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Design of an FIR Digital Filter for a Mobile Robot Navigation Sensors

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Abstract: *Mobile robot navigation involves accurately ascertaining the robot's position and planning and following a route to a target. Successful mobile robot navigation requires precision navigation sensors such as accelerometers, gyroscopes, magnetometers, and GPS. However, the great challenge in such applications is limiting the signal chain noise. However, noise in the signal great impedes such applications. Thus, this paper presented an FIR digital filter design to achieve optimum performance in mobile robot navigation. The FIR window method for digital filter design is fast, convenient, and robust but generally suboptimal. It utilizes the convolution theorem for Fourier transforms. The technique consists of simply windowing a theoretically ideal filter impulse response by some suitably chosen window function. The Hanning window function in MATLAB was used in the filter design. The filter was implemented using a discrete signal, while the discrete-time Fourier transform was employed to calculate the filter's frequency response.*

Keywords: Mobile robot, navigation, noise, FIR filter, window function, MATLAB.

1. Introduction

Mobile robots require numerous sensors to navigate an obstacle-ridden environment successfully. Robot navigation involves accurately ascertaining the robot's position and planning and following a route to a target. The three main types of navigation are celestial, GPS, and map and compass. The fundamental robot navigation problems are localization, which denotes the robot's ability to establish its position and orientation within the frame of reference. Path planning is effectively an extension of localization. It requires the determination of the robot's current position and a position of a goal location, both within the same frame of reference or coordinates [1]. All these require a clean signal from the onboard position, velocity, acceleration sensors. Obtaining a clean signal from a sensor requires removing the unwanted signal in the form of noise using an appropriate filter. A filter is a system that removes unwanted components or features from a signal [2]. In signal processing, filters can be employed to have two uses, namely signal separation and signal restoration. Signal separation is needed when a signal has been contaminated with interference, noise, or other signals. Signal restoration is used to recover a distorted signal [3]. Filters could be analogue or digital. An analogue filter is an electronic circuit operating on continuous-time analogue signals. In contrast, a digital filter performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. Analogue filters are cheap, fast, and have a broad dynamic range in both amplitude and frequency. Digital filters, in comparison, are vastly superior in the level of performance that can be achieved. The convolving and recursive methods are the most typical ways of implementing digital filters. Recursive filters are also called Infinite Impulse Response (IIR) filters, and filters implemented by convolution are called Finite Impulse Response (FIR) filters. FIR filters are better suited for robotic applications.

2. Statement of the Problem

Successful mobile robot navigation requires precision navigation sensors such as accelerometers, gyroscopes, magnetometers, and GPS. However, the great challenge in such applications is limiting the signal chain noise. Thus, this paper presents an FIR digital filter design to achieve optimum performance in mobile robot navigation.

3. Aim and Objectives

This study aims to design an FIR digital filter for a mobile robot navigation system using the window technique. The specific objective of the study is to design an FIR filter having the following specifications:

- Sampling Frequency: 300 Mhz.
- Filter Type: Low-pass.
- Cut-off Frequency: 6.0 MHz.
- Stopband attenuation @ 40 dB at all frequencies above 75 MHz.

4. Literature review

A digital filter is a mathematical algorithm implemented in hardware or software that operates on a digital input signal to produce a digital output signal to achieve a filtering objective. Digital filters work on digitized analogue signals or numbers, representing some variable stored in computer memory. They are used in applications like data compression, biomedical signal processing, speech and image processing, data transmission, digital audio, telephone echo cancellation, and robotic applications. Some advantages of digital filters over analogue filters include linearity phase response. Indeed, its performance does not vary with environmental changes such as thermal variations. Its frequency response can be automatically adjusted if implemented using a programmable processor and its ability to be very low frequencies. The two major classifications of digital filters are FIR and IRR. IIR filters are typically designed based on continuous-time transfer functions. They differ from FIR filters in that they incorporate feedback elements in the circuit. The transfer function of an IIR filter contains both poles and zeros. Its impulse response never decays to zero but get close to zero. In contrast, the FIR filters response to any finite length input is of finite duration because it settles to zero in finite time. They can be discrete-time or continuous-time, and digital or analogue.

The literature has documented several studies that reported FIR filter implementation. For instance, [4] provides a comprehensive review of the various evolutionary optimization-based techniques for FIR filter design. In addition to the review, the reported methods have been analyzed by implementing them on a common platform and comparing them in terms of their effectiveness in meeting the desired specifications. Some well-recognized optimization algorithms based on the ripples present in the passband and stopband, along with the attenuation provided by the stopband, were compared in [5]. More so, the authors in [6] present a detailed review of the basic design approaches applicable for the synthesis of hardware efficient finite duration impulse response (FIR) filters. Both the traditional and heuristic search algorithms have been incorporated and arranged correctly in the review. A linear phase FIR filter was designed using the nature-inspired optimization algorithm known as Cuckoo search. The study also presented a comparative study of Cuckoo search, particle swarm optimization and artificial bee colony nature-inspired optimization methods in the field of linear phase FIR filter design [7]. A new recursive algorithm for the impulse response coefficients of an FIR lowpass filter was developed in [8]. The algorithm was obtained from the differential equation for the amplitude response of a lowpass filter. While the original filter exhibits maximally flat frequency response, the abridging of the impulse response provides a frequency response compared with those obtained by other design methods. The Kaiser window design technique of the bandpass FIR filter was presented in [9]—the design comprised of both software and hardware implementation. The authors in [10] focused on three FIR filter design methods, namely the frequency sampling method, window method, and optimization method to design an FIR filter for a communications system, including transmissions equipment, relay stations, tributary stations, and other data terminal equipment that provides a noise-free signal to security agencies in the event of a disaster.

Similarly, in [11], MATLAB's window function, frequency sampling, and convex optimization methods were employed to design the FIR filter. The experimental results showed that the FIR filters designed were very effective. Design using Kaiser, Rectangular and Tukey window methods with the aid of FDATOOL in MATLAB. From the comparative analysis, Rectangular is the best for the proposed filter design based on the magnitude responses of the three windows.

5. FIR Window Design Method

The FIR window method for digital filter design is fast, convenient, and robust but generally suboptimal. It utilizes the convolution theorem for Fourier transforms. The technique simply windows a theoretically ideal filter impulse response HD(f) by some suitably chosen window function. The following details out the steps for the FIR window design method:

a. Determine the appropriate window function to use.
b. Determine the filter length.
c. Find the 'ideal' impulse response for the filter type.
d. Apply appropriate window function 5. Index, the resulting impulse response, to make filter coefficient set.

5.1. Filter Specification

The following defines the filter specification:

a. Sampling Frequency: 300 Mhz.
b. Filter Type: Low-pass.
c. Cut-off Frequency: 6.0 MHz.
d. Stopband attenuation@ 40 dB at all frequencies above 75 MHz.

5.2. Implementation Steps

The following detailed the implementation steps of the FIR filter using the window method.

Step 1. Determine the appropriate window function to use: The window function that provides a stopband attenuation closer to 40 dB is the Hanning method with 44 dB attenuation.

$$\Delta f = \frac{3.1}{N} \tag{1}$$

Step 2. Determine filter length: The filter length can be calculated from the specified normalized Transition Width as follows-

$$\Delta f = \frac{75}{300} = 0.25 \tag{2}$$

Rearranging and rounding up to the nearest integer gives the value N to be:

$$N = \frac{3.1}{\Delta f} = \frac{3.1}{0.25} = 13 \tag{3}$$

The discrete ideal impulse response for the filter is given by:

$$H_D(n) = 2f_c \frac{\sin(n\omega_c)}{n\omega_c} \tag{4}$$

That is n = - 6……0………6

Where f_c is the normalized cut-off frequency given by:

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$$f_c = \frac{45}{300} = 0.15 \quad (5)$$

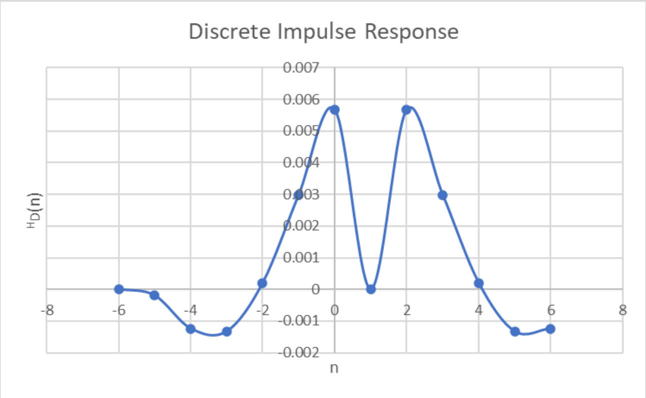


Fig. 1: Ideal lowpass filter discrete impulse response.

The Hanning window function over the same interval is given by:

$$\omega_n = 0.5 + 0.5cos\frac{2\pi n}{N-1} \quad (6)$$

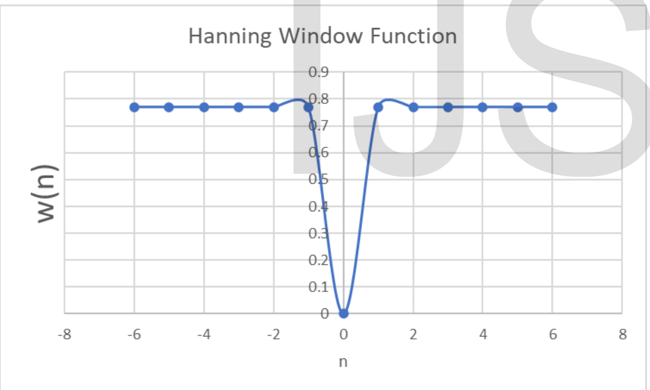


Fig. 2: The Hanning window function.

The windowed discrete impulse response is given by:

$$h(n) = H_D(n) * \omega_n \quad (7)$$

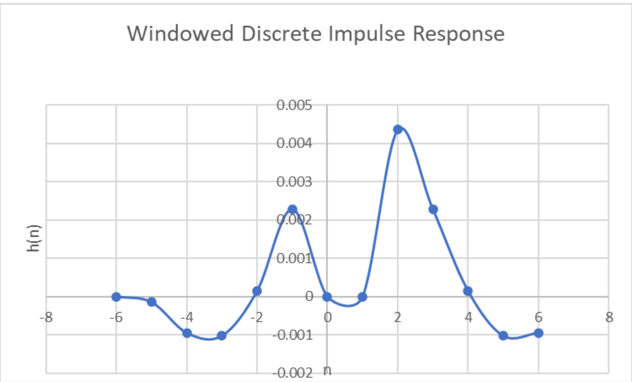


Fig. 3: The windowed discrete impulse response.

However, to get a set of coefficients h_k where k = 0…N-1, we need to shift the index of n by (N-1)/2 to have h_k.

Table 1: The set of filter coefficients h_k

k	Hk
0	-6.5
1	-5.5
2	-4.5
3	-3.5
4	-2.5
5	-1.5
6	-0.5
7	0.5
8	1.5
9	2.5
10	3.5
11	4.5
12	5.5

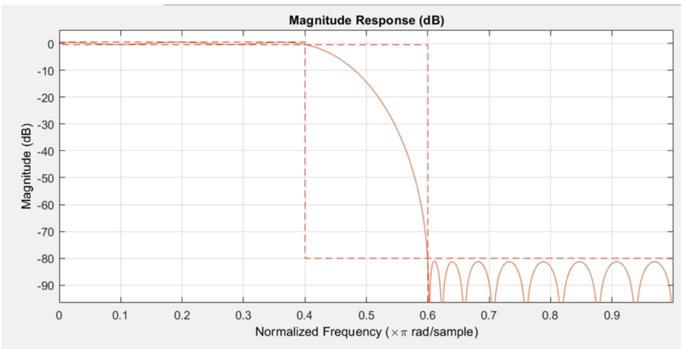
The implementation of the filter with a discrete signal is given by:

$$y_n = \sum_{k=0}^{N-1} h_k x(n-k) \quad (7)$$

The discrete time Fourier transform is used to calculate the frequency response as follows:

$$H(f) = \sum_{k=0}^{N-1} h_k e^{-i2\pi fKT} \quad (8)$$

The plot of the magnitude response is as follows:



6. Conclusion

he noise-free signal from navigation sensors onboard mobile robots such as accelerometers, gyroscopes, magnetometers, and GPS are critical requirements for successful navigation. Robot navigation involves accurately ascertaining the robot's position and planning and following a route to a target. However, noise in the signal great impedes such applications. Thus, this paper presented an FIR digital filter design to achieve optimum performance in mobile robot navigation. The FIR window method for digital filter design is fast, convenient, and robust but generally suboptimal. It utilizes the convolution theorem for Fourier transforms. The technique consists of simply windowing a theoretically ideal filter impulse response by some suitably chosen window function. The Hanning window function in MATLAB was used in the filter design. The filter was implemented using a discrete signal, while the discrete-time Fourier transform was employed to calculate the filter's frequency response.

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