WEP Warwick Evans Publishing

International Journal of Mechanical and Electrical Engineering

ISSN: 3005-9615 (Print), ISSN: 3005-7132 (Online) | Volume 2, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijmee.v2n1.06
Journal homepage: https://wepub.org/index.php/IJMEE/index

Overview of Bridge Crane Control

Dan Lu, Fei Tan

School of Automation and Information Engineering, Sichuan University of Science Engineering, Zigong, 643000, China

ABSTRACT

This paper summarizes the research hotspot of underactuated mechanical system in nonlinear control field, and emphasizes its wide application in practical engineering, including space vehicle, inverted pendulum and navigation system. The Chinese government has supported the construction crane industry through a series of policies and regulations, providing guidance for its safe production and technical specifications. In the context of social development, the application demand of bridge gantry cranes in narrow environments is increasing, and the future development trend will focus on the direction of intelligence, science and technology and humanization. In recent decades, the research results on the positioning and pendulum of bridge crane at home and abroad are divided into open loop and closed loop control methods, and the control methods are described in detail in this paper.

KEYWORDS

Bridge Crane; Underactuated System; Nonlinear Control.

1. INTRODUCTION

Underactuated mechanical systems (referred to as underactuated systems), as a common system, are characterized by the fact that the number of input control variables is less than the number of system output degrees of freedom [1]. Common underactuated systems include space vehicle systems [2], inverted pendulum [3], navigation systems [4], etc. Underactuated system is a typical nonlinear system and is widely used in practical engineering. The in-depth study of underactuated systems is helpful to solve the control problem of general nonlinear systems, so the control of underactuated systems has become one of the research hotspots in the field of nonlinear control.

Our government's support for the construction crane industry mainly through the development and implementation of a series of policies and regulations, such as the Ministry of Housing and Urban-Rural Development issued in 2023 "on the good housing municipal engineering safety production management action to consolidate and improve the work of the Notice" provided for the completion of the construction enterprise safety production license before the end of 2023, To standardize the lifting machinery industry safety technology. In addition, China's relevant departments have also formulated a series of laws, regulations and policies to support the construction lifting machinery and equipment industry. With the development of society, more and more areas of bridge gantry cranes are used, and many Spaces do not support large cranes to work, so such a working environment requires a more efficient bridge crane control method. In the future, the development of cranes to intelligence, technology and humanization is an inevitable trend. China's bridge crane industry has nearly 70 years of development history, from scratch, from small to large, and gradually formed a relatively complete system, becoming one of the fastest growing industries in the machinery industry, providing powerful equipment support for national economic construction. According to the "2022-

2026 Portal crane market Status Survey and development Prospects Analysis Report" released by Hangzhou Zhongjing Zhisheng Market Research Co., LTD. : China's bridge and portal crane manufacturing industry in the "tenth Five-Year" and "eleventh Five-Year" period have made considerable development, in view of China's equipment manufacturing, energy and power, transportation logistics, automotive, shipbuilding, metallurgy, building materials and other strategic industries identified as the top priority for development, the vigorous development of these key industries directly gave rise to the prosperity of the lifting equipment industry. At the same time, China vigorously supports equipment manufacturing, energy and power, transportation and logistics, automobile, shipbuilding, metallurgy, building materials and other industries in the "Twelfth Five-Year Plan", which will further stimulate the demand for equipment manufacturing industries such as Bridges and gantry cranes, so that it can maintain sustained growth.

Bridge crane is a machine that transports heavy objects from a place to a designated location [5], which plays a significant role in engineering cranes and is widely used in Marine, production workshops, construction and port transportation. It is also a typical underactuated system [6], with nonlinear and multi-variable characteristics. Due to its underdrive characteristics and external interference, the cargo will swing for a long time, which seriously affects the work efficiency and safety of the bridge crane. Therefore, it is urgent to design high-performance automatic positioning and anti-swing control methods to improve the work efficiency and safety of overhead cranes.

2. RESEARCH STATUS AT HOME AND ABROAD

Domestic and foreign research on the realization of the dual objectives of bridge crane positioning and pendulum in recent decades has achieved certain results. According to whether state feedback information is needed, it can be roughly divided into two categories [7] : one is the open-loop control method, the other is the closed-loop research method.

2.1. Open-loop Control Status

Open-loop control has the advantage of low cost and easy implementation, without the need for additional sensors to measure the load swing Angle. However, its main disadvantage is that it does not consider the influence of system parameter changes and external disturbances on the control input, resulting in insufficient sensitivity to external disturbances. Common open-loop control methods include input shaping, off-line trajectory planning and optimal open-loop control. In practical applications, it is necessary to weigh its advantages and disadvantages and choose the control method suitable for the system performance and stability requirements.

2.1.1. Input Shaping

Input shaping is a real-time open-loop control technology. Because of its low control cost and excellent swing suppression effect, it has been widely used in feedforward control of bridge cranes. The main idea is to design an appropriate shaper to shape the acceleration signal of the truck by analyzing the swing period of the load. In this way, while ensuring that the vehicle reaches the destination quickly and accurately, it can also effectively inhibit the swing of the load. The input shaping method was originally proposed to solve the control problem of oscillating systems. Subsequently, Sing et al. [8] extended the method to the crane system to solve the problem of load swing, and achieved good results. In order to improve the robustness of the system, subsequent scholars proposed ZVD (Zero Vibration Derivative) shaping methods [9], EI (Extra-Insensitive) shaping methods and IS shaping methods [10]. In order to achieve optimal control performance, several shaping methods are generally combined. Yavuz et al. [11] scholars studied how to use hybrid control methods to perform AI-assisted transportation operations on a simple pendulum under variable conditions, and adopted zero vibration (ZV) input shaping (IS) method. Simple pendulum experimental device for different heights and variable weights. In order to realize closed-loop intelligent control, neural network (NN), generalized regression neural network (GRNN) and radial basis function network (RBFN) are used. Finally, according to the results, it is found that the proposed method contributes to the overall performance, especially in eliminating residual vibration. This could mean that hybrid control methods have the potential for practical applications for AI-assisted transport operations on simple pendulums under different height and variable weight conditions. Although the above shaping method can achieve no residual swing of the load, it is quite sensitive to external interference parameters. In addition, this type of control method is also sensitive to the oscillation frequency, so it is necessary to ensure that the initial swing Angle is as zero as possible when applied, otherwise it may lead to increased oscillation within the load. Therefore, the use of this control method in the actual working environment has some limitations, and its applicability should be carefully considered.

2.1.2. Off-line Trajectory Planning

Off-line trajectory planning is a common method in open-loop control technology. By analyzing the kinematics characteristics of the bridge crane system, the method designs a reference trajectory for the bridge crane, and uses the coupling relationship between the driving part and the underdriving part to achieve the fast and accurate destination and restrain the swing of the load. Zhang et al. [12] proposed an off-line time-optimal trajectory planning method for the first time, and found the optimal trajectory under the constraints of maximum swing Angle, maximum acceleration and maximum velocity through quasi-convex optimization technology. Fang Chunyong et al. [13] planned a smooth S-shaped curve for the vehicle and designed four adjustment parameters, including target running distance, maximum speed, maximum acceleration and initial degree. However, this method can only accurately make the vehicle reach the target position, but can not eliminate the load swing. In practical engineering applications, it is often necessary to combine with other high-performance feedback controllers, such as adaptive controllers, sliding mode controllers and model predictive controllers, to achieve more comprehensive control effects. This combination can help solve the limitations of off-line trajectory planning methods in swing suppression.

2.2. Status Quo of Closed Loop Control

Compared with the strict control environment required by open loop control, closed loop control has higher performance in the control of bridge crane. Because the closed-loop control has real-time state feedback information, the closed-loop control can better maintain the control performance when the bridge crane is faced with the uncertainty of the model and external interference (such as wind force, friction, etc.). Open loop control may be greatly affected in this case, and even lead to control failure in serious cases. In order to improve the robustness of the system, many scholars have conducted in-depth research on closed-loop control. Common closed-loop control methods include linear control, optimal control, intelligent control, adaptive control and robust control. In practical applications, the advantage of closed-loop control lies in the real-time response to system changes and external disturbances, which enables bridge cranes to perform tasks more stably and accurately. This is particularly important in industrial environments where high accuracy and robustness are required.

2.2.1. Linear Method

The linear control methods of bridge crane mainly include PID control and PD control. In order to solve the problem of load swing Angle, Xu Lefeng et al. [14] optimized the conventional PID control parameters of trolley displacement and controlled the swing Angle of lifting load. At the same time, the experimental results of anti-swing control system and non-anti-swing control system are compared and analyzed. Zhang Zhenhao et al. [15] adopted an Auto-Coupling Couple-Integration-differential (ACPID) control method based on state commands for the anti-roll control of two-dimensional bridge crane system. This method has practical application value in the field of high order underactuated control system. Simulation, experiment and comparison with other methods show that it is simpler and more efficient. In fact, most PID and PD control methods usually need to be combined with other algorithms to achieve better control results. Yavuz et al. [16] proposed a new stable nonlinear PID controller and conducted real-time experimental verification on gantry crane system. Through adaptive control technology, the underdrive system is described as a nonlinear mapping of control signals with hyperbolic tangent function, and the proportional error, integral error and derivative error are constrained. Enable the system to produce efficient and robust performance. An enhanced hybrid method based on bionic meta-heuristic particle swarm optimization is used to adjust the gain coefficient. The real-time results show that the performance of nonlinear PID is better than that of traditional PID. Bu Fanzhou et al. [17] proposed a kind of anti-roll control method of fuzzy and PID (Proportion Integral Differential), which integrates particle swarm optimization algorithm. Compared with the traditional PID anti-roll algorithm, the PSO fuzzy PID anti-roll algorithm shows obvious improvement in the aspects of speediness, stability and robustness. In general, PID and PD technologies have been relatively mature and achieved good results in the control of bridge crane.

2.2.2. Optimal Control

Optimal control theory is one of the important research contents of modern control theory. Its main idea is to select the optimal control scheme from a class of allowable control schemes according to the mathematical model of the controlled object, and achieve the optimal performance according to the required index. From the engineering point of view, optimal control is to seek the best control strategy under feasible conditions, so that the control system can optimally reach the target. In industrial applications, there are three main optimal Control strategies, namely Model Predictive Control (MPC) and Linear Quadratic Gaussian (Linear Quadratic Gaussian). LQG and Generalized Predictive Control (GPC).

Model predictive control can adjust multiple control variables, guarantee closed-loop stability, and can consider constraints, making it very useful in dealing with complex control problems. Many scholars have applied model predictive control to the control of bridge crane, and satisfactory experimental results have been obtained. Tysse et al. [18] proposed a new crane control system, which uses an NMPC tracking controller to accurately track the stability dynamics and limit the disturbance of the damping controller while being constrained by the control variables. The experimental results show that the proposed control system is effective in practical application. This research introduces a new control strategy for crane control. Garnier et al. [19] compared two different methods for identifying parameters of a continuous-time state-space model, including parameters for nonlinear static properties. Then, with the help of the identified friction model, the friction compensation control is implemented, which has a significant effect on improving the LQG control performance.

2.2.3. Robust Control

Robust control can maintain excellent control effect on the controlled object without the need for accurate process model and external interference, especially for the control system that takes stability and reliability as the primary goal, and the bridge crane belongs to this kind of system. Sliding mode control is a method known for its strong robustness, so it has been extensively studied by scholars.

The sliding mode control proposed by Nowacka[20] et al can rapidly suppress load swing with limited acceleration and speed. In order to obtain higher accuracy and robustness, sliding mode control is usually combined with other control methods. Cuong et al. [21] applied fractional calculus to sliding mode control (SMC) to build an adaptive robust control system for cranes with variable parameters and unknown wind direction. For comparison, this paper proposes another robust controller based on finite time sliding mode. The simulation and experimental results show that the adaptive fractional-order sliding mode control has advantages, and can track the drive state well and stabilize it under the condition of parameter uncertainty and unknown disturbance. Nguyen et al. [22] proposed a sliding mode control method considering the fuzzy modeling and finite time stability and bounded problems of the bridge crane system. In order to overcome the strong coupling of control inputs, they linearize the bridge crane system with fuzzy technology and establish a fuzzy bridge crane model with appropriate membership function. Considering various external interference factors, SMC method is used to stabilize the fuzzy system and has robustness to these interference signals. Finally, the simulation results of the proposed control strategy are given, and some existing algorithms are compared to verify the effectiveness of the proposed control strategy in the bridge crane system. In order to improve the transient control performance and robustness of the system, Zhang et al. [23] designed a sliding mode control (DESMC) method based on perturbation for 4-DOF tower crane system. The DESMC method produces an observation-based control method that does not require linearization operations and takes full advantage of the beneficial perturbation effects on the crane system. The effectiveness and robustness of the DESMC method are verified by the simulation results.

2.2.4. Adaptive Control

Adaptive control adjusts the input and output parameters online through the response of the system to achieve the optimal or sub-optimal performance index. Generally speaking, the crane will inevitably be affected by external interference, so a lot of research has been done on self-adaptation. Scholars proposed some automatic control methods for crane system, including some open-loop methods, such as input shaping method, trajectory planning method, etc., and proposed an adaptive tracking control method, which achieved good tracking performance under parameter uncertainty and external disturbance. Using passivity, a class of energy functions is designed as Lyapunov candidate functions. Based on this, an adaptive tracking controller is proposed to deal with parameter uncertainty. By means of Lyapunov stability analysis and Lassalle invariance principle, it is proved that the closed-loop system is asymptotically stable. Finally, through a series of experiments, the good performance of the proposed method is verified. Shen et al. [24] proposed a passive-based robust adaptive control method to restate the motion equation of a bridge crane and formulate an adaptive control law to ensure that the system has an output strictly passive (OSP) input-output mapping. The passivity theorem is used to prove that closed-loop systems are input-output stable when OSP negative feedback controllers are implemented. Convergence and boundedness in payload trajectory tracking errors are demonstrated by two candidate OSP feedback controllers, including constant gain and strictly positive Real (SPR) controllers. The proposed control method and the two most advanced control laws in the literature are used for numerical simulation and experiment to prove the practicability of the proposed control method and the improved performance of the proposed SPR controller in the experiment.

2.2.5. Intelligent Control

The idea of intelligent control appeared in the 1960s of the 20th century, and has been better applied. Neural Network (NN) and Fuzzy Logic Contronl (FLC) are widely used in crane systems. Smoczek et al. [25] proposed a method of designing anti-swing crane control system based on fuzzy logic and vertical pole placement method. The crane control system consists of a machine vision system for non-contact measurement of payload swing and an atypical stereo vision system based on a single camera, which is used to capture the stereo pair snapshot of the crane workspace, and a method for safe and time-optimal path planning of the payload using a heuristic graph search algorithm. Consider that cranes are typically controlled by a variety of actions, including lifting, lifting, carrying, and then lowering and grabbing the load. Yavuz et al. [26] demonstrated how to perform AI-assisted transport operations on a simple pendulum under variable conditions using hybrid control methods. The zero vibration (ZV) input shaping (IS) method is applied to a simple pendulum experimental device with different heights and variable weights. Neural network (NN), generalized regression neural network (GRNN) and radial basis function network (RBFN) are used as serial closed-loop intelligent control methods. The results show that the proposed method is helpful to eliminate the overall performance of residual vibration. Reduces the possibility of human error and improves safety, especially in the transport of fragile, sensitive materials or load transfer under dangerous conditions that make operator control very difficult.

3. SUMMARY

With the research of bridge crane control, some achievements have been made. In the future, we can study the more complicated object of double pendulum bridge crane, and study the application of bridge crane in complex and changeable engineering.

REFERENCES

[1] Research on Nonlinear Control Strategy of Underactuated Single-stage Pendulum and Two-stage Pendulum Bridge Crane [D]. Shandong University, 2018.

[2] Yang Yonggang, Yin Yikun. Dynamic surface sliding mode Control of rotorcraft UAV with Extended Observer [J]. Control Engineering: 1-9.

[3] Yu Zongyan, HAN Liantao, WANG Li. Design and Simulation of Linear Active Disturbance Rejection Controller for Linear Inverted Pendulum [J]. Automation & Instrumentation, 2023, 38(12): 85-90.

[4] Zhang Zong-Xin, Yang Chun-xi, Yang Jian-Quan, et al. Trajectory tracking of unsymmetrical underactuated unmanned vehicle with unknown Interference [J]. Control Engineering, 2023, 30(12): 2185-2191.

[5] Wang Jie, QIANG Baomin, HE Zhenxin, et al. Research on System Control Technology of Underdrive Bridge Crane [J]. Journal of Ordnance Equipment Engineering, 2019, 40(11): 116-121+159.

[6] Sun Ning, Fang Yongchun. Review of control methods for a class of underactuated systems [J]. Journal of Intelligent Systems, 2011, 6(3): 200-207.

[7] Chen He, Wu Qing-Xiang, Sun Ning, et al. Review of crane control methods for Large Size Cargo Transportation [J]. Journal of Intelligent Systems, 2022, 17(4): 824-838.

[8] Singhose W. Command shaping for flexible systems: A review of the first 50 years[J]. International Journal of Precision Engineering and Manufacturing, 2009, 10(4): 153-168.

[9] Masoud ZN, Alhazza KA. Frequency-Modulation Input Shaping Control of Double-Pendulum Overhead Cranes[J]. Journal of Dynamic Systems, Measurement, and Control, 2014, 136(2): 021005.

[10] Singhose W, Kim D, Kenison M. Input Shaping Control of Double-Pendulum Bridge Crane Oscillations[J]. Journal of Dynamic Systems, Measurement, and Control, 2008, 130(3): 034504.

[11] Yavuz H, Beller S. An intelligent serial connected hybrid control method for gantry cranes[J]. Mechanical Systems and Signal Processing, 2021, 146: 107011.

[12] Zhang X, Fang Y, Sun N. Minimum-Time Trajectory Planning for Underactuated Overhead Crane Systems With State and Control Constraints[J]. IEEE Transactions on Industrial Electronics, 2014, 61(12): 6915-6925.

[13] Fang Y, Ma B, Wang P, et al. A Motion Planning-Based Adaptive Control Method for an Underactuated Crane System[J]. IEEE Transactions on Control Systems Technology, 2011: 5711693.

[14] Xu Lefeng, Wang Hexin. Simulation Analysis of Crane anti-swing Control System based on PID [J]. Modern Information Technology, 2023, 7(15): 45-48.

[15] Zhang Zhenhao, Zeng Zhezhao, Wang Wei, et al. Auto-pid Anti-roll Control Strategy for Underdrive Bridge Crane [J]. Mechanical Science and Technology: 1-6.

[16] Valluru SK, Kaur M, Kartikeya K, et al. Experimental Investigation of Fully Informed Particle Swarm Optimization tuned Multi Loop L-PID and NL-PID Controllers for Gantry Crane System[J]. Procedia Computer Science, 2020, 171: 130-138.

[17] Bu Fanzhou, Sun Yuguo, LU Fengjiao. Fuzzy PID anti-roll control of bridge Crane based on particle swarm optimization [J]. Ship and Ocean Engineering, 2022, 38(4): 10-14.

[18] Tysse GO, Cibicik A, Tingelstad L, et al. Lyapunov-based damping controller with nonlinear MPC control of payload position for a knuckle boom crane[J]. Automatica, 2022, 140: 110219.

[19] Garnier H, Sibille P, Mensler M, et al. Pilot Crane Identification and Control in Presence of Friction[J]. IFAC Proceedings Volumes, 1996, 29(1): 4533-4538.

[20] Nowacka-Leverton A, Michałek M, Pazderski D, et al. Experimental verification of SMC with moving switching lines applied to hoisting crane vertical motion control[J]. ISA Transactions, 2012, 51(6): 682-693.

[21] Cuong HM, Dong HQ, Trieu PV, et al. Adaptive fractional-order terminal sliding mode control of rubber-tired gantry cranes with uncertainties and unknown disturbances[J]. Mechanical Systems and Signal Processing, 2021, 154: 107601.

[22] Nguyen VT, Yang C, Du C, et al. Design and implementation of finite time sliding mode controller for fuzzy overhead crane system[J]. ISA Transactions, 2022, 124: 374-385.

[23] Zhang M, Jing X, Zhu Z. Disturbance employment-based sliding mode control for 4-DOF tower crane systems[J]. Mechanical Systems and Signal Processing, 2021, 161: 107946.

[24] Shen PY, Schatz J, Caverly RJ. Passivity-based adaptive trajectory control of an underactuated 3-DOF overhead crane[J]. Control Engineering Practice, 2021, 112: 104834.

[25] Smoczek J, Szpytko J, Hyla P. The Application of an Intelligent Crane Control System[J]. IFAC Proceedings Volumes, 2012, 45(24): 280-285.

[26] Yavuz H, Beller S. An intelligent serial connected hybrid control method for gantry cranes[J]. Mechanical Systems and Signal Processing, 2021, 146: 107011.