Relating design of product dimension based on dimensional characteristic propagation chain

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Abstract. The design unit was analyzed and the internal information of it was encoded. At the same time, the dimension information was analyzed and the dimension information model was constructed. The matching constraint is used as the search method, the search direction relative to the constraint direction is determined, the size information in the direction is extracted, and the size propagation chain is constructed according to the size association rules and methods. Correlation propagation is formulated by matching the number of constraints, formulas, economic costs, and processing difficulty as the criterion of size correlation strength. The dimension-related design is accomplished using dimension-related drive variants. Finally, an example is used to verify the effectiveness of the method.

1. Introduction
In product optimization, variations of geometrical parameter will cause changes in the product component shape size or assembly size, and one of the size changes will often cause other sizes to be changed. Resulting in excessive workload and affecting the efficiency of product design [1]. Establishing the dimensional constraints and dimensional transfer relationships in product parts is the key issue that needs to be solved in this paper.

The associated design method provides an efficient way for product size design. Many scholars have done a lot of research on dimension correlation design for many years. Dong Wei [2] used Pro/E database functions and top-down design principles to extract top-level skeleton control parameters and establish a digital model, thereby realizing product-parameter-related design. Liu Zefeng [3] established a mathematical correlation model between key structural dimension parameters of complex products as a low-precision model from the perspective of design formulas and empirical formulas, and used simulation experiments to obtain high-precision multivariate analysis results based on low-precision correlation model of empirical formula. Li Zhenquan [4] classified the parameters of the parts. According to the assembly relationship of the product, establish an assembly-based component parameter relationship. Wei Zongping, Wang Guanglei et al. [5-6] used Inventor software's own adaptive technology that variable technology can accurately express the associated design thinking, to achieve the associated design of the assembly components. Wu Chunxi, Guo Chongying et al. [7-8] use dimensional chain change geometric constraint network and feature matrix to construct assembly dimension chain. The above results have promoted the development of unit dimension-related design. Bao Qiangwei, Fan Yougao et al. [9] Through the establishment of a hierarchical assembly model, based on the relationship between the geometric features of the information unit to
build the transfer relationship diagram of the assembly, in consideration of the search priority based on the realization of the assembly size chain automatically generated. Zheng Sujuan, Huang Hairong, Zhang Kuikui et al. [10] According to the differences in assembly positioning constraints between parts, establish a model, improve the directed graph, and realize the automatic generation of the dimension chain.

Based on these results, the dimension search direction and extract the dimensions based on the construction of the dimensional model, and then determine the size to be changed according to the relationship strength and cost are proposed in this paper.

2. Functional unit model construction

A product can be generally divided into several functional units. These function unit contains various information such as fit, structure, size etc. The design process is to tackle a variety of information within these units to achieve the desired goal. Therefore, the state and content of the unit information will be changes along with the design progresses [11].

2.1. Information model of design unit

In order to deal with the internal information of the design unit more effectively. We use coding to represent assembly, assembly voxels, and size types. As shown in table 1. According to the coding information in table 1, an internal information code can be constructed. For example, the assembly relationship of two structural features is coincident, and the planar-plane voxel matching is used. The corresponding feature size type is long, and the code is: 1022CL.

| Coding | Assembly information | Coding | Structural voxel matching | Coding | Size type |
|--------|---------------------|--------|---------------------------|--------|-----------|
| 10     | coincide            | 20     | Straight line - straight line | CL     | long      |
| 11     | concentric          | 21     | Straight-plane            | KW     | width     |
| 12     | parallel            | 22     | Plane - Plane             | GH     | high      |
| 13     | tangent             | 23     | Plane-surface             | CS     | diameter  |
| 14     | angle               | 24     | Surface-surface           | CR     | radius    |

2.2. Size feature information of design unit

The model features can be divided into two categories: sketch features and physical features. These two mainly include the length dimension, width dimension, height dimension, diameter dimension, radius dimension and angle size information. Sketch size information is the basis for the existence of physical size information. Analysis of the size type shows that it contains the following three types of information:

(1) Characteristic information: The description of the size element feature may also be referred to as the character of the corresponding size unit, such as "R" in radius R5.

(2) Metric information: The value of the described size element, such as "5" in R5.

(3) Matching information: Describes the matching accuracy of the size elements. At the same time, it also reflects the machining accuracy of the parts, such as “0.01” in R5±0.01.

3. Matching feature size propagation chain

3.1. General features analysis

The general assembly constraint relationships in a product include: coincidence, parallelism, tangency and so on. As shown in table 2.

As can be seen from the above table, different assembly constraint will be result in different mating directions. By using the matrix Dir[i,j,k], the fitting direction can be easily determined. The matching feature direction matrix Dir is an inherent attribute in the assort constraint. The principle is to extract
the matching surface normal vector and determine the direction of the normal vector, and the fitting
direction is perpendicular to the normal vector direction.

If it is a single part, the search direction of the size can be directly on the X-axis, Y-axis, and Z-axis,
and then the size can be directly extracted.

**Table 2.** General assembly constraints.

| Coordination constraint | Spatial geometry pose                      | 3D illustration |
|-------------------------|--------------------------------------------|-----------------|
| coincide                | Plane coincidence, normal vector parallel  | ![Image](image1.png) |
| parallel                | Plane parallel, normal vector parallel      | ![Image](image2.png) |
| tangent                 | Two cylindrical faces tangent               | ![Image](image3.png) |
| coaxial                 | Two axis collinear                         | ![Image](image4.png) |

### 3.2. Association size rules

According to the different types of dimensions and the positional relationship or mathematical
relationship between dimensions, the following dimensional association rules are established:

**Rule 1:** In the same design unit or part, there is no relationship of different size types, such as $a$ and $b$ in figure 1.

**Rule 2:** For two identical dimension types in the same unit or part, if one of the two dimension boundaries are enclosed by the other, it can be considered that there is a relationship between them, can be added to the same associated size propagation chain; as shown in figure 1(a), the relationship between $b$ and $c$, $d$ and $e$.

**Rule 3:** For two identical dimension types in the same unit or part, if there is a coincidence between two dimension lines, and there is no inclusion relationship between them, it is necessary to further determine the correlation between sizes and the form of the propagation chain, then such as $f$ and $c$ in figure 1(a).

**Rule 4:** In the same design unit or part, if the two angles have the same reference, the two angles have an associated relationship, such as $\angle a$ and $\angle b$ in figure 1(b).

**Rule 5:** In the same design unit, regardless of the type of dimension and the dimension line, as long as the dimensions $a$ and $b$ have formula or empirical value constraints, the two must be related. Then formulate the size propagation chain according to the formula and experience.

**Rule 6:** The size of the same type of construction can reflect the size of the design unit’s overall propagation chain, called the global size of the association.

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![Image](image5.png)

**Figure 1.** Cell size.
3.3. Assembly constraints and feature size extraction

To analyze the assembly model in 3D environment, we should first extract the constraint relation in the model and the characteristic information contained in the constraint relation, such as matching the size information. Its relational expression is:

\[ G = (F, Y, T, S) \]  

In the formula, \( F = f(i, j) \) is the assembly matrix, Here, 1 means the two-part models have an assembly relationship, 0 means none; \( Y = [y_1, y_2, y_3] \) is an assembly constraint type. Since there are at most three constraint types between two models, \( y_1, y_2, y_3 \) represent three constraint types, and the values are the above assembly relationship in table1. \( T \) is a feature information matrix that participates in the constraint. A constraint contains two features. There are at most three constraints between the two models. Therefore \( T = [t_1, t_2, t_3, t_4, t_5, t_6] \); \( S = [s_1, s_2, s_3, s_4, s_5, s_6] \) is the dimension information corresponding to the matching feature including dimension element characteristics and metrics.

3.4. Construction of assembly dimensional correlation propagation chain

Based on the above mentioned rules in 3.2, a size-related propagation chain is constructed. The establishment process is as follows:

1. Extract assembly constraint information and construct assembly matrix \( F = f(i, j) \);
2. According to \( F \), retrieve the constraint type, and construct the assembly constraint array \( Y \);
3. According to \( F \) extraction assembly feature information, build feature array \( T \);
4. According to \( T \), Search the size information in the distribution feature, construct the size information set \( S \), and determine the matching direction according to \( Y \), finally, determine the size propagation direction;
5. Processing size information according to the matching direction to generate a global size propagation chain or relationship chain;
6. Select a matching feature, retrieve its feature information, and construct a local size propagation chain.

Here, the size propagation chain is in the order in which the dimensions affect each other, and the relationship chain is embodied by a mathematical model.
These results in an assembly size-associated size propagation chain, which provides a basic data model for dimension-related change design. Figure 2 is a flowchart of the construction of a size propagation chain.

4. The size related change design based on the size related propagation chain

4.1. Analysis of dimension propagation chain

The size-associated propagation chain constructed above is divided into two types: one is the size of the propagation chain, the relationship between size and size, which will propagate in the direction of the arrow; the other is associated with the dimension chain, matching feature sizes depend on mathematical relationships. This is mainly determined by the type of the matching features and the constraint relationship between them. For size chain, the constraint between dimensions is that the changed size must satisfy the relational relationship. However, its propagation sequence is not as direct as the size propagation chain. Therefore, it is necessary to simplify the relationship chain to clarify the direction of propagation. In order to facilitate the analysis of the associated propagation chain, this paper regards dimensions as elements, and the relationship between elements and elements are represented by a double-headed line, as shown in figure 3.

\[
\begin{align*}
\text{element}1 &= \text{element}2 + \text{element}3 + \text{element}4 + \text{element}5 \\
\text{or} &\quad \text{element}1 > \text{element}2 + \text{element}3 + \text{element}4 + \text{element}5 \\
\text{or} &\quad \text{element}1 < \text{element}2 + \text{element}3 + \text{element}4 + \text{element}5
\end{align*}
\]

**Figure 3.** Size-related propagation chain model.

In order to simplify the changes resulting from the association, and at the same time to reduce the cost of the changes, the following rules for the propagation of associated dimensional chains were developed:

1. With reference to the strength of the node's association, the strong association of elements can be passed directly;
2. With reference to the strength of the node's association, blocking the weak correlation between elements.
3. Blocking propagation, such as formulas, etc., when the element features are imposed on external sources due to external constraints.
4. When the standard element feature is encountered, the original change propagation is blocked and the change is made according to the characteristics of the standard element.

4.2. Construction of weighted dimension propagation chain

Association strength is defined as the degree of interaction between two features which includes the following aspects.

4.2.1. Index. (1) Number of fits $x_1$: The number of fit between components.
(2) Formula constraint $x_2$: The relationship between the dimensions is determined by the formula or by empirical values.

(3) Economic cost $x_3$: The cost consumed from the material to the design unit product.

(4) Difficulty of production $x_4$: Refers to the degree of difficulty in the process involved from the material to the design unit product.

4.2.2. Specification of use of the indicator system. The related index system provides a reference for determining the strength of the association between elements. However, when using the correlation strength index, each associated propagation chain is considered to be independent. The specific use method is: first determine the basic correlation strength $y_0$ between each element in the propagation chain by the number of fits $x_1$ and the constraint $x_2$, and when the elements have formula constraints, the fit may not be considered, and the basic correlation strength is 1. If there is no formula constraint, the cooperation is the main factor, and the basic strength is determined according to the number of matchings, as shown in Table 3.

| Number of matches $x_1$ | Power level $y_{1i}$ | Formula constraints $x_2$ | Power level $y_{2j}$ |
|-------------------------|----------------------|---------------------------|----------------------|
| 1                       | 0.5                  | have (1)                  | 1                    |
| 2                       | 0.7                  | no (0)                    | 0                    |
| 3                       | 1                    |                            |                      |

Basic strength $y_0$ $\forall i=1,2,3; j=0,1;$. $y_0=1, (x_2=1); y_0=y_{1i}, (x_2=0)$

Then calculate the economic cost $x_3$ and the production difficulty $x_4$ of the part where each element in the dimension chain is located. For the cost, use the part with the lowest cost $x_3'$ in the dimension chain as a reference to calculate the excess cost of other parts relative to the lowest cost part $t$. The calculation method of production difficulty is similar to the economic cost, and its calculation method is as follows:

\[
t_k = \frac{x_{3k} - x_3'}{x_3'}
\]

\[
m_k = \frac{x_{4k} - x_4'}{x_4'}
\]

The correlation strength $y$ is obtained by subtracting the strength values for the elements in the dimension chain for the cost $t_k$ and the excess difficulty $m_k$ from the basic correlation strength value $y_0$, which is only compared in the same dimension chain. The formula is as follows:

\[
y = y_0 - t_k - m_k
\]

4.3. Size related drive variant design

The associated communication chain developed by the associated design technology provides a data foundation for dimension-related design and can improve the efficiency of variant design. For the related propagation chain, the associated change steps are as follows:

(1) According to the design requirements, determine the original changing elements.

(2) According to the change element, search for the associated dimension chain;

(3) Change the association according to the associated dimension chain and the strength of the association. When the level of correlation strength is strong, the change can be propagated along with the related chain, but when the level of the correlation strength is weak, the system prompts blocking and manually determines whether to block. When the related chain is changed, check the association relationship. If it is not satisfied, repeat (3). If it is satisfied, proceed to the next step.
(4) Continue to search for the associated size propagation chain, and perform step (3) until all the associated chains have been searched.

5. Example
Solidworks2013 are used as the basic platform, an system based on size characteristic propagation chain was constructed. Taking a model of a range hood retarder as an example, as shown in figure 4. When the initial requirement is to change the size a, the effectiveness of the method was illustrated in this paper by implementing propagation of other related part sizes as an example.

![Figure 4. 2D diagram of a pulley mechanism.](image)

Extract mating information between parts, the assembly matrix $F$ can be constructed. According to the assembly matrix $F$, it can be seen that the pat2 and the part3 have a matching relationship: concentric and surface fit. Then $Y=[11, 10, 0], T=[axis\text{-stretch2, sleeve-rotation3, axis-stretch2, sleeve-rotation3,0,0]}$ can be built.

According to the above, an axial dimensional relationship chain is constructed: $a > c + d + e + f + g$, $b = c + d$, $e > h$, $c = k$, $a = m + h + b$. For the associated chain $a > c + d + e + f + g$ and $e > h$. Its value is generally set according to the empirical value, so the magnitude of the value is within a certain range. Using $x_1$, get $a = x_1 + c + d + e + f + g$, $e = x_2$, $h$, where $x_1$ and $x_2$ remain unchanged. According to the size relation chain transformation propagation chain planning, the size correlation chain is processed to develop the size propagation chain, as shown in figure 5.

![Figure 5. Weighted dimension propagation chain.](image)

According the abovementioned results change the 3D model. Figure 6 show changes in the length of the shaft. When a dimension changes, the associated dimension change process is as shown in the figure 6.

It can be seen that the method makes the size modification more convenient, and the appropriate fluctuating size is selected through this correlation, which saves the modification time and saves the change cost.
6. Conclusions
A dimension-related design method based on dimensional characteristic propagation chain is proposed in this paper. The method classifies the dimension information according to the direction of cooperation, and constructs a global chain and a corresponding partial chain in the direction according to the constraint direction, and processes it to facilitate the completion of size propagation. The strength of association is used to determine the path that the size change propagates in the dimension chain. This method can minimize the cost of change propagation, improve the automation of relating design. From the above example, we can find that due to the reduction of the size chain, the process of changing the size has changed from a complex multi-dimensional relationship to a linear one, which simplifies the process of changing the size of the change and makes the change more convenient and efficient.

Acknowledgment
The authors would like to thank the National Natural Science Foundation of China (51775239, 50975124) for financial support.

References
[1] Wang Xiaohui and Ren Shouhua 2012 J. Journal of Mechanical Engineering 48(15) 131-136.
[2] Dong Wei and Sun Wenlei 2009 J. Mechanical Engineering & Automation 03 57-59
[3] Li Zhenquan 2013 Study on dimension transfer method based on component priority (Shenyang: Shenyang Institute of Technology) p 55
[4] Liu Zefeng 2013 Complex component multi-component association design technology for uncertain conditions (Hangzhou: Zhejiang University) p 83
[5] Wei Zongping and Qin Shaojun 2009 J. China Manufacturing Informatization 38(17) 26-29
[6] Wang Guanglei, Wu Yuguang and Gou Bo 2015 J. Journal of Machine Engineering 44(1) 76-79
[7] Wu Chunxi 2003 Research on the Automatic Generation of Dimensional Chains for 3D Assembly Drawing (Hangzhou: Zhejiang University) p 33
[8] Guo Chongying, Liu Jianhua and Tang Chengtong 2014 J. Computer Integrated Manufacturing Systems 20(12) 2980-2990
[9] Bao Qiangwei and Fan Yougao 2016 J. Journal of Computer-Aided Design & Computer Graphics 28(11) 1989-1999
[10] Zheng Sujuan and Zhang Kuikui 2017 J. Machine Design and Research 33(2) 122-128
[11] Zhang Xinghua 2013 Research on digital assembly information modeling and sequence planning based on CATIA (Wuhan: Wuhan University of Technology) p123