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A time domain approach for identifying nonlinear vibrating structures by subspace methods

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Abstract

Starting from the perspective of nonlinearities as internal feedback forces, a method in the time domain for the identification of nonlinear vibrating structures is described. Although its formulation is very simple, particular care has to be taken to reduce the ill-conditioning of the problem, in order to find numerically stable solutions. To this purpose the robustness and the high numerical performances of the subspace algorithms are successfully exploited, as demonstrated by the implementation of the method on simulated data from single and multi-degree of freedom systems with typical nonlinear characteristics. The method allows to estimate the coefficients of the nonlinearities away from the location of the applied excitations and also to identify the linear dynamic compliance matrix when the number of excitations is smaller than the number of response locations. The results comparison reported in this paper highlights the key advantage of the proposed method: the capability of treating multi-degree of freedom nonlinear systems holding different types of nonlinearities and the capability of selecting non-negligible nonlinear terms, with a light computational effort and with a limited number of time samples.
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1. Introduction

Identification of nonlinear dynamical systems has been thoroughly investigated in recent years and the number of papers published is the proof of growing interest within the research community and also of its effectiveness within the industrial framework. An exhaustive list of the techniques developed to identify the behaviour of nonlinear dynamical systems is hard to write; a few of these techniques, for instance, had a brief success, being sometimes too complicated or not applicable over a wide range of real Multi-Degree Of Freedom (MDOF) systems. A recent up-to-date article draws a complete picture describing the past and recent developments in system identification of nonlinear dynamical structures [1].

The number of methods developed is large and, generally, no method exists to be adopted whenever, for any type of nonlinearity, system complexity or exciting force. A comprehensive list should include the coherence

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Nomenclature

A	dynamical system matrix of the state-space model
A_c	dynamical system matrix of the continuous time state-space model
B	input matrix of the state-space model
B_c	input matrix of the continuous time state-space model
c	viscous damping coefficient
C	output matrix of the state-space model
C_v	viscous damping matrix
d	deadspace
D	direct feedthrough matrix of the state-space model
f	external force vector
f_{nl}	nonlinear internal force vector
F_E	"input" vector of the NIFO formulation
$g_j(t)$	jth scalar nonlinear function
h	number of degrees of freedom
H	Frequency Response Function matrix of the underlying linear system
H_E	"extended" Frequency Response Function matrix of the nonlinear system
I	identity matrix
i	number of block rows in block Hankel matrices
k	stiffness coefficient
K	stiffness matrix
l	number of columns in block Hankel matrices
L_{nj}	location vector of the jth nonlinearity
m	mass coefficient
M	mass matrix
n	dimension of the state vector
N_{avg}	number of spectral averages
N_i	number of input degrees of freedom (external forces)
N_o	number of output degrees of freedom
$\mathcal{O}_i$	oblique projection matrix
p	number of nonlinear functions
q	dimension of the output vector y
r	time instant
s	number of available measurements
t	time
Δt	sampling period
T	non-singular $n \times n$ similarity transformation matrix
u	input vector
u_r	input at time instant r
$U_{0\|2i-1}$	input block Hankel matrix
v_r	measurement noise at time instant r
w_r	process noise at time instant r
W_p	past inputs and outputs matrix
x	state vector
x_r	state at time instant r
y	output vector
y_r	output at time instant r
$Y_{0\|2i-1}$	output block Hankel matrix
z	generalised displacement
Γ_i	extended observability matrix

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