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# Design on Composite Cascade Mathematical Morphology Filter and Its Application in Signal Processing

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***Abstract*—In order to eliminate the pulse and noise interference of the weak signal, a filtering algorithm based on the composite cascade mathematical morphology is investigated in this paper, which mainly includes the principle analysis of morphological filter, the structure design of the filter element, and the construction of the composite cascade mathematical morphology. Finally, by simulation analysis and experimental verification, the results show that the implementation of the filtering algorithm based on the composite cascade mathematical morphology is simple and fast, and it can effectively filter out the pulse interference and random noise interference of the weak signal such as the actual oil film thickness signal obtained by the fiber optic displacement sensor. Furthermore, the filtering algorithm will play a very important role for the feature extraction of the weak electroencephalography signal.**

***Keywords- fiber optic displacement sensor;oil film thickness; morphological filter***

## I. INTRODUCTION

In order to eliminate the impact of the fluctuating of the light source's optical power and the changing reflectance of the reflective surface, the method of two receiving optical has been used When we dynamically detect the oil film thickness signal by displacement sensor of two-circle reflective coaxial fiber[1]. However, the output characteristics of the displacement sensor with two-circle reflective coaxial fiber will be impact by the environmental of the propagation medium. In the detection process of the oil film thickness, due to the bubbles and impurities of the oil and other factors the impulse noise and random noise are emerge in the signal, affecting the result of measurement[2].

The classical denoising method is using analog filters or digital filter. And among them, the digital filter is more common because of its flexible using. However, the method can't be effective to separate the useful signal from noise when the frequency of interference noise and the frequency of the signal intersect. Mathematical morphology is built up based on integral geometry and random set theory, which is different from those mathematical method based on the time domain and frequency domain. As for the problem of difficultly separating useful frequency from noise frequency, a denoising filtering method based on mathematical morphology is simple, clear physical meaning, practical and effective compared with traditional digital filter algorithm. The algorithm only includes addition and subtraction and the extreme value calculation, not involving multiplication and division it so it operates fast [3]. It was initially applied in the field of image processing of binary images and grayscale images. In recently years this method gradually refer to the one-dimensional field of signal processing such as the field

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of power system [4], voice [5], EEG [6] and vibration signal processing [3,7-10].

The conventional morphological filter processes the signal only by the closing-and-opening and opening-and-closing cascading operation, and can't effectively eliminate the impulse noise and random noise in the weak signal such as the oil film thickness. Therefore, a composite cascade of morphological filter is designed in this paper to conduct the filtering of the oil film thickness signal.

## II. THE PRINCIPLE ANALYSIS OF MORPHOLOGICAL FILTER

The fundamental morphological operations are dilation and erosion, along with the opening operation and closing operation based on which. The definition of the basic operations are as follows [11].

Let $F = (0,1,2\cdots,N-1)$ denote the set of integers and $f(n)$ denote a discrete image signal function, where the range set $\{n\} \subset F$. Denote $g(n)$ as the discrete function of the structuring elements where the range $\{n\} \subset G = (0,1,2...,M-1)$ .and $N > M$ . The erosion $(f\Theta g)(n)$ and dilation $(f \oplus g)(n)$ can be expressed as

$$\begin{aligned}(f\Theta g)(n) &= \min\{f(n+m) - g(m)\} \\ m &\in 0,1,\cdots,\ M-1\end{aligned} \tag{1}$$

$$\begin{aligned}(f \oplus g)(n) &= \max\{f(n+m) + g(m)\} \\ m &\in 0,1,\cdots,\ M-1\end{aligned} \tag{2}$$

The opening operation $(f \circ g)(n)$ and closing operation $(f \bullet g)(n)$ is defined as

$$(f \circ g)(n) = (f\Theta g \oplus g)(n) \tag{3}$$

$$(f \bullet g)(n) = (f \oplus g\Theta g)(n) \tag{4}$$

The opening operation can make the outline of target smooth, remove burrs and isolated points and suppress the signal peak (positive pulse) noise. Meanwhile, the closing operation can fill in the holes and cracks of the groove, bridge, which can filter the signal low (negative pulse) noise. When the two operations combined, it can compensate the positive and negative pulse in the signal filter. By a different order of cascading, closing operation MARAGOS define the morphological opening - closing and close - open the filter using the same size of structuring element:

$$F_{OC}(f(n)) = (f \circ g \bullet g)(n) \tag{5}$$

$$F_{CO}(f(n)) = (f \bullet g \circ g)(n) \tag{6}$$

## III. THE STRUCTURING ELEMENT DESIGN OF MORPHOLOGICAL FILTER

Besides choosing the appropriate calculation to eliminate the noise for the filtering purposes, the selection or design of the structuring elements directly impact on the effect of filter. Ruled as a "probe", the shape and size of structuring elements have direct impact on the filtered result, so different shapes and parameters of structuring elements will produce different results. The structural elements we commonly used mainly include straight line, curve, triangle, circular, oval and sinusoidal as shown in the Fig 1. Calculation results show that it will be able to achieve a better filtering process of target signal when the selected structuring element close to the shape characteristics of the target signal, namely structuring elements can be good

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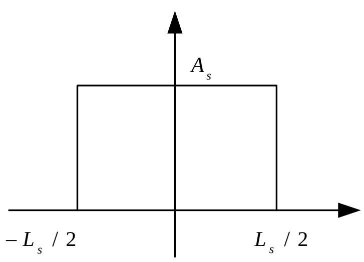
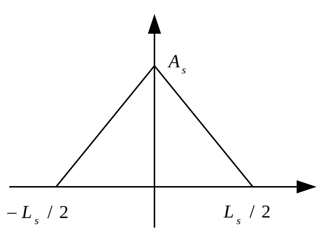
match with the target signal. The two structuring elements commonly used are triangle and semicircle, and their mathematical expressions are defined as formula (7) and (8).

$$g_s(i) = A_s \times (1 - \frac{2|i|}{L_s}) \tag{7}$$
$$(i = -L_s / 2, \cdots, 0, L_s / 2)$$

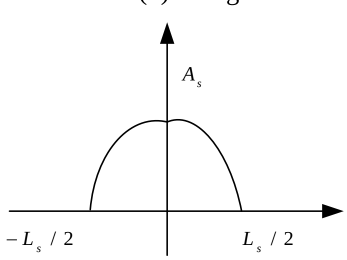
$$g_b(i) = A_s \times \sqrt{1 - \left(\frac{2|i|}{L_s}\right)^2} \tag{8}$$
$$(i = -L_s / 2, \cdots, 0, L_s / 2)$$




(a) straight line




(b) triangle




(c) half hand

Figure 1. The Typical shapes of the structuring elements.

## IV. THE CONSTRUCTION OF THE COMPOSITE CASCADE MORPHOLOGICAL FILTER

The dynamic signal of the oil film measured by the optical fiber displacement sensor, in addition to the useful signal, mainly contains the noise signal brought by the pulse signal, the oil impurities, and the journal surface which are caused by bubbles. When the light transmission medium of the fiber optic displacement sensor is different, it will make a change on output characteristics of the sensor[2]. The change is caused by the reason that the output value of the light propagation in the air is lager than propagation in the oil at the same displacement, thus the interference caused impulse noise in the measurement process.

In order to eliminate the statistical bias phenomenon caused by using a single open - closed, or the closing - open morphological filter, the paper adopts the combination of open - closed and close - opening morphological filter which is shown in equation(9). In order to effectively suppress all kinds of noise signals, the appropriate structure elements must be selected. Some studies have shown that the triangular structure elements are suitable to filter pulse noise signal, and the semicircular structure elements are suitable to filter random noise signal [12-14]. The signal of oil film may include impulse noise and random noise, so the paper proposes the method that adopting the composite cascade morphological filter which has two structural elements to filter the oil film signal, that is, firstly the morphological filter takes triangle as structural elements for filtering the original signal, then the filtered signal is filtered though the morphological filter takes semicircular as structural elements ,and the filtering process can be seen in equation (10) and (11).

$$y(n) = \frac{1}{2}[F_{OC}(f(n)) + F_{CO}(f(n))] \tag{9}$$

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$$y_s(n) = \frac{1}{2}\left[F_{OCs}(f(n)) + F_{COs}(f(n))\right] = \frac{1}{2}\left[(f \circ g_s \bullet g_s)(n) + (f \bullet g_s \circ g_s)(n)\right] \quad (10)$$

$$y(n) = \frac{1}{2}\left[F_{OCb}(y_s(n)) + F_{COb}(y_s(n))\right] = \frac{1}{2}\left[(y_s \circ g_b \bullet g_b)(n) + (y_s \bullet g_b \circ g_b)(n)\right] \quad (11)$$

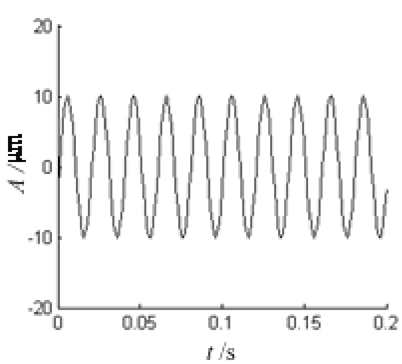
Compared with the single cascade morphological filter [8,12-14],the proposed method in this paper can reduce the impulse noise and random noise of signal effectively.

## V. THE SIMULATION ANALYSIS OF THE COMPOSITE CASCADE MATHEMATICAL MORPHOLOGICAL FILTER

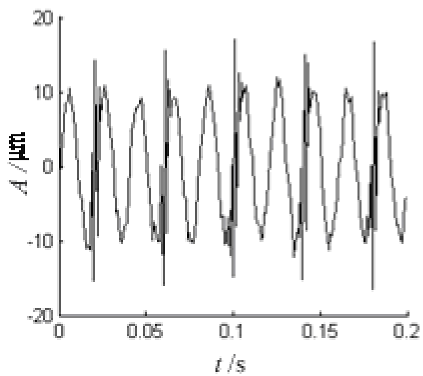
To validate the effectiveness of the filter, the following simulation is done and analyzed. The original signal is the sine wave at a frequency of 50Hz and with the amplitude of 10, as is shown in equation (12) below.

$$x(t) = 10\sin(2\pi \cdot 50t) \quad (12)$$

The sampling frequency of the original signal taken to 1KHz, the sampling points are 200, and it's time domain waveform of the original simulation signal is shown in Fig 2.




(a) the original simulation signal waveform




(b) the simulation signal waveform with noise

Figure 2. The simulation signal waveform

The height of the structural elements is 10, then filter the signal with noise respectively. Considering that the width of the structure element is a single cascade morphological filter and composite cascade mathematical morphological filter. The single cascade morphological filter uses the triangular structural element and the composite cascade mathematical morphological filter uses the structure elements of the triangular and semi-circular. The time domain signal filtered by morphological noise reduction filter is shown in Fig 3.

As can be seen from Fig 3, pulse noise signal and random noise has been well suppressed after the morphological filtering. However, the signal filtered by the single cascade morphological filter has the apparent noise interference in the trough near and the signal filtered by the composite cascade mathematical morphological filter does well in filtering the noise. In order to further illustrate the filtering effect of morphological filter, the SNR of the signal will be calculated by the equation (13).

$$SNR = 10\lg(P_y / P_n) \quad (13)$$

In the equation：

$P_y$ —The signal power of the filtered signal;

$P_n$ —The signal power of the noise.

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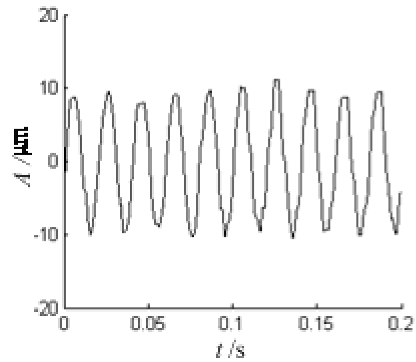
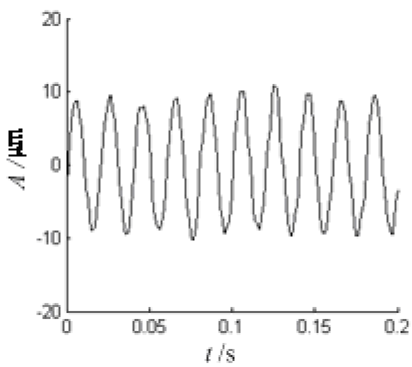
The noise signal can be got by the filtered signal subtracting the original simulation signal.



(a) the signal filtered by the single cascade morphological filter



(b) the signal filtered by the composite cascade mathematical morphological filter

Figure 3. The simulation signal waveform

Calculating by the equation (13), the SNR of the signal filtered by the single cascade morphological filter is 42.561, and the SNR of the signal filtered by the composite cascade mathematical morphological filter is 43.516. Table 1 is the SNR using different filtering methods with the standard deviation of random noise changing. As can be seen from Table 1, the SNR using the composite cascade mathematical morphological filter is lager than that of using the single cascade morphological filter at different intensity of the random noise. Figure 4 is the comparison between original signal and the signal filtered by the cascade mathematical morphological filter, and it can be seen that the noise is greatly suppressed after filtered by the composite cascade mathematical morphological filter, and the degree of coincidence between filtered signal and the original signal is high.

TABLE 1 THE SNR USING DIFFERENT MORPHOLOGICAL FILTERING METHODS

| **Standard deviation** | ***The single cascade morphological filter*** | ***The composite cascade mathematical morphological filter*** |
|---|---|---|
| 1 | 42.561 | 43.516 |
| 2 | 36.733 | 39.918 |
| 3 | 26.747 | 27.481 |

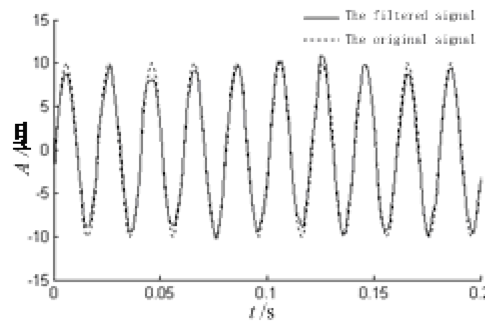


Figure 4. The comparison between original signal and the signal fitered by the cascade mathematical morphological filter

## VI. THE EXPERIMENTAL VERIFICATION OF THE COMPOSITE CASCADE MATHEMATICAL MORPHOLOGICAL FILTER

The oil film thickness signal was measured in the experimental instrumentation shown in Figure 5. The rotational speed is adjusted to 1800rpm, setting the sampling frequency as 1024Hz and the number of sampling as 1024. For analysis, we intercept continuous 256 data points from the collect data. The morphological filter structural height value of 40 and the structure width is taken to be 10. Fig 6 (a) show the original signal waveform of the oil film thickness in X direction, Fig 6 (b) is the signal waveform filtering by the composite cascade morphological filter. In the Fig 6 (a), the waveform of the original signal is messy in time domain, and the value of film thickness emerge negative, this is mainly because the original signal

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are interfered by the impulse noise and random noise. As can be seen from figure 6 (b), the pulse noise and random noise have been significantly suppressed filtering by the composite cascade morphological filter.

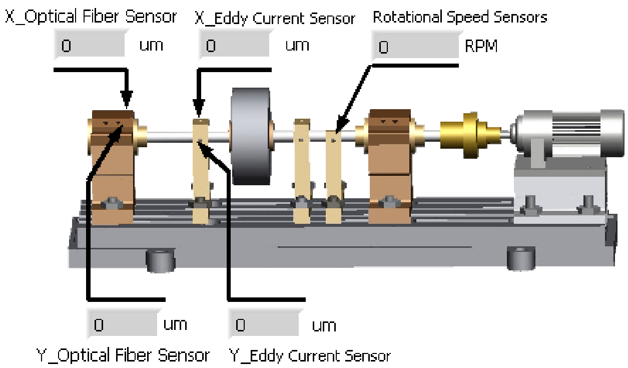
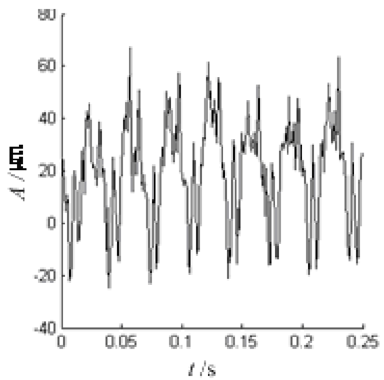
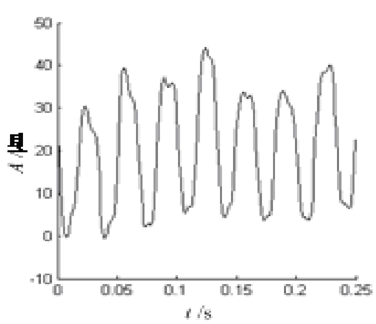



Figure 5. The Experimental Instrumentation for Measuring The Thickness Signal of The Oil Film



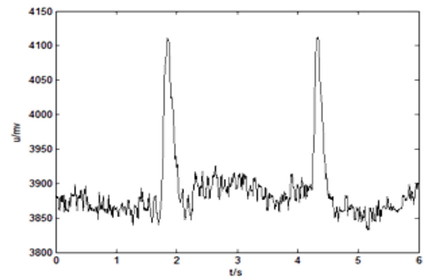
(a) the time-domain waveform of original signal



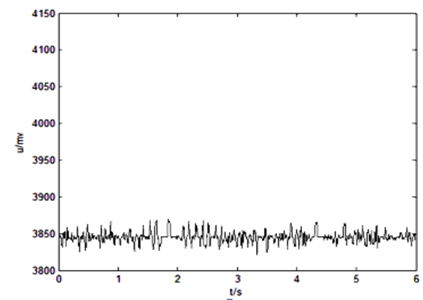
(b) the time-domain waveform after filtering

Figure 6. The time-domain waveformof the oil film thickness Rotor signal measuring at 1800rpm of rotor speed

Composite cascade mathematical morphology filter can play a very good effect in the extraction of the weak electroencephalography (EEG) signal. Fig 7 (a) is containing the ocular artifact resting state EEG data(sampling rate is 128Hz ), Taking 1000 points. Action of blinking eyes caused several spike in the figure. Then the author filter the elements of Electro-oculogram (EOG) using the cascading morphological filter, shown in Fig 7(b). From the Experiments we can see, the morphological filter removaling pulse interference of weak EEG is very effective.



(a) the EEG signal with EOG elements



(b) the EEG signal after filtering

Figure 7. The EEG signal waveform in time-domain

## VII. CONCLUSIONS

Morphological filtering is a non-linear digital signal processing technology, mainly used for the two-dimensional image signal processing. In this paper, a filter based on the composite cascade mathematical morphology is designed for eliminating the pulse and noise interference in the oil film

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thickness signal. Both the simulation analysis and the experimental verification using the actual oil film thickness signal show that the algorithm can effectively filter out the pulse interference and random noise interference. On the basis of the property, the filter based on the composite cascade mathematical morphology will play a very important role for the feature extraction of the weak electroencephalography signal.

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