Efficient Modeling of Ship Structure Based on Image Recognition and Data Retrieval

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Abstract. In order to significantly improve the efficiency of ship structure modeling, an efficient ship structure modeling method based on image recognition and data retrieval is proposed. First of all, the typical Panel has been designed, according to specific data standards, the data and drawings are saved to the database. Then when a new Panel needs to be created, compare the 2D drawings of the structure around the Panel through image recognition to get a similar structure and confirm which Panel's script file in the database is used. Finally, using the standard numbering method, the mapping relationship between the original Panel and the target Panel topology objects and the transformation logic of coordinate data are calculated, and then the target Panel script file is generated. This is the method of efficient modeling in this paper.

Keywords: Image Recognition; Data Retrieval; Panel Efficient Modeling; Artificial Intelligence.

1. Introduction

The amount of work involved in modeling ship structures is immense. 3D CAD interaction is more friendly, but it does not significantly improve the modeling efficiency [1]. In the field of 3D design of ship structures, the application of CAD technology has become important to improve the design quality and shorten the design cycle [2][3]. However, although CAD design software, such as AM, CATIA, SPD [4], has been widely used in the marine industry and has made remarkable achievements in modeling ship structures, its efficiency is still a challenge. Especially in the face of the pain points of ever-compressed design cycles and gradually increasing design costs, it is difficult for traditional CAD modeling methods to bring breakthrough improvements [5].

With the rapid development of computer vision and artificial intelligence technology, great progress has been made in image retrieval. The core of image retrieval systems lies in finding images similar to the query image from a large dataset[6]. These systems usually include three main parts: feature extraction, feature matching, and similarity evaluation. Among them, feature extraction is crucial because unique features such as color, texture, shape, and edges are extracted from each image[7]. These features are representative descriptions of the image content[8]. Subsequently, the extracted features are compared with those of the query image by the feature matching component to determine their similarity. Finally, the similarity score of each image pair is calculated by the similarity evaluation component based on the feature matching results[9], and the retrieval results are sorted accordingly.

Establishing a database of mother ship frames and using image recognition technology for similarity retrieval is an innovative way to achieve efficient ship frame modeling. Recent advances in image recognition, especially in deep learning and computer vision[6], have greatly improved the accuracy and efficiency of image-based similarity retrieval. Using advanced models such as pre-trained visual transformers (ViT) [10], convolutional neural networks (CNN) [11], and feature extraction techniques such as scale-invariant feature transform (SIFT) [12] and histogram of oriented gradients (HOG) [13], similar structures can be quickly identified and extracted from a huge database of mother ship frames. This not only speeds up the design and modeling process but also improves accuracy and reliability. In ship engineering, the rapid retrieval and matching of similar mother ship frames can greatly reduce repetitive tasks, improve production efficiency, and provide strong support for subsequent ship design and manufacturing. Combining image recognition with mother ship frame modeling has great practical significance and broad application prospects.

In this paper, Panel data standard is studied, when the panel is completed, the designer runs the save function as he/she wishes, and does not need to spend a lot of time to build data for AI, so the data can be accumulated in the daily modeling process. Reuse historical data and use image recognition technology to quickly identify similar structures; identify new surrounding structures, replace the original script data, and then quickly generate a new Panel. Based on historical model data, the efficiency of ship structure modeling is greatly improved by using image recognition and data retrieval techniques. Figure. 1 shows the overall framework of this study, including key steps such as plate frame database, image recognition and data retrieval, and coordinate data and topological data conversion.

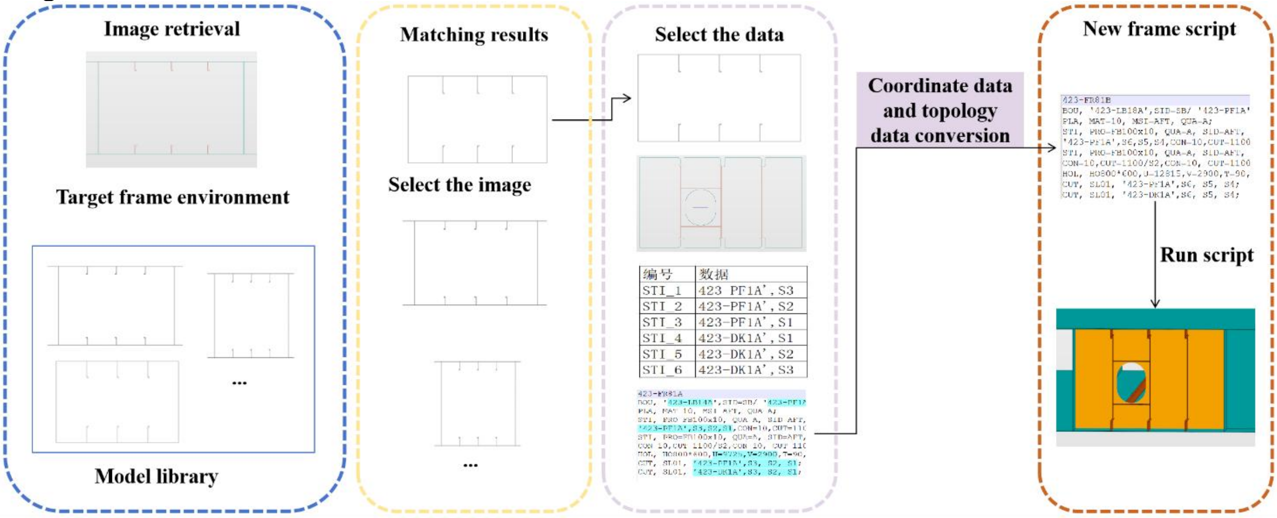


Fig. 1. An overall framework for efficient modeling of hull structures based on image recognition and data retrieval

2. Research on data standards

The database is used to store Panel data for which the design has been completed. In order that Panel can be utilized stably by the AI system to generate high quality target Panel script files, therefore the data standard research is carried out. In the database, a data package is an element. A packet stores a series of data of a Panel, including four files: 2D drawing of the structure around the Panel; 2D drawing of the Panel; script file of the Panel; and table of topology object and vertex number of the Panel.

2.1 Standard for "2D drawing of the structure around a panel"

The standard study of "2D drawings of structures around the Panel" has made the following provisions in three aspects: content of the drawings, projection direction and boundary range.

2.1.1 Content of the drawings

"2D drawing of structure around Panel" needs to exclude Panel itself and only generate projection drawing for the ship structure around Panel.

2.1.2 Projection direction

Obtain the coordinate plane data of the Panel, project it with the normal view of the Panel, and follow the projection direction from the after to the forward, from the top to the bottom, and from the port side to the starboard side.

2.1.3 Boundary range

Using the outline of the Panel as a base, a square border with horizontal emissions and minimum area is generated using the Rotating Calipers Algorithm [14]. Based on this border, a slightly larger border is formed by expanding it outward by 500mm, which is used as the boundary of the "2D drawing of the structure around the Panel".

Follow above standard data, Fig. is a sample "2D drawing of the structure around the panel".

Fig. 2. A sample "2D drawing of the structure around the panel"

2.2 Standard for "2D drawing of a Panel"

The research of standard of "Panel2D drawings" has made the following provisions: the content of drawings and the line standard.

2.2.1 Content of "2D drawing of a Panel"

Panel 2D drawings, which need to include only the structure of the Panel itself. A Panel usually includes features such as plate seams, openings, stiffeners, flange, bracket, etc.

2.2.2 Line standard

The line type on the drawing is based on the standard "Metal Hull Drawing Part 3: Line Type and Numbering" (GB/T 4476.3-2008). With thick solid lines, thick dotted lines, thick double-dotted lines and other different line types abstractly represent different features.

The projection direction standard of "Panel2D drawing" is the same as "2D drawing of the structure around the panel". Follow above standard, Fig. 3 is a sample of "2D drawing of a Panel".

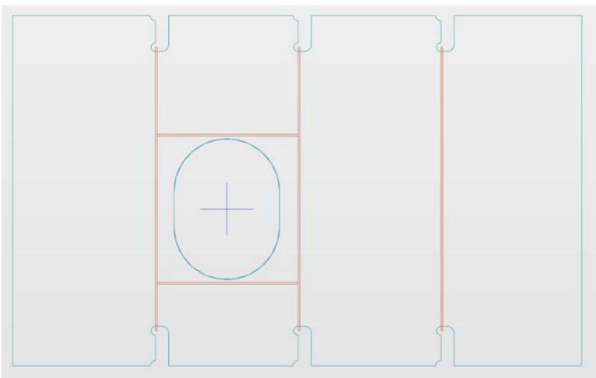


Fig. 3. A sample of "2D drawing of a Panel"

2.3 Standard for "Panel script"

CAD software often provides powerful scripting capabilities to allow users to automate repetitive tasks [15], create custom tools or extend the functionality of the software. Script files can be driven to generate panels, which greatly enhances the flexibility and efficiency of 3D modelling work [16]. The purpose of saving a Panel Script File is to generate a Panel Script File for the target Panel based on this data. Panel script is the core data for efficient modelling of the target Panel.

Different software have their own scripting syntax, e.g. MAXScript for 3ds Max, VBScript for Rhino, Ruby for SketchUp [17], etc. In this thesis, in order to be able to generate the target Panel in the new surrounding structure, it is crucial to identify which data in the script file is refer to the surrounding structure. The following 2 types of data were researched: point coordinate data, and topology data.

2.3.1 Point coordinate data

Many features in the model are positioned by coordinate, so the positions of these features are fixed. When reusing them, it is necessary to calculate the distance according to the coordinate data of the target Panel, rewrite the script file, and locate the features to the new position. For example: hole center, line end point, etc.

2.3.2 Topology data

A large number of features topologies to surrounding structures. When these data are reused, it is necessary to replace the surrounding structure of the original Panel with the surrounding structure of the target Panel, and rewrite the script data to generate the target Panel in the new surrounding structure. For example: Panel boundary topology to other panels, profile topology to other profiles, reference profile to create a penetration hole, are using the topology, the object of the topology is the profile on other panels.

The script also contains a large number of design parameters, which are the initial default parameters for generating panels. The method in this paper reuses these parameters to efficiently generate new panels, so these parameter data are not edited. Fig. 4 Panel script snippet.

```
423-FR81A
BOU, '423-LB14A',SID=SB/ '423-PF1A',SID=BOT/'423-LB10A',SID=PS/Z=2010;
PLA, MAT=10, MSI=AFT, QUA=A;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=PS, NO=1(1)3, '423-PF1A',S1,S2,S3,CON=10,CUT=1100/'423-
DK1A',S3,S2,S1,CON=10,CUT=1100;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=TOP, Z=3315,2475,NO=4,5,S1, CON=10,CUT=1100/S2,CON=10,
CUT=1100;
HOL, HO800*600,U=9725,V=2900,T=90,CNO=1;
CUT, SL01, '423-PF1A',S1, S2, S3;
CUT, SL01, '423-DK1A',S3, S2, S1;
```

Fig. 4. A panel script snippet

2.4 Standard for "Topology object and vertex number"

The purpose of standard numbering of topological objects and vertices of Panel is to provide conversion logic for generating target Panel script file based on original Panel script file. The standard research is mainly carried out in three aspects: the number of vertices, the number of topological Panel and the number of topological profiles

2.4.1 The number of vertices

Use the CAD system API to get the vertices of the panel, starting from the upper left vertex, and numbered clockwise, such as Ver_1, Ver_2... And get the coordinate value of each vertex.

2.4.2 The number of topological Panel

Use the CAD system API to get which panel objects are topological. The top panel is the first element, numbered clockwise, for example, Bou_1, Bou_2... And get the name of each panel.

2.4.3 The number of topological profiles

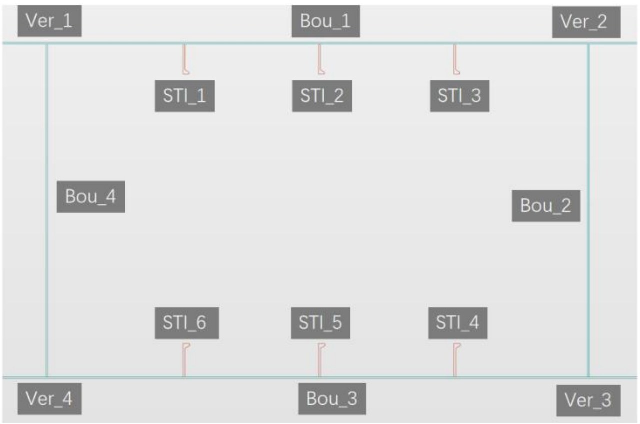
Use the CAD system API to get which profile objects are topological. The top and leftmost profiles is the first element, number clockwise, such as STI_1, STI_2... And get the panel name and profile name for each profile.

Table.1 is the data corresponding to the number. Fig. 5 is a Panel numbered sample.

Table.1 is the data corresponding to the number

Number	DATA
Bou_1	423-PF1A
Bou_2	423-LB10A
Bou_3	Z=2010
Bou_4	423-LB14A
Ver_1	69450, 10940, 4000
Ver_2	69450, 7710, 4000
Ver_3	69450, 7710, 2010
Ver_4	69450, 10940, 2010
STI_1	423-PF1A', S3
STI_2	423-PF1A', S2
STI_3	423-PF1A', S1
STI_4	423-DK1A', S1
STI_5	423-DK1A', S2
STI_6	423-DK1A', S3

Fig. 5. Panel numbered sample



3. Research on generating target Panel

3.1 Process of generate the target Panel

This paper develops the process of generating target Panel. Before modeling the target Panel, 2D drawings of the structure around the target Panel need to be generated, and image recognition technology is used to calculate the similarity with the database. The designer chooses the most similar surrounding structure and the most suitable Panel 2D drawings, that is, a data package is selected. Based on the conversion logic of coordinate data and topology data, generate the script of target Panel and run the script to generate target Panel. Fig. 6 is the main process of generating target Panel.

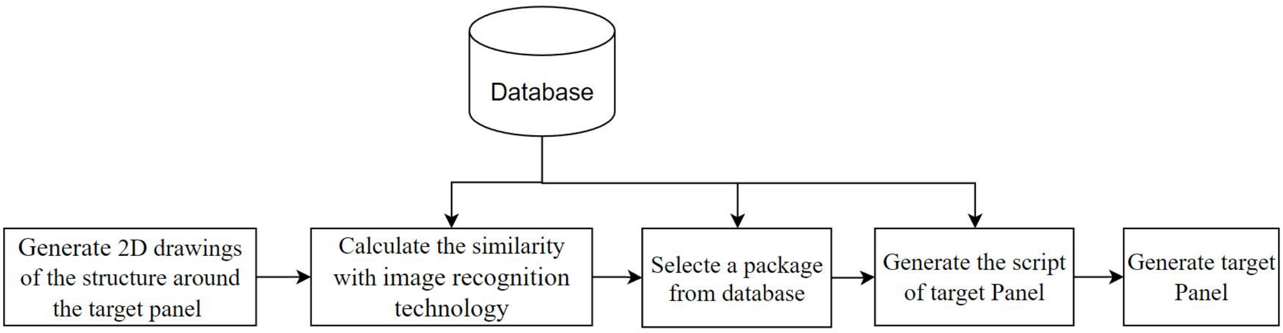


Fig. 6. The main process of generating target Panel

3.2 Ship structure feature recognition technology

For the hull structure feature recognition training, this study proposed an image similarity matching technology based on the Vision Transformer (ViT) model [18] to identify straight plates, curved plates and profiles in the hull structure diagram. The specific process is shown in Fig. 7. This study adopts the method of fine-tuning the ViT model. During the training process, we adopted a 5-fold cross-validation strategy to ensure the stability and generalization ability of the model. The specific steps are as follows:

1) Divide the dataset into 5 subsets.
2) Select one of the subsets as the validation set each time, and the other four subsets as the training set.
3) Perform 5 training and validations to ensure that each subset is used as a validation set once.

The model training is divided into three stages, and each stage is fine-tuned for different feature types:

Straight plate recognition:

In the first stage, the model is trained to recognize the case where the flat plate frame is a full straight edge. The training in this stage mainly focuses on recognizing the straight edge features in the image.

Curved plate recognition:

In the second stage, the model is fine-tuned to recognize planar plate frames with one or more curved edges. The training in this stage mainly focuses on recognizing curved edge features in the image.

Profile recognition:

In the final stage, the model is further fine-tuned to recognize and classify stiffeners arranged on different edges. The stiffeners are classified according to the following features: specification (height of the rib), form (flat steel, ball flat steel, etc.), position (distribution of the rib on the plate) and orientation (ball head direction).

In the image similarity matching process, the technical details are as follows:

Image preprocessing:

First, the input hull structure image is standardized, including resizing, center cropping, conversion to tensor, and normalization according to the pre-calculated mean and standard deviation. These steps ensure the consistency of image input and the stability of model training.

Feature extraction:

The self-attention mechanism of the ViT model [18] is used to divide the input image into blocks, and each block is embedded as a vector. Then, through a series of self-attention layers, the model is able to capture the global and local features of the image. This method is suitable for capturing fine rib features in plane frames.

$$Z_0 = [x_{class}; E(x_1); E(x_2); \ldots; E(x_n)] + E_{pos} \#(1)$$

$$Z_{l+1} = \mathrm{MSA}\big(\mathrm{LN}(Z_l)\big) + Z_l$$

$$Z_{l+1} = \mathrm{MLP}\big(\mathrm{LN}(Z_{l+1})\big) + Z_{l+1}$$

Where Z_0 is the initial input, $E(x_i)$ is the embedded representation of the image block, E_{pos} is the position embedding, MSA is the multi-head self-attention mechanism, MLP is the multi-layer perceptron, and LN is the layer normalization.

Model fine-tuning:

Based on the pre-trained ViT model [19], it is fine-tuned to make it better suited to the feature recognition task of the hull structure diagram. During the fine-tuning process, the cross-entropy loss function (Cross-Entropy Loss) [20] is used to measure the difference between the model prediction and the true label, and the back-propagation algorithm is used for optimization.

$$\text{Loss} = -\sum_{i=1}^{N} y_i \log(\hat{y}_i) \#(2)$$

Where y_i is the true label, and $\hat{y}_i$ is the probability distribution of the model prediction.

Similarity calculation:

Through the extracted feature vectors, we use cosine similarity [21] to calculate the similarity between images. Cosine similarity can effectively measure the directional consistency of two vectors in high-dimensional space, and has a good effect on image similarity matching.

$$\text{Cosine Similarity} = \frac{A \cdot B}{\| A \| \| B \|} \#(3)$$

Where A and B are the feature vectors of the two images, $\cdot$ represents the dot product, and $\|\cdot\|$represents the norm of the vector.

The image retrieval method based on feature vector and cosine similarity in this study effectively realizes the efficient recognition of straight plates, curved plates and profiles in hull structure images, especially the accurate capture of fine-grained features, and realizes efficient matching and retrieval of hull structure images.

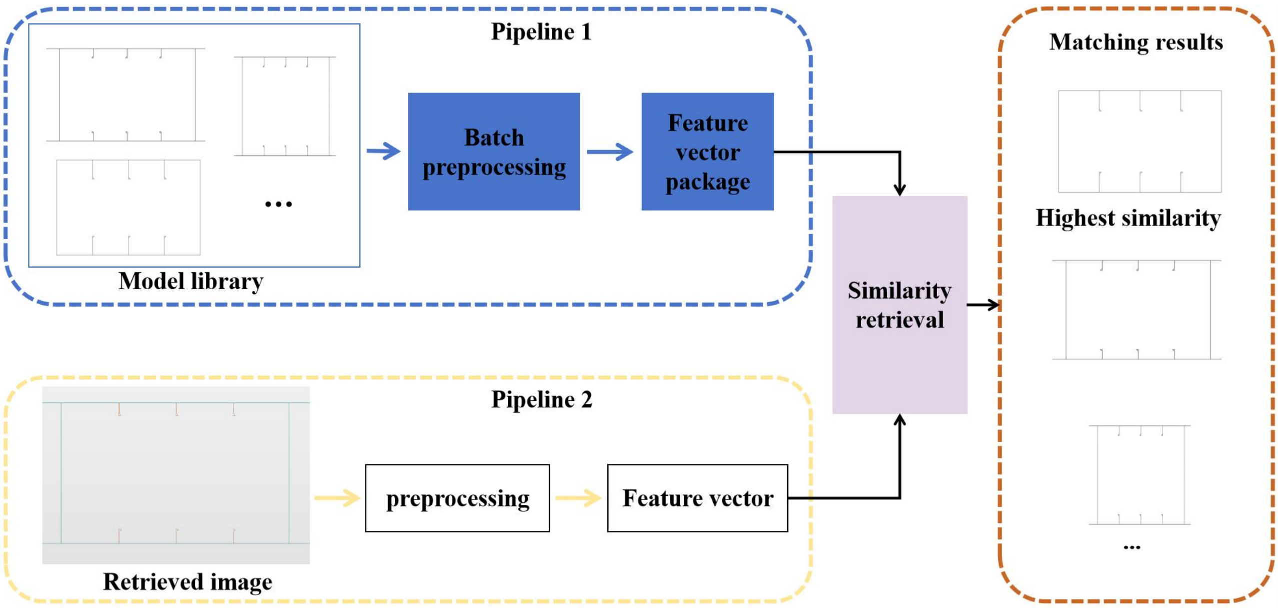


Fig. 7. Ship structure retrieval framework based on two-dimensional plate frame graph.

Input query: A 2D image of the target rack surrounding structure. Pipeline 2: The input 2D image of the rack surrounding structure is first preprocessed, followed by feature extraction. Pipeline 1: Features of all rack structures in the database are extracted and stored as feature bags. The output feature vector from Pipeline 2 is then compared with the feature bags from Pipeline 1. Using similarity measures, the objects most similar to the input query are retrieved.

3.3 Coordinate data and topology objects conversion logic

3.3.1 Coordinate data conversion logic

The coordinate data conversion logic provides the logic for the coordinate data conversion in the script based on the vertex standard numbers above. Taking the hole center coordinate data as an example. When "2D drawing of structure around Panel" is generated, the system identifies the positions that can be used as vertices in the current structure, and obtains the coordinate data of the vertices. Calculate the distance difference (DisU, DisV) between the hole coordinates and the vertex coordinates of the original panel. DisU, DisV is accumulated to the vertex coordinates of the target panel, and the hole coordinates of the target Panel are calculated. Fig. 8 show coordinate data conversion logic

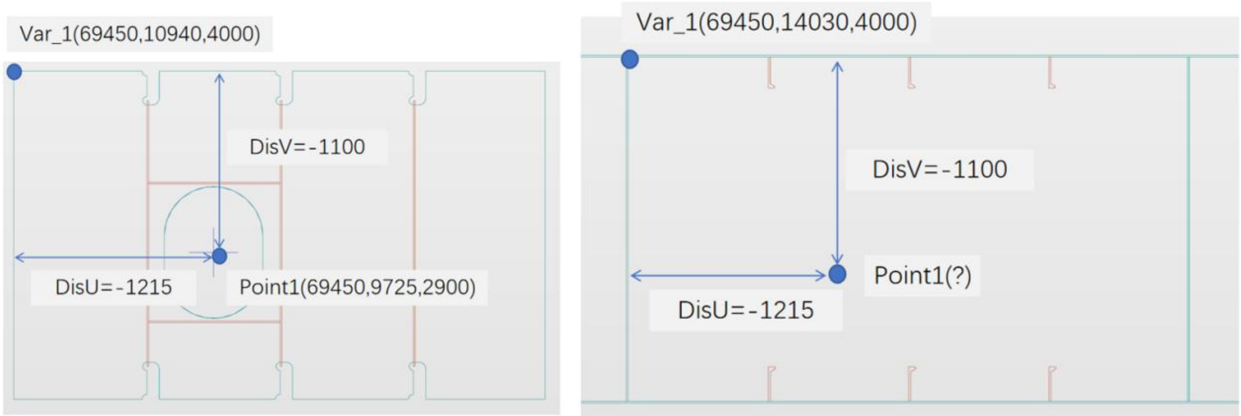


Fig. 8. Logic of coordinate data conversion

3.3.2 Topology objects conversion logic

Based on the Topology number, the mapping relationship between the target Panel and the original Panel topology object is analyzed, and the system automatically replaces the topology object. Take profiles, for example. At the same time of generating "2D drawings of structures around target Panel", the system uses "ship structure feature recognition technology" to automatically identify the profiles in the current surrounding structures, and numbers them according to "The Standard number of topological profiles". At the same time, the topological data of the original Panel is read, and the conversion logic of topological objects is obtained.

Table. 2 is the table of the original Panel topology object. Table. 3 is the table of new structure topology object.

Table. 2 Topology object of original Panel

Number	Topology objects
STI_1	423-PF1A’, S3
STI_2	423-PF1A’, S2
STI_3	423-PF1A’, S1
STI_4	423-DK1A’, S1
STI_5	423-DK1A’, S2
STI_6	423-DK1A’, S3

Table. 3 Topology object of target Panel

Number	Topology objects
STI_1	423-PF1A’, S6
STI_2	423-PF1A’, S5
STI_3	423-PF1A’, S4
STI_4	423-DK1A’, S4
STI_5	423-DK1A’, S5
STI_6	423-DK1A’, S6

3.4 Generate script and model of the target panel

3.4.1 Generate a new script based on the original script

Using "Coordinate data conversion logic" and "Topology objects conversion logic" above, the system automatically edits the original Panel script. Fig. 9 highlights the content is the identified.Fig. 10 is the script of the new panel.

```
423-FR81A
BOU, '423-LB14A',SID=SB/ '423-PF1A',SID=BOT/'423-LB10A',SID=PS/Z=2010;
PLA, MAT=10, MSI=AFT, QUA=A;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=PS, NO=1(1)3,
'423-PF1A',S3,S2,S1,CON=10,CUT=1100/'423-DK1A',S3,S2,S1,CON=10,CUT=1100;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=TOP, Z=3315,2475,NO=4,5,S1,
CON=10,CUT=1100/S2,CON=10, CUT=1100;
HOL, HO800*600,U=9725,V=2900,T=90,CNO=1;
CUT, SL01, '423-PF1A',S3, S2, S1;
CUT, SL01, '423-DK1A',S3, S2, S1;
```

Fig. 9. Highlighted content needs to be converted

```
423-FR81B
BOU, '423-LB18A',SID=SB/ '423-PF1A',SID=BOT/'423-LB14A',SID=PS/Z=2010;
PLA, MAT=10, MSI=AFT, QUA=A;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=PS, NO=1(1)3,
'423-PF1A',S6,S5,S4,CON=10,CUT=1100/'423-DK1A',S6,S5,S4,CON=10,CUT=1100;
STI, PRO=FB100x10, QUA=A, SID=AFT, MSI=TOP, Z=3315,2475,NO=4,5,S1,
CON=10,CUT=1100/S2,CON=10, CUT=1100;
HOL, HO800*600,U=12815,V=2900,T=90,CNO=1;
CUT, SL01, '423-PF1A',S6, S5, S4;
CUT, SL01, '423-DK1A',S6, S5, S4;
```

Fig. 10. The script of the new panel.

3.4.2 Generate the model of new Panel

Import the new Panel script file into the CAD system, and run the script, in the new surrounding structure, using the correct coordinate position, the correct topology of the surrounding objects, to generate the Panel model that meets the needs of engineers. Fig. 11 the Panel being referenced, and Fig. 12 the newly generated target Panel.

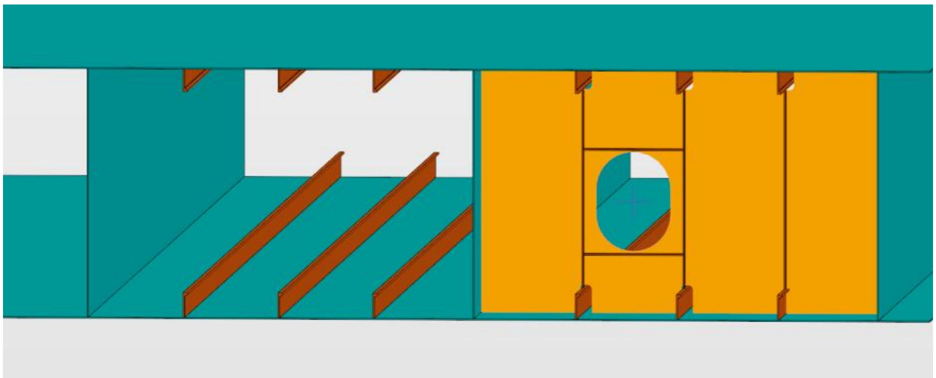


Fig. 11. The Panel be referenced

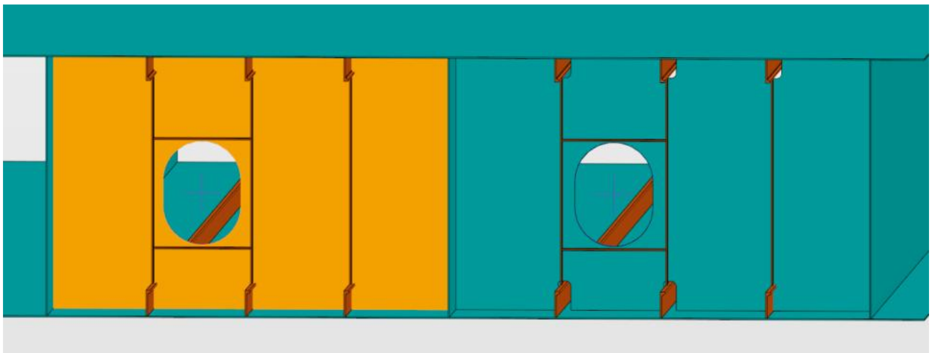


Fig. 12. The newly generated target Panel.

4. Summary

This paper adopts image recognition technology and data retrieval technology to reuse historical design data, thus greatly improving the efficiency of ship structure modelling. The main conclusions are as follows:

1) Research data standards, save Panel data packages, and reuse historical design data adequately.

2) Using AI technology to identify the ship structure features, using image recognition technology to quickly match the similar "2D drawings". Quick access to matching historical data, data reuse is more convenient.

3) Identify the difference between the original panel and the target panel's surrounding structure and coordinate position through the "coordinate data and topology objects conversion logic", edit the difference automatically, and generate a high-quality script file for the target panel.

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