Robotic Tower Crane Modelling Control (RTCMC)

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Abstract

Fast and accurate positioning and swing minimization of payloads in large standing tall tower crane operation are challenging as well as conflicting tasks. Juggling the trolley back-and-forth manually by crane operator to suppress payload swing can make time consuming and cause fatigue. Minimizing the load swing is also primarily limited by the existence of wind disturbance effect triggering higher tower vibration, especially in the high speed course and load is in the end of tower region. Unstable load swing due to wind disturbance, vibration, and operational error would subsequently cause the crane collapse as well risk the whole working environment. Tower Crane Incidents World statistic shows 23% of crane accidents are due to wind disturbance while 38% are operational error.

Motivated by Robotic Tower Crane (RTC), this work investigates solutions to a class of problem where swing suppression is critical to overcoming poor performance of highly nonlinear trolley-tower-payload crane operational control. Since having uneasy tasks for the researchers to explore research works on operating crane, controllers proposed in the past have as well been based on lab-scale prototype or mathematical sketch which would rather become impractical.

While risk free crane operation is desirable in a crane modelling and control, the problem in swing minimization is that disturbance predictions are prone to error due to the variability and complexity of trolley-payload interaction forces. However, the use of robotic tower crane model control (RTCMC) with disturbance rejection observer and linear estimator integral approaches could significantly improve the rejection of disturbances (crane vibration due to wind disturbance, unknown dynamics, and noise) as well as achieve reference tracking of control system beyond the limitations of feedback.

Cranes in construction and shipyard sectors still entirely rely on human operator with manual joystick to perform costly-time consuming tasks since proposed mathematical linear-nonlinear models have never been practical to date. Ignoring some essential parameters in linear model optimization could also pamper the control performance. Vibration impact on the large standing tall tower crane is also another huge contributing factor as it can cause instability during crane operation and windy weather condition. Though wind disturbance issue has been paid much attention in wind turbine control, the vibration impact of wind disturbance on tower crane in construction sectors has widely been ignored. Therefore, to explicitly address the use RTCMC in this new technological era, the principles of crane modelling, optimization, vibration impact, swing minimization, and control issues are required to be reviewed.

This work proposes a range of issues in implementing RTCMC. Firstly, SimMechanics-visualized RTC model development using real tower crane Morrow (Liebherr 71EC) datasheet has been considered. Secondly, wind disturbance model is designed based on Gawronski approach, applies different wind patterns on RTC model, and analyses the vibration impact on the payload swing instability. Thirdly, The best optimized mathematical linear model is derived using improved-linear least square algorithm. Fourthly, to actively reject the disturbances caused by undesired source of inputs or unknown dynamics, LQR-Disturbance Rejection Observer (DRO) Control with Luenberger-based Extended State Observer is introduced. This research further examines the combination of error space approach with estimator, from which it is argued that the LQR-Estimator-Integral Control (LEIC) for linear model is necessary to achieve robust tracking. Finally, in order to achieve robust tracking control of highly nonlinear trolley translation-payload swing working environment fuelled by wind disturbance, LQR-DRO control with torque compensator actuation is implemented on the interaction joints between trolley and payload cables. Several combinations of joints-sensors-actuators-extra links implementations on payload swing were initially tried before considering proposed method.

During simulation trials, proposed RTCMC demonstrated the ability to iteratively achieve desired trolley translation-loadswing geometry. Under this iterative method, all weighting Q-R matrices, Observer gains L matrix, and uncertainties gains have adapted to deferent input conditions and passes were repeated autonomously until pre-specified trajectories of trolley-loadswing were achieved. Evidences of improvements in LQR-DRO and LEIC-Antiwindup controls for linear models as well as LQR-DRO for nonlinear RTCMC are presented.

Tower crane payload swing minimization is one of the oldest challenges in the field of construction automation; despite decades of research, no commercial deployment of a fully autonomous swing minimization has been reported to date in regards to large standing-tall operational tower crane. In the literature, proposed solutions have required stringent preconditions, such as visual scanning of terrain profiles in construction sites, the design of vibration suppression control using sway angle observer with friction disturbance, neural network with GA-based training, etc.. These considerations increase the difficulty of implementing the controller in time. Control solutions in this research focused on simplicity of implementation: general and straightforward reference-tracking control methods were preferred over Tower crane-tailored formulations. The benefit is that, the proposed RTCMC has potential applications to other types of crane operations and global crane research.

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