Curved Plates Positioning and Flexible Brackets Control in Virtual Shipbuilding Simulation

Cheng Huanchong[1,2(✉)], Fan Xiumin[1,2], Zhu Minghua[3], Gu Yan[1,2], and Du Jiwang[1,2]

[1] CIM Research Institute, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
hccheng@sjtu.edu.cn
[2] Shanghai Key Lab of Advanced Manufacturing Environment, Shanghai, China
[3] Jiangnan Shipyard Co., Ltd., Jiangnan, China
zhuminghua@gmail.com

Abstract. Flexible bracket system is a kind of adjustable fixture with many movable pillars and adaptive to curved plates with various sizes and shapes, thus facilitating fast and precise position or assembly of the curved plates. The purpose of this work is to simulate the control process of flexible brackets to fit different curved plates automatically in virtual environment, thus helping process engineers preview the assembly results, adjust and determine the configuration and controlling scheme of the flexible brackets. The proposed methods for flexible bracket simulation are composed of four steps. First, build a virtual environment of the shipbuilding scene. Second, calculate the pose of the digital curved plate model. Third, optimize the pose and layout of the flexible brackets to fit the curve plate. Last, calculate and optimize the control parameters of the flexible brackets. Our virtual simulation method for flexible brackets reduces the workload for pose adjustment and reconfiguration during the real assembly process, contributing higher precision and efficiency for the curved block building.

Keywords: Flexible bracket · Position · Curved plate · Shipbuilding simulation · Collision detection

1 Introduction

Block building is the most commonly applied method in ship building industry, which constructs the ship hull mainly on curved blocks. Curved plates are massively used on curved blocks during the shipbuilding process, consequently, the assembly precision of curved blocks is directly influenced by the position precision of the plates. However, curved plate has large volume, complex 3D shape and complex contour, bringing difficulties in its positioning and assembly process. Traditionally, curved plates are fixed by specific brackets, which are not reusable for plates of different shapes. When position unmatched plates on specific brackets, the shape difference is adjusted by welding or cutting the position part of the brackets. Such adjustment method cost much

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resource on time, labor and material, and its precision relies on the experiment and performance of the technicians. Therefore, traditional manual bracket adjustment method increase the shipbuilding time and still exists precision issues.

An alternative adjustment method is to use flexible bracket system, which is an adjustable fixture with several movable pillars. Flexible brackets are adaptive to curved plates with various sizes and shapes, thus facilitating fast and precise position or assembly of the curved plates. Though flexible brackets controlled by computer can realize fast position of curved plates of different shapes, it needs to simulate and plan the motion of the pillar before on-site application to check the feasibility and precision of the control scheme. As virtual CAD models of shipbuilding parts are available for visualized simulation, it is convenient to simulate the control scheme with model information under virtual environment, providing an intuitive simulation result.

In this work, a virtual simulation environment is presented for simulating the layout, positioning and digital control process of curved block building. Digital controllable models of flexible bracket and curved plates are established under the virtual simulation environment. An active plate position function is proposed to precisely adjust the brackets and plates simultaneously, which supporting the generation of the digital location and layout control scheme of the flexible brackets system. The related works have been surveyed in Sect. 2. The proposed simulation methods are illustrated in Sect. 3. The simulation results of the are shown in Sect. 4. Section 5 concludes our work and provides possible future improvements.

2 Related Works

2.1 Research on Flexible Fixture for Shipbuilding

Fixture and jigs are essential equipment for the construction of curved hull block, the quality and efficiency of ship construction depend on the assembly accuracy of the curved hull block on jigs. As one of the most important equipment in shipbuilding, how to realize its flexibility has become a focus of research all of the world.

Shipyard in japan has begun to use the tubular active jigs in the 1950's [1]. Although the tubular active jigs has many technical improvements, it still cannot fully meet the flexibility needs of modern shipyard.

The flexibility of shipbuilding is originated from the concept of "multi point forming", which is based on the characteristics of flexible and digital manufacturing of multi point forming equipment. David E. Hardt [2] in MIT has carried out the research on the flexible bracket to realize automation for more than ten years and applied to the forming experiment of thin plate parts. By using the closed loop control principle to measure the height of a base body, and thus to control the forming precision, it was an important research direction for the modern flexible bracket technology [3].

Jiangnan Shipyard has tried to make and use NC jigs for curved hull block in shipbuilding for the first time in China [4]. It proposes a new type of NC flexible jigs which kept the advantages of existing jigs. The application of flexible NC jigs could realize the fast and accurate positioning and assembling of curved block parts, to improve the quality and increase the efficiency of the construction of curved blocks.

2.2 Computer Simulation Technology in Shipbuilding

Digital manufacturing has become the main technical means in shipbuilding industry, as its characteristics of quick response, high quality, low cost and good flexibility. In the field of integrated virtual simulation of ship digital construction, shipyards of the worldwide mainly developed virtual simulation software system.

In April 2002, Samsung heavy industry launched the digital shipbuilding system development plan and developed a digital shipbuilding system in two years later [5]. This system can simulate the whole shipbuilding process from steel plate cutting to ship launching in the virtual environment.

Daewoo shipyard launched the simulation system of the construction process of the ship based on discrete time simulation kernel in 2010 [6]. Based on the previous experience of ship construction and digital technology, engineers could built a virtual shipyard in the system, which could simulate the whole shipbuilding process from steel plate cutting to ship launching [7].

Hudong Zhonghua shipyard in China developed its own enterprise information system HDS-CIMS and shell, outfitting and painting integration of ship product design system independently.

3 Method

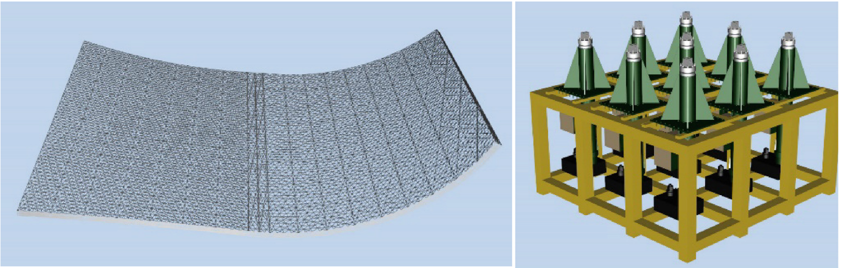
3.1 Overview

Simulating the control process of flexible brackets to fit different curved plates automatically in virtual environment, thereby, to help process engineers to preview the assembly results, adjust and determine the configuration and controlling scheme of the flexible brackets. The major simulation process is divided into five steps:

1. Build a virtual environment of the shipbuilding scene for simulation, which contains curve plate model, flexible bracket model and related objects in workshop.
2. Calculate the pose of the digital curved plate model. An optimization algorithm is proposed to find out the position of the curved plate with the lowest barycenter.
3. According to the pose of curve plate, number and layout of the flexible brackets are automatically calculated to fit the curve plate.
4. Control the position of supporting pillars in the brackets. Real-time collision detection method is used for calculating the contact point between supporting pillar and curve plate.

3.2 Build Virtual Environment

A virtual environment close to the real environment should be built for simulation firstly. This research is based on the VRLAYOUT platform developed by Shanghai Jiao Tong University. As a general developing platform for virtual reality, VRLAYOUT supports multiple formats of 3D model import, real time interactive operation, collision detection between 3D model, etc.



a)Triangle Mesh of Curve Plateb) 3D Modelof Flexible Brackets

Fig. 1. Import curve plate and flexible bracket 3D model

During the simulation, curved plate model, flexible brackets model and other related objects in workshop are required. 3D Model of curved plate is exported from design software TRIBON, and converted to triangle mesh model by VRLAYOUT. 3D Model of flexible bracket, split into one fixed base and nine supporting pillars, is imported to the virtual environment. Figure 1 shows the triangle mesh of curve plate and 3D model of flexible brackets imported into virtual environment.

Then other related 3D models s such as ground, cranes, processing equipment are imported into VRLAYOUT and placed according to the production site. Figure 2 shows the layout result of other related objects in virtual environment.

Fig. 2. Layout related objects in virtual environment

3.3 Calculate the Pose of Curved Plate

Due to the large weight of curved plates used in shipbuilding, it is hard to position and fix them on the flexible brackets. In the production process, the curved plates are usually positioned with the lowest barycenter to increase the stability. The barycenter of a curved plate can be estimated by triangle mesh model in virtual environment. The position with the lowest barycenter is chosen as the fixed position on flexible brackets.

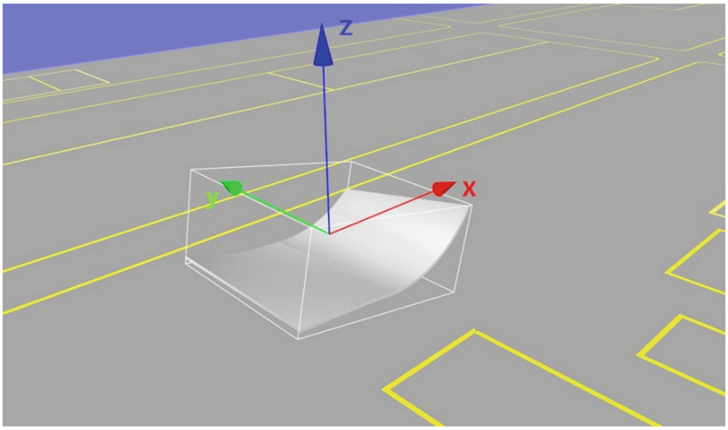


Fig. 3. WCS direction in virtual environment

Calculating the Pose of Curved Plate contains four steps:

1. Sample the Positions for Curved Plate

First, build a world coordinate system (WCS) $oxyz$. In this WCS, o is origin, $+x$ axis points to east direction, $+y$ axis points to north direction, and $+z$ axis points to up direction. Pose of curved plate in the WCS can be described by a 4 × 4 matrix M_q. The initial pose of curved plate is consistent with the WCS. Figure 3 shows the WCS direction in virtual environment.

As the figure shows, the height value of barycenter would change if the curved plate rotated around x axis or y axis, but would remain unchanged if rotated around z axis. Thus, the pose can be sampled by rotate the curved plate around x axis or y axis. A sample point, which can also described by a rotation matrix, is token when curved plate rotated every 1°. M_{ix} and M_{jy} represent rotation matrix rotated around x axis and y axis. The pose matrix of curved plate $M_{qij} = M_{ix} \times M_{jy}$. In the previous formula, i and j represent the rotation angles, the value scope of which are [0,90]. For every pair (M_{ix}, M_{jy}), $i, j \in [0, 90]$, the height of barycenter H_{ij} can be calculated by the pose matrix M_{qij}. In all 8281 pairs, the pose matrix $M_{q\min}$ can be picked out by the minimum value $H_{\min}$ in all H_{ij}.

2. Calculate Z-coordinate of the barycenter

Load the triangle mesh data file of curved plate, and traverse all triangle facets in the mesh. Every triangle facet contains 3 points, $P_i = [x_i, y_i, z_i]^T$, $i \in \{0, 1, 2, 3\}$. The normal of facet $\vec{n} = \overrightarrow{P_1P_2} \times \overrightarrow{P_2P_3}$. Then calculate coordinate of point in every triangle facet in WCS, $P_{iw} = P_i \times M_q$. For every triangle facet T, project the points $P_{iw}, i = \{1, 2, 3\}$ onto xoy plane to get vertical lines $P_{iw}P'_{iw}, i = \{1, 2, 3\}$. Figure 4 shows a pentahedron constructed by $P_{1w}P_{2w}P_{3w}P'_{1w}P'_{2w}P'_{3w}$. The Z-coordinate of the barycenter for this pentahedron $m_{Tz} \approx \frac{P_{1wz} + P_{2wz} + P_{2wz}}{6}$.

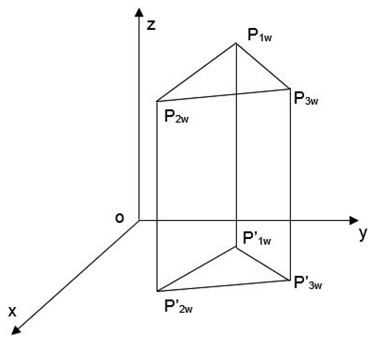


Fig. 4. A pentahedron constructed by vertexes in triangle facet and their projection points

Consider the influence of normal direction of triangle facet, a normal factor σ_T is introduced to describe the coefficient:

$$\sigma_T = \begin{cases} 1, \vec{n} \cdot \overrightarrow{oz} > 0 \\ 0, \vec{n} \cdot \overrightarrow{oz} = 0 \\ -1, \vec{n} \cdot \overrightarrow{oz} < 0 \end{cases}$$

For entire model of triangle mesh, Z-coordinate of curved plate can be calculated by $m_{qz} = \sum_{1}^{n} \sigma_{iT} m_{iTz}$.

3. Calculate the height value of barycenter

Traverse all the triangle facets of curved plate and find $P_{z\min} = \min(P_{iz})$, where P_{iz} are Z-coordinate values among all vertexes in triangle mesh. The height value of barycenter $H = m_{qz} - P_{z\min}$.

4. Calculate $M_{q\min}$ of the curved plate

For every M_{qij}, calculate the height value of barycenter H_{ij}, traverse all pose and get $M_{q\min}$ when the height value of barycenter gets $H_{\min}$.

3.4 Flexible Brackets Layout

In the 3D virtual environment, the bracket pose is set at where the height of barycenter reaches the minimum value, which is denoted by $M_{q\min}$. All vertexes $P_i = [x_i, y_i, z_i]^T$ of the triangular meshes on the curved plates are iterated to calculate their position under the world coordinate system $P_{iw} = [x_{iw}, y_{iw}, z_{iw}]^T = P_i \times M_{q\min}$. During the iteration, the max and minimum value of x_{iw}, y_{iw} are recorded and denoted as $x_{iw\max}$, $x_{iw\min}$, $y_{iw\max}$ and $y_{iw\min}$ respectively. Then the minimum projection rectangle on the *xoy* plane of the bracket is calculated as shown in Fig. 5.

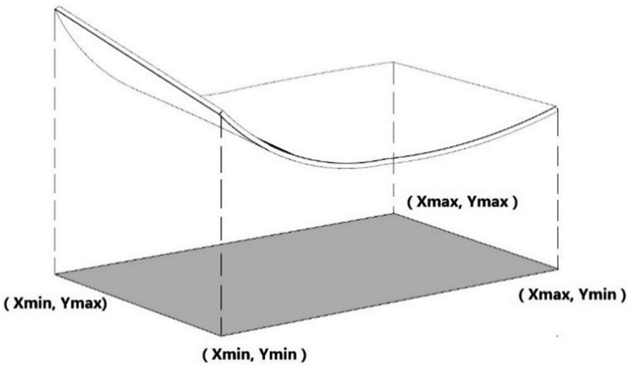


Fig. 5. The minimum projection rectangle of curved plate on *xoy* plane

According to the width of single bracket W_T, the total number of required brackets on both x and y direction under the world coordinate system are calculated by $Num_x = \left\lceil \frac{x_{\max} - x_{\min}}{W_T} \right\rceil + 1$ and $Num_y = \left\lceil \frac{y_{\max} - y_{\min}}{W_T} \right\rceil + 1$. Therefore, the total bracket number used on one curved block is $Num = Num_x \times Num_y$.

3.5 Moving Control of Supporting Pillars

The flexible brackets achieve their flexibility by control the height and the motion of their supporting pillars. Each pillar supports the curved plate, and the goal of the control is to adjust the height of the pillars well fit for the shape of the curved plates supported by the bracket, thus maintaining the shape of the plate during its processing. When the position of the plate is determined, the problem turns into calculating the height motion of the each supporting pillar along its moving direction.

To address the irregular shape of curved plate and supporting pillar, collision detection is used to calculate the contacting point between the end of the pillar and the plate. Intersection checking of the triangular meshes of pillar and plate models are used to check if the two objects contact with each other.

Collision detection have already been realized by VRLAYOUT, which provides an effective detection method based on triangle mesh models. The main steps to calculate the movement of each supporting pillar are as follow:

1. Generate collision model of each supporting pillar and the curved blocks. The model is generated by CDMake provided by VRLAYOUT, and its precision can be set by user.
2. Discretize the max motion path of the supporting pillar along its moving direction. The max upward motion distance is $S_{\max}$, and the discrete step size can set by user. The pose of the supporting pillar along the upward directions denote as M_Z.

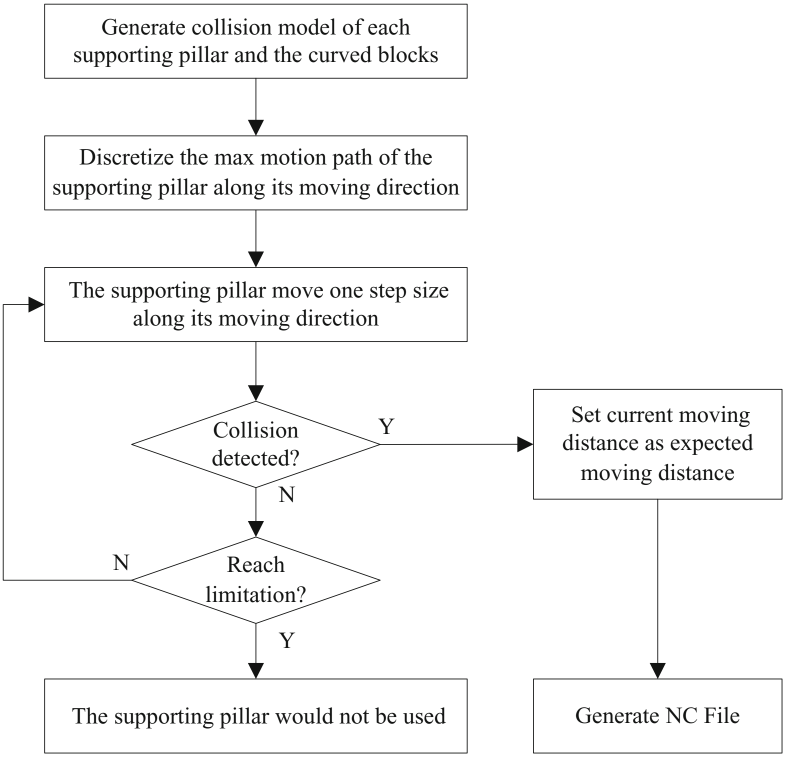


Fig. 6. Flowchart of calculating the moving distance of supporting pillars

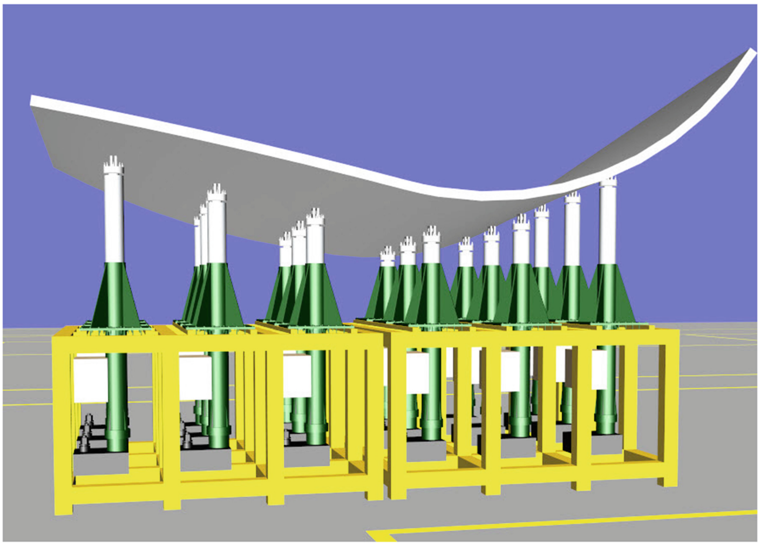


Fig. 7. The result of flexible brackets control in virtual environment

3. Collision detection is performed to determine if the pillar touches the plate, if the result is positive, then all steps are added as the moving distance, or else move to the next step.
4. If no collision detected when the supporting pillar reach the limited position, it means that the supporting pillar would not use in the positioning process, or else the supporting pillar move one step size along its moving direction. Jump to step. 3 with new M_Z and recalculate the collision status.
5. Calculate all moving distance of supporting pillars, record them and generate the NC program file used to control the flexible brackets.

Figure 6 shows the flowchart of calculating the moving distance of supporting pillars. Figure 7 shows the result of flexible brackets control in virtual environment.

4 Results

According to the research above, Flexible Brackets Control System is developed based on VRLAYOUT and concentrates on curved plates positioning in shipbuilding industry. The system has been applied on a shipbuilding corporation and archived a good result. Figure 8 shows the system used in shipbuilding process in this corporation.

In this case, calculating the pose of curved plate and controlling the movement of supporting pillars in flexible brackets help process engineers to determine the fix method and controlling scheme of the flexible brackets. The curved plate has a more precise with a triangle mesh contains about 4.5 million triangle facets. Benefited from multithread optimization, the process of calculating the pose of curved plate costs about 176 s. In flexible brackets controlling process, the collision model precision is set to 0.1 mm, and step size of supporting pillars is set to 0.05 mm to get an accurate result.

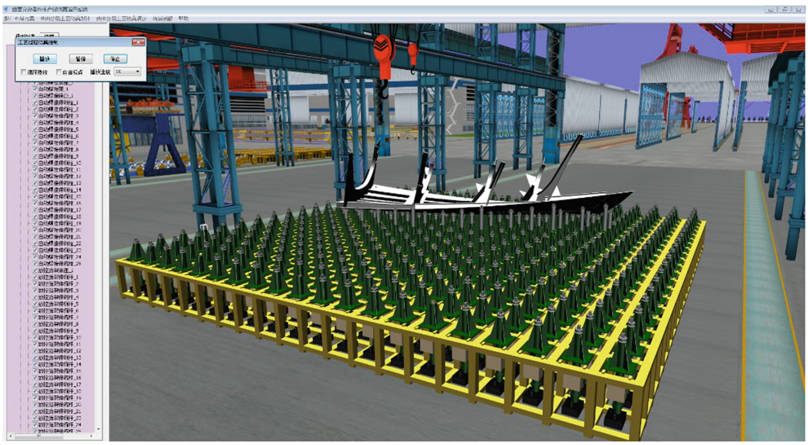


Fig. 8. The system used in shipbuilding process in corporation

The cost time is about 17 m 25 s for calculating the moving distance of 864 supporting pillars in 96 flexible brackets. The simulation contributes higher precision and lesser time cost than traditional methods.

5 Conclusions

This paper proposed a virtual simulation method of flexible bracket for curved hull block building. An implementation of the system is developed based on VRLAYOUT (interactive plant layout with VR) platform. The system proposes a pose simulation method of curved plates and flexible brackets. A collision detection based method is proposed for planning the control scheme of the flexible brackets system. The proposed system provides an interactive, precise and efficient movement planning and controlling tool for flexible bracket planning and for users from shipbuilding industry. The system has been verified and applied on a shipbuilding corporation. By replacing fixed brackets with the flexible ones, the virtual bracket simulation system demonstrates an improvement of the efficiency and reducing the test-cost for the curved-block shipbuilding process.

For further research, an algorithm for searching optimal solution can be added for calculating the pose of curved plate, which can provide more effective method to find the optimal result. The precision of collision detection model can be improved for a more accurate result.

References

1. Kang, W., Lu, C., Gao, X., et al.: Research on the industrial design method of control panel based on man-machine engineering restriction. In: The International Conference on Computer-Aided Industrial Design and, Conceptual Design. Chinese Mechanical Engineering Society, pp. 7–11 (2008)
2. Hardt, D.E., Webb, R.D., Suh, N.P.: Sheet metal die forming using closed-loop shape control. CIRP Ann. Manuf. Technol. **31**(1), 165–169 (1982)
3. Walczyk, D.F., Hardt, D.E.: Design and analysis of reconfigurable discrete dies for sheet metal forming. J. Manuf. Syst. **17**(6), 436–454 (1998)
4. Jun-jie, S., Yang, Y., Jian, W., et al.: Research on flexible manufacturing technology based on NC jigs for curved hull block. Nav. Archit. Ocean Eng. **32**(2), 63–68 (2016)
5. Lee, K., Shin, J.G., Ryu, C.: Development of simulation-based production execution system in a shipyard a case study for a panel block assembly shop. Prod. Plann. Control **20**(8), 750–768 (2009)
6. Cha, J.H., Roh, M.: Combined discrete event and discrete time simulation framework and its application to the block erection process in shipbuilding. Adv. Eng. Softw. **41**(4), 656–665 (2010)
7. Cha, J.H., Park, K.P., Lee, K.Y.: Development of a simulation framework and applications to new production processes in shipyards. Comput.-Aided Des. **44**(3), 241–252 (2012)