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Automated Dimensioning Method of Engineering Drawings for Mechanical Products Based on Curve Chain

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Abstract: An automated method based on the curve chain was proposed for dimensioning of engineering drawings for the mechanical products. According to the internal relation between the features of 3D model feature and elements of 2D drawing, the curve chain was established to reflect the geometric topological structure between the elements. It divides the dimensions into the absolute dimensions within the cure chain and the relative dimensions between the curve chains. The parallel and lengthy relationship between the drawing elements of the constructed X and Y parallel matrix was solved to remove redundant elements in the curve chain and labeled the absolute dimensions of the remaining valid elements. The average minimum weight coefficient was introduced to judge the dependence on the relative dimensions between curve chains. Through the analysis of the overlap between the circular rectangular areas, including all the absolute dimensions of the curve chains, overlapping curve chains were merged, and their dimensions were rearranged to avoid the cross interference between them. The method was seamlessly integrated into the drafting module of product design software NX, and it developed an automated dimensioning system. The examples show that the system has excellent interactivity and robustness in the dimensioning of product engineering drawings. The dimension information is complete, accurate and reliable.

Keywords: Automated dimensioning, engineering drawing, curve chain, mechanical product, weight coefficient.

1 Introduction

Engineering drawing (ED) is the carrier that expresses manufacturing information of product. As an essential part of ED, dimensioning requires a lot of knowledge support, which is a cumbersome and easy to misunderstand the process. According to statistics, dimensioning has turned into a key factor affecting the output of the ED [Cheng, Ni, Liu et al. (2014); Peng, Long, Lin et al. (2019)]. With the improvement of computer-aided

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design (CAD) and digital technology, automated and intelligent design plays a significant role in the manufacture of mechanical products [Li, Long and Zhou (2019); Li, Yang, Liang et al. (2019)]. Automated annotation depends on the perspective projection of a three-dimensional (3D) model when generating a two-dimensional engineering drawing (2DED) in various industrial software, reducing the dimensional integrity of projected features [Yang and Zhang (2017)]. In addition, there are different dimensions and shapes, and the problems of inter-view correlation remain unresolved. Therefore, it is of great practical significance to study the automated dimensioning of 2DED for mechanical product.

Geometric feature extraction and recognition of the labeled object are the first step of dimensioning [Hua and Kui (2015); Jabal, Rahim, Othman et al. (2009); Li, Yang, Zhu et al. (2019)]. Obtain the dimensions of the 2D graphics by extracting features from the original 3D model. However, hidden lines in stand-alone 2D graphics are not recognized. Therefore, Meeran et al. [Meeran, Taib and Afzal (2003)] proposed a method of extracting feature from 2D graphics. With the increasing of complexity and the number of features, the efficiency and integrity of recognition are also important issues worth studying [Keong and Yusof (2012); Venu, Komma and Srivastava (2018)]. Genetic algorithms can improve the efficiency of CAD data search and recognition through group initialization. The identification and extraction of features needs to be rebuilt into a topology that involves the relationship between 2DED and 3D model, which is a key correlation of automated dimensioning [Su, Zhou, Mao et al. (2017); Wen, Tang and Su (2017)].

Dimension chain is a closed group of connected dimensions arranged in a specific order, laying the foundation for the design of dimensional tolerance. Gao et al. [Gao, Wang, Cao et al. (2016)] presented an automated generation method for 3D assembly dimension chains based on feature models. Wang et al. [Wang, Sun, Yao et al. (2014)] defined the absolute value of virtual tolerance as error compensation, which simplifies the process of analysis and calculation. Li et al. [Li, Yao and Wang (2014)] proposed an accurate prediction method to extract relevant assembly information from a CAD model. In addition, the removal of redundant dimensions and the reasonable layout of dimensioning in view [Gibson, Faith and Vickers (2012)] are also important areas of research. Scholars also integrated some methods into CAD software and can apply to automated dimensioning of 2DED for specific products [Sun and Gao (2018); Zhang, Jin and Wei (2014); Zhao and Niu (2014)].

In summary, features and dimension chains are the core of automated dimensioning. There are two aspects to studying dimensioning: building dimension libraries to identify features and label them under a database, and creating links to dimension chains and label elements through constraint analysis. The above research results are based on limited automated labeling specifications, although they can better solve the dimensioning problems, but they are not common. Therefore, an automated dimensioning method based on 2D graphic element recognition and curve chain construction is proposed in this paper. A drawing model with curve chain as the basic graphic element is established, the automated dimensioning and layout optimization methods based on curve chain are studied, and a more compatible system is developed to improve the efficiency and quality of dimensioning.

2 Construction of curve chains

In the 3D model, product is defined by a variety of features, including the main feature, modifying feature and dependent feature, which interrelated on each other. However, this relation is broken in 2D drawing, which is constituted of curves, and features in the original 3D model are represented by contour curves. Thus, it is necessary to rebuild topology among curve elements in a 2D model to reflect a relation of original 3D features, as shown in Fig. 1. Therefore, 2D curve chain is proposed to reconstruct these features. Based on the analysis of elements, we can find a shortest closed loop for each element. There may be share elements in different closed loops, which are defined in the main chain and branch chain. Main chain conforms to the main feature of the 3D model, and branch chain corresponds to modifying feature. In addition, there is only one element, or multiple unshared elements, which are organized according to specific rules, called a separate chain. We express it as a dependent feature of the 3D model.

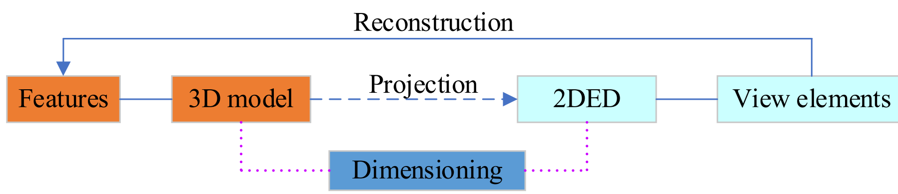

Figure 1: Relationship between 3D model and 2DED of product

2.1 Regular curve chain

There are two kinds of regular curve chains. One is an independent closed loop formed by regular connection of curves, as shown in Figs. 2(a), 2(b) and 2(c), which can also be called a single regular curve chain. Another is that many single regular chains are constructed together according to special arrangement requirements, as illustrated in Figs. 2(d) and 2(e), which is called multi-closed loop regular curve chain, and each of loop is considered as an element of the chain.

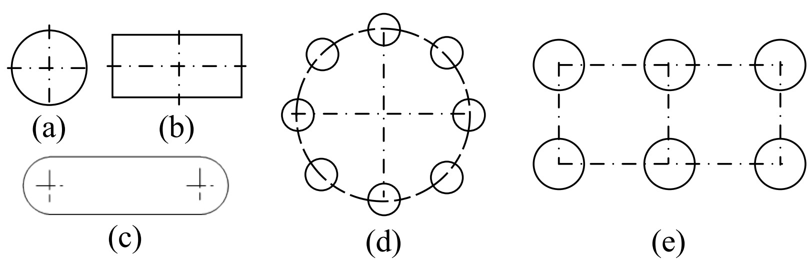

Figure 2: Regular curve chains:(a) circular, (b) rectangle, (c) slot hole, (d) circular array, (e) rectangular array

2.2 Irregular curve chain

Besides regular curve chain, others are irregular curve chain, including irregular single chain and chain with branches. Fig. 3(a) is a closed loop of curves, known as an independent irregular chain. Fig. 3(b) is a curve chain with two first-order branches. For more complex situations, they have a higher order of branches. The core is to work out the main chain. Therefore, a method to calculate the main chain is proposed based on the shortest path and route orientation. P_1 and P_2 in Fig. 3(b) are bifurcation points. Curve $\boldsymbol{l_1}$

passes through P_1, there are two orientations R_1 and R_2, and then reaches P_2 again. As shown in Fig. 3(c), paths from two orientations are different, but route from R_2 is shorter, and orientations of lines $\boldsymbol{l_1}$ and $\boldsymbol{l_2}$ are the same. Therefore, path in R_1 can be determined as the main chain and path in R_2 as its branch chain.

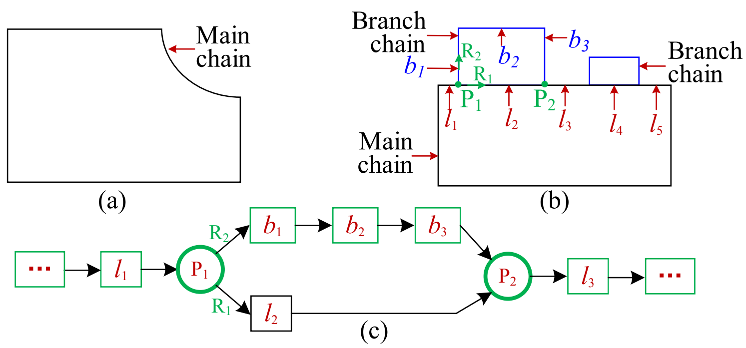

Figure 3: Irregular curve chains: (a) curve chain without branches, (b) curve chain with branches, (c) path of curve chains

2.3 Structural description of curve chain

This method sets clockwise direction as the path orientation of the curve chain and adjusts the direction vector of all curves to clockwise. In this order, it is not possible to build a curve chain that connects from one end to the other, and all curve chains must be closed paths. Fig. 4 is curve chain construction with a branch. There are several paths at each bifurcation point, but correct direction of the main chain and branch chain is unique. If the branch chain of Fig. 4 (b) follows the counterclockwise, it cannot form an effective branch chain.

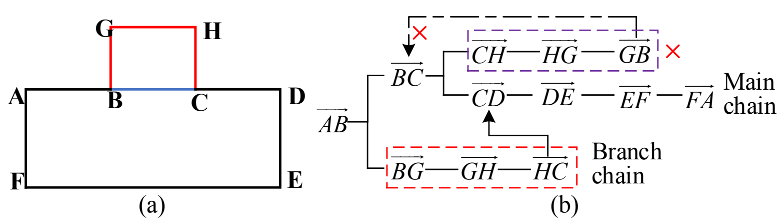

Figure 4: An example of curve chain construction: (a) 2D projection model, (b) curve chain

3 Automated dimensioning

According to the curve chains constructed above, dimensions inside the chain are marked as absolute dimensions, and that of between chains are called relative dimensions. In addition, many redundant dimensions must be eliminated to make the dimensioning accurate and reliable. It is also necessary to avoid the intersection or overlap of dimensions to make layout beautiful. It represents dimensioning process as follows.

3.1 Absolute dimensions

Absolute dimension is an attribute of curve elements in the chain, and that of a regular curve chain is fixed, as shown in Fig. 5. For a curve chain comprising of single regular curves, only absolute dimensions of one of these curves and the layout dimension between the curves need to be labeled, as shown in Figs. 5(c) and (d). However, this layout dimensions dependent on auxiliary curves inside curve chain.

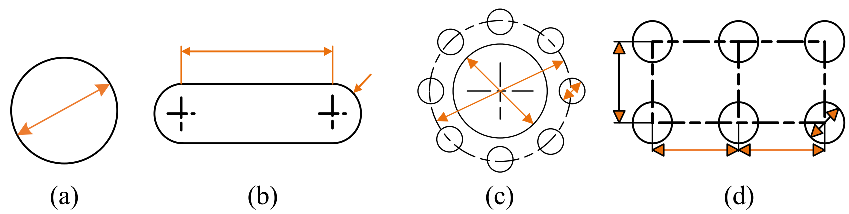

Figure 5: Absolute dimensioning of regular chains: (a) diameter of a circle, (b) radius and length of slot hole, (c) dimensions of circular attachment arrays, (d) dimensions of rectangular parallel arrays

The situation of irregular chain is overly complex and has many branched chains, which brings a lot of challenges to absolute dimensioning. However, curve chain of general mechanical products is composed of straight lines and arcs, which are divided into horizontal lines, vertical lines, oblique lines, and arcs. Matrix X and Y represent vertical and horizontal lines in the curve chain, as shown in Eq. (1). The starting in the matrix is the lowest left-hand element in the view. For example, in matrix X, non-zero elements in each row represent vertical lines in the same vertical position, and their Y coordinate is increasing from left to right in each row. Subscript n denotes that they have maximum n vertical lines at each X position. While m shows that there have m positions with vertical lines. If lines number in a certain position does not reach the maximum value, it marks all subsequent elements of the row as 0. The meaning of matrix Y is the same ones.

$$\mathbf{X}=\begin{bmatrix} X_{11},X_{12},X_{13}, & \cdots & X_{1n} \\ X_{21},X_{22},X_{23}, & \cdots & X_{2n} \\ & \cdots & \\ X_{m1},X_{m2},X_{m3}, & \cdots & X_{mn} \end{bmatrix},\ \mathbf{Y}=\begin{bmatrix} Y_{11},Y_{12},Y_{13}, & \cdots & Y_{1q} \\ Y_{21},Y_{22},Y_{23}, & \cdots & Y_{2q} \\ & \cdots & \\ Y_{r1},Y_{r2},Y_{r3}, & \cdots & Y_{rq} \end{bmatrix} \tag{1}$$

Within a matrix, starting from the first element of the first row, compare it with all elements of subsequent rows, and so on until the second to last row. Such as X matrix, take one of the elements $X_{ij} \neq 0 \quad (1 \le i < m,\ 1 \le i \le n)$ arbitrarily and evaluate its position relationship with any non-zero elements $X_{kl} \neq 0 \quad (i < k \le m,\ 1 \le i \le n)$ in all subsequent rows of the matrix. If starting coordinates Y1 and ending coordinates Y2 of the two elements being compared are equal, the element in latter row is removed and expressed as 0, as shown in Eq. (2). If its latter row is the last row of the matrix, remove itself and keep the element in the last row. After such comparison and deletion, there are no parallel overlapping vertical and horizontal lines in the matrix. The remaining lines are those that need to be marked as absolute dimensions.

$$\begin{cases} X_{ij}(Y_1)=X_{kl}(Y_1) \\ X_{ij}(Y_2)=X_{kl}(Y_2) \end{cases} \begin{pmatrix} X_{ij} \neq 0(1 \le i < m,\ 1 \le i \le n) \\ X_{kl} \neq 0(i < k \le m,\ 1 \le i \le n) \end{pmatrix} \Rightarrow \begin{cases} X_{ij}=0 & (k=m) \\ X_{kl}=0 & (k \neq m) \end{cases} \tag{2}$$

Next, it needs to consider dimensioning of oblique lines and arcs, which are connected to a vertical or horizontal line. They usually connect to other lines. There will be multiple connections between them that need to be judged. If $\overline{a_X}$ is a vertical line, $\vec{b}$ is a tangent of the arc or oblique line and $\overline{c_Y}$ is a horizontal line, it shows a relationship between them in Eqs. (3)-(5) and Fig. 6. If $\vec{b}$ is an oblique line and satisfies the relation as shown in Fig. 6(a), it is a chamfer. If $\vec{b}$ is an arc, there may be four cases, as shown in Figs. 6 (b)-6(d) and 6(e). Only the case in Fig. 6(b) is considered a fillet. For a chamfer or fillet, when labeling the vertical line $\overline{a_X}$, Y2 coordinate should be adjusted to the Y coordinate of $\overline{c_Y}$, Figs. 6(a) and 6(b). It is necessary to label dimensions of fillet or chamfer. In addition, other types of oblique line or arcs should be dimensioned independently. as shown in Figs. 6 (c)-6(e).

$$\cos\theta=\frac{\overline{a_x}\cdot\overline{c_Y}}{\left|\overline{a_X}\right|\left|\overline{c_Y}\right|}=0\Rightarrow\begin{cases}\vec{b}\text{ is an arc, and }\cos\beta=\frac{\overline{a_x}\cdot\vec{b}}{\left|\overline{a_X}\right|\left|\vec{b}\right|}=0\Rightarrow 1/4\text{ outer convex fillet}\\ \vec{b}\text{ is an arc, and }\cos\beta=\frac{\overline{a_x}\cdot\vec{b}}{\left|\overline{a_X}\right|\left|\vec{b}\right|}=-1\Rightarrow 1/4\text{ internal concave fillet}\\ \vec{b}\text{ is an oblique line}\Rightarrow\text{chamfer angle}\end{cases}\tag{3}$$

$$\overrightarrow{a_X}(Y_2)=\overrightarrow{c_Y}(Y)\quad(\overrightarrow{a_X}\text{ is vertical line, }\overrightarrow{c_Y}\text{ is horizontal line})\tag{4}$$

$$\cos\theta=\frac{\overline{a_x}\cdot\overline{c_X}}{\left|\overline{a_X}\right|\left|\overline{c_X}\right|}=-1\Rightarrow\begin{cases}\vec{b}\text{ is an arc, and }\cos\beta=\frac{\overline{a_x}\cdot\vec{b}}{\left|\overline{a_X}\right|\left|\vec{b}\right|}=0\Rightarrow 1/2\text{ outer convex arc}\\ \vec{b}\text{ is an arc, and }\cos\beta=\frac{\overline{a_x}\cdot\vec{b}}{\left|\overline{a_X}\right|\left|\vec{b}\right|}=-1\Rightarrow 1/2\text{ internal concave arc}\\ \vec{b}\text{ is an oblique line}\Rightarrow\text{connecting line}\end{cases}\tag{5}$$

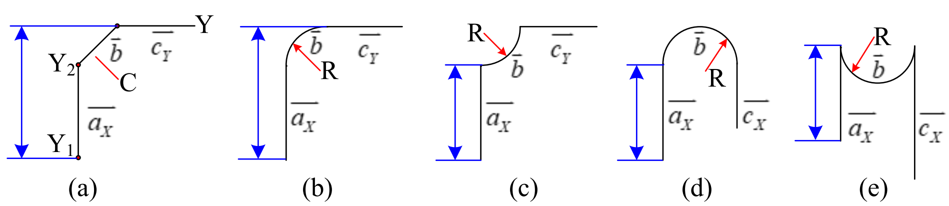

Figure 6: Dimension labeling of vertical line connected with arc and oblique line: (a) chamfer, (b) fillet, (c) 1/4 internal concave arc, (d) 1/2 outer convex arc, (e) 1/2 internal concave arc

3.2 Relative dimensions

Relative dimensions are used to determine position relationship between two curve chains. To make relative dimension labeling more efficient, the priority of different curve chain labeling is given as follows. Priority of regular chain is higher than irregular chain. For the same type of curve chains, the one with fewer elements has a high priority. It labels the relative dimension according to the priority order.

(1) Highest priority: level 1. It is suitable for regular curve chains with only two auxiliary lines. such as circulars and dependent circular arrays.

(2) Medium priority, level 2. It is suitable for regular curve chains with three or more auxiliary lines. Such as slot holes, rectangular arrays.

(3) Medium priority, level 3. It is suitable for irregular curve chains without branches.

(4) Low priority, level 4. It is suitable for irregular curve chains with branches. We prefer curve chains with fewer branches to label.

In principle, a curve chain can be labeled with any curve chain other than itself. Therefore, this paper puts forward the concept of average weight coefficient (AWC) between curve chains. w_X and w_Y are used to represent AWC of X and Y direction between two chains. Then, relative dimensions of two chains with the minimum AWC are labeled. Suppose there are two curve chains, 1 and 2. Coordinates of their vertical and horizontal lines are expressed by X1 (m1, n1), Y1 (r1, q1), X2 (m2, n2) and Y2 (r2, q2), where m and r represent rows, n and q represent columns of matrix. The AWC of chain 1 and chain 2 are expressed by $w_X(1, 2)$ and $w_Y(1, 2)$, of which subscript 1 is master and 2 is slave, as shown in Eqs. (6) and (7). It obtains the minimum AWC, as shown in Eqs. (8) and (9). Then, the absolute minimum distance between the coordinates of the elements on the two curve chains is taken for dimensioning.

$$w_{X(1,2)} = \frac{\sum_{i=1}^{m_1} \left(\left| X_{1_{i1}} - X_{2_{j1}} \right|_{\min} \right)}{m_1} \quad (1 \le \mathrm{j} \le m_2) \tag{6}$$

$$w_{X(1,2)} = \frac{\sum_{i=1}^{m_1} \left(\left| X_{1_{i1}} - X_{2_{j1}} \right|_{\min} \right)}{m_1} \quad (1 \le \mathrm{j} \le m_2) \tag{7}$$

$$w_{X1} = (w_{X(1,2)}, \cdots, w_{X(1,t)})_{\min} \quad \text{(t is the number of curve chains)} \tag{8}$$

$$w_{Y1} = (w_{Y(1,2)}, \cdots, w_{Y(1,t)})_{\min} \quad \text{(t is the number of curve chains)} \tag{9}$$

Fig. 7 shows three curve chains. X and Y coordinate matrices of their vertical and horizontal lines are presented in Eq. (10). Obviously, priority of dimensioning is chain 1, then chain 2 and finally chain 3. Then, to label chain 1, we need to find the minimum AWC between chain 1 and other chains, as shown in Eqs. (11), (12) and (13). Therefore, the relative dimensions X and Y between chains 1 and 3 can be determined by the minimum AWC. Two relative dimensions (chains 1 and 3) and (chains 2 and 3) are labeled in Fig. 7.

$$\mathbf{X}_1 = \left[X_{1_{11}} \right], \mathbf{Y}_1 = \left[Y_{1_{11}} \right], \mathbf{X}_2 = \begin{bmatrix} X_{2_{11}} \\ X_{2_{21}} \end{bmatrix}, \mathbf{Y}_2 = \begin{bmatrix} Y_{2_{11}} \\ Y_{2_{21}} \end{bmatrix}, \mathbf{X}_3 = \begin{bmatrix} X_{3_{11}} \\ X_{3_{21}} \\ X_{3_{31}} \\ X_{3_{41}} \\ X_{3_{51}} \\ X_{3_{61}} \\ X_{3_{71}} \end{bmatrix}, \mathbf{Y}_3 = \begin{bmatrix} Y_{3_{11}} \\ Y_{3_{21}} \\ Y_{3_{31}} \\ Y_{3_{41}} \\ Y_{3_{51}} \\ Y_{3_{61}} \\ Y_{3_{71}} \end{bmatrix} \tag{10}$$

$$w_{X(1,2)} = \left| X_{1_{11}} - X_{2_{11}} \right|, \quad w_{Y(1,2)} = \left| Y_{1_{11}} - Y_{2_{21}} \right| \tag{11}$$

$$w_{X1} = (w_{X(1,2)}, w_{X(1,3)})_{\min} = w_{X(1,3)} \tag{12}$$

$$w_{Y1} = (w_{Y(1,2)}, w_{Y(1,3)})_{\min} = w_{Y(1,3)} \tag{13}$$

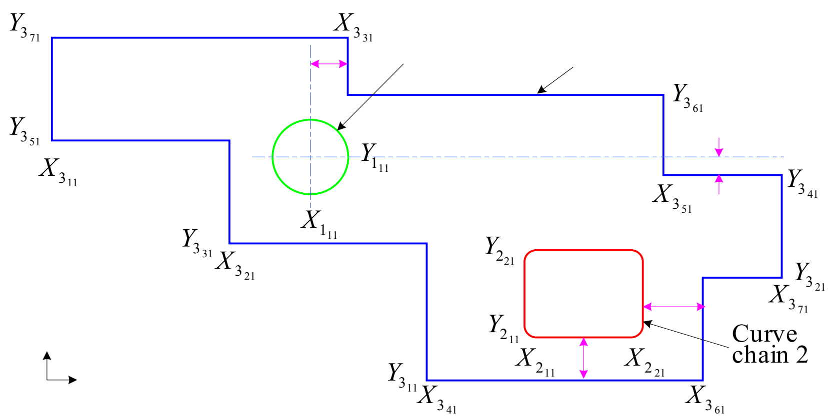

Figure 7: Examples of Relative dimensioning between curve chains

3.3 Dimensions layout optimization

In this paper, only layout of absolute dimensions needs to be adjusted. Relative dimensions between the curve chains are uniformly labeled in the middle of the overlapping segments of the two lines. Absolute dimensions can be divided into X direction dimensions (horizontal line), Y direction dimensions (vertical line) and other types of dimensions (angle, radius, diameter, pitch, etc.). For each chain, the minimum 2D rectangular box parallel to X and Y can be obtained, which is divided into five sub-areas, as shown in Fig. 8(a). If the dimensions are within the curve chain boundary, they can be considered being arranged in the C area. This area is the dimensions layout of other elements except horizontal and vertical lines. It locates all dimensions at the midpoint of their elements. The small dimension is close to the chain, and large dimension is far away from the chain. It arranges dimensions of overlapping elements in the same area in equal intervals from small to large.

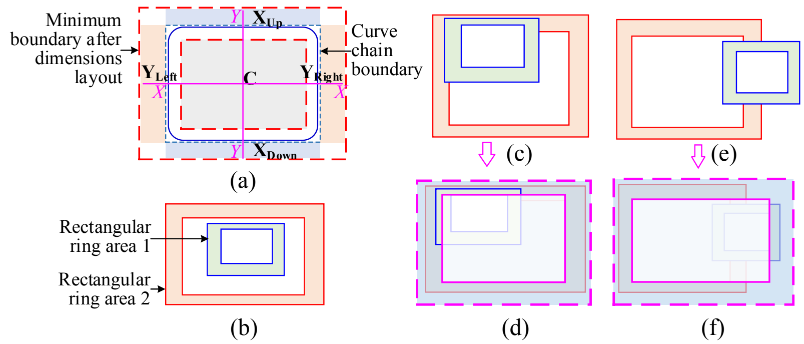

Figure 8: Relationship between two rectangular ring areas: (a) areas dividing, (b) not overlap, (c) one area is totally contained by another and overlap, (d) merged rectangular ring area based on (c), (e) two rectangular ring regions overlap externally, (f) merged rectangular ring area based on (e)

Figs. 8(b), 8(c) and 8(e) shows three relationships between two rectangular areas. The first case is that one area contains the other completely and there is no overlap, as shown in Fig. 8(a), it is no requirement to adjust them. Once the rectangular areas overlap, there will be overlap and intersection between dimensions. Therefore, a method of merging rectangular boxes with curved chains is proposed to adjust the intersection of dimensions. Whether they are overlap internally (as shown in Fig. 8(c)) or externally (as shown in Fig. 8(e)), as long as the two areas overlap, the two chains are merged to solve the smallest rectangular box, as shown in Figs. 8(d) and 8(f). Then, the dimensions of the two curve chains are put together and rearranged according to the layout principle. When judging the overlap of rectangular areas, it gives priority to the curve chain with a small rectangular area.

4 System development of automated dimensioning

4.1 System architecture and modules

To realize the idea and method of automated dimensioning, it seamlessly integrates this method is seamlessly into drafting module of NX software. Fig. 9 shows the system architecture, which consists of three modules, background database and application interfaces. There are three key sub-interfaces, including automated recognition, automated dimensioning, and dimensions automated adjustment. Among them, automated recognition is the most critical, and the output results are the constructed curve chains and their related attribute parameters, which determine the correctness and standardization of subsequent automated dimensioning. Data such as the structure of the curve chains, type of curve elements, attribute parameters and coordinate position matrix are all stored in the background database. It builds automated dimensioning interface on the parameters of the database to label the absolute and relative dimensions of graphic elements. It also stores rectangular areas of the curve chains after dimensioning into the database. Finally, the dimension automated adjustment interface reads the rectangular areas from the database for overlapping judgment, merges the overlapping areas, and adjusts and optimizes the dimensions layout in the view.

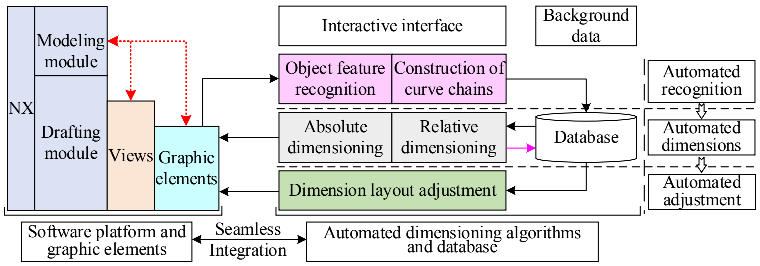

Figure 9: Automated dimensioning architecture

4.2 Operation flow of automated dimensioning

Fig. 10 shows the flowchart and data flow of this system. The first step is to select views, obtain their proportions, and store them in the database. The second step is to traverse all the elements in the view and determine the graphic elements and non-graphic auxiliary elements. The next step is to read the relevant information of the curve elements from the database and construct the curve chains according to the recognition elements. It stores topological structures and coordinate matrixes of the curve chains in the database. The fourth step is to label the absolute dimensions and remove redundant dimensions. The minimum rectangular areas of the curve chains after dimensioning are calculated and stored in the database. The fifth step is to label the relative dimensions of these curve chains. When calculating AWC between curve chains, it is necessary to read all the data of curve chains in the database. After completing the matching between curve chains, matching minimum AWC curve chain information is written into their attribute parameters. The last step is to adjust the layout of the dimensions. The above process shows that the selected views can complete the automated dimensioning through the six key steps of the method and the system.

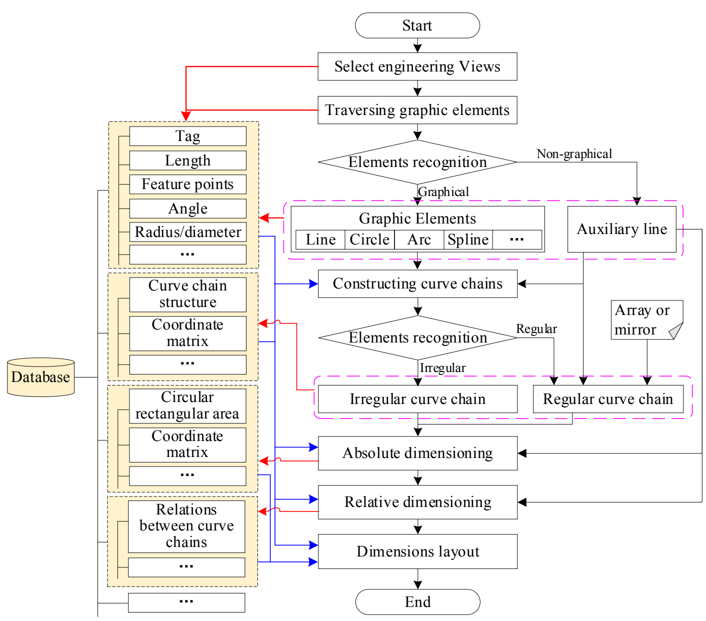

Figure 10: Flow chart and data flow of the system

5 Examples and discussions

Wrinkle frame is a typical plate product, which is often used as a support plate, face plate and bottom plate in a mechanical system, as shown in Fig. 11. This paper chooses one product as an example to label its dimensions automatically. It shows the schematic diagram of the product structure. All the elements in the view are regular curves, and there are no irregular graphic elements such as oblique lines and splines. According to the method and system requirements, the graphic elements are recognized, and it constructs the curve chains. Fig. 12 shows the results of the curve chains construction of the product. It shows the corresponding number of curve elements in Fig. 13. The product has a complex curve chain with branched chains, which are composed of the largest outline of the product. It includes other curve chains in this curve chain. They are two irregular curve chains without branched chains, three attached circular curves, two slot holes chains and eight circular curves.

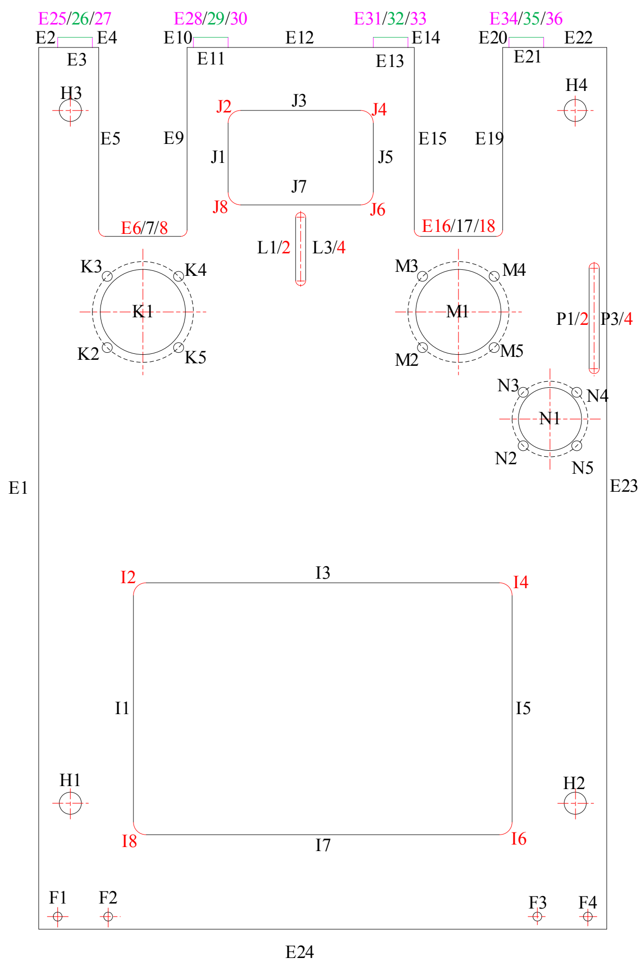

Figure 11: Wrinkle frame product

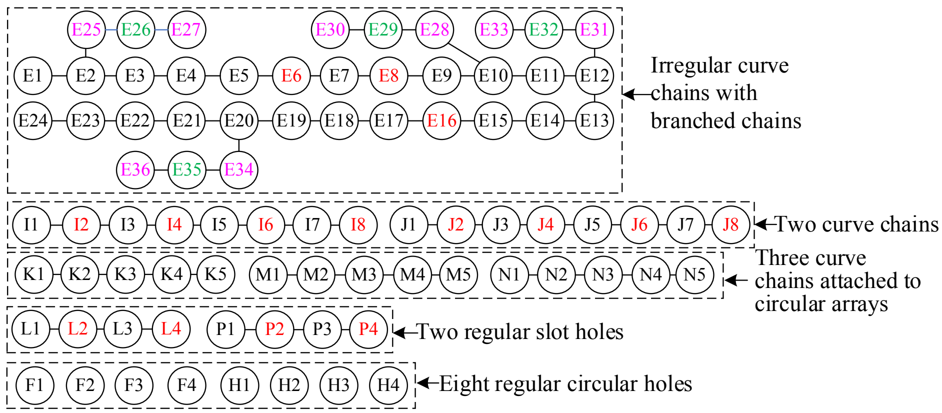

Figure 12: Construction of curve chains of wrinkle frame product

For each curve chain, it constructs two coordinate matrices for dimensioning. Here we show only the most complex of coordinate matrices of the irregular curve chains with branched chains. The X1 and Y1 in Eq. (14) are the original coordinate matrices of the curve chain. Redundant elements are deleted and new coordinate matrices X1' and Y1' are obtained, as shown in Eq. (14). Next, the relative and absolute dimensions are automatically labeled. Dimensioning is consistent with the previous example, which will not be repeated in this paper. The difference is that there are many curve chains in this example, so there may be an intersection and interference between dimensions. However, circular rectangular areas of the curve chains in this example are all included relations, and there is no serious overlap between them. Therefore, there is no need for a wide range of dimensions layout adjustment, only some local relative dimensions layout needs to be fine-tuned. It shows the final dimensioning results of the product in Fig. 13.

$$\mathbf{X}_1=\begin{bmatrix}E1\\E25\\E27\\E5\\E9\\E28\\E30\\E31\\E33\\E15\\E19\\E34\\E36\\E23\end{bmatrix}\Rightarrow\mathbf{X}_{1'}=\begin{bmatrix}E1\\E25\\0\\E5\\0\\0\\0\\0\\0\\0\\0\\0\\0\\0\end{bmatrix},\quad \begin{matrix}\mathbf{Y}_1=\begin{bmatrix}E24&0&0&0&0&0&0&0&0&0&0\\E7&E17&0&0&0&0&0&0&0&0&0\\E2&E3&E4&E10&E11&E12&E13&E14&E20&E21&E22\\E26&E29&E32&E35&0&0&0&0&0&0&0\end{bmatrix}\\ \Downarrow \\ \mathbf{Y}_{1'}=\begin{bmatrix}E24&0&0&0&0&0&0&0&0&0&0\\E7&E17&0&0&0&0&0&0&0&0&0\\E2&0&E4&E10&0&E12&0&E14&E20&0&E22\\E26&E29&E32&E35&0&0&0&0&0&0&0\end{bmatrix}\end{matrix} \tag{14}$$

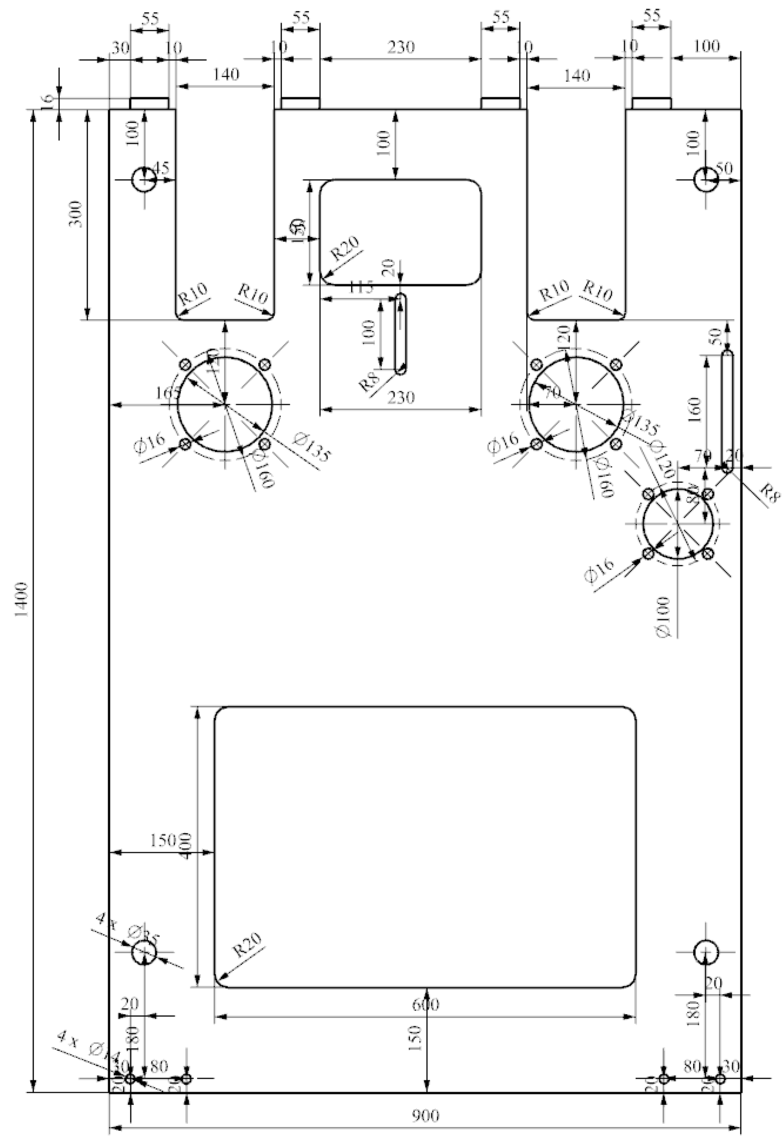

Figure 13: Automated dimensioning results of wrinkle frame product

It compares the results of automated dimensioning and manual dimensioning. It is found that the results of manual work vary from person to person, and the results are not the same. This is a tedious task which requires great patience and is quite easy to miss some dimensions. In this way, the dimensions of the product are not very complete, and the layout of manual dimensioning is not optimal and has a certain randomness. Only one key operation is needed to realize fully automated dimensioning of product view, which improves the efficiency. The dimension of the marked products is complete, and no dimension will be omitted. The style of dimensioning is uniform, and the layout of dimensions is beautiful and reasonable. Here, six indexes are used to evaluate the quality of the dimensions labeled by the method and system. The efficiency between the method and the manual is also compared and analyzed, which are the average statistical results from several mechanical product design engineers with five years of experience. It shows detailed analysis and comparison data in Tab. 1. The results show that the dimensioning efficiency of this example has been improved by 72 times, and the whole process from feature recognition to dimension label takes less than half a minute.

Table 1: Quality and efficiency comparison of dimensioning with different methods

Dimensioning quality		Dimensioning efficiency		
Quality indexes	Quality analysis	Manual (min)	This design system(min)	Efficiency improvement
Absolute dimensions	Excellent (47/48=0.98)	18	0.25	72 Times
Relative dimensions	Good (23/30=0.77)			
Dimensions interference	Excellent (0)			
Dimensions rationality	Excellent (70/78=0.90)			
Non-critical dimensions	Excellent (6/6=1)			
Visual effects	Excellent			

The results of the above analysis show that the system has shown excellent performance in dimensions of completeness, layout, interference elimination and efficiency. However, the system needs further improvement, especially the rationality of local relative dimensions and the relative dimensions between some curve chains. To solve this problem, on the one hand, it can develop dynamic labeling technology through an interactive interface, providing user drag-and-drop function to adjust dimensions dynamically in real time. This improved method combines interactive technology and user design experience factors. It can start this problem from big data. The rationality of dimensions can be obtained by reusing similar data of historical design of mechanical products. It needs a certain amount of data on the accumulation of products and a fast function of drawing analysis. But this is also the only way from automated to intelligent dimensioning. Another important problem is the dimensions mapping relationship between multiple views of a product. Some complex products need multiple views to express, so there will inevitably be duplicated dimensions of the same element between different views. Then, to eliminate these redundant dimensions, the mapping relationship between the curve chain elements of different views needs to be further constructed. The goal is to solve the above problems thoroughly and realize intelligent optimization dimensioning of drawings.

6 Conclusions

In this paper, the automated dimensioning method and system of mechanical product engineering drawing are studied. The main research work and conclusions are summarized as follows:

1) An automated dimensioning method based on curve chain is proposed. The topological relationships of all elements in the drawing can be expressed with sufficient accuracy. On

this basis, the judgment criteria of the regular and irregular curve chain are put forward, and the structural level of the drawing elements is expressed more clearly.

2) The method divides dimensions into absolute and relative dimensions. By comparing elements between coordinate matrices, parallel and equal-length elements are removed and redundancy in absolute dimensions is avoided. The relative dimension pairing of the curve chain is determined by introducing the average weight coefficient.

3) A method to judge the relationship between rectangular areas is proposed to solve the interference between dimensions. Expand rectangular areas by merging curve chains with dimensions intersection, which provides a larger area for re-laying dimensions. In the new rectangular area, the relative dimensions of the merged curve chain are re-layout, avoiding the interference between the relative dimensions, making its distribution more symmetrical and reasonable.

4) This method is seamlessly integrated into the drafting module of NX software, providing great convenience for mechanical product designers. Examples show that the new method and system have good performance in automated dimensioning of mechanical products drawings.

However, in order to further improve the rationality of dimensioning, considering the mapping relationship between multi-view of ED, it is necessary to carry out more in-depth and systematic optimization research on the basis of this method and system. This is also the core and focus of the author's follow-up and ongoing research.

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