1. Introduction

This article investigates the fault detection problem of a roller bearing system, through monitoring the variation of proper orthogonal values of the covariance matrix developed from the highest frequency component, i.e. the IMF of signals decomposed by EMD. All the measured bearing vibration signals are de-noised through a wavelet-based thresholding function, before carrying out fault detection. For comparison, the kurtosis value of a fault signal is also presented, to substantiate the feasibility of an IMF-based fault detection approach.

2. Signal Processing and Feature Extraction

2.1. Wavelet-based De-noising

Unlike a bandwidth-based low-pass filter, the wavelet de-noising scheme does not influence the fundamental nature of the signal, because the wavelet transform may remove the noise according to rescaling in both the frequency and time domain simultaneously. Noise corrupted vibration signal, especially with sharp transients, can be de-noised through the thresholding function in wavelet domains. Depending on properly selected threshold rules, detail coefficients of the decomposed signal are selectively preserved or suppressed.

2.2. Empirical Mode Decomposition (EMD)

Recently, a generalized form of spectral analysis, the Hilbert–Huang transform (HHT), has been developed to tackle non-stationary and nonlinear signal. HHT-based signal processing has two components: the Hilbert spectral transform, and empirical mode decomposition (EMD). The major limitations of Fourier spectral analysis are the assumptions of stationarity and linearity of the underlying signal. It is known that the Hilbert transform of an arbitrary time series $x(t)$ is defined as

$$Y(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau} d\tau$$

(1)

2.3. Proper Orthogonal Decomposition (POD)

Modeling and verification of a dynamic system demands a statistical technique that projects dominant mode to its subspace, namely proper orthogonal decomposition (POD), which is also known as Karhunen–Loève decomposition. The underlying nature of POD represents the empirical modes of a system, and is identical to singular value decomposition (SVD), or principal component analysis (PCA).

3. Experimental Setup and Data Collection

Figures 1 show the time history data measured from the bearing system between 0.1 to 0.2 second without de-noising: one without damage (Figure 1 (a)) and the other one (Figure 1 (b)) having the scratch damage of bearing. The repeated peaks caused by the periodic impact between the faults in the race surface and rolling
elements are clearly exhibited in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Measured bearing signals: (a) healthy condition, (b) damaged condition

4. Fault Detection and Discussions

Having de-noised, elastic waves due to collision of the defect remain intact. Although the overall power of the signal has been moderately reduced, the repeated peaks are clearly remained after wavelet de-noising process. After de-noising, we equally segmented measured healthy and damaged signals into 10 segments, respectively. Using these de-noised segments, EMD is carried out to extract IMFs for both healthy and damaged bearing signal segments. And, Figure 2 and 3 are collection of the first IMFs to develop covariance matrices of healthy and damaged bearing, respectively.

![Figure 2](image2.png)

**Figure 2.** Profile of the collection of the first IMFs from healthy bearing acceleration: 10 segments

![Figure 3](image3.png)

**Figure 3.** Profile of the collection of first IMFs from damaged bearing acceleration: 10 segments

Figure 4 shows the profile of singular values (or equivalently proper orthogonal values) of the covariance matrix of the collection of the first IMFs as shown in Figure 2 and 3. It is obvious that singular values from the fault bearing vibration signal provide higher than normal bearing.

![Figure 4](image4.png)

**Figure 4.** Proper orthogonal values of the collected covariance matrix of the IMFs from segments

5. Conclusions

Experimental validation of a condition monitoring system for a roller-bearing system has been performed. Here, we assumed a bearing fault as a scratch-mark on the surface of the inner race. Before performing fault detection, wavelet-based de-noising has been carried out through a soft-thresholding scheme. After de-noising, EMD is carried out to extract IMFs of collected segments of vibration signals. Finally, the POV of collected IMFs are compared before and after the occurrence of bearing defects.

Acknowledgements

This work was supported by the research program titled “Development of condition monitoring algorithm for the KTX gearbox system using vibration signal” from the Korea Ministry of Land, Transport and Maritime Affairs.