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Procedia IUTAM 22 (2017) 67 – 74

Procedia IUTAM

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IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems

A noise correction embedded identification approach for delays and parameters in nonlinear delay systems

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Abstract

To identify unknown parameters from the noise-polluted measurement in time-delayed systems, this paper proposes the incremental harmonic balance based approach. By assuming that the steady response is periodic and the noise pollution does not change the periodicity of the measured response, this approach expands the ideal and measured response into the form of Fourier series. With this process, the noise correction can be parameterized as the harmonic increments of the measured response so that the noise correction can be determined by the same process of the identification of the unknown parameters. Numerical examples are given to verify the efficiency of the proposed approach. In comparison with the identified parameters without noise correction, the results show that the accuracy of the ones with noise correction is significantly improved. This achievement also implies that the proposed approach is reliable in similar cases of engineering applications.

Peer-review under responsibility of organizing committee of the IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems

Keywords: parameter identification; noise correction; time delay; state dependent delay; nonlinear system

1. Introduction

As an important parameter to the behavior of dynamic system, time delay has attracted extensive discussion from a range of perspectives for decades. Among them, a hot issue is the parameter identification for time-delayed systems. Distinct from the systems without time delay, the motion equation of the delayed system is fundamentally changed to

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Peer-review under responsibility of organizing committee of the IUTAM Symposium on Nonlinear and Delayed Dynamics of Mechatronic Systems
doi:10.1016/j.piutam.2017.08.010

the functional form with respect to time delay. Compared to constructing a particular identification algorithm, it is more difficult to analyze the parameter identifiability of the time-delayed systems. Fortunately, this problem has been figured out in the literature, see [1-3] for time-delayed linear systems and [4-6] for time-delayed nonlinear systems. A common conclusion is that when the system is differentiable with respect to the unknown parameters and has sufficient input-output samples, the unknown parameters are identifiable. From a geometric view, the differentiability ensures gradient existence so that parameter search direction can be defined; the sufficiency ensures the surjective mapping so that the identified parameters are locally or globally unique. These studies provide fundamental theory for parameter identification of time-delayed systems. Following their achievements, one may hence conveniently put his effort on identification algorithm constructing.

The central work in algorithm construction is finding an approach to effectively represent the gradient, or actually finding a method to properly update the unknown parameters. Using the direct gradient definition, Loxton et al [7-9] and Zhang et al [10] developed the identification algorithms for systems with discrete time delays; Hartung [11, 12] developed the algorithm for systems with state dependent delays. Especially, the algorithm proposed in [7-9] applies auxiliary time-delayed system to achieve the gradient calculation instead of standard differentiation. A significant advantage is that it avoids complex mathematical derivation typically when the system has high dimensions. Besides, [7-9], [11], and [12] construct the cost function by calculating the error between the measured response and the estimated response. Therefore, they need to refresh the estimated response by integrating the candidate differential system in every iteration step of parameter identification. When the initial parameters are not properly set, the iteration may take too many steps and the integral may obviously increase the time costing. The algorithm proposed in [10], instead, constructs the cost function by calculating the residue term caused by the difference between the ideal parameters and the estimated ones. Therefore, when the estimated parameters are updated, the cost function can be conveniently refreshed with no requirement of response re-estimating. Apart from the gradient based methods that adopt direct gradient definition, the unknown parameters may also be updated by adaptive methods [13-15], sliding mode observers [16, 17], or other artificial intelligent approaches [18, 19]. These indirect methods may be considered as the synchronization process. Theoretically, they construct a candidate system with tunable parameters, where the coupling with the real system is represented as the error function between the true response and the estimated one. Once the error function vanishes to zero, the response of the candidate system will be synchronized to that of the real system, and the tunable parameters will converge to true values. Due to this kind of instantaneous parameter adaption ability, these synchronization processes are also widely known as online identification methods. However, it does not mean the online methods are better than the offline ones. For example, when the measured response is polluted by noise, it is much easier for an offline method to hold high identification accuracy by evaluating the noise over a sufficient long time period, see [9] and [10].

From the brief review of the studies in parameter identification of time-delayed systems, we noticed that:

- The problem of the parameter identifiability has been basically figured out;
- Parameter identification algorithms have been developed to an extent of systems with state dependent delays;
- Offline methods are preferred for convenient treating of noise-polluted measurements.

Moreover, in our successive research of the parameter identification, we noticed that the noise in the measurement is not necessarily white with zero mean value. For example, when the sensor used for response measuring is ICP® (Integrated Circuit Piezoelectric) or IEPE (Integrated Electronics Piezo Electric) type, the constant component of the response will be automatically neglected because the DC (Direct Current) component is used as power supply of the integrated circuits. We further find that if this kind of DC offset is not corrected in parameter identification, the identified parameters may deviate a lot from the true ones. Besides, when the nonlinearity of a delayed system is not that strong, one may not be able to distinct the higher order response from the noise. This case, in turn, also deteriorates the accuracy of the identified parameters. To fix this problem caused by noise, the most effective way is directly correcting the noise pollution in parameter identification. However, to the best knowledge of the authors, very few studies have been conducted on this intention. Therefore, it excites the motivation of the present paper.

To summarize, the work that we intend to put effort on is proposing an advanced identification approach with noise correction so that the accuracy of the identified parameters can be improved. Besides, taking into account of the achievements mentioned in the bulleted list, the approach would be better to be compatible with cases of both discrete and state dependent time delays, and is preferred to adopt the offline approach for convenient noise correcting. To achieve these goals, we propose the incremental harmonic balance based approach, which is a modification of the