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COMPUTATIONAL COMPLEXITY OF FOUR-BAND WAVELET PACKET DECOMPOSITION IN MOTOR FAULT DIAGNOSTICS

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ABSTRACT
Motor current signature analysis (MCSA) provides continuous and non-intrusive monitoring of motor drives in critical industrial applications. Fourier based techniques are used widely in processing of stator current in such condition monitoring systems, but these techniques have a shortcoming in processing the stator current under varying load conditions. Recently, wavelet packet decomposition (WPD) has become popular in the analysis of non-stationary signals. WPD approach gives better results at the expense of much higher computational complexity limiting its use in zero-blind metering applications where much of the bandwidth is allocated to other metering and networking tasks. Here, the use of four-channel FIR filter banks is proposed to provide fast decomposition algorithms at a lower computational complexity.
Keywords: MCSA, Wavelet Decomposition, Four-Channel Filtering

1. INTRODUCTION
MCSA provides a non-intrusive way to continuously monitor the condition of an induction motor. Both Fourier [1-6] and wavelet transform [7-12] based techniques are used in analysis. It is very common to use half-band FIR filters such as Beylkin, Daubechies, and Vaidyanathan in WPD. WPD has become popular in the analysis of non-stationary signals. WPD approach gives better results at the expense of much higher computational complexity limiting its use in zero-blind metering applications where much of the bandwidth is allocated to other metering and networking tasks. In this study, computational complexity of four-channel FIR filters are compared with commonly used half-band FIR filters such Beylkin, Daubechies, and Vaidyanathan in wavelet packet decomposition. The prototype FIR low pass filter is designed using traditional filter design methods. Then, band-pass and high-pass filters obtained by poly-phase implementation of the prototype filter. The proposed method provides computationally more efficient way than currently used implementation of half-band filters in MCSA without a compromise in the accuracy of motor fault detection.

2. FOUR-CHANNEL DECOMPOSITION
The use of four-channel FIR filters in motor fault diagnosis provides better computational complexity. The prototype FIR low pass filter is designed using traditional filter design methods. Then, band-pass and high-pass filters obtained by poly-phase implementation of the prototype filter. The proposed method provides computationally more efficient way than currently used implementation of half-band filters in motor fault diagnosis without a compromise in the accuracy of motor fault detection.

Multi-band signal decomposition is used widely in image and voice processing applications. Typical four-channel analysis filter bank is depicted in figure 1 where H_0 is a low-pass, H_1 and H_2 are band-pass, and H_3 is a high-pass filters respectively.

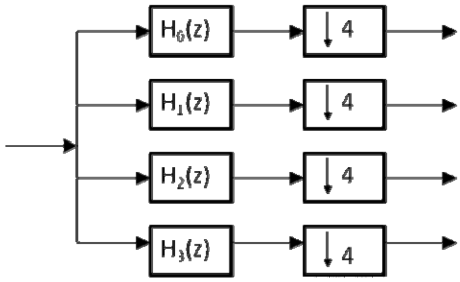

Figure 1. Four-channel analysis filter bank.

Multi-channel decomposition can result in computationally more efficient implementation if the poly-phase decomposition is used.

$$H(z) = \sum_{k=-\infty}^{\infty} h(k) z^{-k} \tag{1}$$

If we define $P_r(z)$ as

$$P_r(z) = \sum_{l=-\infty}^{\infty} h(r + lM) z^{-l} \tag{2}$$

where r=0,1,...,M-1. Then, the filter becomes

$$H(z) = \sum_{r=0}^{M-1} z^{-r} P_r(z^M) \tag{3}$$

In the case of M=2, we have special filters called half-band filters.

$$H(z) = P_0(z^2) + P_1(z^2) z^{-1} \tag{4}$$

In the case of M=3, we have special filters called three-band filters.

$$H(z) = P_0(z^3) + P_1(z^3) z^{-1} + P_2(z^3) z^{-2} \tag{5}$$

Here, we would have three filters: low-pass, band-pass, and high-pass respectively. In the case of M=4, we have special filters called four-band filters. The prototype filter H(z) given in equation 6 is made up of 4 poly-phase parts.

$$H(z) = P_0(z^4) + P_1(z^4) z^{-1} + P_2(z^4) z^{-2} + P_3(z^4) z^{-3} \tag{6}$$

The poly-phase parts of the prototype filter are then used to obtain H_0, H_1, H_2, and H_3 which are low-pass, band-pass, band-pass, and high-pass components in equations 7-10 respectively.

$$H_0(z) = P_0(z^4) + P_1(z^4) z^{-1} + P_2(z^4) z^{-2} + P_3(z^4) z^{-3} \tag{7}$$

$$H_1(z) = P_0(z^4) + jP_1(z^4) z^{-1} - P_2(z^4) z^{-2} - jP_3(z^4) z^{-3} \tag{8}$$

$$H_2(z) = P_0(z^4) - P_1(z^4) z^{-1} + P_2(z^4) z^{-2} - P_3(z^4) z^{-3} \tag{9}$$

$$H_3(z) = P_0(z^4) - jP_1(z^4) z^{-1} - P_2(z^4) z^{-2} + jP_3(z^4) z^{-3} \tag{10}$$

There are two main considerations for the filters used in multi-band decomposition: frequency selectivity and computational complexity. These two topics are discussed in the following sections.

3. FREQUENCY SELECTIVITY

The frequency selectivity of the filters used in decomposition is one of the major considerations for multi-band prototype low-pass filter designed in matlab software is depicted in figure 2. The prototype filter is designed such that its frequency response is similar to that of commonly used half-band FIR filters such as Beylkin, Daubechies, and Vaidyanathan.

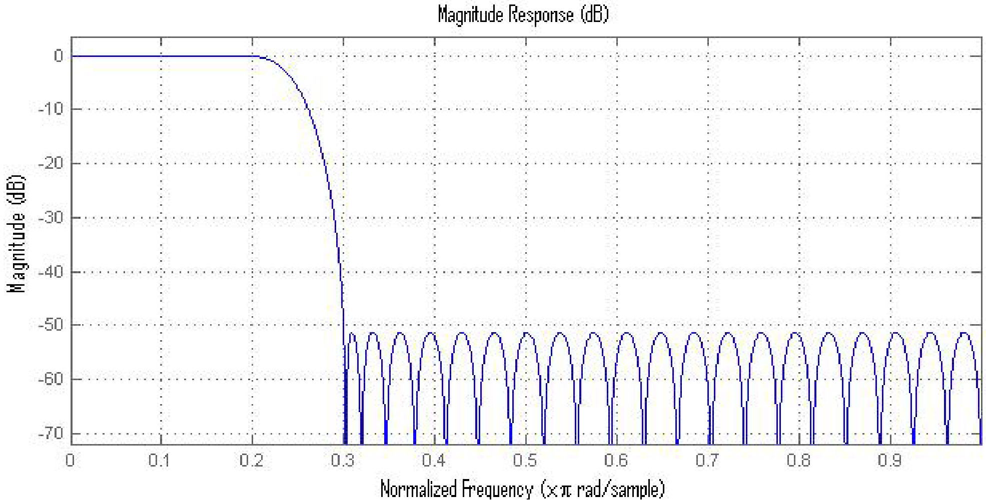

Figure 2. Prototype low-pass filter

The magnitude response of four filters obtained from the prototype is shown in figure 3. It is possible to achieve better frequency response by increasing the filter order at a cost of higher computational complexity. Therefore, there is a tradeoff between finer magnitude response and computational complexity.

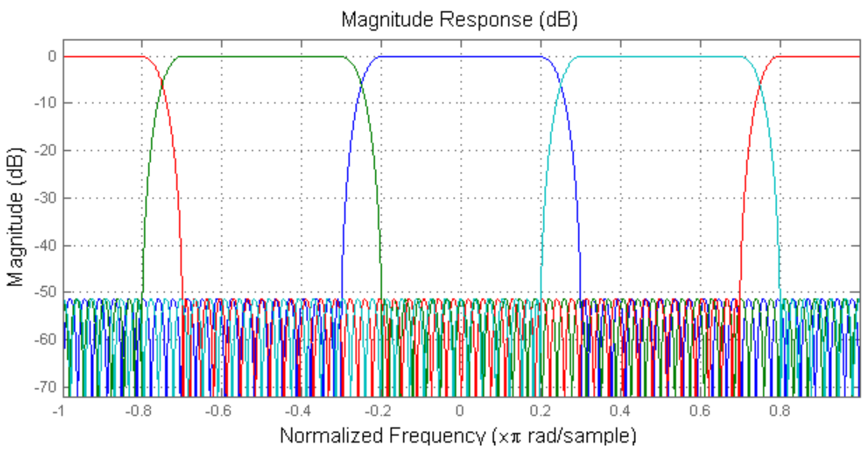

Figure 3. Magnitude responses of four-band filters

4. COMPUTATIONAL COMPLEXITY

The computational complexity of various filter banks can be compared by looking at the number of multiplications required for a full decomposition. The number of multiplications required to fully decompose sampled data of 10000 points into seven levels with commonly used FIR half-band and a four-band filters are given in Table 1.

Table 1. Computational complexity of various FIR filters

Filter Type	# of coefs.	# of filters	# of muls.
Vaidyanathan FIR	24	2	3,360,000
Daubechies FIR (db9)	18	2	2,520,000
Beylkin FIR	18	2	2,520,000
Four-Band FIR	56	1	1,820,000

The data indicates that the proposed approach results in a lower computational complexity than commonly used half-band FIR filters. Since there is a higher level of parallel computation in the proposed algorithm, FPGA implementation may give even further improvement in the performance of computation time.

5. CONCLUSION

Use of four-channel FIR filter banks result in better computational complexity than commonly used half-band FIR filter banks. However, the performance of the prototype filter used to achieve reduced computational complexity should not compromise the accuracy of the analysis results. In this paper, the performance of four-band decomposition with an FIR filter used in motor fault detection is evaluated for computational complexity. The results are compared with commonly used half-band FIR filters such Beylkin, Daubechies, and Vaidyanathan. The data indicates that the proposed approach provides significant reduction in computational complexity when compared to commonly used half-band FIR filters.

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