The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
October 16-20, 2022, New Delhi, India

Digital Twin Model of Marine Robot using Recursive Subsystem Synthesis Method

Sung-Soo Kim*, **Chang-Ho Lee#**, **Jong-boo Han†**, **Jae-beom Jo***, **Hong-Geun Noh***

* Department of Mechatronics Engineering
Chungnam National University
99, Daehak-ro(St), Yuseong-gu,
Daejeon, 34134, Republic of Korea
sookim@cnu.ac.kr

Smart Solution Team
TYMICT
47630, Chadong-ro, Gongju,
Republic of Korea
chlee7868@naver.com

† Ocean System Engineering Research Division
Korea Research Institute of Ships and Ocean Engineering
32, Yuseong-daero 1312beon-gil, Yuseong-gu,
Daejeon, 34103, Republic of Korea
jbhan@kriso.re.kr

Abstract

Marine robots are used in the construction and maintenance of underwater structures. Since these marine robots are operated in a harsh environment, they are usually driven by remote operations. However, remote operations are difficult due to the limitations of sensors used in marine robots. In order to overcome these difficulties, research is being conducted on enhancing the remote operation using a digital twin corresponding to an actual robot [1]. The digital twin of the real marine robot in the virtual environment must be able to accurately predict the behavior of the real marine robot, and at the same time, perform in real-time due to the interaction with the physical twin. Therefore, a real-time multi-body dynamics model of marine robots is required for the digital twin. In this paper, a digital twin model of the marine robot was developed by applying the recursive subsystem synthesis method [2].

The marine robot, in which we are interested, for the digit twin is shown in Fig. 1. It consists of a manipulator arm with a tool plate, a cabin, a base frame, four suspension linkage subsystems, and four track subsystems. The manipulator is driven with four hydraulic motors and two hydraulic cylinder units. The tool plate which is located at the end of the manipulator is also operated by a hydraulic motor. The cabin can swivel with respect to the base frame. Four suspension linkage subsystems are attached to the base frame and each of them is actuated by two hydraulic cylinders. The track subsystem which is composed of a sprocket, a pulley, and a rubber track, can be rotated relative to the suspension link to make the track negotiate rough terrain. The track sprocket is also driven by a hydraulic motor.

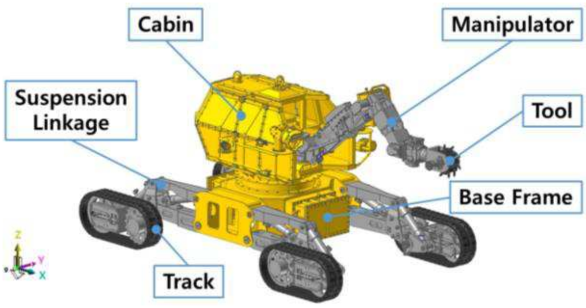

Figure 1: A digital twin of the marine robot (underwater construction robot)

The left picture of Figure 2 shows the topological diagram of the multibody model of the marine robot. A node represents a body and an edge denotes a joint that allows relative motion between connected bodies. It consists of 49 bodies and 62 joints. Thus, the total DOF is 30 (base frame-6, cabin-1, manipulator arm-6, tool plate-1, suspensions 4*3, tracks 4*1).

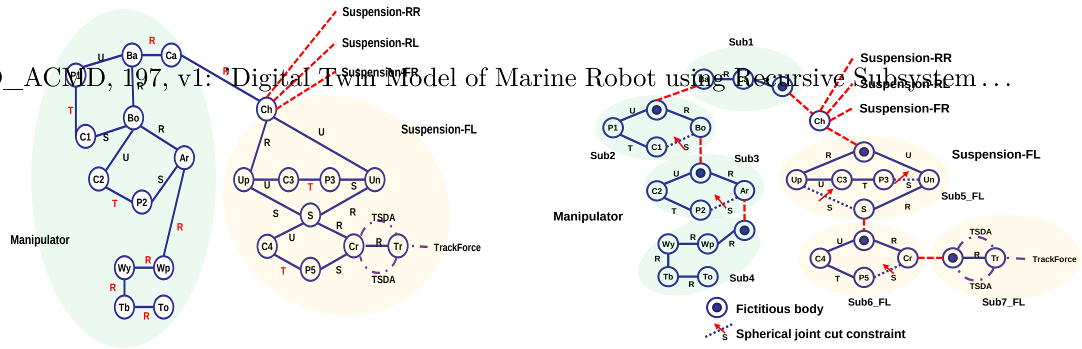

Figure 2: Topology of digital twin and subsystem definitions

To apply the recursive subsystem synthesis method, the cabin-manipulator-tool plate system can be divided into 4 subsystems and the suspension-track system also can be decomposed into three subsystems as shown in the right picture of Fig. 2. For acceleration analysis of the cabin-manipulator-tool plate system, dynamic effects of each subsystem are computed and transferred to the adjacent subsystem recursively from the Sub4-subsystem to the base frame to form the reduced equations of motion for the base frame. Once the base frame translational and rotational accelerations are obtained, then joint accelerations in each subsystem are computed in the recursive fashion from the base frame to the Sub4-subsystem. Similarly, joint accelerations of the suspension-track system can be obtained. Thus, the digital twin model with the recursive subsystem synthesis method is much more efficient than that with the conventional joint coordinate formulation, since several small-sized equations of motion are solved in the recursive subsystem synthesis method.

Figure 3 shows the real-time performance of the developed digital twin model of the marine robot with different numbers of threads of CPU processors in parallel computation. OpenMP-based parallel processing [3] has been realized in PC with Ryzen5 4500U (6 core – 6 thread), maximum clock speed: 4.0GHz, OS: Linux (Ubuntu version 20.04)). As shown in Fig. 3, it is realized 3.9 times faster than real-time in using 5 threads for the 20-second bump run simulation of the marine robot.

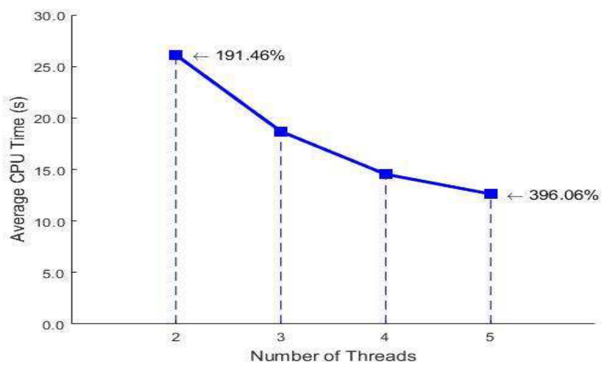

Figure 3: Real-time performance of the developed digital twin model

Acknowledgment
This paper has been supported by an R&D project, 'Development of real-time physical engine for virtual physical integration simulator' sponsored by a grant from Endowment Project of 'Development of Core Technologies for Operation of Marine Robots based on Cyber-Physical System' funded by KRISO (PES4040).

References
[1] Yeu, T.K.; Han, J.B.; Lee, Y.J.; Park, D.G.; Jung, J.J.; Kim, K.H.; Yun, C.H.; Hong, S.; Study on Core Technologies of Marine Robots Operation Based on Cyber-Physical System(CPS), Proc. of The Korean Association of Ocean Science and Technology Societies, IVCC, pp 1231-1232, 2021.
[2] Kim, S.S.; Lee, C.H.: A Recursive Subsystem Synthesis Method for Repeated Closed Loop Structure in Multibody Dynamics. Journal of Mechanical Science and Technology, Vol. 23, No. 4, pp. 946–949, 2009.
[3] Kang, H.C.; Kim, S.S.; Lee, C.H.: Parallel Processing with the Subsystem Synthesis Method for Efficient Vehicle Analysis, Journal of Mechanical Science and Technology, Vol 29, No 7, pp 2663-2669, 2015.