SEMARAK ILMU PUBLISHING

Semarak Proceedings of Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.my/index.php/spaset/index
ISSN: 3083-9807

A Review of Anti-Swing Control for Cranes

Aina Syazwin[1,*], Liyana Ramli[2], Izzuddin M Lazim[2]

[1] Electronic Engineering, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia
[2] Department of Electronic and Electrical Engineering, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia

ABSTRACT

Crane systems play a critical role in industrial operations, enabling the precise movement of heavy loads. However, the inherent complexities, such as pendulum-like swinging and dynamic instability, present significant challenges in their control. This paper provides a review of control strategies employed in crane systems, with a focus on achieving stability, safety, and precision. A feed-forward control strategies such as input shaping are discussed in term of the effectiveness in minimizing the payload swing. Other control approaches are explored for their ability to handle nonlinearities and disturbances. The review emphasizes the need for robust, adaptive control mechanisms that can solve the addressed issues.

Keywords: *Open loop; input shaping; crane systems; control strategies; review*

1. Introduction

There are many types of cranes such as overhead cranes, tower cranes, gantry cranes and many more which are mainly used for lifting heavy objects and moving them from one place to another [1]. Crane systems play a critical role in various industrial applications, from construction to manufacturing, where precise and efficient load handling is essential.

Crane is frequently run by an experienced operator. Basically, it is expected for humans operating cranes to occasionally make mistakes. Inexperienced crane handlers are a common cause of accidents at construction sites [2]. For instance, the crane operator was moving the payload too quickly, which caused the payload to swing. Besides, the crane operators accelerated crane operation to increase productivity or output where many hazardous circumstances might arise when the crane is operated at a faster pace such as extreme payload swings might hit individuals and other objects.

Moreover, in crane systems, there are times when the crane system experiences internal or external disturbances. External disturbances are caused by environmental factors that are beyond the control of the crane operator but affect the crane's motion such as wind and ground vibrations [3]. While internal disturbances arise from the dynamic behavior of the crane system itself [4], often caused by mechanical and operational limitations such as friction and non-zero initial conditions. In crane systems, disturbances can negatively impact performance, leading to issues like load

[*] *Corresponding author.*
E-mail address: ainasyazwin174@gmail.com

https://doi.org/10.37934/spaset.1.1.121125a

oscillation, reduced positioning accuracy, and inefficiency. Therefore, understanding the types of disturbances is essential for developing effective control strategies.

There are three types of crane control strategies which are open loop control, closed loop control, and the combination of these techniques or in other word hybrid [5]. In open loop control design, there are several methods such as input shaping and filters. However, traditional control methods often struggle to mitigate oscillations effectively due to parameter uncertainties and disturbances.

This literature review aims to explore the evolution of crane control strategies, with a particular focus on adaptive input shaping techniques. Adaptive input shaping has emerged as a promising approach to enhance the control of crane systems. By predicting the system's response to input commands, this technique reduces oscillations by shaping the input in such a way that undesired vibrations are minimized. The review will also examine the theoretical foundations, key developments, and real-world applications of this method, providing insights into its effectiveness in crane system control.

2. Literature Review

2.1 Input Shaping Control Strategies

Input shaping is a simple strategy that can be used for reducing oscillation in a system. Input shaping, which involves configuring the impulses' amplitudes and temporal locations, requires a priori knowledge of system parameters such as natural frequency and damping ratio [6]. Development of an input shaping control technique can eliminate the oscillations in a flexible system [7].

There are many types of input shaping such as the Zero Vibration (ZV), Zero Vibration Derivative (ZVD), Zero Vibration Derivative Derivative (ZVDD), Unity Magnitude Zero Vibration (UMZV) and many more. The difference between these types of input shaper are the impulse amplitudes and the time parameters of the input shaping. ZV input shaper is the simplest input shaping technique [8] where it generates a series of impulses that are applied to the system in a way that cancels out the oscillations caused by system dynamics.

Singer and Seering adds an extra impulse to the sequence used in the ZV shaper, became ZVD shaper thereby increasing the system's tolerance to parameter uncertainties while maintaining zero residual vibration [8]. Then, additional derivatives were formed to get more and more robust input shaping design, such as Zero Vibration and two derivatives (ZVDD) [9,10]. However, obtaining more robustness leads to an increase in shaper duration or rise time [11].

To achieve robustness with fast rise time, adaptive input shaping was developed. For robustness, various identification methods were proposed to identify the frequency and damping ratio in real time subjected to the changes in system parameters. However, adaptation was a computational burden in real-time [11]. Then, UMZV shaper has negative impulses which produce a shorter shaper duration than ZV shaper [12]. In fact, UMZV resembles the finite actuated oscillatory system which is suitable for cranes that employ finite actuation states.

While ZV, ZVD, ZVDD and UMZV input shapers are effective at reducing oscillations in dynamic systems, they have inherent limitations that can make them less effective for the time-variant systems. Adaptive input shaping offers several advantages in addressing these issues. The adaptive input shaping was proposed in S. Grazioso *et al.,* [7] using the simplest input shaping namely Zero Vibration Input Adaptive Shaping (ZV-IPS). The method involves training an artificial neural network (ANN) to generate closed-form expressions, enabling real-time estimation of the amplitudes and temporal positions of the impulses. ANN is the term used to describe a computer model assumption of the biological brain. ANN is trained in the learning phase, typically offline until it has mastered its tasks through weight adaptation, then the recall phase is utilized to complete the evaluation or deployment phase. Several adaptive input shapers have been proposed and designed for real-time crane states subjected to payload hoisting [13-15], payload mass variations [13] and wind disturbances [15,16].

2.2 Other Control Strategies

There are several algorithms that can be used for real-time implementation in crane control systems such as fuzzy logic [17–21] Furthermore, optimization is crucial in crane control systems to achieve precise, efficient, and safe operations while minimizing unwanted effects like load sway, energy consumption, and operational delays. The complexities inherent in crane systems such as varying payloads, flexible cables, and external disturbances require finely tuned control strategies to maximize performance. There are also several methods to optimize designed controllers that can adapt uncertainties or varying system parameters.

The particle swarm optimization (PSO) approach is used to optimize controller parameters [22-25]. PSO is an algorithm capable of optimizing a non-linear and multidimensional problem, and it generally achieves decent results with little parameterization. Research outcomes demonstrate that PSO-based approaches can effectively optimize crane motion trajectories, minimize energy consumption, and enhance system efficiency. However, challenges such as the selection of appropriate parameters, convergence speed, and robustness to uncertainties remain areas of ongoing investigation.

Recently, another optimization tool, namely genetic algorithms (GA) is used in [26-29]. GA is one of the popular population-based metaheuristic algorithms. J.H. Holland suggested GA in 1992 [30], taking inspiration from the evolutionary process in biology. Like the Darwinian concept of natural selection, GA aims to determine effectiveness by comparing different variables. The optimization tools using GA is efficient and easier to use as it is a computerized tool.

3. Conclusions

The control of crane systems presents significant challenges due to inherent oscillatory dynamics, external disturbances, and system uncertainties such as varying payloads and environmental factors. Traditional control methods of input shaping have proven effective in reducing oscillations but often suffer from limitations related to robustness, adaptability, and response time. Adaptive input shaping offers a more advanced solution by incorporating real-time feedback, allowing for dynamic adjustment of input commands based on current system conditions. This enhances performance in terms of precision, response speed, and robustness to disturbances and parameter changes.

This review highlights the advantages of adaptive input shaping over traditional methods, including improved adaptability to system variations, reduced sensitivity to modelling errors, and faster system responses. It also shows how adaptive input shaping can address the complexities of crane dynamics in real-time, making it an effective strategy for optimizing crane control in industrial applications. In conclusion, adaptive input shaping is a promising approach for achieving efficient, precise, and safe crane operations, particularly in environments where high-speed performance and adaptability to uncertainties are critical.

Acknowledgement
We want to acknowledge the Ministry of Higher Education, Malaysia for the Fundamental of Research Grant Scheme, FRGS (FRGS/1/2020/TK0/USIM/02/2) and the Faculty of Engineering and Built Environment, USIM for the funding and support.

References

[1] Shao, Xuejuan, Jinggang Zhang, Xueliang Zhang, Zhicheng Zhao, and Zhimei Chen. "A novel anti-swing and position control method for overhead crane." *Science Progress* 103, no. 1 (2020): 0036850419883539. https://doi.org/10.1177/0036850419883539

[2] K. A. Alhazza, Z. N. Masoud, and J. A. Alqabandi, "A close-form command shaping control for point-to-point maneuver with nonzero initial and final conditions," Mech Syst Signal Process, vol. 170, 2022, doi: https://doi.org/10.1016/j.ymssp.2022.108804

[3] S. Xu, H. Dai, L. Feng, H. Chen, Y. Chai, and W. X. Zheng, "Fault estimation for switched interconnected nonlinear systems with external disturbances via variable weighted iterative learning," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 70, no. 6, 2023, doi: https://doi.org/10.1109/TCSII.2023.3234609

[4] 尹海波, "Research of crane system based on multibody dynamics," Mechanical Engineering and Technology, vol. 12, no. 01, 2023, doi: https://doi.org/10.12677/met.2023.121009

[5] L. Ramli, Z. Mohamed, A. M. Abdullahi, H. I. Jaafar, and I. M. Lazim, "Control strategies for crane systems: A comprehensive review," 2017. doi: https://doi.org/10.1016/j.ymssp.2017.03.015

[6] W. Chatlatanagulchai, S. Nithi-Uthai, and P. Intarawirat, "Intelligent backstepping system to increase input shaping performance in suppressing residual vibration of a flexible-joint robot manipulator," Engineering Journal, vol. 21, no. 5, 2017, doi: https://doi.org/10.4186/ej.2017.21.5.203

[7] S. Grazioso, G. Di Gironimo, W. Singhose, and B. Siciliano, "Input predictive shaping for vibration control of flexible systems," in 1st Annual IEEE Conference on Control Technology and Applications, CCTA 2017, 2017. doi: https://doi.org/10.1109/CCTA.2017.8062480

[8] N. C. Singer and W. P. Seering, "Preshaping command inputs to reduce system vibration," Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, vol. 112, no. 1, 1990, doi: https://doi.org/10.1115/1.2894142

[9] Alhassan, Ahmad, Z. Mohamed, Auwalu M. Abdullahi, Amir A. Bature, Ado Haruna, and Nura M. Tahir. "Input shaping techniques for sway control of a rotary crane system." *Jurnal Teknologi* 80, no. 1 (2018). https://doi.org/10.11113/jt.v80.10297

[10] Tho, Ho Duc, Hung Nguyen, and Quoc Chi Nguyen. "Input shaping control of an overhead crane." In *7th Vietnam Conf on Mechatronics (VCM 2014)*, pp. 303-311. 2014. https://doi.org/10.15625/VCM.2014-262

[11] Singhose, William. "Command shaping for flexible systems: A review of the first 50 years." *International journal of precision engineering and manufacturing* 10 (2009): 153-168. https://doi.org/10.1007/s12541-009-0084-2

[12] Singhose, W. E., W. P. Seering, and Neil C. Singer. "Time-optimal negative input shapers." (1997): 198-205. https://doi.org/10.1115/1.2801233

[13] Ramli, Liyana, Z. Mohamed, and H. I. Jaafar. "A neural network-based input shaping for swing suppression of an overhead crane under payload hoisting and mass variations." *Mechanical Systems and Signal Processing* 107 (2018): 484-501. https://doi.org/10.1016/j.ymssp.2018.01.029

[14] Ramli, Liyana, Z. Mohamed, M. Ö. Efe, Izzuddin M. Lazim, and H. I. Jaafar. "Efficient swing control of an overhead crane with simultaneous payload hoisting and external disturbances." *Mechanical systems and signal processing* 135 (2020): 106326. https://doi.org/10.1016/j.ymssp.2019.106326

[15] Abdullahi, A. M., Z. Mohamed, H. Selamat, H. R. Pota, MS Zainal Abidin, and S. M. Fasih. "Efficient control of a 3D overhead crane with simultaneous payload hoisting and wind disturbance: design, simulation and experiment." *Mechanical Systems and signal processing* 145 (2020): 106893. https://doi.org/10.1016/j.ymssp.2020.106893

[16] Abdullahi, Auwalu M., Z. Mohamed, H. Selamat, Hemanshu R. Pota, MS Zainal Abidin, F. S. Ismail, and A. Haruna. "Adaptive output-based command shaping for sway control of a 3D overhead crane with payload hoisting and wind disturbance." *Mechanical Systems and Signal Processing* 98 (2018): 157-172. https://doi.org/10.1016/j.ymssp.2017.04.034

[17] Solihin, Mahmud Iwan, Wahyudi, and Ari Legowo. "Fuzzy-tuned PID anti-swing control of automatic gantry crane." *Journal of Vibration and Control* 16, no. 1 (2010): 127-145. https://doi.org/10.1177/1077546309103421

[18] Ramli, Liyana, Izzuddin M. Lazim, Hazriq Izzuan Jaafar, and Zaharuddin Mohamed. "Modelling and fuzzy logic control of an underactuated tower crane system." *Applications of Modelling and Simulation* 4 (2020): 1-11.

[19] Al-Tuhaifi, Saleh B., and Kasim Mousa Al-Aubidy. "Neuro-fuzzy-based anti-swing control of automatic tower crane." *TELKOMNIKA (Telecommunication Computing Electronics and Control)* 21, no. 4 (2023): 891-900. https://doi.org/10.12928/TELKOMNIKA.v21i4.24044

[20] Liu, Diantong, Jianqiang Yi, and Min Tan. "Proposal of GA-based two-stage fuzzy control of overhead crane." In *2002 IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering. TENCOM'02. Proceedings.*, vol. 3, pp. 1721-1724. IEEE, 2002. https://doi.org/10.1109/tencon.2002.1182666

[21] Pham, Hung Van, Quoc-Dong Hoang, Minh Van Pham, Dung Manh Do, Nha Hoang Phi, Duy Hoang, Hai Xuan Le, Thai Dinh Kim, and Linh Nguyen. "An efficient adaptive fuzzy hierarchical sliding mode control strategy for 6 degrees of freedom overhead crane." *Electronics* 11, no. 5 (2022): 713. https://doi.org/10.3390/electronics11050713

[22] Abdulhamid, Ibrahim Bako, Mustapha Muhammad, and Amina Ibrahim Khaleel. "Control of a Double Pendulum Crane System Using PSO-Tuned LQR." In *2019 2nd International Conference of the IEEE Nigeria Computer Chapter (NigeriaComputConf)*, pp. 1-8. IEEE, 2019. https://doi.org/10.1109/NigeriaComputConf45974.2019.8949631

[23] AB RAHIM, ZAKI HAKIMI, MUHAMAD RAFYQ ROSLAN, LIYANA RAMLI, and IZZUDDIN M. LAZIM. "PSO-based PID-PD controller of a gantry crane with parameter uncertainties." *Journal of Sustainability Science and Management* 18, no. 8 (2023): 159-169. http://doi.org/10.46754/jssm.2023.08.013

[24] Azmi, Nur Iffah Mohamed, Nafrizuan Mat Yahya, Ho Jun Fu, and Wan Azhar Wan Yusoff. "Optimization of the PID-PD parameters of the overhead crane control system by using PSO algorithm." In *MATEC Web of Conferences*, vol. 255, p. 04001. EDP Sciences, 2019.https://doi.org/10.1051/matecconf/201925504001

[25] Jaafar, Hazriq Izzuan, Z. Mohamed, Amar Faiz Zainal Abidin, and Z. Ab Ghani. "PSO-tuned PID controller for a nonlinear gantry crane system." In *2012 IEEE international conference on control system, computing and engineering*, pp. 515-519. IEEE, 2012. https://doi.org/10.1109/ICCSCE.2012.6487200

[26] Al-Dhaheri, Noura, Aida Jebali, and Ali Diabat. "A simulation-based Genetic Algorithm approach for the quay crane scheduling under uncertainty." *Simulation Modelling Practice and Theory* 66 (2016): 122-138.https://doi.org/10.1016/j.simpat.2016.01.009

[27] Hyun, Hosang, Moonseo Park, Dowan Lee, and Jeonghoon Lee. "Tower crane location optimization for heavy unit lifting in high-rise modular construction." *Buildings* 11, no. 3 (2021): 121. https://doi.org/10.3390/buildings11030121

[28] Gwak, Han-Seong, Hong-Chul Lee, Byoung-Yoon Choi, and Yirong Mi. "GA-based optimization method for mobile crane repositioning route planning." *Applied Sciences* 11, no. 13 (2021): 6010. https://doi.org/10.3390/app11136010

[29] Zhu, Xiaohua, and Ning Wang. "Cuckoo search algorithm with membrane communication mechanism for modeling overhead crane systems using RBF neural networks." *Applied Soft Computing* 56 (2017): 458-471. https://doi.org/10.1016/j.asoc.2017.03.019

[30] M. de la Maza, "Book review: genetic algorithms + data structures = evolution programs by Zbigniew Michalewicz (Springer-Verlag, 1992)," ACM SIGART Bulletin, vol. 4, no. 2, 1993. https://doi.org/10.1145/152941.1064724