Automated design rationalization of robot component configuration for in-vessel task of ITER Blanket Remote Handling System

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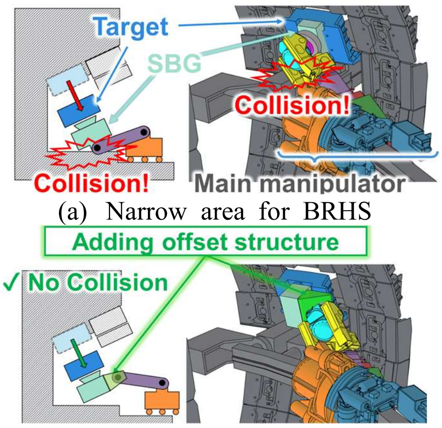
This paper presents the development of an automated design rationalization method for a robotic component of the ITER Blanket Remote Handling System (BRHS). The developed method automates the re-configuration process and the performance evaluation process which require considerable manual efforts in the conventional method. This automation facilitates extensive parameter exploration for multiple design parameters within a realistic timeframe, resulting in the enhancement of design rationality. Using the developed method, we successfully obtained a rationalized design of a BRHS component that satisfies kinematic feasibility, robot joint load reduction, and compactness, which are crucial for the BRHS.

Introduction

Utilizing virtual reality (VR) technologies in robot design is increasingly important. This paper presents an automated design rationalization method utilizing a VR framework, which enables extensive design parameter exploration for the ITER Blanket Remote Handling System (BRHS) [1].

Robotic maintenance systems for fusion devices, including the BRHS, must satisfy challenging requirements such as achieving kinematic feasibility within the constrained in-vessel environment, reducing robot joint load, and downsizing robotic components. Conducting iterative evaluations under extensive design parameters is one of the effective strategies to find design solutions that can address such requirements. However, using the conventional manual method, it is time and effort-consuming to perform repeated re-configurations of the robot (CAD work and setup of kinematic parameters) and performance evaluations with the re-configured models. This inefficiency limits the number of design parameter conditions that can be evaluated, resulting in insufficient design rationality of the robot component, such as a design that is overly conservative and large in dimensions. Therefore, in the developed method, we automated these steps to improve the design process efficiency and enhance the design rationality of the robot.

We conducted the design rationalization of the Shield Block Gripper (SBG), a BRHS component, using the developed method. SBG is used to replace Shield Block (SB) modules, types of Blanket Modules (BM) providing neutron shielding for ex-vessel components. While most SBs can be handled by normal SBGs, SBs in several narrow areas require a special SBG with an offset structure due to kinematic difficulty as shown in Figure 1. Using our method, we successfully obtained the rationalized special SBG design ensuring kinematic feasibility, robot joint load reduction, and compactness. This was difficult to obtain with the conventional method because of numerous possible combinations of design parameters of the offset geometry.



(a) Narrow area for BRHS

(b) Adding offset structure to SBG

Fig. 1 Example of narrow area for BRHS and concept of adding offset structure to the SBG

Developed method/architecture

The developed method was newly implemented as a ROS package. The functionalities of the package can be divided into several steps: configuration of environmental models, re-configuration of the robot, and kinematics evaluation with the re-configured robot. In the environmental model configuration, detailed BM models with 3D geometries that match the actual designs are loaded only around the handling target BM while simplified BM models are loaded elsewhere as environmental models. This balances practical evaluation and computational cost reduction. The re-configuration of the robot and the subsequent kinematics evaluation are integral parts of the required iteration to obtain rationalized robotic component geometry. To enable extensive parameter exploration efficiently, these processes are automated as shown in Figure 2. Taking the SBG with offset structure as an example, the developed method can automatically re-configure the SBG model to the various candidate shapes shown in Figure 3 without any manual CAD work and also automatically evaluate kinematics of whether the re-configured SBG can install the target SB to the VV.

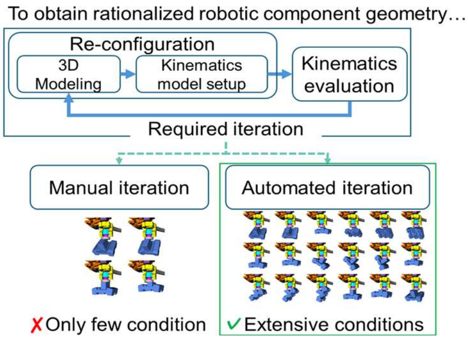


Fig. 3 Efficiency-improved parameter exploration through automation.

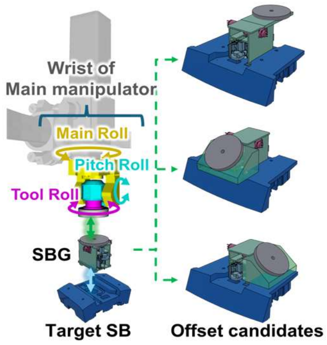


Fig. 2 Joints on wrist part and offset candidates of SBG

Additionally, we implemented a function to generate a report on the required range of motion and the external moment load applied to the robot joints. This allows us to assess not only nominal kinematic feasibility but also whether the loads remain within the design limits. For example, main, pitch, and tool roll joints of the wrist as shown in Figure 3 are subject to spatial constraints, which limit the output torque that can be achieved. Using this function, we can verify that the external loads on these joints during BM handling do not exceed the allowable values.

Demonstration with applying the developed method to the SBG design rationalization

We demonstrated the developed method by applying it to the rationalization of a special SBG for a narrow area, SB above the rail supporting equipment of BRHS. After design parameter exploration that evaluates extensive geometric conditions of the SBG with offset structure, a combination that can satisfy the size compactness of component and robot joint load reduction around the wrist part was selected as the rationalized design parameters.

Compared to the previous SBG design for the narrow area obtained by the conventional method, the rationalized SBG design achieved the following improvements: a reduction in bounding box volume by approximately 15%, a decrease in external moment loads on robot joints due to a rationalized geometrical arrangement that shortens the moment arms from the wrist joints to the target as shown in Figure 4 [2]. The fact that such results were obtained through the developed method demonstrates the applicability of the method.

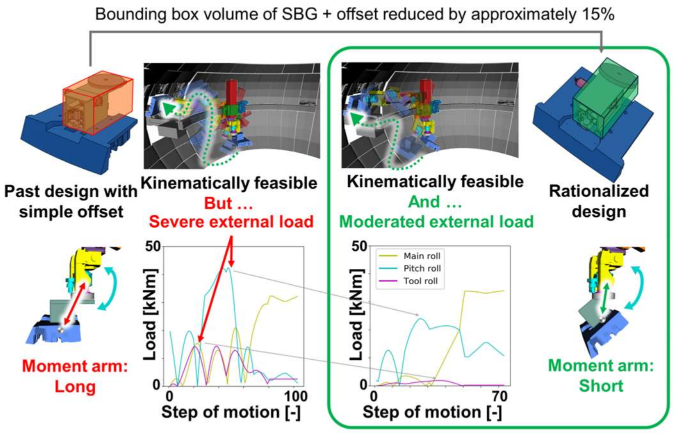


Fig. 4 Comparison of the SBG designs

Conclusion

We developed and demonstrated the effectiveness of the design rationalization method with the automated re-configuration of the robot and kinematics evaluation for the BRHS. The achievements by this study are as follows:

- Reduced manual efforts and improved efficiency to perform extensive design parameter exploration for the robot components;
- Improved the design rationality of the robot component geometry in terms of compactness aspects and structural load aspects, which are important for the BRHS.

References

[1] Y. Noguchi, et al., Fusion Engineering and Design, (2018) 722–728
[2] T. Iwamoto, et al., The 8th QST International Symposium, (2024) Aomori, Japan