Curved Shell Plates’ Manufacturing Support Framework

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論 文 の 内 容 の 要 旨

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（曲がり外板の加工支援フレームワークに関する研究）

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The curved shell plates' manufacturing processes, the cold forming process using press machine and the heating forming process using the gas burner and water hose, carry great risks for no quantitative criteria on the wooden bending template (Kikata) check with human eyes, and great depending on the knowledge, skills and experiences of the workers. Effective design of the manufacturing plan and efficient knowledge elicitation and dissemination during the curved shell plates' manufacturing processes, become a principle problem of the shipbuilding industry.

The aim of this research is:

(1) To facilitate the whole manufacturing process of the curved shell plate by proposing a practical framework.

- To develop manufacturing evaluation method for achieving high and stable quality of the cold forming.
- To develop a virtual environment for facilitating the heating forming stage by replacing the wooden templates with the virtualized templates of high evaluation accuracy and usability.
- To propose knowledge models for eliciting and disseminating the common manufacturing guidelines and detailed instructions.

(2) To evaluate the proposed framework by conducting multiple manufacturing experiments in the shipyard.

A practical framework shown in Figure 1 for facilitating the whole manufacturing process of the curved shell plate is proposed. In this thesis, laser scanner is used for capturing the curved shell plate's 3D shape before and after every manufacturing step. Firstly, the plate is extracted from the raw point cloud data with a lot of obstacles by the Plate Measurement System (MS). The Press Support System (PSS) locates the extracted shape of the curved shell plates onto the press design data after cold forming, and then calculates the displacements and virtualizes the errors to support the cold forming process. By representing both the measured curved shell plate and the generated virtual templates on computer, the Virtual Template System (VTS) reproduces the manufacturing processes in the virtual environment instead of using the real wooden template and provides the workers with the heating manufacturing areas and grades suggested by system. The whole evaluation and operation flow is fully automatized by the Automation Engine (AE). The Knowledge Based System (KBS) facilitates the decision-making process of the curved shell plate's manufacturing plan's design by eliciting the knowledge based on the interviews and the recorded 3D manufacturing scenario data, and then virtualizes the both the explicit and implicit knowledge on computer for beginner workers.

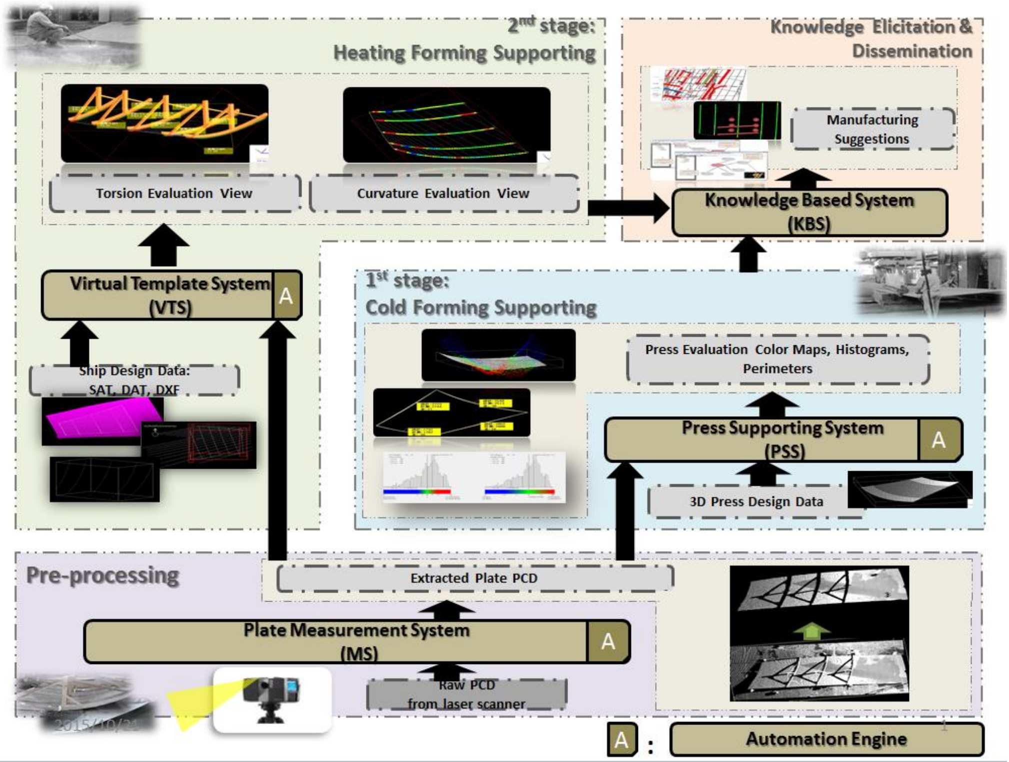

Figure **1** Layout of the proposed framework

Necessary original innovations for realizing the proposed framework were introduced. Interfaces for facilitating the curved shell plates' manufacturing and preserving the manufacturing convention were proposed and developed with high accuracy and high usability. Efficient method for eliciting and disseminating the knowledge existing in the manufacturing processes based on the data recorded by the proposed interfaces was proposed. Original point cloud processing methods supporting the proposed interfaces for extracting the plates' point clouds which are separated by irregular obstacles and for registering them with the design data were developed.

(A) The manufacturing convention preserving interfaces and knowledge elicitation and dissemination methods

The cold manufacturing support interface was generated by comparing the press design data and the measured point cloud of the plate to calculate and virtualize the distance errors and the perimeters of the plate. The plate's areas which the real wooden templates cannot check were also evaluated and visualized by the proposed color map interface. The heating forming support interface was generated by virtualizing the conventional manufacturing process in which the wooden template was used. The wooden templates were virtualized and the manufacturing parameters supporting the conventional manufacturing are calculated on computer. The workers could operate and observe the virtual template in the conventional way to reserve the conventional manufacturing skills and habits.

The knowledge elicitation and dissemination method using Nested Ripple-Down-Rules was proposed. By updating the existing rule base according to the differences between the system-suggested manufacturing plan shown on the proposed interfaces and the worker-used manufacturing plan, the knowledge elicitation process from the expert workers was introduced. By visualizing both the existing rule base and the details of the plate's information, the knowledge can be efficiently disseminated to the beginner workers.

According to the experiments eliciting knowledge using 3 different kinds of plate during totally over 20 manufacturing steps, it showed that the knowledge about the line heating and point heating. These two can be used to manufacture over 90% of the plates in the shipyard was successfully elicited. The elicited rule base was verified though the interviews with the expert workers. The beginner worker successfully manufactured 2 plates using the manufacturing plans suggested by the system in the dissemination experiment. The effectiveness of the proposed method is confirmed.

(B) The point cloud processing methods

As common pre-processing for both the cold forming and the heating forming supporting, the general region growing method was redesigned for achieving high extraction speed and reducing the extraction errors. The method for recognizing the separated parts of the plates' point clouds caused by the obstacles existing in the raw data was developed by proposing the common domain judging standard based on the edges of the extracted domains. The registration method of the measured data and the design data was proposed by pre-setting the registration directions.

In the preliminary experiments conducted in the shipyard, over 200 plates were extracted and registered using the proposed methods. The average extraction time (about 38 seconds per million points without separations) showed that the reformed extraction method can satisfy the practical usage in the shipyard. Besides, about 120 plates separated by different kinds of obstacles were also extracted successfully which demonstrated the effectiveness of the common domain recognition standard. Finally, all of these 200 plates were successfully registered with design data automatically, and the calculated displacement color maps were verified by using the real wooden templates at the end of the manufacturing.

According to the experiment results of the whole framework, the high and stable quality of the cold forming was achieved. The contribution of the cold forming support system for the decrease (average 1.5 hours per plate) of the subsequent manufacturing time and the setback on cold forming was confirmed.

With the proposed interface for heating forming, the manufacturing time was dramatically reduced averagely 30% from that under conventional manufacturing. The interviews with the workers who used the proposed virtual template interface showed that the physical effort was reduced, too. The heating manufacturing time was averagely reduced to about 70% by introducing the proposed framework. The readjustment time due to poor quality was also reduced to about 55%. That the interface outputted by the proposed system can facilitate different kinds of curved shell plate's manufacturing following the conventional manufacturing technics was confirmed.