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Model-Free Adaptive Control Method Applied to Vibration Reduction of a Flexible Crane as MIMO System

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Model-free adaptive control (MFAC) approaches are able to be used when system models are not available and some task- or system-specific conditions are fulfilled. This avoids to require exact mathematical models with respect to consideration of modeling errors even in the case of nonlinear systems to be controlled. The control strategy denoted as model-free when for controller design only the available system data is used. In this contribution based on the knowledge of MFAC, an extension of the existing approach is presented and applied to unknown multivariable systems. The main control idea is that an estimation of real-time system parameters which represent system dynamical variations is realized by using only inputs and outputs. A novel control algorithm is derived by minimizing both output tracking error and its derivative. The designed controller is applied to a flexible crane, representing a class of MIMO systems. The simulation results demonstrate that the vibrations of a crane system could be reduced significantly.

1 Introduction

Model-free control (MFC) is a data-driven control method which only uses available system inputs and outputs to realize control tasks. For control design no mathematical model of the system is needed. Different MFC strategies are proposed in the last decades which can be divided into two groups according to data usage (on-line or off-line data) [1]. A typical MFC method which uses on-line data to generate control algorithm is denoted as model-free adaptive control, and is firstly introduced by Hou et al. [1]. The model-free control method possesses several advantages such as simple structure, low computational load, and guaranteed stability [2]. In mechanical flexible structures motion-induced vibrations are often difficult to be suppressed or reduced. Different model-based control approaches are introduced in which a precise dynamical model of the considered system has to be known. In this paper a model-free controller is designed and applied firstly to an elastic ship-mounted crane represented as MIMO system to reduce oscillations of the boom and the payload. Simulation results show that crane vibrations can be reduced significantly when using the proposed controller.

2 Model-free adaptive control theory

A general input/output (I/O) representation of unknown MIMO nonlinear systems is described in discrete-time [1] as

$$\mathbf{y}(k+1) = f(\mathbf{y}(k), ..., \mathbf{y}(k-m_y), \mathbf{u}(k), ..., \mathbf{u}(k-m_u)), \tag{1}$$

where $f(...)$ is an unknown nonlinear function; while m_y, m_u denotes the unknown order of the system outputs and inputs, respectively. The numbers of system input and output are assumed as known. As discussed in [1], it is assumed that the original system (1) can be expressed as a compact form dynamic linearized data model

$$\Delta\mathbf{y}(k+1) = \Phi(k)\Delta\mathbf{u}(k), \tag{2}$$

where $\Phi(k)$ is a time-varying parameter matrix of the system called Pseudo Jacobian Matrix (PJM) [1] which can be estimated and updated at every time instant k as

$$\hat{\Phi}(k) = \hat{\Phi}(k-1) + \frac{\eta\left[\mathbf{y}(k) - \mathbf{y}(k-1) - \hat{\Phi}(k-1)\Delta\mathbf{u}(k-1)\right]\Delta\mathbf{u}(k-1)^T}{\mu + \|\Delta\mathbf{u}(k-1)\|^2}. \tag{3}$$

The control goal behind is to minimize the output tracking errors $\left\|\mathbf{y}^d(k+1) - \mathbf{y}(k+1)\right\|$ by using the estimated matrix $\hat{\Phi}(k)$. The final control law results to

$$\mathbf{u}(k) = \mathbf{u}(k-1) + \frac{\rho\hat{\Phi}(k)\left[\mathbf{y}^d(k+1) - \mathbf{y}(k)\right]}{\lambda + \left\|\hat{\Phi}(k)\right\|^2}, \tag{4}$$

where $\mathbf{y}^d(k+1)$ denotes the desired ouputs, while η, ρ are step-size constants, and μ, λ denotes weighting factors.

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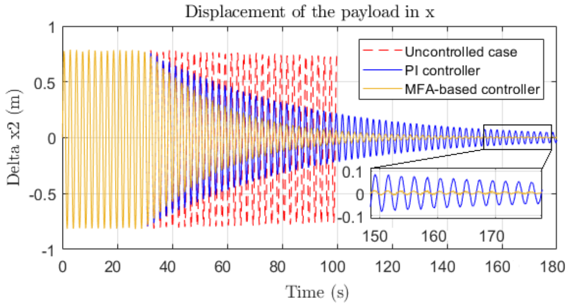

Fig. 1: Vibration control of the payload position in x-direction.

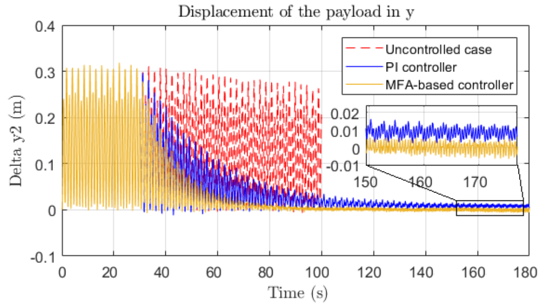

Fig. 2: Vibration control of the payload position in y-direction.

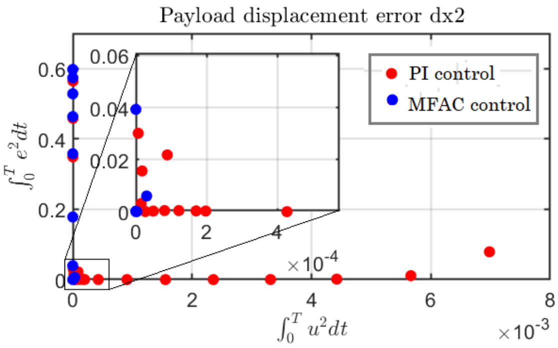

Fig. 3: Control performance evaluation of dx2.

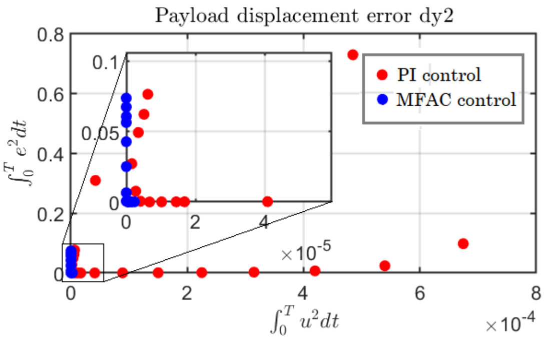

Fig. 4: Control performance evaluation of dy2.

3 Vibration control results of an elastic crane: A first simulation study

The proposed controller is applied firstly to reduce vibration of an elastic ship-mounted crane [3] representing a specific class of MIMO system. Due to non-zero initial position of the payload $\dot{\phi}_{20} = 5$ [rad/s], large oscillations of the payload and the elastic boom would be observed if no controller is applied. The vibration control results of the payload displacements in x- and y-directions are presented in Fig. 1 and Fig. 2, respectively. When using the simulation I/O data from [3] together with design controller parameters, it can be seen that better control results are derived by applying the MFA-based controller compared to the standard PI controller. In addition, the efficiency of two control approaches is also compared for different set of controller parameters (λ and K_p, K_i) by using the criteria [4] $C_{criterion} = [\int_0^T \mathbf{e}^2(t)dt, \int_0^T \mathbf{u}^2(t)dt]$. The results show that the model-free adaptive controller has better control performance in comparison with the PI controller as described in Fig. 3 and Fig. 4.

4 Conclusion

In this paper based on the theory of model-free control, a model-free adaptive controller is discussed and applied to a flexible MIMO crane for vibration reduction purpose. The efficience of the proposed method is verified numerically which shows the improved results.

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