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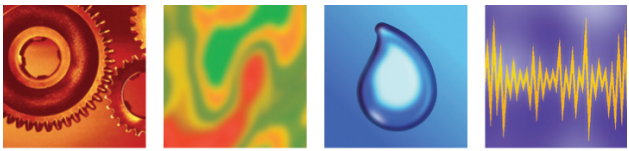

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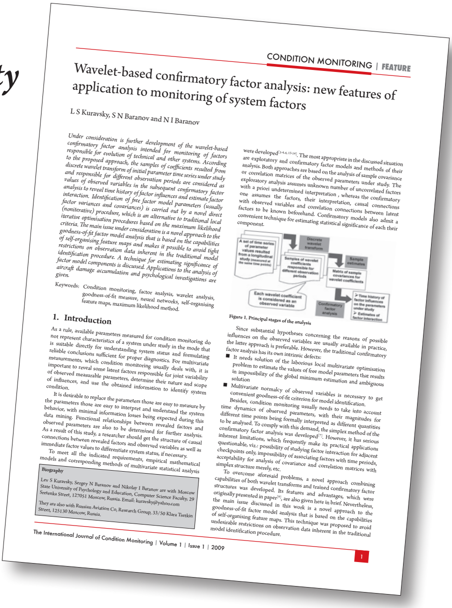

Wavelet-based confirmatory factor analysis: new features of application to monitoring of system factors

L S Kuravsky, S N Baranov and N I Baranov

Under consideration is further development of the wavelet-based confirmatory factor analysis intended for monitoring of factors responsible for evolution of technical and other systems. According to the proposed approach, the samples of coefficients resulted from discrete wavelet transform of initial parameter time series under study and responsible for different observation periods are considered as values of observed variables in the subsequent confirmatory factor analysis to reveal time history of factor influences and estimate factor interaction. Identification of free factor model parameters (usually factor variances and covariances) is carried out by a novel direct (noniterative) procedure, which is an alternative to traditional local iterative optimisation procedures based on the maximum likelihood criteria. The main issue under consideration is a novel approach to the goodness-of-fit factor model analysis that is based on the capabilities of self-organising feature maps and makes it possible to avoid tight restrictions on observation data inherent in the traditional model identification procedure. A technique for estimating significance of factor model components is discussed. Applications to the analysis of aircraft damage accumulation and psychological investigations are given.

Keywords: Condition monitoring, factor analysis, wavelet analysis, goodness-of-fit measure, neural networks, self-organising feature maps, maximum likelihood method.

1. Introduction

As a rule, available parameters measured for condition monitoring do not represent characteristics of a system under study in the mode that is suitable directly for understanding system status and formulating reliable conclusions sufficient for proper diagnostics. For multivariate measurements, which condition monitoring usually deals with, it is important to reveal some latent factors responsible for joint variability of observed measurable parameters, determine their nature and scope of influences, and use the obtained information to identify system condition.

It is desirable to replace the parameters those are easy to measure by the parameters those are easy to interpret and understand the system behavior, with minimal information losses being expected during this data mining. Functional relationships between revealed factors and observed parameters are also to be determined for further analysis. As a result of this study, a researcher should get the structure of causal connections between revealed factors and observed variables as well as immediate factor values to differentiate system status, if necessary.

To meet all the indicated requirements, empirical mathematical models and corresponding methods of multivariate statistical analysis were developed[3-4, 6, 13-14]. The most appropriate in the discussed situation are exploratory and confirmatory factor models and methods of their analysis. Both approaches are based on the analysis of sample covariance or correlation matrices of the observed parameters under study. The exploratory analysis assumes unknown number of uncorrelated factors with a priori undetermined interpretation , whereas the confirmatory one assumes the factors, their interpretation, causal connections with observed variables and correlation connections between latent factors to be known beforehand. Confirmatory models also admit a convenient technique for estimating statistical significance of each their component.

Figure 1. Principal stages of the analysis

Since substantial hypotheses concerning the reasons of possible influences on the observed variables are usually available in practice, the latter approach is preferable. However, the traditional confirmatory factor analysis has its own intrinsic defects:

- It needs solution of the laborious local multivariate optimisation problem to estimate the values of free model parameters that results in impossibility of the global minimum estimation and ambiguous solution
- Multivariate normalcy of observed variables is necessary to get convenient goodness-of-fit criterion for model identification.

Besides, condition monitoring usually needs to take into account time dynamics of observed parameters, with their magnitudes for different time points being formally interpreted as different quantities to be analysed. To comply with this demand, the simplex method of the confirmatory factor analysis was developed[7]. However, it has serious inherent limitations, which frequently make its practical applications questionable, viz.: possibility of studying factor interaction for adjacent checkpoints only, impossibility of associating factors with time periods, acceptability for analysis of covariance and correlation matrices with simplex structure merely, etc.

To overcome aforesaid problems, a novel approach combining capabilities of both wavelet transforms and trained confirmatory factor structures was developed. Its features and advantages, which were originally presented in paper[9], are also given here in brief. Nevertheless, the main issue discussed in this work is a novel approach to the goodness-of-fit factor model analysis that is based on the capabilities of self-organising feature maps. This technique was proposed to avoid undesirable restrictions on observation data inherent in the traditional model identification procedure.

Biography

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