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論 文

Wavelet 변환을 이용한 크레인 와이어 로프 결함 신호처리에 관한 연구

민 정 탁* · 손 동 섭* · 이 진 우* · 이 권 순**

*동아대학교 전기공학과 대학원, **동아대학교 전기 · 전자 · 컴퓨터공학부 교수

A Study on Crane Wire Rope Flaws Signal Processing Using Discrete Wavelet Transform

Jeong-Tak Min · Dong-Seop Sohn* · Jin-Woo Lee* · Kwon-Soon Lee****

**Department of Electrical Engineering, Dong-A University, Busan, Korea*

***Division of Electrical Electronics and Computer, Dong-A University, Busan, Korea*

ABSTRACT : *Wire ropes are used in a myriad of various industrial applications such as elevator, mine hoist, construction machinery, lift, and suspension bridge. Especially, wire rope of crane is important component to container transfer. If it happens wire rope failures in operating, it may lead to safety accident, economic power loss by productivity decline, competitive power decline of container terminal and so on. To solve this problem, we developed wire rope fault detecting system as a portable instrument, and this system is consisted of 3 parts that fault detecting part using hall sensor, permanent magnets and analog unit, and digital signal processing part using data acquisition card, monitoring part using wavelet transform, denoising method. In this paper, a wire rope is scanned by this system after makes several broken parts on the surface of wire rope artificially. All detected signal has external noise or disturbance according to circumstances. So, we applied to discrete wavelet transform to extract a signal from noisy data that was used filter. In practical applications of denoising, it is shown that wavelet pursue it with little information loss and smooth signal display. It is verified that the detecting system by denoising has good efficiency for inspecting faults of wire ropes in service.*

As a result, by developing this system, container terminal could reduce expense because of extension of wire ropes exchange period and could competitive power. Also, this system is possible to apply in several fields like that elevator, lift and so on.

KEY WORDS : *wire rope, hall sensor, MFL, NDT, WT, DWT, denoising, threshold*

1. Introduction

The wire rope of crane is important component to transfer of container and improve of production. As wire rope usually takes charge of total weight of container and then, to hold safety of crane, it is necessary to periodically inspect flaws or deterioration in operating wire ropes. Hence, the maintenance and replacement of wire ropes should be determined based on precise measurement data of wire rope in service.

If it is occurred wire rope's failures, it may breed container terminal's competitive power decline by safety accident, economic power loss, economic power loss and so on. Base on the container terminal's development, if it is developed exactly detection system, we could get loading-unloading efficiency, safety, economic performance and so on. So we developed wire rope fault detecting system that detect to magnetic leakage flux using hall-sensor[1,2].

Generally, there is several noise in detected signal by external environment and hardware status. To denoising this signal, we apply to the DWT(Discrete Wavelet Transform). The Discrete Wavelet Transform (DWT) is a special case of the WT that provides a compact representation of a signal in time and frequency that can be computed efficiently.

Finally, we could decipher status of wire rope by monitoring system that made by visual c++.

*정회원, min0121@donga.ac.kr 051)200-6748

**종신회원, kslee@kaunet.donga.ac.kr 051)200-7739

2. Wire Rope Detecting System

2.1 MFL Experiment

There is many NDT(Non-destructive Inspection) procedures such as optical, acoustical and mechanical methods have been tried to inspection wire rope faults, only visual inspection, ultrasonic wave and magnetic test methods are available in practice. But visual method needs much time to inspect and not exactly, and ultrasonic wave is appeared by ultrasonic generator that so expensive. So we chose magnetic test method that has been developed over the past several decades.

It is general to detect magnetic leakage flux caused by flaw in the wire rope, as shown in Figure 1[3]. Therefore, it may be required to use any magnetic exciting unit (NdFeB permanent magnet) with high intensity of magnetic flux in order to hold saturated rope and to select a suitable sensor having good sensitivity.

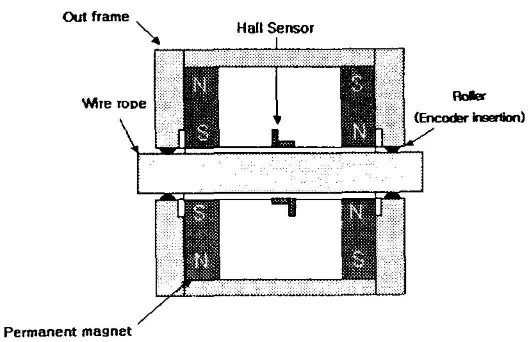


Fig. 1 Hall sensor and magnetic head

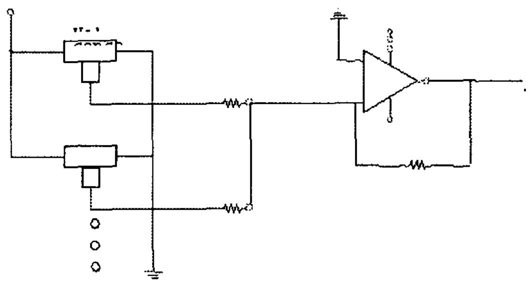
For the purpose of sensing magnetic leakage flux , there are usually 2 types of detecting sensors, which are inductive sensor and hall sensor. The former dependent upon detecting speed, but the latter isn't and it can be easily affected by environmental magnetic flux. So we chose hall sensor(Allegro linear hall sensor).

2.2 Detection System

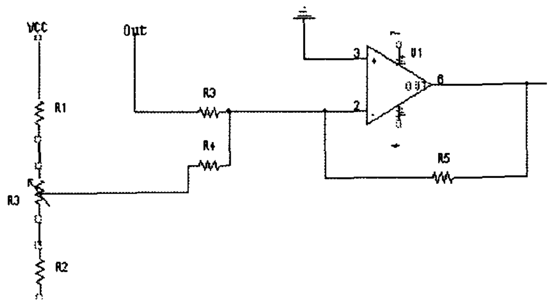
We system to signal processing, display in a monitor and so on. Detection system consists of analog signal processing unit, microprocessor unit.

Figure 2 shows analog signal processing unit.

Signal of hall sensor is low voltage (mV) than magnetic flux density, so this signal has to amplify, and removed unnecessary voltage by off-set circuit. Output of off-set circuits converted into corresponding digital data by DAQ(Data Acquisition) card. We used ACL-711B card that is interfaced to external device such as 7-segment,led and so on.



(a) Hall voltage detection circuit



(b) Off-set circuit

Fig. 2 Analog processing unit

Figure 3 shows shape of detection part.

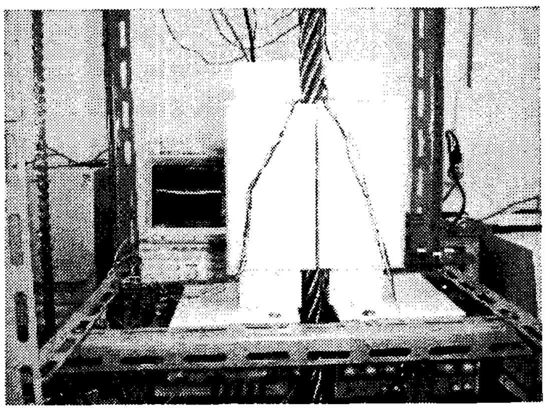


Fig. 3 Shape of detector

3. Signal Processing

3.1 DWT

The wavelet transform(WT) is a technique for analyzing signals. It was developed as an alternative to the short time Fourier Transform(STFT) to overcome problems related to its frequency and time resolution properties. More specifically, unlike the STFT that provides uniform time resolution for all frequencies the DWT provides high time resolution and low frequency resolution for high frequencies and high frequency resolution and low time resolution for low frequencies. In that respect it is similar to the human ear which exhibits similar time-frequency resolution characteristics.[4,5]

The Discrete Wavelet Transform(DWT) is a special case of the WT that provides a compact representation of a signal in time and frequency that can be computed efficiently. The DWT is defined by the following equation:

$$W(j,k)=\sum_j\sum_k x(k)\, 2^{-j/2}\,\Psi(2^{-j}n-k) \tag{1}$$

Wh(t) is a time function with finite energy and fast decay called the mother wavelet. The DWT analysis can be performed using a fast, pyramidal algorithm related to multi-rate filter banks.ere

As a multi-rate filter bank the DWT can be viewed as a constant Q filter bank with octave spacing between the centers of the filter. Each sub-band contains half the samples of the neighboring higher frequency sub-band. In the pyramidal algorithm the signal is analyzed at different frequency bands with different resolution by decomposing the signal into a coarse approximation and detail information. The coarse approximation is then further decomposed using the same wavelet decomposition step. This is achieved by successive highpass and lowpass filtering of the time domain signal and is defined by the following equations.

$$y_{high}[k]=\sum_n x[n]g[2k-n] \tag{2}$$

$$y_{low}[k]=\sum_n x[n]h[2k-n] \tag{3}$$

where $y_{high}[k]$, $y_{low}[k]$ are the outputs of the highpass (g) and lowpass (h) filter, respectively after subsampling by 2,3. Because of the downsampling the number of resulting wavelet coefficients is exactly the same as the number of input points. A variety of different wavelet families have been proposed in the literature. In this paper, we used Daubechies wavelet that has characteristic such that it could signal regeneration by IDWT(Inverse Discrete Wavelet Transform) and compactly supported orthogonal wavelet[6]. Thus, it is making discrete wavelet analysis practicable.

3.2 Denoising

The underlying model for the noisy signal is basically of the following form.

$$s(n)=f(n)+\sigma e(n) \tag{4}$$

The denoising objective is to suppress the noise part of the signal s and to recover f. From a statistical viewpoint, the model is a regression model over time and the method can be viewed as a nonparametric estimation of the function f using orthogonal basis.

The De-noising procedure proceeds in three steps.

(1) Decompose
After choose a wavelet, choose a level N and compute the wavelet decomposition of the signal s at level N.

(2) Threshold detail coefficients
For each level from 1 to N, select a threshold and apply soft threshold to detail coefficients.

(3) Reconstruct
Compute wavelet reconstruction based on the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

It is important point that how to choose the threshold and how to perform the thresholding. In this paper, we used universal thresholding that Donoho and Johnstone propose to use the threshold $\lambda=\sigma\sqrt{2\log(n)}/\sqrt{n}$ on transformed data set y_i/n, where n is the sample size, and σ is the scale of the noise on a standard deviation scale. Univesal thresholding can be hard or soft thresholding with the above defined λ as threshold[7].

4. Experiment

To examine some performances for this detector system, a sealed type wire rope that using crane is prepared. To verify detecting property of the developed system in detail, the rope speed under testing in the laboratory is much less slow than that of practical crane by using DC motor driver. We make flaws like figure 4 artificially and length of wire rope is 1[m].

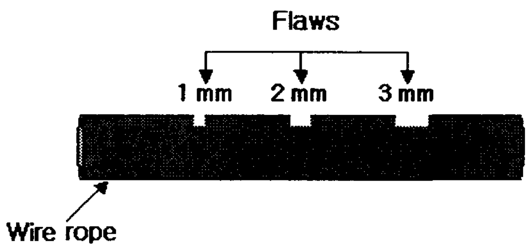


Fig. 4 Shape of wire ropes flaws

The detector system scans wire rope slowly. When pass part that has flaw, hall sensor makes output that is processed by analog unit.

Figure 5 demonstrates an overall schematic diagram for signal flow of flaw detecting system of wire rope.

Output of analog signal process is converted into corresponding digital data by using 12[bit] A/D converter that is set DAQ card. This card drives 7-segment display, led and so on. Converted data is saved in PC and displayed.

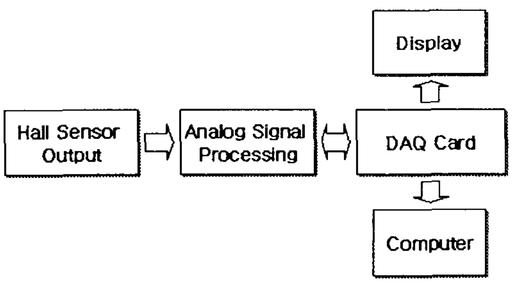
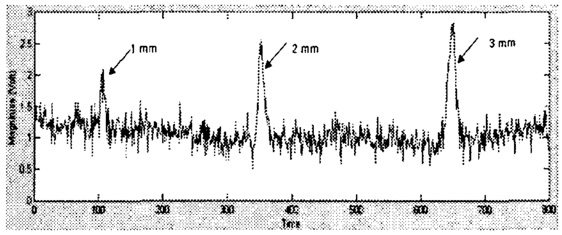
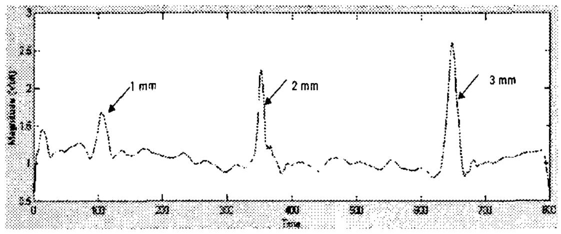


Fig. 5 Schematic diagram for detector

Figure 6 shows the detecting result to be measured by the wire rope flaws detect system. As a result, it can be seen that the output of detector is nearly proportional to the number of broken wires. Electromagnetic instrument to inspect wire defects may be affected by the location of sensor and defect so that its output would sometimes be including external noise or disturbance. Although it is obvious that severe faults can be distinguished from the output, if wire ropes flaw is small, we couldnt divide weather is flaw or is external noise or disturbance.



(a) Originalsigna



(b) Denoising signal

Fig. 6 Comparison of original and denoising signal

To denoising and signal analyze, we used discrete wavelet transform that mother wavelet is Daubechies and decompose at level 4.

As you see the Figure 6, the result of denoising is quite better than original signal that has noise.

We displayed the signal, number of flaw, degree of flaw and so on. Figure 7 shows the screen.

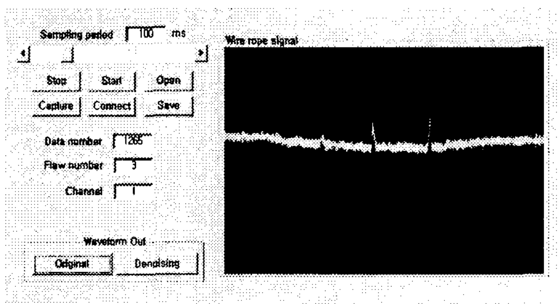


Fig. 7 Screen

Figure 8 is whole system diagram.

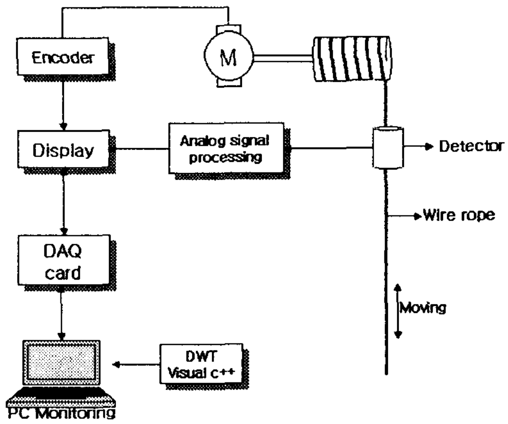


Fig. 8 Whole systems

5. Conclusion

In this paper, we studied on a development of wire rope flaws detection, discrete wavelet transform, method of denoising. The reason of development of this system is that wire rope of crane is important component to container transfer. But if it happens wire rope failures in operating, it may lead to safety accident, economic power loss by productivity decline, competitive power decline of container terminal and so on. So we developed the detector system that as portable instrument, and this system is consisted of 3 parts that fault detecting part, digital signal processing part, monitoring part.

We adopted DWT and denoising method, because it is obvious that severe faults can be distinguished from the output, but if wire ropes flaw is small, we couldn't divide weather is flaw or is external noise or disturbance. As showed up at Figure 6, we could know the signal of denoising is quite better than original signal that has noise.

As a result, by developing this system, container terminal could reduce expense because of extension of wire ropes exchange period and could competitive power. Also, this system is possible to apply in several fields like that elevator, lift and so on.

Our future works is same as following. This experiment is just conducted in a laboratory, so to examine this

detecting system a field test is performed in situation for aged wire ropes installed in a crane. When field test is performed, detector will set top of the cranes wire rope like Figure 9. The reason is because sway of the part is less than another one. Also, signal send-receive may be achieved by radio communication.

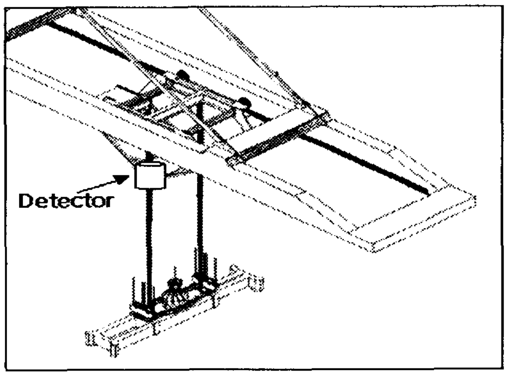


Fig. 9 Detector position on the crane

Acknowledgements

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