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Condition Monitoring Using Nonparametric Control Charts Based on One-Class Support Vector Machine

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1. Introduction

A condition-based maintenance (CBM) has been widely used in many complex systems as a maintenance approach with the rapid growth of sensing technologies. The CBM aims to avoid unnecessary maintenance tasks by taking preventive maintenance actions [1]. The condition of the systems is evaluated by the measurements that are monitored in CBM called indirect condition monitoring [2]. For example, Bae et al. [3] proposed the indirect condition monitoring using control chart based on wavelet spectrum for a steam turbine generator.

In this paper, we propose a nonparametric control chart by specifying the control limit based on one-class support vector machine (SVM) to prevent the failure of systems. The proposed methods are applied to the real data.

2. One-Class Support Vector Machine

One-class SVM has been widely used to deal with novelty detection or one-class classification [4]. The primal optimization problem for the one-class SVM is defined as

$$\begin{aligned} &\text{Minimize} && t(\boldsymbol{w},\xi,\rho)=\tfrac{1}{2}\|\boldsymbol{w}\|^2-\rho+\tfrac{1}{mv}\textstyle\sum_{i=1}^{m}\xi_i \\ &\text{Subject to} && \langle\boldsymbol{\Phi}(x_i),\boldsymbol{w}\rangle+b\ge\rho-\xi_i \\ & && \xi_i\ge 0,\;\; i=1,\dots,m, \end{aligned} \tag{1}$$

Where m is the number of support vectors, $\boldsymbol{w}$ is the solution of one-class SVM, and v is an upper bound on the fraction of outliers. $\boldsymbol{\Phi}(\cdot)$ is the kernel function that performs nonlinear mapping in high-dimensional feature space. The most used kernel functions are the Gaussian radial basis function (RBF) kernel, the Laplace radial basis function (RBF) kernel, and polynomial kernel in Table 1.

Table 1 Kernel function for one-class SVM

Kernel	Equation
Gaussian RBF kernel	$\exp(-\sigma\|\boldsymbol{x}-\boldsymbol{x}'\|^2)$
Laplace RBF kernel	$\exp(-\sigma\|\boldsymbol{x}-\boldsymbol{x}'\|)$
Polynomial kernel	$(\text{scale}\langle\boldsymbol{x},\boldsymbol{x}'\rangle+\text{offset})^{\text{deg.}}$

3. Nonparametric Control Chart

A multivariate control chart is a traditional way of monitoring multivariate data in statistical process control (SPC). *Hotelling's* T^2 control chart is the most widely used multivariate control chart. It requires the assumption that the statistics follow the multivariate normal distribution. However, most multivariate data from complex systems does not follows multivariate normal distribution. To address this limitation, many nonparametric control charts have been proposed [5-6]. Mahalanobis [6] introduced the nonparametric control chart represented by the following Mahalanobis depth measure

$$MD(\boldsymbol{x})=\frac{1}{1+(\boldsymbol{x}-\boldsymbol{\mu})^T\boldsymbol{\Sigma}^{-1}(\boldsymbol{x}-\boldsymbol{\mu})}, \tag{2}$$

with mean vector $\boldsymbol{\mu}$ and variance-covariance matrix $\boldsymbol{\Sigma}$.

4. Applications

The proposed methods are applied the anemometers data. An anemometer is equipment used for measuring speed or direction of air flows physically, and the information obtained from anemometers is utilized in various industries such as Emergency Management, Internet of Things (IoT), etc. Therefore, if the failure of anemometers occurs, it can result in cumulative expenses as well as measuring errors. Fig. 1 shows the result of nonparametric control chart based on one-class SVM. The application result shows that it enables not only the real-time condition monitoring, but also the anomaly detection in advance of the occurrence of failure.

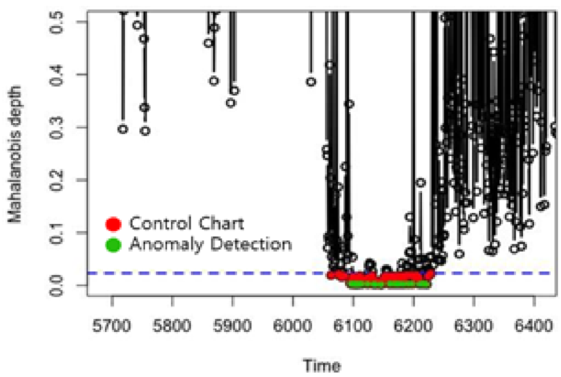

Fig.1 Result of nonparametric control chart

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