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Review

Control strategies for crane systems: A comprehensive review

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ABSTRACT

Crane systems are tremendously utilised in numerous heavy load transportation industries, and therefore, the control of crane systems is a well-established research field. As the last review paper was published more than a decade ago, there is a lack of collected and organised information regarding the latest and the newest updates on control strategies for crane control systems. Hence, this paper presents a comprehensive review of crane control strategies discussing the latest research works during the years from 2000 to 2016. Various crane types and control issues are highlighted, followed by the main focus of this paper, an extensive review of the control schemes for diverse types of crane systems that have been carried out in the 21st century. A brief review on modelling of single-pendulum and double-pendulum crane systems is also given. In addition, anti-sway control systems for industrial cranes that are available on the market is described. This paper summarises most of the related work and also pays a special focus on research trends regarding the control of crane systems that have been previously published in the literature. It is envisaged that this review paper will be helpful to new researchers when identifying research directions for this particular area of interest.

Contents

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1. Introduction

Cranes are machines that are used for transporting heavy loads or hazardous materials from one place to another place. These actions commonly take place in industries such as factories, construction, marine industries and harbour loci. Numerous types of cranes are widely used in many industrial sectors, such as an overhead or bridge crane, a gantry crane, a boom crane and a rotary (tower) crane. They can be classified based upon the degrees of freedom that the support mechanism offers at the suspension point [1].

The issues in a crane system involve the ability of reducing the sway angle of the payload and moving it to a desired position with a fast crane motion [2]. In order to successfully transport the load to a desired point, the load swings need to be minimised [3]. The crane's motion is prone to an excessive load swing that could affect the positioning accuracy, the quality, the effectiveness and the safety. Consequently, a failure to control the sway angles would lead to a difficulty in the automation of the system by the worker, together with a possible damage to the quality of the load or the operating environment around the construction work. In addition, it would take a longer time being required for the task's completion and this may reduce the production volume. Statistics have shown that traditional docking equipment wastes more than 30% for fixing the load per the loading time [4].

Cranes can be controlled by using several approaches for their operations, which usually involve the process of gripping, lifting, transporting the load, then lowering and un-gripping the load. A damping capacity of the system plays a significant role towards the precision motion performance, where its capability can be further improved by applying passive or active damping techniques. External dampers such as dashpots and viscous dampers are examples of the passive alternative [5]. Besides, techniques to reduce crane sways by using a coriolis force produced by a radial spring and a damper [6] and a cable passive damper system [7] were also proposed. On the other hand, feedback or feed-forward control strategies are the active approaches that can be utilised. These strategies are the main focus of what is to be reviewed in this paper. It can be found that for more than one decade, there is no article in the literature that provides a comprehensive review of the control strategies for crane systems. The last review article was published in 2003 [1] and it presented research work between 1961 and 2001. The article reported on two approaches for the modelling of cranes and the various control techniques that were used for several cranes, especially for gantry and rotary cranes. Modelling to obtain an accurate dynamic model of a crane system is an important step towards the development of an efficient and satisfactory controller. In [1], modelling of various single-pendulum cranes were presented in details and has been an established research work. Nevertheless, modelling of double-pendulum cranes was not covered in [1]. A brief review paper was also presented in a conference in 2012 [8]. However, the article focused only on the work that was related to the applications of intelligent control for crane systems.

In this paper, initially, a brief review on modelling of single-pendulum and double-pendulum crane systems during the years from 2000 to 2016 is presented. As there is a lack of information regarding the latest and the newest updates, this paper then focuses on a comprehensive review of control strategies for numerous types of crane systems during the same period. This includes recent work and the latest work with up-to-date control schemes that were not reviewed in the previous review article [1]. The control strategies that are covered in this article are divided into open loop and closed-loop control techniques. In addition, anti-sway control systems for industrial cranes that are available on the market are also described. The goal is to organise and summarise most of the work, and to identify the research focus and the trends in the literature on the control of crane systems.

2. Crane types and control issues

Numerous types of cranes have been used in diverse industrial sectors. These include bridge cranes, gantry cranes, tower cranes (rotary) and boom cranes. In general, these cranes can be categorised into two groups, according to their structures and their motions: (1) Bridge cranes and gantry cranes, (2) Tower cranes and boom cranes. The structures of these cranes are illustrated in Fig. 1. A bridge crane, also known as an overhead crane, operates on an elevated runway system, along a production line, or the length of a factory. Commonly, it has three degrees of freedom (DOF) or hook motions in the *X*, *Y* and *Z* directions. The trolley can move to the right and to the left directions along the girder. On the other hand, the girder is