Mechanical Systems and Signal Processing 46 (2014) 70–81

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Fuzzy crane control with sensorless payload deflection feedback for vibration reduction

Jaroslaw Smoczek *

AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, 30 Mickiewicza Av., 30-059 Krakow, Poland

A R T I C L E I N F O

Article history:
Received 14 August 2013
Received in revised form
30 October 2013
Accepted 23 December 2013
Available online 18 January 2014

Keywords:
Sensorless anti-sway control
Fuzzy logic
Robust control
Interval analysis

A B S T R A C T

Different types of cranes are widely used for shifting cargoes in building sites, shipping yards, container terminals and many manufacturing segments where the problem of fast and precise transferring a payload suspended on the ropes with oscillations reduction is frequently important to enhance the productivity, efficiency and safety. The paper presents the fuzzy logic-based robust feedback anti-sway control system which can be applicable either with or without a sensor of sway angle of a payload. The discrete-time control approach is based on the fuzzy interpolation of the controllers and crane dynamic model′s parameters with respect to the varying rope length and mass of a payload. The iterative procedure combining a pole placement method and interval analysis of closed-loop characteristic polynomial coefficients is proposed to design the robust control scheme. The sensorless anti-sway control application developed with using PAC system with RX3i controller was verified on the laboratory scaled overhead crane.

1. Introduction

Reduction of the vibration is a serious concern for many flexible systems ranging from flexible manipulators arms [1,2] to large industrial cranes which are extensively used for shifting goods in building sites, shipping yards, container terminals and many manufacturing segments [3,4]. Different types of cranes (e.g. container cranes, overhead cranes, tower cranes, jib cranes) realize the transportation operations through moving the cargos suspended at the end of flexible ropes. Thus, the problem of positioning accuracy, effectiveness and safety of cranes operations requires to implement a control system for reducing the pendulation effect.

Numerous researchers have proposed either the open-loop or closed-loop control solutions for vibration reduction, frequently addressing them to an anti-sway crane control problem. The feedback control strategy requires installing a reliable measurement system, that is sometimes difficult to maintain and costly. On the other hand, the open-loop anti-sway crane control systems, developed usually based on the input shaping [5–7] or optimal control theory [8,9], are sensitive to the disturbances owing to the lack of sway angle of a payload feedback. Hence, some works combine the open-loop control scheme with the feedback solutions to reduce swing induced by both the human operator and external disturbances [10].

The soft computing techniques, especially fuzzy logic, are widely employed in the closed-loop control schemes of flexible dynamic systems. The linguistic-rule-based fuzzy controllers are reported in [11–13]. Fuzzy logic-based strategies are proposed for PID gains tuning [14,15] and sliding mode control [16]. Takagi-Sugeno-Kang-type fuzzy controllers are

* Tel.: +48 126173104.
E-mail address: smoczek@agh.edu.pl

0888-3270/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ymssp.2013.12.012

proposed in Refs. [17–19]. Some researchers have adopted off-line or on-line techniques to design the fuzzy rule-based controller implemented in a crane control scheme. Membership functions tuning techniques have been developed based on an inverse dynamic [20], gradient algorithm [21], genetic algorithm [22,23], fuzzy clustering methods [19], and through applying artificial neural network [18,24].

The most of the fuzzy logic-based approaches to an anti-sway crane control problem, which are described in the literature are the linguistic rule-based strategies. The proposed techniques of fuzzy controller designing are mostly applied for only tuning the membership functions parameters for a fixed number of rules involving the training data examples. The robustness of crane control system is also frequently analyzed taking into account only the rope length variation. Furthermore, most of the control strategies are only proved using mathematical models or mechatronic laboratory models. Thus, there is still place for those researchers who are looking for the efficient control laws, software-hardware solutions and measurement equipment of crane control systems that could be implemented in the industrial practice.

This paper proposes a fuzzy logic-based robust feedback anti-sway control system which can be applicable either with or without a sensor of sway angle of a payload. The novelty approach to closed-loop anti-sway crane control with sensorless payload deflection feedback, as well as the interval analysis-based design of fuzzy logic-based control scheme is presented. The sensorless anti-sway discrete-time control approach is based on the feedback signal of payload deflection estimated by a pendulum model formulated as the discrete-time relation between the sway angle of a payload and crane speed. The fuzzy system is applied to interpolate the linear controllers and crane dynamic model parameters with respect to the varying rope length and mass of a payload. The iterative procedure combining a pole placement method and interval analysis of closed-loop characteristic polynomial coefficients was developed to design a fuzzy robust control scheme. The objective of a robust control system design is to find minimum number of operating points at which the discrete-time dynamic crane model parameters are estimated through the open-loop identification experiments and the linear controllers parameters are determined using a pole placement method. The method of designing a fuzzy logic-based scheduling system leads to determine the suitable number of fuzzy rules and fuzzy sets on the scheduling variables universe of discourse and distribution of triangular-shaped membership functions parameters, which satisfy the acceptable range of performances deterioration within the expected range of system parameters variation. The proposed method was applied to design and implement the sensorless anti-sway control system on the laboratory scaled overhead crane using PAC system with RX3i controller.

The paper is organized as follows. Section two describes a fuzzy logic-based discrete-time closed-loop control scheme for a planar model of a crane. In section three, the iterative procedure used to design a complete and coherent rules base (RB) of a fuzzy scheduler is proposed. Section four presents the experimental results obtained on the laboratory scaled overhead crane. Section five delivers the final conclusions.

2. Fuzzy interpolation-based control scheme

The proposed fuzzy logic-based adaptive control scheme of 2D crane is presented in Fig. 2. The sensorless anti-sway crane control system is based on the feedback signals of crane position and speed, rope length, mass of a payload, and sway angle of a payload estimated by a pendulum model assumed as the second-order discrete-time transmittance representing

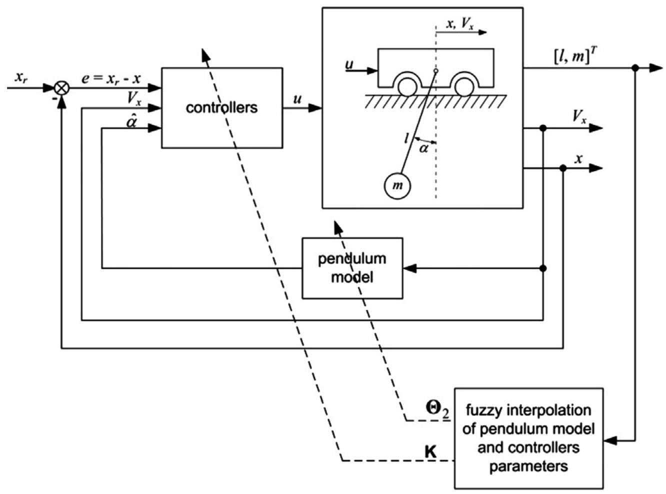

Fig. 1. Control scheme of 2D crane with estimation of sway angle of a payload and fuzzy logic-based interpolation of controllers and pendulum model parameters, where: m – mass of a payload, l – rope length, x_r, x – desired and current crane position, respectively, α, $\hat{\alpha}$- sway angle of a payload, and its estimated value, respectively, u – controlling signal.