Biomorphic control of the stochastic vibrations

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Abstract

The report describes the approach that by modal expansion modules to obtain measurements of natural forms of elastic vibrations. For these modules offer close negative feedback. Biomorphic is based on the possibility of selecting the desired number of modes, depending on the task. Thus, by the control algorithm with a variable number of feedback.

The application of the biomorphic algorithm to the problem of random forced vibrations simply supported beam shown the high efficiency of the algorithm. Comparison with conventional local connections based on PID - regulators, shows that a much smaller amount of feedback, this algorithm provides a greater degree of vibration reduction. Also were investigated the robustness of the algorithm biomorphic control.

1 Introduction

Active suppression of random vibration of structures is an important task of distributed systems. The exciter of such vibrations is often a wind load, various acoustic effects and, to a first approximation, earthquake. The main feature of such problems is the determining influence of the mechanical part of the controlled object, which, due to its spectral properties often produces "coloration" of the random vibrations. The degree of the "coloration" may be so high that such variations are considered as determined with periodic excitation.

In the 60's of the 20th century have been solved the problem of balancing of long rotors [1]. The main feature of these decisions was a small number of sensors, the long system had only two points of its arrangement. Inertial forces of the test masses, which were fixed at different points of the rotor used as vibration exciter.

The ideology of separation control of the elastic object on control of individual modes has been formulated as a modal control [2] and developed in [3,4].

Were carried out successful experiments on the implementation of this approach [5].

Optimization the gain structure and the feedback based on H_2 and H_∞ criteria is described as the most robust in the row articles about the control of elastic objects [6-10]. Comparison with the results of the modal control shows that the using of optimal criteria can reduce the error of structures stabilization. Bat comparison is made for systems with a relatively small number of sensors and activators.

The modal control system is usually used with a given small number of modes, and a limited number of sensors (for example, 9 activators and 9 sensors for the elastic plate, allow you to control own just 2-3 modes).

To restore the missing data using the Kalman filter [11], which in itself reduces the robustness of the control due to presence of the object model inside the filter. This model requires the separate identification of all the parameters of the object, which leads to great influence of the model accuracy to the control quality.

In the synthesis of control systems of elastic object is also used optimal control with local feedback. The parameters of the local controllers are optimized. This controllers connect each sensor to its activator. The number and arrangement of sensors are optimized. As a result of the optimization of sensor failure or any distortion of signals can lead to significant distortions in the system of vibration protection.

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However, wildlife uses whole fields of sensors and their number is constantly increasing in the learning process, as the nervous tissue, in this case, is growing. Modern technologies make it possible to use that experience in a new approach to the management of distributed mechanical systems. Reduction of the cost of electronics and new methods of transmission and processing of data allowed apply in practice the fields of sensors, and comparable with the number of elements of activators [12-15].

Thus, we can ignore the limitations related to a small number of sensors in the development of advanced elastic body control systems. In these conditions, it is possible to improve the accuracy and robustness of the control is not due to optimization of the regulators, but by changing the structure of the control system. Especially as the local feedback limits opportunities for joint control of the activators and the fact thus reduce the efficiency of vibration protection.

2 Biomorphic approach to active vibration protection system

Consider the finite-dimensional model of elastic controlled mechanical object in the linear approximation. The equations have the form such object

$$\begin{array}{l} J\ddot{X} + C_0 X = Bu + Gw \\ Y = CX \\ X(0) = X_0 \\ \dot{X}(0) = V_0 \end{array} , \qquad (1)$$

where X - vector of state variables of the object, with dimension $[n]$, Y- vector of observations with dimension $[m]$, u - control vector with dimension $[l]$, w - vector of external, uncontrollable forces, with dimensions $[q]$, $X_0,\ V_0$ - vector of initial conditions, J - inertia matrix of dimension $[n \times n]$, C_0 - stiffness matrix of dimension $[n \times n]$, G - external force matrix of the linearized equations system of dimension $[n \times l]$, B- control matrix of the linearized equations system of dimension $[n \times q]$, C- observer matrix (equation observing sensors) dimension $[m \times n]$.

In these equations, we do not consider the dynamics of electronic devices for data collection and processing, as well as the dynamics of the power converters that feed activators, considering their much higher frequency than the mechanical part of the object.Standard mechatronic approach [12] suggests that the feedback sensor located in places application control actions so, the numbers m and l are the same and we can construct $m$feedback loops. In each of them we organize control in the form

$$u_i = -H_i y_i, \qquad (2)$$

where u_i - the components of the control vector, y_i- the component of observation vector, H_i- the operator control system in the i- feedback loop. Typically used PID - regulators, in the space of placeLaplace $H_i(p)$ is a fractional rational function with denominator and numerator of the second order.

This approach approximates the part of the object, which is controlled by the feedback loop in the form of concentrated mass and elastic ties. This model reflects the real situation approximately.

We use to control the decomposition approach [2]. The eigenforms form of an elastic object gives nonsingular transformation matrix S such that $SJ^{-1}C_0S^{-1}$ is diagonal.

Multiply both sides of the system (1) on a matrix S and make the change of variables $SX = q$, then we obtain the system

$$\begin{array}{l} \ddot{q} + 2N_0\dot{q} = -\Omega_A q + SJ^{-1}u + SJ^{-1}Gw \\ Y = CS^{-1}q \\ q(0) = SX_0,\ \dot{q}(0) = SV_0 \end{array}, \tag{3}$$

where q - the vector of a eigenmodes of an elastic object with dimension $[N]$, which will replace the vector of state variables, $2N_0\dot{q}$ - damping.

A problem may be the definition of a vector according to the sensors, but from the beginning, we believe that the sensor is sufficient, that is, the information matrix (C^TC) - not singular. So we use the generalized matrix inversion for the recovery procedure $C^{-1} = (C^TC)^{-1}C^T$, while

$$q = S(C^TC)^{-1}C^TY. \tag{4}$$

Equations (3) are connected, which prevents limit the number of variables q to control with variable number of feedbacks. As part of biomorphic approach suggests choosing control u as $u = kF(q^* - q)$, where q^*- the set the value of modules form, k- gain coefficient, which can generally be the operator (eg, PID - controller), F - matrix, such that $SJ^{-1}BF$a diagonal structure. Let us assume that the choice of such a matrix F is possible. Then from (1) we obtain

$$\begin{array}{l} \ddot{q} + 2N_0\dot{q} = -\Omega_0 q + k\Lambda_B(q^* - q) + SGw \\ q = S(C^TC)^{-1}C^TY \\ q(0) = SX_0,\ \dot{q}(0) = SV_0 \end{array}. \tag{5}$$

Here N_0, Ω_0, Λ_B - the diagonal matrix q- vector form module whose dimension is equal to the number of feedback loops.

3 Vibrations of an elastic beam under external random moment

As a model of the object is selected beam Bernoulli simply supported at the ends. Model of the beam is shown in Figure 1.

Vibrations of a beam excited the application in the middle of a random bending moment. The angle of rotation of the tangent to the center line beam at each time is measured in ten transverse sections, chosen uniformly along the beam, except the ends. In these sections can be applied control moments, in order to reduce the amplitude of the steady oscillations. Dynamics equations of the beam

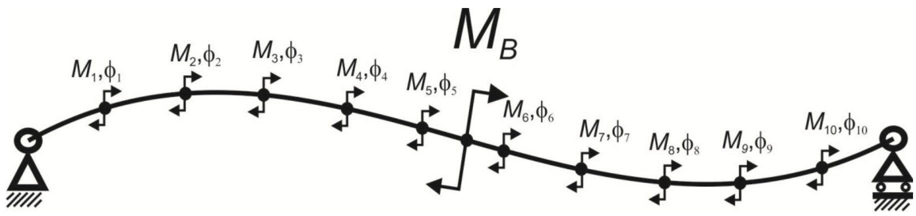

Figure 1: Model of a controlled beam with ten drives

$$EIw^{IV} + \rho A\ddot{w} = 0, \tag{6}$$

where w - cross travel, $x\rho$ - longitudinal coordinate measured from the left end of the beam, ρ- density of beam material, I- the moment of inertia of the cross section, E-Young's modulus of the material A- a beam cross sectional area.

The boundary conditions reflect the way to fix the ends of the beam length l

$$w_{x=0} = 0, \quad M_{x=0} = 0,$$
$$w_{x=l} = 0, \quad M_{x=l} = 0,$$

where M- bending moment of the beams.

The initial state corresponds to the straight configuration

$$w_{t=0} = 0, \quad \dot{w}_{t=0} = 0.$$

The solution of (6) will be sought in the form of a series of orthogonal forms $u_k(x)$:

$$w(x,t) = \sum_{k=1}^{\infty} u_k(x) q_k(t), \tag{7}$$

where

$$q_k(t) = \frac{2}{l}\int_0^l w(x,t) u_k(x) dx. \tag{8}$$

In a computer model of the beam length $l = 1470$ mm, the lowest natural bending frequency of which is $\lambda_1 = 20\frac{rad}{c}$, the expansion was implemented in four forms. Forms of free oscillations are calculated analytically. Focused external moment was taken as $M_B = \sum_{i=1}^{40} \sin\left((\omega_0 + ki)\, t\right)$, ω =$5\frac{rad}{c}$, ω_0 =$1\frac{rad}{c}$, k - was chosen such that the sum $\omega_0 + ki$ to be in the range $[1; 200]\frac{rad}{c}$. Sensors that measure the angle $\vartheta(x,t)$, located in ten sections along the beam evenly, eliminating the ends. The numbering of the sensors was carried out, starting at the left end of the beam.

See Figure 2 for the second sensor readings.

4 Local vibration reduction

Control moments $M_l(t)$ are applied in the same section where the sensors are rotation angles. Feedback control performed by measuring the angles

$$M_l = -K_l \vartheta(x_l, t),$$

where K_l - the feedback factor in the section l. The coefficients of the feedback will be taking the same in all sections and equal $K_l = 100\ \frac{Nm}{rad}$.

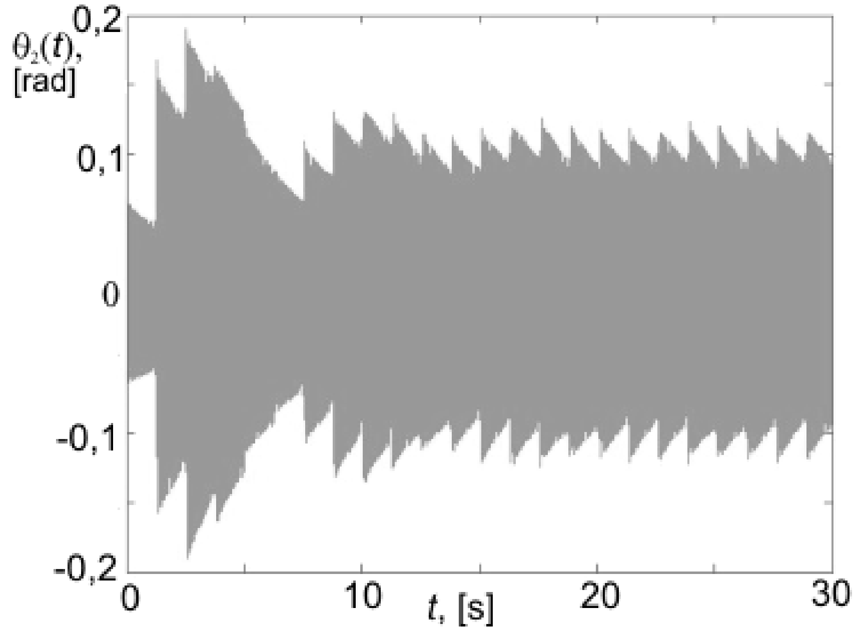

Figure 2: Oscillogram of feedback signal from the sensor number 2 under forced

5 Biomorphic control

We modify the feedback control with the proposed concept of biomorphic control.Calculate the scalar product of the vector formed by the values of the angles in the sections where the mounted sensors, and the vector of the k- mode of vibration, made up of the values calculated in the same sections q_k:

$$M_l(t) = -K_l \sum_{k=1}^{m} s_{k,l} q_k(t).$$

Weight coefficients $s_{k,l}$ will be individualized for each section. As will be apparent to the task they must be proportional to their own forms $\vartheta_k(x_l)$.

Figure 3 shows the data from the second sensor. Gray highlighted result of feedback control by measuring. The black curve corresponds to the case where the control points generated by the formula $\mu_l(t) = K_l \sum_{k=1}^{4} s_{k,l} q_k(t)$ when the control has four feedbacks. Weighting factors are assigned as follows $s_{k,l} = \widehat{\vartheta}_k\ (x_l)$. The estimation $\widehat{\vartheta}_k\ (x_l)$ was made to the first significant digit. Feedback coefficients were equal $K_l = 100\ \frac{Nm}{rad}$.

6 Conclusions

Analysis of the results shows that the accuracy of biomorphic control by two orders higher than that of the standard method with a set of local control loops at a comparable number of feedback loops and the same gain.

Please note that the error in setting the parameters management system was very large (almost up to the sign), and the quality control is still higher than in the standard case.

Thus, the proposed algorithm has good robustness, which allows using it in practice.

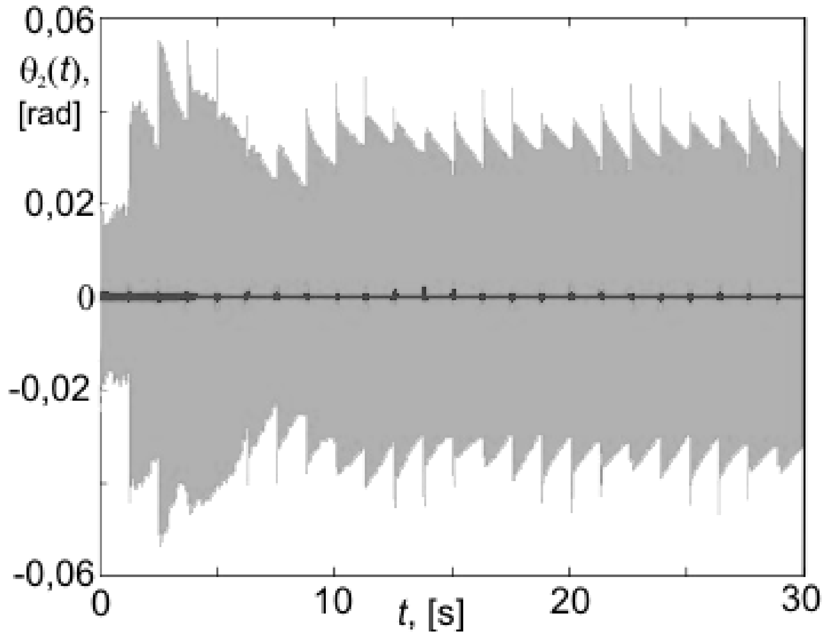

Figure 3: Waveform signal sensor number 2. Results of the control for the ten local loop (gray) and biomorphic control with four forms (four feedback loop), rounded matrix F coefficients to the first significant digit (black).

Acknowledgements

The financial support of the Austrian Center of Competence in Mechatronics (hereinafter ACCM).

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