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Control Engineering Practice 15 (2007) 1135–1148
CONTROL ENGINEERING PRACTICE
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A modified empirical mode decomposition (EMD) process for oscillation characterization in control loops

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Received 11 May 2005; accepted 29 January 2007
Available online 30 March 2007

Abstract

This paper focuses on a new method for characterizing oscillations in measurements from control loops in chemical processes. The proposed method uses a modified empirical mode decomposition (EMD) process to uncover all the zero-crossings in the data. It is shown that this procedure characterizes the following attributes of the oscillations: (i) non-constant mean, (ii) time instances when the oscillations are present, (iii) strength of the oscillations at different times, (iv) time period of each sweep of oscillation. The proposed approach is tested on more than 150 industrial control loop data and results obtained for 10 loops are discussed. The utility of the characterization approach in the area of oscillation analysis is also discussed.
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Keywords: Oscillation detection; Oscillation diagnosis; Performance monitoring; Signal analysis; Empirical mode decomposition

1. Introduction

It is well known that performance degradation in control loops manifest as one or more of the following: (i) poor set point (SP) tracking, (ii) oscillations, (iii) poor disturbance rejection and (iv) excessive final control element variation. Industrial surveys over the last decade indicate that only about one-third of industrial controllers provide acceptable performance and about 30% (Bialkowski, 1993; Desborough & Miller, 2001; Ender, 1993) of all control loops oscillate. Since oscillations can lead to loss of energy and off-spec products, isolating the root cause for oscillations is important for improving the performance of the oscillating control loops. Automatic detection of oscillation can be used to focus the operators' attention on control loops that might have performance problems and has become a standard activity. Analysis of oscillation in control loops is approached as a two-step process, namely, oscillation detection followed by oscillation diagnosis. The methods proposed for oscillation diagnosis assume that oscillation has, *a priori*, been detected. Oscillation diagnosis can suffer when the oscillation detection procedure fails or reports inaccurate oscillation periods. In this work, a novel oscillation characterization scheme that can directly provide metrics for oscillation diagnosis is proposed. First, a brief description of existing oscillation detection methods is provided.

1.1. Background

Hägglund (1995) proposed a technique to detect oscillating loops "on-line" using the IAE criterion and an "off-line" procedure to find the root cause of oscillation. This method does not assume any particular shape for oscillation and only requires that the measurement deviate significantly beyond a threshold. Hägglund (1995) also proposed a diagnostic procedure for finding the source of oscillation and eliminating it. The diagnostic procedure is carried out by disconnecting the feedback (i.e. switching the controller to manual mode). This approach is simple and efficient, and probably the most comprehensive

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0967-0661/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.conengprac.2007.01.014

procedure available for diagnosing the root cause of oscillations. However, switching the controller to manual mode may not be always allowed. Further, it may not be possible for a control engineer to apply this approach on thousands of loops in a routine fashion. Thornhill and Hägglund (1997) presented an off-line technique for detecting oscillations using a regularity factor. This method requires the user to specify the root mean square value of the noise and a threshold. Miao and Seborg (1999) used autocorrelation function and proposed an oscillation index (0—no oscillation, 1—highly oscillating). Industrial experience appears to be favorable and oscillations were detected with reasonable reliability. Thornhill and Hägglund (1997) and Thornhill, Huang, and Zhang (2003) proposed a set of procedures to detect and diagnose oscillating loops using off-line data. Desborough and Harris (1992) combine the techniques of controller performance assessment along with operational signatures (OP-PV plots) and spectral analysis of the controller errors for diagnosis and have tested their approach on industrial loops. Recently, Tangirala, Shah, and Thornhill (2005) presented a new visualization tool termed as power spectral correlation map (PSCMAP) to detect plant wide oscillation. Matsuo and Sasaoka (2005) presented an interesting oscillation detection procedure using wavelet transforms. Wavelet analysis, currently a popular tool for analyzing non-stationary data, is essentially an adjustable window Fourier spectral analysis. It gives a time-frequency characterization of the signal and is useful in analyzing data with gradual frequency changes. Although wavelet analysis is promising, its success depends on several factors such as the number of levels, choice of mother wavelet and scaling filter, and importantly, the level considered for analysis. Hence, automating wavelet analysis for thousands of industrial control loops to detect/diagnose oscillations will be a difficult task (Srinivasan, 2005). Figs. 1 and 2 show industrial loops that were diagnosed (by plant engineers) to limit cycle due to high static friction in control valves. It is seen that the oscillations have time varying frequency and magnitude, and is also intermittent. The use of FFT/Spectral, correlation methods (Miao & Seborg, 1999; Pryor, 1982; Thornhill et al., 2003) or computing the area under the signal between successive zero crossings (Forsman & Stattin, 1999; Hägglund, 1995; Thornhill & Hägglund, 1997) can detect oscillations in the signal only under restrictive assumptions such as the data is stationary and the oscillations are periodic. However, these methods are prone to error in detecting and estimating the frequency or period when the process data has non-constant mean. Careful observation of industrial data often indicates more than one oscillation mode due to a combination of: slow changes in SP, constant effect of external disturbances and hardware faults.

1.2. Focus of this work

The techniques presented so far were intended to detect the presence of oscillation in control loops. Some techniques also report the corresponding oscillation period. However, if by some means, from the data analysis one can extract the start and end time of oscillations along with their respective zero-crossings, then using these attributes of oscillation, the following tasks can be performed:

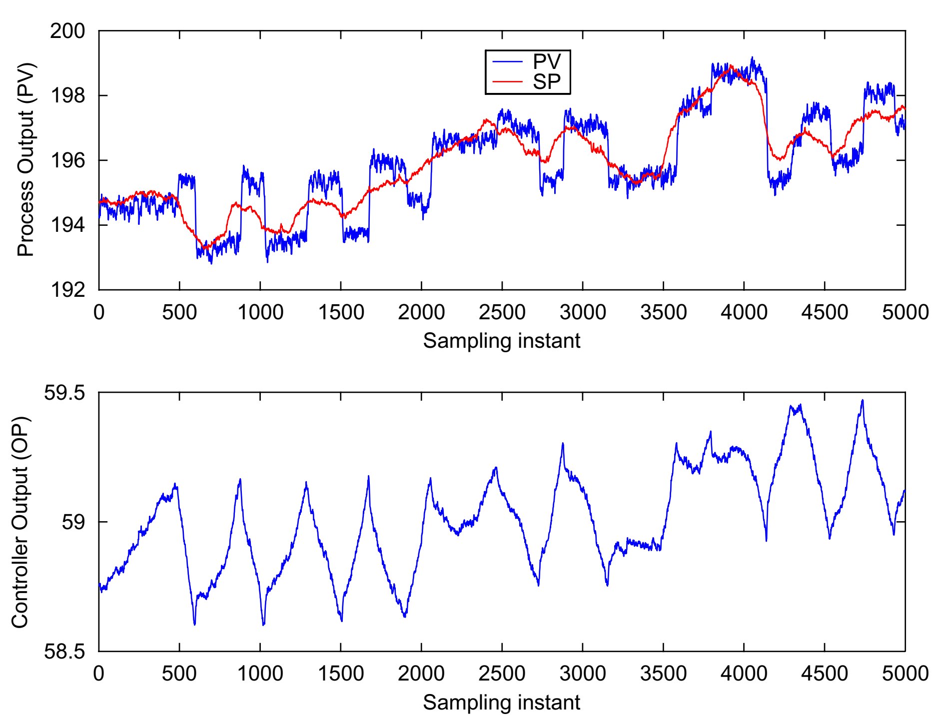

Fig. 1. Flow loop with slowly varying set-point (SP) and oscillating due to high static friction in the control valve.

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