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# A 3D SIMULATION SYSTEM FOR MOBILE HARBOURCRANE BASED ON VIRTUAL PROTOTYPING TECHNOLOGY

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***Abstract:*** *Since the demand for transportation by marine container ship has increased, the concept of Mobile Harbour Crane (MHC) was proposed by KAIST aiming to transport amount of goods from the large container ship that trouble to anchor in the water shallow ports to their destination. Due to working on the sea, the MHC has appeared swing of payload that is induced by external disturbances such as wind and wave. This is difficult to control crane to pick or release a container. This paper proposes a virtual simulation technology by building the prototype in 3-D environment to investigate the dynamic behaviors of MHC. Simulation results archived can improve in design phase of both mechanical system and controller for MHC.*
***Key words:*** *mobile harbor crane, virtual prototype, virtual simulation, dynamic, ADAMS.*

## 1. INTRODUCTION

The concept of MHC system is an overhead crane system that is mounted on a floating platform to load and unload containers from container ship to vessels or vice versa. Due to working on the sea, the MHC has more problems than conventional crane that is fixed on ground. One of the critical problems is a swing of the load caused by improper control of trolley and external disturbances such as wave, wind on the sea. This swing is particularly serious, because it could cause damage to devices and the surrounding systems.

Several controlling schemes were proposed for anti-swing cranes that are equipped with many types of sensors to detect the sway angle of load. The swing angle signal must be processing and estimation before feedback to the controller. Study (Yoshida et al., 2008) used camera as a non-contact sensor to visual feedback control of crane. A 3D camera installed on the trolley and measured the 3D position of load. Study (Kim et al., 2003) also proposed system includes a multi-variable state feedback anti-sway controller with an integrator, a sway velocity observer, and a sway angle detection method in which an inclinometer is used to replace for the vision system. However, these systems have high cost, difficulty in maintenance and reduce the longevity when working in the sea environment. Study (Ki-Ru Park) introduced a new approach that used a tri-axial accelerometer to estimate the swing. In this approach, the swing angle is measured by the accelerometer based on the difference of the fixed points between the trolley and spreader. A device that is designed to observe and estimate the swing angle combination with a sliding mode controller to reduce the swing due to the continuously moving base. On the other hand, the paper introduces a virtual prototyping simulation technology that is integrated with ADAMS (Automatic Dynamic Analysis of Mechanical system) and MATLAB for designing mechanical and control system of MHC without the necessity to build a physical prototype. This method is more economical because it doesn't need to equip with the expensive measurement devices, but it guarantees precision and efficiently in design for a complex mechatronic system.

## 2. DYNAMIC MODEL OF THE MHC

The MHC system includes the overhead crane that is installed on the floating body. The trolley moves along the length and width of the ship on the frame system to transfer the container from one place to another, and the spreader is suspended by four cables through the trolley used to clamp or release the container. While the MHC is floating on the sea, it is affected by three motions such as roll, pitch and yaw. To simplify the motions of the MHC, the following assumptions are made as:

(1) The floating body was supposed to be placed relatively in the Cartesian coordinate. Hence, the yaw motion in absolute coordinates can be neglected.
(2) This study considers the movement of the trolley along the x-axis and the swing of load that induced by the trolley motion along the z-axis which is considered as one of the disturbances of the control system.
(3) The swing motion of payload is considered similarly a pendulum motion.
(4) The friction force on the trolley and the stretch of rope are negligible.

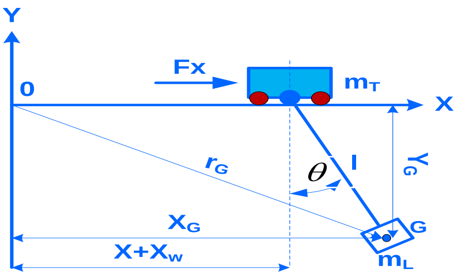


Fig.1. Modeling of the mobile harbour crane dynamics

The motion equation of the MHC based on the Lagrange equation:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = T_i \quad (i=1,2,3,4) \tag{1}$$

Where, L=T-V is the Lagrange equation, V is the potential energy, T is the kinetic energy, $q_i$ is generalized coordinator $(x,y,\theta)$ and $T_i$ is the external force $(F_x)$.

$$T = \frac{1}{2}m_T\,\dot{x}_a^{\,2} + \frac{1}{2}m_L(\dot{x}_a^{\,2} + l^2\dot{\theta}^2 + 2\dot{x}_a l\dot{\theta}\cos\theta) \tag{2}$$

$$V = -m_L g l\cos\theta \tag{3}$$

$$L = \frac{1}{2}m_T\dot{x}_a^{\,2} + \frac{1}{2}m_L\dot{x}_a^{\,2} + \frac{1}{2}m_L l^2\dot{\theta}^2 + m_L\dot{x}_a l\dot{\theta}\cos\theta + m_L g l\cos\theta \tag{4}$$

The Lagrange equations of translation motion of the trolley and rotational motion of payload are:

$$(m_T + m_L)\ddot{x}_a + m_L l(\ddot{\theta}\cos\theta - \dot{\theta}^2\sin\theta) = F_x \tag{5}$$

$$l\ddot{\theta} + \ddot{x}_a\cos\theta + g\sin\theta = 0 \tag{6}$$

The x denotes the relative distance between the trolley and the crane base coordinate. The $x_w$ is the displacement of the trolley induced by waves with regard to absolute coordinate.

$$x_a = x + x_w \tag{7}$$

The linearization can be made by considering the sway angle is small, as a result: $\sin\theta \approx \theta; \cos\theta \approx 1, \dot{\theta}^2 \approx 0$. The equations of motion (5) and (6) can be rewritten as:

$$(m_T + m_L)\ddot{x}_a + m_L l\ddot{\theta} = u \quad (8)$$

$$l\ddot{\theta} + \ddot{x}_a + g\theta = 0 \quad (9)$$

Where, u represents the input, $x_a$ represents the trolley position and $\theta$ represents the rotation of payload. The state variables of the system can be assigned as follows:

$$x_1 = x_a;\ x_2 = \dot{x}_a;\ x_3 = \theta;\ x_4 = \dot{\theta}\ . \quad (10)$$

Hence the state equations are:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix} = \begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & \dfrac{m_L}{m_T}g & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -\left(\dfrac{m_T+m_L}{m_T}\right)\dfrac{g}{l} & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} + \begin{bmatrix}0\\ \dfrac{m_L}{m_T}\\ 0\\ -\dfrac{1}{l.m_T}\end{bmatrix}u \quad (11)$$

$$y = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} + \begin{bmatrix}0\\ 0\end{bmatrix}u \quad (12)$$

## 3. DEVELOPING A VIRTUAL SIMULATION MODEL FOR THE MHC

To improve the design process both the mechanical and control system for the MHC, this paper proposes developing the virtual prototype model based on combining of ADAMS and MATLAB software (Figure 2).

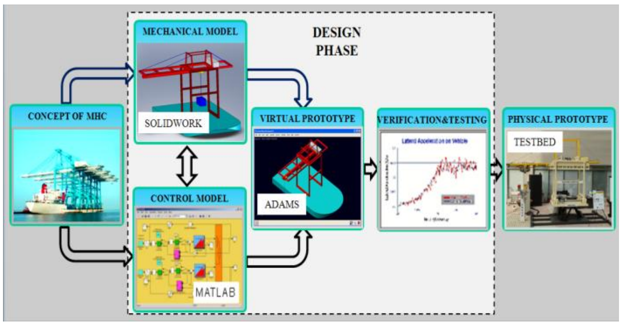


Fig.2. Developing the virtual prototype model

### 3.1 Building the 3-D mechanical modeling for the MHC

To design the 3-D simulation model for the complex mechanism structure as the MHC, ADAMS is difficult to implement by itself. Hence, the design process for this 3-D model was made using a professional mechanical design software, namely SOLIDWORKS. Then the geometrical model was exported to ADAMS/View using a file format is Parasolid.x_t. The dynamic model was built in ADAMS/View following the geometrical constraints. The coordinate mass of the float is fixed on the center of Cartesian coordinate through revolute joint. The float is swayed following the equation (x(t)=Asinωt). The frame is mounted on the float and translated through the translational joint. The trolley slides on the frame along the z direction by the translational joint. The container is jointed to the trolley through the spherical joint. The dynamic mechanical simulation process is implemented in ADAMS/View to investigate behaviour, collision, peak load, movement range, and the parameters of the MHC.

### 3.2 Developing the control system for the MHC

Building the control system of the MHC is developed based on ADAMS/Control and MATLAB/Simulink. Firstly, the inputs and outputs variables should be defined in the ADAMS model and then is exported to MATLAB/Simulink. This ADAMS model creates a subsystem in the MATLAB/Simulink which has the inputs and outputs as defined before. The controller is built in SIMULINK to control for this model. Several controllers can apply to suppress the sway angle of payload of MHC such as fuzzy, PID, sliding…

This paper proposes to use the PID controller. The PID controller has the form as:

$$u(t) = K_p e(t) + K_I \int e(t)dt + K_D \dot{e}(t) \quad (13)$$

Where, e(t) is input signal, u(t) is output signal, $K_P$, $K_I$, and $K_D$ are the proportional, integral, and derivative coefficients, respectively. The PID control scheme is shown in figure 3.

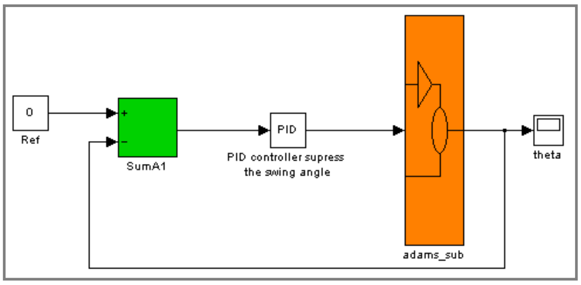


Fig.3. The PID control scheme to suppress the swing of load

## 4. CONCLUSION

The virtual simulation technology is introduced in this paper to apply for the MHC. Based on the simulation results from ADAMS model, could investigate the behaviour correctness of the mechanical system. Moreover, thanks to the possibility it's virtual measurements that can determinate any parameters of the system without the physical prototype equipped sensors. Based on simulation results achieved (Fig.4), we could evaluate the high applicability of this technology, which is implemented in the virtual model for the complex mechanical system. This technology brings several advantages such as reduce time and cost, improve the quality and efficiency of product in design phase as well as it guarantees precision as in the real model.

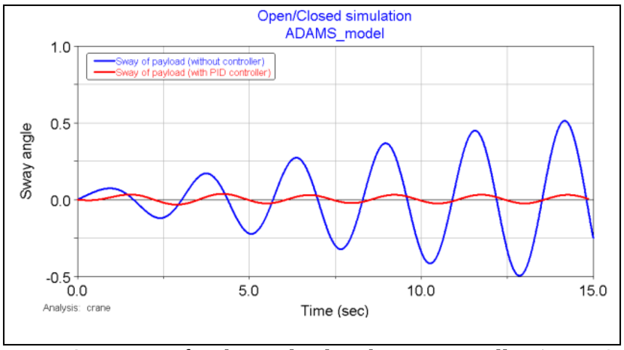


Fig.4. Anti swing for the payload with PID controller ($K_P$=1.6; $K_I$=0.2; $K_D$=0.1)

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