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Time-Frequency-Based Fatigue Data Editing For Automotive Applications

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ABSTRACT

This paper presents fatigue data editing (FDE) techniques using time-frequency domain. The time-frequency methods identified and extracted higher amplitude segments and produced shorter edited signals. Based on the comparison of the edited signals resulted, it was found that the wavelet transform gave the shortest signals. It was able to summarize strain signals up to 77% and maintain more than 90% of the statistical parameters and the fatigue damage. Meanwhile the short-time Fourier transform and the S-transform summarized the signals only of 23% and 22%, respectively. It proved that the wavelet transform was the best technique for FDE, especially for the automotive applications.

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INTRODUCTION

According to the literatures, among the fatigue data editing (FDE) techniques developed based on the time-frequency domain were short-time Fourier transform (STFT), wavelet transform (WT) and S-transform. Since the time-frequency domain is new in the FDE, it is important to compare those techniques. Thus, the objective of this work is to find out the best time-frequency technique for the FDE. It was performed comparing modified signals resulted by each technique. This comparison was based on the shortest edited signal with the maximum statistical and fatigue damage retaining. This work is expected can give a contribution to the fatigue studies, especially in shortening fatigue data.

Literature review:

Morrow [1] is one of strain-life models that can be used for applications involving the effects of the mean stress. The model is represented as:

$$\varepsilon_a = \frac{\sigma'_f}{E}\left(1 - \sigma_m / \sigma_f'\right)\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \tag{1}$$

The fatigue damage for each loading cycle D_i can be calculated as:

$$D_i = \frac{1}{N_f} \tag{2}$$

The Palmgren-Miner rule is then used to calculate the cumulative fatigue damage D of a variable amplitude loading block, and it is defined as follows (Palmgren, 1924; Miner, 1945):

$$D = \sum\left(\frac{n_i}{N_f}\right) \tag{3}$$

The r.m.s. is the 2nd statistical moment used for determining the total energy contained in a signal. The r.m.s. of discrete data can be calculated as:

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$$r.m.s. = \left\{ \frac{1}{n} \sum_{j=1}^{n} x_j^{\ 2} \right\}^{1/2} \tag{4}$$

In addition, the kurtosis is the 4th statistical moment that is very sensitive to spikes and it represents the continuation of peaks in a time series loading. The kurtosis for a set of discrete data can be expressed as follows:

$$K = \frac{1}{n(SD)^4} \sum_{j=1}^{n} \left(x_j - \bar{x} \right)^4 \tag{5}$$

The STFT is performed by dividing signal analysed into smaller segments, where fast Fourier transform (FFT) is applied to each segment (Patsias, 2000; Kim, 2007) aiming to produce frequency information. The STFT function can be defined as follows (Pinnegar, 2003):

$$STFT(t, f) = \int_{-\infty}^{\infty} h(\tau) w(t-\tau) \exp(-2\pi i f \tau) d\tau \tag{6}$$

The WT can be classified as either continuous or discrete (CWT or DWT). Generally, the wavelet coefficient is expressed as (Misiti *et al*. 2008):

$$C_{(a,b)} = \int_{-\infty}^{+\infty} f(t) \psi_{a,b}(t) dt \tag{7}$$

The S-transform is also applying Fourier transform only at a small part of the signal in certain time (Stockwell *et al*. 1996). Itcan be expressed as:

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) \frac{|f|}{\sqrt{2\pi}} e^{-\frac{(\tau-t)^2 f^2}{2}} e^{-i2\pi ft} dt \tag{8}$$

Methodology:

Several FDEs based on the time-frequency domain have been found in the literatures. The FDE techniques were used for editing strain signals measured at a lower suspension arm of cars driven on different road surfaces. In this current study, the ability of the techniques were compared based on the edited signals resulted. The technique with the shortest edited signal was named as the best one.

RESULT AND DISCUSSIONS

The STFT-based FDE has been developed by Abdullah *et al*. (2007) used to edit a signal of 160 seconds measured on public road surface. The edited signal produced was 124 seconds maintaining 90% and 94% of the statistical and fatigue damage values, respectively. Next, Nizwan (2009) developed the S-transform-based FDE used to edit a 60-second signal measured on country road. Maintaining 90% of the statistical parameters and 95% of the fatigue damage, a 47-second edited signal was produced. Furthermore, Putra (2010) developed a FDE involving the WT. The technique extracted a 146-second highway signal to produce a 37-second edited signal. The technique maintained 93% and 98% of the statistical and fatigue damage values, respectively. The original and edited signals resulted by each technique are shown in Figure 1-3. All the edited signals maintained more than 90% of the statistical and fatigue damage values. However, it was found that the WT gave the shortest edited signal compared to other techniques, since it could reduce length of a signal up to 75%.

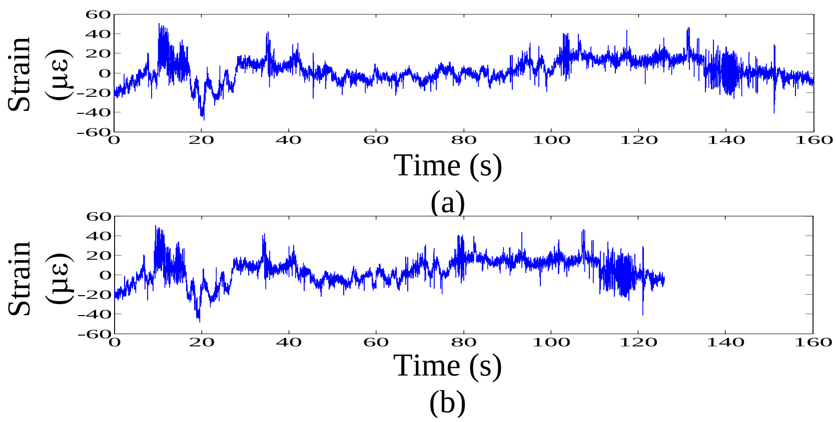

Fig. 1: The STFT: (a) original, (b) edited.

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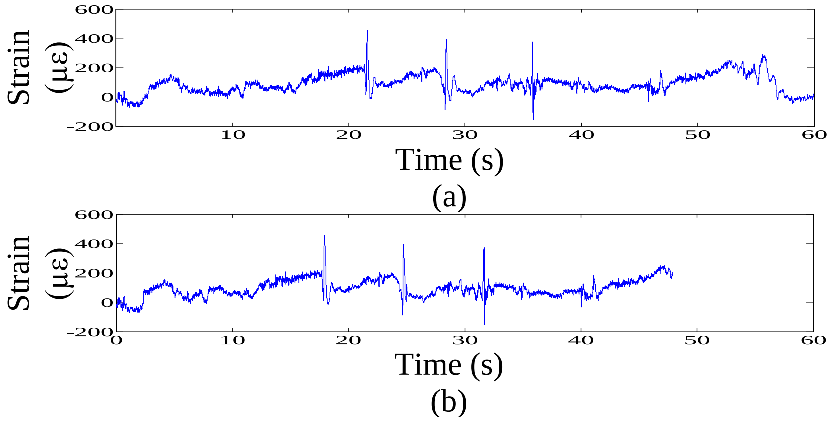

Fig. 2: The S-transform: (a) original, (b) edited.

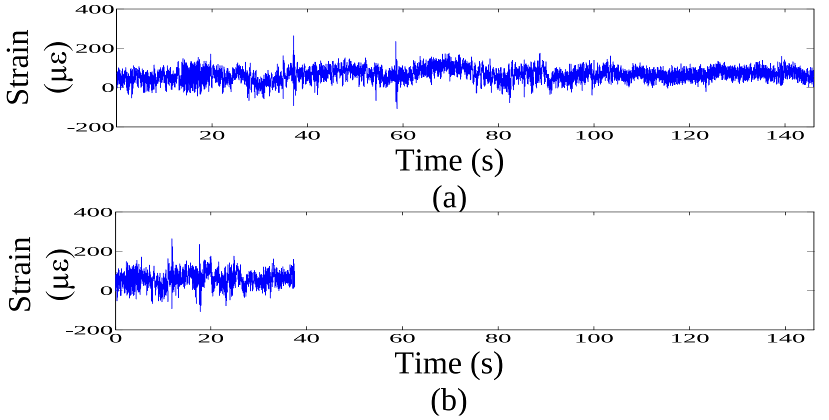

Fig. 3: The WT: (a) original, (b) edited.

In order to prove that the WT was the best technique for the FDE, all data extracted using other techniques also were extracted using the WT. From the results, it was found that the WT could produce shorter data than other techniques did. For the STFT, it was able to shorten the signal up to 23%. However, using the WT, the signal was shortened up to 58%, or 35% shorter than the STFT was. For the 60-second signal extracted using the S-transform and resulted 47 seconds, the edited signal was only 14 seconds using the WT. It was 55% shorter than the S-transform was. Figure 4 shows the results of the extraction processes.

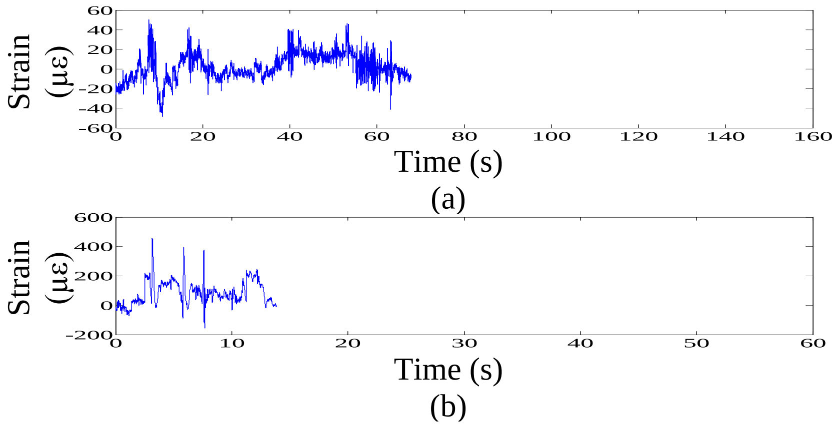

Fig. 4: The modified signals using the WT: (a) 68 seconds, (b) 14 seconds.

Conclusion:

This work discussed on the FDE for extracting the fatigue features measured at a lower suspension arm of sedan cars. In the last decade, several FDEs were found involving the STFT, the WT and the S-transform. In this study, the techniques were compared in order to find out the best one. From the analyses, it was found that the

WT was the best technique for the FDE. It was because the technique could shorten a fatigue signal up to 77% and maintained the fatigue damage of 98%. The change of the statistics was only 7%.

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