Using wavelet transforms to suppress light interference in the optoelectronic monitoring system of the weft thread break

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Abstract. The article presents the results of studies on interference suppression in optoelectronic methods for monitoring weft thread weaving looms on the basis of linear image sensors caused by inhomogeneities of the background created by sources of natural or artificial light sources in a controlled image scene. Existing solutions that use linear or nonlinear filtering are focused primarily on the processing of two-dimensional images on personal computers and are unsuitable for use in embedded applications. In particular, their use is also ineffective for solving the above problem, when the useful signal is defined as the difference between the output signals of the photodetector taken at a fixed time interval. As studies have shown, in this case, the best result is the use of discrete wavelet - transform.

1. Introduction
The weft thread breakage detection system is included in the design of any weaving loom, as the thread breakage or its end causes a defect on the woven fabric. However, on some weaving machines, for example, such as a circular weaving machine for the production of woven sleeves SYJ850-6S [1, 2], thread breakage can cause not only defects, but also lead to a complete disruption of the machine’s operation, as in this machine shuttle shuttles weave the sleeve, spinning around it and passing through the longitudinal threads. If the weft thread breaks, its tension will disappear, and it will be able to hook onto the rotating shuttles and tear off all the other weft yarns.

The function of thread breakage control in such machines is performed by compensators - thread guides, which also create additional tension on the thread in order to loosen its jerks during work. At the moment of thread breakage, compensators due to the spring are deflected to the side and touch the metal rim, thereby closing the electrical circuit that starts the machine stop system. Since the threads may be slightly oiled, there is a risk of oiling the compensator hook, which can break electrical contact. The failure can also be caused by weakening of the spring, penetration of dirt into various parts of the compensator, oxidation of conductive areas. One of the ways to solve this problem is the use of contactless control methods based, for example, on the use of machine vision systems [3, 4]. However, the solution of one problem leads to the appearance of another, namely the problem of the impact on the recorded signal of significant interference, caused primarily by the presence in the control area of significant uneven and intermittent background lighting in a production environment, which in turn leads to a decrease in the accuracy of identification. Such interference can be created by sources of both natural and artificial lighting. This was the reason for conducting research aimed at suppressing this type of interference.
2. The principle of operation of the monitoring system and description of the cause of interference emergence

In [1], it was proposed to use an optical-electronic system based on linear CCD photodetectors to control thread breaks. The system was based on a differential method of generating an information signal. For this purpose, the images of the support shaft with the weft threads adjacent to it was projected onto a photodetector. A matrix sensor with a frame resolution of 1920x1080 instead of a linear detector was used as a photodetector in the experiment. A fragment of the video stream generated by such a sensor is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1. A video stream fragment.**

The analyzed signal was formed from this stream as the difference between two signals received from the same frame line of the matrix sensor with an interval of 4/30 s or 4 frames (that is, 1-5 frames, 2-6 frames, etc.). This interval was optimal because it allowed to get rid of slowly changing background highlights without attenuating the useful signal. However, if a sharp change in illumination occurs in the interval between signal readings, the useful difference signal is strongly masked by the difference background signal, and it is impossible to identify the thread break point without additional processing. This effect is most pronounced if the light source is switched on or off between signal samples. As an example, Figure 2 shows the case when the light source is switched off during the operation of the monitoring system and a thread breakage occurs at about the same time. The initial recorded video stream for these cases is shown in Figure 2a.

![Figure 2](image2.png)

**Figure 2.** a) the original video stream of image lines recorded by a photodetector, b) the difference signal corresponding to this video stream, obtained by subtracting the video stream lines from one another, spaced L = 4 lines from each other.

In the Figure 2a, the pixel line number of the image of the video stream is directed along the x axis, and the number of the registered original frame is displayed along the y axis, which is directed from top to bottom. The difference signal shown in Figure 2b was determined by the formula

\[ \text{subtraction}_{\text{lines}}(x, y) = \text{line}(x, y) - \text{line}(x, y + L), \]  

(1)

where \( \text{line}(x, y) \) is the row of the original image, \( L \) is the number of past frames between the two registered signals, \( x \) – the number of pixels, \( y \) – the frame number.
The moment of switching off the light (that occurred on the 181st line or 181st frame) corresponds to a sharp decrease in the brightness of the image and a sharp increase in the difference signal (Figure 2b). After the light was turned off at frame 213, a thread was broken in the vicinity of the 400th pixel (Figure 2a). This cliff is represented in Figure 2b by a sharp single peak, which, as can be seen from the figure, has an amplitude less than the interference signal. Therefore, it cannot be defined by a simple discriminant method by fixing the moment when the difference signal exceeds a given threshold. An attempt to increase the signal-to-noise ratio using high-frequency digital filtering of a differential signal did not give the desired effect, since sharp background drops, having practically the same spectrum as the useful signal, can also be present on the background. Since in the background inhomogeneity the proportion of low-frequency components is greater than in the useful signal, a spectral representation of the signal could be used to identify a thread break, for example, using the discrete Fourier transform. However, if the background illumination almost does not vary in intensity along the image line, but has sharp boundaries, the reliability of identification in such cases will be extremely low, and if switching on the light and breaking the filament in time coincide, then it is impossible at all. For the reasons listed above, and also due to the fact that the Fourier transform has a fairly large computational complexity, it was decided to use alternative methods for signal identification and processing, namely methods based on wavelet transforms [5-10].

3. Continuous wavelet transform

Recently, wavelet-based filtering has been applied more and more. This is due to the fact that the wavelet transform is localized both in time and in frequency (or in scaling), which makes it possible to localize interferences in both time and frequency with high resolution. Therefore, wavelet analysis is widely used in solving many problems related to the problems of analyzing and synthesizing signals, for compressing and processing images, compressing large amounts of data, and solving some differential equations [11–16]. As already noted, the spectrum of non-uniform illumination lies more in the low-frequency region, and if the thread is torn off, the spectrum will contain mostly high-frequency components. Thus, it can be assumed that the wavelet transform will allow to more clearly emphasize this feature. This assumption is confirmed by Figure 3, which shows the wavelet transform of a single-line difference signals corresponding to a thread break and turning off the light.

These conversions were performed on the Matlab system using the following program code:

```
% WaveletName - wavelet type, one of the parameters of the continuous
% wavelet transform function cwt ()
WaveletName = 'amor';
% video_line (:,N) - line N from the video stream
% Wavelet transform of the difference signals before and after turning off
% the light:
[cwt_light_dt,period]=cwt(video_line(:,179)-video_line(:,183),WaveletName);
% Wavelet transform from a difference of signals before and after
% a thread break:
[cwt_break_dt]=cwt(video_line(:,211)-video_line(:,215),WaveletName);
```

The type “amor” was chosen as the basis because of its greatest sensitivity to the required frequencies compared to other available types of 'morse' and 'bump'. As can be seen from figure 3, the spectra of the difference signals are completely separated. The scaling (frequency) coefficient for interference caused by light switching off lies in the region above 40. The spectral components in the range of coefficients 0-10 almost does not depend on the nature of the signal. Therefore, they is also due to the presence of interference in the signal, but caused, presumably, by small displacements of threads along the shaft between frames. Then, keeping only the informative part corresponding to the range of coefficients (10-40) in the received scalograms, we can get a filtered signal with significantly suppressed interference caused by the background non-uniformity created by the light off.
Figure 3. Wavelet transform of a differential one-dimensional signal from a single line of the image for the cases of switching off the light (a) and breaking the filament (b).

Figure 4 shows the result of such a conversion to the signals filtered by the method described, corresponding to lines 181 and 212 of the two-dimensional difference signal shown in Figure 2b. To obtain it, the code was used

```matlab
filter_range = [1/40, 1/10]; % frequency domain boundaries;
filtered_line_break = icwt(cwt_break_dt, period, filter_range);
filtered_line_light = icwt(cwt_light_dt, period, filter_range);
```

Figure 4. Filtered by a wavelet filter difference signals from a single line of a differential signal (Figure 2b): a) a case of turning off the light, line 181; b) case of thread break, line 212; c) combination of signals from the two previous graphs.

The appearance of significant negative components in the signals create a picture that is almost symmetrical about the abscissa axis, is due to the exclusion of low-frequency components from them, including zeroing the constant component. More clearly, the result of wavelet filtering is shown in Figure 5, which shows projections onto the Z axis (amplitude axis) of filtered signals from each image line. If prior to filtering, the maximum value was observed at the point (181, 228), that is, at the point of maximum background heterogeneity, then after filtering, the extremum of the signal shifted to point (212, 385), which is the break point.
Figure 5. The dependence of the projections of the filtered (as in Figure 4) signals on the Z axis on the frame (line) number of the difference signal in the video stream shown in Figure 2b. Reported outliers correspond to the moments when the light is turned off and when the thread is broken.

As you can see, the use of filtering using a continuous wavelet transform allows you to solve the problem, and with less computational complexity, and more efficiently than using the Fourier transform. However, the use of the described method in embedded systems implies its mandatory optimization to speed up the calculation and saving the power source energy in the case of powering the device from the battery. In addition, the above method cannot be used for some wavelets and its practical implementation in online mode will require the use of high-performance microcontrollers, which limits the scope of the possible application of the method. Consider the possibility of reducing the computational complexity, and consequently, reducing the requirements for the computing resources of the microcontroller, due to the transition from a continuous wavelet - conversion to discrete.

4. Discrete wavelet transform
The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations obeying some defined rules [9, 10]. It replace the original number series by its approximation component and a set of detailing components corresponding to different levels of decomposition (detail). Since DWT is focused on digital online data processing by means of microprocessor technology, the simplest Haar wavelet is used as the basis, and the transform itself is implemented using the rather simple Mallat algorithm [10].

To filter a signal in Matlab using a single-level transform, its wavelet image is first determined using the $[c_A, c_D] = dwt(s,'wname')$. Here $s$ is the original signal, $c_A$, $c_D$ are the coefficients of approximation and detail, and $wname="haar"$ is the type of wavelet used in the $dwt$ function for conversion. Then the inverse transform is performed using the function $s = iwdt(c_A, c_D, [0 0], F2)$, where $F2$ is found from the expression for the high-pass filter $[F1, F2] = wfilters('haar', 'h')$.

The result of applying the described filtering procedure for a single-level conversion is shown in Figure 6. It can be seen that, after suppressing the low frequencies, the influence of interference was reduced to a level comparable to filtering using continuous conversion. However, the useful signal also turned out to be greatly weakened, since part of its spectrum was in the filtered region. From this it follows that for filtering it is necessary to apply a multi-level transform with preserving only high-frequency levels.
In the case of a multilevel transformation, the wavelet - image was found using the function
\[ [C, L] = \text{wavedec}(s, N, 'wname') \]
where \( N \) is the number of transformation levels, \( C \) is the total decomposition array in all levels, \( L \) is the array containing the values of indices of the levels boundaries in the array \( C \).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1}
\caption{The result of applying a wavelet filtering for: a) a single line of the difference signal (Figure 2b) and b) for the entire signal.}
\end{figure}

For the inverse transform, the function \( s = \text{waverec}(C, L, 'haar') \) was used, where part of the coefficients were preliminarily cleared from the array \( C \). The study showed that the best (and at the same time not requiring large computational resources) result is achieved using \( N = 4 \) and 3rd and 4th levels of detail. For this, \( c(1: l(1)) = 0 \) and \( c(l(5): end) = 0 \) has been set. The initial array of coefficients for such a conversion for a single line is shown in Figure 7, and in Figure 8 - the result of filtering the entire difference signal, as well as its comparison with filtering using the previously considered continuous transformation.

As can be seen from Figure 8, the ratio of the maximum signal level caused by a thread breakage to the maximum of the interference signal caused by switching off the light source is \( 0.4065 / 0.2579 = 1.58 \) when using continuous conversion for wavelet filtering and \( 36.17 / 21.33 = 1.69 \) when using discrete conversion. Thus, using a discrete transform filtering is even slightly better than applying a continuous transform. At the same time, it requires for its implementation much lower computational costs and can be implemented on microcontrollers of the average price range.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image2}
\caption{Discrete wavelet transform (an array of \( C \) coefficients) for a single line of the difference signal (Figure 2b) and four levels of decomposition (elements 897 ... 1793 - 1st level, 449 ... 897 - 2nd level, 225 ... 449 - 3rd level, 113 ... 225 - detailing coefficients of the 4th level, and 0-113 - its approximation coefficients).}
\end{figure}
Figure 8. The result of applying wavelet filtering when using continuous (a) and discrete four-level transform with preservation of coefficients of the 3rd 4th level for the inverse transform (b).

5. Conclusion
In this article has been examined the possibility of using wavelet transforms to filter out interference caused by non-constant illumination of the control area. The result was analyzed when a continuous wavelet transform, as well as with multi-level and single-level discrete wavelet transform was using for interference suppressing. It is shown that the discrete multilevel transformation in terms of filtering quality is not inferior to the use of continuous transformation for these purposes. Analyzed and selected optimal wavelet levels and their number, at which the influence of background lighting is minimized.

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