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Design of a Dynamic Simulation Platform for Verifying Unloading Automation Algorithms in Grab Type Ship Unloader

Ga-Eun Jung [1,], Jae-In Lee [1], Seok-Ju Lee[2], and Chang-Uk Kim [3]*

[1] Dept. of Electrical Engineering, Changwon National University, Changwon 51140, Republic of Korea

[2] Industry-University Cooperation Foundation, Changwon National University, Changwon 51140, Republic of Korea

[3] R&D Center, S-Material Handling Co., Ltd., Changwon 51395, Republic of Korea

Abstract. The transformation of seaports into smart ports has increased interest in the automation of Grab-Type Ship Unloaders (GTSU), which are essential for unloading bulk materials like coal and iron ore. Automated GTSU systems enhance operational safety, reduce energy consumption, and lower carbon emissions, offering significant advantages over conventional systems. This study presents the development of a dynamic simulation platform for validating GTSU unloading automation algorithms designed for smart ports. The crane system within the dynamic simulation platform is implemented in Modelica as a continuous-time system. The input of the crane system model is the speed of each driving part, and the output is the position of each driving part. Simulation results were verified by comparing the actual and simulated operating positions. The errors from the actual displacement of the trolley and hoist were 0.35 m and 1.10 m, respectively. The proposed simulation platform demonstrates potential for accelerating the development and deployment of fully automated GTSU systems, contributing to the realization of smart port operations.

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[*] Corresponding author: jge0367@gmail.com
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1. Introduction

Seaports are being transformed into 'smart ports' equipped with unmanned automation technology [1]. Along with seaports automation, there is growing interest in the automation of Grab-Type Ship Unloader (GTSU) that unloads coal and iron ore from bulk carriers [2]. Automated GTSU systems ensure safety while offering financial benefits through energy efficiency and reduced carbon emissions, setting them apart from conventional systems. The GTSU automation aims to replace human tasks with sophisticated sensors and control systems [3]. As one of the GTSU automation functions in smart ports, manual operation methods must be replaced by automated algorithms.

This paper presents the design of a dynamic simulation platform for verifying GTSU unloading automation algorithms. To simulate scenarios similar to real-world environments, a dynamic model reflecting the behavioral characteristics of GTSU was developed. In addition, a 3D model reflecting the actual specifications of the GTSU equipment was applied so that the unloading operation can be intuitively visualized.

When the speed data of each driving unit is input into the dynamic simulation platform, the behavior simulation is performed by converting it into position data through integration over time. The dynamic simulation results are verified by calculating the error distance through comparison with the actual movement displacement.

The errors from the actual displacement of the trolley and hoist were 0.35 m and 1.10 m, respectively. The maximum angle of the grab was simulated to be 15.2 degrees, which requires the application of anti-sway control in the future. The proposed GTSU dynamic simulation platform will be effectively utilized to implement a fully automated unloading system.

2. Mathematical Model of the GTSU

The GTSU consists of a trolley, hoist, and grab, and can be expressed in a simplified form as a crane system [6]. The configuration of the crane system is shown in Figure 1. It is expressed as a cart and a pendulum, and the crane system can be described as a free body diagram.

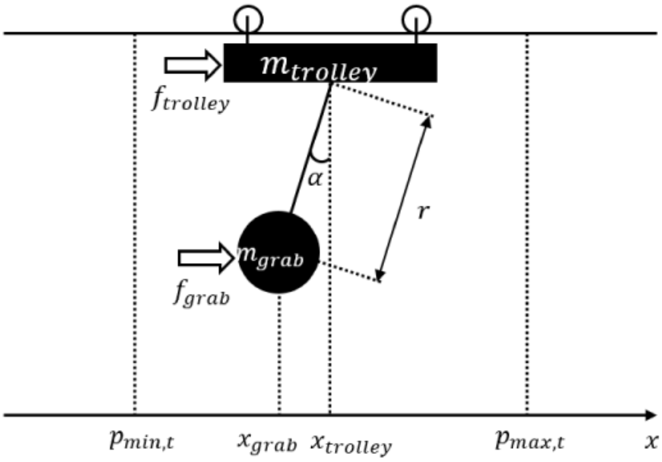

Figure 1. Configuration of the crane system

When applying the cart-pendulum model to the GTSU, the cart is replaced by a trolley and the pendulum is replaced by a grab. The trolley is driven by a motor force f_c, and the pendulum is subjected to a disturbance f_d. The trolley is position controlled to reach the desired position specified by the user. The variables and parameters of the cart pendulum free body diagram are shown in Tables 1 and 2 [4].

Table 1. Model variables

Symbol	*Description*	*Unit*
θ	Angle of the cable	rad
$f_{trolley}$	Input force of the trolley	N
f_{grab}	Grab disturbances	N
$x_{trolley}$	Position of the trolley	m
x_{grab}	Position of the grab	m

Table 2. Model parameters

Symbol	***Description***	***Unit***
$d_{trolley}$	Friction coefficient of the trolley	0.5 kg/s
$d_{trolley}^{brake}$	Friction coefficient of the trolley with activated brake	10^5 kg/s
d_{grab}	Friction coefficient of the grab	0.01 kg/s
g	Gravity	9.81 m/s^2
$m_{trolley}$	Mass of the trolley	58,000 kg
m_{grab}	Mass of the grab	27,000 kg
$p_{max.t}$	Maximum position of the trolley	42 m
$p_{min.t}$	Minimum position of the trolley	0 m
l	Length of the wire rope	5 m

The crane system is a nonlinear model, and its mathematical formula is expressed as follows [5]:

$$\ddot{x}_{trolley}(m_{trolley}+m_{grab}\theta) = -d_{trolley}\dot{x}_{trolley}+f_{trolley}+f_{grab}\theta + m_{grab}\sin\sin\theta\left[l\dot{\theta}^2+g\cos\theta\right]-d_{grab}\dot{x}_{trolley}\theta \tag{1}$$

$$l^2\ddot{\theta}\left[m_{trolley}+m_{grab}\theta\right] = \left[f_{grab}\frac{m_{trolley}}{m_{grab}}-f_{trolley}+d_{trolley}\dot{x}_{trolley}\right]l\cos\theta - \left[g(m_{trolley}+m_{grab})+m_{grab}l\dot{\theta}^2\cos\cos\theta\right]l\sin\theta - d_{grab}\left[\frac{m_{trolley}}{m_{grab}}(\dot{x}_{trolley}l\cos\theta+l^2\dot{\theta})+l^2\dot{\theta}\theta\right] \tag{2}$$

$$x_{grab} = x_{trolley}+l\sin\theta \tag{3}$$

3. Dynamic Simulation Platform

A dynamic simulation platform is implemented to verify the automated operation algorithm of the GTSU. Input and output of the dynamic simulation platform are the operation speed of each drive unit and the operation position of the GTSU. The operation positions which are the output of the dynamic simulation platform are compared with the actual operation positions to verify the automation algorithm.

In this study, CATIA 3DEXPERIENCE software was used to design the dynamic simulation platform. The dynamic simulation platform can be divided into two parts, including dynamic equations based on the motion equations and a 3D model that visualizes dynamic operation. The dynamic equation is applied through the Modelica component, where the dynamic equation code is written based on the equation of motion.

Figure 2. shows the control block diagram based on the motion equations of the main driving units, trolley, hoist, and grab. In the trolley part, the operation speed is converted into force and input, while in the hoist and grab parts, the operation speed of the drive units is directly input. The speed of each drive is the PLC data converted from RPM unit speed data for equipment control. Table 3 shows the maximum speed of each drive part.

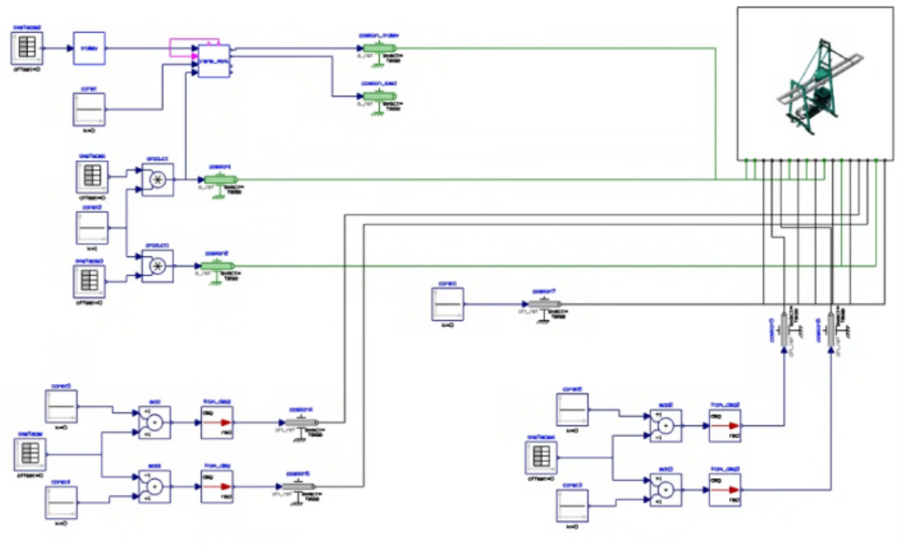

Figure 2. Dynamics-based GTSU drive block diagram

Table 3. Maximum speed of the main drive unit

Motion	***Speed***	***Unit***
Hoist/Lower	152 / 183	m/min
Open/Close	183 / 152	m/min
Trolley traverse	190	m/min

4. Simulation Results

The GTSU dynamic simulation was performed by inputting the speed of each driving unit derived through the automatic control algorithm. The actual displacements of movement for the trolley and the hoist are 42 m and 30 m, respectively. The speed data for each drive part are shown in Figure 3. The system is simulated for 73 s. The results are shown in Figure 4. The results include position of each driving part and grab angle data according to the input speed. As a result of the simulation, the trolley moved 41.65 m and returned, and the hoist moved 28.90 m and returned. The errors from the actual displacement of the trolley and hoist were 0.35 m and 1.10 m, respectively.

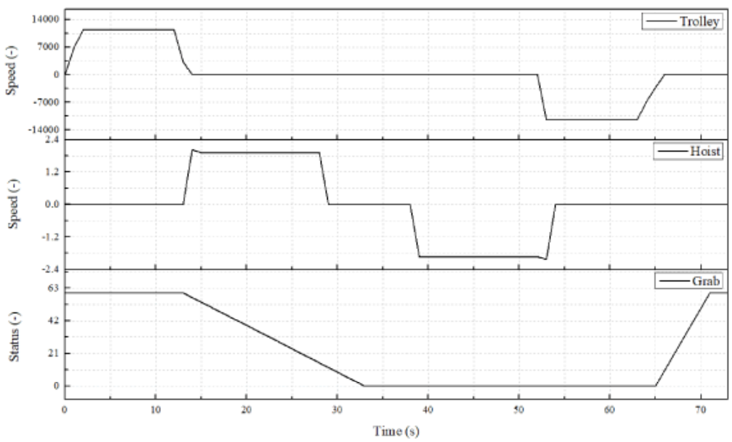

Figure 3. GTSU speed data for each drive part (simulation input)

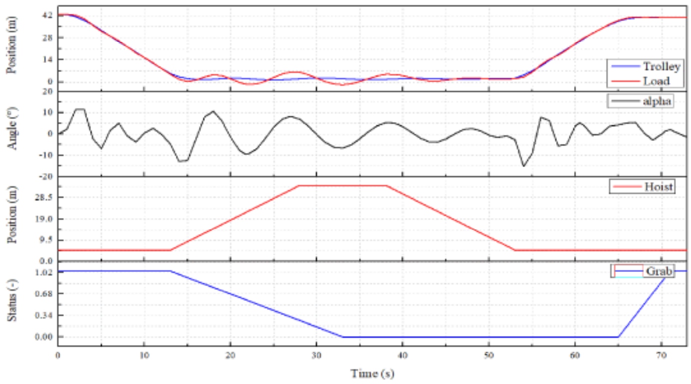

Figure 4. Simulation result using the dynamic simulation platform

When analyzing the angle of the grab, the maximum angle was simulated to be 15.2 degrees. The sway angle can affect work efficiency and safety. In the future, we plan to secure the safety of automated control through anti-sway control.

5. Conclusion

This paper presents the development of a dynamic simulation platform for validating GTSU unloading automation algorithms. The crane system within the dynamic simulation platform is implemented in Modelica as a continuous-time system. The dynamic simulation platform designed based on the GTSU motion equations receives predicted speed data and simulates the moving positions. Simulation results were verified by comparing the actual and simulated operating positions. The errors from the actual displacement of the trolley and hoist were 0.35 m and 1.10 m, respectively. The dynamic simulation platform is expected to serve as a critical tool for advancing smart port operations, bridging the gap between algorithm design and real-world implementation.

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