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DYNAMIC SIMULATION AND CONTROL ALGORITHM DEVELOPMENT FOR AUTOMATION IN SHIPYARD PRODUCTION OPERATIONS

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ABSTRACT

Block lifting operations in shipyards are traditionally conducted manually using cranes. In this study, the control method of the block lifting operation was suggested for more accurate and efficient operation. Firstly, the Model Predictive Control (MPC) method was applied to address the underactuated problems prevalent in crane operations in shipyards. Meanwhile, to reduce the computation time of the MPC method, the dynamics model of the floating crane, which is a multibody system, was formulated by using the embedding technique. Finally, we formulated an optimization problem that could minimize deviations from the target position and orientation of the block. Especially, the physical constraints on the position of the block, and the threshold of the control inputs were applied to the MPC method. The method was successfully validated in block erection simulations, handling disturbances and constraints effectively.

1 INTRODUCTION

The process of block erection in shipyards requires crane operation of lifting, transporting, and lowering the block. The floating cranes are often utilized for moving blocks on the quays. The crane controls the block through wire ropes, making it an underactuated system, which is difficult to control using conventional method. In order to ensure safe operations, it is crucial to maintain precise control over the position and orientation of the block, to avoid potential risks. Actual operations are generally performed manually by operators. In this study, the block erection operation was presented for accurate and efficient control and automation, and we applied Model Predictive Control (MPC) for the block erection operation in shipyards.

2 THEORETICAL BACKGROUNDS

The underactuated system is a system which has more degrees of freedom than the number of the control inputs (Lee et al. 2021). Cranes are commonly classified as underactuated systems since the actuators have no direct influence on the swinging block (Zelei and Stepan 2012). Control of the underactuated system is a challenging problem, and it is hard to apply traditional control methods (Lee et al. 2021). In this study, we adopted MPC method to control the crane, which has been proven to be effective for underactuated system in the previous studies. The motion of the block was controlled by MPC, which consists of an optimizer and a plant model. The optimization problem was constructed by using control inputs as design variables, sum of the deviations between the desired and actual output as an objective function, and constraints which implies the boundary of the control inputs and physical limitations. First, the plant model calculates the crane's motion over a certain period based on arbitrary control inputs. The results are then sent to the controller, where the control inputs are recalculated through optimization to ensure the crane moves in the desired manner. By repeating this iterative process several times, the control inputs can be fine-tuned to ultimately direct the crane's motion in the intended direction

The proposed method was applied to the specifications of an actual maritime crane. The motion equations of the maritime crane in the plant model are as follows.

$$\tilde{\mathbf{M}}\ddot{\mathbf{q}} + \tilde{\mathbf{k}} - \tilde{\mathbf{F}}^{e} = 0,$$

$$\left(\tilde{\mathbf{M}} = \mathbf{J}^{T}\mathbf{M}\mathbf{J},\ \tilde{\mathbf{k}} = \mathbf{J}^{T}\mathbf{M}\dot{\mathbf{J}}\dot{\mathbf{q}},\ \tilde{\mathbf{F}}^{e} = \mathbf{J}^{T}\mathbf{F}^{e}\right)$$

where **M** is mass matrix, **q** is generalized coordinates, **J** is velocity transformation matrix between absolute and generalized coordinates, and $\mathbf{F_e}$ is external forces (Lee et al. 2018). A dot over a variable denotes its derivative with respect to time. The task of transporting the block through the crane was controlled using MPC, and as a result, it was observed that the block moved appropriately towards the desired value.

3 APPLICATION

We applied the suggested method to the step value tracking and trajectory tracking problem in the simulation of block transporting operation in a shipyard (Figure 1). The simulation was performed based on the in-house code with C# language. The equation of motion of the floating crane was formulated, and the optimization model to calculate the optimal control inputs were implemented in the simulation. For realistic applications, we considered the delay of the control inputs, modeling uncertainties of the block, and unexpected external forces due to environmental loads. As a result, the block deviated by no more than 0.06m from the target trajectory, and the block's roll motion achieved the desired value within 1 degree.

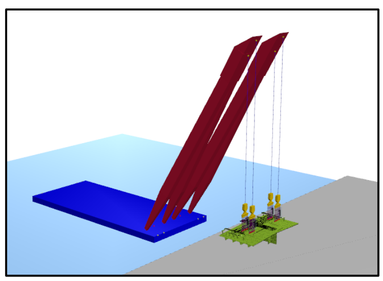

Figure 1: Block erection operation simulation by floating crane

4 CONCLUSIONS

This study proposed an MPC-based control method for precise and efficient block erection operations in shipyards. The method was successfully applied to the underactuated crane operations.

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