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Enhancement of double integration procedure through spectral subtraction

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ABSTRACT

The presence of noise during dynamic measurements is one of the main sources of errors during integration procedures. To overcome this problem a methodology involving spectral subtraction of the noise amplitude from the signal is presented where noise characteristics are specified during 'silence' periods. This technique has been used for speech enhancement, and in this paper it is used to improve the integration procedure. The performance of the method is evaluated by means of both synthetic and real applications and by comparison with standard integration procedures. The proposed method has proven to lead to improved results, being a convenient way to address the integration problem, when noise is a major source of errors in the signal.

1. Introduction

A major problem regarding monitoring concerns the measurement of dynamic displacements. Often, the displacements are calculated from measurements of velocities, or accelerations, which demand a single or double integration, respectively. Besides errors related to acquisition, truncation and conversion from analogue to digital domain [1–3], significant errors in both low and high frequencies can arise when applying an integration procedure [4–6]. Hysteresis of the sensor, temperature effects, tilting and presence of noise are main sources of errors in the integration procedure [7–9].

The problems related to integration of dynamic records, in the field of earthquake engineering, have been addressed by several authors. Boore and Bommer [3] presented a survey on the standard available tools for the processing of seismic data, including both baseline corrections and low and high-pass filtering. Baseline corrections allow for adjustments in the low frequency range [10,11], while filtering can be applied for both low and high frequencies [3]. A general conclusion among the authors who study strong-motion recordings due to earthquakes [12–14] is that accurate determination of the permanent displacement is troublesome, often leading to miscellaneous results, specially due to the difficulties in computing the low frequency response of the displacement.

One of the sources of low frequency errors in the double integration procedure is the presence of noise in the signal. Tough for the most scenarios the noise errors can be removed by methodologies comprising filtering or baseline corrections, as soon as the noise frequencies match the main components of the signal, the integration procedure tends to magnify the errors caused by the presence of noise. Since noise and signal share the same frequencies, high-pass filtering or baseline corrections can correct for the deviation of the signal, but cannot remove the noise from the signal.

Liu and Pang [15] and Smyth and Wu [6] presented a methodology based on Kalman filtering [16] to overcome such problems. This technique consists of a recursive method where results are corrected by a prediction, based on the state space equation of the problem. The main difficulty of this procedure concerns the estimation of the process covariance [17,15], which often needs to be tuned to improve the results.

Jones and Levy [18] and Lodoño et al. [19] presented a technique based on the Karhunen–Loève transform [20]. This procedure involves the calculation of the eigenvectors from the correlation matrix of the results. The eigenvectors, which exhibit the lowest eigenvalues corresponding to noise are removed. The limitation of the method is found when the signal and noise fall within the same frequency range. This leads to a high covariance, and hence prevents proper noise removal.

In the present paper, an alternative method based on spectral subtraction [21–23] is presented. The method is based on the application of a technique for enhancement of speech signal to the integration problem. It takes advantage of the noise record to improve the signal by means of subtraction of the noise spectrum from the original signal spectrum.

This method by itself does not solve the problem of the double integration procedure. Instead, it is a tool to support the predictions of the real displacement by intervening in one of the causes of errors in the integration procedure, which is the presence of noise during signal acquisition.

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