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Analysis of traffic-induced vibrations by blind source separation with application in building monitoring

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Abstract

The paper presents an approach that may enable the separation of the vibrations induced by underground traffic from the vibrations induced by other sources, based on Second Order Blind Identification (SOBI) algorithm. The signals recorded in different locations of an instrumented building are mixed signals from different internal and external vibration sources. The blind source separation algorithm will estimate the independent vibration sources together with their mixing model. This model can be used to determine the contribution of each source in different measurement points, to evaluate the effect of the vibration sources and their potential for building damage. The above approach has been tested in simulation and on a building subject to different traffic forms.

Keywords: Blind source separation; Second-order statistics; Traffic-induced vibration; Building monitoring

1. Introduction

The vibration problem, produced by different sources, frequently arises in building monitoring. Common internal vibration sources are machinery, elevators and the activities of occupants. External sources include earthquakes, wind, blasting and construction operations, road and rail traffic, airborne vibrations [6]. During the last three decades, the interaction problem between moving vehicles and buildings has drawn much attention. The advent of high-speed digital computers has made it possible to analyze the interaction problem with more sophisticated buildings and vehicle models.

Noise and vibrations from road and rail traffic through residential areas are ones of major concern, because nearby buildings and residential areas need to be protected from them. Like most vibration problems, road and rail traffic vibrations can be characterized by a source-path-receiver scenario. Vehicle contact with irregularities of the road and rail surface induce dynamic loads, that generate stress waves, which propagate in the soil, eventually reaching the foundations of adjacent buildings and causing them to vibrate. Road traffic vibrations are caused by heavy vehicles such as buses and trucks. Passenger cars and light trucks rarely induce vibrations that are perceptive in buildings. Road traffic tends to produce vibrations in the range from 5 to 25 Hz. Rail traffic vibrations are produced in a similar way by vehicle contact with irregularities in the rail surface. The produced vibrations in this case are in the range from 60 to 100 Hz, according with [6].

The problem of vibration caused by underground traffic is discussed in [7,12,13]. Other aspects of the vibration analysis of bridges under moving vehicles and trains can be found in [1]. The environmental problems of vibrations,

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caused by train/traffic, construction activities and factory operation, and other man-made sources are investigated in [9], for their prediction, control and mitigation, to improve the quality of life. Vibration of bridges and buildings under moving vehicles and trains is of great theoretical and practical significance in civil engineering.

The paper presents an approach able to separate the vibrations induced by underground traffic from the vibrations induced by other sources, based on blind source separation, when Second Order Blind Identification (SOBI) algorithm is used.

The recorded vibrations in different locations of an instrumented building are mixed signals induced by internal and external vibration sources. The blind source separation algorithm will estimate the independent vibration sources, as well as the mixing model of these signals. This model can be used to determine the contribution of each source in different measurement points, to evaluate the effect of vibration sources and their potential for building damage. The approach has been tested in simulation and on a building subject to different traffic forms.

The outline of this paper is as follows. In Section 2, we present the blind source separation problem, which includes: problem formulation, identificability of model, algorithms. In Section 3 we discuss the Second Order Blind Identification (SOBI) algorithm and some aspects concerning its implementation. Finally, we present, in Section 4, a case study concerning the separation of the vibrations induced by underground traffic from the vibrations induced by other sources, based on SOBI algorithm, and conclusions.

2. Blind source separation

2.1. Problem formulation

Blind source separation (BSS) deals with the problem of recovering multiple sources from their mixture [8].

The simple model for BSS assumes the existence of n independent signals $s_1(t), \ldots, s_n(t)$ and the observation of as many mixtures $x_1(t), \ldots, x_n(t)$, these mixtures being linear and instantaneous, i.e.

$$x_i(t) = \sum_{j=1}^{n} a_{ij} s_j(t) \tag{1}$$

for each $i = 1, n$. This is compactly represented by the mixing equation

$$\mathbf{x}(t) = \mathbf{A}\mathbf{s}(t) \tag{2}$$

where $\mathbf{s}(t) = [s_1(t), \ldots, s_n(t)]^T$ is an $n \times 1$ column vector collecting the source signals, vector $\mathbf{x}(t)$ collects the n observed signals and the square $n \times n$ "mixing matrix" $\mathbf{A}$ contains the mixture coefficients. The BSS problem consists in recovering the source vector $\mathbf{s}(t)$ using only the observed data $\mathbf{x}(t)$, the assumption of independence among the entries of the input vector $\mathbf{s}(t)$ and some possible a priori information about the probability distribution of the inputs. It can be formulated as the computation of an $n \times n$ "separating matrix" $\mathbf{B}$ whose output $\hat{\mathbf{s}}(t)$

$$\hat{\mathbf{s}}(t) = \mathbf{B}\mathbf{x}(t) \tag{3}$$

is an estimate of the vector $\mathbf{s}(t)$ of the source signals.

A "source" means here an original signal, i.e. independent component. "Blind" means that we have very little, if any, information on the mixing matrix, and make little assumptions on the source signals.

BSS is closely related to the Independent Component Analysis (ICA). ICA is one method, perhaps the most widely used, for performing blind source separation.

In many applications, it would be more realistic to assume that there is some noise in the measurements, which would mean adding a noise term in the model:

$$\begin{aligned} \mathbf{y}(t) &= \mathbf{A}\mathbf{s}(t) \\ \mathbf{x}(t) &= \mathbf{y}(t) + \mathbf{n}(t) \end{aligned} \tag{4}$$

2.2. Identificability of the ICA model

The identificability of the noise-free ICA model has been treated in [4]. By imposing the following fundamental restrictions (in addition to the basic assumption of statistical independence), the identifiability of the model