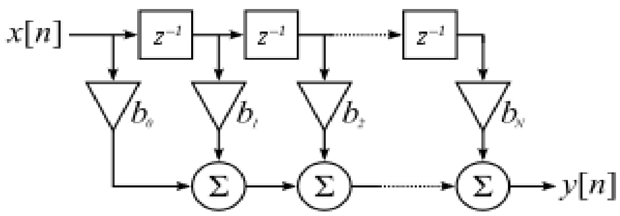

Fig. 1. Structure of FIR filter [3]

Another type is the IIR filter which has an infinite response to impulse signal. This feature is due to the feedback process in IIR. A general structure of IIR filter is shown in Figure 2 [3].

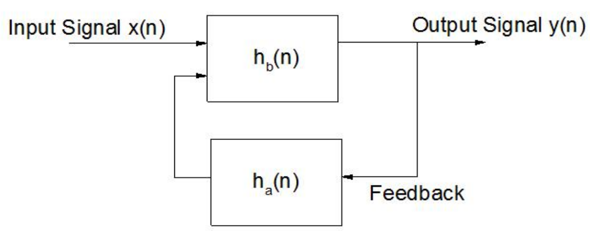

Fig. 2. Structure of IIR filter [3].

Although FIR can theoretically do the filter function compared to IIR [8], it is constrained to the number of sections of the filter and the filter order [9]. As such, if both filters are chosen for the same requirement [10] [11], it is expected to get IIR with lower order, which will be investigated in this paper [12]. Thus, this project presents the design of IIR and FIR filters for the same requirement. Finally, both are simulated in MATLAB [13] [14] and compared in terms of response and order.

The main purpose of this paper is to acquire a thorough understanding of the differences between IIR and FIR filters, using simulation. Therefore, the objectives of this paper are to:

- Design and simulate bandpass FIR and IIR filter with minimum order.
- Present and analyse the response using simulation in MATLAB.

- Compare and confirm the theory about IIR and FIR in terms of filter order and filter response.

2. Related Work

In this section, previous studies on FIR and IIR filters are examined for their advantages and disadvantages.

A. FIR Filter: Finite impulse response (FIR) filters are of limited precision at low frequencies, are generally complex and take longer convergence. Table 1 indicates the most important studies on this topic.

Table 1. Previous Study for FIR Filters

No	Name	Author	IIR	FIR
[7]	Digital IIR Filter Design Using Differential Evolution Algorithm	Ulrich Heute	√	√
[15]	Design of Doubly-Complementary IIR Digital Filters, using a Single Complex Allpass filter	Vaidyanathan,' P. Regalia: And S. K. Mitra	√	
[16]	Denoising of ECG Signals Using FIR & IIRFilter: A Performance Analysis	Saxena, MS Chhavi Upadhyaya, Vivek Gupta, Hemant Kumar	√	√

Ulrich Heute et al. [7] studied the FIR filter and the IIR filter and found that the FIR filter depended on the current and previous values of the input signal, while the IIR filter depended not only on the input but also on the output of one or more of the previous values. Vaidyanathan et al. [15] indicated that a wide class of pairs in IIR had a real coefficient and a double complement. The resulting implementation of this project has significant structural losses**.** Saxena et al. [16] studied FIR and IIR filters to remove high-frequency noise. Whereas the FIR result was better than the IIR in de-noise, the standard deviation of the IIR filter is closer to the desired output.

B. IIR Filters: Infinite impulse response (IIR) filters are linearly dependent on a specified number of outputs and inputs. Table 2 indicates the most important studies on this topic.

Table 2. Previous Study for IIR Filters

NO	NAME	AUTHOR	IIR	FIR
[9]	Differential Evolution Design of an IIR-Filter with Requirements for Magnitude and Group Delay	Rainer Storn	√	
[17]	A Weighted Least Squares Algorithm for QuasiEquiripple FIR and IIR Digital Filter Design	Yong Ching Lim, JuHong Lee, RongHuan Yang	√	√

[18]	Comparison of the Design of FIR and IIR Filters for a Given Specification and Removal of Phase Distortion from IIR Filters	Ranjushree	√	√

Rainer. [9] studied the IIR filter and also studied the response and size of the filter, where he used the general-purpose reduction of the filter to the maximum. Yong Ching et al. [17] proposed a new iterative algorithm to derive a response weighting function that works in small squares and produces a similar design. Ranjushree [18] studied the design of FIR and IIR filters, where the response of the FIR filter was linear while the IIR filter had no linear response. After applying the complex circuit, the design of FIR and IIR is left to the choice of the designer who can select the same specifications for both candidates.

3. Our Methodology

The general methodology of this project are given in sequence in the following steps:

- Collect the filter information given in the filter requirement.
- Open MATLAB software and start to write m-file code.
- Specify the filter design as required (response type, design method, frequency normalization, attenuation, etc.).
- Run MATLAB code and view the results.
- Save the response results for both IIR and FIR.
- Compare IIR and FIR in terms of response and order.

The filter requirements for this project are given in Table 3 below.

The main text starts at the top of the page and continues in a one-column format. Place an indentation for each paragraph starting from the first in all sections or subsections. There is no space between paragraphs within the text. Add an 11-point space after the text in each section or subsection.

Table 3. Filter Out Specs

Filter Spec.	Value
First stopband frequency (normalised)	0.4
First passband frequency (normalised)	0.45
Second stopband frequency (normalised)	0.55
Second passband frequency (normalised)	0.65
First stopband attenuation	40dB
Second stopband attenuation	50dB
Passband ripple attenuation	0.5dB

These specifications are applied to the filter as in Figure 3.

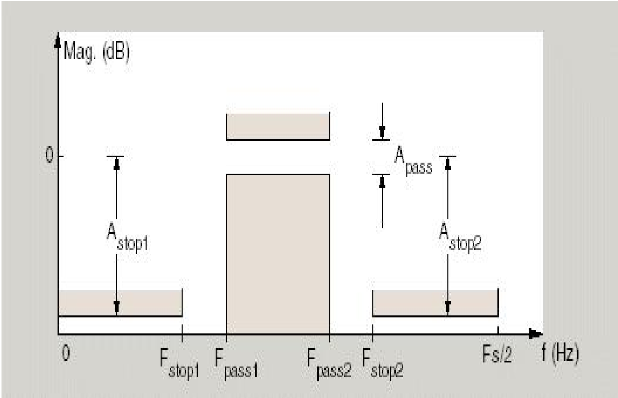

Fig. 3. Specifications of band-pass filter

4. Rustles and Analysis

Both IIR and FIR filters are designed based on the minimum order, magnitude specifications, and design method and response type.

The first step is to know the minimum order for IIR filters using the following m-file code:

```
Ws=[0.4 0.65]  % stopband frequencies
Wp=[0.45 0.55]% passband frequencies
Rp=0.5   % ripple attentuation
Rs=50    % stopband attentuation
[n,Wp] = ellipord(Wp,Ws,Rp,Rs)  % find the minimum order n
```

Whereas the m-file code for the minimum order of FIR filter is given as:

```
Fst1 = 0.4;             % 1: (Stopband)
Fpa1 = 0.45;             % 1: (Passband)
Fpa2 = 0.55;             % 2:  (Passband)
Fst2 = 0.65;            % 2: (Stopband)
Dst1 = 0.01;             % 1:  (Stopband)
Dpa = 0.028774368332;   % Passband Ripple
Dst2 = 0.0031622776602; % 2: (Stopband Attenuation)
dens   = 20;             % (Density Factor)
 [N, Fo, Ao, W] = firpmord([Fst1 Fpa1 Fpa2 Fst2], [0 1 0],
 [Dst1 Dpa Dst2]);.
```

It is found that the FIR filter can be designed as a minimum order of 65 while the IIR can be built for same specifications with 10. The magnitude response, group delay and impulse response are presented in the next sections.

A. ***Magnitude Response of IIR and FIR Filter:*** Figure 4 shows the frequency responses of a 10-order elliptic IIR filter with 65 equiripple FIR filter. It is noticed that these two filters have comparable magnitude responses. However, the IIR filter response is sharper than the FIR filter response. The knee of the FIR filter changes in the transition region along the frequency range. The identical response requires excessive number of taps for the FIR filter to be as identical as the IIR response.

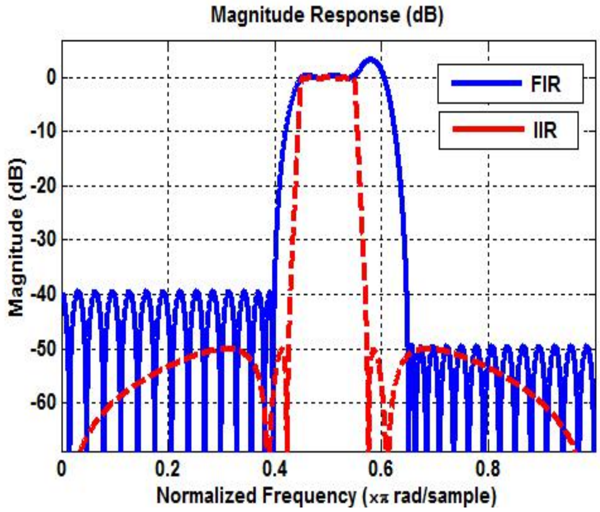

Fig. 4. Magnitude response of FIR and IIR filters in dB scale

The magnitude is also displayed in linear scale as shown in Figure 5. It is clear that IIR fit a good response while FIR shows an overshoot and a slow transition from pass status to stop status.

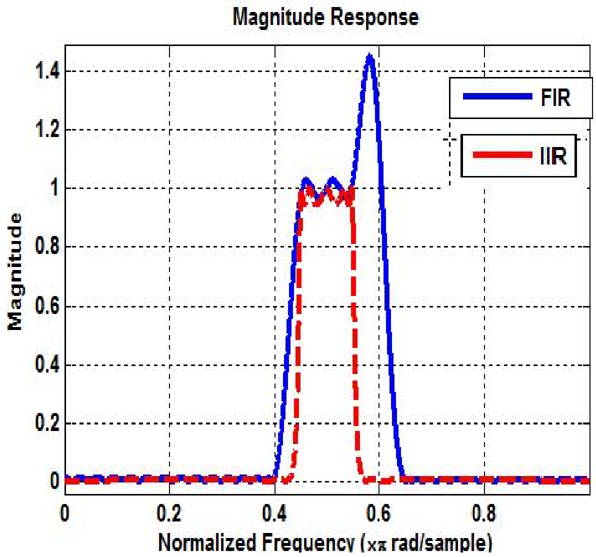

Fig. 5. Magnitude response of FIR and IIR filters

B. Group Delay Response of IIR and FIR Filter: The FIR filter has a constant group delay of 39 and the IIR filter has a lower group delay but non-stable. The group delay for IIR has a sharp increase at 0.45 and a sudden decline to 0.5 as shown in Figure 6. This group delay has a direct effect on the response of the filter to step signal. Meanwhile, the constant group delay in FIR labels the FIR response as slow but stable.

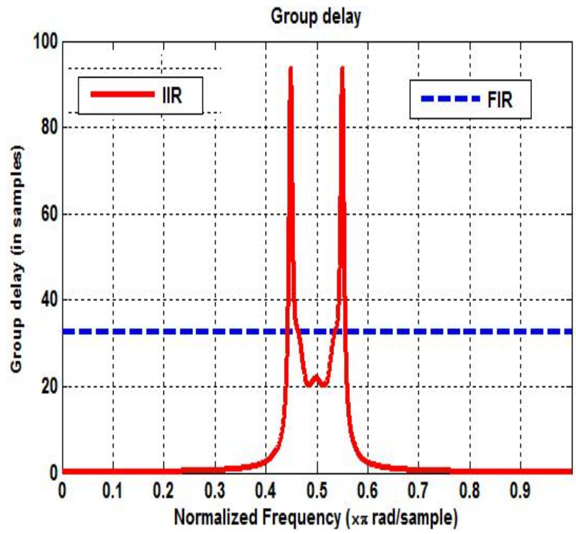

Fig. 6. Group delay response of FIR and IIR filters

C. Impulse Response of IIR and FIR Filter: The FIR has finite duration as a repose for impulse signal. However, this is not the case for the IIR filter where it has infinite duration for impulse response as shown in Figure 7 and Figure 8.

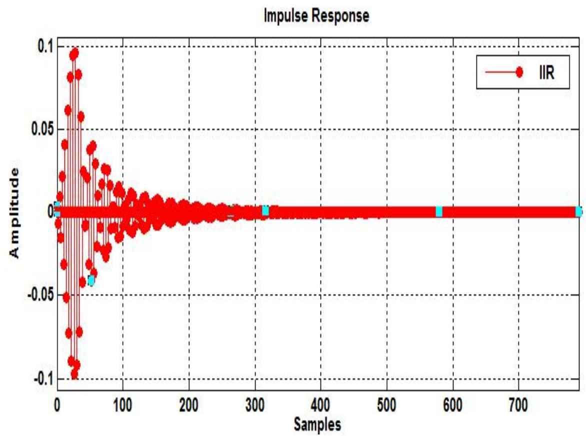

Fig. 7. Impulse response of IIR filters

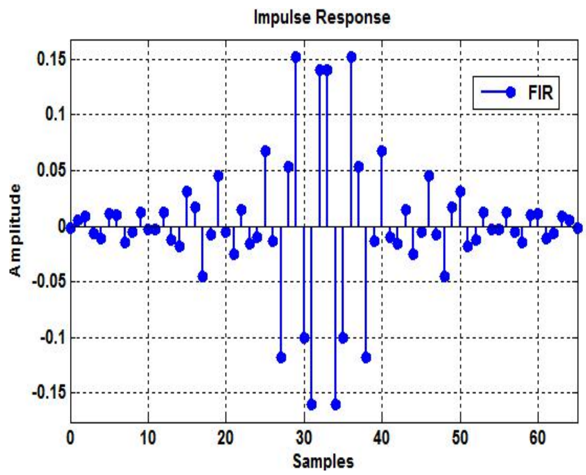

Fig. 8. Impulse response of FIR filters

D. Step Response of IIR and FIR Filter: The group delay and impulse response are the main differences between FIR and IIR filters. The FIR filter has a finite response while the IIR filter has an infinite long impulse response.

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Further, the FIR filter has a slow response to step signal since it appears at the middle as in Figure 9 while IIR has a quick response as shown in Figure 10.

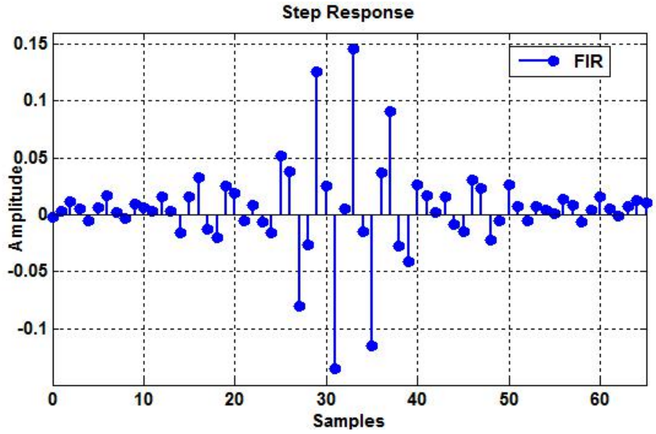


Fig. 9. Impulse response of FIR filters

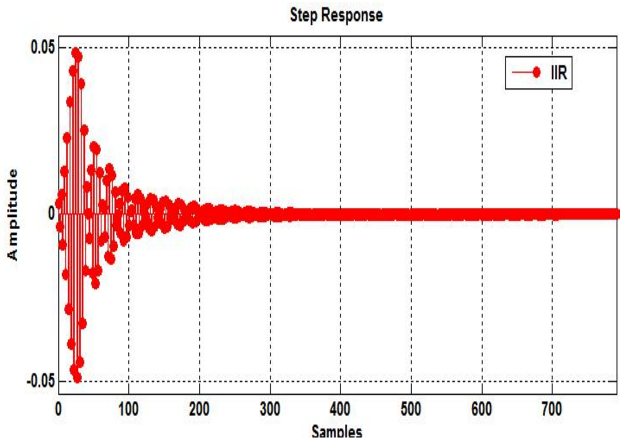
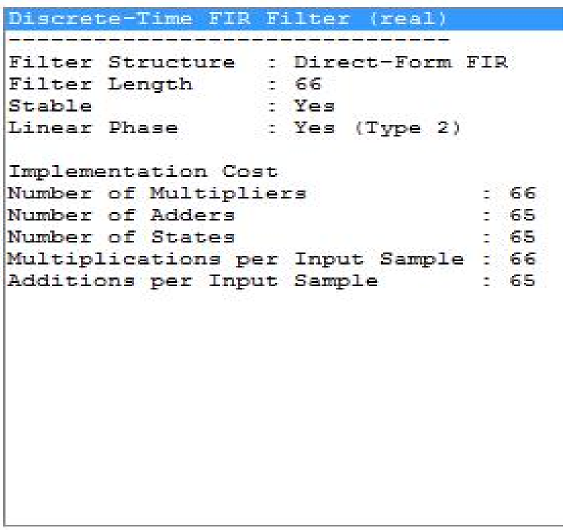


Fig. 10. Impulse response of IIR filters

The developed FIR filter has 66-filter order with 66 multiplier and 65 adders as shown in Figure 11. The same results can be obtained in IIR with only 10-filter order, 26 multiplier, and 19 adders as shown in Figure 12.



```
Discrete-Time FIR Filter (real)
-------------------------------
Filter Structure  : Direct-Form FIR
Filter Length     : 66
Stable            : Yes
Linear Phase      : Yes (Type 2)

Implementation Cost
Number of Multipliers            : 66
Number of Adders                 : 65
Number of States                 : 65
Multiplications per Input Sample : 66
Additions per Input Sample       : 65
```

Fig. 11. Implementation cost of FIR filters

```
Measurements
Sample Rate              : N/A (normalized frequency)
First Stopband Edge      : 0.4
First 6-dB Point         : 0.44637
First 3-dB Point         : 0.44793
First Passband Edge      : 0.45
Second Passband Edge     : 0.55
Second 3-dB Point        : 0.55207
Second 6-dB Point        : 0.55363
Second Stopband Edge     : 0.65
First Stopband Atten.    : 50 dB
Passband Ripple          : 0.5 dB
Second Stopband Atten.   : 50 dB
First Transition Width   : 0.05
Second Transition Width  : 0.1

Implementation Cost
Number of Multipliers             : 26
Number of Adders                  : 19
Number of States                  : 10
Multiplications per Input Sample  : 26
Additions per Input Sample        : 19
```

Fig. 12. Implementation cost of IIR filters

The counterpart m-file code is also shown below

```
function Hd = IIR_Ellip
Fst1 = 0.4;  % 1: (Stopband)
Fpa1 = 0.45; % 1: (Passband)
Fpa2 = 0.55;  % 2: (Passband)
Fst2 = 0.65;  % 2: (Stopband)
Ast1 = 40;    % 1: (Stopband Attenuation)
Apa = 0.5;   % (Passband Ripple)
Ast2 = 50;    % 2: (Stopband Attenuation)
h = fdesign.bandpass('fst1,fp1,fp2,fst2,ast1,ap,ast2', Fstop1, Fpa1, ...    Fpa2, Fst2, Ast1, Apa, Ast2);
Hd = design(h, 'ellip', ...    'MatchExactly', 'both', ...    'SOSScaleNorm', 'Linf');
fvtool(Hd)
Fsto1 = 0.4;            % 1: (Stopband)
Fpa1 = 0.45;            % 1: (Passband)
Fpa2 = 0.55;            % 2: (Passband)
Fst2 = 0.65;            % 2: (Stopband)
Dst1 = 0.01;            % 1: (Stopband Attenuation)
Dpa = 0.028774368332;   % (Passband Ripple)
Dst2 = 0.0031622776602;  % 2: (Stopband Attenuation)
dens   = 20;            % Density Factor
 [N, Fo, Ao, W] = firpmord([Fst1 Fpa1 Fpa2 Fst2], [0 1 0], ...    [Dst1 Dpa Dst2]);
b  = firpm(N, Fo, Ao, W, {dens});
Hd = dsp.FIRFilter( ...
   'Numerator', b);
fvtool(Hd).
```

5. Comparison Between FIR and IIR

Table 4 illustrates a detailed comparison between FIR and IIR filters, where the comparison is made to the minimum order, response, and stability.

Table 4. Comparison Summary Between IIR and FIR Filters

Filter	FIR	IIR
Minimum Order	65	10
Response	Finite impulse response Slow transition from pass to stop Constant group delay slow due to higher group delay Implementation cost is high	Infinite impulse response due to the feedback Have a sharper knee on the transition to pass and stop bands. Lower group delay but unstable Fast due to lower delay in signal propagation Fast as in step response Implementation cost is lower than IIR
Stability	Fast but non stable	Slow but stable

6. Conclusion

This paper has simulated and verified the performance of IIR and FIR filters using simulation in MATLAB. FIR Bandpass filter and IIR bandpass filters are simulated. The results that are presented in this paper indicate that although IIR has a lower cost, it is unstable. The FIR filter on the other hand, is slow but stable. IIR filter also shows sharp knee with much lower number of hardware requirements. Thus, it is obviously beneficial to choose a suitable filter based on the requirements of each application.

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مجلة كلية العراق الجامعة للهندسة والعلوم التطبيقية

اداء مرشحات IIR و FIR بأستخدام محاكاة الماتلاب

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المخلص. تتشابه المرشحات الرقمية مع المرشحات التناظرية من حيث قدرتها على إزالة الضوضاء غير المرغوب فيها من الإشارة الأصلية .تنقسم المرشحات الرقمية بشكل أساسي إلى نوعين بناءً على الاستجابة النبضية للمرشح .مرشحات استجابة النبضة النهائية FIR واستجابة النبضية اللانهائية IIR . تهدف هذه الورقة إلى اكتساب فهم شامل للمحاكاة بين مرشحات FIR و IIR . سميت مرشحات FIR بهذا الاسم لأن الاستجابة ثابتة على صفر في فترات زمنية محددة ، على عكس مرشح IIR ، الذي يعمل بفترات غير محددة . بما أنه يمكن استخدام المرشحات في تطبيقات مختلفة ، فيمكن استخدامها لتكييف إشارة مجال الوقت من خلال تخفيف محتوى التردد غير المرغوب فيه.