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Antisway Control of a Crane on an Offshore Support Vessel Based on the Hardware-in-the-Loop Simulation

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Ship-mounted cranes are used widely in the transportation and installation of heavy loads at sea. To minimize the sway motion induced by the harsh environment, the cranes are equipped with antisway-compensation equipment. To effectively test the feasibility of the antisway algorithms at the early design stage, the hardware-in-the-loop simulation (HILS) technique can efficiently be used for the proposed technique of this study. In this study, it is applied to the example of the antisway control of a crane on an offshore support vessel during the installation operation of subsea equipment using the HILS.

INTRODUCTION

The cranes on an offshore support vessel (OSV) are used for offshore transportation and the installation of subsea equipment at sea (Hong et al., 2016). An OSV-mounted knuckle boom crane is shown in Fig. 1. The knuckle boom crane can perform various tasks, as it is characterized by the design of a folded knuckle that is attached to an extension rod.

During the installation operation, the sway motion of the suspended load (e.g., subsea equipment) is inevitable. In addition, the wind at sea can intensify the sway motion. Meanwhile, the waves induce the OSV motion, and the OSV motion induces motions of the suspended load directly or indirectly. In this situation, the installation operation by the crane sometimes pauses under harsh environmental conditions to avoid above-deck collisions, those between the suspended load and the ship structure, or those between the suspended load and the crane boom (Jeong et al., 2016). Therefore, a controller with a suitable antisway control algorithm is necessary to significantly reduce the residual sway motion of the suspended load.

In most cases, the reduction of the sway motion is achieved by the crane control. Abdel-Rahman et al. (2003) provided a well-classified review of the crane control. Gjelstenli (2012) used the cascade control method to solve the antisway problem for the offshore crane. More recently, Ramli et al. (2017) also conducted a comprehensive review of the control strategies for different crane types. Most of the researchers concentrated on the overhead crane, tower crane, and boom crane. Abe et al. (2011) used radial basis function networks for the trajectory planning of overhead cranes and reduced the payload sway motion. In addition, an experiment was conducted to verify the proposed controller. Le et al. (2013) presented the sliding-mode control method for a tower crane to suppress the load sway motion and the tracking of a trolley to the desired position. An antisway controller for overhead crane based on multi-sliding mode method was investigated by Xu et al. (2012). Duong et al. (2012) considered the antisway control for a tower crane by using a recurrent neural network. Also, Wu et al. (2016) applied an adaptive fuzzy controller, which is a nonlinear method, to a tower crane without the requirement of a detailed mathematical model of the crane. However, the knuckle boom crane is not the subject of most of the previous studies.

The knuckle boom crane, however, exhibits underactuated behavior, since the number of actuators is fewer than those of the systemic state variables. Therefore, the control mechanism becomes more complex, leading to a more difficult controller design. Only a few works of the literature have focused on this crane type. Bak et al. (2011) performed the tool-point control for a hydraulically actuated knuckle boom crane. Maczyńsk and Wojciech (2012) proposed an additional auxiliary system to reduce the load oscillations. The additional system can directly force the hoist wire rope to control the payload sway angle. Chu et al. (2015) established a multidomain system for the knuckle boom crane and implemented an antisway control. In these studies, the antisway controller was designed by the controlling of the movement of the crane tip.

In the present study, the antisway controller for a knuckle boom crane on an OSV is considered. The control mechanism of the antisway controller is described in Fig. 2. First, a motion refer-

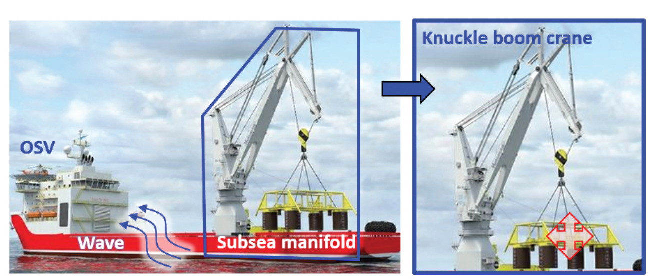

Fig. 1 OSV and knuckle boom crane

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KEY WORDS: Antisway control, HILS (hardware-in-the-loop simulation), multibody dynamics, offshore supply vessel, sliding mode control, hydraulic actuation system, knuckle boom crane.