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Multibody system dynamics simulator for process simulation of ships and offshore plants in shipyards

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ABSTRACT

Since various existing simulation tools based on multibody system dynamics focus on conventional mechanical systems, such as machinery, cars, and spacecraft, there are some problems with the application of such simulation tools to shipbuilding domains due to the absence of specific items in the field of naval architecture and ocean engineering, such as hydrostatics, hydrodynamics, and mooring forces. Thus, in this study, we developed a multibody system dynamics simulator for the process simulation of ships and offshore structures. We based the simulator on six kernels: the multibody system dynamics kernel, the force calculation kernel, the numerical analysis kernel, the hybrid simulation kernel, the scenario management kernel, and the collision detection kernel. Based on these kernels, we implemented a simulator that had the following Graphic User Interfaces (GUIs): the modeling, visualization, and report GUIs. In addition, the geometric properties of blocks and facilities in shipyards are needed to configure the simulation for the production of ships and offshore plants, so these are managed in a database and connected to a specific commercial CAD system in shipyards. We used the simulator we developed in various cases of the process simulation of ships and offshore plants. The results show that the simulator is useful for various simulations of operations in shipyards and offshore industries.

1. Introduction

Requests for accurate dynamic analysis using a simulation tool have been increasing in many engineering fields, including in the shipbuilding industry. Unlike the conventional mechanical systems such as cars and machinery, all ships and offshore structures differ in purpose, shape, and size [1]. Thus, even though process planning may be set up based on the experience of similar ships and offshore structures, many unexpected problems may occur during their production. For example, an interference between a block and the wire ropes, the desynchronization between the cranes, the excess of the maximum tension of the wire ropes, etc. can occur during the production of ships and offshore plants. Fig. 1 shows such problem during production in shipyards.

Moreover, due to the recent increase in the demand for offshore plants and new-concept ships, new manufacturing methods in shipyards are frequently reviewed with simulation, including with dynamic analysis, to confirm their availability and safety [2]. Since various existing simulation tools based on multibody system dynamics focus on conventional mechanical systems, such as machinery, cars, and spacecraft, there are some problems with the application of these simulation tools to shipbuilding domains due to the absence of specific items in the field of naval architecture and ocean engineering, such as hydrostatic, hydrodynamic, wake, and mooring forces. Therefore, some recent studies focused on developing a simulation tool for the shipbuilding process based on the multibody system dynamics theorem.

The remainder of this paper is as follows. Section 2 reviews previous works related to this study. In Section 3, the developed multibody system dynamics simulator for the shipbuilding process is introduced. Its application to shipbuilding follows in Section 4. The last section summarizes this study and briefly discusses the next study.

2. Related works

There are various open-source-based or commercial software programs that are based on the multibody system dynamics theorem. However, there are few cases of their application to the

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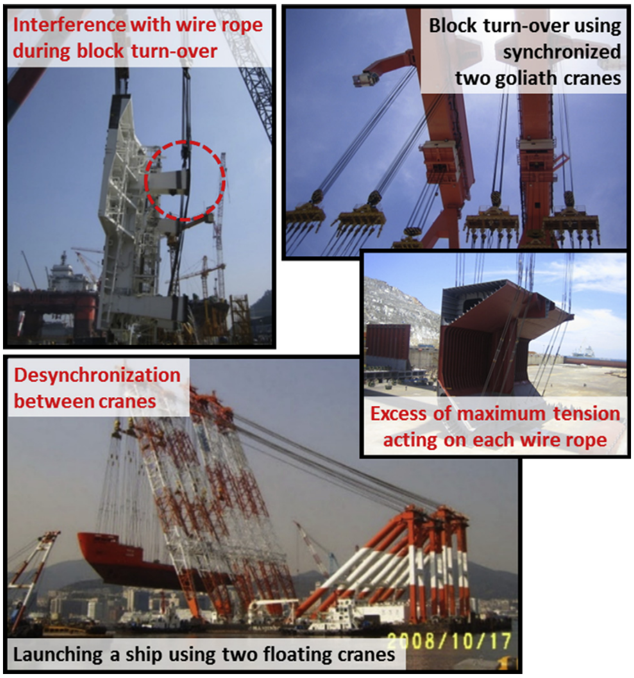

Fig. 1. Some problems during the production of ships and offshore plants.

simulation of the shipbuilding production process, because it is difficult for these systems to support shipbuilding-friendly external forces such as hydrostatic and hydrodynamic forces.

ADAMS (Automatic Dynamic Analysis of Mechanical Systems) is a software system with a number of integrated programs that help engineers perform three-dimensional kinematic and dynamic analyses of mechanical systems [3,4]. ADAMS generates equations of motion for multibody systems using augmented formulation. The user can define any multibody system composed of several rigid and flexible bodies that are interconnected by joints. ADAMS supplies various types of joints, such as fixed, revolute, and spherical joints. Various external forces can also be applied to multibody systems, but hydrostatic and hydrodynamic forces, which are the dominant forces exerted on the floating platform and are often used in shipyards, cannot be handled by ADAMS. ODE (Open Dynamics Engine) is an open-source library for simulating multibody dynamics [5]. Similar to ADAMS, ODE derives equations of motion for multibody systems using augmented formulation. However, ODE can treat only rigid bodies, not flexible bodies. Moreover, it cannot handle hydrostatic and hydrodynamic forces. RecurDyn [6] is a three-dimensional simulation program that combines dynamic response analysis tools and finite element analysis tools for multibody systems. It is two to 20 times faster than other dynamic solutions because of its advanced fully recursive formulation. Various joints and external forces can also be applied to multibody systems, but RecurDyn cannot handle hydrostatic and hydrodynamic forces.

Unlike these programs that are based on multibody system dynamics, MOSES (Multi-Operational Structural Engineering Simulator) is a simulation program that can analyze the motion of a single body in a fluid by applying hydrostatic and hydrodynamic forces to it [7]. With this program, a restrictively connected multibody system cannot be simulated because the program does not support a connective relation between the bodies, but a simulation that considers hydrostatic and hydrodynamic forces as external forces is possible. Thus, MOSES is often used for ocean simulation for a floating single body in shipyards.

In other areas of study that do not use the aforementioned programs, some researches related to shipbuilding domains have been conducted. Cha et al. proposed and developed a simulation framework for the dynamic analysis of the shipbuilding production process [8,9,10]. Based on Cha et al.'s studies, the formulation of multibody system dynamics was changed in order to make automated dynamic analysis efficient, and the component-based scenario management and GUIs were enhanced in this study. The aforementioned related works are summarized and compared with this study in Table 1.

3. Multibody system dynamics simulator for ships and offshore plants

3.1. Configuration of the multibody system dynamics simulator

Fig. 2 shows the configuration of the multibody system dynamics simulator developed in this study. The developed simulator has three layers: the Database, Kernels, and Graphic User Interface (GUI). The core function of the kernels layer is to simulate the operations in shipyards and offshore industries. It has six components: the multibody system dynamics kernel, force calculation kernel, numerical analysis kernel, hybrid discrete event system specification (DEVS)/discrete time system specification (DTSS) kernel, scenario management kernel, and collision detection kernel. The GUI layer is based on these kernels and supports the users' simple simulations from various cases in shipyards or offshore industries. In addition, the geometric properties of the block and facilities in shipyards are needed to configure the simulation for the production of ships and offshore plants, so these are managed in the database layer. In the following sections, the kernels and GUI layers are described in detail.

3.2. Kernels

As mentioned in the previous section, the developed system has six core kernels. The function and role of each kernel are as follows.

3.2.1. Multibody system dynamics kernel

The crane systems in shipyards are all multibody systems in which multiple rigid bodies are joined together. Thus, we developed the dynamic analysis kernel for the multibody system. The computer methods used in the automated dynamic analysis of multibody systems that consist of rigid bodies are generally classified into two main approaches [11]. In the first approach, the configuration of the system is identified using a set of Cartesian coordinates that describe the locations and orientations of the bodies. This approach is called "augmented formulation." In the second approach, relative joint variables are used to formulate a minimum set of differential equations of motion, and two types of formulation use relative joint variables: embedding formulation and recursive formulation. However, embedding formulation has difficulty with automatically modeling multibody systems, so a multibody system dynamics kernel was developed based on recursive formulation [12] in a previous study [13]. To validate the developed kernel, the analysis results were compared with the data measured from a shipyard. This comparison confirmed that the simulation and measured data differed by only 10%. This 10% difference might have been caused mainly by the uncertainty of each multibody system and environmental factors, so we are planning to consider this uncertainty a factor of each term.

The dynamics of a rigid body system are described according to the system's equations of motion, which specify the relationship between the forces that act on the system and the accelerations they produce. The developed kernel contains the algorithms for the following two calculations: the calculation of the forward dynamics, or of the acceleration response of a given rigid body