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Structural Safety 28 (2006) 392–406
STRUCTURAL SAFETY
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Support vector regression for on-line health monitoring of large-scale structures

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Received 20 November 2005; accepted 1 December 2005
Available online 10 March 2006

Abstract

Large-scale, structural health monitoring remains a challenge especially when I/O measurement data are contaminated by high-level noise. A novel approach that uses incremental support vector regression (SVR), a promising statistics technology, is proposed for large-scale, structural health monitoring. Due to the potential properties of this novel SVR, the SVR-based approach makes structural health monitoring accurately and robustly. A sub-structure strategy is utilized to reduce the number of unknown parameters in the health monitoring formula, thereby making large-scale structural health monitoring possible. Lastly, an incremental SVR training algorithm adopted for the SVR-based approach not only markedly reduces computation time, but identifies structural parameters on-line. Numerical examples show that results of this SVR-based approach for large-scale structural health monitoring are accurate and robust, even when observed data are contaminated with different kinds and intensity levels of noise.
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Keywords: Support vector regression; Sub-structure; On-line; Robust health monitoring

1. Introduction

Civil, mechanical, or aerospace structures may be damaged during strong natural disasters or rapidly deteriorate because of age, underlining the need for a robust methodology to monitor structural health. Although much attention has been paid to damage detection problems using such methods as neural networks and statistic filters [1–3], structural health monitoring remains a challenge, particularly when input and output (I/O) measurements are contaminated by high-level noise. Related function estimation methods therefore need further investigation to ensure robust structural health monitoring. For linear regression problems, robustness statistics aim at describing the structure best fitting the bulk of the empirical data using the function

$$y_i = \boldsymbol{w}^{\mathrm{T}}\boldsymbol{x}_i + b, \tag{1}$$

where $(\boldsymbol{x}_i, y_i)$ is a set of measurements $(i = 1, \ldots, N)$, $\boldsymbol{w}$ a regression coefficient vector, and b the model offset.

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0167-4730/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.strusafe.2005.12.001

The classical regression approach is the least squares (LS) method, which provides easy computation but is sensitive to outliers, i.e., a data point that is located far from the rest of the data. Support vector regression (SVR) is a novel statistical technology with robustness. A least squares version (LS-SVR) extends the SVR theory. It offers a concise formulation and rapid computation, but is not robust to non-Gaussian noise [4–6]. A comparison of these regression methods (LS, SVR, and LS-SVR) is provided to clarify their basic concepts and mathematical backgrounds. Next, an SVR-based approach for large-scale structural health monitoring by a sub-structural strategy is suggested. Lastly, a 30-DOF shear-building and a 52-DOF truss are used as structural health monitoring examples to show the efficiency of the proposed approach.

2. SVR basic concepts

2.1. Least squares method (LS)

For easy understanding of the SVR, we begin with the LS method which minimizes the sum of squared residuals

$$R_{\mathrm{LS}} = \sum_{i=1}^{N} (y_i - \boldsymbol{w}^{\mathrm{T}} \boldsymbol{x}_i)^2. \tag{2}$$

The LS estimator, a statistic cornerstone, is sensitive to outliers. LS derivatives therefore have been developed to make robust regressions. The least median squares (LMS) method [7] aims at minimizing the least median of the squared residuals instead of their sum as in the LS method. It gives enhanced performance by replacing the mean by the much less sensitive median. Another statistical technique for linear model estimation is the least trimmed squares (LTS) method [8], which minimizes the trimmed sum of residuals squares and provides a robust alternative to the classical LS regression method. Other robust estimators, such as the total LS and S-estimators [9], also can withstand a high level of contamination including outliers and leverage points.

2.2. Support vector regression (SVR)

The support vector machine (SVM) is an exclusively data based modeling technique with a powerful potential for function estimation application. It originally was developed for classification (SVC) purposes before extension to regression (SVR) problems [5,10,11]. Unlike the Gaussian loss function (Fig. 1a) used in the LS method, a novel ε-insensitive loss function is adopted in the SVR. The best loss function for estimate depends on the distribution of observation noise, e.g., Gaussian loss function is better for unbiased estimates, whereas the Laplace (least modulo) loss function (Fig. 1b) is better under Laplace noise conditions. In the real world, the noise distribution usually is unknown and far from both the Gaussian and Laplace noise

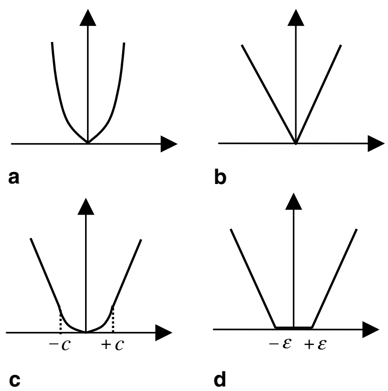

Fig. 1. Loss functions in different regression methods. (a) Gaussian, (b) Laplace (c) Huber and (d) ϵ-insensitive.

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